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SCIENCE FOR A SUSTAINABLE DEVELOPMENT

TRANSITION PATHWAYS TO EFFICIENT (ELECTRIFIED) TRANSPORT FOR HOUSEHOLDS

«TRANS2HOUSE»

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FINAL REPORT

TRANSITION PATHWAYS TO EFFICIENT (ELECTRIFIED) TRANSPORT FOR HOUSEHOLDS

"TRANS2HOUSE"

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Acronyms, Abbreviations and Units

A_0	Amount of recurring cost
A_t	Amount of one-time cost at a time t
AHP	Analytic Hierarchy Process
BELSPO	Belgian Science Policy
BEV	Battery Electric Vehicle
CO	Carbon monoxide
CNG	Compressed Natural Gas
CO_2	Carbon dioxide
DER	Distributed Energy Sources
DOE	Degree of Electrification
EV	Electric Vehicle
FU	Functional unit
GDSM	Group Decision Support Methods
GWh	Giga Watt hour
HEV	Hybrid electric vehicle
I	Real discount rate
ICE	Internal Combustion Engine
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCC	Life Cycle Cost
LHV	Lower Heating Value
Li	Lithium
LPG	Liquefied Petroleum Gas
MAMCA	Multi-Actor Multi-Criteria Analysis
NEDC	New European Driving Cycle
NiMH	Nickel Metal Hydrid
NO_x	Nitrogen oxides
PHEV	Plug-in Hybrid Electric Vehicle
PV	Photovoltaic
PV	Present Value
SO_x	Sulphur oxides
TtW	Tank-to-Wheel
TCO	Total Cost of Ownership
VMT	Vehicle Miles Travelled
VAT	Value Added Tax
WtT	Well-to-Tank
WtW	Well-to-Wheel
µCHP	Micro Combined Heat and Power

Executive summary

A. Context

The European 20-20-20 objective aims at reducing greenhouse gases by 20 %, increasing the share of energy from renewable sources by 20%, as well as achieving an overall increase of 20 % in energy efficiency by the year 2020. Meeting this objective will not be straightforward; several studies predict even an increase in energy consumption for the coming years. A shift to a more rational energy use is essential in attaining these objectives. This transition must be supported by the demand side of the economy. Therefore this project aims at households and how to achieve a decline in their energy consumption. Consumers are generally in favor of ecologically friendly transformations regarding energy usage and production, but their environmental consciousness is not translated in adapted consumption patterns and behavior. Therefore it is necessary to better understand the factors that influence household energy consumption and to formulate driving forces to shift existing barriers (social, cultural, technological, economic, legislative and political). The scope of the investigation is the personal mobility part of the household energy consumption. To introduce 20% of renewable energy in 2020, storage is considered as an essential element to absorb the green energy when it is produced without overloading the network. If the charging periods of the electrified cars can be controlled, they can be transformed into flexible consumers in the distribution grid. This would help both politicians as well as the energy distribution companies. In the European Competitiveness Report, the energy market liberalization is one of the most important drivers of competitiveness while their innovation focus moves towards cost-reducing technologies and consumer services. Electric vehicles (EVs) and plug-in hybrid vehicles (PHEVs) are seen as a core part of this innovation. Recently, EV and PHEV are receiving a tremendous interest from consumers, car manufactures, politicians and energy companies, who are now finding themselves ready to be a part of the introduction of these types of cars. So it seems that a transition of the whole mobility concept is about to happen in favor of an electrified propulsion system. But are we ready for this change? Which actions can be taken to facilitate this transition and which ones to make this change even more beneficial? How can policy steer households in an energy efficient way?

B. Objectives

The main objective of the Trans2House project is to investigate how to develop driving forces and shift the social, cultural, technological, economic and political barriers to household energy consumption reduction. The focus is on personal transport, as a part of the household. Public transportation, electric scooters and bicycles however fall out of the scope of this project. This study also aims at assessing the transition towards EVs and PHEVs for Belgium and its regions, while having a critical eye on their impact on the sustainability goals as defined in the EU 20-20-20 objective. It considers also the budgetary impact on households, the impact on employment and related economic issues like the competitiveness of Belgium. Due to the higher energy efficiency, a reduction in fuel consumption is expected when introducing electrified transport. This will result in a decrease in fuel expenses for households. Whether the fuel saving leads to less CO_2 emissions strongly depends on the way the extra electricity need will be produced. The electrified vehicles can extend the green energy production by being flexible consumers if their charge moments are controlled. Other emissions as NO_x and small particles are in all cases diminishing and in addition no pollutants are emitted where the vehicles are driving. These considerations have been explored in this project and transformed to the Belgian situation.

C. Main conclusions/recommendations

The technical implications of the roll-out of electric vehicles in Belgium have been assessed. In a distribution grid with a low amount of electrical vehicles to be charged, the impact on the local grid of the electrical vehicles is rather low and probably non-problematic. In distribution grids where the density of electrical vehicles is relatively large, the main problems that will occur are: an increased peak power through the distribution transformers and distribution feeders, an increased voltage drop over the feeders and an increased unbalance in the three-phase system.

For the purpose of evaluating various powertrain types in terms of environmental impact and primary energy consumption over their entire life time, life cycle assessment (LCA) is being used. Different scenarios for BEV’s using different types of electricity have been compared with conventional and alternative vehicles. When combining all environmental impacts in one single score, BEVs powered with wind power and hydropower and the Belgian electricity mix have the lowest effects.

A total cost of ownership (TCO) has been conducted in order to investigate the financial attractiveness of electric vehicles (battery electric and plug-in hybrid electric) compared to conventional petrol, diesel, LPG and CNG cars. We found that for city cars, the higher purchase costs for EVs entail a large difference in TCO compared to the conventional cars. Even though the fuel operating costs are much lower, they cannot outweigh the high purchase costs. Within the medium car segment, the difference between the conventional and the electric vehicles is lower. This seems to be due to the fact that their purchase costs are closer to those of the conventional cars. In general, the purchase cost of electric vehicles is highly linked to the size of the battery pack, and not to the size of the electric vehicle.

Given the fact that EVs have some positive characteristics (low driving cost, high environmental performance…) as well as some negative ones (high purchase price, limited driving range…), today's' consumers still opt for a conventionally powered vehicle. The investigation of the purchasing behavior underlines the importance of knowledge within the purchasing process. The gathering of this knowledge is regarded as very important, especially for new products that are relatively unknown for the current consumers. Also, the role of group influence on the consumer's choice should not be neglected.

Countering the limited driving range for BEVs, on average between 100-150km, we investigated with a travel behavior assessment, the average daily mileage and the average mileage per trip, based on travel data from Onderzoek Verplaatsingsgedrag Vlaanderen (OVG4.2). We found that 65% of the average travelled distance per day by car is lower than 40 kilometers, while only 6% of all the car trips, made by Flemish people, is longer than 40 kilometers. This means that almost 94% of Flemish citizens use a car for trips of less than 40 km. This illustrates that electric vehicles are already suitable for a large amount of travel decisions.

The final step of this project consisted of elaborating a set of policy measures fitting into the different transition pathways. These measures can be used by policy makers in order to facilitate the specific transition pathway towards electric vehicles. The arrangement of the set of policy measures was done in a qualitative way, just as the estimation of their budgetary, economic, employment, social and environmental impacts. We distinguished between two types of policy measures: quick-win initiatives and tailor-made measures. The former category is not a priori linked to any specific transition pathway. Such quick-win measures are relatively easy to implement, and will probably constitute an important factor to a successful breakthrough of electromobility. The stakeholders agreed on the fact that both the transformation pathway (which can be considered as the baseline) and the de- and re-alignment scenario should not be supported.

D. Contribution of the project in a context of scientific support to a sustainable development policy

The Trans2House project and the introduction of (PH)EVs can stimulate the development of the scientific potential in different strategic areas:

- anticipating on the future needed scientific and technological knowledge (concerning smart grids, (PH)EVs and renewable energy sources);

- scientific support for authorities required to meet local, regional, federal or international goals in the field of emission control and energy savings, such as the “Energy – Climate” package approved by the European Council in December 2008. The results of the project will help to investigate the possibilities for meeting different targets;
- a Belgian research potential to be involved in various European and international research initiatives, addressing the roll-out of EVs and the development of smart grids. All the developed models and databases have the possibility to be adapted or extended to different countries;
- help to introduce, develop and promote a more sustainable personal transportation system.

Practically the project will contribute to the development of scientific knowledge and instruments:

- the development of databases with technical and environmental parameters for different types of (PH)EVs and conventional vehicles;
- the development of environmental indicators to evaluate the overall environmental performance of different types of (PH)EVs;
- an energetic well-to-wheel assessment of (PH)EVs to analyze their contribution to the possible decrease of household energy consumption;
- understanding the driving forces which can stimulate households as an important part of the demand side;
- models to compare the costs of different energy vectors (fossil fuels, nuclear fuels,
- renewable energy sources, electricity, hydrogen...) for the transport sector, taking into account not only the private costs but also a series of external costs such as environmental impacts throughout a product’s life cycle, costs such as price volatility associated, while bearing in mind that costs may vary in time: some energies that are more expensive in the short term may turn out to be cheaper in the long term;
- scenarios to forecast the influence of the Belgian supply mix on the overall energy efficiency of households and the environmental benefits of more renewable energy sources;
- a Multi-Actor Multi-Criteria Analysis (MAMCA) will evaluate transition pathways and policy measures on their efficiency, feasibility and acceptability. The role

which public authorities can play in terms of energy choices and clean transport technologies will be analyzed.

E. Keywords

(Plug-in Hybrid) Electric Vehicles, households, transport, electricity network, smart grid, charging infrastructure, energy, environment, transition pathways, Life Cycle Cost analysis, Life Cycle Assessment, barriers, purchase behavior, travel behavior, MAMCA, stakeholder validation

1. Introduction

1.1 Context

Consumers generally support ecologically friendly transformations regarding energy usage and production, but their environmental consciousness is not translated in adapted consumption patterns and behavior. Therefore it is necessary to better understand the factors that influence household energy consumption and to formulate driving forces to shift existing barriers (social, cultural, technological, economic, legislative and political). Recently, electric vehicles (EV) and plug-in hybrid vehicles (PHEV) are receiving a tremendous interest from consumers, car manufactures, politicians and energy companies, who are now finding themselves ready to be part of the introduction of these types of vehicles. The push from political side can be explained in several ways. A private car consumes about the same amount of energy as the electricity needed for a private house. Due to the higher efficiency of an EV and a PHEV compared to traditional cars and due to the stationary production of electricity in power plants, these cars can be much cleaner than the traditional ones and may be cheaper in use for households. EVs and PHEVs may play a substantial role in the energy reduction and greenhouse gas emission goals of the 20-20-20 objective. These are important political aspects. Politics also push the EVs and PHEVs forward to save the European car industry, supporting the European strategy for growth and jobs according to the Lisbon policies. For electricity companies, EVs promise an increased electricity demand and many of them are eager to install the charging infrastructure to exploit the EV as quickly as possible. EVs also introduce electric storage in the grid, which is a new concept to be exploited at low voltage distribution level. To introduce 20% renewable energy in 2020, storage is considered as an essential element to absorb the green energy when it is produced without overloading the network. Renewable energy, such as wind power, is often not produced when it is needed. If the charging periods of the electrified cars can be controlled, they can be transformed into flexible consumers in the distribution grid. This would help both politics and the energy distribution companies. In the European Competitiveness Report of the European Commission, the energy market liberalization is one of the most important drivers of competitiveness while their innovation focus moves towards cost-reducing technologies and consumer services. EVs and PHEVs are seen as a core part of this innovation.

So it seems that a transition of the whole mobility concept is about to happen in favor of an electrified propulsion system. But are we ready for this change? Which actions can be taken to facilitate this transition and which ones to make this change even more beneficial? From an energy demand viewpoint, the introduction of EVs will raise the electricity demand only by a few percent[1]. On the other hand, if all EVs are recharged at the same moment, the electric grid will be overloaded. The introduction of environmentally friendly cars, such as EVs and PHEVs will need the introduction of a smart grid, which knows when to charge the batteries of the individual vehicle. The introduction of a smart grid is an opportunity to make the power grid more reliable and efficient.

1.2 Objectives

The main objective is to investigate how to develop driving forces and shift the social, cultural, technological, economic and political barriers to household energy consumption reduction. The focus is on personal transport, as a part of the household. Public transportation, electric scooters and bicycles are beyond the scope of this project.

This study also aims at assessing the transition towards EVs and PHEVs for Belgium and its regions, while having a critical eye on their impact on the sustainability goals as defined in the EU 20-20-20 objective. It also considers the budgetary impact on households, the impact on employment and related economic issues like the competitiveness of Belgium.

Due to the higher energy efficiency, a reduction in fuel consumption is expected when introducing electrified transport. This will result in a decrease in fuel expenses for households. Whether the fuel saving lead to less CO_2 emissions, strongly depends on the way the extra electricity need will be produced. The electrified vehicles can extend the green energy production by being flexible consumers if their charging moments are controlled. Other emissions as NO_x and small particles are in all cases diminishing and in addition no pollutants are emitted where the vehicles are driving.

These considerations have been explored in this project and transformed to the Belgian situation.

1.3 Methodology

To achieve these objectives, a multidisciplinary approach has been used, in which the different tasks are performed by the different partners.

On the basis of a literature review, a preliminary “state-of-the-art” has been carried out on different topics, more specifically on :

- the Belgian electricity network,

[1] A Belgian fleet containing 10% EVs means more or less 500.000 EVs on the roads (assuming that there is a total of 5 million Belgian vehicles). The total electricity consumption is 110 GWh (220Wh/km x 10.000 km/year x 500.000 EVs), which is only 1,375% of the total annual electricity consumption in Belgium.

- experiences of previous (PH)EV deployment projects with focus on infrastructure,
- technological development of (PH)EVs and their relevant components,
- energy use and sustainability indicators of (PH)EVs and conventional vehicles (e.g. oil dependency, renewable energy, greenhouse gases and environmental impact)
- overview of transition pathways in past and ongoing initiatives
- transport and mobility related incentives for the use of (PH)EVs in households

During the second phase, the core of the project, the different impacts of the roll-out of EVs and PHEVs have been assessed. The impacts on the electricity grid and on households have been examined from a technological, environmental, economic and social point of view.

First an impact study of the roll-out of (PH)EVs in Belgium on the existing electricity grid has been performed from the perspective of the production and distribution side (up to the household plug). What are the basic requirements of the electricity grid to support a first introduction of (PH)EVs in Belgian households? Different aspects have been considered, like charging concepts, standardization, safety, infrastructure cost, energy management, billing scenarios, communication, end user interaction, etc. To improve energy efficiency in households, the local electricity network should be made more intelligent (“smart grids”). Therefore more and more investments are done on the installation of local, renewable energy production systems, like PV and µCHP. The introduction of a huge amount of such distributed energy resources (DER) will have a major impact on the electricity grid if too much power goes back into the net. By combining the local production and demand in an intelligent way further cost savings can be established. An overview of the basic set of tools needed to match local power and demand on household level has been made up.

Due to the higher energy efficiency, a reduction in energy consumption is expected when driving (PH)EVs. A well-to-wheel (WtW) energy analysis can be used to analyze the energy consumption of different vehicles. Such an analysis considers both direct (or tank-to-wheel) and indirect (or well-to-tank) energy use (energy consumption during the production and distribution of the fuel or electricity). The WtW approach allows a consistent comparison of vehicles using different fuels (petrol, diesel, liquefied petroleum gas, compressed natural gas, bio-fuels, etc.) and/or different drive train technologies (internal combustion engines, hybrid electric drive trains, battery electric drive trains, fuel cell electric drive trains, etc.). Direct energy consumption is linked to the use of a vehicle. (PH)EVs have, in general, lower energy consumption due to the high energy efficiency of an electric motor in comparison with a combustion engine.

In the case of vehicles operating with an internal combustion engine, the indirect energy consumption is related to the extraction and transportation of the raw materials for the fuel production, together with the energy linked to refining and distributing the carburant. When considering the use of (PH)EVs, the indirect energy is the energy consumption related to electricity generation and distribution. Energy efficiency of (PH)EVs also depends on the way the extra electricity need is produced on the charging moment. Therefore the Belgian supply mix has been investigated on a certain moment. With the introduction of smart grids, electrified vehicles can extend the green energy production by being flexible consumers. The environmental impact of (PH)EVs has been analyzed using the Life Cycle Assessment (LCA) methodology, which is a standardized methodology (Consoli et al., 1993; ISO14040, 1997). LCA has already been applied several times in the context of road vehicles (see (Davison, 1999; Nicolay et al., 2000; Chainet, 1999) in particular). The results and models of the CLEVER project (Van Mierlo et al., 2011) have been adapted and extended for this purpose. Besides the well-to-wheel emissions, the LCA also includes cradle-to-grave emissions (related directly and indirectly to vehicle production and end-of-life processing of the vehicle). The environmental data gathered have been converted and allocated to a set of indicators for pollutants and waste loading in the following life cycle impact analysis. Retained classes are acidification, eutrophication, greenhouse gases, chemical toxicity indicators, depletion of the ozone layer, consumption of renewable and non-renewable energy, waste production and land-use. The effects of the emissions are weighted and quantified within each impact category. The total effect for each effect category is obtained by multiplying the inventory interventions by the respective characterization factors (e.g. zinc equivalents, CO_2 equivalents, etc.).

A Total Cost of Ownership (TCO) analysis is used to determine the cost per kilometer for the lifecycle of the car, a method also described as a Life Cycle Cost analysis. All the anticipated costs associated with the purchase and the use of a car are included in this analysis. By making the real cost per kilometer visible, it can give households an insight in their vehicle expenses over time. The TCO has been calculated for vehicles with conventional fuels (e.g. diesel, gasoline), alternative fuels (e.g. LPG, CNG) and alternative propulsion systems (battery electric vehicles and plug-in hybrids). As such, an indication of the cost-efficiency of electric vehicles compared to other vehicle technologies can be given, taking into account different electricity prices. In order to better understand the importance of the environmental friendliness in the purchase decision of consumers, insights will be gained from data available from the CLEVER project (Van Mierlo et al., 2011).In the frame of this project, a large scale survey has been performed including questions on the willingness to pay for environmental friendliness, household income, number of cars in the household etc. As such, it is possible to identify which types of households display a preference for environmentally friendly vehicles and for which households electric vehicles can become an interesting option.

Consequently, it has been investigated whether the limited driving range and longer recharging times of electric vehicles would really represent barriers for considering electric vehicles in daily travel decisions. The focal point is to analyze the current travel behavior of conventional car use and to examine the practical feasibility of including the use of electric cars in daily travel decisions. The analysis of the current travel behavior has been performed on data available from OVG4.2 (OVG, 2011). Based on this information, different types of traveler groups could be identified, characterized by certain travel behaviors. For each of these travel clusters, it has been subsequently identified to what extent the use of an electric car can be proposed as a feasible alternative for the use of a conventional car. Also a qualitative study has been performed on social barriers, incentives, driving forces and stimulations relative to the use of EVs by households in Belgium. This study has been based on the comprehensive study of energy and transport related behavior of households qualified as forerunners in the related fields. Those forerunners have been interviewed on their experience of change and on their expectancies and potential projects related to the use of EVs. The results of those interviews allowed to identify barriers (social and financial), potential incentives, the driving process of changes while comparing the new change (moving to EVs) and an already lived through process of important change. The initial resistance towards new technologies needs to be overcome, the refilling/charging infrastructure needs to be built, the new technologies need to be tested in real life conditions, etc. The (PH)EV are a fine example of a valuable technology that has the potential to become a ‘chicken or egg’ problem, only an integrated approach tackling the different aspects can offer a solution. This integrated approach can be covered by transition pathways, which comprise the different steps needed in the process towards electrified transport for households.

Since (PH)EVs have typical limitations but also offer specific benefits, it is imaginable that these vehicles will not be applied in the same manner as the classical fossil fuel vehicles. Several smaller EVs being shared by communities for short distance trips (cities, shopping,…), a few PHEVs with significantly larger range and capacity for the occasional long distance holiday trips, etc. Transition pathways have been developed towards these new mobility concepts and thus stimulating the roll-out of (PH)EVs. Typical transition elements are part of the pathways, such as definition of experiments and demonstration projects needed to facilitate the transition, definition of milestones, stakeholder consultation, etc. These pathways have been adapted to the typically Belgian situation and based upon a range of input sources already realized in previous tasks of the project. An additional survey has been performed to provide extra input, consulting key stakeholders. This has provided relevant information of the current and future key players on the Belgian market (car manufacturers, electricity production and distribution, but also lease companies, cities, large shops, …). What is feasible from their point of view, what is realistic, which are the barriers that need to be overcome, etc. The developed preliminary transition pathways have been validated by a multi-stakeholder process. The preliminary results of the transition process have been presented to different actors in the field and target groups in Belgium, to ensure efficiency, feasibility, acceptability, etc. of the elements in the pathways. The participants of the stakeholder meetings have been able to present their views on the proposed transition elements and the process as a whole. The most appropriate method that enables the integration of the results and that allows for an assessment of several transition pathways is the Multi-Actor Multi-Criteria Analysis (MAMCA), developed by the department MOSI-T (Macharis, 2000; Macharis & Boel, 2004). The MAMCA explicitly includes the stakeholder's opinions in the evaluation of different policy measures. As such, the MAMCA is able to support the decision maker in his final decision as the inclusion of the different points of view leads to a general prioritization of proposed policy measures. The results of the multi-stakeholder validation were then taken into account to define a final set of transition pathways. Specific attention has been attributed to the distillation of a number of policy measures dedicated to the stimulation of the transition process towards an electrified transport for households. This set of new and adequate policies has been designed to affect household energy consumption used for transport in a positive way. Also their budgetary, employment, social, environmental and economic impacts have been highlighted. This final set contains measures to be taken on a short, medium and long term, and is also compared with the way the same issues are handled in neighboring countries.

2. Impact analysis on the electricity grid

2.1 Impact on the distribution grid

To charge the battery of an electric vehicle, it will be connected to a low voltage distribution grid. Generally speaking, the distribution grid is designed so that the power rating of the grid infrastructure is larger than the maximal expected peak power demand, in order to take into account a future increase in power demand. So the introduction of a small number of electrical vehicles within one neighborhood will not immediately lead to problems with the distribution grid infrastructure. However, as the number of electrical cars increases, it is more likely that certain problems will occur: an increased peak power through the distribution transformer, an increased voltage drop over the feeders and an increased unbalance. Electric vehicles are being charged at a relatively high power level compared to most electrical devices in a household, and for a relatively long period. Since most owners of an electric vehicle require that their car charges overnight to be fully charged in the morning and most electric vehicles are possibly plugged-in at approximately the same time in the evening, a large peak load occurs on the grid in the evening. In addition to this, the peak load from the electric vehicles might coincide with the traditionally present residential evening peak power demand.

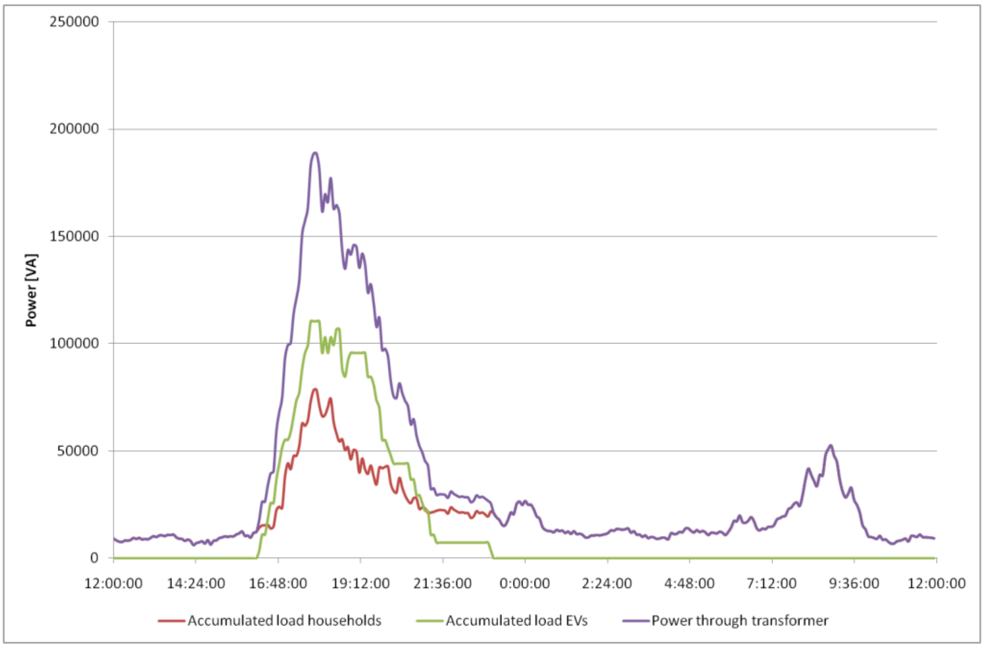


Figure 1: Power through the transformer, accumulated load of the households, and the accumulated load of the electric vehicles for the example scenario.

When the power peak exceeds the rating of the transformer, infrastructure investments have to be done in order to be able to accommodate the charging of the electrical vehicles. The occurrence of an exceeding power peak will happen more often in neighborhoods with a high penetration of electric vehicles, and in dense distribution grids, where the occurring power peak through the distribution transformers is already close to the maximum. A distribution feeder is mainly resistive, so when a load is connected to the distribution grid, the power flow causes a voltage drop over the feeder. Standard EN50160 stipulates that the voltage on a distribution feeder should be between 230/400 V ± 10%. In order to make sure that this condition is met, the length of a distribution feeder as well as the amount of houses connected to the same feeder is limited. When a lot of electric vehicles are being charged at the same time, the voltage drop over the distribution feeder increases. The possibility exists that the grid voltage drops below the limit set by the standard at the peak load moments. An increased voltage drop is more likely to occur in distribution grids with relatively long feeders (e.g. in rural areas), or feeders with a lower cross-section and thus a higher resistivity (e.g. overhead lines instead of cables).

Figure 2: Voltage drop at the end of a feeder when electrical vehicles are present.

In Belgium, the electrical grid is set up as a three-phase system. A lot of households have a single-phase connection, and by making sure that every phase is practically equally loaded, the three-phase distribution system is balanced. In a perfectly balanced three-phase system, no current flows through the neutral of the system. In residential areas it is possible that the electrical vehicles will be connected with a high-power dedicated single-phase connection. The high-power single-phase connections might provoke an increased unbalance on the distribution feeders. This unbalance causes large current flows in the neutral of the three-phase system, and consequently causes shifting of the neutral point. The neutral point shifting provokes an unbalanced voltage between the three phases of the system, and for example a voltage drop is further increased by the unbalance in the system, as is illustrated in Figure 3.

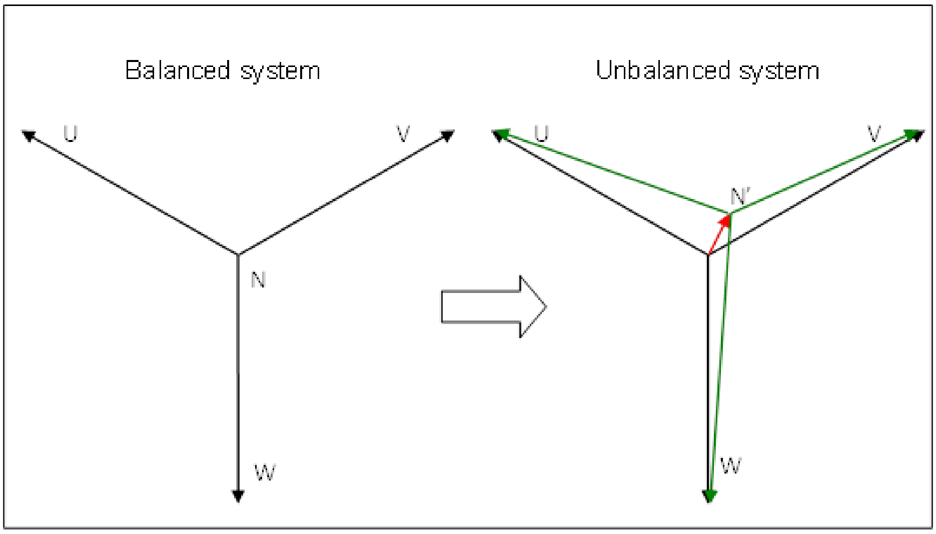


Figure 3: Neutral reference point shifting in an unbalanced three-phase system.

2.2 Impact on the transmission net

With a high penetration ratio of EVs (> 20%) problems might occur with the transmission net. Firstly, the load on the grid increases mostly in the 70 kV and 150 kV transmission voltage levels. Because of the increased grid-load, some grid elements will be overloaded. Overloaded grid elements are especially found in areas where the grid elements are now already relatively highly loaded, without the charging of electric vehicles. These grid elements are mainly found in areas with a relatively high population and little industry. A second problem that occurs when the electric vehicles are charged, is found in the n – 1 safety rule. (N-1)-safety means that any single element in the power system may fail without causing a succession of other failures, leading to a total system collapse. Together with avoiding constant overloading of grid elements, (N-1)-safety is a main concern for the grid operator. A lot of grid elements only transport a relatively low amount of energy in normal conditions, however, when a grid-problem occurs, such as the fall out of a line, transformer or generator, these lines have to be able to withstand a higher loading, in order to maintain a stable transmission grid all over Belgium. This n-1 safety rule cannot be met in some areas when electric vehicles need to be charged.

2.3 Impact on Electricity production

The electrical energy the electric vehicles will be charged with, needs to be generated somewhere, and the introduction of electric vehicles will thus lead to an increase of the electricity consumption. In Clement 2007 is stated that the total energy consumption in Belgium will increase by 5.1% by 2030 (“The Consumption of Electrical Energy of Plug-in Hybrid Electric Vehicles in Belgium”, Clement 2007), under the assumption that 30% of all cars are electric vehicles by then. The electricity production in Belgium is generated by a mix of different types of power plants using different types of fuel: nuclear, coal, natural gas, liquid fuel, water (pumped), wind, other (biomass, photovoltaic,…). Obviously the emissions of those plants determine the gain in emissions when replacing internal combustion engine vehicles with electric vehicles. Coal-fired plants will disappear in the coming years to reduce emissions by the energy sector. Liquid fuel plants are often peak power plants. These plants are designed for a relatively short run time to produce peaks in power. It is likely that these peak power plants will be activated more frequently when higher penetration ratios of electric vehicles are reached. They have a significantly higher operating cost, than other power plants, and have higher emissions than gas fired plants. The use of these peaking plants has to be avoided when charging electrical vehicles.

2.4 Smart Grid solutions

Electric vehicles are typically connected to the grid for a relatively long period (e.g. during the night at home, or during the whole day at work), but the vehicles need a smaller period of that time to be charged (if they are connected to the grid every day). In most cases, the electric vehicles do not need to be charged at the exact instant when they are plugged-in. So, for most users, shifting or postponing the charging does not imply a lower comfort. By introducing a control and communication system that coordinates the charging, through postponing and/or pausing the charging of the vehicles in a coordinated way, a lot of grid issues can be solved. A control system can be worked out that makes sure that the car charging at home does not happen when a lot of power is used for other appliances. This control system can make sure that the car only charges at off-peak hours. The control system can be expanded to a system that coordinates the charging of all vehicles in the same distribution or even transmission grid, in order to make sure that the impact of the charging of all cars on the grid is minimized. By implementing such a control system, it is theoretically possible to avoid most of the otherwise occurring power peaks, unwanted voltage drops, and grid unbalances. Initiatives to incorporate the charging of electric vehicles into the existing regulation of electricity infrastructure and markets are needed. The question now rises whether it is legal to install public or private charging poles within the current legal framework.

2.5 Grid regulatory issues

Several situations are possible when installing public electric vehicle charging poles.

1. The distribution system operator expands the public distribution grid, and provides one point of connection for each charging pole. In this case, the charging poles are no different from other points of connection: each charging pole has its own supplier of electricity. From the point of view of the distribution system operators, this is the best option: the supply and billing of the electricity is very transparent and practically nothing changes with respect to the current situation.

2. The charging poles do not have their own connection with the public grid, but several poles are supplied through the same point of connection with the grid, this single point of connection has its own supplier of electricity. This situation creates a private distribution grid. An important issue herein is that generally speaking, private distribution grids, i.e. grids that are not exploited by an official distribution system operator, are forbidden in Europe. It is thus also forbidden by the regulators to resell energy.

Some distribution systems are private grids anyhow, such as certain industrial sites, large shopping centers, holiday parks, etc. In these situations it is not opportune or simply not cost efficient to have one point of connection for each electricity user. In these cases, the reselling of energy fits in a 'wider provision of services', and the supply of electricity is only a minor part of the total amount of services offered.

The question is whether in this case the provision of electrical energy through the car charging poles fits in a wider provision of services. For example, in this case it is strictly not legally allowed to sell electricity by the kWh, because the selling of electricity must only be a small part of the provided services. In some cases (e.g. companies that offer parking spaces to their employees etc.) this is a viable option, however, in a public car charging station, this is not so clear.

For the public charging stations a policy of tolerance is carried out by the regulators. It is assumed that for as long the charging infrastructure is depreciated the price for charging will reflect much more then only the provided energy. In order to recover the initial investment cost for the charging infrastructure, it is stated that it concerns an admissible form of a private network, in the context of a broader provision of services.

3. Instead of having one 'fixed' supplier of electricity for each charging pole, it is also possible that each car owner charges its car through their own electricity supplier. In that case, one single point of connection must be able to have multiple suppliers of electricity. The distribution system operators are not quite eager on this idea, because this system is very different and much more complex than the system is today. Possible barriers associated with this model and which must be addressed in the long term are *inter alia* the interoperability and the serious communication requirements.

3. Impact analysis on households

3.1 Impact on energy use and environment

VUB-ETEC calculated the impact that a (PH)EV has on energy use. Due to the higher energy efficiency of electrified vehicles, a reduction in energy consumption is expected when driving (PH)EVs. First the energy consumption of different vehicles is assessed on a well-to-wheel (WtW) basis. A well-to-wheel analysis makes a consistent comparison between different types of vehicles possible. A well-to-wheel energy analysis considers both direct (tank-to-wheel) and indirect (well-to-tank) energy use (energy consumption during the production and distribution of the fuel or electricity). The well-to-wheel approach allows a consistent comparison of vehicles using different fuels (petrol, diesel, liquefied petroleum gas and compressed natural gas) and/or different drive train technologies (internal combustion engines, hybrid electric drive trains and battery electric drive trains). The impact on environment of (PH)EVs is investigated. The environmental impacts of (PH)EVs are analyzed with the Life Cycle Assessment (LCA) methodology. Next to the well-to-wheel emissions, the LCA includes cradle-to-grave emissions (related directly and indirectly to vehicle production and end-of-life processing of the vehicle). In order to create a methodological framework for the practice of LCA on one hand and to ensure that all requirements of the methodologies are met, the International Standardization Organization (ISO) has published two standards, namely, the ISO 14040 (ISO 14040, 2006) and the ISO 14044 (ISO 14044:-, 2006). The LCA framework from (UNEP, 2011) is used to perform the LCA task in the TRANS2HOUSE project. This framework holds several subtasks (goal and scope definition, Life Cycle Inventory, Life Cycle Impact Assessment and interpretation of the result).

3.1.1 Goal and scope definition: Defining LCA objectives and functional unit

The intended purpose of TRANSHOUSE is to analyze the environmental performance of (Plug-in Hybrid) Electric Vehicles, (PH)EVs, in a Belgian context and to benchmark these vehicles with conventional vehicles in order to provide policy makers with recommendations to promote transition towards BEV and PHEV for Belgium. The assessment covers following aspects:

- The comparison of the WTW energy performance of (PH)EVs with their conventional competitors;
- Evaluate and compare the life cycle impact of different vehicle technologies (petrol, diesel, LPG, CNG, HEV, PHEV and BEV) within the same vehicle category (small family car);

- Integrate manufacturing and end-of-life phases of specific components of electric vehicles (power electronics, electric motors, batteries) in environmental vehicle assessments.

The scope of the LCA is to investigate the environmental impact of the personal mobility part of the household. This is an important part of the household's environmental impact as a private car consumes about the same amount of energy as the electricity needed for a private house. The assessment compares the environmental impacts of vehicles with different conventional (diesel, petrol) and alternative fuels (LPG and CNG) and/or drive trains (internal combustion engines and battery and hybrid electric vehicles). The functional unit is the central hub of any life cycle assessment, since it provides the reference to which all other data in the assessment are normalized. Basically, a functional unit (FU) is the basis on which different products are to be compared. The functional unit in TRANS2HOUSE is a distance, as the primary function of a passenger car is considered to be transporting a person over a certain distance. TRANS2HOUSE is analyzing electric vehicles and as these vehicles will mainly be used in urban areas, a low annual driving distance is considered. The variation from 2007 to 2010 of the ages of all the Belgian end-of-life vehicles treated in Belgian authorized recycling plants have been assessed by FEBELAUTO (FEBELAUTO, 2011) and an average lifespan of 14,1 years has been obtained from (Statbel, 2012). Next to the average lifespan, an annual mileage of 8000 km has been taken into account for city vehicles. The functional unit is described as driving 112.800 km (8000km/year for 14,1 years) with the considered small family passenger car in Belgium.

3.1.2 Inventory analysis and data collection

The life cycle inventory (LCI) is the collection of all the needed materials, chemicals, energies and all the emissions related to the fulfillment of the functional unit (driving 8000km/year for 14,1 years = 112.800 km). In the TRANS2HOUSE project, a special data gathering strategy has been developed and executed for that issue. The results include all the life cycle steps (production, transport, use phase, maintenance and end-of-life) of a vehicle in a Belgian context manufacturing and maintenance of road infrastructure is taken into account as well. When specific Belgian data are not available, average European data are considered. The Ecoinvent Database (Swiss Centre for Life Cycle, 2007) is the reference LCI database of the TRANS2HOUSE project. It contains about 4000 datasets of products and services covering energy, transport, building materials, wood, chemicals, electronics, mechanical engineering, paper and pulp, plastics, renewable fibers, metals, waste treatment and agricultural products. Each dataset contains all the resources and all the emissions (towards soil, air and water) linked to the production of the corresponding product or service. The LCI modeling is done using the SimaPro software. In order to make a fair comparison, equivalent vehicles with different technologies were chosen for the LCA. In Table 1 equivalent vehicles are listed and some tailpipe emissions are compared together with fuel consumption. These vehicles are a compact size and follow the newest European Emission standards (Euro 5). The vehicle specifications were measured on the NEDC (New European Driving Cycle) driving cycle.

Table 1: Tank-to-Wheel emissions of different vehicle technologies [g/km] and fuel consumption according to NEDC

Fuel	CO_2	CO	HC	NO_x	PM	Fuel consumption
Petrol, VW Golf	134	0,24	0,023	0,021	0	5,8 l/100km
Diesel, VW Golf	99	0,37	0,038	0,130	0,001	3,8 l/100km
LPG, VW Golf	169	0,33	0,032	0,012	0	7,1 l/100km
CNG, Fiat Punto	115	0,53	0,042	0,022	0	6,4 m^3/100km
Hybrid, Toyota Auris	93	0,17	0,034	0,006	0	4 l/100km
PHEV Opel Ampera	27	0,184	0,0167	0,0006	0	1,2 l/100km 13 kWh/100km
BEV, Nissan Leaf	0	0	0	0	0	17,3 kWh/100km

3.1.3 Energetic Well-to-Wheel assessment

To compare the energetic performances of different vehicle Technologies, a Well-to-Wheel (WTW) approach is used. A WTW analysis consist of a Well-to-Tank (WTT) part, covering the fuel production, and a Tank-to-Wheel part (TTW) covering the usage of the vehicle. In an energetic comparison the WTT phase covers the energy losses during the production of the energy carrier (exp. petrol or electricity), excluding the energy content. The TTW part covers the energy content, during usage of the vehicle the energy carrier is transformed in mechanical motion and thermal heating. The fuel consumption of the vehicles was measured on the NEDC (New European Driving Cycle) driving cycle. An overview of the WTW energy consumption is shown in Figure 4. The WTW energy consumption is calculated based on the cumulative energy demand (VDI, 1997) for the different fuels from (Dones R. et al., 2007). The cumulative energy demand includes all direct and indirect energy uses throughout the life cycle of the fuel and the energy content. The WTW energy consumption is then divided between WTT (well-to-tank) and TTW considering the lower heating value (LHV) from (CONCAWE, 2007). It can be distinguished that hybrid electric vehicles use less energy than all other considered technologies, BEVs running on the Belgian electricity mix of 2020 or electricity produced with natural gas consumes the same levels of energy compared to the HEV. The electricity mix in Belgium in 2012 and 2020 is taken from the national renewable energy plan in Belgium, following the Directive 2009/28/EC (NAP, 2010). A BEV running solely on wind energy is the most energy efficient vehicle. Of course different energy sources exist, including renewable and non-renewable sources. Figure 5 shows the different renewable and non-renewable energy sources. When considering depletion of energy sources, only non-renewable energy should be taken into account as well as the depletion rate of the energy source. In the left corner of Figure 7 the impact on energy depletion is given expressed in depletion of fossil fuels, taking the renewability and the availability of an energy source into account. PHEVs and BEVs use a smaller amount of petroleum based energy and contribute less to the depletion of non-renewable fossil energy.

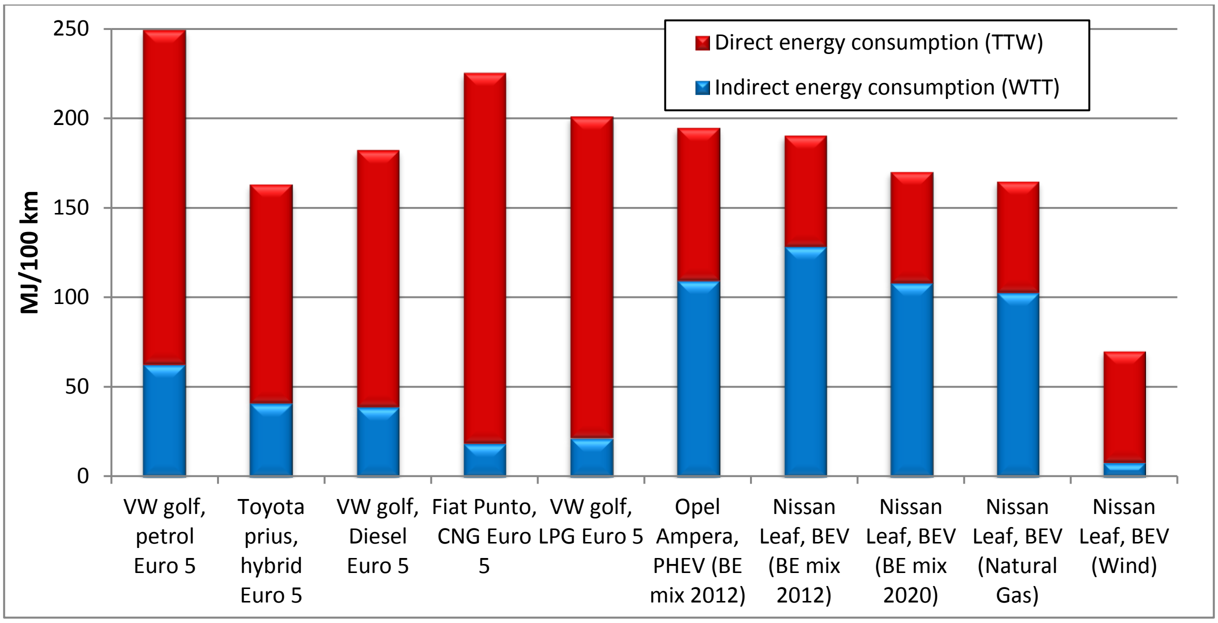


Figure 4: WTW energy usage of different vehicle technologies

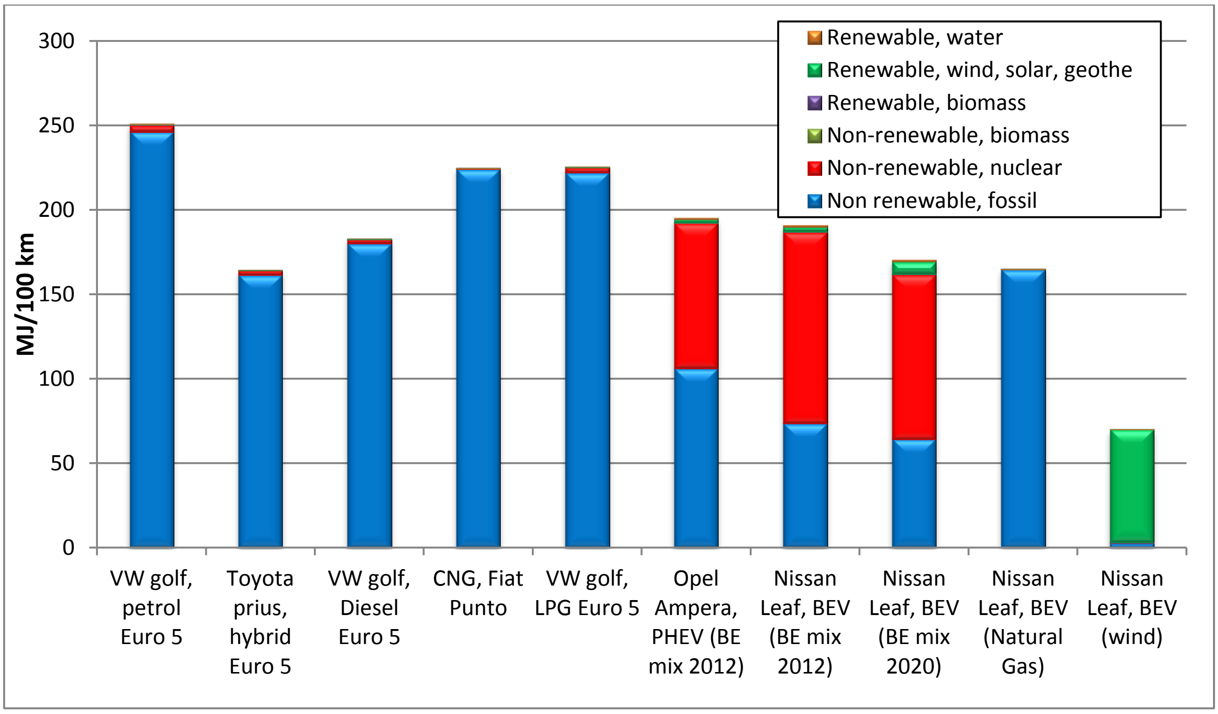


Figure 5: WTW renewable and non-renewable energy sources

3.1.4 Environmental comparison

The environmental impacts of (PH)EVs are analyzed with the Life Cycle Assessment (LCA) methodology. In the Life Cycle Inventory phase (LCI) the well-to-wheel emissions and the cradle-to-grave emissions (related directly and indirectly to vehicle production and end-of-life processing of the vehicle) are included. The inventory phase is converted and allocated to a set of indicators for pollutants and waste loading in the life cycle impact analysis. The effects of the emissions are weighted and quantified within each impact category. After the completion of the LCI, the different elementary flows that are linked to a product system need to be converted into environmental indicators. These indicators allow quantifying and comparing the potential environmental impacts of the different product systems. This step of the LCA is called Life Cycle Impact Assessment (LCIA). ReCiPe is used as the preferred environmental impact assessment method for translating the LCI in environmental impacts with characterization factors. ReCiPe (Goedkoop M.J, 2009) is a follow up of Eco-indicator 99 (Goedkoop and Spriensma, 2000). and CML 2002 (Guinée, J.B et al., 2002) methods. It integrates and harmonizes a midpoint and an endpoint approach in a consistent framework. Life cycle assessment is used to analyze environmental impacts caused by human behavior. Anthropogenic activities create interventions (for example the emission of carbon dioxide) with the environment, creating an environmental effect (for example climate change). In Life Cycle Impact Assessment this is called the midpoint impact category. Following midpoint impacts are covered in RECIPE and are taken into account in TRANS2HOUSE:

- climate change;
- ozone depletion;
- terrestrial acidification;
- freshwater eutrophication;
- marine eutrophication;
- human toxicity;
- photochemical oxidant formation;
- particulate matter formation;
- terrestrial ecotoxicity;
- freshwater ecotoxicity;
- marine ecotoxicity;
- ionizing radiation;
- agricultural land occupation;
- urban land occupation;
- natural land transformation;
- depletion of fossil fuel resources;
- depletion of mineral resources;
- depletion of freshwater resources.

These environmental effects bring damage to areas that the society wants to protect (human health, ecosystem quality and resources). Midpoint and endpoint characterization factors are calculated on the basis of a consistent environmental cause-effect chain, except for land-use and resources. The endpoints are normalized and weighted in order to sum up the three damage categories into a single score. The environmental mechanism is summarized in Figure 6.

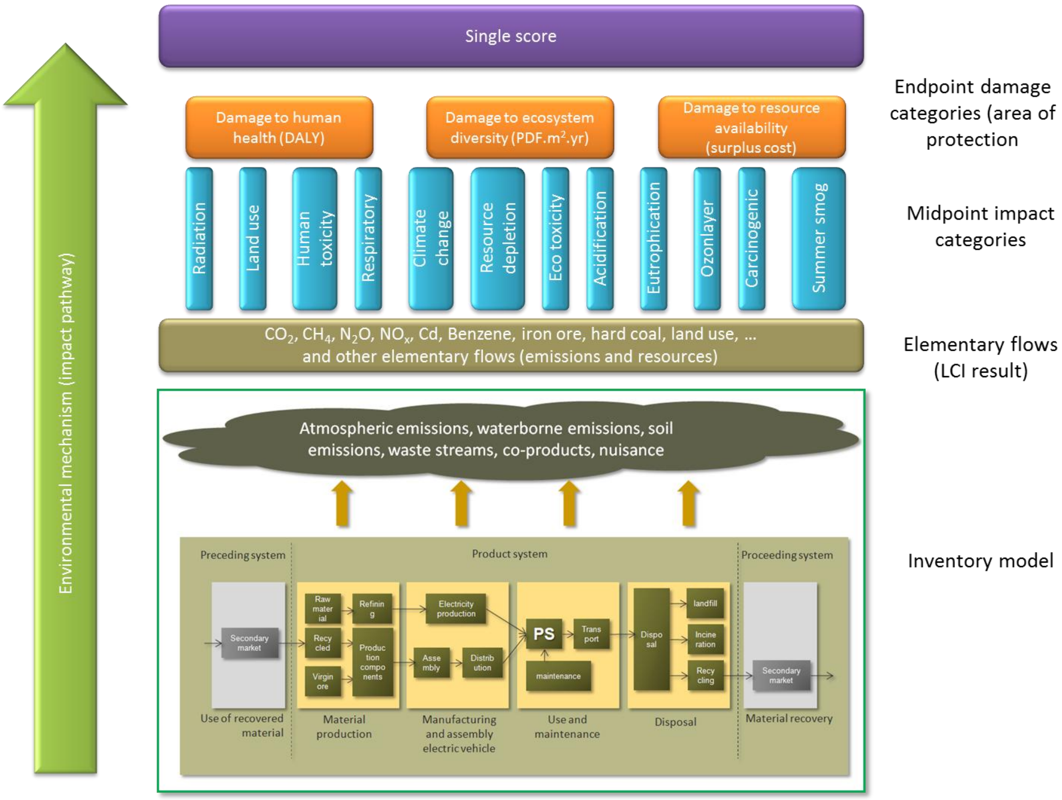


Figure 6: Impact categories and pathways covered by the ReCiPe methodology

Figure 7 illustrates a selection of midpoint impacts of different vehicle technologies. The graphs show the results of the calculated impacts on climate change, metal depletion, terrestrial acidification and fossil depletion of the different considered vehicle technologies. The BEV has the lowest impact on climate change when charged with Belgian electricity, which has a large share of nuclear electricity. A BEV is a tailpipe (or Tank-to-Wheel) free technology. However, the Well-to-Tank step emits more carbon based emissions compared to the other vehicles. As electricity can be produced from various sources, including renewable energy, BEVs have the opportunity to become even less polluting in the future when well managed. Different scenarios of BEV using different types of electricity have been compared to assess the influence of the electricity production technology on the LCA results of BEVs. The BEVs powered with wind power, hydropower or nuclear power have very low effect on climate change, since there are no conversion emissions related to electricity production. They are followed by the scenarios of the Belgian electricity mix, the European electricity mix and natural gas electricity production, which also result in a low effect on climate change in comparison to diesel and petrol vehicles. In extreme scenarios, in which BEVs are for 100% powered with oil or coal based electricity, the LCA results shows that BEV have climate change comparable to the ones of diesel cars. Thanks to the hybridization of the drive train, the hybrid vehicle manages to decrease fuel consumption and accordingly the impact on the climate change. As a consequence the hybrid vehicle has the lowest impact of all internal combustion engine vehicles, lower compared to the PHEV.

Fuel saving technologies are reducing the total life cycle carbon emissions significantly, mostly by lowering the WTW carbon emissions. Therefore, the balance of the carbon footprint between life cycle stages is relatively changing towards the production of the components. Figure 7 also includes the emissions related to the production of the vehicle. In absolute terms, the WTW stage still remains the most important life phase. When a BEV is only powered with renewable energy or nuclear energy, the embedded carbon of the vehicles' components becomes the majority of the impact on climate change, since there are no tailpipe emissions neither conversion emissions related to electricity production. The component 'life cycle EM' includes the production as well as the end-of-life treatment of the electric motor.

The CNG vehicle has the lowest impact on terrestrial acidification, followed by the BEV using average Belgium electricity (BEV, BE mix 2010). The petrol vehicle has the largest impact on air acidification, this is due to the impact of the petrol production in which NO_x and SO_x are the leading emissions for the acidification impact. The influence of diesel production on acidification is lower compared to the petrol production. On the other hand are the TTW emissions of NO_x and SO_x of a diesel car higher. A positive trend can be distinguished for the TTW emissions, due to stricter European emission limits for NO_x en SO_x. The impact of the production of copper and steel are the main contributors for the 'raw material' phase. The acidifying emissions during the assembly of the car are introduced by the usage of electricity. The calculation of the terrestrial acidification has also revealed that the production of a battery for a BEV, PHEV and a hybrid vehicle has a significant impact on the overall result of terrestrial acidification. Battery recycling is important when dealing with terrestrial acidification. The petrol, LPG and CNG vehicles have the largest impact on fossil depletion. The petrol vehicle has the highest fuel consumption, which explains the high WTT impact. In the impact assessment it is assumed that the depletion of the fossil fuel takes place when transforming the crude oil in the ground to a refined fuel. Therefore, no impact is defined in the TTW step, as the WTT step already counts for the total depletion. Figure 8 shows the weighted and normalized impacts on a single score. When combining all impacts in a single score, the BEV has the best overall result, followed by the PHEV. Fossil depletion has the biggest influence on the overall result when comparing vehicles, followed by the human health aspect linked to climate change.

BEV are having a larger impact on human toxicity due to the mining of copper for the electric parts and the mining of uranium for the nuclear power plants.

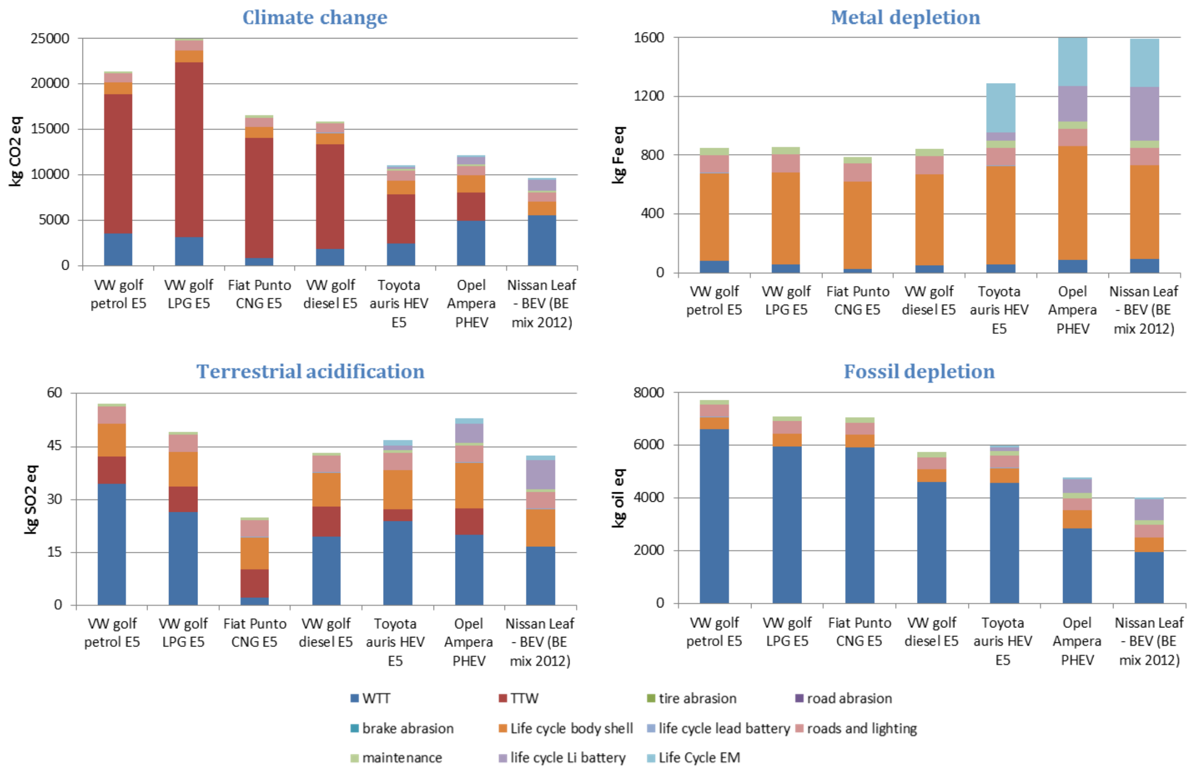


Figure 7 : environmental comparison of different vehicle technologies with a selection of midpoint impact categories

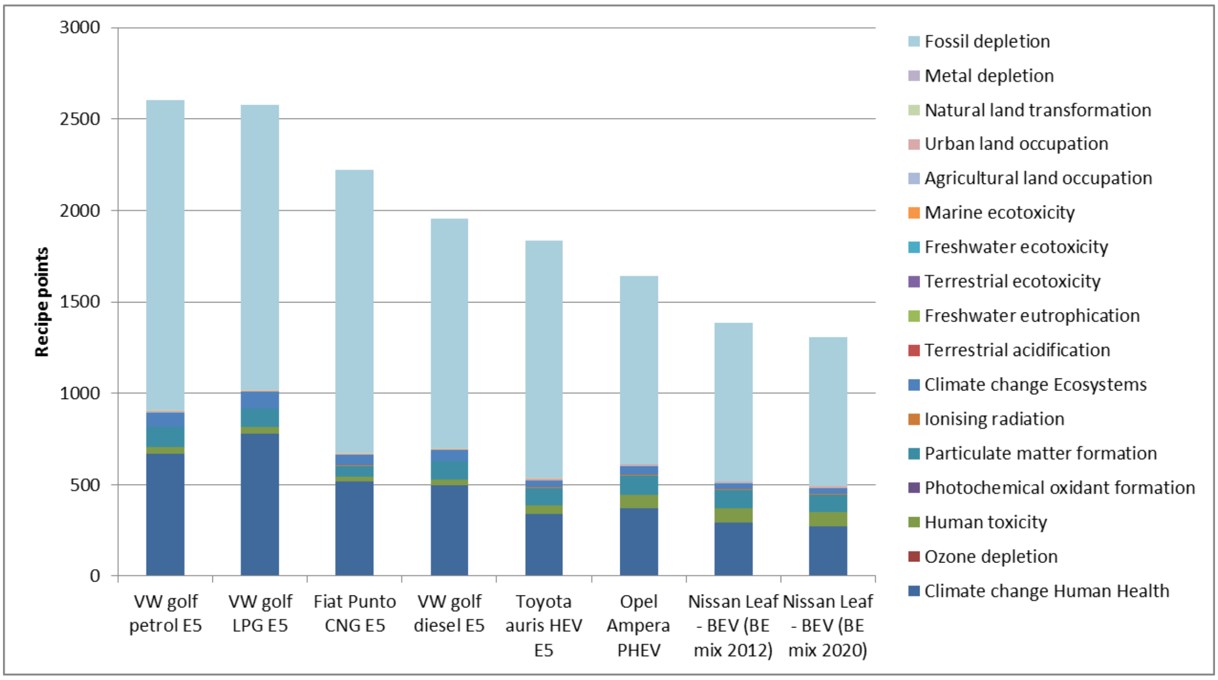


Figure 8 : environmental comparison of different vehicle technologies with all impact categories weighted on a single score (Recipe points)

3.1.5 Interpretation and uncertainty

Many scenarios can be built to assess the environmental impacts of a car. The variability of the different situations can be taken into account due to the fact that VUB-ETEC has built mathematical models expressing ranges of specific types of cars. Due to this mathematical model, performing a sensitivity assessment is easily being done. Often the environmental impact of a vehicle calculated with a Life cycle assessments is shown as one single value. This approach approximates the environmental impact of a vehicle, but fails to provide decision-makers with a wide view on the possible effects of their decisions. The complexity, uncertainty and variability of the system are not well approximated with one single value. Uncertainties are an inherent part of LCA and should not be avoided but embraced and made explicit in the result. Identifying and integrating uncertainties in the end result should provide decision makers with a more robust interpretation of the results. An example of a range based vehicle LCA can be found in (Van Mierlo et al., 2009). It should be noted that the more uncertainties that are taken into account, the more the overall uncertainty of the results increases. At first this might seem contradictory to the general aim of reducing global uncertainty of the result, as studies ignoring to take uncertainty into account seem to provide a more certain result. However, including different sources of uncertainty in LCA is decreasing the ignorance of not accounting for it. The aim of addressing uncertainty in LCA is to reduce and to incorporate uncertainties in the result. It should be noted that it is not possible to take all uncertainties out of LCA. Many sources of uncertainty exist in LCA: data variability, data inaccuracy, measurement errors, unrepresentative data, temporal variability, geographical variability, data gaps, choice based uncertainty, … . There are various types of uncertainties and ways to classify them. (Heijungs R. and Huijbregtsb M. A.J., 2009) shows some of the different typologies that exist in literature. Three classes of uncertainties are investigated in TRANS2HOUSE:

- Parameter uncertainty: insufficient knowledge of the true value of a parameter;
- Modeling uncertainty: uncertainty in life cycle impact assessment due to normalization, weighting and methodology;
- Scenario uncertainty: Choice based uncertainty: choice of functional unit, goal and scope definition, allocation procedures, future trends.

These three classes are explored in the task report on LCA, however parameter uncertainty is the most explicit uncertainty and is discussed in Figure 9. Figure 9 shows the parameter uncertainty on the endpoint impact of the different vehicle technologies assessed in TRANS2HOUSE. The endpoint impact is divided in three categories: ecosystems, human health and resources. The error bar shows the uncertainty of the result with a 95% confidence interval. Following uncertainties are included:

- Variability between different vehicles

  The variation between different vehicles with the same technology is taken into account. All vehicles have ranges in their key important environmental parameters such as fuel consumption, weight and tailpipe emissions (CO_2, CO, HC, CH_4, N_2O, NO_x, SO_x, PM)

- Measurement errors, gaps in the background data, unrepresentative data

  In the Ecoinvent database, the inputs and outputs involved in a unit process are expressed with single values. According to how the inventory data have been measured or collected, different types of uncertainty may exist on these data. When the inputs and outputs are from a measurement campaign, the uncertainty is measured and expressed in quantitative term. When uncertainty information is not available for average data coming from one single source, a qualitative approach, the pedigree matrix, is used to approximate an uncertainty level.

- Data unrepresentativity due to differences between NEDC and real life emissions

  The New European Driving Cycle (NEDC) does not resemble real driving conditions. A literature study has been used to come up with factors to go from NEDC values to real driving conditions. Factors were calculated for fuel consumption and tailpipe emissions (CO_2, CO, HC, NO_x, PM). It should be noted that including this factor in the result not only the uncertainty bars increase, but also the mean value itself.

Figure 9 shows the result of calculating the damage that the midpoint impacts have on the endpoint categories and combining the endpoint damages in a single score, using a normalization and weighting step. The method used is ReCiPe Endpoint (H) V1.04. In Figure 9 it can be noticed that a BEV with Belgian electricity (BE mix 2012) has the best overall environmental score when compared with other vehicle technologies, followed by the PHEV and the HEV. As climate change and fossil depletion play an important role in the endpoint categories, vehicles with some sort of electrification have the lowest impact. New diesel vehicles are on average evaluated better compared to similar petrol vehicles, due to lower CO_2 emissions and fuel consumption. However, due to the fact that in real life diesel vehicles emit more PM and NO_x emissions than stated in the certificates of conformity using the NEDC, the uncertainty bars show a large overlap with petrol vehicles and situations in which the diesel car scores worse than the petrol car.

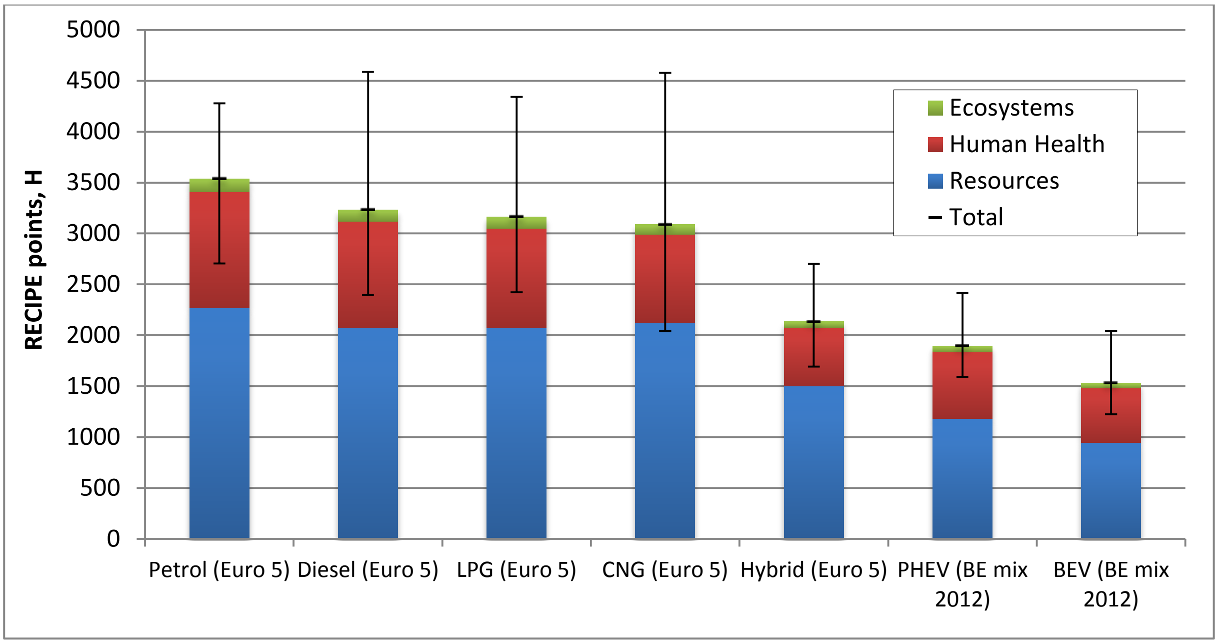


Figure 9 : Uncertainty on the endpoint impact of different vehicle technologies

3.2 Total Cost of Ownership

3.2.1 Introduction

Within the decision process of a new car, financial factors are regarded as very important. Here, consumers should not only look at the initial purchase cost of the vehicle. Many other costs occur during the ownership of a car. Therefore, in this chapter, a total cost of ownership (TCO) analysis has been elaborated on different types of vehicles in order to clear up the financial attractiveness of electric vehicles (EVs), compared to conventional ICE (internal combustion engine) vehicles. Only when the TCO of an EV becomes comparative, consumers could opt for these greener vehicles.

3.2.2 TCO Methodology

The costs associated with a vehicle occur at different moments in time. Therefore, in order to have a correct TCO, it is needed that that we calculate the present value of all the occurred costs. The present value methodology makes use of a discount rate. The discount rate can be defined as “the rate of interest reflecting the investor’s time value of money (Mearig, Coffee, & Morgan, 1999). It can be either a real discount rate (excluding inflation) or a nominal discount rate (including inflation). It is recommended to use the real discount rate for TCO calculations. This eliminates complex accounting for inflation within the present value equation. The nominal interest rate is also known as the long-term interest rate on state bonds.

In general, the total cost of ownership is calculated in three steps:

1. Analysis of every stream of periodic costs;
2. Calculation of the present value of the one-time and the recurring costs;
3. Division of the present value by the number of kilometers during the vehicle lifetime in order to produce a cost per kilometer.

3.2.3 Scope of the research

For this research, the total cost of ownership of the following cars is included.

Table 2: Vehicles used in TCO calculation

Brand	Type	Technology	Segment
Citroen	C1	Petrol	City car
Citroen	C1	Diesel	City car
Citroen	C1	LPG	City car
Mitsubishi	iMiev	Battery electric	City car
Peugeot	iOn	Battery electric	City car
Citroen	C-Zero	Battery electric	City car
Renault	Zoe Z.E.	Battery electric	City car
Tazzari	Zero	Battery electric	City car
Volkswagen	Golf	Petrol	Medium car
Volkswagen	Golf	Diesel	Medium car
Volkswagen	Golf Bluemotion	Diesel	Medium car
Volkswagen	Golf	LPG	Medium car
Opel	Zafira	CNG	Medium car
Toyota	Prius	Hybrid	Medium car
Toyota	Auris	Hybrid	Medium car
Nissan	Leaf	Battery electric	Medium car
Renault	Fluence Z.E.	Battery electric	Medium car
Opel	Ampera	PHEV	Medium car
Toyota	Prius PHEV	PHEV	Medium car

Two car segments have been investigated: the small city cars and the medium sized cars. All of these are compared for different vehicle technologies: petrol, diesel, LPG, CNG, hybrid, battery electric and plug-in hybrid electric. This way, we are able to investigate the financial attractiveness of electric vehicles.

3.2.4 Parameters and assumptions

Within the total cost of ownership calculation, several parameters and assumptions have to be defined. First, some general assumptions need to be defined: the average lifetime of the vehicle, the average mileage per year and the total mileage per vehicle lifetime. Next, the parameters are discussed. They can be divided into 2 main parameters: the financial costs and the operating costs (related to the usage of the car).

3.2.4.1 General assumptions

In Belgium, the average lifetime of a vehicle is 14,1 years. However, the average Belgian consumer only owns the vehicle for 7 years before selling it. The average annual mileage is 15.000 kilometers per year.

3.2.4.2 The vehicle financial costs

The financial costs associated with the purchase of a new vehicle include the initial purchase price, the possible governmental subsidies and the vehicle registration tax.

Purchase price

The purchase price for the vehicles in this TCO calculation include the VAT (value added tax, 21% in Belgium), but exclude possible reductions or promotions by the dealer. All prices are retrieved from the website of Autogids (www.autogids.be) and are of December 2011. For a few vehicles that are not yet on the market or that are not listed on the Autogids website, the estimated purchase price is gathered from the manufacturer's website. Vehicles depreciate over time. The loss of value due to depreciation is the highest in the first years of the vehicle's lifespan. Depreciation rates not only vary according to the fuel or drive train, they also vary according to brand image, mileage, vehicle class…However, in this analysis, we only take into account the difference in fuel and drive train. The total percentage written off after 7 years is 74% for diesel, 79% for petrol, 82% for LPG, 83% for CNG and 84% for EV (Van Mierlo, Maggetto, Meyer, & Hecq, 2001).

Governmental subsidies

As from July 1st, 2007, Belgian consumers can receive a governmental subsidy when buying a low CO_2 emitting vehicle. On December 1st 2011, the Belgian government decided to drop the CO_2 ecobonus. However, since the Trans2House project is a two year project (2010-2011), we tend to include this ecobonus in the TCO calculations. In the sensitivity analysis, we will discuss the effect on TCO when the ecobonus would disappear.

Vehicle registration tax

The vehicle registration tax has to be paid once, when purchasing the vehicle. Up to February 29 2012, the amount due is calculated according to the fiscal horsepower or the kW of the vehicle. After that date, it will be calculated on the basis of CO_2, the EURO norm and the age of the vehicle.

For the purchase of a battery electric vehicle, the minimal amount of registration tax (61,50 euro) has to be paid.

3.2.4.3 The operating costs

The operating costs linked to the usage of the car are: the fuel operating costs, the yearly taxation (road tax), the insurance cost, possible battery costs and the maintenance costs.

Fuel operating costs

The fuel or electricity consumption whilst driving can take up a large amount of the TCO. In this analysis, we use the following prices for fuels and electricity. The prices for petrol and diesel are the average maximum prices for November 2011 (petrol=1,59€/l; diesel=1,50€/l; CNG=0,59€/l; LPG=0,64€/l; Electricity=0,125€/kWh). The price for electricity is the average of day and night tariff for November 2011.

Road tax

The yearly road tax in Belgium depends on the fiscal horsepower.

Insurance cost

In Belgium, the civil liability premium is obliged for drivers. This premium is based on different parameters: driver's age, domicile, bonus-malus… In addition, the civil liability premium can be complemented with an omnium insurance, which depends on the actual value of the car.

For this TCO calculation, the insurance was obtained at Touring Insurances (www.touring-verzekeringen.be). For every vehicle, the same driver was "created": born on 1/1/1975, married, employee, driving license since 1/1/1993, never lost his insurance, first owner of the vehicle, purchase of the vehicle on 1/12/2011, vehicle used for private and home-work movements, Bonus-malus of 3, 15.000 km per year.

Battery costs

The battery pack of battery electric vehicles has a limited lifespan. In this TCO calculation, we replace the battery pack according to the warranty given by the manufacturer. This is often linked to the total mileage or to a certain number of years. When replacing the battery pack, we consider a price of 500 euro per kWh.

Maintenance costs

Maintenance costs include tire costs, costs for small and large maintenance and costs for annual car inspection (Testaankoop, 2007), (GOCA, 2010). Tire costs depend on the vehicle type and annual mileage, and are assumed to be replaced every 50.000 km (Testaankoop, 2007). Costs for small and large maintenance are seen as costs necessary to keep the vehicle operational. This includes the oil replacement, the revision of the brakes… In general, the maintenance costs for EVs are lower compared to ICE vehicles, since EVs have less moving components, they face less temperature stress and do not need oil and filter replacements (Van Vliet, Kruithof, Turkenburg, & Faaij, 2010) (Werber, Fischer, & Schwartz, 2009). As for the maintenance costs of hybrid cars, they are considered to be the same as those for ICE cars (Goedecke, Therdthianwong, & Gheewala, 2007).

3.2.4.4 Overview of data for TCO calculation

Table 3: Vehicle data used in TCO calculation

Car	CO_2	Purchase price	Registration tax	Road tax	Insurance Civil liab.	Insurance Omnium	Technical control	Tyre cost	Maintenance cost	Consumption
Citroen C1 Petrol	103	€ 9.740	€ 61,50	€ 133,32	€ 251	€ 545	€ 152	€ 495,76	€ 564,88	4,5 l/100km
Citroen C1 Diesel	109	€ 11.896	€ 61,50	€ 215,42	€ 251	€ 561	€ 152	€ 495,76	€ 564,88	4,1 l/100km
Citroen C1 LPG	95	€ 11.740	€ 61,50	€ 364,10	€ 251	€ 545	€ 212	€ 495,76	€ 564,88	5,7 l/100km
Mitsubishi iMIEV	0	€ 34.890	€ 61,50	€ 73,79	€ 247	€ 1.092	€ 124	€ 495,76	€ 180	12 kWh/100km
Peugeot iOn	0	€ 35.755	€ 61,50	€ 73,79	€ 247	€ 1.112	€ 124	€ 495,76	€ 180	12 kWh/100km
Citroen C-Zero	0	€ 35.836	€ 61,50	€ 73,79	€ 247	€ 1.120	€ 124	€ 495,76	€ 180	12 kWh/100km
Renault Zoe Z.E.	0	€ 20.000	€ 61,50	€ 73,79	€ 250	€ 1.035	€ 124	€ 495,76	€ 180	15 kWh/100km
Tazzari Zero	0	€ 24.188	€ 61,50	€ 73,79	€ 300	€ 1.100	€ 124	€ 495,76	€ 180	14 kWh/100km
VW Golf Petrol	144	€ 20.647	€ 495	€ 256,61	€ 299	€ 847	€ 152	€ 585,04	€ 520,38	6,2 l/100km
VW Golf Diesel	119	€ 21.447	€ 123	€ 256,61	€ 284	€ 813	€ 152	€ 585,04	€ 520,38	4,5 l/100km
VW Golf Diesel BM	104	€ 22.337	€ 123	€ 256,61	€ 284	€ 859	€ 152	€ 585,04	€ 520,38	4,0 l/100km
VW Golf LPG	149	€ 21.460	€ 123	€ 256,61	€ 280	€ 828	€ 212	€ 585,04	€ 520,38	9,2 l/100km
Opel Zafira CNG	138	€ 27.444	€ 61,50	€ 446,08	€ 313	€ 1.120	€ 212	€ 783,36	€484,71	7,8 l/100km
Toyota Prius hybrid	89	€ 28.190	€ 495	€ 297,40	€ 303	€ 1.360	€ 152	€ 674,24	€419,66	3,9 l/100km
Toyota Auris hybrid	89	€ 24.490	€ 495	€ 297,40	€ 302	€ 1.112	€ 152	€ 674,24	€419,66	3,8 l/100km
Nissan Leaf	0	€ 36.990	€ 61,50	€ 73,79	€ 288	€ 1.152	€ 124	€ 674,24	€ 180	15 kWh/100km
Renault Fluence Z.E.	0	€ 26.620	€ 61,50	€ 73,79	€ 300	€ 1.215	€ 124	€ 674,24	€ 180	15 kWh/100km
Opel Ampera	27	€ 44.500	€1,239	€ 739,73	€ 269	€ 1.317	€ 124	€ 674,24	€419,66	6,7 l/100km 22,5 kWh/100km
Toyota Prius PHEV	59	€ 36.100	€ 495	€ 297,40	€ 288	€ 1.152	€ 152	€ 674,24	€419,66	3,3 l/100km 20 kWh/100km

3.2.5 Results

This section represents the private total cost of ownership for the 2 segments of vehicles: city cars and medium cars. First, the cost structure of the TCO is given. Here, each cost parameter can be investigated separately. Secondly, the yearly cost and the cost per kilometer are illustrated. All TCO calculations include the parameters and assumptions from the previous chapters. The insurance cost is the full omnium cost.

3.2.5.1 Results for city cars

Figure 10 illustrates the cost structure for city cars. As for the depreciation cost, the difference between the ICE vehicles (the first three cars) and the electric vehicles (the last five vehicles) is quite elevated. This is mainly due to the higher initial purchase price of the EVs. Within the five EVs, the Renault Zoe ZE and the Tazzari Zero have a lower depreciation cost. This is because Renault remains the owner of the battery pack (the customer has to lease the battery pack) and because the Tazzari Zero is a more compact vehicle and has a smaller battery pack compared to the other EVs. When looking at the fuel cost, the opposite result is shown: EVs have a much lower fuel cost than ICE vehicles. Today, the price of electricity (for EVs) is still quite low compared to the high petrol and diesel prices. The LPG car (Citroën C1) illustrates that this fuel type still offers an interesting alternative to the conventional petrol and diesel cars. As for the insurance costs, due to the high purchase prices, the full omnium cost for the EVs is more than twice as large compared to the ICE (internal combustion engine) cars. In chapter 3.2.6.2, the effect of having only a civil liability for the cars is shown. The rectangular bars below the x-axis represent the governmental subsidies.

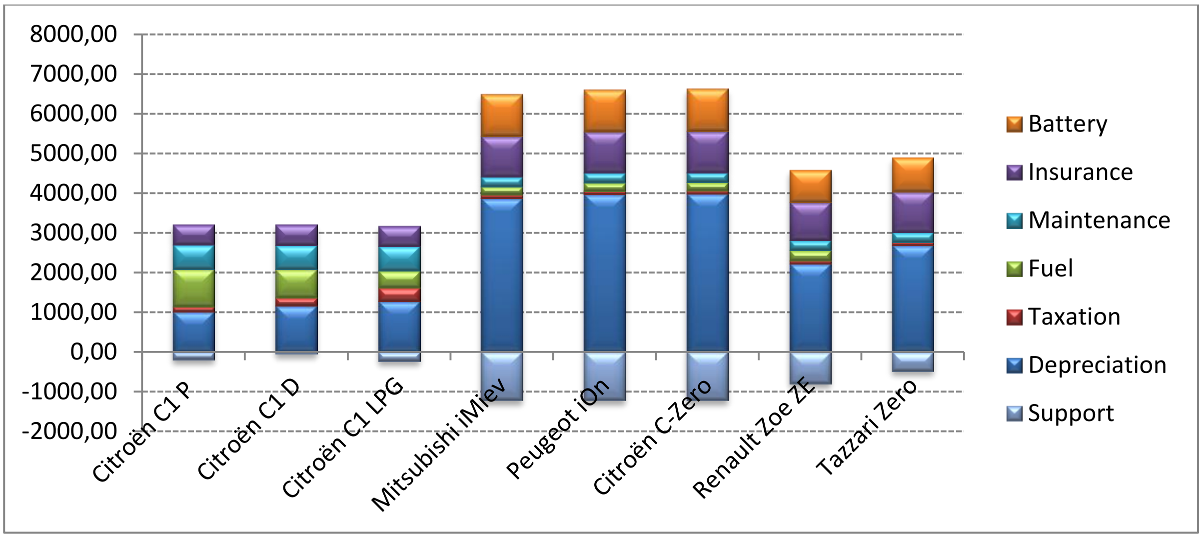


Figure 10: TCO for city cars – cost structure

Figure 11 shows the yearly cost (bars) and the cost per kilometer (small circles) for the city cars. This result takes into account the “negative” governmental subsidies. Here, the price difference for the total cost of ownership between the EVs and the ICE cars is clear. The electric Mitsubishi, Peugeot and Citroën are almost twice as costly, and the Renault and Tazzari are respectively 25% and 50% more costly.

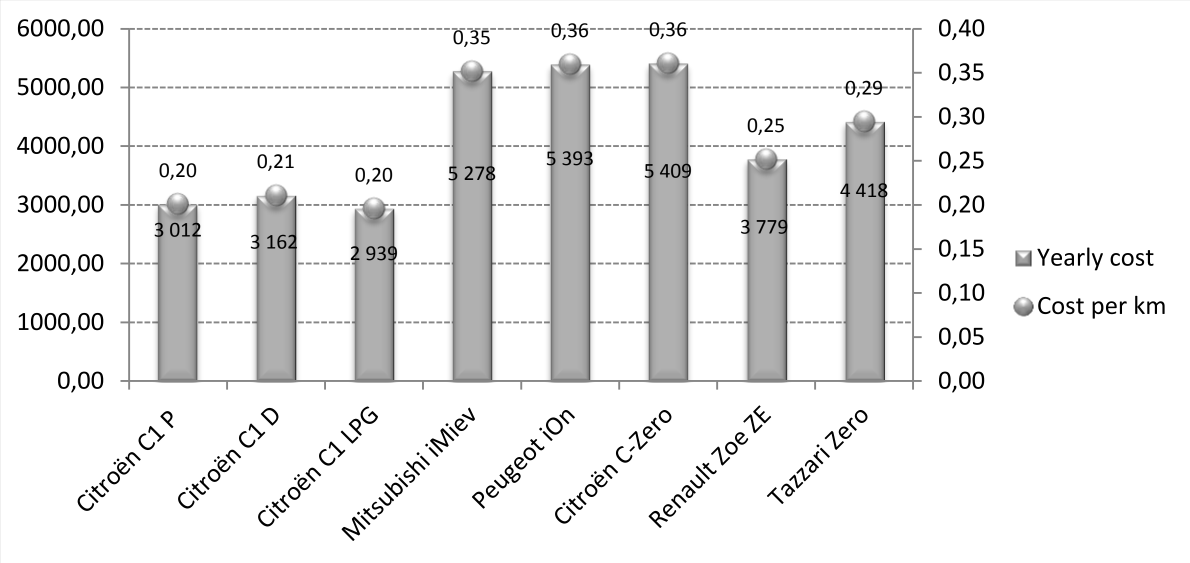


Figure 11: TCO for city cars – yearly cost and cost per km

3.2.5.2 Results for medium cars

Figure 12 depicts the cost structure for the medium cars. Here, similar conclusions can be drawn as for the city cars. The depreciation costs of the EVs and PHEVs are higher compared to the ICE cars, but the difference between both technologies is not as high as for the city cars. On the other hand, the fuel costs are again significantly lower. Due to the fact that the purchase prices for the ICE cars and the EVs in the medium car segment are less dispersed, the insurance costs are also closer to each other. The electric Nissan Leaf does not have a battery cost because the manufacturer's warranty exceeds the total mileage of the vehicle in this TCO calculation. Figure 12 also illustrates the order of magnitude of the governmental subsidies for battery electric vehicles (30% of purchase price, with a maximum of € 9.190).

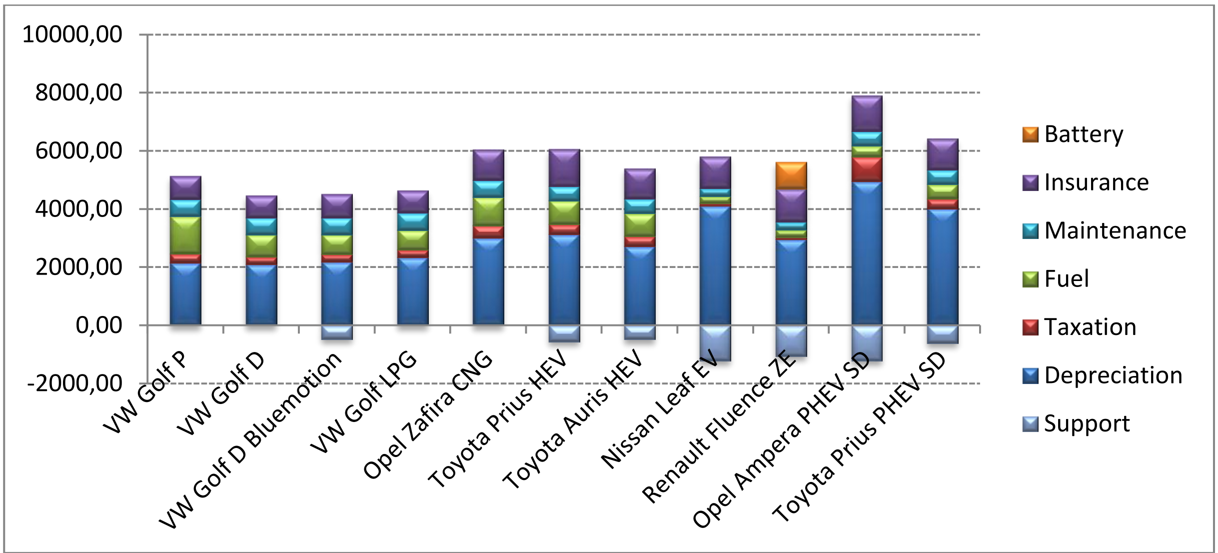


Figure 12: TCO for medium cars – cost structure

Finally, Figure 13 illustrates the yearly cost and the cost per kilometer for the medium cars. The cost per kilometer ranges from 0,27 euro/km (Volkswagen Golf diesel Bluemotion) to 0,45 (Opel Ampera PHEV). It is interesting to see that the EVs (Nissan Leaf and Renault Fluence ZE) are financially attractive compared to the conventional ICE cars. The PHEVs however are still around 25% more expensive as the conventional cars.

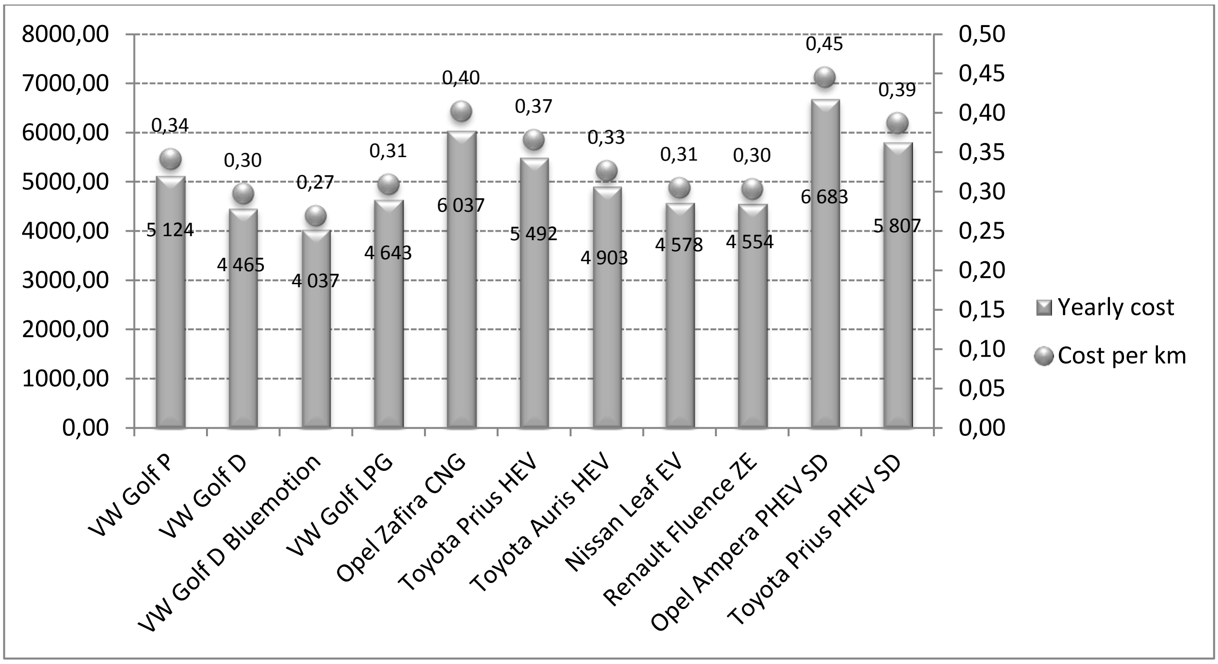


Figure 13: TCO for medium cars – yearly cost and cost per km

3.2.6 Sensitivity analysis

The calculations of chapter 3.2.5 were based on several parameters and assumptions. In order to examine the robustness of these findings, this chapter includes several sensitivity analyses. The results of these sensitivity analyses are a yearly cost and a cost per kilometer, and can be found in the full report of this task. The governmental subsidy for EVs and low CO_2 emitting vehicles has quite an impact on the TCO calculations. In the sensitivity analysis, we exclude these subsidies, EVs become between 11% and 27% more expensive if there would be no subsidies. For the conventional ICE cars, only the Volkswagen Golf Bluemotion, and the Citroën diesel and LPG become more expensive, be it with 6% to 10%. The two hybrid vehicles in the TCO calculation become 10% more expensive. When the government would step away from the subsidies for EVs, the market introduction of this new technology could be hampered. In the TCO calculations of chapter 3.2.5, we used the full omnium insurance cost for the cars. However, many drivers still opt to only take the civil liability option. Hereunder, the TCO analysis includes the (cheaper) civil liability for all vehicles. As expected, the TCO decreases for the BEVs (15% - 19%), the PHEVs (14% - 15%) and the ICE cars (9% - 13%). Hence, electric vehicles become more attractive.

3.3 Purchase behavior

3.3.1 Introduction

The purchasing process for an electric vehicle (EV) differs from that of a conventional vehicle. Due to several vehicle characteristics, both positive (low driving cost, high environmental performance…) and negative (high purchase price, limited driving range…), current consumers are not yet fully convinced and still opt for a conventionally powered vehicle. However, based on different market share forecasts, the market potential for electric vehicle could evolve in the future. In this chapter, the barriers and drivers for the purchase of electric vehicles are discussed. These are subdivided into 5 factors: technical, environmental, economic, market and psychological factors. Next, the purchase behavior for electric vehicles in Belgium is discussed. Finally, several market share forecasts are discussed.

3.3.2 Barriers and drivers for the purchase of electric vehicles

Many studies state that consumers consider the environmental factor in their purchase decisions (Bunch, Bradley, Golob, Kitamura, & Occhiuzzo, 1993; Ewing & Sarigollu, 1998). A greener vehicle will be preferred, all other things being equal. However, it is not clear to what extent the environmental friendliness factor affects the final purchase decision of a car. Many other factors also influence the purchase decision. In a survey conducted by the Vrije Universiteit Brussel (VUB-MOBI, 2011), a range of advantages and disadvantages of the electric car was asked to be evaluated by 1.196 respondents. The results are depicted in the two next figures: Figure 14 identifies the main drivers for EV adoption while Figure 15 shows the main barriers.

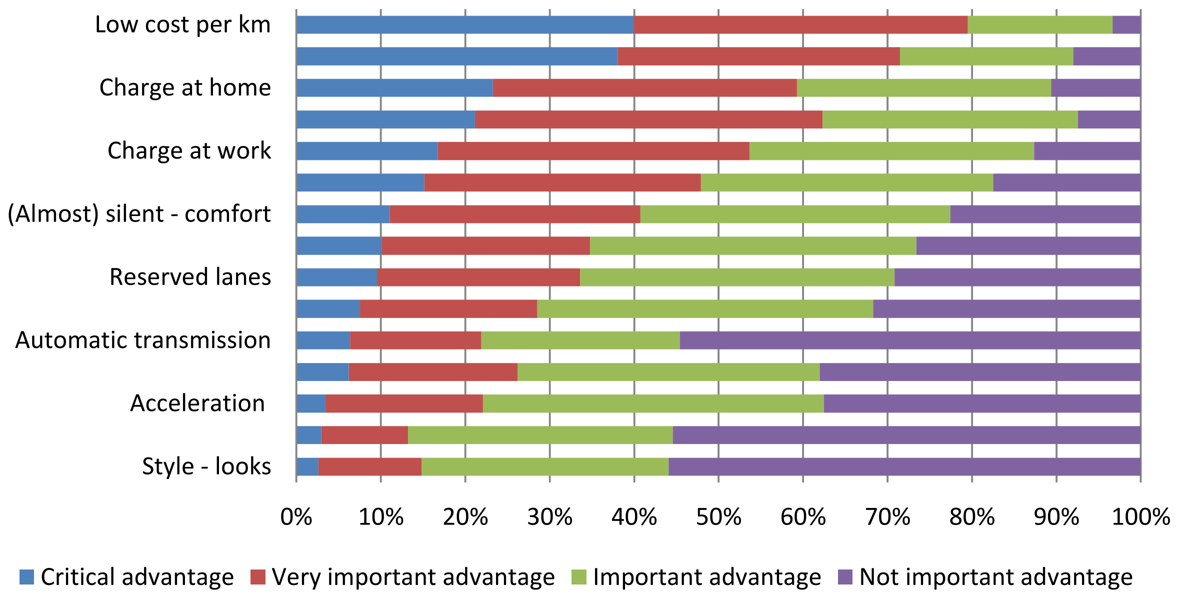


Figure 14: Drivers for EV adoption (VUB-MOBI, 2011)

Figure 14 shows that the two most important advantages of electric vehicles are the relative low cost per kilometer and the green image. These are followed by other cost factors such as government incentives (4th) and free parking facilities (6th). As for the charging location factors, these are considered essential with the possibility to charge home (3rd) and at work (5th). The possibility for smart-phone applications and the style and looks of the EVs are perceived as the least important advantages.

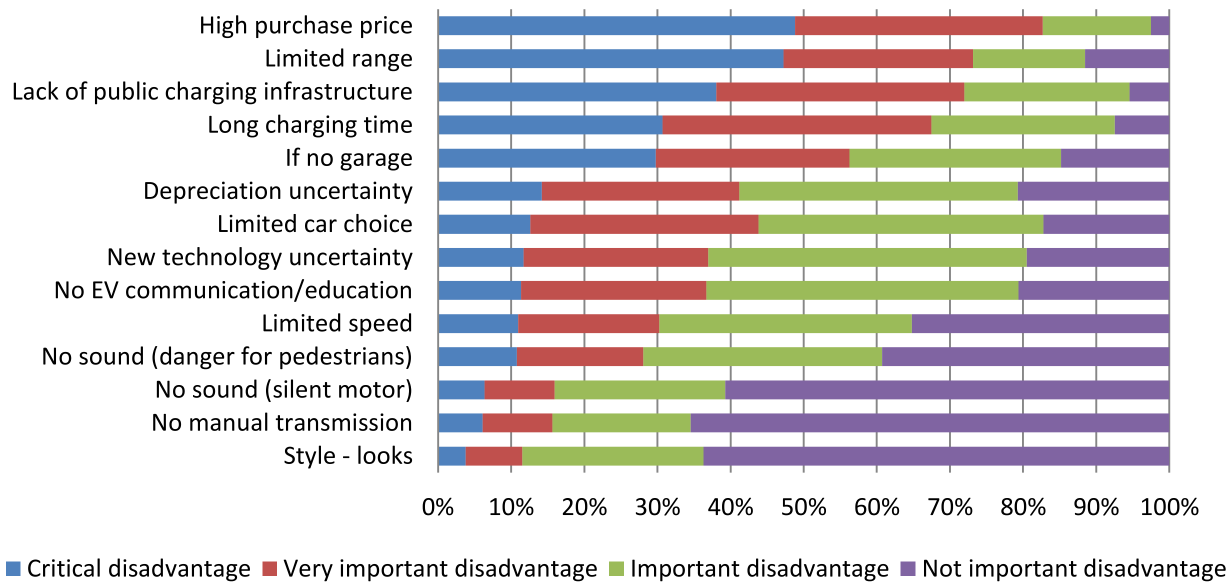


Figure 15: Barriers for EV adoption (VUB-MOBI, 2011)

Figure 15 identifies the elevated purchase price and the limited driving range as the two critical barriers for the adoption of electric vehicles. The scarcity of the charging infrastructure, the long charging times and the impossibility of charging at home when not having a private parking space or garage are perceived as the next most important barriers. The absence of sound, the automatic transmission and the style and looks are perceived as the least important disadvantages of EVs. Based on a literature review, the Clean (Van Mierlo et al., 2011) recent study conducted by the Vrije Universiteit Brussel (VUB-MOBI, 2011), the objective of this section is to give an overview of the identified barriers and drivers affecting the consumer's choice. The different factors were grouped into five categories: technical, environmental, economic, market and psychological factors.

3.3.2.1 Technical factors

A deployment of charging stations could give a strong signal to consumers, convincing them that EVs are a trustable option. However, it is essential not to forget the convenience aspect in infrastructure needs. Charging times also influence purchase behavior. These are followed by the range limitation as a critical factor in the choice for an electric vehicle. The three factors are described in this section.

Accessibility to the infrastructure

Among the different types of electric vehicles (hybrids, plug-in hybrid electric vehicles, battery electric vehicles (BEVs), etc.), the more the degree of electrification increases, the more the driver depends on the charging infrastructure. The most extreme case is when the vehicle is a battery electric vehicle, where the driver relies fully on the grid. The access to the infrastructure is therefore a particular concern given the best usage for battery electric vehicles is situated in urban areas. However, a part of the population lives in townhouses or apartments, making it hard to charge at night. Home charging at night is perceived as the most convenient way to charge, given the long charging time and the lower cost of electricity during the night (Skippon & Garwoord, 2011). Not having a convenient place to charge at night is therefore a critical barrier. This was also identified in the survey conducted by the Vrije Universiteit Brussel (VUB-MOBI, 2011). However, Belgium should not face such a constraint since 70% of households own a garage and most of the cars supplied can be directly plugged-in on usual plugs (SPF Economie, 2010).

Resulting from the night charge opportunities, creating an outdoor charging network should not be the only target. The average travel patterns of Belgian citizens enables to drive the average every day distances on a single night charge (SPF Economie, 2010). However, projects to develop a charging station network along the road or in public and office parking spaces are still considered useful as they can influence the consumer perception of EVs. In Belgium for example, installing a charging station (outside the house) entails a reduction of 40% on investment with a maximum of 250€ (Service Public Fédéral FINANCES, 2011).

The infrastructure characteristics

The charging time is a particular concern for every plug-in electric vehicle, but particularly for BEVs, when a long stop is needed along the road to charge the battery. The problem for companies is to design batteries that can charge quickly without overheating the battery cells. But even if this progress is made, the infrastructure might not deliver as much power as the battery can take: for example, residential electrical circuits usually provide less than 2kW (for 120V, 20A), and a special circuit for dryers and electric stoves provide up to 7kW (for 240V, 40A) (Thomas, 2009). The former is called level 1 and the latter level 2 in EV business language. Table 4 shows the estimated time needed to charge different batteries for EVs with the different charging levels. On a level 2 (the best available circuit in homes), the charging time for a BEV with a range of 241km (56kWh) would take about 7,3 hours. This seems acceptable only for night charging.

For charging on the road, a new level has been developed: it is the third level, commonly called ‘fast charging’. Assuming that batteries can charge this fast, the same BEV (56 kWh) would need almost 1 hour to be fully charged. However, 1 hour is still hard to accept for certain occasions. No driver wants to wait along the road for such a long time during their holidays.

Table 4 : Estimated minimum recharging time for BEVs (Thomas, 2009)

Vehicle range (km)	Energy required from grid (kWh)	Level 1 charging time (hours)	Level II charging time (hours)	Level III charging time (hours)	
		120 V, 20 A	240 V, 40 A	480 V, 3Φ	
		1.9 kW	7.7 kW	60 kW	150 kW
241	56	29.2	7.3	0.9	0.4
322	82	42.7	10.68	1.4	0.55
483	149	77.6	19.40	2.5	0.99

Next to charging stations, alternatives are offered by the market. Battery swapping stations allow EVs to swap their empty battery at the station and get a fully charged one provided by the network. This procedure has the advantage of having a comparable procedure as a fuel fill up: it lasts a couple of minutes, it is convenient and safe to use since the swapping system is automatic (Van den Bossche, 2003). Another recent development is the inductive charging system. It allows EVs to charge without the use of cables (Loukil, 2011). The most common way of inductive charging is the static option: the electric vehicle is parked on a specially equipped surface while the battery can be charged (Brown, Mikulin, Rhazi, Seel, & Zimring, 2010). The second option is called dynamic inductive charging: here, the EV does not need to be stationary; it can drive over special lanes and the battery charges whilst driving (Chan & Chau, 1997). This way, driving range and charging infrastructure could become less needed (Ing, 2011). Again, safety could be improved since no exposed conductors have to be manipulated (Bradley & Frank, 2009). However today, Belgium has no battery exchange stations and no inductive infrastructure. Therefore, EV adopters have to rely on their home chargers or the early quick chargers network.

Limited driving range

The accessibility and convenience concerns of the infrastructure gives much more importance to battery energy storage and their delivered range as no driver wants to cope with finding a charging station and wait some time before he can keep driving.

In literature, the limited driving range for electric vehicles is often referred to as the “range anxiety”. The limited capacity of batteries coupled with a limited charging infrastructure and long charging times could scare the driver and could take away the idea of flexibility, which is commonly associated with conventional cars. BEVs suffer from this handicap as they rely exclusively on their battery capacity.

Hence, BEVs usage seems to address very specific travel patterns and better suit niche markets where short ranges are the essential aspect (for more information, we refer to task 3.5 of the Trans2House project,where the focus lies on travel behavior for EVs). However, even if the daily travel patterns in Belgium would fit the performances of BEVs, range anxiety is still at stake, making it an essential barrier for a BEV purchase. Indeed, consumers focus rather their purchase decision on their maximum distances than on their average ones.

Infrastructure characteristics and future battery innovations are the two axes to act on to improve BEV attractiveness. New developments like NiMH (Nickel-Metal Hydride) batteries already deliver higher performance in energy, power, temperature, ultra-fast recharge capability and cost reduction (Fetcenko, et al., 2007). Even more recent improvements in Li-ion cells have shifted the EV industry from NiMH technology to this upgraded battery. This switch is mainly due to better energy storage characteristics (MIT, 2010).

Another way to lower range anxiety is to choose a lower DOE than BEVs. PHEVs and other lower DOE vehicles can use the well-established gas station network to keep driving in case of power shortage. Moreover, new interesting innovations are coming to the market. The results are promising: higher life expectancy, more compact size, reduced costs and quick charging times.

Given the current infrastructure though, range anxiety remains and discourages the purchase for electric vehicles. However, the potential offered by the future technologies could broader commercialization.

3.3.2.2 Environmental factors

A BEV is a zero emission vehicle. When driving, it produces no noise, no CO_2 or any other emissions. However, the electricity used to power the car has been produced. When analyzing car emissions, it is therefore essential to use a well-to-wheel analysis that considers the emissions of the whole product cycle. A better assessment of the EVs' positive impact on CO_2 emissions can be made by evaluating the power mix of the electric grid. In carbon intensive countries like China and India, the substitution of ICE vehicles by EVs would hardly reduce CO_2 levels. On the other hand, if the power generation-mix would make use of renewable and nuclear energy like in Europe, EV integration could save 55 to 60% of CO_2 emissions (BCG, 2009). Next to the positive CO_2 effects, EVs also allow to lower the damage on human health created with ICE vehicle emissions, mainly CO, NO_x and SO_x. The pollution is concentrated outside cities improving air quality in highly concentrated living areas.

Carbon dioxide (CO_2) is a preferred measure to rate the ecofriendliness of vehicles. Unfortunately, this indicator only considers the global warming effect of the vehicle without assessing the damages on human health, urban welfare and the production impact of the vehicle. In this respect, another rating tool was developed: the Ecoscore. It has been developed in Belgium according to the well-to-wheel method to evaluate the overall vehicle environmental performance. It considers noise (10%), global warming contribution (50%), damage on human health (20%) and damage on ecosystems (20%), giving a rating from 0 (extremely polluting) to 100 (no pollution at all) (Timmermans, Matheys, Van Mierlo, & Lataire, 2006). The tool can be discussed, especially in terms of the weight attributed to each factor, but it is considered as a trustable measure.

3.3.2.3 Economic factors

Consumer trade-offs between fuel costs and purchase price are believed to be essential in choosing the optimal DOE. Increasing its level to a 100% electric level increases the battery costs in a large extent but decreases fuel costs. To simplify costs assessment, literature uses total cost of ownership analyses to measure how competitive the different type of vehicles are on a financial level (Delucchi & Lipman, 2001). For more information on total cost of ownership for EVs, we refer to WP3.3 of the Trans2House project. Because consumer sensitivity to fuel costs and purchasing price is different (Indiana University, 2011), costs are assumed to be better interpreted if divided by their time nature. Therefore, costs are classified into three classes. First, fixed costs consist of every cost consumers occur when purchasing their vehicle. Second, variable costs include each vehicle cost that can be calculated on a per kilometer basis. Finally, the third cost category, half way between variable and fixed costs, takes account of the annual costs.

3.3.2.4 Market factors

Given the technical and economic barriers, automotive manufacturers are faced with strong uncertainties in the market. It is unclear if the environmental performance of electric vehicles will attract demand because of the nascent stage of the market. As conventional ICE cars are getting cleaner and cleaner, this advantage tends to lower. As a result, the development of the electric vehicles supply is not diversified, limiting the choice of consumers (SPF Economie, 2010). This in turn decreases the adoption rate of EVs and gives less incentives for automotive manufacturers to develop the market. If the EV market wants to unlock from this chicken-and-egg problem, regulations and policies need to come supporting the development of the market. As described in the economic factors, the market receives already fiscal incentives. However, uncertainty remains in the market given the unknown evolution of these policies.

3.3.2.5 Psychological factors

The CLEVER project(Van Mierlo et al., 2011) highlighted the “locked-in” barrier that faces new technologies when penetrating a market. Consumers are known to be reluctant to change. Even if a new technology is superior, many consumers fear to adopt it (Belleflamme & Peitz, 2010). The reason behind this is multiple: the lack of information, the low technology expectations in the future and the consumers’ inertia are only some of the potential causes. The lack of information on the new technology can be a strong barrier since the potential adopter needs to invest time and efforts to compare a new alternative with its usual purchase options, adding an additional cost to the uninformed consumers (Young, Hwang, McDonald, & Oates, 2009). The majority of the population only has a very limited knowledge about electric vehicles; they know the technology exists but they cannot really compare it with the conventional vehicles given the low information they have. This group is not likely to switch technology soon since they do not consider electric vehicles as an alternative option.

Another factor explaining the lock-in effect of consumers on the conventional vehicles is the low expectation in the penetration of the new technology. The consumers observe a set of signals which define their expectations: word of mouth, the infrastructure coverage, marketing communication, etc. All these events participate in building confidence in the new technology. The penetration of the electric vehicle technology is in the end a matter of network effects. The essential development step is the product launch until the critical mass is reached. Before this step, network effects are in favor of conventional vehicles and contribute in locking the consumers in the old technology. But once the critical mass is reached, network effects help catching new adopters (Belleflamme & Peitz, 2010). However, reluctance to change is part of human behavior and it is even worsened when the purchase decision of an EV is studied in its context. The choice does not occur without any background. Conventional cars have surrounded us for decades. They are anchored deep in our culture. The freedom of the road and the flexibility of the car are images that still stick to the conventional cars. This element takes an important part in the psychological lock-in effect of the consumers on the conventional vehicles.

3.3.3 Purchase behavior for electric vehicles in Belgium

The online survey conducted by Vrije Universiteit Brussel (VUB-MOBI, 2011) also included a choice-based conjoint experiment in order to investigate the preference structure of Flemish consumers for the purchase of a new car. The selected method is particularly interesting since it allows estimating the importance of each factor in the final purchase decision: the survey uses a discrete choice model to evaluate the trade-offs made by consumers when choosing an electric vehicle and the utilities of every factor is obtained. It is a recognized method in the field of new product development by marketers (Hair, Black, Babin, & Anderson, 2010).

Based on a data set of 1.196 respondents collected in May 2011, Figure 16 illustrates the relative importance of each attribute when considering a choice between an electric vehicle and a conventional one. The most critical factor is the purchase cost. It is responsible of 18,5% of the decision. Next, annual costs are responsible of 14,5% of the decision. It is interesting to stress that variable costs are the fourth influential factor, owning a share of 11,5%. As a result, costs are the most important factors in the choice between an electric and a conventional vehicle.

However, the charging convenience must not be neglected: being the third most critical factor, the charging time is responsible for 12,3%. Also in the technical factors, the limited range is responsible for 10% and the infrastructure coverage takes almost 8% of the decision. The accessibility to the grid is likely to be the lowest factor given the usage of the vehicle. Because it fits the urban mobility needs and because the daily distances can be done on a single night charge, the driver will barely use public infrastructure. But if he needs it, he prefers to take time finding an access point rather than wasting time at a charging station.

The survey also considered top speed in the choice trade-offs. The choice-based conjoint experiment gives an importance of more than 11% in the consumer choice procedure, being more important than limited range and infrastructure coverage. However, Figure 15 showed that top speed was of much lower importance than the range and the infrastructure coverage. The difference must come from some disqualificative levels in that factor. If an electric vehicle has a top speed of 80 km/h, it is likely that the top speed factor will receive a high importance in the purchase decision since it cannot legally access highways. But if the electric vehicle has a top speed of 120 km/h, the influence of the factor will be less critical with a conventional vehicle. Finally, the brand image of the vehicle has the same influence as the green image of the vehicle with a share of 7% each in the final decision.

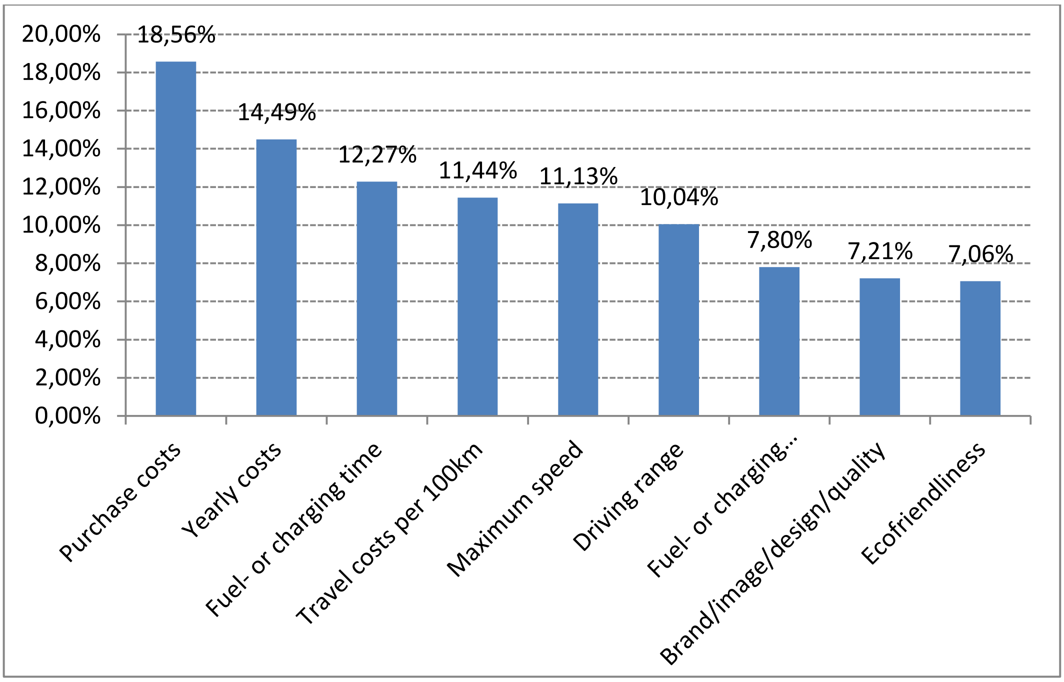


Figure 16: Relative importance of vehicle attributes (VUB-MOBI, 2011)

Costs factors are thus the most important purchase factors, followed by the technical factors. In particular, the purchase price is the most influential factor.

3.3.4 Market share forecasts for electric vehicles

During the last decade, many studies have investigated the sales potential of electric vehicles. Given the dominance of current conventional vehicle technologies (petrol and diesel), the evolution towards electrified transport is likely to take some time.

Looking at the Belgian situation, the Vrije Universiteit Brussel held a large scale Flemish study, in which the market potential for EVs was studied (VUB-MOBI, 2011). The results are depicted in Figure 17. Here, the projection for BEVs is separated from that of PHEVs. In 2020, the market potential for BEVs is situated around 6% of the yearly sold new vehicles in Flanders, while the market potential for PHEVs is around 4%.

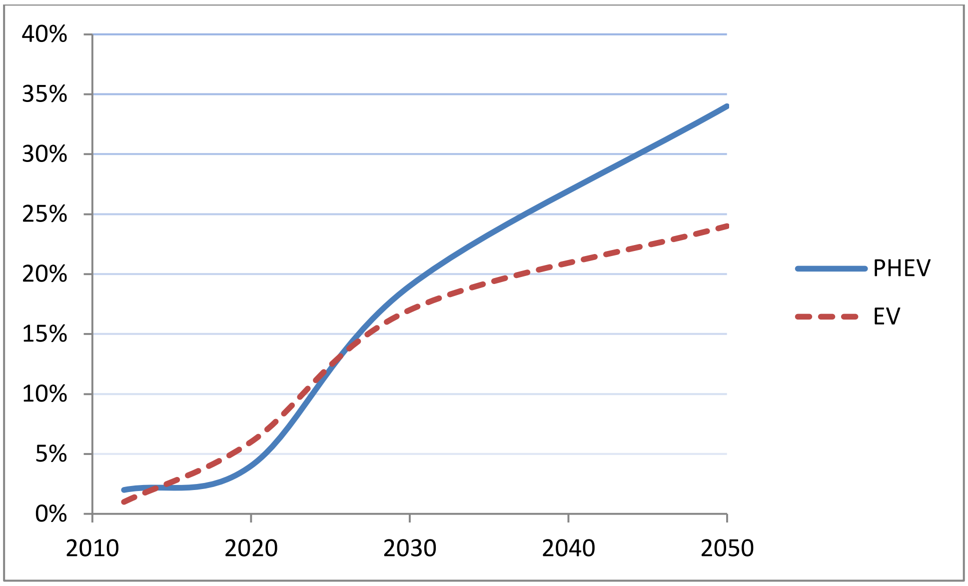


Figure 17: Market projections for EVs in Flanders until 2050 (VUB-MOBI, 2011)

3.4 Travel behavior

3.4.1 Introduction

Two barriers of electric vehicles are closely linked to the way people like to travel: the driving range is limited to on average 150 km and the network of charging infrastructure is still very scarcely implemented. However, travelling by car is very common in Belgium and it is perceived as a degree of freedom. Hence, in this chapter, we have investigated how EVs are linked with the travel behavior in Belgium.

The focus of this study lies on battery electric vehicles (BEVs). Other types of electric vehicles such as plug-in hybrid electric vehicles (PHEVs) do not have the limitation in driving range and are thus more easily implemented in the driving patterns of Belgian citizens.

3.4.2 Travel behavior

Travel behavior of an individual includes all his or her movements with all the different travel modes and for all possible purposes.

3.4.2.1 Travel data used for this study: OVG4.2

The aim of this research was to use the BELDAM (Belgian Daily Mobility) study (Cornelis *et al.*, 2012), which is financed by the Federal Government of Mobility and Transport, to link with BEVs characteristics. However, because the BELDAM research has not yet been completed, we need to use other data sources. The previous Belgian version is called MOBEL and took place in 1999. Unfortunately, this dataset is out of date in order to make valid statements for BEVs. Therefore, we focus on results from a travel survey conducted in Flanders from September 2009 until September 2010. This study is called OVG 4.2 – Onderzoek Verplaatsingsgedrag Vlaanderen (OVG, 2011), which is the second edition of the fourth survey that takes place in the framework of this investigation. OVG 1, 2, 3 and 4.1 took place earlier. In order to justify this survey choice, we refer to the results of the MOBEL-study (2000). Hubert and Toint (2002) found, based on the results of MOBEL, that the travel behavior of Flemish citizens scarcely differs from that of the entire Belgian population. A similar trend can be noticed when we study the percentage of trips of less than 40 kilometers. Of all Flemish citizens, 66% make trips less than 40 km. For Belgium, 65% of all trips are less than 40 km. For the other regions, Wallonia and Brussels, this is 61% and 71%. Moreover, the average number of trips per day is identical for both the Flemish region and Belgium, namely three trips. Generally, we can assume that travel behavior of a Belgian is (almost) the same as that of a Fleming.

3.4.2.2 Why Flanders is an interesting location for BEVs?

There are several reasons why Flanders, the northern part of Belgium, is an interesting area to investigate the market potential of BEVs. In 2010, the Belgian population comprised 10.839.905 citizens and more than half of them, 6.251.983, lived in Flanders[2]. The region has a high building and population density, which results in relatively shorter distances which have to be covered. Another argument in favor of Flanders is the fact that cities and communities are not far from each other. This means that BEVs easily can be used to travel from one location to another. Furthermore, it is an advantage that the different regions are well accessible thanks to well-developed roads. The length of the freeways in Flanders equals about 900 km, while the total length of all Flemish roads amounts to a total of 70.000 kilometers[3].

First, this research focuses on several general travel behavior characteristics. Thereafter, the focus has converted to electric vehicles and data have been discussed with respect to characteristics of BEVs. Since only a handful of people in Belgium already own an electric vehicle, it may not be forgotten that data of conventional car use has been used. However, even if it does provide the possibility to learn more about travel patterns of individuals, people might still change their travel routines when they eventually own an electric vehicle (Christensen, Kveiborg & Mabit, 2010).

3.4.3 Car travel behavior of Flemish citizens: general information

The OVG study (OVG, 2011) illustrates that most Flemish citizens use their vehicle every day (47%). When a car is not used every day, it is still used at least once a week in most cases (42%). These two categories represent almost 90% of the population. Based on this information, it can be stated that Flemish people use their car a lot. It is

[2] FOD Economie, K.M.O., Middenstand en Energie. Wettelijke bevolking per gemeente. <http://statbel. fgov.be/nl/modules/publications/statistiques/bevolking/cijfers_bevolking_1_1_2009.jsp>. Consulted on 5 March, 2011.
[3] Vlaanderen.be. Agentschap Wegen en Verkeer. <http://wegen.vlaanderen.be/index.php>. Consulted on 5 March, 2011.

also interesting to explore how the car is being used compared to others transport modes. This can be done based on the average number of trips per day, which amounts to about 3 for people living in Flanders. 13 kilometers is the average length of the trips. In the OVG-study, a trip is defined as “going outdoors, mostly with a specific destination”. The automobile is a very popular mode of transportation: more than 60% of all trips are car trips, be it as a driver or as a passenger (OVG, 2011). Next to grouping trips based on the transport mode, the number of kilometers that is covered per day can also be divided according to the different transport modes. The average distance covered by Flemish citizens amounts to about 37 km per day. More than 65% of the total mileage per person per day is covered by car (driver and passenger).

3.4.4 Linking travel behavior tot electric vehicles: is there a potential market?

3.4.4.1 Number of kilometers

Battery electric vehicles have a limited driving range. This entails that the length of the trips people make becomes a new and interesting objective within the research on travel behavior. Individuals will not rapidly change their travel behavior. First, they need to be informed about the possible alternatives that exist for their current travel habits (Brög, Erl and Mense, 2002). This might already cause problems since many individuals are not aware of the electric vehicle technology (Golob and Gould, 1998). However, information related to the technology alone is not enough, there are also other requirements. In order to be able to decide whether an electric vehicle could satisfy the travel needs of individuals without having to adapt his travel routines, two areas need to be investigated: the driving range of current BEVs and the amount of kilometers that Flemish citizens cover on a daily basis. Table **5** illustrates 14 BEVs that are currently available on the Belgian market (or that will be available in the upcoming months) and their maximum driving range.

Table 5: Driving ranges of battery electric vehicles (almost) available on Belgian market (Own setup, based on manufacturers’ websites)

BEV	Driving range	BEV	Driving range	BEV	Driving range
Citroën C-Zero	130 km	Peugeot iOn	130 km	Reva L-ion	120 km
Ford Focus BEV	160 km	Renault Twizy Z.E.	100 km	Tazzari Zero	140 km
Mini E	160 km	Renault Kangoo Z.E.	160 km	Tesla Roadster	340 km
Mitsubishi iMiev	130 km	Renault Fluence Z.E.	160 km	Volvo C30 EV	150 km
Nissan Leaf	160 km	Renault Zoe Z.E.	160 km		

As shown, the ranges vary between 100 and 160 kilometers, with the exception of the Tesla Roadster that has an electric range of 340 km. However, this last vehicle is a sports car and costs around €100.000 and is thus not the average car in the Belgian fleet. Of course, it has to be taken into account that these distances are determined under normal conditions. According to Christensen, Nørrelund and Olsen (2010), there is a difference between the distance that electric cars should be able to cover officially and what they can cover in practice. The authors state that vehicles with a proclaimed range of 80-160 kilometers can most of the times be driven for a distance of about 50-120 kilometers. Due to the impact of external conditions on the vehicle autonomy, people have to take into account a safety margin at all times of having access to (fast) chargers. The car is often used to cover short distances (OVG, 2011). Flemish citizens even use their car to cover a trip distance of less than one kilometer. It is stated that 64,50% of the average travelled distance per day by car is lower than 40 kilometers. Only 6,18% of all the car trips, made by Flemish people, is longer than 40 kilometers. This means that almost 94% of Flemish citizens use a car for trips of less than 40 km. Golob and Gould (1998) concluded that people always tend to overestimate the range that they really need. They did experiments with prototype electric vehicles in Southern California in 1995-1996. The distances the participants of the study daily covered were measured and they were within the range of the electric vehicles available on the market at that time. Even though the participants were aware of this, they were still convinced that vehicles should have a higher range. People have perceptions about the range of a car and these are rigid. This means that even when it would be possible, in practice, for an individual to make all the trips he has to make with an electric vehicle; it might occur that he does not want to buy one due to his perceptions.

3.4.4.2 Charging infrastructure for BEVs

Charging facilities in Belgium

The number of electric vehicles in Belgium is still very limited. Moreover, it is not easy for those few BEV owners to charge their vehicle at public infrastructure. There is a relationship between the two aspects; people will persist to have a reluctant attitude to buy an electric vehicle since very few recharging poles have been installed, while the producers of the recharging equipment hesitate to extend the charging network since few electric vehicles were sold in the past. This can be considered as a chicken-and-egg situation. In December 2011, there were more or less 150 public charging stations in Belgium. Most of them are located in or near Brussels and on private and semi-professional domains. The figure also reveals that there are more charging opportunities in Flanders compared to Wallonia. For electric vehicles to become successful, this situation will have to change. Belgium also has to catch up with other European countries, for example the Netherlands, where already more time and money has been invested to install recharging infrastructure. In 2012, about 10.000 recharging spots will be operational in the Netherlands, which is a very sharp difference with Belgium[4].

[4]Duurzaam op weg. Samenwerken en kennis delen over duurzame mobiliteit. <http://www.duurzaamopweg.nl/nc/home/groepen/elektrische-mobiliteit/laadpunten-in-nederland/?sword _list%5B%5D=laadpunten>. Consulted on 12 March 2011.

Fast chargers, battery swapping and inductive charging

Fast chargers (typically as from 40 kW) will charge the electric vehicle at a higher rate than normal chargers. However, these chargers also have some disadvantages:

- High infrastructure cost
- Impact on energy grid if clustered (this can be tackled by installing an energy buffer, however, this is again quite costly)
- Impact on battery lifetime (Christensen, Nørrelund & Olsen, 2010)

Moreover, the energy capacity of BEVs can be “refilled” by replacing the entire battery pack with a fully charged battery pack. This process is called battery switching or battery swapping. This system has already been used for industrial appliances and has already been demonstrated for road vehicles (Maggetto et al., 1983). Recently, battery swapping stations have regained interest through the company Better Place. However, battery swapping systems does not eliminate the fact that people will have to stop regularly during longer trips. Individuals or households that own more than one vehicle might solve this problem by using one of their other vehicles for these longer trips. Individuals and households that only own one vehicle on the other hand, will have to search for other alternatives. One solution might be, for example, to rent a conventional vehicle. Another option is to use other means of transport, for example public transport.

Another way of charging the battery of the BEVs is through inductive charging systems. Here, the battery is charged without it being cabled to the electricity network. Using magnetic waves, the BEV can be charged whilst standing still (static induction) of whilst driving (dynamic induction). Advantages of this system are the user friendliness, the level of safety (no usage of cables), a lower risk of vandalism (because the charging infrastructure is located underground), and the preservation of the landscape. However, current prices for inductive charging infrastructure are still quite elevated and the energy efficiency level is not yet as high as compared to conductive charging systems (with cables).

Location of recharging points

In order to integrate BEVs in society, it is necessary that the charging infrastructure is installed in a well-organized way. The more recharging spots are available, and the better these are located, the easier it will be to cope with the limited range of a battery. The risk of getting stranded will decline.

It is important that charging infrastructure for BEVs is well located. Activity analysis, which has already been part of travel behavior for a long time (Kurani and Turrentine, 2002), might help to determine where charging poles or battery swapping stations need to be located. When an individual drives a BEV, the location, duration and timing of the activities are even more important due to the limited driving range of those vehicles.

Because one trip too far or adding one extra activity to a series of activities might mean being stranded. This implies that a good planning is necessary.

Locations can be determined based on activities. However, fuel stations are also often mentioned as places to install the required infrastructure to establish public recharging spots. On January 1st, 2011, there were 3.209 filling stations operational in Belgium[5].There are several reasons why this would be beneficial for fast chargers:

- Most filling stations are strategically located along roads with lots of traffic
- People already know where the stations are located
- Conventional car owners are already accustomed to the idea of having to refuel at petrol stations

In order to install the charging infrastructure for electric vehicles, it is necessary to know the number of people that need to charge during the day. For some people, it might be sufficient when they can charge their vehicle during the night. For others, however, it can be necessary to recharge once or even several times during the day.

Christensen, Nørrelund and Olsen (2010) have investigated families in Denmark with only one car in order to determine their charging requirements. The results show that in many cases it would be sufficient to charge the BEV at home. Taking into account the limited average daily mileage covered in Belgium, an identical result could be expected. The need for fast charging decreases when the range of the vehicle increases.

Charging from a vehicle point of view

The long charging requirements could also be investigated from a vehicle point of view. In a study from General Motors (2001) the location of the vehicles was monitored for an entire week. On weekdays, a vehicle is parked at home for about 50% of the time during the day and for about 95% during the night. During weekends, these figures are respectively 70% and 90%. During week days, the vehicle is parked at work for about 30% of the time. This indicates that there are plenty of charging opportunities for electric vehicles, both during the night (at home) and the day (at home and at work).

3.4.4.3 Vehicle occupancy

An argument that might dissuade potential customers from buying an electric vehicle is their size. Some electric vehicles only have seating capacity for two people which might cause problems for some trips. However, classifying trips according to the number of individuals aboard of the vehicle illustrates that people drive alone most of the time. For almost half of all trips, there are no additional passengers aboard of the vehicle.

[5] Belgische Petroleum Federatie (BPF), 2010. Evolutie van het aantal tankstations in België. <http:// www.petrolfed.be/dutch/docs/tab_fig_2010/Tabellen/T29_nl.pdf >. Consulted on November 12, 2011.

When the driver does not travel alone, he is most often accompanied by only one passenger. Trips with vehicle occupancy of two individuals, a driver and one passenger, represent almost one third of all trips. Transporting three or more passengers is rather rare. The average vehicle occupancy rate in Belgium is 1,84 persons. This parameter can differ based on the type of trips that are included (OVG, 2011). Off course, consumers buy a vehicle taking into account different forms of usage, for example the daily trip to the train station (alone) or the yearly trip to the south of France (whole family). However, this last trip could be done with another (larger) car within the family car fleet, a rented vehicle of public transport. This way, the single trips can be done by for instance an EV or (electric) scooter.

3.4.4.4 Segmentation for BEVs: a focus on households

Studies on electric vehicles often focus on households as one of the interesting target groups for the purchase of BEVs. Hence, it is interesting to focus on some household characteristics and aspects of households' travel routines. Acquiring insight on factors like for example household car ownership and vehicle miles travelled can be an essential step in understanding how households would react when they would expand their vehicle fleet with an electric vehicle or even replace a diesel or gasoline vehicle by a BEV in the future.

Household characteristics

Households can be divided into different groups: with and without children. Other factors that can be used to make subgroups are: the age of the children, the age of the head of the household, or the ages of the heads of the household in the case there are several. Other factors that matter are the jobs of the members of the household, or the fact that they are retired or not. These different groups are in fact developmental phases which are called life cycles (Baines, Fill & Page, 2011). Households that are in different life cycles have other travel desires. Another factor that could affect the willingness to buy an electric vehicle is lifestyle. This attribute focuses more on the consumption pattern of the household.

A study of Turrentine, Sperling and Kurani (1992) states that the households that are most willing to buy a BEV, are households with children and mid-aged adults. The authors suspect that those households often have more routine driving patterns compared to other households. In most cases these households use the car to go to work *or* to drive the children to school.

Another factor that, according to the authors, contributes to a greater willingness to purchase a BEV is that this group usually has higher incomes as opposed to other households. This might help to reduce the influence of a higher purchase price, which is a serious obstacle for other households.

Turrentine et al. (1992) also state that some retired households tend to reject the electric vehicle because they use their car for weekend and holiday travel. For those households, a limited range is the most important barrier.

Households buy vehicles to fulfill their travel needs. When one car is not enough to fulfill them, it is possible that a second vehicle is added. When this is not yet sufficient, another additional vehicle could enter the household fleet. However, it is important to bear in mind that the purchase of a car is still considered as an acquisition with serious financial consequences (Mohammadian and Miller, 2003). According to Handy and Krizek (2009), the decision to expand the household vehicle fleet with another vehicle is generally considered as a decision on the mid-term. People seem to weigh the benefits and disadvantages of the purchase rather than to buy a car impulsively.

Multivehicle households and their travel behavior

Most Flemish households own only one vehicle. Less than 30% of the households in Flanders are multivehicle households of which most of them own two vehicles.

An expansion of the household does not always entail a rise of the average number of vehicles within the household. Even when households consist of 6 or more members, the average number of vehicles owned by those households remains below 2.

According to Kurani and Turrentine (2002), there is a growing tendency of households to acquire diversified vehicles since this would enhance the versatility of their vehicle fleet. Being versatile, they try to be able to cope with different situations. Preferences of household members also play a role in this behavior (Golob, Kim and Ren, 1995).

Households also seem to value the fact that electric vehicles can be recharged at home which eliminates trips to gasoline stations. Even in the case that BEVs are often smaller than internal combustion cars is not experienced as a barrier by most multivehicle families (Kurani & Turrentine, 2002). However, it implies that households have to take this capacity constraint into account when they allocate vehicles to household members.

Important in this framework, is the number of kilometers that is covered with each vehicle within a multivehicle household. The term that is used to describe this distance is VMT (vehicle miles travelled). VMT is also a component of travel behavior. This means that, just like other indicators of travel behavior, VMT is influenced by several factors. According to Golob, Kim and Ren (1995), the amount of kilometers that is covered with each vehicle depends on household, driver and vehicle characteristics.

An example of a household characteristic that has a positive impact on vehicle miles travelled is income (Handy and Krizek, 2009). Other examples are the number of vehicles available within the household, age of household members and household size.

The impact of an electric vehicle within a household vehicle fleet

Kurani and Turrentine (2002) stated that in most multivehicle households, a limited range for one vehicle is not really experienced as a barrier. This is especially the case when the household is a hybrid household (Kurani, Turrentine & Sperling, 1996). They have defined hybrid households as households that possess multiple cars with different driving technologies (diesel, petrol, hybrid cars).

It remains important for potential customers of BEVs to know what the impact of replacing a gasoline or diesel car by an electric one, or expanding their vehicle fleet with an electric vehicle, will be on their mobility and travel patterns. The use of travel diaries might enable households to learn more about the amount of kilometers they cover on a daily basis with each vehicle they own. However, since many households are not yet familiar with the technology of electric vehicles (Golob & Gould, 1998), this might not be enough to convince them of the possibilities the technology might offer them.

Organizing trials could be useful to solve this problem. In that case, households have the opportunity to really experience the effects of having an electric vehicle within their vehicle fleet for a period of time. This might enable them to learn whether they would have to adjust their travel routines and if so, how these routines would have to change. This research method also gives them the opportunity to get acquainted with the technology of the battery-powered vehicles, as well as with the costs related to driving them and the fact that they need to be charged on a regular basis.

Golob and Gould (1998) have used trials to discover consumer acceptance of electric vehicles. Participating households could use an electric two-passenger vehicle for two weeks. This capacity constraint may have affected the results of the study. They concluded that people overestimate their travel needs. Even when they were confronted with the actual distances that they covered on a daily basis, participants were still convinced of the fact that cars should be able to cover large distances. Several reasons might explain this behavior. It is possible that people want to be able to make unexpected or unplanned trips. Another possibility is that people associate cars with freedom and being able to cover small and large distances whenever you need to cover them.

Golob and Gould (1998) stated also that when a multivehicle household would buy an electric vehicle to replace a gasoline or diesel alternative that is part of their vehicle fleet, about 88% of the trips that were made per day with the authentic vehicle, will be made with the electric one in the future. For longer trips, other transport means need to be found. A household could, for example, use another car of its vehicle fleet or rent a car. It is also possible that households change the way they allocate vehicles to the different household members. They can use the internal combustion vehicle(s) less for short trips and make those with the electric vehicle, while the longer trips can be made with a vehicle without a limited range.

This demonstrates that people might adapt their travel behavior when they acquire an electric vehicle. This has been confirmed by Golob and Gould (1998) through trials.

3.5 Social barriers, incentives, driving forces and stimulations

3.5.1 Introduction

This part consists of a qualitative study of barriers, driving forces and incentives for the use of electric vehicles by households in Belgium. The study is based on an analysis of a sample of household behavior that can be described as innovative in the fields of energy and mobility. The topic may also be of interest to households generally sensitive to environmental issues and technophiles.

3.5.2 Construction of the sample

3.5.2.1 Existence and characteristics of a pioneer group

What stands out from different market studies (The City of New York, 2010; Zpryme, 2010; Deloitte, 2011; EurotaxGlass, 2011; J.D. Power, 2010; Accenture, 2011) is that there seems to be a pioneer group of potential EV buyers. The importance of this group varies according to backgrounds and studies. A series of specific elements about first potential purchasers can be brought out. The group consists of people who generally care about the environment, who are technophiles and ready to some extent to pay more to purchase this type of car.

The original hypothesis adopted at the outset implies the presupposition that there is a homology between on the one hand the precursory behaviors in terms of behaviors towards energies (and/or towards mobility) and on the other hand the question regarding the potential use of EV.

However, if the aforementioned examined studies can validate this hypothesis, it seems to us that this hypothesis may prove to be slightly too restrictive. Indeed, it is about discerning possible innovative behaviors in terms of consumption in relation to the purchase of a car equipped with a technology of different motorization but which aims to replace the classic car.

The criteria of choice of a car do not coincide necessarily to the choice of a type of energy. It’s not because you are an “innovator” in terms of energy saving that necessarily you will be a pioneer in other fields. Can energy saving be considered as innovative?

It is also interesting to try to comprehend the obstacles of the purchase and/or the use of EVs of one of the groups who seems to be more disposed to do so, the technophiles. Besides people who are in line with energy saving or energy production, or people who use means of transport, we will hold a number of people who fit the right technophile profile in our sample.

3.5.2.2 The specificity of the choice of a car

The symbolic dimension linked to cars is more important than the one linked to a type of insulation or a means of heating. The choice of a car exceeds widely the question of the satisfaction of a need of mobility.

The criterion of a minimal autonomy of 480 km mentioned in the study of Deloitte (2011) is a case in point. It turns out that the great majority of drivers travel less than 80 km. This need of autonomy is linked to big transhumance during holidays and to the “potential” it represents. However, this idea of autonomy is sometimes also more or less implicitly linked to the idea of ecology, under the slightly fallacious argument that if a car can run for a long time with a full tank it means it consumes less.

Besides the fundamental question about the “need of having a car”, there are numerous and various means to satisfy this need. The choice of a vehicle and their number often takes place in the family unit. This choice is the result of arbitration between the different resources and demands of this unit (ANSAY, 1997).

Does the EV appear to be an answer to this need or are they still a rather remote substitute for conventional vehicles? In terms of economy, does EV compete on the same market as the other cars? Are they goods that we can easily, more or less or not at all substitute to?

The question surrounding the reputation of the product also arises. A lot of consumers ignore or don’t know EVs and their different variants very well. Thus, it is not obvious that these different variants are a possible alternative choice for these consumers.

Moreover, nowadays the supply of this type of vehicles remains very weak because it is limited to certain segments of the automobile market. The existing electric vehicles are far from being available everywhere and delivery time can be very long.

3.5.2.3 Characteristics of the sample

In order to form a sample that corresponds at best to this group of potential buyers we have selected people who are in 3 categories. The first category concerns the people who go through an approach of energy saving or production. The second category concerns people who have changed their behavior in regards to mobility or who recently bought a new vehicle. This category is also further completed with people who are keen to buy an EV (but they haven’t yet). The third one concerns people who have a technophile profile. The people from the first category are people who did work for insulation, who built (or adapted an existing accommodation) a passive accommodation or an accommodation that consumes less energy or people who installed solar panels. The second category includes people who sold one or every vehicles they had, who have used other means of transport, who have recently bought a new vehicle or who wanted to buy an EV. The third category concerns people who are fascinated by the technology. The interested reader will find a descriptive chart in the appendix, which describes the sample. Here it is clearly an informed choice sample. People in our sample have been deliberately selected according to the criteria we held.

3.5.2.4 Method

Our survey concerned 23 people. It has been done in semi-directive interviews with face-to-face meetings. The public we targeted were households. The interviews have been carried out from May to November 2011. We made sure to diversify the profiles between the predefined categories as well as in terms of gender (11 women, 12 men).

Except for one person, all the other questioned persons had at least one vehicle in his or her family. The majority of the surveyed people (20 of 23) didn't know that the survey was about EVs. Even though, they didn't prepare the interview, the respondents were aware that the survey would be about mobility and energy questions. However, we should remind that to complete the second category, two people who already knew the theme/topic of the survey have been selected.

3.5.3 Criteria of choice of a car

If we want to understand the social barriers, the bridles/curbs and incentives at the use of EVs, it seems essential to understand what leads people of our sample group to pick one or the other model. In other words, it seems important to write out a list of choice factors of a car for people of our sample.

The criteria are those mentioned at least once by one of the people in our sample. They are presented here in the order of frequency of quotation. The more different people have cited a criterion, the more it ranks high.

The criteria involved are about the volume of the car, the purchasing price and the use cost, the environmental impact, the security, the look, the comfort, performances, the availability, the reliability and a number of other additional criteria. It has to do with categories that we have established after following the analysis of the verbatim of our survey. These categories have been set out from elements that were mentioned by the respondents of our survey.

Volume is one of the criterions most often mentioned. Here, volume means the size, the available space. Most of the time, it is chosen according to the maximum use of the car, according to the maximum number of children in reconstituted families, according to the maximum volume of objects to transport, according to the desired amount of comfort for long distances. These uses are not necessarily the most recurrent.

The purchase price and the cost of use are also factors in the choice often evoked. It is a criterion which importance varies more particularly according to how the car is held. We have brought together the purchase price and the cost of use because most of the time these two elements are evoked at the same time.
A concern about the environmental effects of cars also arises. However it is important to stress that our sample, considering the used criterions, gathers together people who are concerned about environment. We should note that here we don't judge the pertinence of criteria used by purchasers but rather the invocation of environmental rationality that they evoke.

3.5.4 Perceptions of the electric vehicle

We can distinguish three great categories of perception. The first, the most common, is characterized by ignorance. Secondly, the perception of these vehicles by people who apparently don't reject this type of motorization and finally at the third perception of these vehicles by people who plan explicitly to buy this type of vehicle.

3.5.4.1 The indifferent people

First, we should stress that EVs are rarely evoked spontaneously. However, if we suggest it (if we question them explicitly about EVs, by asking them if they have already heard about EVs or a similar question) every interviewed person is aware of the existence of EVs. Nevertheless, most of them are unable to associate the EV to a brand or a precise model.
As a consequence it seems fundamental for us to look into the knowledge of the EV product itself before speaking about incentives and barriers to the use of EV.
For the majority of interviewed people, the EV is not spontaneously envisaged as a choice for a car. The EV is not viewed as a fully-fledged car. Today, the EV can't be considered as a car or as a substitute but rather like another category of product possibly supplementary to the actual vehicles.
If the objective is that the EVs replace eventually the vehicles with an internal combustion engine, the question of the identification of one or another barrier of one or another curb/bridle don't seem the fundamental element to us. Reluctances are not necessarily on one or another characteristic of the EV but on the global point that these vehicles don't enter into the range of possible choices.
The EV is most of the time associated with a potential urban use.

3.5.4.2 A conceivable choice in the future

However, for some people, the electric motorization is not excluded in itself. It is even considered as a likely characteristic of their future car, in a more or less near future or even remote. In this category, we can also include those who want to buy an EV but who consider that they are not currently finalized and that it is not a real vehicle yet.

3.5.4.3 A current or a short-term choice

The presented perception is the result of the analysis of the verbatim of people that we knew wished to buy an EV or people who told us they wanted to buy one too during our interviews.
Here, it's not a matter of considering the EV like a strange object anymore. The EV is considered as a serious car and could be a conceivable or planned product to buy.
It is considered as a usual car but still seen as a small car.

3.5.5 Barriers at the buying of an electric vehicle

Beyond the global perception of an EV as a fundamentally different product compared with traditional cars, inconceivable in the possible choices, or like a car possibly conceivable in the future, there is a number of barriers linked to certain expected and precise characteristics of the EV compared with elements seen as essential in the choice of a car.
These elements are especially the autonomy, the non-availability in the desired category, the supposed power of the cars, their reliability, their real advantages concerning environment, the danger that there represent for pedestrians, their supposed purchasing price as well as the consequences inherent to the massive plebiscite of this type of car and the lack of support and information of garage owners.
The evoked criteria by people who plan to buy an EV overlap certain criteria we have already evoked before. Those criteria are the price, the autonomy and the non-availability in the desired category.

3.5.6 Incentives for buying electric vehicles

On the contrary, a number of supposed characteristics constitute attractive factors for this type of motorization. For people in general, the reduction of the consumption of fossil fuel and energies, the personal energy independence seems to have, at least in terms of awareness, an influence on the wish of having an EV in the future. The rising cost of other energies, the reputation, the feeling of being inscribed in the track of progress, the silence, the expected savings and the connection with the evolution of driving styles.

For people who want to buy now or in the near future an EV, the pursuit of energy autonomy, the reduction of the consumption of fossil fuel, the commercial option

proposed by the manufacturers or the sellers (combination of car proposal: one EV and one location formula for holidays), the feeling to be in the sense of progress, the making available of parking space...
Having the feeling of being able to produce ourselves the energy that we consume seems to be an important incentive in the choice of electric motorization.
Whether he owns solar panels or wants to install them soon, the potential consumer of an EV establishes clearly and spontaneously the link between these two behaviors.

3.5.7 Hybrid cars

As we have already mentioned, hybrid cars are generally better defined and comprehended by interviewed people. It is a category of cars which are part of the possible.

3.5.7.1 Barriers to the hybrid

The considerations about purchasing price are certainly the barriers the most often evoked. Doubts about real performances of hybrid cars, the non-availability in the wanted range, doubts about real environmental qualities of cars constitutes the other barriers against hybrid cars.

3.5.7.2 Incentives to the hybrid

Energy autonomy, subsidy, the feeling to be in the sense of progress, environmental factors constitute the incentive to buy hybrid vehicles.

4. Transition pathways

4.1 Overview on transition pathways

Past and present transition pathways towards electric mobility and alternative fuels like bio-ethanol and natural gas have been identified and analyzed. It was useful to see how bio-ethanol became one of the primary vehicle fuels in Brazil in the 1980s, as a result of a complete package of governmental measures. A similar phenomenon was observed in Argentina and in Sweden, as a result of the promotion of natural gas and biofuels, respectively, as an important alternative for petrol.

In order to see what could be learned from other countries regarding e-mobility action plans, we arranged a list of pilots from a set of European countries, some of them with very ambitious targets. More details on this overview can be found in the report of subtask 1.5.

4.2 Preliminary transition pathways

4.2.1 How the scenarios were built

In the final phase of the project, the results found in the previous tasks were tried to be translated into a set of possible scenarios towards more electromobility in the future. In what follows, these scenarios are called ‘transition pathways’, since they are based on scientific insights (Geels and Schot, 2007; Verbong and Geels, 2010) in change typologies of socio-technical systems (of which the ICE vehicle is one). Socio-technical systems deal with technology within a broad societal context (e.g. cultural components, embeddedness in lifestyles...). Moving forward from the existing situation therefore requires a systemic approach that should be broadly borne by several levels of society, over a significant time span.

The so-called ‘Mobility Vision Integrated Process’ was merged with the fore mentioned insights from transition science, with a view to conceive four clearly different transition pathways: the transformation pathway, the technological substitution pathway, the de- and re-alignment pathway, and the reconfiguration pathway.

4.2.2 Description of the scenarios

More in particular, these scenarios were arranged as follows.

The transformation pathway starts from a situation where modest changes in the landscape cause pressures in the socio-technical regime. Therefore, the regime sometimes has to adapt, by allowing new niche innovations (e.g. electric cars) to enter the market. Although existing regime actors (e.g. existing car manufacturers) need to respond to the changed public opinion and consumer preferences, the modifications in their guiding principles remain modest. Such a pathway generally will bring about a 'transformed' regime, leaving the main characteristics of the existing one intact, through cumulative adjustments and reorientations. In essence, this pathway most resembles a business-as-usual scenario.

In the technological substitution pathway, landscape pressures produce significant tensions in the existing regimes, creating 'windows of opportunity' for new innovations. This scenario completely depends on the existence of a shock, in order to let emerging technologies enter the market more easily. The shock can be either external (i.e. originating outside policy making) or internal (i.e. influenced by policy making). The result is that new technologies (e.g. electromobility) gather momentum and the newcomers start to compete with incumbent regime actors.

As a third alternative, the reconfiguration pathway was presented. In this scenario, we assume that the existing regime, under pressure of landscape evolutions, adopts new components (e.g. electric vehicles) as add-ons or replacement components to the existing regime. As the number of new components increases, the system gradually gets reconfigured. Compared to the transformation pathway, the basic architecture of the regime gets substantially altered this time, because the accumulation of new add-ons completely reshapes the system. The role of the newcomers now consists of supplying the system with the components necessary to face the landscape pressures.

Finally, evolutions in the landscape can be that far-reaching that the existing regime cannot keep pace. Consequently, the regime faces major internal problems, collapses, erodes and de-aligns. The period of uncertainty that follows is characterized by the co-existence of multiple niche-innovations and widespread experimentation. The experiments initially pop up on a regional level. Eventually, one option (e.g. the electric car) becomes dominant, leading to a major restructuring of the system (re-alignment). This scenario is called the de- and re-alignment pathway.

Table 6 : Transition pathways with their most important characteristics (based on Geels & Schot, 2007)

	Transformation	**Technological substitution**	**Reconfiguration**	**De- and re-alignment**
Main actors	Regime actors and outside groups	New firms competing incumbent firms	New suppliers and regime actors	New niche actors
Type of (inter)actions	Outside groups voicing criticism; incumbent actors adjust regime rules	Newcomers develop novelties that compete with established technologies	Regime actors adopt component-innovations, developed by new suppliers. Still, a certain level of competition exists between old and new suppliers.	Incumbents cannot respond to changed situation. New entrants compete for resources, attention and legitimacy. Eventually one novelty wins, resulting in a restabilization of the system.
Key concepts	Outside pressure, institutional power struggles, negotiations, adjustment of regime rules	Fierce market competition and power struggles between incumbent and new firms	Cumulative component changes in the regime because of landscape pressures, followed by new combinations of components, changing interpretations and new practices	Erosion and collapse, followed by period of uncertainty and changing interpretations, new winner and restabilization

4.2.3 Key stakeholder interviews to define MCA criteria

In October 2011, a set of key stakeholders have been interviewed. Key players from each of the following sectors were heard: consumer organizations, governments, automotive, energy supply and environmental organizations.

The aim of these interviews was to extract a number of criteria, identified as being crucial factors/conditions to force a (PH)EV breakthrough. Or, in other words, to find out what issues should be tackled first to allow (PH)EVs to become a success. The output of the interviews is summarized in Figure 18. Please note the significant amount of overlap between the different stakeholder groups' favorite criteria: e.g. the need for fair fuel prices, in line with the external costs, was expressed by energy suppliers as well as government officials and environmental organizations.

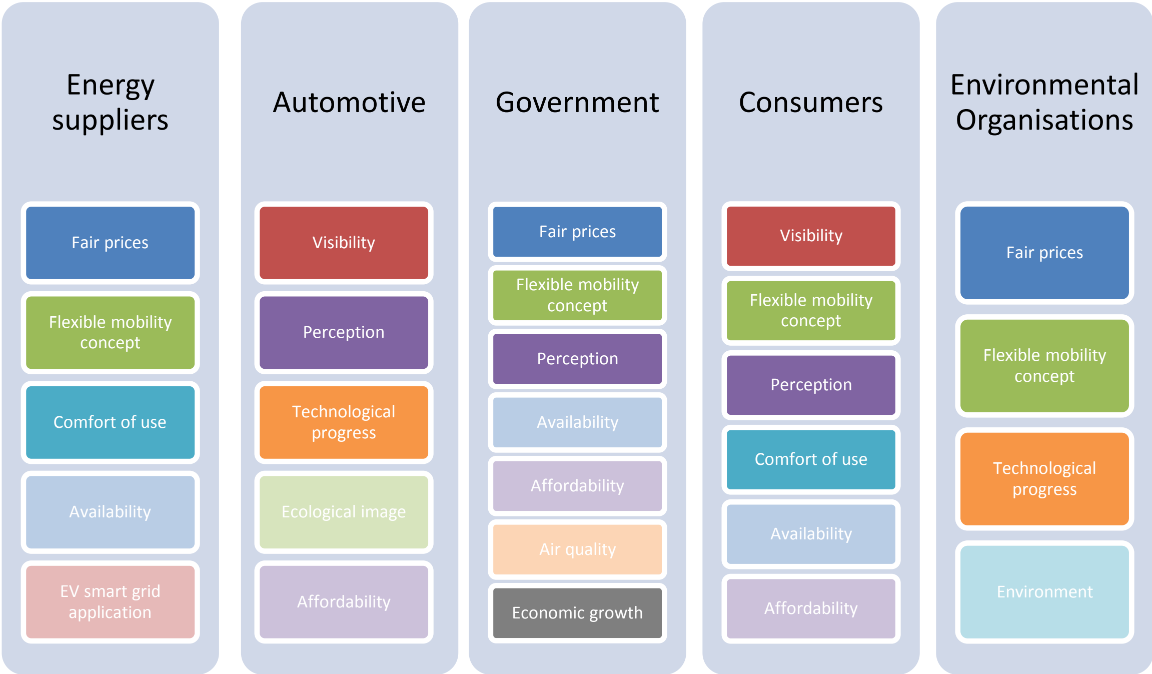


Figure 18: Overview of key stakeholder interview outputs

For each of the criteria, a concise description is provided in the list below.

- Fair prices: internalize the external cost for each fuel (including electricity), so that consumers are facing correct prices
- Flexible mobility concept: encourage new mobility concepts where the focus is rather on vehicle use than on vehicle ownership, and the combined use of different modes gets facilitated
- Comfort of use: increased availability of standardized recharging infrastructure and the development of an increased driving range
- Visibility: enlarging the visibility of (PH)EVs for the end consumer
- Perception: deliver objective information on (PH)EVs in order to avoid prejudices (e.g., with respect to the driving range)
- Technological progress: encourage technological progress, for example in fuel efficiency (both conventional and (PH)EV cars) and sustainable material use
- Availability: increase the availability of different (PH)EV makes and models
- Affordability: make (PH)EVs financially more attractive to the end consumer, for example by providing purchase subsidies or by trying to lower the total-cost-of-ownership (TCO)
- (PH)EV smart grid application: use (PH)EVs to balance electricity supply and demand, as part of a smart grid

- Ecological image: stimulate car manufacturers to stress their ecological image and get a competitive advantage when they have (PH)EVs in their product range and their competitors do not
- Environment: take into account the WtW impact of fuels (incl. electricity), encourage the use of renewable energy and focus on achieving the European climate goals
- Air quality: diminish the impact on local air quality, especially in an urban context
- Economic growth: foster the development of a competitive advantage and/or job growth for Belgium in the (PH)EV industry

4.2.4 Fixing the combinations criteria-transition pathways

After having defined the pathways and the criteria defined by the key stakeholders, each of the criteria was evaluated against each of the scenarios (alternatives). This was done in order to define how well each of the criteria performs under each of the four situations/pathways. An expert consultation under the form of several consortium meetings was organized in order to fix the criteria-pathway combinations as mentioned in Table 7. These data were used as an input in the multi-actor multi-criteria analysis (MAMCA).

Table 7 : Combinations of criteria-pathways, as a result of the question 'How does criteria X perform on transition pathway Y?', ranging from very well (+++) to very bad (---)

	Transformation	Technological substitution	Reconfiguration	De- and re-alignment
Fair prices	--	+	+++	-
Flexible mobility concept	-	--	+++	++
Comfort of use	-	+++	++	+
Visibility	--	++	+	-
Perception	+	++	+++	-
Technological progress	-	+	++	--
Availability	-	+++	+	-
Affordability	-	++	+	-
(PH)EV smart grid application	--	+	++	-
Ecological image	++	---	++	+
Environment	-	+	++	-
Air quality	-	++	+++	++
Economic growth	+	+++	++	-

5. Multi-stakeholder validation

5.1 General approach

In the next phase of the project, a broader set of stakeholders were asked to score each of the criteria found previously, based on their importance to force a (PH)EV breakthrough. In order for the resulting data to be useful for the MAMCA later on, this was done through a pairwise comparison survey. The result was a specific ranking of the criteria for each stakeholder group.

Given the results of the pairwise comparison of the criteria by the broader stakeholder group on the one hand, and the expert valuation of the criteria-pathway combinations (Table 7), the MAMCA tool was able to rank each of the transition pathways according to their preferability. This was done separately for each stakeholder group, and aggregated for all stakeholder groups (giving an arbitrary weight of 20% to each group). Consequently, the respondents of the pairwise comparison survey actually provided their implicit preference for one scenario over another by preferring one criterion over another, as these criteria are directly linked with the pathways according to Table 7.

5.2 MAMCA methodology

Evaluating transport related projects implies having a method that is able to take into account different conflicting objectives and can reconcile tangible and intangible criteria. Including different stakeholders in the decision making process is an important, and within the transport sector, often crucial factor for successful implementation of certain measures. To evaluate the different pathways towards electric mobility, a multi-actor multi-criteria analysis (MAMCA) is used. This technique combines the conventional MCA with the notion of stakeholders in an explicit way (Macharis, 2000). Overall, the methodology consists of 7 steps, as shown in Figure 19.

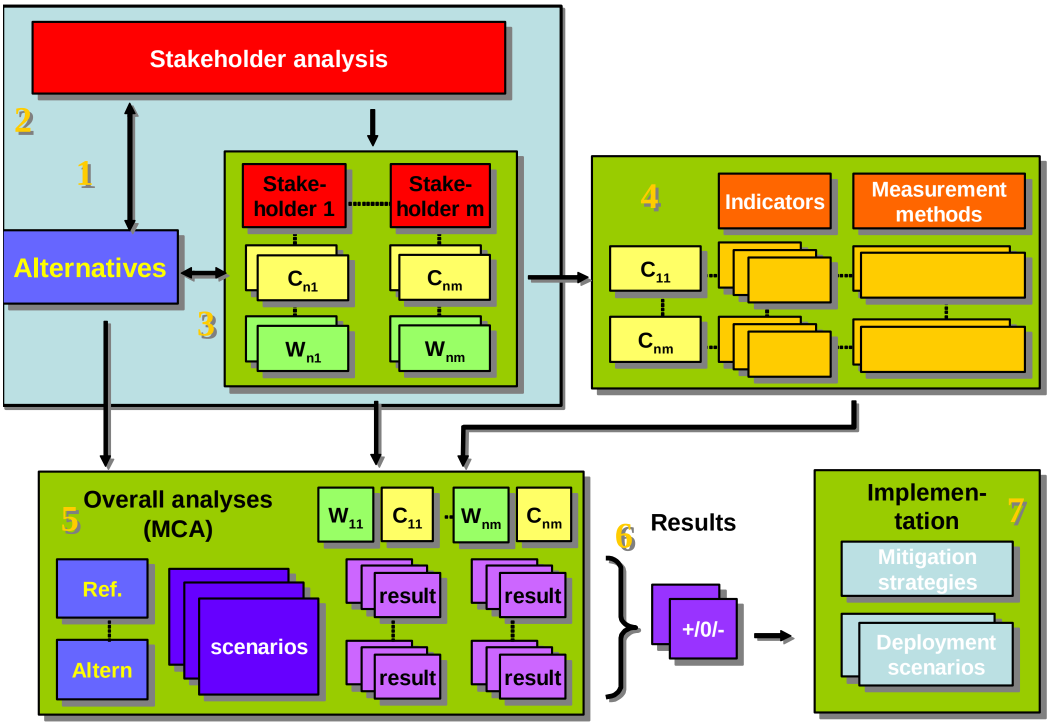


Figure 19 : The seven steps of the MAMCA methodology (Macharis, 2000).

The first step is the definition of the problem and the identification of the alternatives. These alternatives can represent different policy options, actions or scenarios (transition pathways in our case) that are to be evaluated. Next, in step 2, the various relevant stakeholders, as well as their key objectives, are identified (see 4.2 and 5.1). In step 3, these objectives are translated into criteria and then given a relative importance (weights). The choice and definition of evaluation criteria are based on the identified stakeholder objectives and the purposes of the alternatives considered. Subsequently, for each criterion, one or more indicators are constructed that can be used to measure to what extent an alternative contributes to each individual criterion (step 4). Indicators can be direct quantitative indicators (like money spent, reductions in CO_2 emissions achieved) or it can be qualitatively scored on an ordinal indicator (e.g. high/medium/low). Moreover, the measurement method for each indicator is also made explicit (e.g. willingness to pay, quantitative scores based on macroscopic computer simulation). This permits measuring each alternative performance in terms of its contribution to the objectives of specific stakeholder groups. Steps 1 to 4 can be considered as mainly analytical, and they precede the 'overall analysis', which takes into account the objectives of all stakeholder groups simultaneously and is more synthetic in nature. The fifth step is the construction of the evaluation matrix, aggregating each alternative contribution to the objectives of all stakeholders (see Table 7). After that, in step 6, the multi-criteria analysis yields a ranking of the various alternatives and shows their weak and strong points. The MAMCA provides a comparison of different strategic alternatives and supports the final decision maker in its final decision by pointing out for each stakeholder which elements have a clearly positive or negative impact on the sustainability of the considered alternatives. Afterwards, the stability of the ranking can be assessed through sensitivity analyses. The last stage of the methodology includes the actual implementation of the policy measure (step 7). Once the decision is made, steps have to be taken to implement the chosen alternative by creating deployment schemes.

Step 1: Defining the problem and the alternatives

In chapter 4.2, the different alternatives or scenarios to be considered and investigated within this MAMCA are given and described. Briefly stated, the following four scenarios or pathways will be compared with the aid of a multi-actor multi-criteria analysis (MAMCA):

- Transformation pathway
- Technological substitution pathway
- Reconfiguration pathway
- De- and re-alignment pathway

Step 2 & step 3a: Stakeholder analysis & defining criteria

Figure 18 already showed the identified stakeholders as well as the selected criteria within the context of electromobility in Belgium. These different criteria are weighed against each other in the following step (step 3b).

Step 3b: Allocation of weights to the criteria

In order to let the stakeholders express their preference for the different criteria, weights are allocated. There exist several methods for determining the weights: direct rating, point allocation, trade-off, pairwise comparisons, etc. The latter procedure, developed by Saaty (1980), proves to be very interesting in this case. The relative priorities of each element in the hierarchy are determined by comparing all the elements of the lower level against the criteria with which a causal relationship exists. For this purpose, an online survey has been created and has been sent out to the same 43 participants which were already contacted in the previous step (for an overview of these participants, see Annex A). Figure 20 shows a screenshot of the online survey, where each stakeholder had the opportunity to indicate his preference intensity for a specific pair of criteria in a user friendly environment. By means of the drop-down menu, stakeholders could indicate whether they find one criterion more (or less) important than the other one.

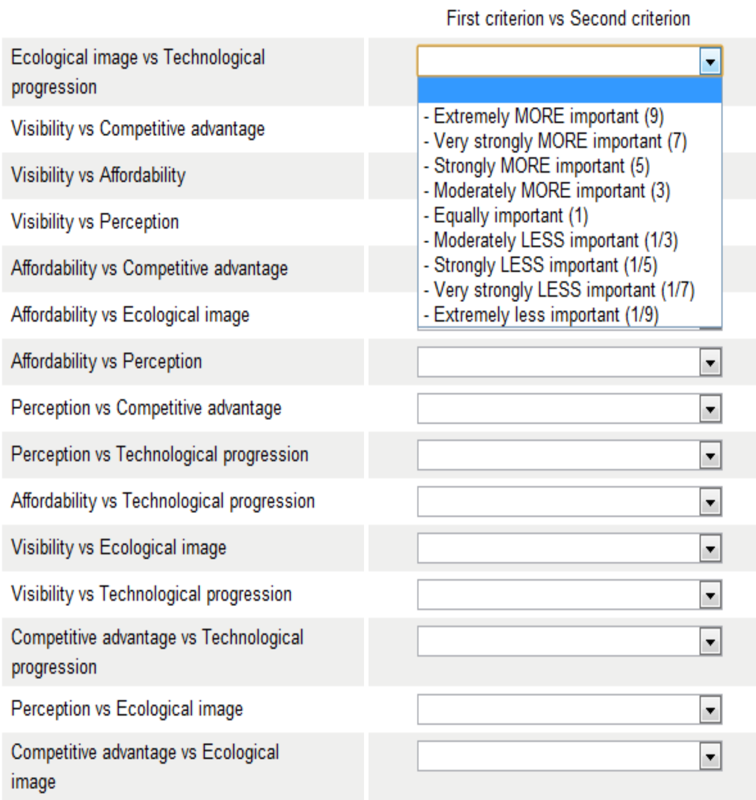
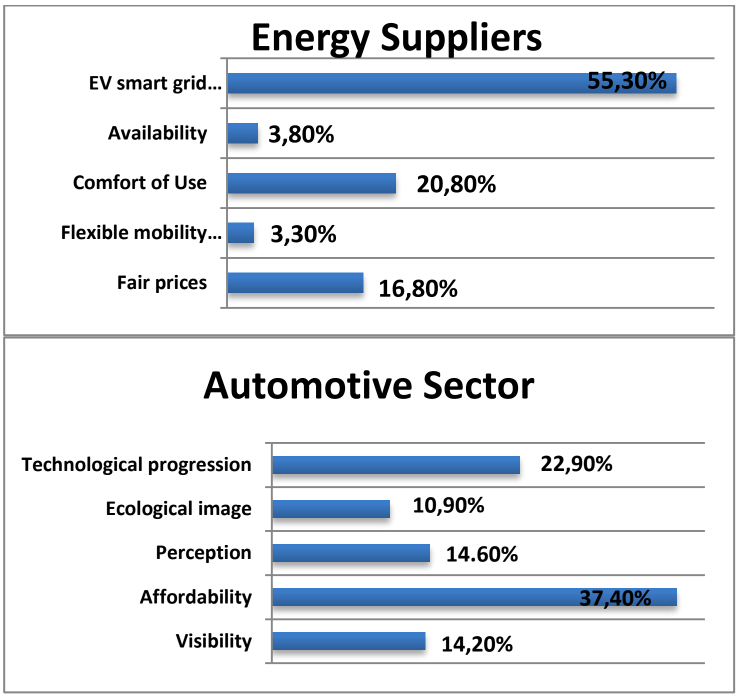


Figure 20 : Screenshot of the online survey based on Saaty's AHP.

Figure 21 gives the results of the weight distribution for which several participants of each stakeholder group provided their input. As different members within a stakeholder group were consulted, the geometric mean is calculated to bring the evaluations together (suggestion of Saaty (1995)).



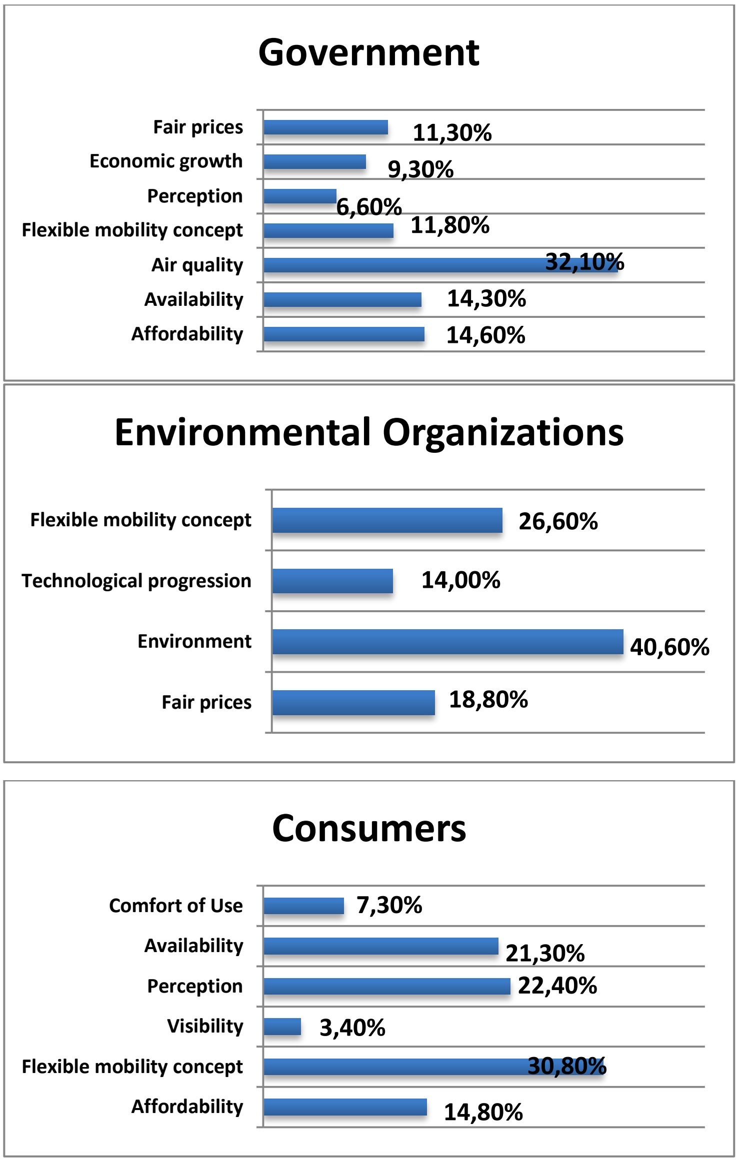


Figure 21 : Weight distribution of the different criteria.

Not surprisingly, the Belgian government and environmental organizations are rather concerned about environmental criteria like improving air quality and environmental impact (in general), while affordability is selected as the most important criterion for the automotive sector (but also gets a high score within the stakeholder groups of the government and consumers). This indicates the importance of offering a PH(EV) at a reasonable price. Consumers have given the highest score to the criterion ‘flexible mobility concept’, indicating that future mobility also has to take into account the multimodal, more sustainable, aspect. This criterion gets a rather high score for government and environmental organizations too. Energy suppliers did select ‘EV smart grid application’ as their most important criterion, which indicates the importance of balancing the electricity grid, hereby using wind and solar energy more efficiently.

Step 4: Criteria, indicators and measurement methods

In this step, the criteria identified by the different stakeholders are ‘operationalized’ by constructing indicators that can be used to measure to what extent an alternative contributes to each individual criterion. As mentioned before, most indicators are quantitative in nature though a more qualitative approach can also be used. Figure 22 illustrates the use of the indicator construction in several steps. In the first step, a criterion is selected for which the indicator will be built. Next, an indicator is constructed that allows measuring the contribution of each alternative for that specific criterion (step 2). In step 3, the measurement method is made explicit, either in a quantitative or qualitative way. Based on literature research in combination with expert consultation, each alternative performance can now be measured in terms of its contribution to this specific criterion (step 4). Finally, with the aid of pairwise comparisons, the alternatives can be compared for the specific criterion, based on the Saaty-scale (Saaty, 2008) (step 5).

For this analysis, table 7 gives a clear overview of all different criteria and their respective contribution to the different alternatives. Experts from the Vrije Universiteit Brussel and VITO have made the pairwise comparisons. This contributed in giving a scientific foundation in the evaluation process of the different alternatives.

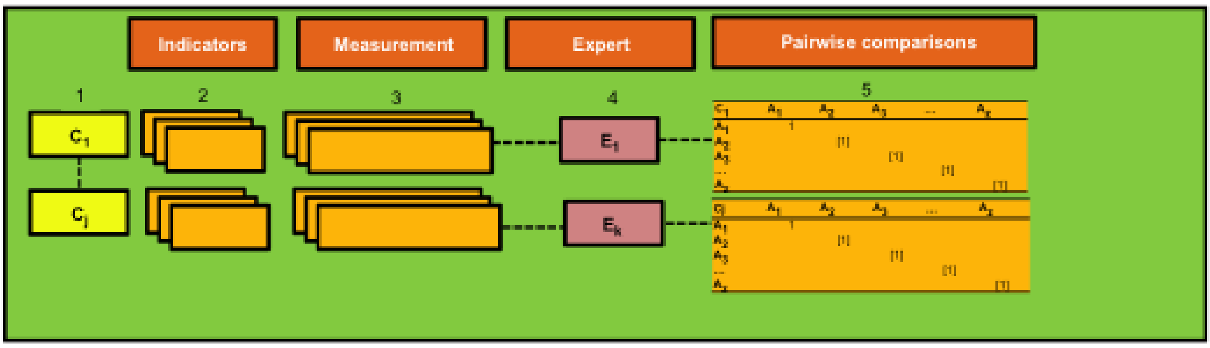


Figure 22: Indicator construction

Step 5: Overall analysis and ranking

In order to assess the different alternatives, any multi-criteria decision analysis can be used. In fact, the second generation multi-criteria analysis methods, the group decision support methods (GDSM) like GDSS-PROMETHEE (Macharis et al., 1998), AHP (Saaty, 1989) and ELECTRE (Leyva-López & Fernández-González, 2003) are well suited for application in the MAMCA methodology as they are able to cope with the stakeholder concept. In this step, the evaluation of the alternatives is inserted in the evaluation table, no matter what kind of method chosen.

For the application under consideration, the software tool Expert Choice was used (ExpertChoice, 2000), based on Saaty's AHP method. This software combines the weight allocation (Figure 21), performed by the stakeholders and the performance valuation of the alternatives (Table 7), assigned by the experts.

Step 6: Results of the MAMCA

The MAMCA developed in the previous step leads to a multi-actor view of the different transition pathways. This is illustrated in Figure 23. On the horizontal axis, the 5 stakeholder groups are displayed. The rectangular bars at the bottom and the corresponding values on the left axis indicate that each stakeholder group was given the same weight (20%) as they are considered to be equally important. The values on the right axis represent the scores of the different transition pathways. On the 'OVERALL' axis, a general prioritization of the transition pathways is given for all stakeholders and for all criteria.

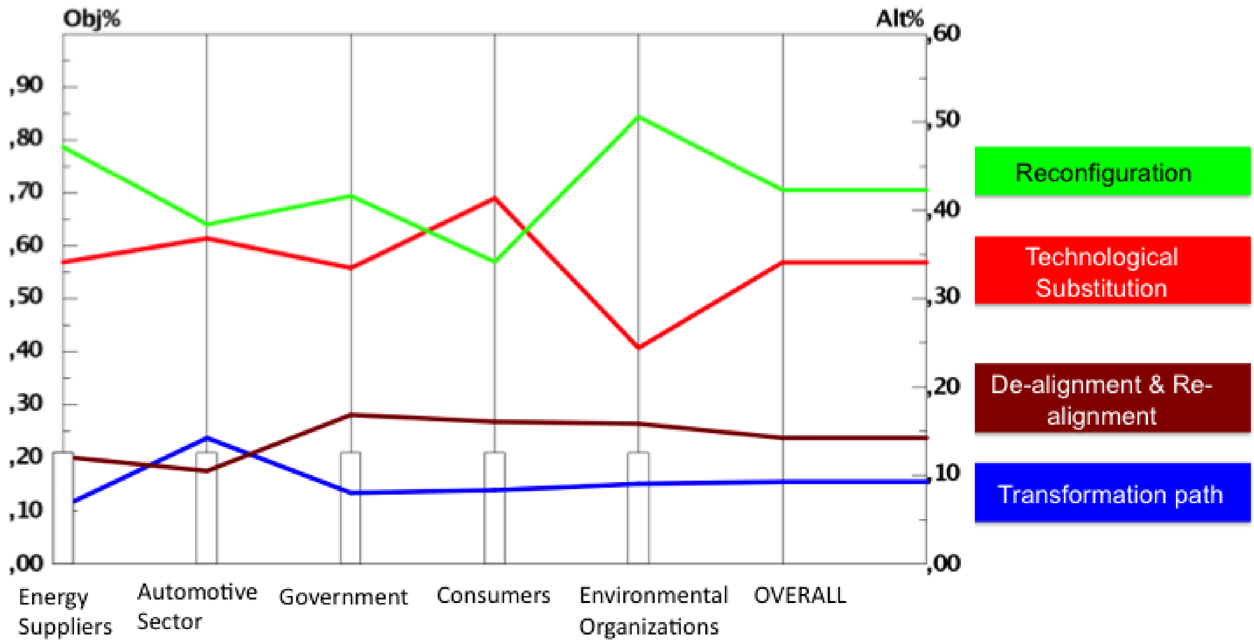


Figure 23 : Multi-Actor view.

On Figure 23, it can be seen that the pathway 'reconfiguration' has the strongest support from the total group of stakeholders involved, followed by the pathway 'technological substitution'. The 'de-alignment & re-alignment pathway' and the 'transformation pathway' are found to have little support from the stakeholder groups.

More important than this overall ranking is the insight in the weak and strong points of each transition pathway for the different stakeholder groups. A deeper understanding of the viewpoints can be obtained by investigating each stakeholder group individually. Figure 24 to Figure 28 show the outcomes of energy suppliers, the automotive sector, governments, consumers and environmental organizations, respectively.

Within these figures, the size of the bars indicates the weight of each criterion, based on the input from the stakeholder group. Note that the position of the color curves (referring to the different pathways) is a result of the combination of both the stakeholder responses (Figure 21) and the criteria-pathway weights (Table 7).

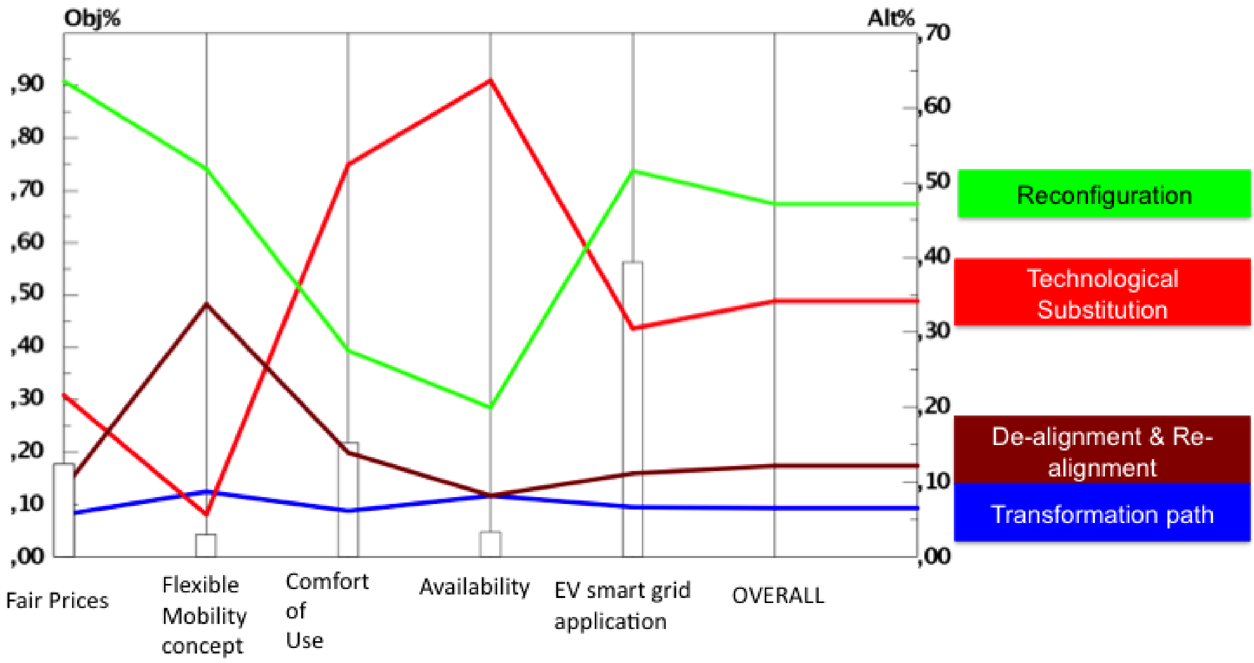


Figure 24 : Energy suppliers.

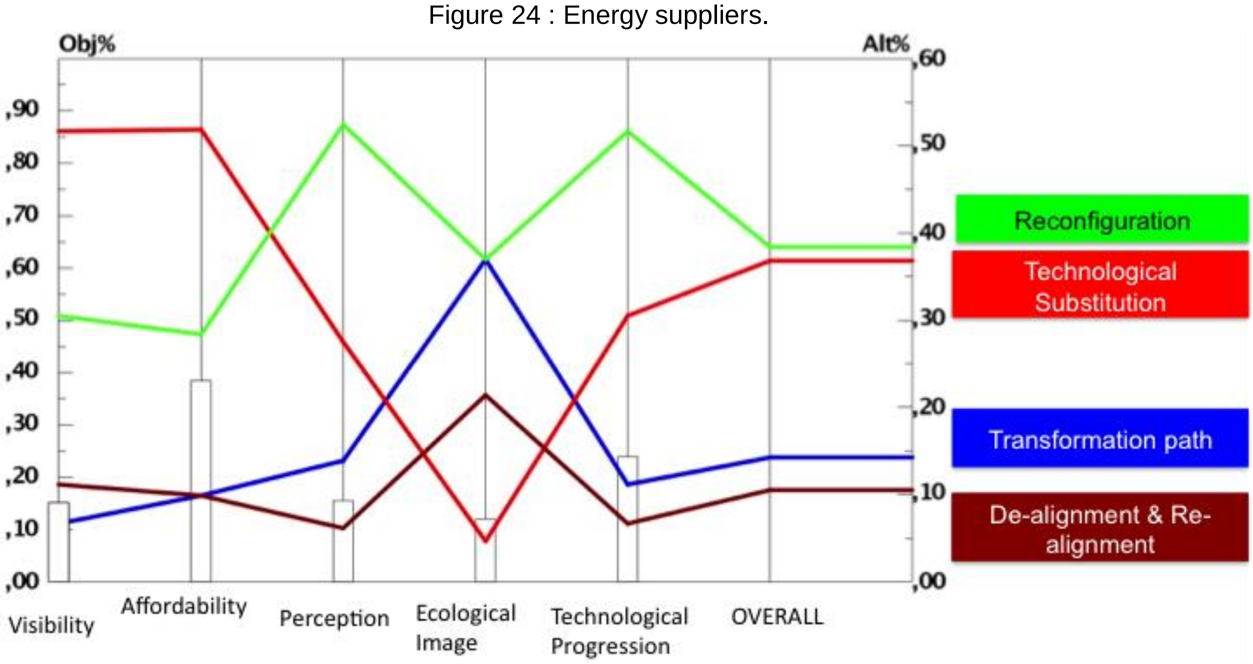


Figure 25 : Automotive sector.

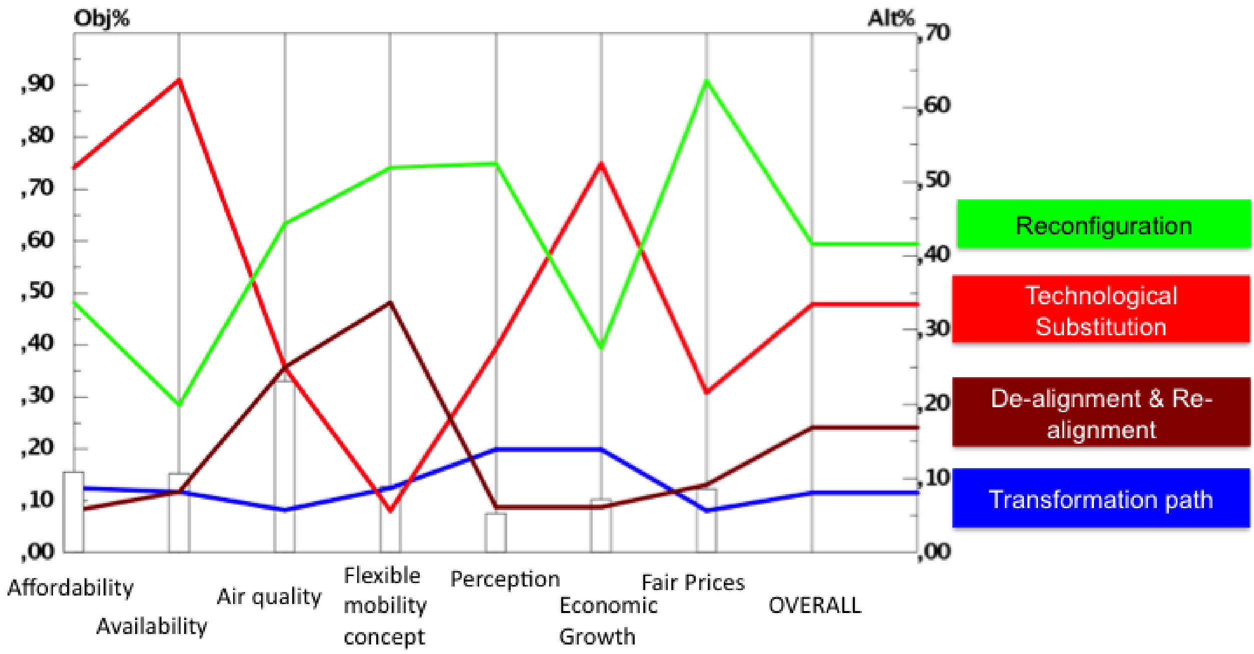


Figure 26 : Government.

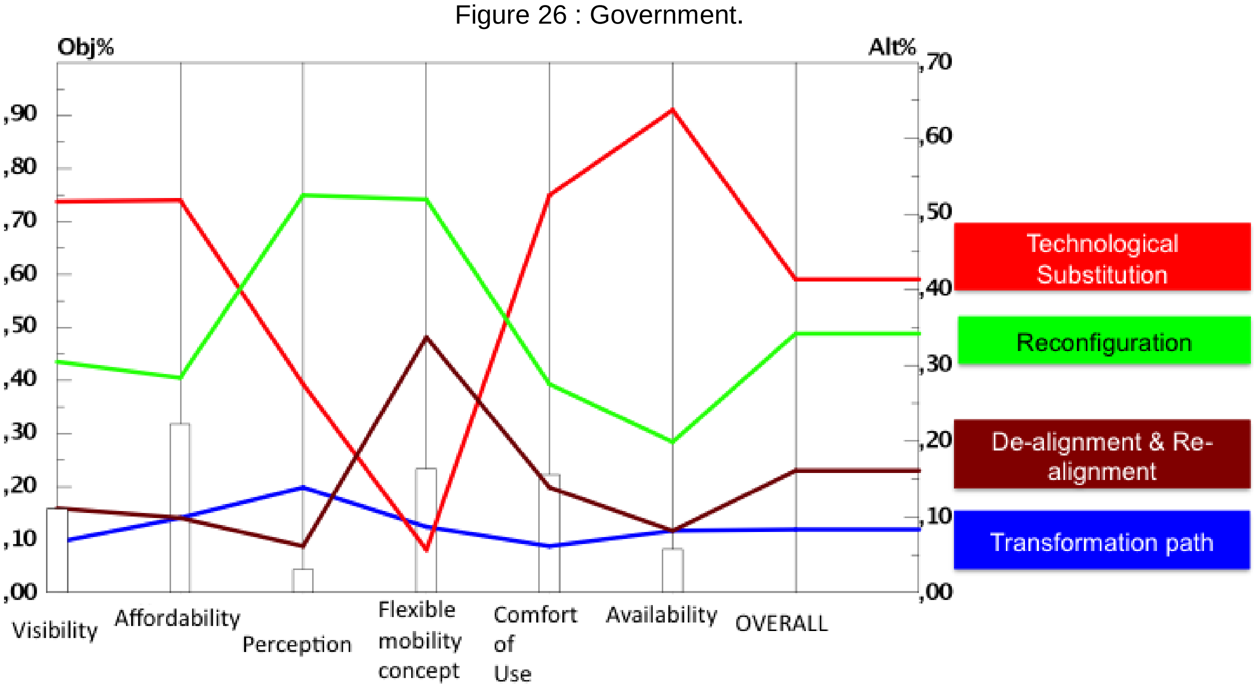


Figure 27 : Consumers.

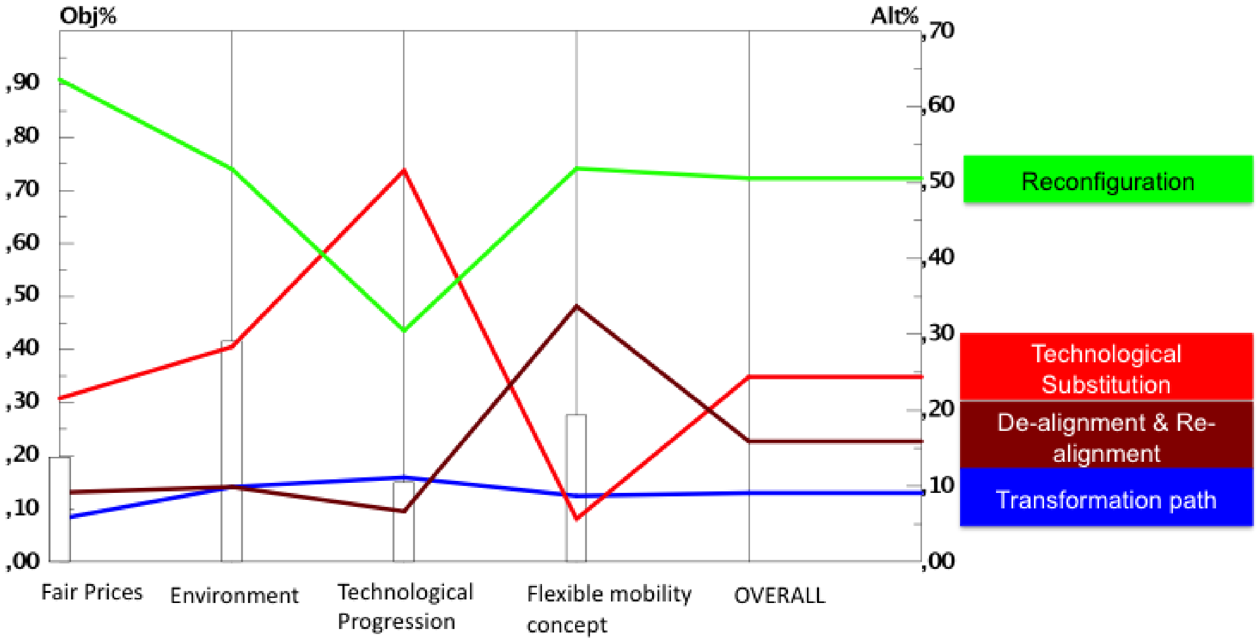


Figure 28 : Environmental organizations.

The MAMCA illustrated that within the stakeholder group energy suppliers (Figure 24), the multi-actor trend could be followed. Within this stakeholder group, 'EV smart grid application', 'comfort of use' and 'fair prices' are the most important criteria to be obtained. The reconfiguration path is ranked high with respect to the criteria 'EV smart grid application' and 'fair prices', the technological substitution scenario scores good on 'comfort of use'. This resulted in ranking reconfiguration higher in comparison to technological substitution. The technological substitution scores bad on the 'flexible mobility' concept and this results (for this criterion) in a completely different prioritization of the different scenarios, compared to other criteria. This information could indicate that when choosing for a certain scenario, it might be important to deal with all involved criteria, so a better score could be gained for these criteria.

For the stakeholder group automotive sector (Figure 25), the reconfiguration pathway is, based on the selected criteria, the most preferred one. For them, it can be seen that the technological substitution pathway scores high on 'visibility' and 'affordability' but rather bad on 'ecological image'. With respect to 'ecological image', even the transformation pathway and de-alignment & re-alignment scenario score better. Taking into account this strengths and weaknesses in defining further scenarios could help in creating more support from different stakeholder groups.

For the government (Figure 26), we see that some criteria are giving conflicting results in comparison to the overall score. For 'economic growth' for instance we see that the technological substitution pathway scores better than the reconfiguration pathway. This figure ranks the different scenarios like the overall score in the multi-actor view. The reconfiguration path contributes to the most important criterion 'air quality'.

For consumers (Figure 27), the analysis resulted in a rather different ranking compared to the other stakeholder groups. Within this stakeholder group the technological substitution pathway is ranked higher than the reconfiguration path. This is mainly due to the fact that a high weight has been given to ‘affordability’ and ‘comfort of use’. Both criteria score better within the technological substitution pathway. Unlike it scores badly on ‘flexible mobility concept’, it was still found to have the highest support within this stakeholder group.

For the environmental organizations (Figure 28), the reconfiguration pathway is the most preferred scenario. Still, for ‘technological progress the technological substitution outperforms the reconfiguration pathway.

Step 7: Implementation

This is the final step of the MAMCA. The information on each stakeholder’s position, gathered from the previous steps, helps tremendously in identifying implementation pathways and additional policy measures. In this step, it is possible to include new alternatives or modify existing ones as more insight into the advantages and disadvantages of a certain alternative for each stakeholder is generated. This would then create a feedback loop towards the beginning of the procedure.

6. Conclusions

6.1 Technical

In a distribution grid with a low amount of electrical vehicles to be charged, the impact on the local grid of the electrical vehicles is rather low and probably non-problematic. In distribution grids where the density of electrical vehicles is relatively large, the main problems that will occur are: an increased peak power through the distribution transformers and distribution feeders, an increased voltage drop over the feeders and an increased unbalance in the three-phase system. When these problems occur, expensive infrastructure investments (cable reinforcements, installation of a transformer with higher rate, etc.) will need to be done in order to maintain a good power quality. Another option to avoid or postpone infrastructure investments is the integration of intelligence in the charging infrastructure of the electrical vehicles.

6.2 Environmental

For the purpose of evaluating various powertrain types in terms of environmental impact and primary energy consumption over their entire life time, life cycle assessment (LCA) is a very useful and powerful tool. Different scenarios for BEV's using different types of electricity have been compared. BEVs powered with wind power, hydropower or nuclear power appear to have very low greenhouse effect, since there are no conversion emissions related to electricity production. They are followed by the scenarios of the Belgian electricity mix and natural gas electricity production, which also have very low greenhouse effect in comparison to diesel and petrol vehicles. In extreme scenarios, in which BEVs are for 100% powered with oil or coal based electricity, the LCA results shows that BEV have climate impacts which are comparable to the ones of diesel cars. As the environmental impact of a vehicle throughout its entire life is a complex system, uncertainties are integrated in the end result, providing decision-makers with a wider view on the possible effects of their decisions.

6.3 Economic

A total cost of ownership (TCO) has been conducted in order to investigate the financial attractiveness of electric vehicles (battery electric and plug-in hybrid electric) compared to conventional petrol, diesel, LPG and CNG cars. The TCO calculation was done for 19 vehicles, which were split up into two segments: city cars and medium cars.

We found that for city cars, the higher purchase costs for EVs entail a large difference in TCO compared to the conventional cars. Even though the fuel operating costs are much lower, they cannot outweigh the high purchase costs. The electric Renault Zoe

ZE and the electric Tazzari Zero are a bit cheaper than the Mitsubishi iMIEV, the Peugeot iOn and the Citroën C-Zero. This is due to the fact that Renault leases its batteries and because Tazzari offers a smaller vehicle.

Within the medium car segment, the difference between the conventional and the electric vehicles is lower. The electric Nissan Leaf and the electric Renault Fluence ZE (with battery lease) seem financially comparable to their conventional rivals. This seems to be due to the fact that their purchase costs are closer to those of the conventional cars.

In general, the purchase cost of electric vehicles is highly linked to the size of the battery pack, and not to the size of the electric vehicle. This could explain the relatively high cost for the electric city cars and the comparable cost for the medium cars in the TCO calculation of this report.

The sensitivity analyses illustrated that the disappearance of the subsidies for electric and low CO2 emitting vehicles could highly hamper the introduction of the EVs, since their TCO increase with on average 11% to 27%. On the other hand, when the customer would opt for a civil liability insurance instead of a full omnium insurance, the TCO decreases with 15% - 19% for the BEVs and with 14% - 15% for the PHEVs.

6.4 Purchasing behaviour

Given the fact that EVs have some positive characteristics (low driving cost, high environmental performance…) as well as some negative ones (high purchase price, limited driving range…), today's' consumers still opt for a conventionally powered vehicle.

First, several theories on purchase behaviour are discussed. The decision-making process is investigated: the 5 subsequent steps as well as the participants are discussed. We identify 4 types of buying behaviour and classify the purchase of a car as a "complex buying behaviour", since it requires high involvement from the consumer and because there are significant differences between the different automotive brands. We underline the importance of knowledge within the decision-making process. The gathering of this knowledge is regarded as very important, especially for new products that are relatively unknown for the current consumers. Also, the role of group influence on the consumer's choice should not be neglected. Other people may impact the final decision. The purchase of an electric vehicle can be seen as a new technology acquisition. Therefore, we discuss the adoption curve for new technologies, in which different types of consumer groups are highlighted: the innovators, the early adopters, the early majority, the late majority and the laggards. Today, the market for electric vehicles is still situated in the first phase of the innovators. Finally, we stress that there can be a difference between the attitude consumers have towards a certain purchase and the final decision they make. In literature, this is called the attitude-action gap.

Next, we have discussed the barriers and drivers for the purchase of an electric vehicle. These are subdivided into 5 groups: technical, environmental, economic, market and psychological factors. We also refer to some conclusive findings of the Flemish survey conducted by the Vrije Universiteit Brussel (VUB-MOBI, 2011). For instance, the knowledge on electric vehicles in Flanders is still very limited. This may have an impact on the attitude consumers have towards this new product. Moreover, both the advantages and the disadvantages of electric vehicles are rated by the consumers. On the positive side, the low driving cost, the ecofriendliness and the ability to charge at home are considered as the main advantages of EVs. Otherwise, the high purchase price, the limited driving range and the lack of charging infrastructure are perceived as the main barriers.

The purchase of an electric vehicle differs from that of a conventional ICE car. We identify the relative importances of vehicle attributes within the purchase process of a new car. Here, the purchase costs, the yearly costs and the fuel or charging time are considered the most important. In general, costs (purchase, yearly and driving) are very important within the purchase process. Hence, we investigated the willingness to pay for an EV. Is seems that almost 50% of Flemish consumers want an EV to cost roughly the same as a conventional ICE car.

Finally, several market projections for electric vehicles, both on European and on Belgian level, are discussed. The market for EVs is still nascent, but forecasts indicate that within the upcoming 10 years, the market share of EVs could grow to around 5-10% of annual vehicle sales.

6.5 Travel behavior

Based on travel data from Onderzoek Verplaatsingsgedrag Vlaanderen (OVG4.2), we found that the car is used on a daily basis for almost half of the trips committed. When we add the people who use the car several times a week, this number reaches almost 90%. Countering the limited driving range for BEVs, on average between 100-150km, we investigated the average daily mileage and the average mileage per trip. We found that 64.50% of the average travelled distance per day by car is lower than 40 kilometres, while only 6.18% of all the car trips, made by Flemish people, is longer than 40 kilometres. This means that almost 94% of Flemish citizens use a car for trips of less than 40 km. This illustrates that electric vehicles are already suitable for a large amount of travel decisions.

In December 2011, there were more than 150 public charging stations available in Belgium. However, these stations are defined as slow chargers: in order to fully charge the battery of a BEV, the driver is bound to wait between 6 and 8 hours. For longer distances, quick chargers, battery swapping stations and inductive charging infrastructures have a potential in the future. The location of the charging infrastructure is of high importance. Even given the fact that home charging will be dominant, the need for an integrated network of charging stations alongside the road, on public parking, etc is high. We also found that having a private parking space of a garage is a crucial factor for home charging. From a vehicle point of view, on average, a vehicle is parked at home for about 50% of the time during the day and for about 95% during the night. During weekends, these figures are respectively 70% and 90%. During week days, the vehicle is parked at work for about 30% of the time. This indicates that there is enough time left to charge the BEV, given that there is a suited infrastructure.

Finally, we focused on households in general and segmented different potential markets for BEVs. Lately, there has been an increase in the number of multi-vehicle households. In Flanders, 71% of all households have 1 car or none, while 25% of all households have 2 cars. A battery electric vehicle could thus be part of this multi-vehicle household, where household members always have a conventional vehicle when they need to travel longer distances.

In general, we can conclude that the travel behaviour of people is not opposed to what a BEV can provide.

From this research, several recommendations on the travel behaviour for BEVs can be drawn:

- It is important to inform the consumer. Consumers need to fully understand the current state of art of electric vehicles. Many are still trapped into the prejudices of the last generation of BEVs. Of course, informing the consumers will not eliminate the barriers to implement BEVs in Belgium, but it will certainly benefit the perception.
- Consumers should be able to use the technology through test trials. Today, electric vehicles are still unreachable for many people. Testing them could be the first step into the discovery of a possible substitution for our future transport system. Moreover, these trials can show people how BEVs can fit into the daily travel patterns.
- Create a BEV-friendly environment. Through the use of special driving lanes (e.g. bus lanes) and better located dedicated parking spaces for BEVs in public places, the experience of owning a BEV can be improved.

6.6 Social barriers

One of the most characteristic social barriers highlighted in the interviews is the weak spontaneous reputation of the EV. Most people, even people among those who consider buying an EV, are unable to name a brand. Thus, for most, the EV remains only a concept. That fact contrasts with hybrid cars known and mentioned by most of our sample. This category is mainly associated with the Toyota Prius. In light of the interviews, one of the main barriers of buying EVs remains for potential buyers, the weak reputation of the product. However, we should note that at the time of our data gathering, the supply of these types of vehicles was relatively limited.

Beyond the global perception of electric vehicles as a fundamentally different product compared with traditional cars, inconceivable in the possible choices, or like a car possibly conceivable in the future, there is a number of barriers linked to certain expected and precise characteristics of the EV compared with elements seen as essential in the choice of a car.

These elements are especially the space, the price and ranges (city cars or road cars). A number of reluctances are also expressed concerning the supposed power of the cars, their reliability, their autonomy, their real advantages concerning environment, their supposed purchasing price as well as the consequences inherent to the massive plebiscite of this type of car.

On the contrary, a number of supposed characteristics constitute attractive factors for this type of motorisation. The personal energy independence seems to have, at least in terms of awareness, an influence on the wish of having an EV in the future. The feeling of being inscribed in the track of progress, the reduction of the consumption of fossil fuel and energies expected in the long term constitute the main incentive factors.

7. Recommendation: Final Transition Pathways for policy support

7.1 Performance of the scenarios

As mentioned before, the reconfiguration and the technological substitution pathway clearly outperform the other two scenarios. The MAMCA analysis revealed that the reconfiguration pathway is preferred by all stakeholder groups but one, viz. the consumers (i.e. the ones that will need to use electric vehicles in the end). The fact that the latter group picked the technological substitution rather than the reconfiguration scenario, does not need to be an insurmountable problem. It is to say, the detailed results of the MAMCA analysis have provided valuable insights in the main objections towards certain scenarios some stakeholder groups may have, and the policy measures indicated further on should be specifically suited to tackle these problems.

7.2 Practical applicability of the results

The final step of this project consisted of elaborating a set of policy measures fitting into the different transition pathways. These measures can be used by policy makers in order to facilitate the specific transition pathway towards electric vehicles. The arrangement of the set of policy measures was done in a qualitative way, just as the estimation of their budgetary, economic, employment, social and environmental impacts. The construction of a draft list of policy measures was initiated by the consortium partners, but the fine-tuning happened at the Trans2House stakeholder workshop in December 2011.

We distinguished between two types of policy measures: quick-win initiatives and tailor-made measures.

The former category is not a priori linked to any specific transition pathway. Such quick-win measures are relatively easy to implement, and will probably constitute an important factor to a successful breakthrough of electromobility. For example, we think of measures like improving people's perception on (PH)EVs, increasing the share of renewable in the electricity mix, and making intelligent choices regarding infrastructural investments (i.e. acknowledging the fact that the majority of the charging demand can be covered by residential rechargers). We feel that these measures have to be taken into account from the beginning in order not to miss the low hanging fruits.

Afterwards, some tailor-made policy measures are proposed for each scenario. We know that the stakeholders agreed on the fact that both the transformation pathway (which can be considered as the baseline) and the de- and re-alignment scenario should not be supported. The proposed list of measures under these two scenarios was therefore chosen to be rather concise.

Possible measures for the technological substitution and the reconfiguration pathway were elaborated in more detail (see Figure **29**). As much of the proposed measures influence the broader system as a whole, their budgetary, economic, employment, social and environmental impacts were indicated in the report of subtask 4.3, where relevant.

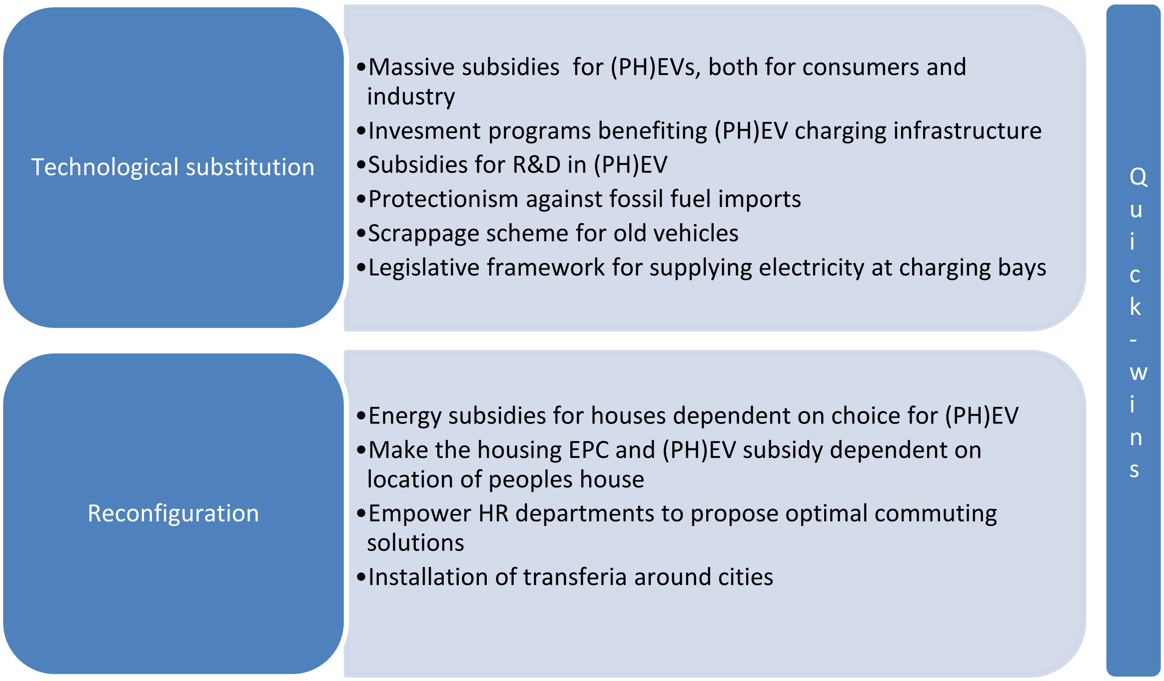


Figure 29: Examples of possible policy measures in the two preferred scenarios

In the technological substitution pathway, vast amounts of resources are needed to push the (PH)EV technology into the system. The availability of (PH)EVs in this scenario will probably be higher than in any other pathway, partly thanks to massive R&D spending. Consequently, the consumers can win by this scenario in the sense that the product range greatly increases. However, much of the governmental spending on this technology push might eventually flow away to foreign car manufacturers. We have to be aware of these dangers before deciding to push off for such a scenario.

The reconfiguration pathway basically starts from the idea of establishing interlinkages between different sectors. Therefore, it is also difficult to implement such a strategy on a state level. Taking action on a broader supranational level would be more appropriate. It may take longer to reach a stabilized system in the reconfiguration pathway compared to the scenario of technology substitution, but the incremental steps taken in between could add greater value in the former case (e.g. by building efficient intercity public transport on a regional level). It should be clear from this discussion that there is no such thing as a clear guidebook for policy makers to apply in each of the policy pathways. Apart from the quick-wins mentioned earlier, we are not sure about which measures should be taken first. Starting a transition involves a lot of learning: the start could be difficult, but once the ‘transition turbine’ is working, it expands and involves more and more sectoral ‘blades’. The great thing about the reconfiguration pathway is that these cross-sectoral links really change the social tissue, that it allows new ideas to be embedded and spread across the society as a whole. Although the driving forces of this pathway are often supranational, the openness of the reconfiguration pathway is very much suited for new innovations to be cultivated with a bottom-up approach.

8. Dissemination and Valorization

The members of the Trans2House consortium have been very active in the dissemination of the results obtained in the project. Many papers have already been published in scientific journals, conference proceedings or other media and some are to be published in the near future. By giving presentations and by participating at conferences and workshops on a national and international level, the results have been spread on a large scale. Through participation in such workshops and conferences, the researchers have been able to get a thorough training and learn more on the topics addressed in this project. This will lead to two PhD theses (Kenneth Lebeau and Maarten Messagie) which will be defended in the near future and the results of the project will also provide input to other PhD theses. To share documents and reports within the consortium, an intranet website has been used. Also different meeting were organized with the consortium members and stakeholders. A detailed overview of the different presentations and participations to conferences, colloquia, workshops or other events is given in the following sections, in a chronological order. A list of the publications made by the consortium is presented in chapter 11 of this report.

8.1 PhD theses

MESSAGIE, Maarten, « Environmental assessment of electric vehicles » (preliminary title), to be defended around 2013.

LEBEAU, Kenneth, « Electric vehicles : investigation of purchase and travel behavior. » (preliminary title), to be defended around 2013.

RANGARAJU, Surendraprabu, « Environmental impact assessment of Intermittent renewable electricity sources: Implications for electric and hybrid electric vehicles » (preliminary title), to be defended around 2016.

SANFELIX FORNER, Javier, « Environmental assessment method adapted to electric vehicles components and identification of relevant eco-design strategies” (preliminary title), to be defended around 2016.

8.2 Presentations at scientific colloquia/conferences or workshops

Messagie M., Faycal-Siddikou Boureima, Nele Sergeant, Joeri Van Mierlo, Jean-Marc Timmermans, Cathy Macharis (2012) Environmental breakeven point, an introduction into environmental optimization for passenger car replacement schemes, Urban Transport Conference 2012, A Coruna, Spain

Sergeant N., Messagie M., Boureima F., Timmermans J., Turcksin L., Macharis C., Van Mierlo J. (2012) Validation of the Well-to-Wheel approach in the Ecoscore methodology with Life Cycle Assessment for passenger cars, Urban

Boureima F., Messagie M., Sergeant N., Matheys J., Van Mierlo J., Turcksin L., Macharis C. (2012) Transport Conference 2012, A Coruna, Spain, Environmental assessment of different vehicle technologies and fuels in a Belgian context, Urban Transport Conference 2012, A Coruna, Spain

Messagie M., Lebeau K., Boureima F., Sergeant N., Macharis C. and Van Mierlo J. (2012) Influence of the uptake of electric vehicles on the impact on climate change of an entire future vehicle fleet, a 2020 Brussels perspective, Electric Vehicle Symposium 26th edition, Los Angeles, California, May 6-9

Messagie M. (2012) Lecture ‘Groene voertuigtechnologieën’, Stad Gent, 2012

Messagie M. (2012) Lecture in course ‘Sustainable mobility’ of VUB, 2012

Messagie M. (2012) Lecture ‘Groene voertuigtechnologie’, FOD Mobiliteit, 4 & 6 October 2011

Messagie M. (2012) Lecture ‘Ecologische voertuigen vandaag en morgen’, UPV, 7 april 2011

Messagie M. (2012) Lecture Groene voertuigtechnologieën, Willemsfonds Oostende, March 2011

Macharis C., Van Mierlo J., Lebeau K., Messagie M. (2011) Study Trans2House, Edition:Plug-in the Grid, Paving the Way for electric vehicles, Brussels

Messagie M. (2012) Lecture for UPV, Milieuvriendelijke voertuigen, 7/10/2010, Koksijde, Belgium

Messagie M., Boureima F., Matheys J., Sergeant N., Timmermans J., Macharis C., Van Mierlo J. (2010) Environmental performance of a battery electric vehicle: a descriptive Life Cycle Assessment approach, Edition:The World Electric Vehicle Symposium and Exposition (EVS)

Messagie M., Boureima F., Sergeant N., Matheys J., Turcksin L., Macharis C., Van Mierlo J. (2010) Life Cycle Assessment of conventional and alternative small passenger vehicles in Belgium, Edition:IEEE VPPC 2010, Vehicle Power and Propulsion Conference, Lille, France, Life Cycle Assessment of conventional and alternative small passenger vehicles in Belgium

Mulder G., Denys T., Messagie M.,, Van Mierlo J. (2010) State of the art analysis on the introduction of electric vehicles: first results from the Belgian Trans2House project, Edition:2nd European Conference SmartGrids & E-Mobility, State of the art analysis on the introduction of electric vehicles: first results from the Belgian Trans2House project, published by: OTTI Renewable Energies

Messagie M., Turcksin L., Matheys J., Coosemans T., Macharis C., Van Mierlo J.(2010) I-SUP conference, Innovation for Sustainable Production, Poster presentation, Environmental and economic comparison of a hybrid and a conventional city bus for public transport, Eco18-21/04/2010, Bruges

Messagie M. (2010) Lecture for VOKA and Elecrabel: “Samen duurzaam onderweg – een visie op duurzame mobiliteit.”, 5/5/2010, Antwerp

Mulder G., Denys T., Messagie M., Van Mierlo J. (2010) “State of the art analysis on the introduction of electric vehicles: first results from the Belgian Trans2House project”, Smart Grids & e-Mobility conference Brussels 2010.

8.3 Participations (without presentation) to scientific colloquia/conferences or workshops

Mobimix.be (platform on ecological fleet management), Project of the Bond Beter Leefmilieu (BBL) financed by the Flemish Governement, 2008-2010: Participation to several meetings of the steering group.

WATT-Roadshow (demonstration of enviromentally friendly vehicle technology), Project of the Bond Beter Leefmilieu (BBL) financed by the Flemish Governement, 2010: Participation to several meetings of the steering group.

Life Cycle Assessment and Environmental Systems Analysis, PhD course, NTNU, 9-20 August 2010, Trondheim, Norway.

Advanced LCA – consequential modeling, PhD course, Aalborg University Denmark, 11-12 May 2010, Aalborg, Denmark.

“From theory to data analysis - an overview of multivariate data analysis methods and their applicability” VUB, 2 April 2010, Brussels.

Milieuvriendelijke voertuigtechnologieën, Vrije Universiteit Brussel, 2010-2012, Brussels: Class taught by Prof. Joeri Van Mierlo .

Verkeerskunde, Vrije Universiteit Brussel, 2010-2012, Brussels: Class taught by Prof. Joeri Van Mierlo.

LC-IMPACT Uncertainty Workshop 2012, ETH Zurich, Friday 20 January 2012

EARPA, European Automotive Research Partners Association, Task force Materials and design, 2012, Brussels

MaterialSource, Hasselt, Maart 2011

Studienamiddag “CO2 – Wat na 2012 voor de industrie”, Ingenieurshuis, 31 januari 2011, Antwerpen

Electromobility Event, 13 January 2011, Cologne

EARPA, European Automotive Research Partners Association, Task force Materials and design, 2011, Brussels

VBO, Hoe de belemmeringen voor de ontwikkeling van ELECTRISCHE VOERTUIGEN in België wegnemen? 20/01/2011

European Commission, International Reference Life Cycle Data System (ILCD) Handbook “Recommendations based on

existing environmental impact assessment models and factors for Life Cycle Assessment in a European context” 26/10/2010, Brussels

MIP3, Milieu- en energietechnologie Innovatie Platform, Themagroepvergaderingen, 04/02/2011, Brussel

EARPA, European Automotive Research Partners Association, Task force Materials and design, 2010, Brussels

INESPO meeting, Belspo, 31/05/2010, Brussel

LINEAR project, Local Intelligent Networks and Energy Active Regions, Brugge 2010

Changing the way people move, 365 Energy Group, 16/02/2010, Amsterdam, The Netherlands.

Lighthouses of Sustainability – European Concepts for competitive Bio-based Chemicals, Representation of the Free

State of Bavaria to the European Union, 3-4/02/2010, Brussels, Belgium.

9. Publications related to the project

9.1 Peer reviewed publications

MESSAGIE, M., BOUREIMA, F., MATHEYS, J., SERGEANT, N., TIMMERMANS, J.-M., MACHARIS, C. and VAN MIERLO, J. (2010). ‘Environmental performance of a battery electric vehicle: a descriptive Life Cycle Assessment approach’, The 25th World Electric Vehicle Symposium and Exposition (EVS25), Shenzhen, China, 5-9 November 2010.

MESSAGIE, M., BOUREIMA, F., SERGEANT, N., MATHEYS, J., TURCKSIN, L., MACHARIS, C. and VAN MIERLO, J. (2010). ‘Life Cycle Assessment of conventional and alternative small passenger vehicles in Belgium’, IEEE VPPC 2010, Vehicle Power and Propulsion Conference, Lille, France, 1-3 September 2010.

TURCKSIN, L., MACHARIS, C., LEBEAU, K., BOUREIMA, F., VAN MIERLO, J., BRAM, S., DE RUYCK, J., MERTENS, L., JOSSART, J.-M., GORISSEN, L. and PELKMANS, L. (2010), “A multi-actor multi-criteria framework to assess the stakeholder support for different biofuel options: the case of Belgium”, *Journal of Energy Policy*, 39, 200-214.

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LEBEAU, K., TURCKSIN, L., MAIRESSE, O., MACHARIS, C. and VAN MIERLO, J. (2010). “European car taxation systems: an overview and a proposal for reform”, *Transportation Research Part A: Policy and Practice,* submitted for publication.

MAIRESSE, O., MACHARIS, C., TURCKSIN, L., SERGEANT, N. and T. DENYS (2010), “Perceived effectiveness of policy measures to promote green car purchases: a Rasch analysis”, *Transportation Research Part A: Policy and Practice,* submitted for publication.

LEBEAU, K., TURCKSIN, L., MAIRESSE, O. and MACHARIS, C. (2010), « How can European governments stimulate the purchase of environmentally friendly vehicles? A multi-actor multi-criteria analysis », Selected Proceedings WCTR conference, July 11-15, 2010, Lisbon, Portugal.

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MICHIELS, H., DENYS, T., VERNAILLEN, S., SCHROOTEN, L. and BECKX, C. (2010), "Transition pathways towards a greener mobility", Het Ingenieursblad (Magazine of the Royal Flemish Society of Engineers), Nr. 4, August-September 2010.

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TURCKSIN, L., MAIRESSE, O. and MACHARIS, C. (2011). “A policy based weighted averaging model to predict green vehicle purchase”, *International Journal of Environmental Research Public Health*, submitted for publication.

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9.2 Trans2House scientific reports

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Annex A: Invited participants to online survey

Surname	First name	Company	Sector
Michiels	Pol	Febiac	automotive
Wibaut	Jean	GM/Opel	automotive
Vinckx	Luc	GM/Opel/Saab	automotive
Dekoning	Koen	Toyota	automotive
Schuybroek	Karl	Renault	automotive
Vanden Bergh	Christian	Citroën	automotive
Doms	Wim	Peugeot	automotive
Aerts	René	Volvo Cars Belgium	automotive
Van Leuven	Peter	Volvo	automotive
Van Aken	Gerry	LeasePlan	automotive
Goossens	Pieter	Athlon Car Lease	automotive
Meeus	Marcel	Umicore	automotive
Van Geyt	Leo	ThePluginCompany	automotive
Louis	Stefan	EMROL	automotive
Creytens	Stephan	Blue Corner	automotive
de Borrekens	Patrick	Newteon Benelux - HF Motors nv	automotive
Bart	Vereecke	eNovates	automotive
MONS	Bert	Agoria	automotive
Gisquière	Geert	Cambio autodelen	automotive
Decrock	Philippe	Confederatie FEDERAUTO vzw	automotive
De Ridder	Joeri	ASBE	automotive
Guido	Franco	Ineltra Systems	automotive
van Wijk	Elias	Punch Powertrain nv	automotive
Vancoillie	Karel	Touring	Consumers
Matienko	Maarten	VAB	Consumers
Muyshondt	Leo	Test Aankoop	Consumers
Verhelle	Tony	Autogids	Consumers
Biesemans	Fanny	Eandis	Energy
Rombouts	Jan-Willem	REstore	Energy
Verbeeck	Jeroen	SPE	Energy
Wynants	Maarten	GDFSUEZ Energy Services	Energy
Becue	Ines	Eandis	Energy
Vanderbeuren	Roel	BBL	NGO
Thijs	Joeri	Greenpeace	NGO
Cockx	Jeroen	LNE	Government
Van Mierlo	Tania	LNE	Government
Tindemans	Hans	Mobiliteitsraad Vlaanderen (MORA)	Government
Hollander	Sarah	Leefmilieu Brussel	Government
Dal Molin	Loïk	Leefmilieu Brussel	Government
Théate	Pascal	Waalse Administratie Leefmilieu	Government
Speybrouck	Johan	Mobile-for	Government
De Saunois	Jo	Gemeentelijk Autonoom Parkeerbedrijf Antwerpen	Government
Duyck	Francis	B-Parking	Government