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FACULTEIT BEDRIJFSECONOMISCHE WETENSCHAPPEN
master in de verkeerskunde: mobiliteitsmanagement
(Interfacultaire opleiding)

Masterproef
Added value of activity based models in the debate on electrical vehicles

Promotor :
De heer Davy JANSSEN

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Masterproef voorgedragen tot het bekomen van de graad van master in de verkeerskunde , afstudeerrichting mobiliteitsmanagement

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Abstract

The road transport sector is entirely dominated by internal combustion engine vehicles; therefore faced with many challenges including high oil dependency, increasing environmental pollution and climate change which endanger human health. Therefore, the electric vehicle has been in the forefront of road transport research. While electric vehicle is a major break-through in the road transport sector, they have their own challenges. The main issue in this paper is "If two vehicles (one gasoline/petrol vehicle and any type of electric vehicle) are present in a household it is therefore imperative to model, who will use which car and for which trip type?" The main goal of this thesis is to decide the vehicle choice per trip when both an electric vehicle of any kind and an internal combustion engine vehicle are present within the same household. Data was collected using an online questionnaire. The method used to analyze the data was Analytic Hierarchy Process (AHP). The stated preference questionnaire also provided data used for the pair-wise comparisons used in the AHP model. In the AHP model, three vehicle alternatives; status quo or internal combustion engine (ICE) vehicle, Plug-in hybrid electric vehicle (PHEV) and all-electric vehicle (EV) were used with five criteria to obtain the best suited vehicle to swap with the status quo. The result was in favour of all-electric vehicle (EV). Which means EV is the most suited vehicle to be considered in the swapping model. Any future research should model the swapping process between the status quo and EV.

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INTRODUCTION

Passenger car use has a large share in the transport sector and this trend is expected to increase further in the future. The road transport sector today is almost entirely dominated by internal combustion engine vehicles with about 95% dependency rate of transport on fossil fuel (Hacker et al., 2009). In the transport sector, light-duty vehicles account for about 60% of energy use and greenhouse gas emissions (Yang and McCarthy, 2009). In Europe in 2004, out of the 30% of total final energy consumed by the transport sector, road transport consumed 82% which was responsible for 25% of CO_2 emissions (Perujo and Ciuffo, 2009). The road transport sector faces challenges due to the kind of vehicles that are predominant on the roads which is characterized by ever increasing pollution, high oil dependency, and climate change to name a few.

Background and problem definition

Personal mobility in Western countries has increased from 17km a day in 1970 to 35km in 1998, resulting to environmental pollution (from emissions) and damage to health (Panis et al., 2008). Because of the ever increasing travel distance of motorist to perform their daily activities, and due to the fact that people are very interested in the comfort standards of their own vehicles and to enjoy their privacy, they fall in love with their personal vehicles as most of them do not choose to commute by public transport. The quest for ways to lessen the consequences of this trend has driven research in the direction of the electric vehicle.

While breakthrough in the road transport sector is anticipated by using the electric vehicle, the electric vehicle brings along its own problems of deployment; which include batteries that are not robust enough, high cost of battery as well, the question of the electric grid to withstand the increased demand for electricity as a result of recharging (Plug-in electric vehicles and batter electric vehicle), and reduced travel distance as compared to internal combustion engine vehicles. The electric energy available for charging and recharging of electric vehicles depends on the electric grid; and the costs and amount of emissions from electric vehicles depends on the quantity, location and timing of vehicle electricity demands.

Although the driving range or travel distance of electric vehicle depends on the robustness of the battery, it is also influenced by the daily activity patterns of the individual or house hold (that is location, duration and kind of activities that they carry out from day to day). This means that the travel range of the electric vehicle depends on the spatial-temporal linkages between the kinds of activities that individuals or households carry out as part of their daily activity schedule. The variety of and numerous daily activities that individuals/households perform constitute the core of the limitations of the conventional (4-step) transport model and the travel activity data provides insight on the effects of widespread adoption of the electric vehicle (Kang and Recker, 2009). It also touches on the demographic characteristics of the household. As a result of the afore mentioned limiting factors of the electric vehicle, its market penetration in the near future depends on the technological advancements in the direction of battery robustness, and individual/household perception of electric vehicle and associated user behaviours. These are issues that transport decision makers, politicians and manufacturers of automobiles have to consider so as to increase the market penetration of electric vehicle in the future. Therefore, there is the need for more research in this regard so as to lesson these ills that are present in the road transport system today. Also, households need to consider the advantages of using electric vehicle and include it in their fleet of vehicles. The ownership of multiple vehicles with different characteristics in a household would encourage and promote swapping of the vehicles according to their characteristics and characteristics of the trips (purpose of trip and distance to be covered). The choice of second vehicle is of paramount importance in order to perform swapping behaviour between household fleet of vehicles with different characteristics. This brings about the clear statement of problem of this thesis which is "If two vehicles (one gasoline/petrol vehicle and any type of electric vehicle) are present in a household, it is therefore imperative to model who will use which car and for which trip type?"

Motivation and objectives

The introduction and background raised a lot of questions which need to be answered. Interests on how to attempt answers to these questions pave the way for solutions to many of the issues raised herein. This include seeking solutions to the over dependency of the road transport sector on fossil fuels which is a source of greenhouse gas emissions and resultant environmental pollution. Is the electric vehicle seen as one of the best solution to solve these problems? If that is the case, then the electric vehicle will become popular in these households. However, we will find this out later on in this paper. which type of electric vehicle is best suited to reduce these problems. Then several aspects of electric vehicle use have to be studied. One of these is car swapping behaviours when an electric vehicle and internal combustion engine vehicle are present at a given time in a household with more than one person with driving license.

Looking at the history of papers and projects that are found in this domain, most of them do not report on vehicle swapping between members of same household. Even the few found only used discrete choice to model vehicle choice and not vehicle swapping per say, (to the best of my knowledge) but took a different underpin.

This thesis is designed as an attempt to enhance the current state of the knowledge that involve the use of electric vehicles in the household by investigating how hybrid households carryout vehicle swapping. By hybrid households, we mean households that own both normal internal combustion engine vehicle and a type of electric vehicle. The geographical scale of this study is meant to be Belgium though there is limited number of electric vehicles that are deployed in this area. The main statement of goal of this master thesis is to decide the vehicle choice problem, when both an "electric vehicle" and an internal combustion engine vehicle are present within the same household. The actual swapping process is beyond the scope of this paper.

LITERATURE REVIEW

Relevant literature related to this thesis will examine the use of activity based models as a superior modeling approach for predicting transport demand (over four-step models). Electric vehicles are portrayed as one of the best ways to reduce emissions from transport as compared to other fuel modes as their deployment means reduction of transport sector reliance on fossil fuels. Effects of Individual/household behaviours when they own an electric vehicle including driving behaviour, adaptation to trips and trip planning (and re-adjustments), charging behaviour (time, place, and frequency), and trip rescheduling are of importance. Electric vehicle is presented as what the future holds for the transport sector. It will demonstrate the effects of vehicle fuel type on daily activity patterns of individuals (agents) and/or households. In the following section, we make an overview of electric vehicle; a discussion on travel demand approaches is made by throwing more light on the superiority of activity based models over the traditional 4-step model. This will be followed by an overview of the sales and the ownership of electric vehicles in Belgium, and finally the use and application of Analytic Hierarchy Process in transport related research.

Background of electric vehicle

According to the Encyclopedia of Science & Technology Online, electric vehicle is "a ground vehicle propelled by a motor that is powered by electrical energy from rechargeable batteries or other source on board the vehicle, or from an external source in, on, or above the roadway". The electric vehicle has many advantages over internal combustion engine vehicles (ICEVs) as they promise much environmental advantages and enormous energy savings together with cost benefits that arise from both maintenance and operating costs (Kurani et al., 1994). Electric vehicles have the advantage of being charged in many places ranging from home, work place, and other convenient places, unlike fuel for the ICEV that can only be purchased from the fuelling station. One important characteristic of the electric vehicle is that electrical energy is being store in the battery, this plays down on the driving range of the vehicle as the battery has low energy density and can be easily depleted after few kilometers travelled (Kurani et al., 1994; Kang & Recker, 2009). They went ahead to report that electrical vehicle should not be a complete substitute for ICEVs as they too have their own new capabilities as well as limitations. This means that limited travel range and long charging time of battery present enormous challenge of selling electrical energy to drivers who usually drive for long distances and have been used to quick and fast refueling.

Travel demand modeling approaches: 4-steps Vs. Activity-based.

The aggregate approach or first generation of transport models involve the traditional 4-step model that model trip generation and attraction, distribution, modal split and traffic assignment. This model is very simplistic and does not take into consideration interactions of trips within a trip chain, interaction between different tours and also does not consider the fact that travel is a derived demand which is demand for activity that need to be performed.

Literature on Activity based models reports that they are derived from improvement of the traditional 4-step model. The traditional 4-step transport models take trip as the starting point of the models, trips are modeled starting from their generation, distribution over geographical space, modal split and their assignment to the various road networks. These models have been inadequate in handling many important policy issues though there have registered success in their application to some extent, for example construction of a new transportation infrastructure (Algers et al., 2001).

The limitations of the traditional 4-step model have led to the emergence of more complex travel forecasting models namely tour based models and activity based models. These new generation of travel demand models have the following features: (1) an activity-based structure , which implies that travel demand is derived from daily activities carried out by households/individuals within the household, (2) a tour based platform where a tour instead of the basic trip is used as the basis of analysis, (3) micro-simulation modeling techniques that use households and individuals within the household at a fully disaggregate level, which convert travel and activity related choices from fractional probability models outcome into a series of decisions among the discrete choices. An ideal activity-based model is one that takes into consideration activity participation along a particular time frame as constrained by time, space and social networks; accounting for interdependency among individuals within the household, among individual trips, and trips within the same trip chain (Kochan et al., 2008).

Over the past decades, a strong debate over the use of activity based models to further the understanding and to better appreciate the impacts of emerging transportation policies; and to improve travel demand forecasting has been made (Doherty et al.). One of the main issues raised in the debate is how individuals conduct their travel behaviours. This means interdependency exists between the various activities that are performed, where, when, for how long, with whom, which transport mode and route choice made (Doherty et al.). Households respond to changes in transport policies in a complex manner and in many ways, some of which include reorganization of trips into tours, reassignment or redistribution of trip/task among members of the household, and revision and /or rescheduling of activities and travel plans as a whole (Doherty et al.)

Activity based models with their in-depth analysis of how people carry out their activities in time and space go a long way to give a good perspective on the strategies involve in doing so.

This holds true for other urgent transport policies like use of electric vehicles. The key question here is how people will adapt and change their travel activity decisions and behaviours. The outcome of this decision is often what is modeled in activity based models. It has been argued that people make and adapt their activity and travel decisions based on the prevailing transport (Travel Demand Management, TDM) policies (Doherty and Miller, 2000); this is to say that people respond to TDM policies by readjusting the spatial-temporal aspects of their activity patterns. The increasingly complex travel pattern and the need to estimate any changes that result from changes in new transport policies in other to better appreciate travel behaviour can only be well developed using activity based models due to their complex nature (Shiftan, 2003). The superiority of activity based models over other transport models makes it the best policy tool for transport demand modeling.

Electric vehicle sales and ownership in Belgium

Fossil fuel consumption has become a grave concern to the European Union and Belgium in particular. Belgium imports all of its petroleum, coal and natural gas needs. Ever rising fuel prices and environmental pollution have been confronted by great move towards the use of renewable and clean energy solutions. The gross energy dependence of Belgium presently stands at 77.9%, with a 79.3% dependence on foreign oil (Global Automobile Team, 2010; ACEA, 2012)

The ownership of electric vehicle is still very low in Belgium. The market for hybrid vehicles and electric vehicles is still developing. Hybrids and electric vehicles sales stand at roughly 1% in the entire Belgian vehicle market, with Toyota's Hybrid (parallel hybrid electric vehicle) being the most popular (Global Automobile Team, 2010). Other hybrid electric vehicles owned by Belgians include Lexus, REVA, Honda, and BMW. Volvo (C30), Peugeot (3008 Hybrid4), Mitsubishi (i-Miev), and Ford (Focus) are also active in the electric vehicle sector and have announced their intentions to market electric vehicles in Belgium in the nearest future. However, hybrid and electric vehicle ownership is expected to gradually increase from a few hundreds to a few thousands over the next five years, approaching 10.000 units by 2015 (Global Automobile Team, 2010) .

By the year 2020 to 2025, a majority of stakeholders in Europe (and Belgium, specifically) forecast a realistic market share for new electric vehicles at 3 to 10% (European Parliament, 2010). The market penetration of electric vehicles will depend on how fast the technology behind it (battery) develops and how individuals/households perceive and accept electric mobility. In the EU-19, if the current trend of new vehicles sales of approximately 15.000.000 vehicles in 2009 continues, this will result to between 450,000 and 1.500.000 electric vehicle units sold by 2020 to 2025 (European Parliament, 2010).

The Belgian government has however created several incentives to encourage and promote the ownership of electric vehicle. These incentives include a 30% federal tax credit (maximum Euro 9,000) when a new electric vehicle is purchased. The subsidies are somehow different in the various regions in Belgium. In the Flemish region, the government gives a 30% and a 50% subsidy for the purchase of electric vehicle and electric motorcycle respectively; while in the Walloon region, the government offers a 75% subsidy (up to Euro 25.000) for the purchase of a new electric vehicle (Global Automobile Team, 2010).

Furthermore, Belgium does not presently have adequate charging infrastructure to support electric vehicles that depend on energy from the electric grid. There are a meager 19 charging stations in the whole of Belgium with a majority of them located in the Flemish region. In order to expand on the sales and ownership of electric vehicles in Belgium, charging stations must be developed, and also the issue of integrating the charging stations into the electric grid must be carefully addressed.

Electric vehicle user's recharge behaviour

Households/agents who own electric vehicle exhibit a variety of charging behaviour which influences the deployment of electric vehicle in the society. Charging behaviour is very important for policy makers and analysts since the incremental economic, environmental and societal benefits of electric vehicles depends on the agent's driving and recharging behaviour (Davies and Kurani, 2010).

A handful of literature on electric vehicles report on various charging scenarios among which are Davies and Kurani, 2010; Axsen and Kurani, 2009; Baptista et al., 2010; Lemoine et al., 2006; Kurani et al., 1994; Balducci, 2008; Axsen and Kurani, 2008; Clement-Nyns et al., 2010; Geth et al., 2010; and Knapen et al. Upon owning an electric vehicle, the owners adopt a new lifestyle whereby they plug in the vehicle to charge immediately they arrive their homes in the evening and unplug before they drive the vehicle the following morning. In this case they adjust to driving only over the distance which can be powered by the electric battery thereby avoiding being left stranded by their car on the way. Depending on the charging behaviour performed, the distribution of electric energy used to recharge electric vehicle according to time-of-day could affect the amount of energy provided by the electricity providers as they will try to meet up with the extra demand. Depending on the way electric energy is produced and distributed, various regions of the country may be affected by the manner in which the electric vehicles are recharged. Also, time-of-day is an important determinant of the charging load on the electric grid. While night-time recharging will help level-up the demand and increase efficiency of the system, daytime recharging may worsen the prevailing demand peaks (Davies and Kurani, 2010).

Household/Agent's perception of electric vehicle and driving/charging behaviour

Households or agents' perception of electric vehicle is influenced by the distance within which the vehicle can cover with the energy contained in the vehicle's battery. Therefore travel range is vehicle's major drawback at this stage of vehicle electrification. This perception is known as "range anxiety" (van Haaren, 2011). It is therefore, important to investigate what the agent's expectation of the range requirement is like for an electric vehicle of some sort.

Agents are scared by the fact that they can be left stranded by their vehicle on the way because of the complete depletion of the battery. The agent's range anxiety is affected by vehicle characteristics like battery energy density and recharge times. Van Haaren (2011) recounts a recent study done in the US by Deloitte who found out that 80% of participants in the survey expected a driving range of 100 miles or more from the electric vehicle. Also, more than 60% of agents want to carry out all daily activities in just one charge to a distance of 200 miles and more. The new generation of electric vehicle has driving range of 120-180km according to the manufacturer if they are only driven at a maximum speed of 80km/hour, with normal temperatures, and without air conditioning. However, drivers fear the validity and application of the driving range specified by the manufacturer because if the speed exceeds 80km, the vehicle which should run for 180km before the battery is depleted may finally run only for 120km (Christensen et al., 2010).

Unlike refueling the ICE vehicles which is simple and possible in many public places, and above all taking a short span of time; many drivers perceive the recharge of electric vehicle to be time consuming and recharge points are presently scarce away from home. Electric vehicles take a longer time to recharge; depending on the recharge method, the time needed to charge some batteries to full capacity range from 30 minutes (80% quick-charge) to 48 hours (slowest wall-outlet charge for Tesla Roadster) (Van Haaren, 2011).

The perception of the electric vehicle by households has led to behaviours that help them adapt while using their electric vehicle. Many households decide to use their normal ICE vehicles when electric vehicle’s limitation had to be overcome. In the same survey carried out by Van Haaren (2011), 100% of participants agreed that there is no doubt that electric vehicle is needed for 'daily use', it appeared that they learnt to tackle the electric vehicle's limited driving range by having a conventional ICE vehicle to be used for longer trips. It makes sense to say here that households make use of their electric vehicle when commuting (Van Haaren, 2011) since daily commute is typically made up of short fixed distances and employee's parking spaces is the first place where charging stations would be installed.

The use of Analytical Hierarchy Process (AHP) in transportation research

AHP is a method for formulating and analyzing decision based on intuition. Analytic Hierarchy Process shall be described in greater detail in the later parts of this paper. AHP has been applied to numerous practical transportation problems in the near past.

Poh and Ang (1999) used Analytic Hierarchy Process to analyze alternative fuels for land transportation in Singapore for the years 2020 to 2030. Four alternative fuels were included in their analysis, namely: status quo (normal internal combustion vehicle using petrol or gasoline), oil and electric vehicles (EV), oil and natural gas vehicles (NGV) and methanol vehicles. They used six criteria to determine the best fuel alternatives in year "X" in Singapore. These criteria were: supply, emission, technology, cost, consumer preference and safety. In their case, they used an iterative forward and backward AHP planning process to identify and evaluate a set of policies that could be used to reduce the gap in a case whereby the preferred plan deviates from the most likely future scenario.

Their results showed that the use of electric vehicle is the best fuel alternative for the year 2020 to 2030 in Singapore. In other to help the land transport sector move in the desired direction, they identified a set of policies that will help achieve this goal. Financial incentives were found to be the most effective to steer consumers in the direction of the desired social choice of using electric vehicle.

Tzeng et al. (2005) used Analytic Hierarchy process in a multi-criteria analysis of alternative-fuel buses for public transportation in Taiwan. The aim of their research was to evaluate the best alternative-fuel buses that were suitable for the urban area and to explore the future direction of its development. The main alternatives evaluated in their paper were; gasoline-electric, diesel-electric, CNG electric and LPG electric. Basing their work on the global development results, they considered 12 alternative fuel modes namely: conventional diesel engine, compressed natural gas (CNG), liquid propane gas (LPG), fuel cell (hydrogen), methanol, electric vehicle (opportunity charging), direct electric charging, electric bus with exchangeable batteries, hybrid electric bus with gasoline engine, hybrid electric bus with diesel engine, hybrid electric bus with CNG engine and hybrid electric bus with LPG.
Tzeng et al. used 11 evaluation criteria to evaluate the various alternatives. The criteria included energy supply, energy efficiency, air pollution, noise pollution, industrial relationship, costs of implementation, cost of maintenance, vehicle capability, road facility, speed of traffic flow and sense of comfort.

Their results showed that hybrid electric bus is the most suitable alternative for public transportation at the moment which will contribute to improving the quality of the environment. They found out that in a long run when the technological characteristic of other modes such as the electric vehicles is improved, electric vehicle will become most suitable alternative.

Winebrake and Creswick (2003) also applied AHP to evaluate the future of hydrogen fuelling systems for transportation. They made use of scenario analysis to build their evaluation model. Their results provided more insight into the opportunities and barriers for commercialization of hydrogen fuelling systems for transportation, as well as served as a methodological opportunity for using AHP as a future tool. In the same way, Halog et al. (2003) used AHP to make an assessment of electric vehicle battery technologies in 2003 and presented their findings at the 8th International Conference on Environmental Science and Technology that held in Lemnos island, Greece from 8 - 10 September 2003.

In this paper, a similar approach as the ones used by Poh and Ang (1999), Tzeng et al. (2005), Winebrake and Creswick (2003) and Halog et al. (2003) is applied whereby various vehicles are used and compared following certain criteria to get the best suited vehicle choice to swap with the status quo. We will use five criteria to make a choice within three vehicle alternatives while making use of various vehicle and trip characteristics. This will be explained in detail later on in this paper.

METHODOLOGY

A Stated Preference Survey was carried out to obtain important data from individuals/households. Some of the data is used as input into and analyzed by Analytical Hierarchy Process (AHP). This means qualitative information is converted into qualitative information and modeled to obtain the results. The online Stated Preference Survey is used to assign weights to the various vehicle pairs and between pairs of criteria in the pair-wise comparisons which are analyzed by the AHP. An overview of the various vehicle alternatives used in the analysis shall be presented later on in this paper. Also, the various criteria used in the analysis will be given below together with the details of the steps involved in the AHP procedure.

The choice of AHP over other methods such as discrete choice models, Q method and Biogeme (to mention a few) was because of imprecision in the assessment of relative importance of the ratings of alternatives in relation to various attributes. The reasons for imprecision in this case would be as a result of unquantifiable (converting qualitative to quantitative) information, unobtainable information, incomplete information and partial ignorance of electric vehicles demonstrated by most households/individuals.

Stated Preference Survey

This paper made use of the result of an online questionnaire that was designed on www.thesistools.nl. The stated choice survey (see questionnaire used in appendix 1) was designed concerning electric vehicle use and associated behaviour and sent to respondents mostly in Belgium. The first part of the survey was made up of questions about socio-economic and demographic characteristics of households or members of households. The second part was made up of activity-based related questions that relate to distance over which respondents travel to perform various activities. This part is important because it has a direct relationship with travel range of electric vehicle and range anxiety of agents. The third part is made up of questions that ask respondents to assign weights to pairs of criteria in terms of meeting the goal and also pairs of vehicle alternative in relation to meeting the criteria. These weights were then used as input into the AHP analysis to make meaningful conclusions.

The unit of the survey was the household, even though data on trips and individuals was also collected. The main idea was that households with more than two individuals with drivers license and two vehicles at their disposal are motivated to fulfill vehicle swapping behaviour. The criteria were for respondents to state their perception of electric vehicle, best electric vehicle choice, and associated behaviour when they own it. The survey was stated choice because electric vehicle ownership in Belgium is very low as stated above, so respondents were simply stating associated behaviours related to electric vehicle use if they owned one.
Questions were asked about 5 criteria; namely eco-friendliness, range anxiety, practical considerations (convenience), economic reasons (fuel cost savings) and social image and status. Also questions were asked about 3 alternative vehicles including 2 electric vehicle types: plug-in hybrid and battery electric vehicle; in terms of meeting the criteria.

Analytic Hierarchy Process

This paper will make use of the Analytic Hierarchy Process tool to analyze the data from the stated preference survey to obtain the most suitable vehicle choice for swapping with the ICE vehicle the household already owns. The Analytic Hierarchy Process (AHP) tool is a measurement method for formulating and analyzing decisions. The theoretical framework for

AHP as used by Saaty (1980) is a decision support tool which can be used to solve complex decision making problems (Berrittella et al., 2007) while also accommodating many different perspectives and priorities. It is therefore reasonable to ascertain that AHP support decision makers to make decisions involving their knowledge, experience and intuition. The AHP methodology by Saaty (1980) as reported by Berrittella et al. (2007) is a good example to follow for hybrid household vehicle swapping modeling.

In this case of vehicle choice for car swapping, AHP decomposes the decision problem into elements, according to characteristics that they share in common, and their levels, which correspond to the common characteristic of the elements. The first level which is the topmost is the 'nucleus' of the problem or ultimate goal, at the intermediate level is the criteria, while the lowest level is made up of the "decision alternatives". The hierarchy is complete only when each element of each level depends on all the elements of the level directly above it; otherwise, it is defined as incomplete. The elements of each level are compared in a pair-wise manner with respect to specific element in the previous upper level.

The pair-wise comparison scale as used in the AHP tool by Saaty (2008) can be seen on appendix 2. By using this pair-wise comparison scale, qualitative judgments are converted into numerical values, also with intangible attributes.

In order to compute the priorities of the elements, a judgment matrix is assumed as follows:

$$A= \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \end{bmatrix} \qquad \textit{Eq. (1)}$$

Where; a_{ij} represents the pair-wise comparison rating between the element i and element j of a level with respect to the next level directly above it. The entries a_{ij} are governed by the following rules: $a_{ij} >0$; $a_{ij}=1/a_{ji}$; $a_{ii}=1\ \forall i$

The priorities of elements in matrix A can be calculated by finding the n^{th} root of the sum of products to get the vector W.

Normalizing vector W, it becomes the vector of priorities of elements of one level with respect to the next upper level. λmax is the largest eigenvalue of the matrix A.
When the pair-wise comparison matrix satisfies transitivity for all pair-wise comparisons, it is said to be consistent and validates the relation that follows:

$$a_{ij} = a_{ik}a_{kj} \qquad \forall i,j,k \tag{Eq. 2}$$

In order to maintain reasonable consistency when deriving priorities from paired comparisons, Saaty (1980) state that the number of factors must be nine or less. Analytical Hierarchy Process (AHP) allows inconsistency, but also provides a measure of the inconsistency in each set of judgments. The consistency of the judgmental matrix can be determined by a measure called the consistency ratio (CR), defined as:

$$CR = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{Eq. 3}$$

Where; CI is the consistency index and

RI is the Random Index.

Saaty (1980, 2000) provided average consistencies (RI values) of randomly generated matrices (see appendix 3). CI for a matrix of order n is defined as:

$$\mathrm{CI} = \frac{\lambda\mathrm{max} - \mathrm{n}}{\mathrm{n} - 1} \tag{Eq. 4}$$

The general rule is that a consistency ratio of 0.1 or less is considered acceptable. However, this threshold is 0.08 and 0.05 for matrices of sizes four and three respectively. Higher values should be elicited again as the judgments may not be reliable or trusted.

Once the local priorities of elements of different levels are available, in order to obtain final priorities of the alternative a_i, the priorities are aggregated as follows:

$$S(a_i) = \sum_k w_k S_k(a_i) \tag{Eq. 5}$$

Where: w_k is the local priority of the element k and

$S_k(a_i)$ is the priority of alternative a_i with respect to element k of the upper level.

Assessment of the various alternatives in the AHP model

The principal parameter for defining alternative solutions to the vehicle used by any member of the household at any given time is the source from which the vehicle gets its energy. According to data collected from the stated preference survey that was conduction to boost knowledge of writer including that gained from related literature, alternative vehicles were classified into four major groups: the status quo (which is internal combustion engine, ICE vehicle), hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV) and the Battery or all- electric vehicle (EV). The electric vehicles which are recharged using electricity (PHEV and BEV) are of extreme importance in this study. An assessment of the various alternatives according to criteria that apply to all vehicle types is important in order to apply weights to be used in analysis in the AHP model.

Status quo

The status quo is assumed to be the first car owned by the household. The source from which the vehicle gets its energy is an internal combustion engine that uses fossil fuel, therefore emits huge amount of pollutants and greenhouse gases into the atmosphere. They cover long distances and refueling is possible only at fuelling stations. The fuel efficiency of these vehicles is quite low as compared to electric vehicles. They are the cheapest in terms of purchase cost and more expensive to run than the other alternatives.

Hybrid electric vehicles (HEVs)

The major components of this type include a gasoline engine, electric motor, generator, transmission, fuel tank for gasoline engine, and batteries for the electric motor (Deal, 2010)
These are vehicles that are powered by an internal combustion engine that can be used on conventional internal combustion engine vehicles and by an electric motor that uses energy that is stored in the battery. The battery of the HEVs receives power from the operation of the internal combustion engine within.

The HEV has better fuel economy and better performance over the conventional ICE vehicle. With HEVs, fuel economy can be greater than 50% when compared with internal combustion engine counterparts, the main reason being that the electric vehicle battery works side-by-side with the ICE and takes over the task at relatively low speeds (Gilbert and Perl, 2005). It is important to note that fuel use of conventional vehicles at low speeds is very high, with fuel use at 5 to 10km/hr being typically about three times that at 40 to 50km/hr (Gilbert and Perl, 2005). On the other hand, the electric motor therein delivers maximum torque at low speeds. This makes the hybrid vehicles unlike their conventional counter parts to exhibit better fuel economy especially in the urban areas where driving speed is lower than on high ways. Also, the additional power that is being provided by the electric motor makes the HEV to use smaller engines, which results to better fuel economy and enhanced performance at the same time (NREL, 2011). In addition to having high fuel economy, HEVs also have low green house gas emissions in addition to the power and driving range advantage of conventional ICE vehicles.

An important feature of HEV is that they do not require electric energy to charge their battery, instead, they capture kinetic energy lost during breaking i.e. regenerative breaking (NREL, 2011), as they switch off the ICE when decelerating or stationary, and by mechanically adding power to the battery when full throttle is applied (Gilbert and Perl, 2005; NREL, 2011). However, this vehicle type will not be included in the analysis because of low market penetration rate.

Plug-in Hybrid Electric Vehicles (PHEVs)

The technology of PHEVs is built on the experience of HEVs. A plug-in hybrid electric vehicle is a vehicle that has batteries which can be connected to a grid to charge and an internal combustion engine that can automatically provide energy to the vehicle when the energy in battery is depleted (Balducci, 2008). These vehicles receive their power from built-in internal combustion engine as well as electrical energy stored in the battery. The battery pack of PHEVs is larger as compared to those of HEVs, making it possible to run over pretty long distances of about 10 to 40 miles by only using electric energy. This distance is commonly called "all-electric range" of the vehicle (NREL, 2011). A PHEV's battery has a capacity that is 5 to 10 times larger than that of HEV, but less than 0.25 to 0.33 times that of EV (Markel, 2010).

The batteries of PHEVs can be charged in many ways (NREL, 2011): by using an electric source outside the vehicle, by using internal combustion engine, or through regenerative breaking. This means that PHEVs combine the energy sources of HEVs, in addition to using an external electric source of power from the electric grid. Therefore, if the vehicle is never plugged-in to charge, the fuel economy will just be the same as that of HEVs. On the other hand, if the battery is fully charged and driven for a distance as short as its all electric range, it is possible for the vehicle to use just electric power only.

All-electric vehicles (EVs)

All-electric vehicle operates entirely on electricity, its technology is still in its developing stages. Battery electric vehicles or all-electric vehicles use a battery to store the electrical energy that powers the motor, and the battery is charged by plugging it into an electric power source. The EV itself produces zero emissions even though production of electricity at the source may contribute to emissions and they perform efficiently under low-load conditions (Tzeng et al., 2005). Key disadvantages of EV include EVs have a shorter travel range than their conventional ICE counterparts when they have on a full tank of gas/petrol and also PHEVs, have long recharging time for battery. For example, all-electric Tesla Roaster has a 220-mile range; and the Nissan Leaf can travel between 62 and 138 miles on a single charge, depending on the driving style, topography and speed (NREL, 2011). NREL (2011) also recounts a report of the U.S. Department of Transportation Federal Highway Administration which states that 100 miles is sufficient for more than 90% of all households' vehicle trips in the United States.

ANALYSIS AND RESULTS

Before I start with the analysis, I will first of all present the socio-economic and demographic characteristics of the respondents and the average distance over which respondents travel to perform various activities. The total number of respondents that answered the questionnaire was 50.

Looking at the sex composition of respondents, 78% of them were male while only 22 were female. 40% of respondents were married and 60% unmarried. 82% of them were employed and 18% unemployed. The educational background of respondents was sub-divided into three sections; 14% of them had high school degree, while 38% and 48% had bachelor and master degrees respectively. When the respondents were ask how many members in their house hold own a driver's license, 26.53% said 3 or more members in their household owned a driver's license while 53.06% and 10% said 2 and 1 member of their household owned a driver license respectively.

As far as activity-based travel distance is concerned, results from the questionnaire showed that a great majority (approximately 85%) of the respondents travel for less than 60km per day to perform various individual activities (see figure 1 below) with all respondents travelling only for 40km or less to bring/take children from school. The activities under consideration were work, shopping, bring/pick children from school, leisure and visits.

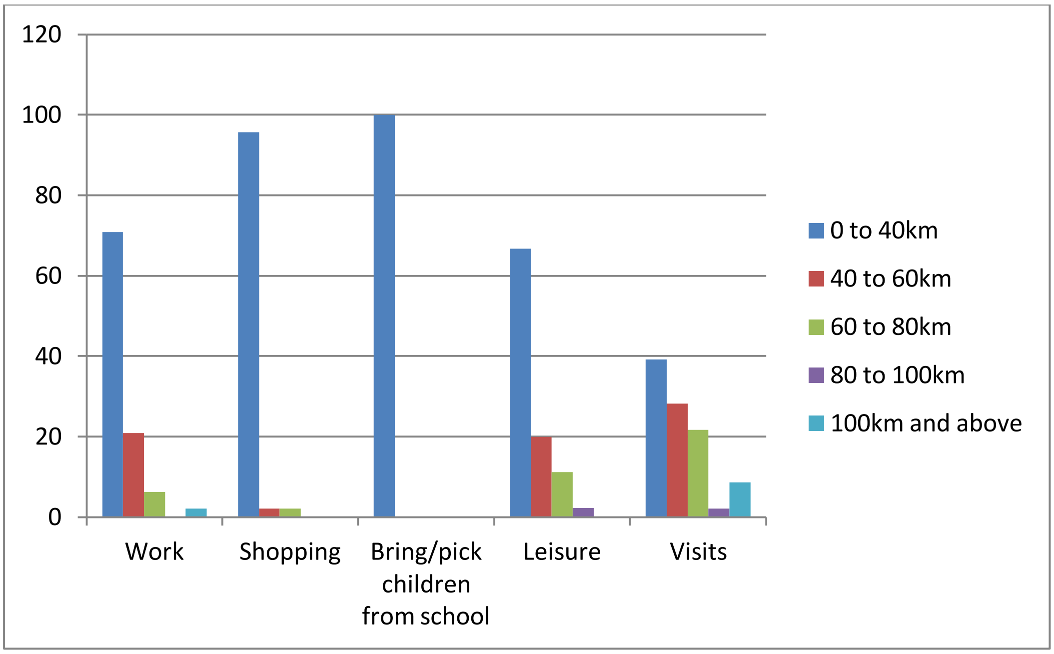


FIGURE 1: Percentage of daily travel distance per activity

However, when the general average travel distance per day was considered, the trend showed some slight increase in the daily average distance as the percentage of respondent who travelled for a longer distance slightly increased as shown in figure 2 below.

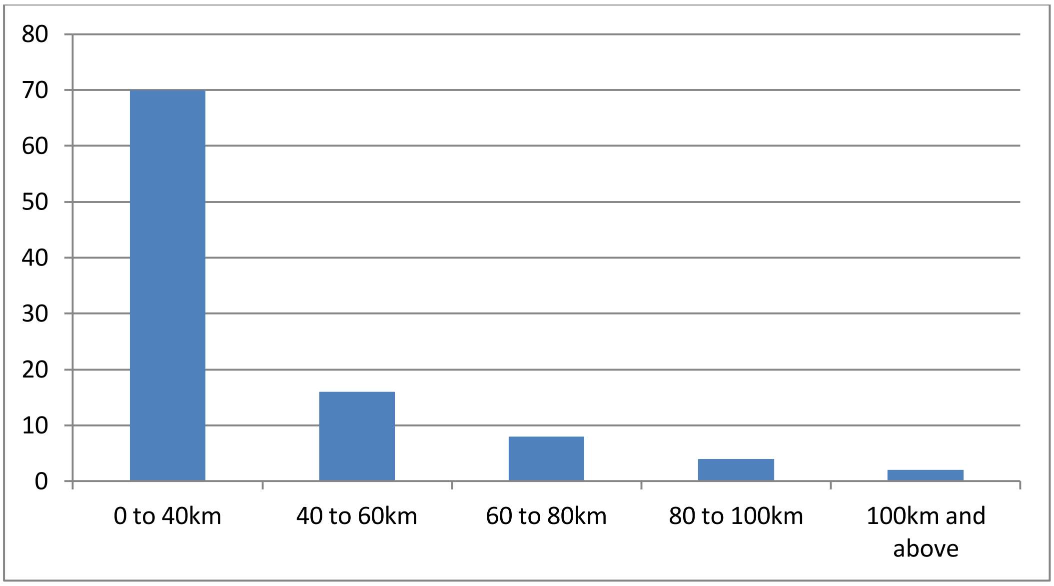


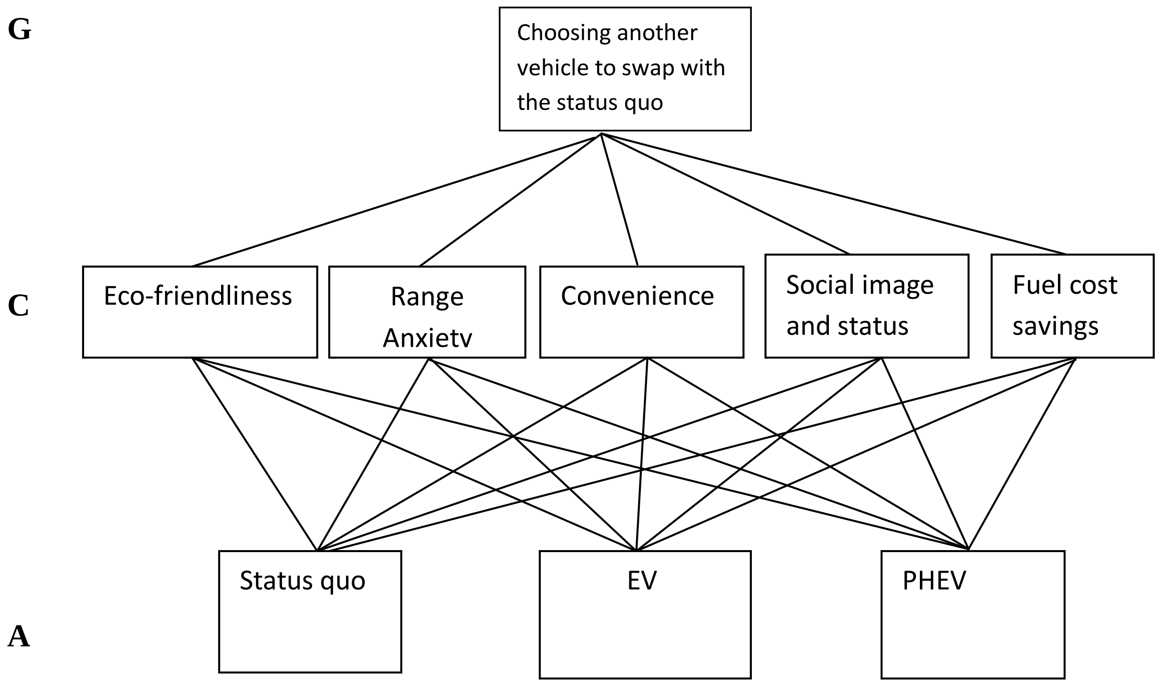
FIGURE 2: General average daily distance travelled

After presenting this background of the respondents/responses, the next step is to analysis the data using the Analytic Hierarchy Process.

The AHP Model

An AHP model is designed to determine the well-suited vehicle type to swap with the status quo. Figure 3 depicts the hierarchy used in the model. At the top of the hierarchy is the goal. The goal of the AHP analysis is to choose a suitable vehicle choice from the field of three vehicles to swap with the status quo. The second level represents the criteria used to reach the goal. The selecting criteria to be considered are eco-friendliness (emission reduction potentials), Range anxiety (related to travel range), convenience (practical reasons), social image and status (social reasons) and fuel cost savings or efficiency (economic reasons). While the lowest level shows a list of identified alternatives used in the decision analysis. The various alternatives to be considered in this analysis include the conventional gasoline/petrol vehicle (status quo), plug-in hybrid electric vehicle (PHEV) and battery electric vehicle or simply electric vehicle (EV). Each box in the diagram represents a node. Hybrid electric vehicle (HEV) shall not be considered in this analysis because of low market penetration rate.

FIGURE 3: The hierarchy in the AHP model



Where, “G” stands for Goal, “C” for Criteria and “A” for alternatives.

Following standard AHP methodology, a series of pair-wise comparisons were made between the alternatives with respect to each criterion. The priorities were then obtained as outcome of the pair-wise analysis involving all nodes. The nodes at each level were compared in pairs with respect to their contribution to the nodes above them. The results of these comparisons were entered into a matrix which was processed mathematically to derive the priorities for all the nodes on the level. The comparison was done by first comparing the alternatives to the criteria and then comparing the criteria with respect to importance in reaching the goal. Since they were three alternatives, each one was compared with each of the others; therefore three pair-wise comparisons were made with respect to each criterion: Status quo vs. PHEV, Status quo vs. EV, and PHEV vs. EV. For each comparison, judgment was first made of the weaker vehicle of the pair with respect to the criterion under consideration. Then a relative weight is assigned to the other vehicle of the pair. This was done for all five criteria.

Alternatives vs. Criteria

When the alternatives were compared with respect to the criteria used, priorities were obtained for each alternative for all the five criteria.

Eco-friendliness

When the priorities for alternatives were calculated using eco-friendliness, the eigenvector or relative importance of priorities obtained for status quo, PHEV, and EV were 0.082, 0.236, 0.682 respectively. This showed that EV is the most important vehicle choice (with a priority value of 0.682) followed by PHEV (with priority of 0.236), then the status quo (0.082) is least important alternative. The CR <0.1, therefore the pair-wise comparisons is consistent. Detail calculations can be found on appendix 4.

Range anxiety

When range anxiety of each of the alternatives was used to calculate the priorities of the alternatives, the eigenvector or relative importance obtained for status quo, PHEV and EV were 0.117, 0.268, and 0.614 respectively (see appendix 5). The results showed that EV is the most important vehicle choice (with a priority value of 0.614) as far as range anxiety is concerned. This was followed by PHEV (0.268), and the status quo is least important with 0.117. The CR was 0.058, showing that it was consistent.

Convenience

Also, when convenience was used to calculate the priorities of the alternatives, the eigenvector was 0.291, 0.604, and 0.105 for status quo, PHEV and EV respectively (see appendix 6). The results showed that PHEV had almost tripled the second runner-up (status quo) when convenience was used. This is because PHEV uses both fossil fuel and electric energy so can be charged at home as well as refueled at the fuelling station. EV has least priority because of long charging times mostly at home.

Social status and image

However, when the alternatives were compared in terms of social status and image, the results showed that PHEV had the highest priority (see appendix 7). This was followed by EV, and the least was status quo. The eigenvector or relative importance was 0.126, 0.458 and 0.416 for status quo, PHEV and EV respectively. This is because electric vehicles are very expensive to purchase and warrant support from the government to motivate households to buy them. It is reasonable to say that the increase in the price of electric vehicle is proportional to the size of its battery. This result is surprising.

Fuel cost savings

Furthermore, the eigenvector derived when fuel cost savings is used for status quo, PHEV and EV is 0.085, 0.271 and 0.644 respectively (see appendix 8). This showed that EV has the highest advantage when it comes to fuel cost savings (approximately three times more than second runner-up), followed by PHEV. The status quo had the least advantage when this criterion was used. This means the running cost of electric vehicles is generally lower than that of gasoline vehicles with running cost decreasing with increase in vehicle electrification. The CR is 0.05 showing consistency.

Criteria vs. the Goal

As soon as the evaluation of the different vehicle types (the alternatives) with respect to their strength in meeting the criteria was done, next was the evaluation of the criteria in terms of reaching the goal. Once again, this was done by pair-wise comparison whereby 10 pairs were derived from the 5 criteria. The importance of the criteria in terms of meeting the goal was calculated using the matrix on appendix 9.

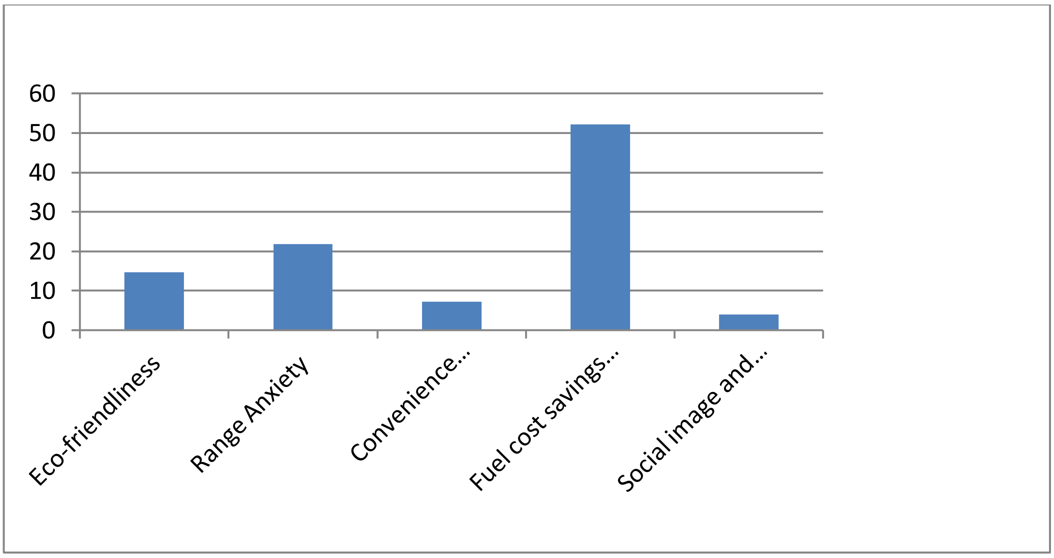


FIGURE 4: Graphical representation of criteria in terms of reaching the goal

The priorities are shown in the normalized eigenvector on the right of the matrix. A graphical presentation of the results obtained is showed on figure 4 above. The results showed that members of households would swap between vehicles mostly because of economic reasons mainly to save on the cost of fuel. Also, when swapping between vehicles, range anxiety is the second most important criteria that they consider. The third criteria was practical reasons mainly convenience. The least important criterion was social status and image. The eigenvector of relative importance was 14.7%, 21.8%, 7.3%, 52.2% and 4.0% for Eco-friendliness, Range anxiety, Convenience (practical reasons), economic reasons (fuel cost savings) and social image and status respectively. The CR of the pair-wise comparison is 0.136.

Computing final priorities

As soon as the priorities of the Criteria with respect to the Goal, and the priorities of the alternatives with respect to the Criteria were calculated, it was then possible to calculate the priorities of the alternatives with respect to the Goal. This was just a matter of multiplying and adding priorities over the whole of the hierarchy.

TABLE 1: Priorities of criteria with respect to the alternatives

Criterion	Priority vs. Goal	Alternative	A	B	C
Eco-friendliness	0.147	Status quo	0.082	x 0.147=	0.012
		PHEV	0.236	x 0.147=	0.035
		EV	0.682	x 0.147=	0.100
			1.000		0.147
Range anxiety	0.218	Status quo	0.117	x 0.218=	0.026
		PHEV	0.268	x 0.218=	0.058
		EV	0.614	x 0.218=	0.134
			1.000		0.218
Convenience	0.073	Status quo	0.291	x 0.073=	0.021
		PHEV	0.604	x 0.073=	0.044
		EV	0.105	x 0.073=	0.007
			1.000		0.072
Fuel cost savings	0.522	Status quo	0.085	x 0.522=	0.044
		PHEV	0.271	x 0.522=	0.141
		EV	0.644	x 0.522=	0.336
			1.000		0.521
Social image and status	0.040	Status quo	0.126	x 0.040=	0.005
		PHEV	0.458	x 0.040=	0.018
		EV	0.416	x 0.040=	0.017
			1.000		0.040

TABLE 2: Priorities of alternatives with respect to reaching the goal

	Priority with Respect to					
Vehicle Type	**Eco-friendliness**	**Range anxiety**	**Convenience**	**Fuel cost savings**	**Social status and image**	**Goal**
Status quo	0.012	0.026	0.021	0.044	0.005	0.108
PHEV	0.035	0.058	0.044	0.141	0.018	0.296
EV	0.100	0.134	0.007	0.366	0.017	0.624

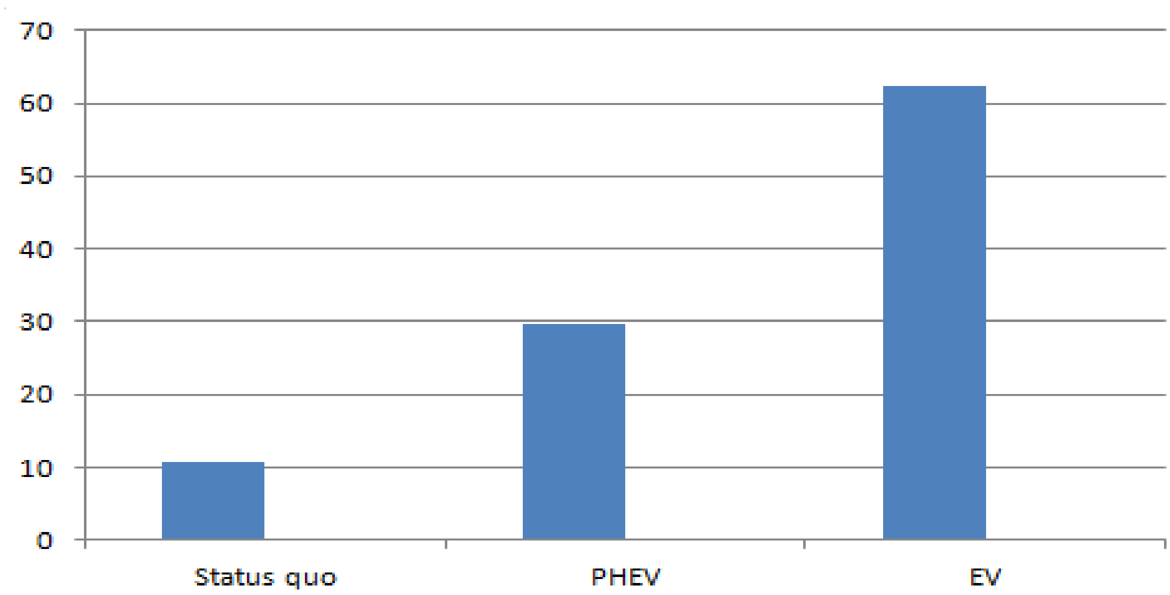


FIGURE 5: Vehicle alternative in terms of reaching the goal

The results show that the best vehicle choice to swap with the status quo is the EV with a priority value of 0.624; the second choice is the PHEV with a priority value of 0.296. The third and last vehicle choice is to swab with the status quo is the status quo itself with a priority of 0.108. Therefore the final conclusion from the AHP analysis using the five criteria used above is in favour of EV. This means that the actual swapping process will be between the status quo and the EV, where various swapping behaviours are performed. A study of the various behaviours is beyond the scope of this paper.

Validating the AHP results

The consistency ratio (CR) is a very important check on the validity of the results obtained from the matrix used in AHP analysis. Normally speaking, Saaty stated that the CR of a matrix should be equal to or less than 0.1 for the results to be considered consistent; otherwise the weighting is elicited and should be corrected. It is very important to note here that some of the results herein were not consistent. This is the case for Convenience (0.757), Social status and image (0.448) and the matrix for criteria in terms of meeting the goal (0.136). The results of the other matrices were consistent. Some reasons responsible for inconsistent in some results presented in this paper are that the weights used in pair-wise comparisons were obtained from an online questionnaire. The respondents were asked if they were informed about electric vehicles, only 30% of respondents said they were well informed, while 38% said they had some information; and 30% and 2% said that have an idea and have no idea respectively. This means only one third of respondents were confident about their answers.

REPORTING/DISCUSSION

In the debate over electric vehicle use, certain characteristics of electric vehicle are used to convince potential buyers to at least accept the electric vehicle as a second vehicle choice for the household for the moment and why not the best choice in the long run pending technological breakthroughs in battery technology in the future. In order to buy a new vehicle, there are characteristics or features of the vehicle that the manufacturers use to educate the buyer. Some of these features include highest speed, maintenance cost, fuel cost savings, benefits on emission reduction and in the case of electric vehicles (PHEV and EV) the travel range. Therefore in order to shape the purchase intentions of potential hybrid households and encourage the use of electric vehicles, the analysis above used some of these features to make a comparison between various vehicles according to their characteristics.

When the five criteria were compared in terms of reaching the goal, EV had a good performance for most of the criteria (eco-friendliness, range anxiety and fuel cost savings). This is in line with the conclusions (social view point) obtained by Poh and Ang (1999) which indicated that the best alternative fuel option for Singapore for year X is the EV, and they further stated that there should be a gradual conversion of private vehicles to run on electricity. In the same line, Berrittella et al. (2007) in their paper on evaluation of transport policies to reduce climate change impacts concluded that the best alternative policy to reduce adverse climate change impacts was "the tax schemes aiming at promoting environmental-friendly transport modes”. This is one of the most superior characteristics of electric vehicle, and the electric vehicle that performs best in this regard is the EV (all-electric vehicle).

To justify the results obtained from this analysis, when respondents were asked to state the average distance over which they travel to perform various activities per day, results of the survey showed that 94% of respondents travel for a distance of 80km or less per day with 86% travelling 60km or less per day. This result is in line with the results of Panis et al. (2008) who said personal mobility in western countries has increased from 17km per day in 1970 to 35km per day in 1998. This makes the use of electric vehicle very obvious by a majority of the households. For the 8% of respondents who travel over 80km per day on average, they can use the EV as a second choice. Therefore, 94% of households are potential electric vehicle users as they travel mostly for shorter distances within the travel range of the EV. Even when individuals within a household travel long distances or carry out a chain of activities and whose travel distance per day is more than the travel range of the electric vehicle, they could swap vehicles as per the trip characteristics, with the individual who takes a shorter trip to use electric vehicle. This study found out that perceived barrier for the use of electric vehicle which is travel range limit will not actually be an important barrier for the use of electric vehicle by a potential hybrid household in Belgium. This finding therefore suggests that if potential households are supplied with adequate information about electric vehicles, multi-vehicle households who buy new vehicles would consider owning at least one electric vehicle in their vehicle fleet if their prices are subsidized.

The fact that fuel cost savings is the most important criterion when the importance of the criteria are considered in terms of meeting the goal shows that EV, which performs best with this criteria is a potential alternative to consider by households. This holds true also for range anxiety (travel range related) and eco-friendliness, with ICE-vehicle performing worst when these criteria are used. These three characteristics are also very important tools to use in the debate over electric vehicles use. The fact that these characteristics make the EV (and PHEV) to dominate the ICE vehicle is a point to reckon with.

Even though when respondents were asked which electric vehicle they would prefer to use, 43.75% preferred PHEV as opposed to 35.42% for HEV and to the greatest surprise only 20.83% preferred EV; this could be attributed to the fact that when asked if they were informed about electric vehicles, only 30% of respondents said they were well-informed about electric vehicle, 38%, 30% and 2% said they had some information, had an idea and had no idea respectively in that order. The fact that the electric vehicles (EV first and PHEV second) were found to be the best vehicle choice to swab with ICE (internal combustion engine) vehicle in the final analysis is a strong bonus point to be used in the debate over electric vehicles. Even if the perception of electric vehicle by household is blinded by perceived range anxiety, the advantages of using the PHEV would still overcome those of ICE-vehicle while maintaining some degree of advantages as far as reaching the goal of electric vehicle (reducing emissions and dependency on fossil fuel) is concerned.

CONCLUSION AND RECOMMENDATIONS

This study found out that a majority of households in Belgium could conveniently use (battery) electric vehicle, and the other portion of the population adopting the EV as a second vehicle choice in their fleet of vehicles. Therefore, with great technological breakthrough in battery technology, perceived barrier for the use of electric vehicle which is travel range limit will not actually be an important barrier for electric vehicle use by a potential hybrid household in the long run. This finding therefore suggests that if potential households are supplied with adequate information about electric vehicles with the advantages they have on fuel cost savings and emissions reduction multi-vehicle households who choose to own a new vehicle would consider owning at least one electric vehicle assuming that their prices are subsidized.

Generally in the debate over the use of electric vehicles, potential households can be motivated to consider EV as their second vehicle choice in a short run assuming that their first choice was ICE vehicle. In the long run when battery technology is expected to be at its peak, electric vehicle would gain more popularity among households who have the slightest regards on cutting on their fuel cost savings and have concern for the environment.

What one can say here with confidence is that when vehicle characteristics are jointly considered for second vehicle choice for the household, fuel cost savings and emissions reduction are very important for the debate over electric vehicle use.

In order to motivate the use of electric vehicles, households need to be provided with adequate information about electric vehicles and there is need to increase charging infrastructure in public parking spaces in Belgium beside government subsidies on the purchase costs. Companies, organizations and institutions should be encouraged to provide public charging stations in their parking infrastructure.

LIMITATIONS AND FUTURE RESEARCH

The responds rate for the questionnaire was low. Out of about 150 respondents contacted to answer the questionnaire, only 50 respondents finally answered. The reason for low responds rate as revealed by some people who did not answer the questionnaire was that they were not verse with the whole notion of electric vehicle. This made them to be reluctant to answer the questionnaire.

Any future research in the direction of electric vehicles to compliment this study should include more criteria and sub-criteria, and more vehicle alternatives in the AHP model. This would make the model to include a lot of detail characteristics of the various vehicle alternatives and behavioural aspects to be used in the pair-wise comparisons. For example, refueling or recharging time, fuel availability and top speed are some important characteristics that some households may be interested in when they make new vehicle purchase decisions. Finally, future research should examine the actual swapping behaviour that is manifested by households when they own ICE-vehicle and EV vehicle as reported by this study. It should show factors that determine which vehicle is used when, over what distance, to where and for what purpose. Driving and charging behaviour of individuals or household could also be investigated.

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REFERENCES

1 ACEA (2012), Overview of purchase and tax incentives for electric vehicles in the EU (website: www.acea.be)

2 Algers S., Eliasson J. and Mattsson L. (2001) Activity-based model development to support transport planning in the Stockholm region.

3 Arturo E. G. (1991) Evaluation Of Potential Hybrid Electric Vehicle Applications: Vol I. Research Reports, California Partners for Advanced Transit and Highways (PATH), Institute of Transportation Studies, UC Berkeley

4 Axsen J. and Kurani K. (2009) Anticipating PHEV Energy Impacts in California. Institute of Transportation Studies, UC Davis

5 Axsen J. and Kurani K. S. (2008) The early U.S. market for PHEVs: Anticipating consumer awareness, recharge potential, design priorities and energey impacts. Institute of Transportation Studies, UC Davis, Carlifornia.

6 Balducci (2008) Plug-in Hybrid Electric Vehicle Market Penetration Scenarios

7 Balducci P. J. (2008) Plug-in hybrid electric vehicle market penetration scenarios.

8 Baptista P., Toma’s M. and Silva C. (2010) Plug-in hybrid fuel cell vehicles market penetration scenarios. International Journal of Hydrogen energy 35 (2010).

9 Berrittella M., Certa A., Enea M. and Zito P. (2007) an Analytic Hierarchy Process for the Evaluation of Transport Policies to Reduce Climate Change Impacts, Climate Change Modelling and Policy (CCMP)

10 Christensen L., Nørrelund A. V. and Olsen A. (2010). Travel behaviour of potential Electric Vehicle drivers. The need for charging.

11 Clement-Nyns K., Haesen E. and Driesen J. (2010) The Impact of Charging Plug-In

Hybrid Electric Vehicles on a Residential Distribution Grid. IEEE Transactions on Power Systems, VOL. 25, NO. 1, FEBRUARY 2010

12 Davies J. and Kurani K. S. Households' Plug-in Hybrid Electric Vehicle Recharging Behavior: Observed variation in households' use of a 5kWh blended PHEV-conversion

13 Deal W. F. (2010) Going green with electric vehicles. Resources in technology and engineering

14 Doherty S. T., Miller E. J., Axhausen K. W. and Gärling A Conceptual Model Of The Weekly Household Activity-Travel Scheduling Process

15 Doherty S. T., Miller E. J., Axhausen K. W. and Gärling T. : A conceptual model of the weekly household activity-travel scheduling proces.

16 Doherty, S.T., and Miller, E.J. (2000) A computerized household activity scheduling survey. Transportation, 27, (1), 75-97.

17 Eren Özceylan (2010) A Decision Support System to Compare the Transportation Modes in Logistics. International Journal of Lean Thinking Vol. 1, Issue 1 (June 2010)

18 European Parliament (2010) Challenges for A European Market For Electric Vehicles. ITRE 2010

19 Fakhra J. (2011) Electric Vehicle Acceptance: A Household Study. 2011 International Conference on Petroleum and Sustainable Development IPCBEE vol. 26 (2011)

20 Geoff C. (2004) The Analytic hierarchy Process (AHP). Pearson Education Limited 2004

21 Geth F., Willekens K., Clement K. and Driesden J. (2010) Impact-analysis of the charging of plug-in hybrid vehicles on the production park in Belgium.

22 Gilbert R. and Perl A. (2005) Energy and transport Futures

23 Global Automobile Team (2010) Electric Vehicles; Europe in Brief. A reference guide for U.S. exporters, 2010-2011 Edition

24 Greene D. L., Duleep K. G. And McManus W. (2004) Future Potential of Hybrid and Diesel Power trains in the U.S. Light-Duty Vehicle Market

Gwo-Hshinung T., Cheng-Wei L. and Serafim O. (2005) Multi-criteria analysis of alternative-fuel buses for public transportation. Energy Policy 33 [Elsevier 2005]

25 Hacker, F., R. Harthan, et al. (2009). Environmental impacts and impact on the electricity market of a large scale introduction of electric cars in Europe - Critical Review of Literature -. ETC/ACC Technical Paper 2009/4 - July 2009: 169.

26 Halog A., Sagissaka M. and Inaba A. (2003) Assessment of electric vehicle battery technologies using fuzzy linguistic and AHP. 8th Internationl Conference on Environmental Science and Technology. Lemnos island, Greece, 8 - 10 September 2003

27 Harry T. R. (2011) The Electric cars Challenge. Technology and Engineering Teacher

28 Int Panis L., Beckx C. and Arentze T. (2008) An integrated activity-based approach for air quality issues

29 Kang J. E. and Recker W. W. (2009) An activity-based assessment of the potential impacts of plug-in hybrid electric vehicles on energy and emissions using 1-day travel data. 2009 Elsevier Ltd.

30 Karplus V. J. (2008) Prospects for Plug-in Hybrid Electric Vehicles in the United States: A General Equilibrium Analysis. Massachusetts Institute of Technology.

31 Knapen L., Kochan B., Bellemans T., Janssens D. and Wets G. Activity based models for countrywide electric vehicle power demand calculation

32 Kochan B., Bellemans T. Janssens D. and Wets G. (2008) Assessing the Impact of Fuel Cost on Traffic Demand using Activity-Based Models. Travel Demand Management TDM Vienna 2008

33 Kurani K. S., Torrentine T. and Sperling D. (1994) Demand for Electric Vehicles in Hybrid Households: An Exploratory Analysis. Institute of transportation Studies, University of California at Davies

34 Kurani K. S., Turrentine T. and Sperling D. (1994) Demand for electric vehicles: An exploratoryanalysis.

35 Lemoine D., Kammen D. M. and Farrell A. E. (2006) Effects of Plug-In Hybrid Electric Vehicles in California Energy Markets

36 Markel T. (2010) Plug-in Electric Vehicle Infrastructure: A Foundation for Electrified Transportation

37 McNally M. G. (1996) An Activity-Based Microsimulation Model for Travel Demand Forecasting. Center for Activity Systems Analysis, Institute of Transportation Studies, UC Irvine

38 Mock P., Hülsebusch D., Ungethüm J., and Schmid S. A. (2009) Electric vehicles – A model based assessment of future market prospects and environmental impacts. Institute of Vehicle Concepts, Stuttgart, Germany

39 National Renewable Energy laboratory, NREL (2011) Electric-Drive Vehicle Basics. Energy Efficiency & Renewable Energy

40 Nemry F., Leduc G. and Muñoz A. (2009) Plug-in Hybrid and Battery-Electric Vehicles: State of the research and development and comparative analysis of energy and cost efficiency

41 Paleti R., Eluru N., Bhat C. R., Pendyala R. M. Adler T. J. and Goulias K. G. (2010) The Design of a Comprehensive Microsimulation of Household Vehicle Fleet Composition, Utilization and Evolution

42 Papalexandrou M. A., Pilavachi P. A. and chanzimouratidis A. I. (2007) Evaluation of liquid bio-fuels using the Analytic Hierarchy Process. Proceedings of European Congress of Chemical Engineering (ECCE-6) Copenhagen, 16-20 September 2007

43 Patricia B., Catarina R. and Carla S. (2011) Plug-In Vehicle Acceptance and Probable Utilization Behaviour. Journal of Transportation Technologies, 2012

44 Patricia B., Ma´rio T., and Carla S. (2009) Plug-in hybrid fuel cell vehicles market penetration scenarios. international journal of hydrogen energy 3 5 (2 0 1 0)

45 Perujo A. and Ciuffo B. (2009) Potential Impact of Electric Vehicles on theElectric Supply System: A case study for the Province of Milan, Italy

46 Poh, K.L., Ang, B.W. (1999) Transportation fuels and policy for Singapore: an AHP planning approach.

47 Ramanathan R. (2001) A note on the use of the analytic hierarchy process for environmental impact assessment. Journal of Environmental Management [Academic Press 2001]

48 Reza B. (2010) Evaluation of land use-transportation systems with the Analytic Network Process. The Journal of Transport and Land Use Vol. 3. No. 1 [Spring 2010]

49 Saaty (2008) Decision making with analytic hierarchy process, Int. j. Services Sciences, Vol. 1, No 1, 2008

50 Saaty T. L. (1990) How to make a decision: The Analytic Hierarchy Process. European Journal of Operational Research 48 (1990) 9-26

51 Schrooten L., De Vlieger I., Int Panis L. and Torfs R. (2006) Activity based emission model for sea-going vessels. REIMS, Transport and Air Pollution, vol.2, no.107, pp.297-303, 2006

52 Shang G. and Zaiyue Z. (2010) Calculating Weights Methods in Complete Matrices and Incomplete Matrices. Journal of Software, Vol. 5, No. 3 March 2010

53 Shiftan Y. (2003) Acitivity-based modelling as a tool for better understanding travel behaviour). 10th International Conference on Travel Behaviour Research, Lucerne, 10-

15 August 2003

54 Shiftan Y. (2006) The use of activity-based modeling to analyze the effect of land-use policies on travel behavior. Springer-Verlag 2007

55 Shiftan Y., Ben-Akiva M., Proussaloglou K., de Jong G., Popuri Y. kasturirangan K. and bekhor S. (2003) Activity-Based Modeling as a Tool for Better Understanding Travel Behaviour 10th International Conference on Travel Behaviour Research

56 Skoog S. (2009) Power Sources for Hybrid Electric Vehicles. Lund University

57 The Report of an Expert Panel (2011) Plug-in Electric Vehicles: A Practical Plan for Progress. School of Public and Environmental Affairs at Indiana University

58 Turrentine T., Delucchi M., Heffner R. R., Kurani K. S. and Sun Y. (2006) Quantifying the benefits of hybrid vehicles. Institute of Transportation Studies, UC Davis

59 Turrentine T., Lee-Gosselin M., Kurani K. and Sperling D. (1992) A Study of Adaptive and Optimizing Behavior for Electric Vehicles Based on Interactive Simulation Games and Revealed Behavior of Electric Vehicle Owners

60 Tzeng G., Lin C. and Opricovic S. (2005) Multi-criteria analysis of alternative-fuel buses for public transportation Elsevier Ltd. Energy Policy 33 (2005)

61 van Haaren R. (2011) Assessment of Electric Cars‟ Range Requirements and Usage Patterns based on Driving Behavior recorded in the National Household Travel Survey of 2009. Earth and Environmental Engineering Department, Columbia University.

62 Van Roy J., Leemput N., De Breucker S., Geth F., Tant P. and Driessen (2011) An Availability Analysis and Energy Consumption Model for a Flemish Fleet of Electric Vehicles

63 Went A., Newman P. and James W. (2008) Renewable Transport: How Renewable Energy and Electric Vehicles using Vehicle to Grid technology can make Carbon Free Urban Development. Curtin University Sustainability Policy (CUSP) Institute.

64 Winebrake J. J. and Creswick B. P. (2003) The future of hydrogen fuelling systems for transportation: An application of perspective-based scenario analysis using the analytic hierarchy process. Technological Forecasting & Social Change

65 Yang C. and McCarthy R. (2009) Electricity Grid: Impacts of Plug-In Electric Vehicle Charging. Institute of Transportation Studies, UC Davis

66 Yoram W. and Saaty T. L. (1980) Marketing Applications of the Analytic Hierarchy Process. Management Science Vol. 26. No. 7, July 1980

APPENDICES

Appendix 1: Personal online questionnaire

Top of Form

Topic: Added advantage of Activity-based model in the debate on electric vehicle

The aim of this survey is provide data to help us model how people decide to use which car for which trip type when the household has a gasoline car and an electric car or a hybrid car present at same time for a household with more than a licensed person to drive. This car swap modeling process is based on certain characteristics of the various vehicle options and behavioural factors of the household members. The swap process is assumed to take place when both vehicles are present at a given time for both (or more than two) household members. The usual barrier to own a full electric vehicle (battery operated only) is the distance it can travel with a fully charged battery. For this reason, plug-in hybrid cars (battery + gasoline operation)are more accepted. This factor plays a role in the choice \ swap process this survey deals with. By gasoline fuelled cars, it is meant cars with normal internal combustion engines whether petrol or diesel fuelled.

Start

1.

What is your sex?

2.

Are you married?

3.

Are you employed?

4.

What is your level of education?

5.

How many members are there in your household?

6.

How many members of your household own a driver's license?

7.

How many cars do you have in your household?

8.

What is the average distance you travel per day by car?

9.

Can you give the average distance (km) over which you travel to perform the following activities

	0 to 40km	40 to 60km	60 to 80km	80 to 100km	Above 100km
Work	○	○	○	○	○
Shopping	○	○	○	○	○
Bring/pick children from	○	○	○	○	○

school Visits					
Leisure	○	○	○	○	○
Visits	○	○	○	○	○

10.

Are you informed about electric vehicles?

11.

If there is at least one car (gasoline car) in your household and you were given an option to own another vehicle which is an electric vehicle, which kind of electric vehicle will you prefer?

12.

If both, the gasoline car and the electric (or hybrid) car were available to your household at a given time during the day, will you consider car swapping with your partner?

13.

If yes, what are the factors that influence your willingness to swab between cars?

In the following section we would like to elicit your opinion as expert on transportation research. This section is made of pair-wise comparisons of certain criteria in terms of achieving the goal of getting the most favorable vehicle choice to swab with the conventional gasoline vehicle that is already present in the household. This will be done by applying weights from the Saaty's scale of 1 to 9 to each criteria, for the weight that one criteria has over the other with respect to meeting the goal. In this case the inferior criteria is given a weight of 1 and the superior criteria any weight from 2 to 9 accordingly. This will be applied also when applied weights to pairs of vehicle alternative in terms of meeting the various criteria.

SAATY SCALE

Numerical Values----------- Verbal Scale----------------------------- Explanation

1 ---- -------------Equal importance of both elemen------------- Two elements contribute equally

3 ----Moderate importance of one element over another ----- --Experience and judgment favour one element over another

5 ----Strong importance of one element over another ---------- An element is strongly favoured

7 ----Very strong importance of one element over another -----An element is very strongly

dominant

9 ---- Extreme importance of one element over another ------- An element is favoured by at least an order of magnitude

2,4,6,8 ---- ------------Intermediate values ---------- Used to compromise between two judgments

Please apply weights to these pairs of criteria below in terms of meeting the goal of choosing the most suitable vehicle to swap with a gasoline vehicle.

14.

For the following questions, please apply weights to the pairs of criteria below in terms of meeting the goal of choosing the most suitable vehicle to swap with gasoline vehicle. (NB: Inferior criteria should have a weight of 1, while superior criteria should have a weight from 2 to 9)

	weights
Eco-friendliness (emissions reduction)	
Range anxiety (of driver)	

15.

	weights
Eco-Friendliness (emissions reduction)	
Practical reasons (convenience)	

16.

	weights
Eco-friendliness (emissions reduction)	
Economic reasons (fuel cost savings)	

17.

	weights
Eco-friendliness (emissions reduction)	
Social reasons	

(social image and status)

18.

	weights
Range anxiety (of driver)	
Practical reasons (convenience)	

19.

	weights
Range anxiety (of driver)	
Economic reasons (fuel costs savings)	

20.

	weights
Range anxiety (of driver)	
Social reasons	

(social image and status)	

21.

	weights
Practical reasons (convenience)	
Economic reasons (fuel costs savings)	

22.

	weights
Practical reasons (convenience)	
Social reasons (social image and status)	

23.

	weights
Economic	

reasons (fuel costs savings)	
Social reasons (social image and status)	

24.

Please apply weights to the following vehicle alternatives in terms of Eco-friendliness abilities (From a driver point of view). (NB: Inferior vehicle should have weight of 1, while superior vehicle should have a weight from 2 to 9)

	weights
Gasoline (normal) vehicle	
Plug-in hybrid electric vehicle	

25.

	weights
Gasoline (normal) vehicle	
Battery electric vehicle	

26.

	weights
Plug-in hybrid electric vehicle	
Battery electric vehicle	

27.

Please apply weights to these vehicle alternatives based on how you as a driver, perceive the importance of travel range \ range anxiety when deciding to swap cars for following ownership scenarios (NB: Inferior vehicle should have weight of 1, while superior vehicle should have a weight from 2 to 9)

	weights
Gasoline (normal) vehicle	
Plug-in hybrid electric vehicle	

28.

	weights
Gasoline (normal) vehicle	

Battery electric vehicle	

29.

	weights
Plug-in hybrid electric vehicle	
Battery electric vehicle	

30.

Please apply weights to these pairs of vehicle alternatives in terms of practical reasons (convenience). (NB: Inferior vehicle should have weight of 1, while superior vehicle should have a weight from 2 to 9)

	weights
Gasoline (normal) vehicle	
Plug-in hybrid electric vehicle	

31.

	weights

Gasoline (normal) vehicle	
Battery electric vehicle	

32.

	weights
Plug-in hybrid electric vehicle	
Battery electric vehicle	

33.

Please apply weights to these pairs of vehicle alternatives in terms of economic reasons (fuel cost savings). (NB: Inferior vehicle should have weight of 1, while superior vehicle should have a weight from 2 to 9)

	weights
Gasoline (normal) vehicle	
Plug-in hybrid vehicle	

34.

	weight
Gasoline (normal) vehicle	
Battery electric vehicle	

35.

	weight
Plug-in hybrid electric vehicle	
Battery electric vehicle	

36.

Please apply weights to these pairs of vehicle alternatives in terms of social reasons (social image and status). (NB: Inferior vehicle should have weight of 1, while superior vehicle should have a weight from 2 to 9)

	weights
Gasoline (normal vehicle	
Plug-in hybrid electric vehicle	

37.

	weights
Gasoline (normal) vehicle	
Battery electric vehicle	

38.

	weights
Plug-in hybrid electric vehicle	
Battery electric vehicle	

39.

What in your opinion do you think can be done by government to encourage the future use of electric vehicles?

40.

What do you think can be done to encourage car swapping between gasoline vehicle (for long distances) and electric vehicle (for short distances)?

41.

Which other factors do you think is important for members of same household to perform car swapping?

42.

What would be your reasons to own/use an electric vehicle (select all that apply)?

- ☐ Economic/fuel costs savings
- ☐ Environment /reduced emissions
- ☐ Technology
- ☐ Convenience and home charging advantage

- [ ] Comfort
- [ ] Low noise level
- [ ] Fast acceleration rate
- [ ] Social status and image

43.

Was the questionnaire understandable?

Submit survey

Appendix 2: Absolute weights applied to qualitative paired comparisons

Intensity of Importance	**Definition**	**Explanation**
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another, its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Resiprocals of above	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	A reasonable assumption

(Source: Saaty, 2008, p. 86)

Appendix 3: The average consistencies of random matrices (RI values)

Size	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

(Source: Saaty 2000, page 264)

Detailed calculations

Appendix 4: Matrix for Eco-friendliness

Eco-friendliness					
Alternatives	Status quo	PHEV	EV	nth root of sum of products	Eigenvector
Status quo	1	¼	1/6	0.347	0.082
PHEV	4	1	¼	1.000	0.236
EV	6	4	1	2.884	0.682
Total	11	5.250	1.417	4.231	1.000
T*E	0.902	1.239	0.966		
Lamda max	3.1				
CI	0.05				
CR	0.08				

Appendix 5: Matrix for Range Anxiety

Range Anxiety					
Alternatives	Status quo	PHEV	EV	nth root of sum of products	Eigenvector
Status quo	1	1/3	1/4	0.437	0.117
PHEV	3	1	1/3	1.000	0.268
EV	4	3	1	2.289	0.614
Total	8	4.333	1.583	3.726	1.000
T*E	0.936	1.161	0.972		
Lamda max	3.069				
CI	0.03				
CR	0.058				

Appendix 6: Matrix for Convenience

Convenience					
Alternatives	Status quo	PHEV	EV	nth root sum of products	Eigenvector
Status quo	1	1/3	4	1.101	0.291
PHEV	3	1	4	2.289	0.604
EV	¼	1/4	1	0.397	0.105
Total	4.3	1.6	8	3.787	1.000
T*E	1.251	0.966	0.840		
CI	0.394				
CR	0.757				

Appendix 7: Matrix for Social status and image

Social status and image					
Alternatives	Status quo	PHEV	EV	nth root of sum of product	Eigenvector
Status quo	1	1/4	1/3	0.437	0.126
PHEV	4	1	1	1.587	0.458
EV	3	1	1	1.442	0.416
Total	8	2.25	2.33	3.466	1.000
T*E	1.008	1.031	0.969		
CI	0.233				
CR	0.448				

Appendix 8: Matrix for Fuel cost savings

Fuel cost savings					
Alternatives	Status quo	PHEV	EV	nth root of sum of products	Eigenvector
Status quo	1	1/4	1/6	0.347	0.085
PHEV	4	1	1/3	1.101	0.271
EV	6	3	1	2.621	0.644
Total	11	4.25	1.5	4.069	1.000
T*E	0.935	1.152	0.966		
Lamda max.	3.053				
CI	0.027				
CR	0.05				

Appendix 9: Matrix for criteria in terms of reaching the goal

Criteria	Eco-friendliness	Range Anxiety	Convenience (Practical reasons)	Fuel cost savings (Economic reasons)	Social image and status	nth root of sum of product	Eigenvector
Eco-friendliness	1	1/3	4	1/5	5	1.059	0.147
Range Anxiety	3	1	4	1/5	4	1.572	0.218
Convenience (Practical reasons)	¼	¼	1	1/5	3	0.519	0.073
Fuel cost savings (Economic reasons)	5	5	5	1	6	3.758	0.522
Social image and status)	1/5	¼	1/3	1/6	1	0.289	0.040
Total	9.45	6.83	14.33	1.77	19	7.197	1.000
T*E	1.389	1.489	1.046	0.924	0.760	5.608	
CI	0.152						
CR	0.136						

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Richting: **master in de verkeerskunde-mobiliteitsmanagement**
Jaar: **2013**

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