

Electric Vehicles: a cost competitive game changer or technology's false hope?

Total Cost of Ownership analysis of Electric Vehicles for the 2015 - 2030 timeframe

Delft University of Technology

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Electric Vehicles: a cost competitive game changer or technology's false hope?

Total Cost of Ownership analysis of Electric Vehicles for the 2015-2030 timeframe

by

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EXECUTIVE SUMMARY

The transport sector is a major contributor to greenhouse gas emissions and pollution in cities. The sector emitted 8,7 gigatonnes of CO₂ in 2012. In order to meet the two degrees scenario target, the emissions of the sector would need to decline to 5,7 gigatonnes of CO₂ in 2050. Electric Vehicles (EVs) can help to achieve this goal and many governments introduced policies to make EVs more attractive to consumers. As a result, the cumulative global EV stock grew from almost none in 2009 to about 750.000 EVs by the end of 2015.

However, the retail price of the current electric vehicle remains significantly higher than a conventional car and their performance is inferior with respect to their range. Academic and non-academic studies to the cost development of EVs for the coming 15 years are non-consistent and differ considerably from each other. The main problem of the research is that there is no Total Cost of Ownership (TCO) study that extensively analyses the (recent) literature available to estimate the total TCO for EVs and identifies the main uncertainties that influence such cost estimates.

Therefore, this research aims to (1) compose a framework to identify the factors influencing the TCO, and their mutual interactions and (2) use that framework to create multiple scenarios for the cost development pattern of EVs for the 2015-2030 period. Two research questions are formulated for this research:

Question 1: *“What factors influence the total cost of ownership development of electric vehicles and what is the relationship between those factors?”*

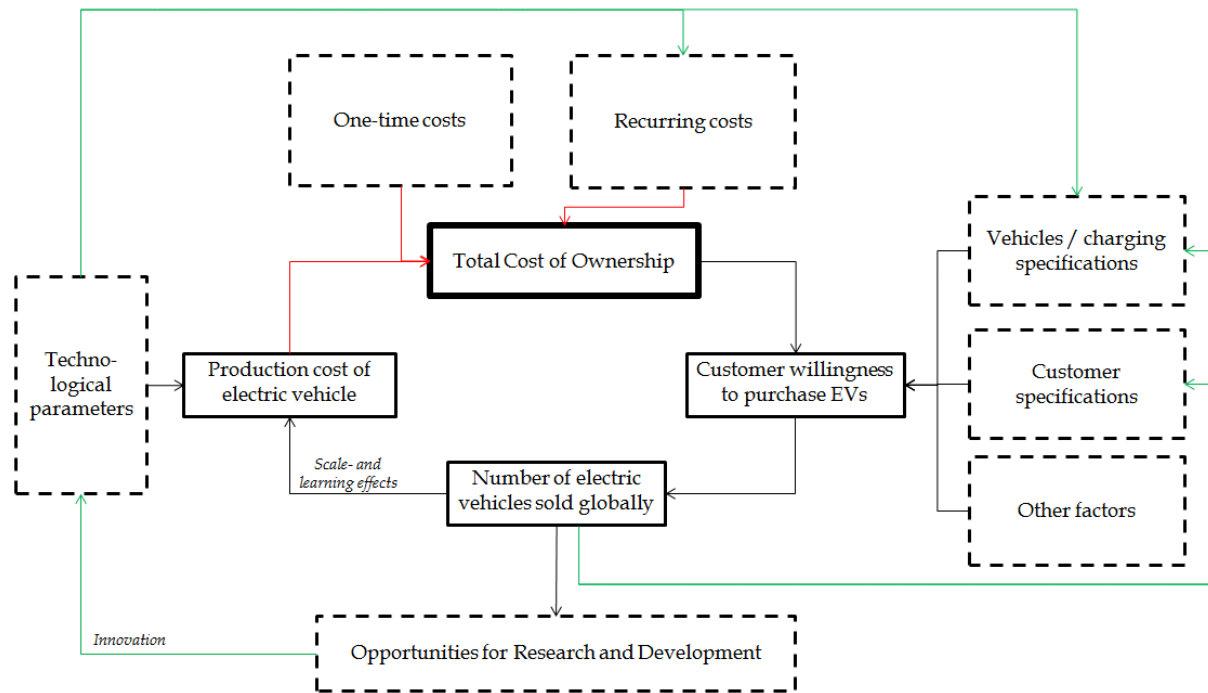
And:

Question 2: *“How will the total cost of ownership of the electric vehicle develop up to 2030?”*

Instead of only using cost literature like previous cost development studies, this research includes a second literature stream called technology selection literature. Scholars of this second literature stream research the diffusion pattern of breakthrough technologies and factors that may influence the technology selection and dominance of products. These two literature streams are, together with general EV literature, the basis for the desk research used to create a TCO framework (research question 1). This framework is validated and optimized by means of 17 interviews with EV experts from different scientific and industry backgrounds. The framework is then used to identify the most crucial factors that need to be included to calculate the TCO for a C-segment BEV. In order to answer the second research question, a combination of qualitative and quantitative data is used.

The findings of the first research question show a new total cost of ownership framework, which is significantly more comprehensive than the frameworks used in previous studies. By combining the two literature streams we not only found direct factors – such as production costs, maintenance and charging costs – that may affect the TCO. Many indirect factors play a role as well, such as: technological superiority of the product, the development of charging infrastructure and customer specifications. These and other factors determine the (relative) willingness to purchase an EV. As this influences the buying behaviour, a positive (negative) willing to purchase indirectly affects the future TCO through higher (lower) demand of EVs and higher (lower) new investments in R&D. In the end this leads to lower (higher) productions costs via new opportunities for R&D or higher (lower) scale- and learning effects. This is a reinforcing cycle, which includes various bypasses and feedback loops. A schematic overview of the simplified framework is shown below.

In total, 34 factors are identified which directly or indirectly influence the TCO. Based on the desk research and the interview, eight factors are marked as crucially important. Among these are the production costs, the range and government policies.



All direct factors and the factors that are identified as important are included the TCO calculations to answer the second research questions. If possible, the factors are operationalized (such as maintenance costs). The other factors are part of the demand scenarios (such as variety of EV models). Using a combination of (1) data from other studies, (2) open data and (3) databases owned by CE Delft, a new TCO for the 2015-2030 period is determined for a C-segment BEV and a conventional reference car. The results are presented in a 2x2 matrix, which differentiates between the presence/absence of government influences and two user profiles. With regards to the latter, the first user profile represents a consumer who uses the car frequently, while the second user uses the car less frequently. From a technological perspective, the results clearly show the BEV does not become competitive before 2030 (assuming the absence of government influences). From a consumer perspective (assuming the presence of government influences), the BEV becomes competitive for first user profile in 2019 in the optimistic scenario and 2024 in the neutral scenario. It does not become competitive before 2030 in the pessimistic scenario. For the second user profile it does not become competitive before 2030. The results also show there is a triangular relationship between the cost development (TCO), range development and the producer's indirect costs. All these three factors are pressing issues that need to be addressed (become more favourable) to enhance consumer and producer attractiveness. Yet, when one is favoured, the other will be disadvantaged.

Among the scientific contributions, the following are recalled: combining two literature streams for the case of EVs makes this report unique. It contributes to the stream of cost literature, as this research shows the framework is more comprehensive than previous TCO frameworks, which might be used for other cases and industries as well. In addition, it contributes to the technology selection literature, since this research shows the factors that are extracted from these scholars can be used for other purposes than technology selection, in this case cost development.

Among the managerial and policymaker contributions, the following are recalled: Managers should be aware cost studies might not reflect reality, since frameworks are heavily simplified. This research attempted to compose a more comprehensive framework. Furthermore, the C-segment BEV can become competitive (assuming government influences are presented), but only when the car is frequently used. Since the producer's indirect costs are not incorporated in the current retail prices of EVs and since range enhancement requires higher relative production costs, the TCO will be under pressure by these two other forces in the coming 15 years. Therefore, it would be unrealistic to allocate all cost reductions to TCO reductions, as these two other forces require attention in the near and mid-term future as well. Government policies play a crucial role as well, as they can increase the playing field to release the pressure on these related forces.

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LIST OF ABBREVIATIONS

EV	Electric Vehicle
TCO	Total Cost of Ownership
ICEV	Internal Combustion Engine Vehicle
HEV	Hybrid Electric Vehicle
BEV	Battery Electric Vehicle
EREV	Extended Range Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
OTC	One Time Costs
RC	Recurring Costs
R&D	Research & Development
OEM	Original Equipment Manufacturer
VAT	Value Added Tax
ADAS	Advanced Driver Assistance System
RPE	Retail Price Equivalent
NEDC	New European Driving Cycle
BPM	Belasting van Personenauto's en Motorrijwielen (Vehicle registration tax)

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1

INTRODUCTION

Electric vehicles are booming on a global scale. The adoption rate of multiple types of electric vehicles (EVs) seems to take off and governments attempt to accelerate this trend by means of policies that favour EV owners. Yet the cost of acquiring an EV is significantly higher than a conventional gasoline/diesel car. This master thesis elaborates on the total ownership costs of the electric vehicle up to 2030. In this chapter first the problem statement is introduced and the scientific relevance of the research is made clear. Next, the objective of this research is formulated and research questions are identified. These will act as the foundation for this master thesis.

1.1 Problem statement

Although Total Cost of Ownership (TCO) studies to EV business cases have been conducted in the past, the results vary considerably. In addition, as we point out later in this study, the industry and academia do not seem to agree what the cost development of the EV will look like from now until 2030. To resolve these issues, this study aims to determine the main factors that influence the TCO and to provide scenarios for the cost development pattern of the EV. This paragraph further introduces this topic and concludes with the gap between the current and desired situation.

1.1.1 Introduction of electric vehicles

The transport sector is a major contributor to greenhouse gas emissions and pollution in cities. The sector accounted for 28% of overall global energy consumption and emitted 8,7 gigatonnes of CO₂ in 2012, which increased 2% each year since 2000 on average. In order to meet the 2 degrees scenario (2DS)¹ target, the emissions of the sector would need to decline to 5,7 gigatonnes of CO₂ in 2050. The introduction of zero emission cars like electric vehicles can contribute to this decline of CO₂. In order to achieve this goal, many nations introduced fuel economy regulations and use fiscal policy to increase EV deployment. The cumulative global EV stock grew from almost none in 2009 to about 665.000 EVs by the end of 2014. Yet according to the IEA it will be hard to meet the 20 million global stock target by 2020 (IEA, 2015)².

Also the Dutch government committed itself to stimulate the introduction of EVs in 2010 for multiple reasons. First, it wants to stimulate the development of these technical products and components to increase the competitiveness of the Dutch economy. Second, EVs are more efficient than Internal Combustion Engine Vehicles (ICEVs) and initiate the switch from fossil fuels to the possibility of renewables energies. Third, it contributes to the CO₂ reduction goals of the government and will also improve the quality of life in cities because of the reduction in polluting gases like NO_x and particulate matter. The Dutch government has set the target to introduce the EV on a large scale, with at least 200.000 EVs by 2020 and a mature market in 2025 with about 1 million EVs (Rijksoverheid, 2011).

Ever since, the government has started up multiple initiatives to stimulate Research and Development (R&D) programs, provided rebates for owners of EVs and invested in charging stations (Rijksoverheid, 2011). As a result the number of EVs is increasing in the country to almost 100.000 in 2015, of which the majority are plug-in hybrid vehicles (Figure 1). This still only accounts for a small

¹ The 2DS describes a scenario that limits the average global temperature increase to 2°C. It sets the target to cut CO₂ emissions by more than half in 2050 compared to 2009 and decline thereafter. IEA recognizes that an increase of more than 2°C results in a dangerous form of climate change (IEA, 2015).

² This target is the combined number of all the individual countries that set an EV target for 2020.

amount in the total passenger car fleet. In 2015, 9% of the new car registrations was a plug-in hybrid or EV with range extender and full electric vehicles accounted for 0,6% of the total new registrations. Charging points for EVs also increased threefold between 2013 and 2016 to 19.000 stations (RVO.nl, 2015). The government expects the market share of electric transport to increase significantly in the coming ten years (Rijksoverheid, 2011).

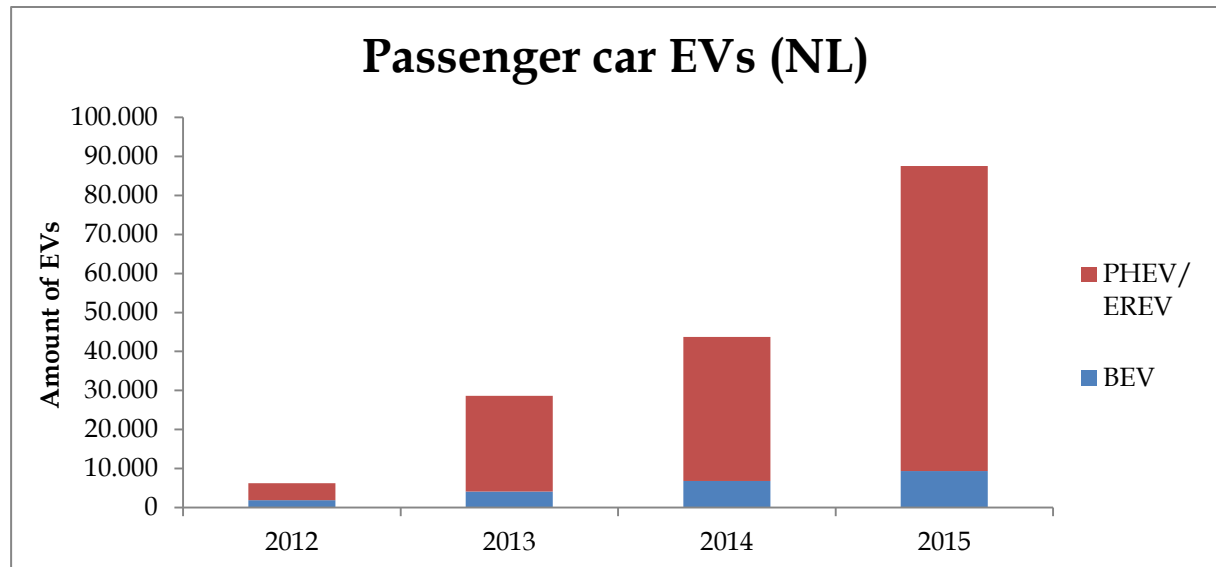


Figure 1: Amount of passenger car EVs in the Netherlands (RVO.nl, 2015).

1.1.2 Cost of EVs as a barrier to adoption

However, the achievement of the Dutch and global goals with respect to EVs cannot be taken for granted. There are multiple barriers that prevent EVs to penetrate through the mass market. One of the most important barriers is the high cost of acquiring an EV compared to conventional cars, a price differential of up to €15.000 (Cluzel & Lane, 2013; Thiel, et al., 2010).

Based on surveys from the NRC³, respondents ranked the costs as the principal barrier to buy an EV (National Research Council, 2013). Even when the high purchase costs are spread over the lifetime of the car, the EV is still not very attractive (Nemry & Brons, 2010; Windisch, 2014). This is also acknowledged by Adepetu & Keshav (2015), who conducted research to the balance between the electric driving range and price reductions. They conclude that the price is a more important factor than the increase of range (Adepetu & Keshav, 2015). Although experts consistently argue cost reductions will take place over the course of time, there is no consensus to what extent this cost reduction will occur (Cluzel & Lane, 2013; Steinhilber, et al., 2013; Catenacci, et al., 2013)

The estimated cost trends for the upcoming 10 to 15 years are non-consistent and differ considerably from each other (as will be discussed in paragraph 1.2). The development of the EV is not an isolated case, but is affected by social-technological parameters with many uncertainties. For example, the adoption rate can change when a radical innovation occurs in one of the components. If for example a new type of battery is invented, it could totally change the business case of the EV. In addition, government policies can make the EV more attractive by means of fiscal policies or emission regulations. Other technologies might influence the need or desire of an EV as well. The concept car sharing for example, might totally change the world of mobility as we know it (Nijland, et al., 2012).

³ The National Research Council is a private non-profit institution which advises the US government and informs public opinion.

1.1.3 Conclusion

The main problem, the gap between the current and the desired situation, is that there is no TCO study that extensively analyses the (recent) literature available to estimate the total TCO for EVs and identifies the main uncertainties that influence the cost estimates. This research aims to identify the factors influencing the TCO and shape multiple scenarios for the cost development pattern of EVs from now until 2030. These costs not only cover the price of acquiring the car, but the total cost of ownership including infrastructure, cost of electricity, maintenance, etc.

1.2 Scientific and managerial relevance

From a scientific perspective, the contribution of this research is to fill the knowledge gap in the literature between the stream of technology selection scholars and cost development scholars (as will be explained in Chapter 2). More details about what factors influence the TCO and the relationships between them are provided, as no such research has been conducted before. This can be used to increase the accuracy of determining a TCO for EVs. This is unique compared to other studies that solely focus on specific parameters (e.g. only on the acquisition price of a car). The limitations of the current cost studies are briefly reviewed below.

We selected the EV cost related studies that were published within the last five years⁴, since at that point in time the EV industry kicked in (IEA, 2015). The seven remaining studies that actually calculated and forecasted a TCO into the future have been reviewed. There are more valuable studies which on first sight may fit as well, but they are either dated or focus on policy effects so final future TCO is not determined (van Vliet, et al., 2010; CE Delft, 2011; Windisch, 2014). A systematic overview of the seven selected studies can be found on the next page (Table 1). It is rather complex to compare the direct results of the studies, since TCOs can be calculated in per energy unit, per distance or in years. In addition, one should compensate for the different assumptions each study uses, for example: the annual mileage, base year currency, discount rate and car type/segment. Therefore, we focus on the methodology used in the studies.

The top-down⁵ study by Thiel, et al., (2010) for example uses a 5-10% learning curve for different components based on other studies in the automotive industry, but uses only one source for all technological forecasts up to 2030. In addition, only the retail price is included, not the TCO. The calculations of Weiss et al. (2012) are also limited to the sticker price and assume a learning curve of 17% for the lithium-ion batteries. They also applied a different top-down methodology: it extracts the ex post experience curve of the Hybrid Electric Vehicle (HEV) and applies it to the Battery Electric Vehicle (BEV) ex ante. Others used bottom up approaches to calculate capital costs of individual components and sum those in their TCO model (Palencia, et al., 2014; Contestabile, et al., 2011; Wu, et al., 2015). However, the sources used to determine the costs are rather limited and sometimes not explained. Some included the Plug-in Hybrid Electric Vehicle (PHEV), but none of the studies included the Extended Range Electric Vehicle (EREV) in their study.

It is difficult to compare the quantitative TCO results between the studies for the aforementioned reasons. Yet it is notable that for example Weiss et al. (2012) concludes the purchase price of the BEV will be breakeven in 2026, while Thiel et al. (2010) concludes the retail price will remain higher than the ICE car. The tremendous difference in expected cumulative stock is also a sign of the uncertainty and assumptions that one has to make. Categorization is also an issue, as some studies show the tipping point for an EV to be considerably different depending on the assumed annual mileage and car segmentation (Contestabile, et al., 2011; Wu, et al., 2015). To conclude:

- TCO results seem contradicting, even when differences in base year, methodology and assumptions are taken into account.

⁴ There are many proponents and opponents in the world of EVs. We limited our studies to the academic papers and the studies published by 'prominent' institutions or organizations.

⁵ The definition and methodology for both a 'top-down' and 'bottom-up' study are explained in Chapter 3.

- There is not much consistency about the expected cumulative stock, which may greatly influence the results through scale- and learning effects.
- Some studies fail to include a comprehensive literature review in which costs of components are compared.
- Categorization of assumptions might have a striking effect on the results, but is only applied in a few studies.
- Most studies are based on secondary data, i.e. other literature. Only one study uses interviews as a tool to validate the data.

From a managerial perspective, this thesis might provide relevant insights for different problem owners: the government and commercial companies that invest in the electric vehicle market.

The government committed itself to the introduction of the EV in The Netherlands. The government can enhance the adoption rate of EVs by increasing the subsidies and other financial discounts for owners of EVs, but generally wants to minimise such spending. The results of this research can be used to adapt the fiscal policy for EVs for different moments in time from now until 2030 and for different user groups.

Some commercial companies invest a lot in the infrastructure and technologies for EVs as we speak. The results of this research can provide detailed insights in the cost development of EVs and hence help to make sound decisions about investments in the EV industry.

Table 1: Different cost studies to EVs.

Author (year)	Assumptions	Methodology	Cum. Stock in target year	Base year / target year	Results for BEV	BEV / PHEV / EREV	Remarks	Peer-reviewed?
(Thiel, et al., 2010)	Vehicle specs based on a specific car / technology forecasts based on a single source	Top down, 5-10% learning curve	24,6 mil BEV / 115,1 mil PHEV	2010 / 2030	Purchase costs for BEV will be €3200 higher in 2030 and PHEV will be €3100 higher in the medium scenario	✓ / ✓ / X	Calculations are limited to purchase price, not TCO	Yes
(Weiss, et al., 2012)	Assumes a learning curve of 17% for electrification	Top down, uses expert experience curve of HEV to apply on BEV ex ante	145 mil BEV	2010 / 2035	Purchase costs for BEV is 100 € ₂₀₁₀ kW ⁻¹ in 2035 compared to 103 € ₂₀₁₀ kW ⁻¹ for ICE, breakeven in 2026	✓ / ✓ / X	Calculations are limited to purchase price, not TCO	Yes
(Lee & Lovellette, 2011)	Assumes gasoline prices increase and battery costs decline	Bottom up, but only key parameters included (retail price, maintenance, fuel, discount rate)	N/A	2011 / 2025	TCO for BEV is \$3478 and cheaper than ICE PHEV is \$449 more expensive in 2025 in real terms	✓ / ✓ / X	Very limited cost model	No
(Crist, 2012)	Assumes vehicle specs based on specific cars	First calculates TCO for 2012, then identifies many scenarios with (unsupported) arguments	N/A	2012 / NA	General conclusion: BEV remains more costly than ICE	✓ / X / X	Focus is mainly on TCO in base year, less on forecasting	No
(Palencia, et al., 2014)	Assumes general mid-size sedan specs and national parameters from Colombia	Bottom up, but each component costs is based on a single source	N/A	2010 / 2050	TCO for BEV is \$3000 a year and ICE is about \$4000 a year in real 2010 USD	✓ / X / X	Neglects disposal costs	Yes
(Contestabile, et al., 2011)	Assumes a 5% learning rate for the powertrain. Multiple vehicle specs, scenarios and market segments	Bottom up, but each component costs is based on a single source	N/A	2011 / 2030	TCO for a 50km range BEV is lower than ICE, a 100km BEV is slightly cheaper and a 200km range BEV is way more expensive than ICE.	✓ / ✓ / X		Yes
(Wu, et al., 2015)	Assumes different market segments and use cases. Technological parameters based on multiple sources, but many not academic. Vehicle specs based on one source	Bottom up, based on other sources	N/A	2014 / 2025	TCO for BEV/PHEV will remain higher than ICE until 2025 (ct €/km), except for long driving distance small cars. Yet the TCOs of all types will converge over time.	✓ / ✓ / X	Uses interviews for validation	Yes

1.3 Research framework

The total cost of ownership of electric vehicles is influenced by a range of factors, which are identified along this research. In addition, it is expected these factors also influence each other. On a very high aggregation level, a simplified framework is presented in order to formulate research questions (Figure 2). It is explained along the following categories:

1. The factors and relations;
2. The input assumptions;
3. The total cost of ownership forecast.

ad 1. The factors and relations

As shown in the figure below, the factors are the independent constructs and influence each other and the total cost of ownership. These factors can range from technical factors, like innovations in the battery technology, to economies of scale or social factors like the image of the EV. Equally important are the relationships between the factors and between the factors and the TCO. The exact identification and number of these factors and relations are part of the research objective and cannot be concluded upon in this paragraph.

ad 2. The input assumptions

In order to develop a TCO forecast, one is forced to make predictions about costs in the future. Since nobody can tell for sure what will happen in the development of EV, many studies use different scenarios. The chosen scenario will affect the TCO, e.g. an over-optimistic energy price would be beneficial for the EV business case. This is also true for assumptions about the car owner. A car owner driving 5.000 kilometres annually will experience a different TCO than an owner driving 40.000 kilometres a year. For this research it is important to recognize these variations to provide realistic results. As assumptions and scenarios may influence the resulting TCO forecast and the effect of some factor, it is depicted as a moderating construct in the figure.

ad 3. The total cost of ownership forecast

Together the different factors and the assumptions/scenarios determine the TCO forecast of this research, which is the dependent construct in this research.

To conclude, the figure below (Figure 2) is a preliminary research framework which shows there are factors influencing the TCO. These factors and relations may indirectly or directly relate to the TCO, but they may also influence each other. In this stage we do not know exactly how this framework will look like, but Figure 2 represents a generic version.

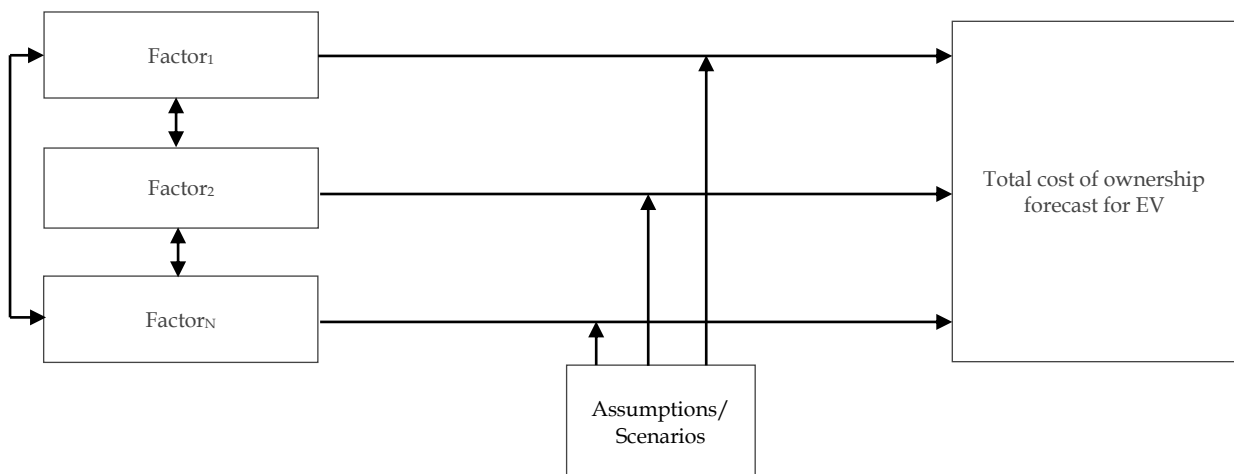


Figure 2: Preliminary research framework.

1.4 Research objective

A research objective formulates the aim of the research. For this research, the objective is twofold:

The first objective is to identify the factors, and their mutual interactions, that influence the total cost of ownership of EVs;

And:

The second objective is to provide a total cost of ownership forecast for the electric vehicle up to 2030 using multiple scenarios.

Total cost of ownership in this case is defined as the cost of owning a passenger car, since they constitute the biggest proportion of road transport emissions. This means that TCO is investigated from a consumer's perspective, not from a social perspective (e.g. external costs are not included). Electric vehicles are plug-in electric vehicles (PHEV/EREV) or full electric vehicles (BEV). A time period until the year 2030 is used because of the uncertainties in EV development. It becomes less reliable to estimate the TCO over the course of time and other studies use the 2030 timeframe as well. The period of ownership differs among consumers, so multiple ownership periods are taken into account.

1.5 Research questions

Based on the conceptual model and the objective two core research questions are formulated:

Question 1: *"What factors influence the total cost of ownership development of electric vehicles and what is the relationship between those factors?"*

The following sub questions are relevant:

1. What factors influence the TCO?
2. How do these factors relate to the TCO and each other?
3. To what extent does each factor influence the TCO?

Question 2: *"How will the total cost of ownership of the electric vehicle develop up to 2030?"*

The following sub questions are relevant:

1. How can the TCO be calculated?
2. What are the cost estimations of each relevant factor?
3. What are the scenarios and assumptions in order to calculate the TCO?
4. To what extent do the factors influence the TCO?

The sub questions are answered in order to answer the main question. All questions are answered in the report in the conclusion of the relevant chapter.

1.6 Research scope

The development of electric vehicles has become a large discipline over the course of time. Due to both time constraints and the necessity to conduct an in-depth analysis, the scope of this research is limited by the following criteria:

1. The research is limited to passenger cars and excludes trucks, busses, etc. Passenger cars account for the largest portion of the total energy demand, about 60% (IEA, 2015, p. 98).
2. An electric vehicle is defined as a car that uses an electric motor and in which energy is stored in a battery.
3. In this study, we consider Plug-in Hybrid Vehicles (PHEVs), Battery Electric Vehicles (BEVs) and Battery Electric Vehicles with a range extender (EREVs). HEVs are excluded, because it mainly

relies on the ICE technology. Also, HEVs are recognized as a incremental innovation based on ICE technology rather than a radical innovation like the BEV/PHEV/EREV. Hence it is very likely the HEV technology will act as a substitute for the current ICE technology in the future (Sierzchula, et al., 2014).

4. The Netherlands is used as a reference when country-specific variables are required, such as taxes.

1.7 Structure of this report

After this introduction (Chapter 1), two literature streams are discussed in the theory section (Chapter 2). This concerns the scientific literature about total cost of ownership and technology selection theories in general, which prove to be relevant for the remainder of the report.

Once the theory is defined and discussed, the methodology section (Chapter 3) explains how the data is retrieved, analysed and presented. It also discusses methods that increase the validity and reliability of this research.

The next two chapters both chronologically answer the research questions and the accompanying sub questions as introduced in paragraph 1.5. Chapter 4 is of qualitative nature: a framework is developed that presents the factors which influence the TCO of EVs and the relationships between those factors. In Chapter 5 a quantitative approach is taken to determine the TCO range for BEVs for the 2015-2030 time period.

In Chapter 6 the results are concluded upon and in the subsequent Chapter 7 discussion highlights the implications of the results for science, companies, managers and policymakers.

2

LITERATURE ON TOTAL COST OF OWNERSHIP AND TECHNOLOGY SELECTION

For this research two literature streams are distinguished and explained: cost literature and technology selection literature. This chapter briefly introduces these two literature streams and how they are combined in order to answer the research questions.

The first paragraph describes what we call the cost literature stream, and describes how costs of technologies and products are determined. The estimation of costs can be done via a bottom-up engineering assessment or top-down by means of experience curves. In addition, the concept of total cost of ownership is explained and we define how TCO for automotive is built up in the academic literature.

The second stream focuses on technology selection. First the introduction of breakthrough technologies is explained as defined in the literature. Next we focus on the factors that influence such technology selection and dominance.

2.1 Cost literature

Cost literature is often used to determine the current and future costs of products and/or services. In the first part the total cost of ownership is defined. In addition, an example of how the TCO is built up in other EV cost studies is given. This however does not explain how future costs are estimated. This is discussed in the other two subparagraphs. First, the top down experience curves uses historic data to predict future costs using a learning curve. Second, the bottom up engineering assessment places a monetary value on each component of a product and investigates different R&D opportunities to calculate future costs.

2.1.1 Total cost of ownership

Total Cost of Ownership (TCO) is a purchasing philosophy in order to understand the true costs of buying a particular good or service (Ellram & Siferd, 1998). A TCO analysis covers all costs occurring over the lifetime of the object. For a vehicle, this includes one-time costs like the purchase costs, but also reoccurring expenses like fuel and maintenance costs (Redelbach & Friendrich, 2012). Since TCO takes into account all the costs over the life cycle, it can be used as an evaluation tool to compare different products (Hurkens, et al., 2006). This is especially important for the comparison of conventional and electric vehicles, since the latter have relatively high purchase prices, but might face lower operating expenses (Wu, et al., 2015). A limitation of using TCO is the need to identify assumptions for the driving characteristics of the owner (Redelbach & Friendrich, 2012). For example, the annual mileage will affect the TCO results, but may be unique for each individual. Yet there it is necessary to use multiple scenarios to account for these assumptions.

The total cost of ownership from a customer's perspective looks like presented in Figure 3. These factors relate directly to the TCO. The next chapter focus on the additional forces that influence these factors as depicted below.

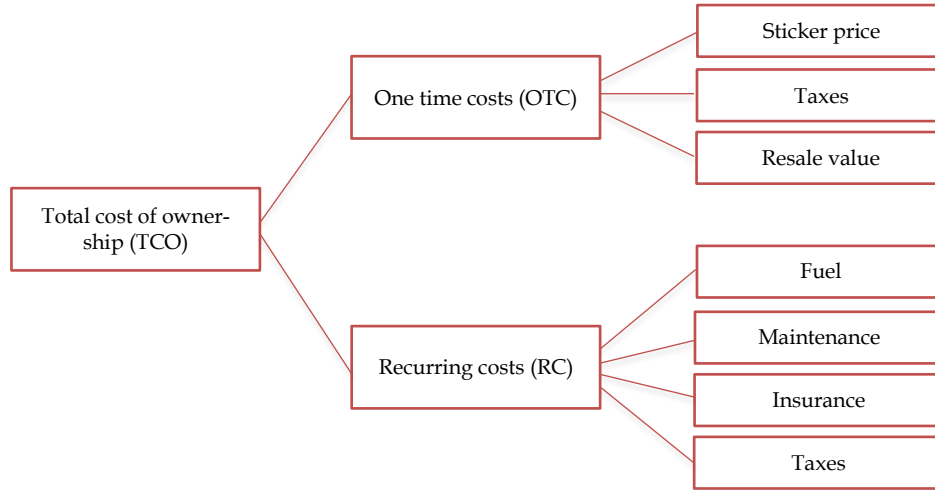


Figure 3: Total Cost of Ownership framework in many studies (Redelbach & Friendrich, 2012; Wu, et al., 2015; Windisch, 2014).

The one time costs represent the acquisition costs when buying the vehicle in year t . The underlying costs can be categorized in the actual sticker price of the vehicle plus the related taxes when purchasing a car and minus the residual value when selling or disposing the car. The residual value is dependent on the holding period of the first owner and some other technical parameters. The reoccurring costs are affected by the fuel costs, maintenance costs, insurance costs and taxes (e.g. ownership taxes, fuel taxes, VAT). In terms of mathematics, the TCO can be determined by the following equation:

$$TCO = OTC + \sum_{n=1}^N RC \times \frac{1}{(1+i)^n} \quad (1)$$

In this equation (1) TCO represents the total costs of owning the car for the holding period, the OTC represents the One Time Costs and the RC represents the Recurring Costs. These costs are discounted for future expenses with i being the discount factor and n the holding year starting with 1.

2.1.2 Top-down cost estimation: experience curves

In general, the experience curve shows that performing a repetitive task results in a fixed production cost reduction each time the cumulative output doubles (Hax & Majluf, 1982). These curves are used as a tool to predict future cost reductions by analysing the historic cost reductions of a technology. Based on historical data, the past cost reduction can be visualised in a graph that describes the costs as a function of the cumulative output. In order to predict future cost reduction, researchers extrapolate this curve for up to 50 years in the future. Relatively young markets are usually developed by early adopters, niche products and government support. This creates much potential for improvements (learning by doing and learning by using) which leads to potential cost reduction (Neij, 2008).

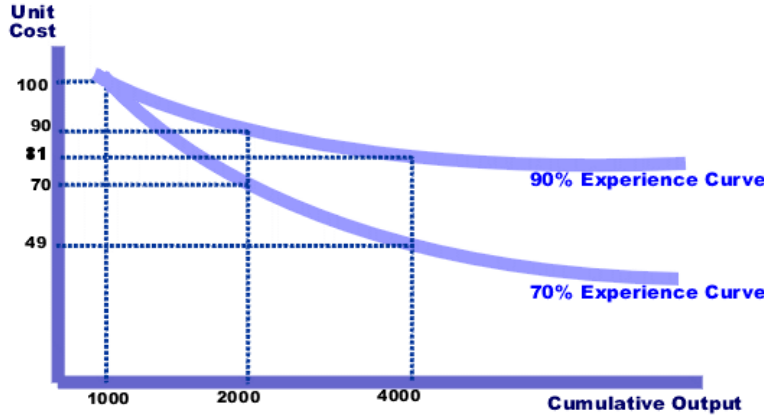


Figure 4: Example of an experience curve (MarketingMixx, 2011).

The experience curve or learning curve was first observed in the 1930s on a plant level to analyse the decline in man-hours per unit of a manufacturing company, since they become more efficient when more units are produced (Cunningham, 1980). Nowadays, they are used on an aggregate industry level for a specific technology, to map technological change as it was generalized by the Boston Consulting Group in the '70s (Nemet, 2006; Day & Montgomery, 1983). The usual form as explained by Ferioli, et al. (2009) is as follows (Ferioli, et al., 2009):

$$C(x_t) = C(x_0) \frac{x_t^{-b}}{x_0^{-b}} \quad (2)$$

In this equation x_t represents cumulated production, $C(x_t)$ the cost of a product at x_t , $C(x_0)$ and x_0 are respectively the cost and cumulated production at an arbitrary starting point. Finally, b represents a positive learning parameter. The learning rate itself can be written as the relative cost reduction in percentages after each doubling for production, hence (Ferioli, et al., 2009):

$$LR = 1 - 2^{-b} \quad (3)$$

So if the $LR = 20\%$, the cost will decline by 20% if experience doubles and it is said the experience curve has an 80% slope, assuming real monetary terms. Be also aware the equation is independent of time, as in period of rapid growth the cost will decline faster (Day & Montgomery, 1983).

The cost reductions, as expressed by the experience curve, can be attributed to three main components. First, the term learning by doing is used for all increased efficiency of labour related improvement as capacity increases. It encompasses improved work methods, specialization and more experienced personnel. Second, technological improvement includes process improvement in terms of standardization of work processes or automation as output increases. Finally, economies of scale are based on the notion that an increase in throughput does not require an equivalent increase in capital investment and overhead functions (Candelise, et al., 2013; Nemet, 2006; Day & Montgomery, 1983).

Experience curves are an effective tool to analyse long term historical data in order to forecast future cost reductions. In this research experience curves are used to predict future costs as well. Yet it is important to keep in mind this methodology projects historical trends. The limitations are widely mentioned in the literature. Especially the failure to account for radical innovations can be problematic for a relatively immature technology as the electric vehicle market. An alternative method to estimation future cost is a bottom-up approach called engineering assessment, which is discussed in the next paragraph.

2.1.3 Bottom-up cost estimation: engineering assessment

While the top-down method uses historical information about the industry or technology and extrapolates those into the future, the bottom-up method can also be used when no data is available (Candelise, et al., 2013). Although less mentioned in the scientific literature as a tool, the bottom-up method is based on a set of inputs on a very detailed component level to come up with estimation of future costs. In this report we call this method engineering assessment, although different names are used interchangeably and no common name is recognized in the literature.

Engineering assessment usually starts with an extensive literature review about a specific technology. Many details are provided in terms of the manufacturing process, materials used and individual components of the product. This way it is possible to determine the direct and indirect cost attributed to the process. Cluzel and Douglas (2012) use this approach to predict battery costs. They start at the lowest level with material costs. Next, they estimate the costs to produce the battery pack. Finally, they use fixed assumptions for overhead costs, yields, financing and production volume (Cluzel & Douglas, 2012). In order to estimate potential future cost reductions, new trends in product design, production processes and use of materials are identified. Next to gathering technology specific data, also expert judgments are used for cost estimations and reductions (Candelise, et al., 2013; Neij, 2008).

2.1.4 Relation to this research

At first sight this literature stream provides enough basis to develop a TCO for EVs, as it was done in many previous studies (refer to paragraph 1.2). We could have set up a TCO framework (e.g. the one of Figure 3), and used the top-down and/or bottom-up method to estimate future costs. However, we argue it seems a rather simplistic approach when compared with reality. Scale- and learning effects for example, are 'hidden' in the sticker price in Figure 3. In reality, we suspect this is more complex and the figure does not represent how such effects progress.

It is therefore concluded cost development theory is not enough to compose a TCO framework. In order to increase the quality, a second literature stream is incorporated in this research: technology selection literature. These scholars focus on why some new technologies/products reach a dominant position in the market and others are not (den Hartigh, et al., 2016). Although this is beyond the notion of TCO, it definitely influences the costs, for example through selections and demand effects. Since current TCO frameworks seem to be 'too simple', we include this second stream of literature. In the next paragraph this second stream is discussed and combined with the first literature stream.

2.2 Technology selection literature

From a theoretical point of view, EVs are a niche product which tries to enter the mass market. This diffusion pattern of breakthrough technologies describes how hi-tech products might develop over time. Not only price is a factor for a technology to become the mainstream product, but there are additional factors. First, the typical diffusion pattern of breakthrough technologies is described. It is also recognized some consumers are willing to pay a premium price for a new product. Second, the concept of technology dominance is discussed. Whether a technology becomes dominant is dependent on different factors.

2.2.1 Diffusion pattern of breakthrough technologies

The diffusion of new products that involve breakthrough technologies often consist of an S-shaped curve in terms of adoption rates relative over time (Ortt, et al., 2007). According to Ortt & Delgosaie (2008) the innovation phase covers the period when the technology is invented up to the first commercial market introduction (Ortt & Delgosaie, 2008; den Hartigh, et al., 2009). In the subsequent adaptation phase the market is unstable and the price/performance ratios are rather poor. Multiple small scale products or technologies are introduced and either become popular or fail. This is because the communication across the industry is not well organised and the performance is still below an acceptable level, a prerequisite for large scale introduction of a product since manufacturers of com-

plementary goods (like charging stations, infrastructure) demand many users for mass production. The market stabilisation phase is the phase in which the large scale diffusion really takes off, which is mostly depicted by an S-shaped curve (den Hartigh, et al., 2016). The dominant design is acknowledged at this stage and mass production is the logical consequence (Ortt & Schoormans, 2004; den Hartigh, et al., 2009).

Likewise, the customers that buy a product with a poor price/performance ratio can be categorised in the 'innovators' or 'early adaptors' category. These people have an intrinsic commitment for the technology and do not mind to pay a premium price. In order to enter the mass market, also known as the early and late majority category, the technology should be reliable and proven. Also the infrastructure should be at an acceptable level and the price/performance ratio should be more favourable than the current ICE technology (Mohr, et al., 2010).

2.2.2 Technology selection and dominance

Currently the electric vehicle operates in a 'niche' area in the automotive market, but it is about to enter the mass market (Tsang, et al., 2012). Some studies argue the EV technology is superior compared to ICEV technology. However, superiority does not necessarily mean the technology will be adopted by the mass market (van de Kaa, et al., 2014). Other forces also encourage selection of one or more technology standards. This dominant design may be a single product, a family of products or the process by which products are provided (Schilling, 1998).

An important factor is network effects, as they may influence the selection process of a technology. The concept of direct network effects exist when the user's individual benefits increases as more consumers (installed base) use the same technology. When the base of users increases, the technology becomes more attractive and adjacent complementary technologies are developed as well, which are called indirect network effects. The effect of installed base and complementary goods reinforces each other, since installed base increases the development of complementary goods and the availability of these goods attracts a bigger installed base. This may sometimes result in a winner takes all market (Schilling, 2002; Suarez, 2004; van den Ende, et al., 2012). According to Schilling (1998), many markets force one technology to become dominant resulting in technological lock in, which means there is no room for other technologies in that market (Schilling, 1998). However, this is not always the case. To quote Schilling (2002): *"It is important to note that not being locked out is not the same as being locked in."* (Schilling, 2002). In other markets two technologies may exist next to each other, but other would-be technologies are locked out of the market (Schilling, 2002; van den Ende, et al., 2012). Once a technology achieved dominance, manufacturers, distributors and consumers can benefit from the increased compatibility the standard enables by economies of scale (van de Kaa, et al., 2014).

But there are more factors influencing technology selection and dominance. Kaa, et al. (2011) conducted research to other factors which lead to dominant design⁶, which resulted in a framework of factors (van de Kaa, et al., 2011). These factors have been tested in various case studies about standard battles. In van de Kaa & de Vries (2015), three case studies in the field of data communications were conducted, and concluded the framework was more complete than previous frameworks in the literature (van de Kaa & de Vries, 2015). In another study by van de Kaa, the factors have been tested in the building automation industry for different types of platforms using a multi-criteria methodology (van de Kaa, et al., 2014b). Most of these cases relate to the empirical context of information technology and telecommunications (van de Kaa & de Vries, 2015; van de Kaa, et al., 2014b; van de Kaa, et al., 2014c) or consumer electronics (van de Kaa & de Vries, 2015; van de Kaa, et al., 2014c).

In total, 29 factors were identified, which can be merged in five general categories. The first category concerns the characteristics of the supporter of the technology. This includes factors like financial strength, brand reputation and learning orientation. The second category is about characteristics of the

⁶ Following Kaa, et al. (2011) dominance is defined as more than 50% of new installations use the technology for a significant amount of time to account for day-to-day fluctuations (van de Kaa, et al., 2011).

technology itself. This involves technological superiority, but also compatibility and complementary products. Third, the strategy used to win a battle influences the outcome as well. Pricing strategy, timing of entry and marketing communications will increase the market share. The fourth factor relates to other stakeholders: the number of units of the technology actually in use (installed base), a player exercising a lot of influence – also called a ‘big fish’ – and regulations. Finally, market characteristics impact the outcome as well. The bandwagon effect which implies when some users chose a technology others will follow, network externalities which implies the utility for a user increases when more users choose the technology and the numbers of options available (van de Kaa, et al., 2011). A full list of the factors identified by Kaa, et al. (2011) can be found in the appendices (APPENDIX I).

2.3 Reflection

In this chapter two literature streams are discussed. Cost literature mainly focuses on the estimation of costs and future extrapolation or prediction of these costs. Technology selection forces somebody to analyse the technology or product itself, the surrounding market it is in and other exogenous factors to determine factors that may influence the technology selection and dominance process.

Many of the TCO studies that are discussed in Chapter 1 (paragraph 1.2), use a similar framework as presented in Figure 3 and then apply either a top down or bottom up method. Therefore, the cost literature presented in paragraph 2 of this chapter may be straightforward.

The technology selection literature may not be directly related to cost development. However, it provides supplementary guidance to research which additional factors may be important for technology selection. Hence, these factors influence the product’s attractiveness and thus the technology’s adoption rate. Following the experience curve, if the adoption rate increases, the unit costs will decline.

Now these two literature streams are discussed, it is our expectation the TCO framework is not as simple as the one presented in Figure 3. Therefore, in this research we attempt to develop a more extensive TCO framework using these two literature streams instead of just one. This not only result in a framework that more accurately determines the TCO, but also identifies new factors and relations which may be important to the future of EVs.

3

METHODOLOGY

In this chapter the methodology of this research is discussed. This is briefly explained in the first paragraph. Then we go into the details and explain the unit of analysis, which is the entity that is analysed in this research, is established. Second, three ways of data collection are discussed. Third, criteria are set to judge whether a study is relevant, but more importantly, reliable enough to be used for this research. Furthermore it is explained how the interviews are used to verify the collected data. Finally the reliability and validity of this research are explained.

3.1 Methodology used in this research

In this research many “how”-questions needs to be answered. Therefore, an exploratory case study is used (Yin, 1994). A second reason to use case studies is their strength of generating novel theory (Eisenhardt, 1989). To some extent, at least, this is applicable since we combine two literature streams which is unique. The first research goal is to set up a new TCO framework using the two literature streams of cost literature and technology selection literature (Chapter 4). To our knowledge this has not been done before, so the goal is to compose an initial exploratory framework with factors and its relations. A combination of a desk research and interviews is conducted to achieve this. The literature of the desk research composes of the cost studies (first literature stream) and the technology selection studies (second literature stream). In addition, many building blocks (both factors and relations) can also be derived from other literature that focuses on EV development in general (refer to Table 6, fourth column). Therefore this is also extensively used. The interviews are a method to validate the initial results of the desk research and wherever necessary improve the framework. The final result is a comprehensive framework that represents the factors and relations affecting the TCO, which proves to give more insight in the TCO than previous studies.

The second research goal is to calculate a TCO for the 2015-2030 timeframe (Chapter 5). The TCO is used to determine which factors and relations are included in the calculations. Subsequently, a combination of open data and data from CE Delft is used to calculate the TCO from a consumer’s perspective. Multiple scenarios are used when the uncertainty is high. In addition, different user cases are taken to see the effect of government influences and driver characteristics. Finally, a sensitivity analysis is conducted to see the effect of individual parameters. The final result is a TCO development for the 2015-2030 period for a C-segment BEV compared to an ICEV reference case for multiple scenarios and cases.

3.2 Unit of analysis

The unit of analysis is the major entity that is analysed in a research study. Primarily, this level can be derived from the research question (Sekaran & Bougie, 2009; Yin, 1994). Based on the introduction, this means the unit of analysis in this research is on the car segment level, since we want to determine the average TCO range for a car segment. There are also numerous studies that have conducted research for a specific car model. In that case one would pick various car models and compare those to each other.

The advantage of the latter unit of analysis is that one has realistic, actual specifications of some car models, for example a Nissan Leaf. Most of the specifications like power, weight, price and fuel consumption are public and hence it is easy to compare different models.

The main disadvantage is that results based on just a few models are not generalizable. Within a model, there are still many variations due to the buyer options, which alter the specifications. In addition,

specifications for one particular car model are also difficult to extrapolate to the future, since one does not know if it can be used as a natural example for other models. Finally, in this research the focus is on the future TCO of EVs in general, not on the price competitiveness of individual models from a particular car manufacturer.

In short, based on the arguments above, the aggregation level of car segments would best fit this research. This means, if applicable, we used the average data of the cars within that particular segment to account for all cars in that class.

3.3 Data collection

The data for this research is collected in three ways. First, qualitative data collection is used for the first research question. Second, quantitative data collection is used, mainly for the second research question. Third, interviews are conducted for both research questions. These three forms of data collection is an iterative process to provide different perspectives, as is done more often in case studies (Eisenhardt, 1989). In this paragraph these three methods are discussed.

3.3.1 Desk research: qualitative data collection

In order to answer the first research question (*Which factors influence the total cost of ownership development of electric vehicles and what is the relationship between those factors?*), factors and their interactions need to be identified. One way to do this is to scan the literature and extract the factors from previous studies of Chapter 2 (both cost studies and technology selection studies). This is done from the narrow scale to a wide scale (Figure 5), starting with other cost- and technology selection studies. Next, we take a broader perspective by researching the uncertainties and barriers regarding the EV. Finally, we take a look at the EV landscape to identify more indirect topics, such as governmental policies and the future of mobility itself.

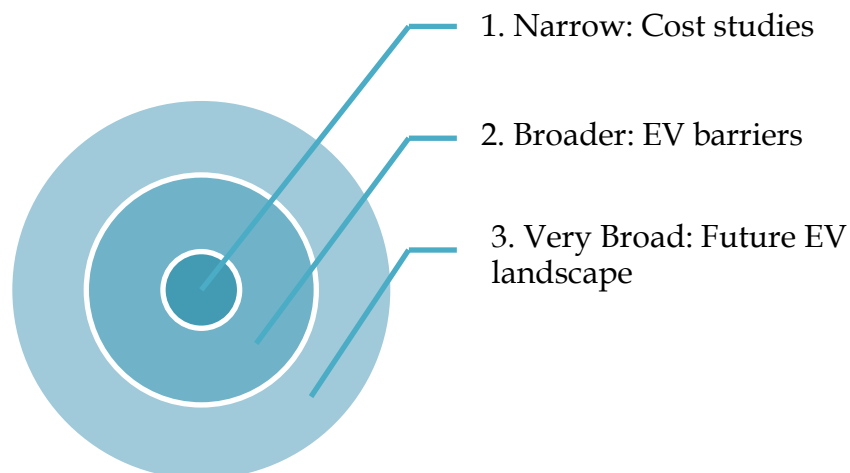


Figure 5: Visualization of this chapter: working from the inside out.

In APPENDIX II a list of keywords can be found, which are used for searching the literature. Google Scholar, Science Direct and Scopus are used to search for the scientific literature. Next to searching in the databases directly, we also use the so called snowballing effect. Starting from a very narrow perspective the bibliographies of these studies are used to find comparable studies and to find studies with a broader perspective. This process enables reference harvesting to widen the perspective and collect a variety of literature. Since much non-academic literature is cited as well in the peer-reviewed papers, we also include this 'grey' literature in our studies.

In total more than 120 sources are found. Of those 120 sources, just nine conducted future cost analysis for EVs (level 1, figure 3) and 14 studies researched barriers to EV adoption (level 2, figure 3). A table with cost studies is discussed in Chapter 1. A table with the barriers can be found in the appendices (refer to APPENDIX XIII). The remainder of the studies discussed (parts of) the EV introduction either

as part of a larger research scope, policy documents, non-academic web pages or contained quantitative data. This latter is discussed in the next subparagraph.

3.3.2 Desk research: quantitative data collection

The quantitative data is mainly used to answer the second research question (*How will the total cost of ownership of the electric vehicle develop up to 2030?*). There are one or two exceptions, in which quantitative data is used to support the arguments in Chapter 4. For these datasheets, e.g. the increase in supply of electric vehicle brand models, non-scientific data is used as there is no alternative. These applicable references are included in a footnote or appendix to the figures in Chapter 4.

For the data in Chapter 5, both scientific as well as non-scientific literature is used. This data is collected using the same method as explained for the qualitative data collection (3.3.1). For cost figures, the main focus is on cost studies about EVs or individual components. For non-cost related data (e.g. demand), other literature that focuses on a broader perspective is used. As there is not much scientific quantitative data available, the academic papers often refer to grey literature, which may be reports published by big consultancy firms or official institutions. Therefore, these studies are used for this research as well.

3.3.3 Interview set up

Interviews are used to validate the data from the literature and to verify whether all information was taken into account. Using the large professional network of consultancy and research firm CE Delft, we were able to set up interviews with experts in the electric vehicle market from various companies and governmental agencies.

Expert interviews are preferred since it is the best way to obtain the most recent information. This is important because the electric vehicle industry is in a rapidly changing environment. We prefer semi-structured interviews over unstructured interviews because the latter is mainly used for preliminary information gathering, while the former results in a more in-depth understanding about specific variables of interest (Sekaran & Bougie, 2009, p. 196). Since there is a clear set of questions to be answered based on the literature review, semi-structured interviews will provide in-depth knowledge of how the experts would cope with uncertainties and assumptions identified in the desk research. The experts' know-how is important, so a purposive sampling is applied to select the right experts. Nevertheless, experts from different disciplines with diverse positions in various organisations are interviewed to reflect the diversity of the population (Sekaran & Bougie, 2009).

Questions are tailored to the expertise of the interviewee, e.g. the focus for battery manufacturers is on the battery technology and less focused on for example maintenance of other car components. The preferred way to interview is face to face, but some interviews are conducted by a conference call on request of the interviewee and for the international interviewees. In total 17 interviews are conducted, of which three international (of which two via email).

Table 2: List of companies interviewed for this research.

Segment	Companies
Automotive branch	Renault, H-D Systems, GridCars
Charging infrastructure	Fastned, The New Motion
Knowledge organisations	ICCT, CE Delft, PBL, ANWB
Energy companies	Nuon
Insurance companies	Achmea, Meeus
Universities	TU Delft, TU Eindhoven, Hogeschool Rotterdam, Hogeschool van Amsterdam
Governments	City of Amsterdam

The list of semi-structured questions is distinguished between questions relating to the TCO framework (Chapter 4) and the cost/EV development (Chapter 5). Before the interviews were conducted, a preliminary TCO framework was developed based on the literature study. This framework is shown to all the interviewees (except interview 15,16,17 due to time constraints), either in a simplified version or the detailed one, depending on the background of the interviewee. For the other topics the focus is

tailored to the background of the interviewees due to a limited timeframe. A list of which topics are discussed with whom can be found in the table below (Table 3).

Table 3: Background per interviewee and the topics discussed during the interview.

Interview	Back-ground	Framework explanation	Vehicle technology	Battery	Maintenance	Charging	Demand	Depreciation
1	Science	In detail			✓			✓
2	Science	In detail			✓		✓	✓
3	Science	In detail		✓		✓	✓	✓
4	Automotive	Simplified	✓	✓	✓	✓	✓	✓
5	Charging	Simplified				✓	✓	✓
6	Government	Simplified				✓	✓	
7	Research/consulting	In detail		✓	✓	✓	✓	✓
8	Non-profit	Simplified	✓	✓			✓	
9	Energy	Not discussed			✓		✓	
10	Research/consulting	In detail		✓	✓	✓	✓	✓
11	Research/consulting	Simplified	✓	✓	✓		✓	✓
12	Science	Simplified				✓	✓	
13	Non-profit	Simplified			✓		✓	✓
14	Automotive	Not discussed	✓	✓	✓	✓		✓
15	Insurance			N/A: only insurance				
16	Insurance			N/A: only insurance				
17	Charging	Not discussed				✓		

All interviews containing more than three questions are recorded, which is agreed upon by the interviewee in all cases. The interviewees are told to express their own opinion, inform the interviewer if they simply do not know the answer to a certain question and that they are not obliged to answer in case of confidential information. The interviewees approved the summaries of the interviews by email. All information derived from the interviews is mentioned in the summary.

3.4 Data analysis

Once the data is collected, it was valued using a standard set of criteria and disregarded if necessary. In this section, the criteria and procedure of data analysis is discussed.

3.4.1 Desk research: qualitative data analysis

Qualitative data from the literature is obtained to answer the first research question. Studies that explicitly discuss factors that influence the TCO are incorporated to develop the TCO framework. For the selection of studies the following criteria are used:

- The study is not older than five years (>2010), since at that point in time the EV industry kicked in (IEA, 2015);
- The study attempts to provide a clear explanation why a factor is relevant;
- The study is preferably scientific, but at least recognized by the industry⁷.

When a factor that influences the TCO is found, it is extracted and explained in Chapter 4. Based on the original study, it is identified as directly or indirectly influencing the TCO and connected to any

⁷ Recognized by the industry means it is cited in an academic paper or published by an organization with a reputation in the field of energy or transport (e.g. the International Energy Agency).

other factors if applicable, also based on that particular literature source. If other studies argument additional relationships with other factors, it is connected as well. Finally, this results in a preliminary framework based on the desk research, which is validated and adjusted by means of expert interviews. A list of the studies used for each factor is shown and discussed at the end of Chapter 4 (Table 6).

3.4.2 Desk research: quantitative data analysis

In the previous paragraph (3.2) it is explained that quantitative data from the literature is obtained to answer the second research question. As mentioned, we also use non-academic literature, especially when there are not many studies available. The publication date is also less strict than for the first research question, since less cost studies are available. For the selection of studies the following criteria are used:

- The study is not older than ten years (>2006);
- The study attempts to determine its own cost calculations, i.e. not just referring to other sources;
- The study is preferably scientific, but at least recognized by the industry.

Some studies consider more than one scenario for the cost development of EVs, depending on e.g. demand or R&D investment. If there are more than four scenarios, only the most realistic scenarios as explained by the original author are presented in the analysis.

In order to distinguish the very relevant or reliable studies from the less relevant or reliable studies, we assess the studies on the following criteria:

1. Comprehensiveness: Scores high if the methodology is clearly explained, assumptions are mentioned, and when sources are made available if applicable. This increases the replicability of the study.
2. Scientific foundation: Scores high if the study is peer-reviewed, scores medium if it is acknowledged by a prominent well-known industry leader or consultancy firm and scores low if none of the above is applicable.
3. Date: Scores high when the study is more recent, since more recent data is incorporated and predictions have a better chance to be accurate.
4. Type of EV: if the type of EV is categorized, there is a better chance the data is reliable, since it is accounted for in the study.

These criteria are applied on all cost estimations in Chapter 5, unless stated otherwise. The criteria are summed to obtain an impression of the overall quality of the studies (by means of a +, +/- or -). More relevant/reliable studies have more impact in the final TCO calculations of this research, while less reliable studies are excluded. The exact methodology is explained per topic in Chapter 5, as the amount of data varies greatly among different topics.

The cost figures of the studies are compared with each other in Excel and presented in this report using graphs and charts. In order to compare cost estimations from different studies, the numbers are presented in Euros₂₀₁₅ and corrected for both inflation and currency exchange rates. If the base year of the study is not available, it is assumed to be one year before the date of publication. The inflation rates may alter between different products. If no specific inflation for a certain production can be found, the general inflation numbers are used. The inflation, currency and exchange rates used are included in the appendices (APPENDIX III).

3.4.3 Interviews: data analysis

The interviews are used for both the qualitative part (Chapter 4) and the quantitative part (Chapter 5). Regarding the former, the framework is shown (either simplified or detailed) and explained. If the interviewee agrees but has no comment, it is not explicitly included in the interview summary. If the

interviewee disagrees, wants to elaborate or wants to include a new factor/relationship, it is included in the summary. The related factors are underlined in the summary. If the new factor/relationship is supported by at least two interviewees, it is included in the final framework.

For the quantitative part, cost literature can be discussed with an interviewee, if he/she is considered to be an expert on the particular topic according to the table above (see Table 3). It is difficult to rely on specific cost data by means of interviews because many interviewees do not know exact cost curves either. If they do know, they usually do not want to share them because it is confidential information. Hence the data becomes very subjective. Therefore cost figures from the literature are discussed instead, and the interviewees are asked whether they agree. When a new number/figure is obtained from an interview, it is always verified during a second interview before using it. If the author is not sure whether the data is reliable, it is either not used or used in the form of multiple scenarios.

3.5 Validity and reliability

Triangulation is a method used to increase the validity and reliability of this research. Triangulation requires multiple sources or methods that lead to the same results (Sekaran, 2009, p. 384). In Chapter 4, method triangulation is used, since a desk research is conducted first. The preliminary results of that process are validated through interviews. This verification process increases the likelihood of the results being correct. In Chapter 5, the quantitative data is retrieved from multiple sources in different years and different settings, such as an academic setting or an industry focus. This data is also verified by means of expert interviews and is adjusted accordingly. In addition, if possible, different methods of calculating future costs are considered. For example the battery costs, of which data is extracted from the literature but it is also calculated using an experience curve. Finally, reliability is maximised by documenting all data, both quantitative and qualitative, and procedures taken ensure another researcher can replicate this research (Yin, 1994).

4

RESULT I: THE TCO FRAMEWORK

Many other cost studies (refer to paragraph 1.2) use a TCO framework like presented in Figure 3 (refer to paragraph 2.1), which only include the stream of cost literature to determine future EV costs. As already mentioned in Chapter 2, we argue there may be more at stake. Current TCO frameworks are very simplified and hence cannot be used without modifications and improvements. In order to do so, a second literature stream of technology selection theory is included as well. In this chapter these two streams are combined to develop a revised TCO framework which more accurately resembles real life situations, improving the TCO framework which is available in the literature up to now.

In this chapter the factors that influence the total cost of ownership of electric vehicles and the relationship between them are identified. At the end of the chapter, we conclude with a schematic overview that shows how the TCO and the identified factors are related. First, a basic version of the conceptual framework, at a high aggregation level, is presented and explained. This simplified framework is the foundation of the remainder of this chapter: each category is explained in a separate paragraph in which the individual factors are discussed based on the results of the desk research and the interviews. In the concluding paragraph the full framework is presented and the research questions are answered.

4.1 Introduction of the TCO framework

As explained in the methodology chapter of this study (Chapter 3), the identification of the factors influencing the total cost of ownership of EVs is done by means of an extensive literature review and interviews. In total 34 factors are identified, which may relate to the TCO directly or are connected to another factor which on its turn relates to the TCO. Various feedback loops between the factors are identified as well.

It may be an overload of information to show the final framework at once and hence difficult to understand the explaining arguments that support this framework. Therefore a simplified version of the framework, which is based on the final version, is developed. In this simplified framework interconnected factors are merged into categories. These categories are discussed and demerged again in the following paragraphs. At the end, the total framework is shown to provide the reader with total overview of the framework. So, instead of explaining the iterative process the researcher went through in order to develop the framework, rather the results are discussed based on the final framework in a simplified version.

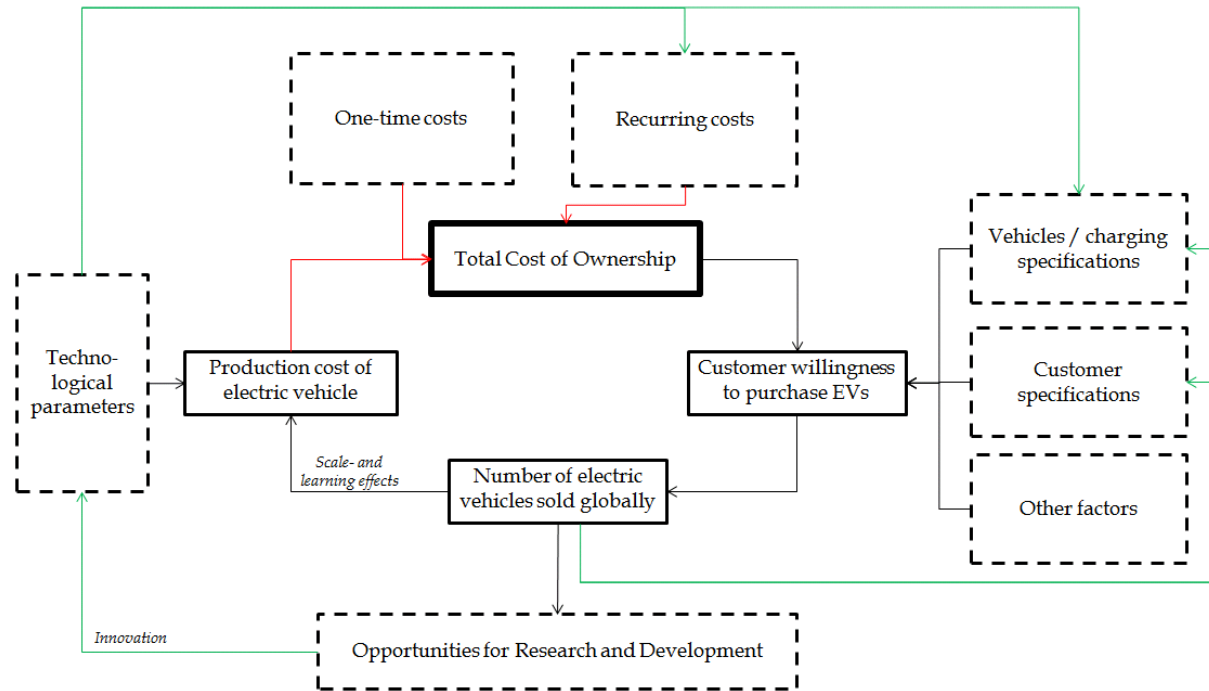


Figure 6: The simplified conceptual framework of influencing factors to the TCO.

The framework as shown in the figure above (Figure 6) is the simplified version of the final framework. In this figure the non-dashed boxes represent factors that influence the TCO directly or indirectly. The dashed boxes are categories, a group of multiple factors which are explained later in this chapter. Red arrows directly influence the TCO, while black arrows indirectly influence the total cost of ownership. Green arrows represent a connection between different categories or feedback loops.

It becomes immediately clear Figure 6 differs on many fronts compared to Figure 3. The upper part (One-time costs / Recurring costs) of Figure 6 incorporates all variables of Figure 3. Newly added variables are the customer's willingness to purchase EVs (on the right), the actual and anticipated demand figures (at the bottom) and technological parameters which influence production costs (at the left). As a whole, the figure includes multiple feedback loops, meaning there are reinforcing factors at work.

The central factor in this framework is the total cost of ownership, which is prominently presented in the figure. It may be possible this framework reveals new insights for other goals as well (e.g. the adoption rate of EVs or its future demand). In this research we only look at the effect of the factors on the TCO, not on its effect on other 'goals' (such as future demand).

In the following eight paragraphs the framework is explained piece by piece and reflected to the theory in chapter 2. In the next paragraph the effect of scale- and learning effects on the production costs are discussed.

4.2 Scale- and learning effects and production costs

The inner circle of the framework consists of four factors: the TCO, willingness to purchase, number of EVs sold and the unit production costs. Connecting these factors with one another basically represents the principle of scale- and learning effects as explained in Chapter 2.

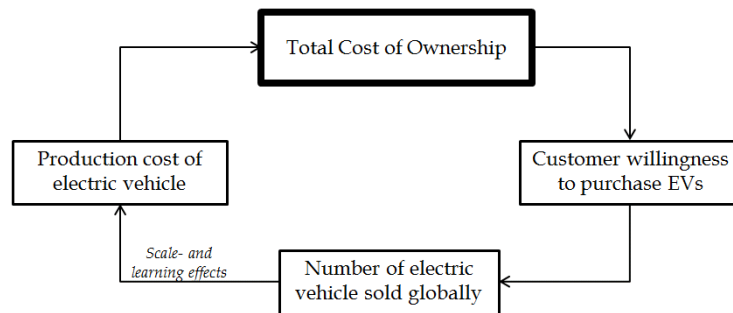


Figure 7: The inner circle of scale and learning effects.

In order to explain this inner circle (Figure 7), start at the total cost of ownership. Suppose the TCO declines, subsequently the attractiveness of the product will go up. Hence, the willingness to purchase an EV increases. When the attractiveness increases, more consumers will decide to acquire an electric vehicle. This means on a global scale the number of vehicles sold will increase as well, which means the installed base increases.

The relations between these three factors are supported by many studies, which argue the high price is the main barrier to EV attractiveness and adoption (Tsang, et al., 2012; Boulanger, et al., 2011; Brown, 2013; Perujo, et al., 2012; Cluzel & Lane, 2013). In one interview the interviewee conducted research to the EV adoption and explained that in case the price of an EV (and thus the TCO) would go down, more people would consider to buy one (Interview 10).

The principle of scale- and learning effects now learns the production cost, which is the fourth factor, of a single EV will decline, because of standardization, efficiency gains and more experience as explained in Chapter 2. The notion of scale- and learning effects to forecast future EV costs has been done in previous studies (Thiel, et al., 2010; Weiss, et al., 2012; Windisch, 2014).

The production cost may act as a proxy for the sticker price, so a decline in production will eventually result in a lower sticker price of the EV. This is also acknowledged by other studies (Weiss, et al., 2012; Palencia, et al., 2014; Contestabile, et al., 2011).

Some other studies which do not include cost calculations but discuss the introduction of EVs into our society also acknowledge scale- and learning effects to be an effect for TCO reduction (FHA, 2009; Green, et al., 2014; Wiederer & Philip, 2010; Sierzchula, et al., 2014; CE Delft, 2011; Hill, et al., 2015; Redelbach & Friendrich, 2012; ARF & McKinsey, 2014). In addition, in all interviews this principle was acknowledged by the interviewees (Interview 1-14). Some respondents think scale- and learning effects are the most important factor to cause a decline in the EV's total cost of ownership (Interview 2,4-10,12,14).

To conclude, scale and learning effects are of the most important notions that influence the TCO and therefore it is given a prominent place in the framework. This can be supported by (1) the fact that other cost studies to EVs also used scale- and learning effects, (2) many other studies acknowledge such effects to be important, (3) all interviewees acknowledge scale- and learning effects to be apparent for EVs and (4) 12 interviewees list scale- and learning effects to be in their top 3 list of factors that influence the TCO.

Besides production costs, there are other factors directly influencing the total cost of ownership of EVs. In the next paragraph, the category of one-time costs is introduced and discussed.

4.3 One-time costs

The first category is called 'one time costs' and represents costs that the EV buyer has to pay only once and other factors influencing such costs. The production cost of an EV is one of these factors, but is already discussed in the previous paragraph. The remaining factors are:

1. The profit margin, including pricing strategy and OEM competition;
2. The resale value;
3. Fiscal policies.

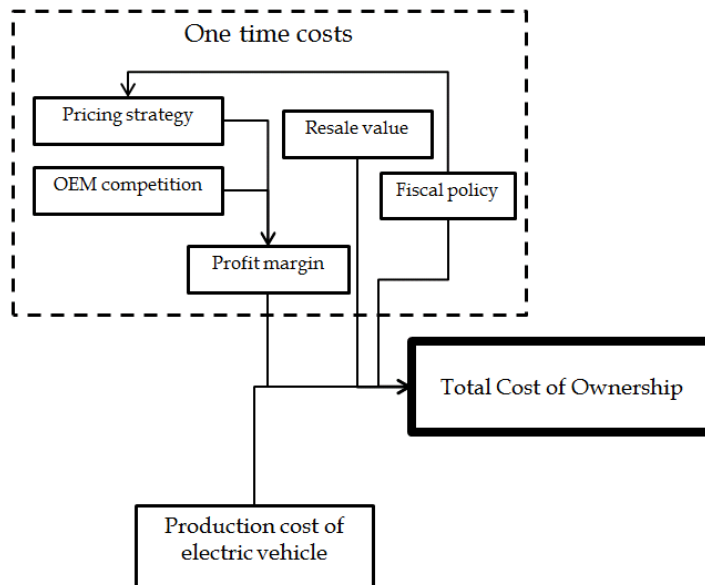


Figure 8: Category 'one time costs' and its relation to the TCO.

4.3.1 The profit margin

In the previous paragraph it is concluded the production cost acts as a proxy for the sticker price of a car. In reality it would be logical the manufacturer would add a mark-up which is the profit margin for the producer. The size of the profit margin is not found in the literature as it is confidential information and companies are not willing to disclose it. However, in one interview the interviewee mentioned a factor of 1,5-1,7 between production costs⁸ and selling price for ICEVs. For EVs, the interviewees estimate the factor is 1,0 or even 0,9 because the sticker price is a barrier to EV adoption (Interview 7,11). This is called a *pricing strategy*. Pricing strategy is also a factor that influences technology dominance as discussed in Chapter 2. Van de Kaa, et al. (2011) argues temporarily lowering the prices below costs is a strategy to build installed base and increase attractiveness (van de Kaa, et al., 2011). This trend is also acknowledged in other interviews although exact numbers are not known. It was expressed this cannot continue forever and such strategies are only temporarily. Therefore interviewees expect that either the sticker price increases or the production costs will decline more than the sticker price when a certain percentage of the market share is reached. At which point that will be and within what timeframe is unknown (Interview 10).

There is another factor that may increase pressure on the profit margin: more *competition*. Over the last 15 years only two new players made it on the list of the top 15 automotive manufacturers. But current trends show this might change. Mobility providers like Uber will try to capture the shared mobility market. Tesla, BYD and others are new car manufacturers which focus exclusively on EVs. Technology firms like Google, Apple and Dyson have announced to step in the automotive sector as well (Google, 2016; Wakabayashi, 2015; Shead, 2016). These trends may lead to new partnerships between traditional Original Equipment Manufacturers (OEMs) and new players and may increase the pressure on incumbent players. Hence, a change competition may also squeeze profit margins and increase the supply of EVs (McKinsey, 2016).

⁸ Production costs were defined as costs to produce the vehicle without R&D, overhead, marketing, etc. (Interview 11).

4.3.2 The resale value

The automotive sector has a large second-hand market in which petrol and diesel cars are traded among consumers. The price of these cars is approximated quite accurately due to the size of the market. For EVs the case is different: there are almost no EVs traded yet in the market. In addition, battery deterioration might decrease the value of the car as a whole significantly. Research to the resale value is not available (see paragraph 4.1) (Windisch, 2014; Wu, et al., 2015). Wu, et al (2015) uses a CPI index⁹ to estimate a resale price. He expects the resale value of BEVs to be up to a factor 2 compared to ICEVs in the average scenario because the retail price of the BEV is relatively high. Redelbach & Friedrich (2012) use the same depreciation rate for both ICEV and BEVs, based on an ADAC database¹⁰ but do not provide detailed information about how these numbers are extracted (Redelbach & Friedrich, 2012). Windisch (2014) on the other hand applies the same resale value for both ICEVs and BEVs, because:

“Resale values of EVs and their batteries will be subject to the still uncertain future offer of, and demand for, these vehicle.”

(Windisch, 2014)

In the interviews all interviewees with whom this topic is discussed agreed the resale value of current EVs is generally lower, mainly because of the uncertainty about the battery quality after e.g. 10 years (Interview 1-5,7,10,11,13,14). Other arguments are the relatively large improvements in technology, which leads to creative destruction (Interview 1-3,7,10) and the fact that current EV-buyers are not interested in second hand cars at all (Interview 2,3,10). Some interviewees expect this trend to stabilize in the direction of the normal ICEV in the future when the uncertainties is taken away (Interview 3-5,11) while others expect EVs to have a higher resale value than ICEVs because the maintenance costs are lower (Interview 1,2,7,13,14). One interviewee argues the conventional depreciation is not a good foundation for EV depreciation as e.g. Tesla updates their cars wireless. This means the performance of the car increases after one bought it. In addition, he expects that when there is a good second battery market, the battery might be sold to this secondary market (Interview 13).

It is difficult to conclude whether EVs have a better or worse depreciation rate. Some studies use a high resale value based on theoretical assumptions, while others ignore it because of a lack of real world data. In the interview everybody agreed the resale value is generally lower, but at the same time recognized that might change in the future. Whether or not this value is higher or lower will be discussed in Chapter 5, but for now we conclude the uncertainty hampers EV adoption¹¹.

4.3.3 Tax/Fiscal policy

When somebody buys a car, it is generally subject to different types of taxes, which varies per country. For the Netherlands, next to the general Value Added Tax (VAT) one has to pay a registration tax (also known as BPM).

If governments want to stimulate the use of EVs, for example for reasons as explained in Chapter 1, they usually use fiscal policies to promote EVs. This can be very effective, especially because the price is currently a barrier (as discussed in Chapter 1). In the Netherlands for example, people who buy an EV do not have to pay the registration tax (Tietge, et al., 2016). The USA provides a credit for EVs based on the size of the battery. The total credit is limited to \$7500 (IRS, 2016). Such direct fiscal policies directly lower the sticker price of the car and hence the TCO.

However, not all benefits may end up at the EV owner. According to one interviewee, the pricing strategy of OEMs is adjusted based on the country's fiscal policy. This means that the sticker price of an EV is higher when the tax credit is increased (Interview 1)

⁹ CPI is an acronym for Consumer Price Index, a factor that measures price changes of products and services for households.

¹⁰ ADAC is the biggest automotive club in Germany.

¹¹ Note that this research does not distinguishes the difference between lease and private car owners. For the former, the resale value may not applicable (Interview 1).

The one time costs have been discussed in this paragraph. In the next paragraph the reoccurring costs are discussed.

4.4 Recurring costs

The second category is called 'recurring costs' and represents costs that the EV buyer has to pay during the time he/she owns the car. This category consists of the following factors:

1. Charging costs, including energy consumption and electricity prices;
2. Maintenance;
3. Insurance;
4. Fiscal policy;
5. Discount rate¹².

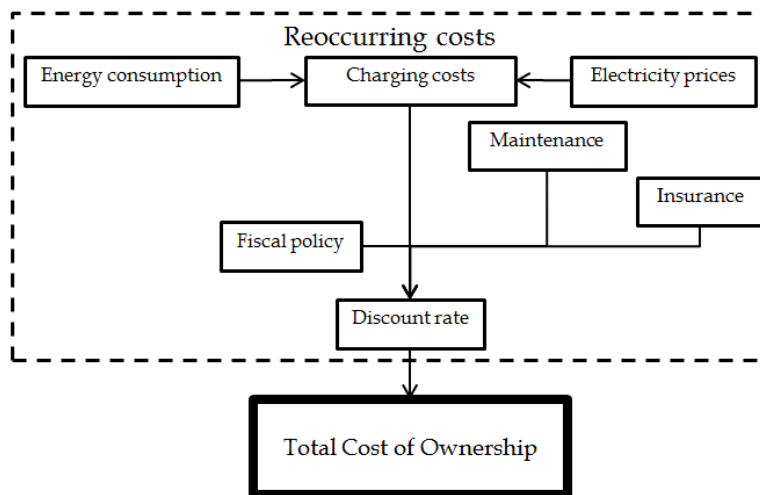


Figure 9: Category 'recurring costs' and its relation to the TCO.

4.4.1 Charging costs

Charging the EV is part of the TCO framework on two levels: First, one needs to pay for the electricity used, which is directly dependent on the energy prices as depicted in the figure above. Second, the amount of electricity required for driving one kilometre depends on the energy consumption of the vehicle.

Compared to ICEVs which are usually refuelled at a petrol station, recharging an EV can be done at any location along the electricity grid. In this study charging is distinguished in two functional categories:

1. Residential / workplace chargers;
2. Public charging points.

ad 1. Residential / workplace chargers

Home charging requires a garage or private parking next to the house in order to plug in. About 25% of the people have a garage in the Netherlands of which most of them live in the rural areas (Interview 5,6,12) (Nemry & Brons, 2010). The price paid is the electricity price for the consumer. One interviewee expects this to decline (Interview 5), while others argue it will increase (ECN, 2015). In addition,

¹² Although the discount rate may not be an expenditure from a consumer's perspective, future costs are discounted and it influences the TCO. Therefore it is included in this framework.

charging infrastructure must be acquired and installed. This is a one time premium for the consumer, for example when a home charger is acquired.

ad 2. City public charging points

Public charging points are usually exploited by commercial parties, the investment costs of public charging are not a direct input for the TCO of the EV owners. However, such commercial parties need to recoup their investment, which leads to premium on the electricity price. Currently the government provides subsidies for these charging points, so it is difficult to predict what the future prices for EV owners will do (Interview 6). Some expect these to decline (Interview 5) because of economies of scale and high utilization rates, while others expect these to go up once subsidies stop (Interview 12).

For both ways of charging the government plays an important role as well. Next to subsidies for charging point on a local level, much of the energy costs consist of different forms of taxes which are set by the national government (Interview 5). In the cost development section (Chapter 5) the costs are reviewed and incorporated in the TCO.

4.4.2 Maintenance

Costs are involved regarding expected maintenance and unexpected repairs. This is a recurring cost and applicable for both EVs and ICEVs. However, the maintenance costs of an electric vehicle could potentially be lower compared to conventional cars. This is because an EV, and BEVs in particular, has less movable parts and the construction of the powertrain is less complex (Cleary, et al., 2010; van Vliet, et al., 2010; Windisch, 2014; Crist, 2012). Other reasons why EVs are faced with lower maintenance costs is because electric motors have less running hours because there is no idle mode and EVs have less wearing on the brakes with the introduction of regenerative braking (Cleary, et al., 2010). This was also acknowledged by the majority of the interviewees (Interview 1,2,4,7,10,13,14). One interviewee responded that this benefit only starts after several years, since in the beginning ICEVs are rarely subject to maintenance as well (Interview 11). This is confirmed in Interview 13.

However, there are counter arguments as well. The biggest problem to calculate the benefits is the lack of available data (Interview 2,10). Some studies therefore neglect potential benefits and use similar maintenance costs as ICEVs (Palencia, et al., 2014; van Vliet, et al., 2010). Also, the costs mentioned above are usually considered as scheduled maintenance costs. Since the technology is still immature, there is no data about unscheduled costs. Hence, these costs could potentially cancel out some of the benefits (Cleary, et al., 2010). Another concern is battery deterioration that potentially leads to the replacement of the pack after a certain amount of years (CE Delft, 2011).

Some expects the maintenance costs to decline in the future as technology matures, the maintenance schedules are optimised and increased maintenance competition (Interview 2,4,14).

4.4.3 Insurance

Insurance costs are reoccurring costs that one has to pay every month or year to provide financial protection against physical injuries or car damage from e.g. car accidents. Insurance fees are based on the sticker price of the car, the weight of the car and the expected miles driven (Interview 15,16).

Three cost studies incorporated insurance costs in their calculations (Crist, 2012; Windisch, 2014; Wu, et al., 2015). Windisch (2014) applied a 20% reduction for BEVs and a 20% increase for PHEVs compared to ICEVs, based on some insurance offers in France. No arguments are given for these adjustments. Crist (2012) did not apply a price differential between EVs and ICEVs since there is no reason to believe there should be. Wu, et al. (2012) did not explain how the costs are built up.

Since the acquisition price of an EV is generally higher than an ICEV, the insurance fees increase as well. Based on two interviewees who work with a Dutch insurance company, there is no reason to assume insurers use different rates than ICEVs. The insurance fees are based on sticker price, weight of the car and characteristics of the owner (e.g. expected kilometres a year driven). This means when

the sticker price and weight of an EV equals the ICEV, the fee should be similar as well. This interviewee at the insurance company has no reason to believe this will change in the future as more EVs will be introduced, unless self-driving cars are introduced (Interview 15). This is confirmed in an email from another insurance company (Interview 16).

4.4.4 Tax/Fiscal policy

Just like in the one time costs category, several taxes exist for owning or using a car. In the Netherlands, this involves a road tax and a tax on private use of a company car.

In order to stimulate the introduction of EVs, there are tax benefits for Dutch EV owners as well. The company car tax, a taxable benefit arising from private use of company cars, is also lower (4%) than for ICEV (14%-25%). In addition, people owning a BEV do not have to pay road taxes and PHEV owners only pay half (Tietge, et al., 2016). Government policies in general will be extensively discussed in subparagraph 4.7.1.

4.4.5 Discount rate

If one compares future expenditures with present expenditures the former are mathematically discounted. This is because of the notion of 'marginal rate of time preference', which argues money available right now is worth more than the same amount in the future even when inflation would be absent (Boardman, et al., 2011). Once the discount rate is increased, the future amount of money is worth less in the present.

Tsang, et al. (2012) mentions the time value of money is also applicable for EVs. First, consumers place low value on future savings and secondly research has shown consumers have difficulties to understand the fuel/energy benefits. EVs have lower operating costs than ICEVs but this benefit is not recognized yet by consumers (Tsang, et al., 2012; Windisch, 2014). Also, even if EVs are cost competitive with conventional cars, the EV will still face an uphill battle since consumers are used to ICEVs (Brown, 2013).

The need for a discount rate is discussed in the interviews as well. Some interviewees mentioned that especially consumers value future benefits less than current benefits. According to some interviewees, an e.g. break-even point of seven years is already too long and will not convince consumers to switch an ICEV to an EV (Interview 1,5,6,10).

Different discount rates are used in the literature. Lee & Lovellette (2011) for example use a 15% discount rate in their average scenario and a 30% discount rate in their more extreme scenario (Lee & Lovellette, 2011) (Interview 11). Windisch uses a 4,8% real discount rate (excluding 1,7% inflation), which is based on the long term costs of 5-year loans (market interest rate). Others use a 4% to 5% discount rate as well (Crist, 2012; Thiel, et al., 2010; Weiss, et al., 2012; van Vliet, et al., 2010).

All recurring factors are discussed. All factors up until now directly influence the total cost of ownership of the EV owner. For the next three categories, factors are discussed that indirectly influence the TCO by means of a change in willingness to purchase.

4.5 Vehicles / Charging specifications

As mentioned earlier, costs of a car are an important parameter that affects the willingness to buy. However, costs are not the only aspect. An electric vehicle and the supply equipment rely on different techniques than a conventional car and this also influence the attractiveness. Six factors are identified:

1. Range;
2. Charging infrastructure;
3. EV performance;
4. ICEV performance;
5. Variety of EV models;
6. Emission regulations.

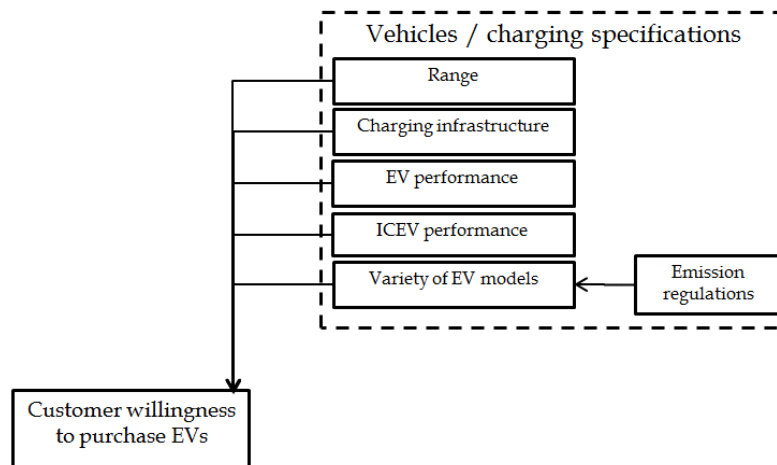


Figure 10: Category 'vehicles / charging specifications' and its relation to the willingness to purchase.

4.5.1 Range

The range of an EV is significantly lower than the range of a conventional car. The inferior battery performance, especially regarding the amount of energy it can store, limits the range of the electric vehicle (Axsen, et al., 2010; Elkind, et al., 2012; Brown, 2013). This lack of performance results makes the car less attractive for prospective consumers (Perujo, et al., 2012; Cluzel & Lane, 2013; National Research Council, 2013; Steinhilber, et al., 2013). Progress in battery technology will increase the electric range of EVs (Nemry & Brons, 2010; ARF & McKinsey, 2014). Nevertheless, the advertised range is significantly lower than the actual range because of driving patterns, less regenerative braking, use of air conditioning and environmental (weather) circumstances (Windisch, 2014). Based on the literature review, the range is together with the high purchase costs the biggest barrier to EV adoption (refer to APPENDIX XIII, as will be discussed later on).

The interviews support this problem. The majority of the respondents argues the physical range limits the introduction of EV (Interview 1,4,6-9), and three of them rank range in their top 3 hampering effects (Interview 1,6,7,10). Many interviewees argue the inferior performance is the main reason why consumers tend to buy a PHEV or EREV instead of BEV. If the range would increase, the market potential of PHEVs/EREVs becomes smaller because of the complexity of a dual system. However, whether the range will really increase in the upcoming decades is hard to tell, among others because a decrease in battery prices can lead to a trade-off between a direct decrease in sticker price or an increase in range. Some interviewees express they expect the range to increase to more than 250-350 km and then the prices will fall (Interview 3,6-8).

For the popular BEV models of which some data is available, the range is plotted over time (Figure 11). In this graph the EPA range is used¹³, which is a standard in the USA for combined city and highway driving (EPA, 2016). In the lower and medium segment, the advertised range increased from about 115 km range to 175 km range in 2016. For four models the estimated range is not EPA tested yet (marked by shaded dots). In the high E-segment (e.g. Model S) the range remains quite constant.

¹³ EPA range estimates are considered to be more accurately representing real-world driving patterns than European NEDC range estimates. Therefore, EPA data is used throughout this report.

The original datasheet can be found in the appendices (APPENDIX IV). To conclude, although the range hasn't been increased a lot between 2011-2014, it seems to accelerate in the recent years and years to come. This supports the arguments that the range will increase in the next few years. There is no data for 2018 models yet.

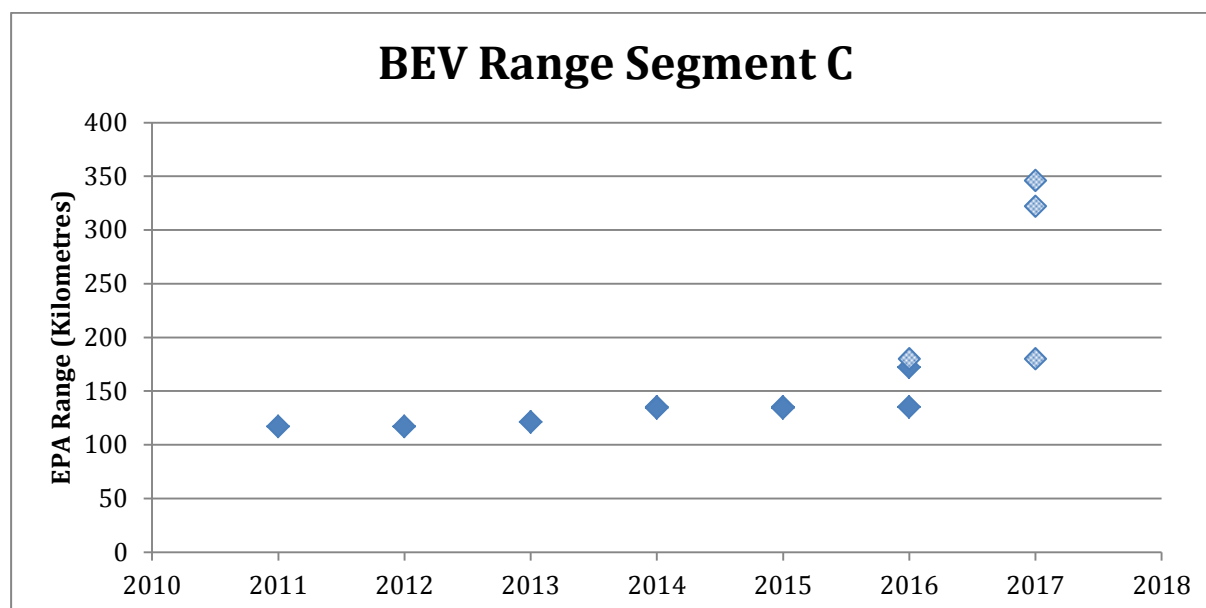


Figure 11: Range of C-segment BEVs over the course of time (includes LEAF, e-Golf, Bolt, Model 3 and Ioniq Electric). See APPENDIX IV for the literature references.

4.5.2 Charging infrastructure

The global amount of charging points is increasing. Globally, in 2012 only 46.000 'slow' charging points were installed. By 2014 this increased to 940.000. The number of level 3 fast charging is also speeding up, to 15.000 by 2014 (IEA, 2015). A detailed discussed of the different types of charging levels is included in the appendices (APPENDIX V).

There seems to be a relation between the amount of charging points and the EV adoption rate. A study by Sierzchula, et al. (2014) concluded the amount of points had a significant impact on the number of EVs, though the results between nations are widely varying (Sierzchula, et al., 2014). This is the main argument for many nations to stimulate the acceleration of charging spots in a country. Yet, there are some barriers regarding charging divided into four categories:

1. Limited number of charging stations;
2. Lack of standards and regulation;
3. The future of charging;
4. EV charging is a hassle.

ad 1. Limited number of charging stations

The infrastructure of charging points is currently very limited, which offers no solution for consumers experienced to range anxiety (Windisch, 2014; National Research Council, 2013; Elkind, et al., 2012). Especially fast charging opportunities are limited compared to conventional gas stations. To cite Tsang, et al. (2012):

"Consumers are reluctant to purchase vehicles that cannot be easily fuelled, and fuel providers are reluctant to provide a service for vehicles that do not exist."

(Tsang, et al., 2012)

Charging stations are a complementary good to EVs and hence indirect network effects play an important role here according to technology dominance scholars (van de Kaa, et al., 2011; van den Ende,

et al., 2012). Though, this could be a perceived barrier, since the utilisation of charging stations remains fairly low. Electricity itself is widely available in advanced countries but might be lacking in some emerging countries (Cluzel & Lane, 2013).

ad 2. Lack of standards and regulation

If there are no standards, attractiveness of the EV declines. The network of petrol stations is very flexible: the pumps being used are standard, every car can be refuelled at any gas station and there are only limited types of fuel. In the electricity market the exact opposite takes place: there are no regulations for charging points, there are different types of chargers, no clear standards for the charging points are available and there is no widespread availability of fast charging. Especially the lack of interoperability of charging hampers the EV adoption and attractiveness (Boulanger, et al., 2011; Nemry & Brons, 2010; Steinhilber, et al., 2013). So, based on the theoretical notion of technology dominance in Chapter 2, it seems the automotive sector is locked-in regarding gas stations and a standard battle is ongoing in the charging industry in which compatibility is not yet reached (van de Kaa, et al., 2011). A more detailed explanation of the standards is explained in the appendices (APPENDIX VI).

ad 3. The future of charging

Although the plug type war seems to be settled, some other charging technologies might compete in the future. Battery swapping was initiated a few years ago, but the leading company for this technology filed for bankruptcy in 2013. Induction charging is another alternative method, in which physical sockets are replaced by wireless induction charging. Various pilots started this year. Finally, charging could be complemented by the so called smart grid, in which the energy grid is balanced and EVs act as a buffer. This could potentially save costs. A detailed description of these three technologies can be found in the appendices (APPENDIX VI).

As was evident from the interviews, the future of charging has not been mapped out yet. If one assumes the hypothetical situation that the automobile stock consists mainly of EVs, how will the future charging system look like? Some argue it is easily possible to increase the charging points in e.g. Amsterdam from 2.000 to 4.000, but it becomes difficult when every parking place needs one (e.g. 200.000) (Interview 6,12). Another interviewee does not see that as a potential problem (Interview 8). Some think fast charging is the only alternative and think fast charging will be the primary way of charging (Interview 5). Others indeed agree fast charging could be an option (Interview 3,10). But some think public charging becomes the standard, while fast charging is more or less an 'emergency' option (Interview 6-8). They argue one of the benefits is 'convenience charging', the fact that you can charge while not using the car, so therefore home charging will remain dominant in combination with public charging (Interview 3,6-9,14).

ad 4. EV charging is a hassle

Many interviewees claimed a better charging infrastructure is key to increase the adoption of EV (Interview 1-4,10,13). Following from the two issues above, it results in quite a hassle to charge an EV. This includes looking for a charging spot, a long recharge time and sometimes moving the car when it is recharged.

Especially the long recharge time of EV is backed by academic literature (Tsang, et al., 2012; Boulanger, et al., 2011; Perujo, et al., 2012; Steinhilber, et al., 2013). A slow charging point (e.g. an electricity outlet used in households) will entail battery charging up to eight hours depending on the battery size (Windisch, 2014). The interviewee of Fastned expects the amount of fast charging point to increase the upcoming years. The power output of a fast charging point will also triple from 50 kW to 150 kW in the next two years. In five years they expect to upgrade up to 350 kW. Then it would only take a few minutes to fully recharge the car (Interview 5).

Other respondents question this issue, since unlike you have to charge the car while using it (just like refuelling the ICEV), one can charge it when not using it and therefore the charging time becomes less important (Interview 6,7,9).

So in order to increase the amount of charging points, investment is needed. However, (public) charging points require a considerable amount of investment and are faced with the typical 'chicken-and-egg' problem: customers will not buy EVs until there is a dense charging network, but investors do not want to invest in charging points as long as there are no EVs (Green, et al., 2014).

4.5.3 EV performance

Technological superiority is one of the factors that may lead to technology dominance (van de Kaa, et al., 2011; Suarez, 2004; van den Ende, et al., 2012; van de Kaa, et al., 2014; Schilling, 2002). Although the technology selection scholars do not explicitly discuss EVs, logically this means that EV performance could play a role as well since it represents technological superiority relative to the ICEV performance. However, this factor is hardly discussed in the EV literature. Some interviewees argue the superior driving experience is a reason for consumers to consider an EV (Interview 1-3,6,7). The acceleration rate of an EV for example is higher compared to an ICEV. In addition, from a social perspective the car makes less noise. This can be a positive effect since car nuisance is considered annoying (Interview 6). It could also be considered dangerous because of a potential increase in accidents. However, according to an EV expert this is not part of the debate anymore (Interview 2). Another interviewee told that based on a survey he conducted, there is a significant amount of EV owners that prefer the performance of an EV compared to an ICEV. He also argued that nobody had foreseen this additional benefit (Interview 3).

4.5.4 ICEV performance

Although not actively discussed in most of the interviews, all interviewees recognized the ICEV performance influences the willingness to purchase because a consumer will compare the disruptive EV technology to the status quo ICEV technology. If ICEV technology progresses fast, e.g. in terms of fuel consumption reductions, it may become harder for EVs to gain market share (Interview 2,4,6,7,10,11). A detailed research on ICEV technology is not within the scope of this research, but the fact it plays a role has to be incorporated in the framework.

4.5.5 Variety of EV models

The supply of electric vehicles in terms of vehicle segments and brands is still limited. Brand loyalty is strong among car buyers due to perceived reliability and the owner's identity construct. An increasing number of car manufacturers bring an EV to the market, but still only a limited amount of EVs are available (Cluzel & Lane, 2013; Windisch, 2014).

Yet, only two out of 14 studies mentioned the variety of models has a hampering effect. According to an interviewee the literature often forgets this rather important issue, according to him (Interview 1). Other interviewees explicitly mentioned the variety of models is important, because consumers simply want something to choose (Interview 2,6,7). The other interviewees agreed with the factor as it is shown in the framework (Interview 3,4,8,9,10). The figure below (Figure 12) shows the number of BEV models in production worldwide. This number seems more optimistic than reality proves to be, because it involves all models and types on a global scale. At the same time, in 2015 just two C-segment BEVs were for sale in The Netherlands.

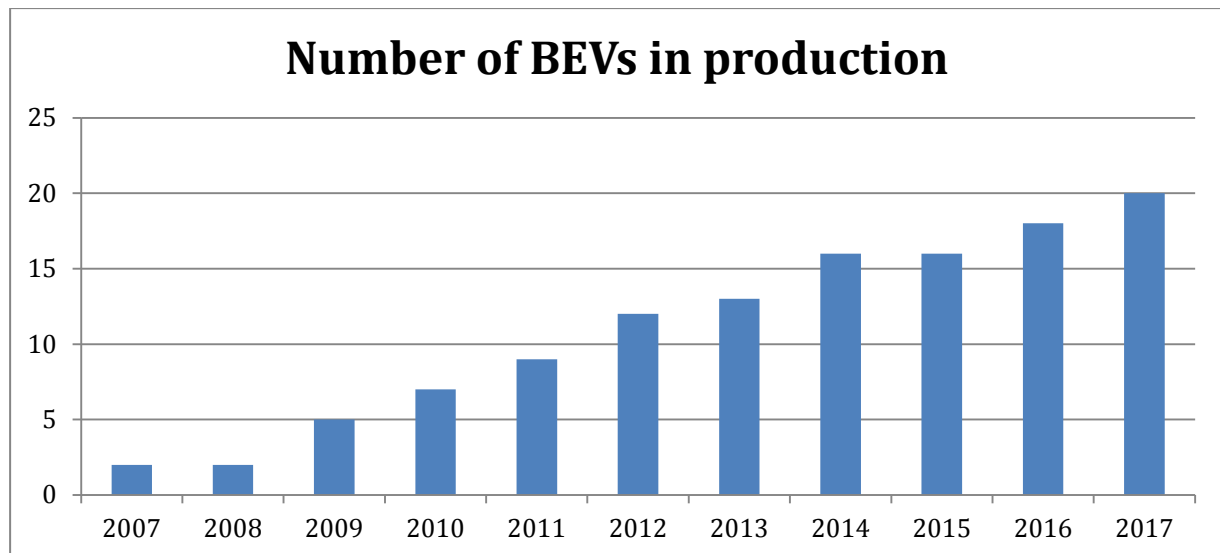


Figure 12: Number of BEVs in production worldwide (all segments). See APPENDIX VII for the datasheet.

4.5.6 Emission regulations

International emission regulations may force the industry to scale up EV production and promotion. The influence of regulations on technology selection is also mentioned in technology selection studies (van de Kaa, et al., 2011). There are for example international regulations on emission targets for the transport sector. In 2015, fleet average CO₂-emissions must meet 130 g/km in the European Union. By 2021 this target has to be declined to 95 g/km. Post-2021 targets are still in progress. The US have adopted similar regulation – though a little bit less strict – and already set a target of 89 g/km for model year 2025 (DieselNet, 2015). If producers have a certain target below the average ICEV, producers are forced to either reduce the price of an EV or increase the price of an ICEV. The former is only a temporary effect, as current EV prices are already close to the production costs (refer to 4.3.1). Another possibility is to increase the variety of models in order to provide the consumers with more options which also lead to a CO₂ reduction for the average car fleet (Interview 5,7).

4.6 Customer specifications

Next to the factual and objective specifications of vehicles and charging, subjective and perceptions of consumers play a role as well. These are outlined in this paragraph and divided into the following factors:

1. Customer understanding;
2. Symbolic and affective motives;
3. Range anxiety;
4. Income elasticity;
5. Bandwagon effects.

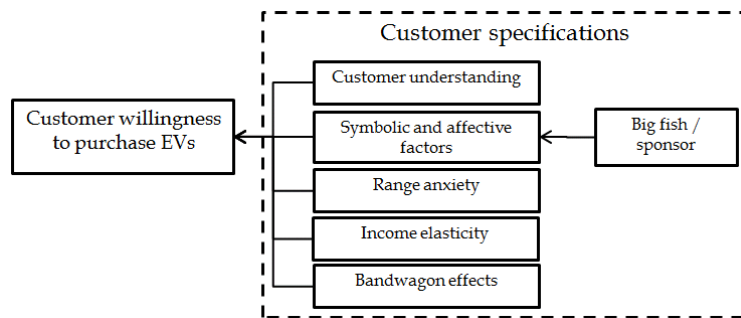


Figure 13: Category 'customer specifications' and its relation to the willingness to purchase.

4.6.1 Customer understanding

The acceptance of a new product or technology is not only determined by the performance of that technology, but also of the perceived performance by the customer (Muller-Seitz, et al., 2009). In order for a customer to accept the technology, they need to understand it (Interview 2,3,7).

The literature identifies a lack of consumer understanding, meaning many people are unfamiliar with the technology which prevents them from buying an EV (Elkind, et al., 2012; Boulanger, et al., 2011). This is confirmed by Cluzel & Lane (2013), who distinguished technology 'enthusiasts' from the mass market. While the former is willing to pay a premium, the latter group is concerned regarding reliability and will only switch to an EV once it is a proven concept (Mohr, et al., 2010).

This is confirmed in the interviews. There are negative associations with EVs: consumers do not know how to find a charging point, or whether or not it takes a lot of time to find one. Also, some people do not know how to install a charging point at home. According to some, the perceived hassle is bigger than the actual hassle (Interview 2,3). This lack of understanding can be taken away. A few years ago many people raised concerns about the safety of EVs, for example because the car makes less noise and what would happen if an EV would crash into water. Two interviewees explicitly mentioned the way consumers look at EVs has changed significantly. Nobody is raising any concerns about such issues anymore (Interview 2,3). It was argued transparency is key in such cases, for example to provide objective EV performance information to consumers. The EPA system in the US, which labels each car with information about the TCO and range, is a very good example (Interview 2).

4.6.2 Symbolic and affective factors

Rather than instrumental functions (a car brings you from A to B, enabling activities), Steg (2005) argues there are symbolic and affective functions as well. Symbolic functions are a way to express yourself or your social position. One can also compare his/her car with others, which may provide status or set the social norms. Affective motives are the emotional part of driving, for example the fact that driving affects somebody's mood or joy (Steg, 2005). Based on the interviews, it seems the image of the EV is important. The first EV owners were willing to pay a premium price because of environmental awareness, but an EV was considered 'nerdy'. In the last few years the image of the EV changed from 'nerdy' to a 'cool' product (Interview 3).

"Using a car is more than a means of transport."

(Steg, 2005)

This shift might to a large extent be attributed to Tesla (Interview 3,12). Tesla actually changed the image of the EV by its strategy to first focus on a high performance sports car and subsequently focus on the mid end segment (Interview 3). Tesla's position as sponsor seems to continue, as they received already 400.000 pre-orders for their new Model 3, a car that is not expected to be released before the end of 2017 (Warren, 2016). Although there is no quantitative evidence, it seems likely Tesla's strategy translates in a higher attractiveness of EVs in general. This was also acknowledged in the interviews (Interview 2,3,7,10,12). In line with technology dominance studies this factor is called a *Big Fish*: a

player that can exercise buyer power and influence the attractiveness of the technology (van de Kaa, et al., 2011).

"Electric car used to have a very dull image 20 years ago. The sex appeal of EVs dramatically increased because of Tesla."

(Interview 12)

4.6.3 Range Anxiety

Range anxiety is not the same as the actual EV range, but refers to the psychological fear of being stranded (Hacker, et al., 2009; Boulanger, et al., 2011; Azadfar, et al., 2015) (Interview 1,3,7). Some (potential) EV drivers experience the range anxiety, in which they will drive extremely cautious or are not willing to buy an EV because of the fear of a depleted battery (Tsang, et al., 2012). Rationally seen this is a misconception: 75% of the trips do not exceed 160 kilometres. This means the majority of the trips can be driven on a single charge. Yet, consumers tend to buy a car based on the maximum usage, not on the average usage (Boulanger, et al., 2011; Windisch, 2014) (Interview 3).

Meanwhile, the utilization rates of charging points remain fairly low, especially those along the highway (Green, et al., 2014). This is because, for example in Germany, about 90% of the daily car travel length is less than 50 kilometres, which can easily be reached between two charges.

Range anxiety might be resolved by either an increase in range or more charging points. This is confirmed by the literature, who argues a dense public charging network might not be a technical prerequisite to the emergence of the EV market but due to consumer perception is necessary for mass market adoption (Cluzel & Lane, 2013; Nemry & Brons, 2010).

4.6.4 Income elasticity

Based on a study of PBL and CE Delft, income elasticity plays a role as well whether consumers are willing to pay more for a car. This notion of income elasticity of demand argues that when somebody's income increase, the costs of owning a car increases as well (Geilenkirchen, et al., 2010). This is confirmed in the interviews as well. Once the income goes up, the willingness to pay increases as well (Interview 1,7,10). One interviewee acknowledged the relation to income elasticity and willingness to purchase, but also mentioned he expects this effect to remain very small for the upcoming 15 years because the average welfare will not increase significantly (Interview 7). The extent to which the willingness to purchase increases is unknown, since the case of EVs might be different than for conventional cars. In the PBL report the proportion for costs to own a (conventional) car is estimated at 0,32 on the short term and 0,81 in the long run (Geilenkirchen, et al., 2010).

4.6.5 Bandwagon effects

The bandwagon effect refers to the phenomenon that when some consumers acquire a certain product, others will also be more inclined to buy the same product. As discussed in Chapter 2, this effect contributes to the dominance of a technology (van de Kaa, et al., 2011). The interviews confirmed this applies for the adoption of electric vehicles as well (Interview 3,5,10). Fastned even thinks this effect will contribute to what they call the 'smoking'-effect: it will become socially unacceptable to drive in an ICEV simply because there are cheaper and cleaner alternatives in the future just like it is socially unacceptable to smoke in public areas nowadays (Interview 5). As the co-founder of Fastned mentions in a blog:

"Now, try explaining to your neighbors that you have again chosen for a noisy, noxious diesel car which damages the health of their children. The more electric cars on the road, the higher the social pressure on internal combustion engines."

(Langezaal, 2015)

4.7 Other factors

Three factors that are extracted from the literature and interviews did not match any of the categories above and will be discussed in the miscellaneous group:

1. Government policies;
2. Institutional factors;
3. Change in mobility landscape.

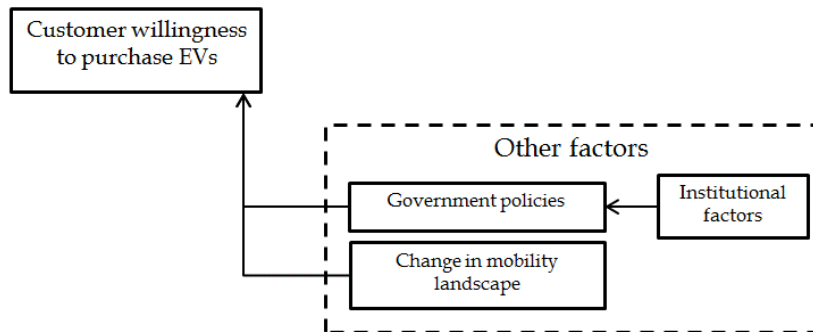


Figure 14: Category 'other factors' and its relation to the willingness to purchase

4.7.1 Government policies

The box 'government policies' in the figure above is defined as all non-fiscal policies, since the latter were already discussed in the previous paragraphs. There are various options of non-fiscal policies, especially for regional and local governments. The city of Amsterdam for example stimulates full-electric taxis by giving them a priority queue at the taxi stand. From 2021 only BEV taxis are allowed at taxi stands near the central station. Individual consumers also get priority for a parking permit in Amsterdam if you acquire an EV. The municipality also stimulates to increase the number of charging points in the city (Interview 6) (Gemeente Amsterdam, 2016).

On the national level, sometimes politicians call for more ambitious government support for the EV. The Indian government is working on a program to become a 100% electric vehicle nation by 2030, according to Power Minister Piyush Goyal (Economic Times, 2016). The Netherlands have set ambitions to exclusively sell zero emission vehicles (EVs or hydrogen cars) by 2035 in the 'Energieakkoord' (SER, 2013). In addition, the labour party in The Netherlands (Partij van de Arbeid), published a document which proposes to ban new ICEVs from 2025 on (Vos, 2016).

Whether such statements become reality anytime soon is to be seen. Nevertheless, such ambitions can contribute to policies that benefit EVs over their alternatives. More strict regulation will force OEMs to focus on EVs because ICEVs' production costs become more expensive, which will increase the supply and the associated scale economies for EVs (Davies, 2015).

The most recent 'Diesel Scandal'¹⁴ might also affect the EV boost indirectly. Some non-scientific sources think the testing procedure will represent real-world driving emissions instead of test drives. This will make it more difficult for manufacturers to comply with the regulations (Voelcker, 2015; Davies, 2015).

According to some interviewees, government policies are very important for the success of EVs as it is not a self-supporting business yet (Interview 6,10-12). Others are more certain EVs will be the future, but acknowledge the speed of EV adoption is very dependent on government policies (Interview 5).

¹⁴ In 2015, it was revealed Volkswagen had implemented special software with recognized a 'test drive', in which less emissions were emitted (Houtekamer, 2015).

4.7.2 Institutional factors

Tsang, et al. (2012) argues institutional factors are a barrier to EVs. In the past, the EVs experienced resistance from car manufacturers and companies operating in the fossil fuel industry, hereby influencing political decision making. They promote the status quo and attempt to influence policy makers and the general public. There are notable examples in which regulations were relaxed due to lobby activities of the industry, e.g. the California zero emissions mandate of 2001 (Tsang, et al., 2012). Although there is no scientific evidence this still happens today¹⁵, there are suggestions a \$10 million campaign is launched to attack EV subsidies and promote the petroleum industry in 2016 (Stone, 2016). Institutional factors are also recognized in the interviews and can influence government policies and emission regulations (Interview 1-3,7,10). According to one interviewee, the big automotive companies do not want to change because they have heavily invested in the ICEV technology (Interview 2). Some interviewees however argue not all companies of the automotive industry are against EVs, so it can also have a positive effect (Interview 1). Vice versa, institutional barriers could potentially also favour EVs over ICEV instead of the other way around. Lobbies like these don't have to be effective in the end. Van de Kaa, et al. (2013) investigated a situation in which the Chinese government failed to push through a standardization because of decentralisation and misaligned between government departments and levels (such as local, regional, or EU level) (van de Kaa, et al., 2013).

4.7.3 Change in mobility landscape

BEV mobility is ranked number three as key trending disruptive technology in the automotive, according to executive survey by KPMG (KPMG, 2016). If a whole shift in the mobility paradigm would occur, the TCO framework might change as well. According to McKinsey there are two adjacent disruptive technologies in the automotive industry besides electrification. Autonomous driving and connectivity could change the way we use and own cars (McKinsey, 2016).

Advanced driver assistance systems (ADAS) are introduced for new cars nowadays to increase safety. Examples of features are lane keeping assistance, adaptive cruise control and automated emergency brake. This is the first step and may ultimately lead to fully self-driving cars (Texas Instruments, 2015). ADAS will increase customer's understanding and trust in the technology. Once technological and regulation issues are resolved, about 15% of the passenger vehicles sold in 2030 can be fully self-driving (McKinsey, 2016).

In combination with the connectivity revolution, the traditional business model of car ownership may shift to a model of shared mobility. Instead of buying an "all-purpose" vehicle, consumers can choose the best solution on demand using their smartphone. One out of ten new cars sold in 2030 might be a shared vehicle, hereby reducing the private use vehicle sales. This will be especially attractive in big cities and densely populated areas (McKinsey, 2016).

Hence, a shift in the mobility paradigm might also alter the TCO business framework which is currently used for TCO calculations. Whether this has a positive or negative effect on the attractiveness of EVs cannot be concluded upon, since it's difficult to incorporate a change in paradigm with many variables. Yet many interviewees consider it as a positive effect. Self-driving cars could for example switch automatically in order to charge one after another (Interview 9). In the interviews the possibility of a change in mobility paradigm and influence on the willingness to purchase an EV was recognized as well (Interview 1-3,7,9,10). Like one interviewee said:

"I don't know how a car in the future will look like, but I do know it will not look like a car as we know it now."
(Interview 3)

¹⁵ Since the information presented in newspaper is not backed up by academic literature, it will not be presented in Table 23.

4.8 Opportunities for Research & Development

The subsequent category is 'opportunities for R&D' which is a resulting phenomenon when the number of electric vehicles increases. More EVs sold lead to R&D investments, but there is also an anticipating effect working through market factors as will be explained below.

1. R&D investments;
2. Market factors.

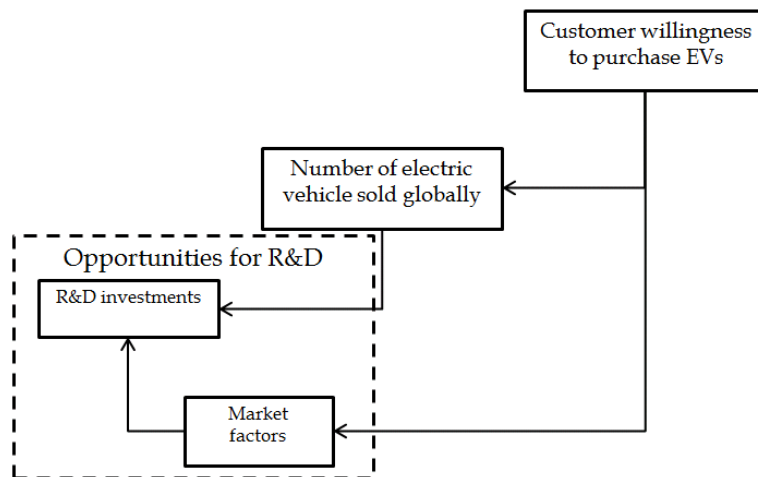


Figure 15: Category 'opportunities for R&D' and its relation to the number of EV sold globally.

4.8.1 R&D investments

Research & Development in the EV industry can lead to cost declines for producers and eventually consumers. When cheaper materials and new production techniques can be commercialized it may result in significant cost savings, but upfront investments are required. Once more EVs are sold on a global scale, more money will circulate in the electric vehicle market. The speed of development of EV technologies is highly dependent on the growth rate of the EV market. Technological progress maintain at a steady level when the market is low but is dramatically accelerated when the market starts to grow, since investments will increase when there is a big potential market (Orbach & Fruchter, 2011; Hacker, et al., 2009). On the other hand one could argue the demand on its turn is dependent on the performance of the EV and thus the battery. This leads to the typical chicken-egg problem. If performance is hampered, the battery size increases which results in an expensive and less attractive vehicle. In all interviews it was verified the R&D investments would go up once the EV market accelerates¹⁶. However, the extent to which the interviewees think it leads to a direct cost decrease differs. Some think innovations are key for a decline in TCO (Interview 2,3,8), while others argue innovations are less to be contributed to a cost decline and the scale- and learning effects are more important (Interview 4,6,7,10).

4.8.2 Market factors

As discussed in the previous subparagraph, more EVs will result in more R&D investments. However, there is also an anticipating effect on this. To quote an interviewee:

¹⁶ It seems logical to assume government subsidies for R&D investments also directly increase the R&D investments. This is not incorporated in the model due to the absence of data on this matter.

"If investors and others assume a growth in the EV market, the investments will increase."

(Interview 1)

In this framework this anticipating phenomenon are called market factors. Market factors can be influenced by e.g. a policy change, which stimulate consumers to acquire an EV or alternatively place a disadvantage for ICEVs. Market factors basically show the (un)certainly in the market. As general technology dominance theory argues, if the uncertainty is high, the investment decisions are usually postponed (van de Kaa, et al., 2011). As discussed in one of the interviews (Interview 1), any factor influencing willingness to pay could exert an anticipating effect on R&D investments via the market factors¹⁷. For reasons of simplicity the arrow is drawn from willingness to pay to market factors.

To conclude, both actual numbers of EVs sold as the estimated number will affect the R&D investments. How R&D may influence the production costs is discussed in the next paragraph.

4.9 Technical parameters

The technical parameters represent how the car is produced and what materials are used. This process is influenced by R&D, e.g. by means of new material use or new chemistries for batteries. The technical parameters are the foundation for the final production costs, which on its turn influence the TCO. Next, the following parameters are discussed:

1. Vehicle specifications;
2. Battery technology;
3. Commodity prices.

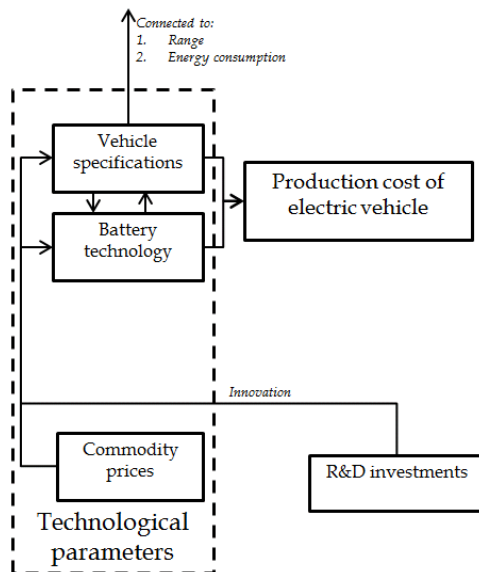


Figure 16: Category 'technological parameters' and its relation to the production cost of EVs.

4.9.1 Vehicles specifications

In paragraph we discuss three aspects that may lead to cost reductions:

1. Drag reductions;
2. Energy efficiency;
3. Production efficiency.

¹⁷ In this research we have not investigated which factors may influence the market factor and to what extent, so that could be a starting point for future research.

ad 1. Drag reductions

The average mass of new cars in Europe and the US increased in the early 2000s due to safety features (airbags, vehicle structure), noise reduction and luxury features but remained constant (on average) ever since 2005. Meanwhile the fuel economy remained constant, indicating a relative improvement in fuel consumption if accounted for the increased weight. Since the weight remained constant, the fuel economy increased every year (EPA, 2013; Kay, et al., 2013).

The energy flow of a typical conventional ICE vehicle is depicted in the figure below (Figure 17). Since the efficiency of an electric motor is much higher than a combustion engine, the overall efficiency increases as well. However this also means weight and air/rolling resistance will take a larger proportion of the total efficiency loss. This means a reduction in weight is even more important for EVs to enhance the fuel efficiency.

Weight reductions for all types of cars is expected, but without reducing the size of the car or removing utilities since it will most likely not be accepted by the public (EPA, 2013). Material improvement will be the largest contributor for this reduction with the introduction of carbon fibres, high strength steel and magnesium technologies (Kay, et al., 2013).

Hill, et al. (2015) for example expects a 100-150kg reduction in all EV types in the car segment C. BEVs will carry just an additional 10 kilograms more than ICEV in 2030. PHEV/EREV will remain an additional 20-80 kg heavier due to the dual technology (Hill, et al., 2015). TNO, et al. (2011) expects BEVs will decline 20 kilograms between 2020 and 2030 (TNO, 2011).

Since drag becomes more important for electric vehicles, more effort is put into the reduction of aerodynamic drag and rolling resistance as well. Drag factors of 0.15 are possible for a four-seater car, while current cars have a coefficient of 0.25. Rolling resistance can be optimized by low resistance tyres and a monitoring system that signals when the pressure is below a certain level. Since these efforts are relatively inexpensive it not likely it will increase the retail price (Kay, et al., 2013).

Some additional opportunities were identified during the interviews. A reduction in weight will require less battery weight and more lightweight braking system, so this reinforces each other (Interview 1,3,4). This is a positive feedback loop between vehicle specifications and battery technology.

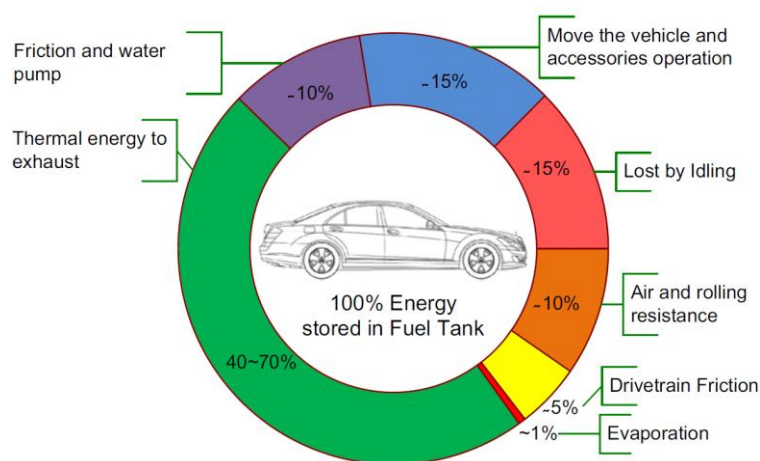


Figure 17: The typical energy flow of ICEVs (Fui Tie & Wei Tan, 2013).

ad 2. Powertrain

As mentioned earlier, the energy efficiency of an ICE is fairly poor with 20% conversion rate. An electric motor on the other hand is capable of converting electricity into kinetic energy with a 90% efficiency rate. Nevertheless, with the introduction of batteries new energy losses arise. The battery itself also has an efficiency rate, and they are subject to a certain self-discharge rate. Therefore, the tank-to-wheel efficiency of an EV is estimated between 60-80% (Hacker, et al., 2009). Another improvement is regenerative braking, in which the battery is charged by means of braking with the electric motor (TNO, 2011). About 50% of the braking energy can be recovered and stored in the battery. Dependent on the driving range, it can increase the EV range with 10%-25% (Fui Tie & Wei Tan, 2013).

ad 3. Production efficiency

Many studies argue scale economics are applied to battery prices, but they interact with the other components as well. The assembly production lines of cars are highly standardized. Platforms are used, which means one production line can make components for different types of models. This is to maximize standardization and hence minimize costs (Interview 7). The question remains whether entirely new production lines have to be developed for EVs. Based on the interviews, this seems to be dependent per car brand.

For the VW e-Golf and the Chevrolet Volt many components can be produced using the same platform as their ICE version, so economies of scale are already maximized except for the battery and electric parts. Yet final assembly is still not exactly similar than an ICEV, so there is some room for improvement. Whether this improvement is significant or can be neglected is not clear. Many interviewees (Interview 2,4,5,8) argue we are talking about a serious amount of costs (Interview 2,4,5,8), while according to others, these costs are very small (Interview 11,13).

For manufacturers like Tesla, Renault and the Nissan LEAF new production lines were developed since the vehicles is not derived from an existing ICEV model. Hence, it is likely the utilization of these production lines is quite low since a relatively low number of EVs is sold at present. Once the market growth and number of models per manufacturer increases, the efficiency will increase as well (Interview 2,4,5,11).

Related but another production inefficiency is the fact that ICEVs, BEVs, PHEVs and EREVs are developed next to each other which probably involves costs as well. Also the overhead costs of the EV development, such as the design of the model and software, could be lower per unit once production is scaled up (Interview 3).

4.9.2 Battery technology

The pricing of EVs compared to conventional cars is mostly affected by the price (and performance) of its battery. Axsen, et al. (2010) defines it as “the battery problem”, in which inadequate battery performance does not yet meet the requirements for large scale commercialization (Axsen, et al., 2010; Elkind, et al., 2012; ARF & McKinsey, 2014). Costs of the battery make up to half of the total vehicle’s production costs. The price of the battery is widely recognized as the most hampering issue for large scale adoption in the mass market in the literature (Tsang, et al., 2012; Boulanger, et al., 2011; Brown, 2013; Perujo, et al., 2012; Cluzel & Lane, 2013). In the interviews almost all interviewees placed the battery price within the top 3 reasons why TCO of EVs is higher than ICEVs (Interview 1-10).

In this paragraph we limit our discussion to lithium-ion battery, the common product for BEVs and most PHEV/EREVs. An explanation of different kind of batteries and their performance differences can be found in the appendices (APPENDIX VIII). An explanation of lithium-ion battery theory is also included in the appendices (APPENDIX IX), as well as an discussion about battery manufacturing (APPENDIX X). The general characteristics of the battery are discussed briefly. For a detailed discussion, please refer to the appendices. The following characteristics are distinguished:

1. Current performance;
2. Future performance.

ad 1. Current performance

For lithium-ion batteries there is a trade off between power and energy (refer to APPENDIX IX). Lithium batteries usually meet the required specific power, so the main challenge is to increase the energy density. Compared to other batteries li-ion has a relative well specific energy (150 Wh/kg), but it still accounts for just 1% of the energy density of gasoline (13.000 Wh/kg) (Young, et al., 2013). Although pure lithium also has a high specific energy (12.000 Wh/kg), just a fraction of the battery is composed of lithium. The remaining materials have a much poorer specific energy (Cluzel & Douglas, 2012). Therefore, much effort is put to extend the capacity of the battery. Current R&D research focus on the material improvement of the electrodes to increase their capacity (charge per unit of weight) (Cluzel & Douglas, 2012; Perujo, et al., 2012; Dinger, et al., 2010). In January 2016 for example, material im-

provement research was conducted in a lab for lithium-ion (NMC) batteries to improve the cycle life and capacity (Lin, et al., 2016).

Hacker, et al. (2009) predicted seven years ago that in the midterm future the energy density increase would reach a 150 Wh/kg and a total battery weight of 200 kilograms. This is quite correct given the current technology status (Hill, et al., 2015). In the long run the energy density is expected to increase to 300 Wh/kg (Cluzel & Douglas, 2012; Hacker, et al., 2009).

Deterioration of the battery can be expressed as calendar life and cycle life. The former occurs due to an aging effect, e.g. the chemical reactions between the materials. This results in capacity loss and can not be stopped but can be reduced by temperature control. The latter is due to lithium deterioration because the battery is used and can be reduced by oversizing the battery. Obviously the deterioration rates affect the total cost of ownership, especially when the battery is considered 'end of life' before the vehicle's 'end of life' (Lunz, et al., 2012). Reliable data on deterioration is not yet available, since the introduction of current lithium-ion based batteries were only introduced less than 10 years ago (Young et al). Some studies assumes a cycle life of 1000 cycles and 7 years, which could be improved to 3000 cycles and 12 years if li-ion batteries are to be improved up to the 2025-2030 timeframe (Gerssen-Gondelach & Faaij, 2012; Cluzel & Douglas, 2012). The International Energy Agency has a more optimistic perspective and assumes a cycle life of 6000 which can be improved up to 10.000 till 2018 (IEA, 2015). Azadfar, et al. (2015) assumes at least 3200 cycles for current li-ion batteries (Azadfar, et al., 2015). Two interviewees expect new batteries to have a slower deterioration because of increased battery monitoring and better cell balancing (Interview 3,7). Another interviewee agrees and expects battery to be useful for car at least 10-12 years (Interview 11).

ad 4. Future performance

Yet there are opportunities for new technologies beyond the lithium-ion era. The lithium-sulphur is currently in the demonstration phase and if it would enter the commercial market by 2025 it could theoretically contain a specific of 2500 Wh/kg (500 Wh/kg in practice) by 2030. At present this battery is still very unstable when exposed to high temperatures and it experiences a poor cycle life at this point. Lithium-air, which is still in the development stage, has an even greater potential, up to 11.000 Wh/kg theoretically (1000 Wh/kg practically), but no breakthrough is expected before 2030 (Cluzel & Douglas, 2012; Gerssen-Gondelach & Faaij, 2012). According to Catenacci, et al. (2013) it is doubtful whether li-air will make it on to the commercial market before 2030 (Catenacci, et al., 2013). Based on the real historic development time of current li-ion batteries, we can estimate the time lapse between a concept in the lab and successful commercialization will take about 10 to 15 years (APPENDIX XI) (Cluzel & Douglas, 2012).

Another complementary solution might be the use of electrochemical capacitors (also known as ultra-capacitors). Ultra-capacitors they would not substitute batteries, but when it is combined with a battery it could level out high power demands. This way it can extend the life cycle of the battery by up to five times, reduce battery cycling range and lower cooling requirement (Perujo, et al., 2012; Kay, et al., 2013). An expert however clearly mentioned ultra-capacitors are way more expensive and there is no power limitation for current lithium-ion batteries right now, so it would not solve any problem (Interview 11).

Most interviewees agree the lithium-ion technology reaches its limits of performance and a battery breakthrough is necessary to drastically increase EV performance / reduce costs. Some interviewees do not expect a battery breakthrough that will cause dramatic decline in prices, because they are all in lab phase and it would take more than 15 years to commercialize (Interview 2,10).

Others think big innovations in battery chemistries will take place in the next 15 years, among others because the commercialization process can be speed up by means of computer simulations (Interview 3,8). Others simply dare not to choose and say it is not impossible but they do not know (Interview 11).

4.9.3 Commodity prices

A potential risk would be the scarcity of the required battery materials, and hence its price development¹⁸ (Catenacci, et al., 2013). It is widely accepted that materials like aluminium, steel and copper are not posed to scarcity. The only materials that could become scarce in the upcoming years are lithium and cobalt, according to Hacker, et al. (2009). Yet, despite concerns in the literature, there is no founded indication lithium reserves will be depleted in the foreseeable future up to 2030. To quote researchers at the Argonne National Labs (US): “Known lithium reserves could meet world demand to 2050”. Although the price can increase, it is still a fraction of the battery’s total production costs (Boulanger, et al., 2011; Goldman Sachs, 2015) (APPENDIX XII).

Cobalt is a different story though. The rare earth material is listed on the European Critical Raw Material list and is the largest risk in terms of material scarcity for batteries. About one third of the total cobalt supply is used for the production of batteries. Since about half of the total earth’s supply is located in the politically unstable Democratic Republic of Congo, supply forecasts are difficult to predict. The report’s predictions only go as far as 2020, but the gap between supply and demand is closing, which could lead to an increase in price (EC, 2013).

In this paragraph vehicle technology, battery technology and the commodity price risk has been discussed. To conclude, both the literature as well as the interviews acknowledges the battery price is the most hampering effect for the TCO of EVs.

4.10 Conclusion

All factors influencing the TCO that are found during the desk research or the interviews have been discussed in the paragraphs above. In total we found 34 factors either directly or indirectly influencing the TCO. Based on the results, an initial TCO framework is shown in the figure below (Figure 18). This framework is just a way to see the broader perspective of EV cost development, but there may be more factors or relationships present in reality. Future research could increase the robustness of this framework. In Chapter 1 two research questions were established. Let us now reflect on the first RQ and related sub questions.

Question 1: “What factors influence the total cost of ownership development of electric vehicles and what is the relationship between those factors?”

The following sub questions are relevant:

1. What factors influence the TCO?
 2. How do these factors relate to the TCO and each other?
 3. To what extent does each factor influence the TCO?
-

ad 1. What factors influence the TCO?

Table 6 below shows all the factors and their empirical evidence by literature source or interview. Most of the direct factors that influence the TCO (marked by the red arrow in the figure) are also included in other cost studies for EVs (first few factors of Table 6). The exception is the profit margin and the accompanying pricing strategy and OEM competition, as many cost studies use the production costs as a proxy for sticker price or use the sticker price directly. Innovation and/or scale and learning effects are incorporated in other studies as well, but it is often unclear how the predicted production numbers are estimated.

We claim there are many more indirect factors that play a role in the TCO development which are often neglected in cost studies, especially the factors influencing the willingness to purchase. Many of these are backed by technology selection literature in Table 6. Although not verified in the interviews or literature, it is the author’s opinion these factors may play a critical role in the EV adoption rate, especially because both innovation and scale and learning effects are subject to the typical chicken-egg

¹⁸ Material analysis is limited to the battery production process since that is most significant difference compared to ICEVs.

problem. Factors like customer understanding and symbolic and affective factors just to name a few are the requisites to ‘kick-start’ the reinforcing cycle of scale economics and innovations to bring down the TCO. Using such a framework for TCO calculations may also improve the quality of the TCO estimations in future research.

ad 2. How do these factors relate to the TCO and each other?

As shown in the figure, the red arrow represents a direct relationship between the factor and the TCO. The black arrows represent an indirect relationship. Green arrows represent feedback loops or a connection between the factors themselves, bypassing the TCO. It is important to note that there might be more relationships, especially of the ‘green arrow’ kind. One could for example argue that emission regulations also influence the pricing strategy of the OEM. The author chose to only visualize the feedback loops that are backed by literature and/or mentioned in the interviews multiple times, if only because the framework would become very difficult to read and interpret if more relationships were drawn.

This TCO framework presents the relationships between the factors based on the desk research and interviews. It is important to note this is an initial exploratory framework and not set in stone. Future research is necessary to determine the robustness of this framework. Nevertheless, the framework shows the relationships between the factors and the TCO is more complex than those of previous cost studies.

ad 3. To what extent does each factor influence the TCO?

First of all, of each factor and/or relationship it was only investigated what its effect is on the TCO. As mentioned in the beginning of this chapter, it could be possible some factors may also influence other purposes, such as the future demand. Although the author acknowledges the framework may be useful for these purposes in the future, this was out of scope for this research. Second, this study is a descriptive research which identifies and relates factors influencing the TCO of EVs. The extent to which a factor influences the TCO is one of the mediocre results of this research. Due to the scope of this research a survey to rank all the factors was impossible, so that could be a basis for future research. Besides that, one would also consider to quantify the more subjective factors like customer understanding.

However, it is possible to mark each factor either ‘important’ or ‘less important’. This is based on two methods. First, the factors that are identified in the literature as critical (APPENDIX XIII). Second, each interviewee was asked to select his/her top 3 important factors for the TCO development (Table 4).

Table 4: Interviewees’ top 3 selection of most important factors for the TCO.

Top3 / Interviewee	Priority 1	Priority 2	Priority 3
1	Production costs (scale/learning effects)	Government policies	Range
2	Production costs (scale/learning effects)	Battery technology	Charging issues
3	Battery technology	Production costs (scale/learning effects)	Charging issues
4	Production costs (scale/learning effects)	Charging issues	Government policies
5	Production costs (scale/learning effects)	EV Performance	Government policies
6	Production costs (scale/learning effects)	Range	Variety of EV models
7	Production costs (scale/learning effects)	Range	Charging issues
8	Production costs (scale/learning effects)	Range	-

9	Production costs (scale/learning effects)	Range	-
10	Production costs (scale/learning effects)	Range	Government policies
11	Production costs	Range	Resale value
12	Production costs (scale/learning effects)	Range	Charging issues
13	Production costs	Range	-
14	Production costs (scale/learning effects)	Range	-

If a factor is marked 'important' by at least two independent sources, it is considered to be 'important' in for this research. Eight factors are considered to be important (Table 5).

Table 5: Distinction between important and less important factors.

Factor	Interview top 3	Critical barrier?	Conclusion
Production costs	14 interviews	13 studies	Important
Profit margin	-	-	Less important
Resale value	1 interview	1 study	Important
Tax/fiscal policy	-	-	Less important
Charging costs/infrastructure	-	-	Less important
Maintenance	-	-	Less important
Insurance	-	-	Less important
Discount rate	-	-	Less important
Range	10 interviews	13 studies	Important
Charging infrastructure	5 interviews	9 studies	Important
EV performance	1 interview	-	Less important
ICEV performance	-	-	Less important
Variety of EV models	1 interview	2 studies	Important
Emission regulations	-	-	Less important
Customer understanding	-	7 studies	Important
Symbolic and affective motives	-	-	Less important
Range anxiety	-	-	Less important
Income elasticity	-	-	Less important
Bandwagon effect	-	-	Less important
Government policies	4 interviews	-	Important
Institutional barriers	-	1 study	Less important
Change in mobility landscape	-	-	Less important
R&D investments	-	-	Less important
Market factors	-	-	Less important
Vehicle specifications	-	-	Less important
Battery technology	4 interviews	-	Important
Commodity prices	-	-	Less important

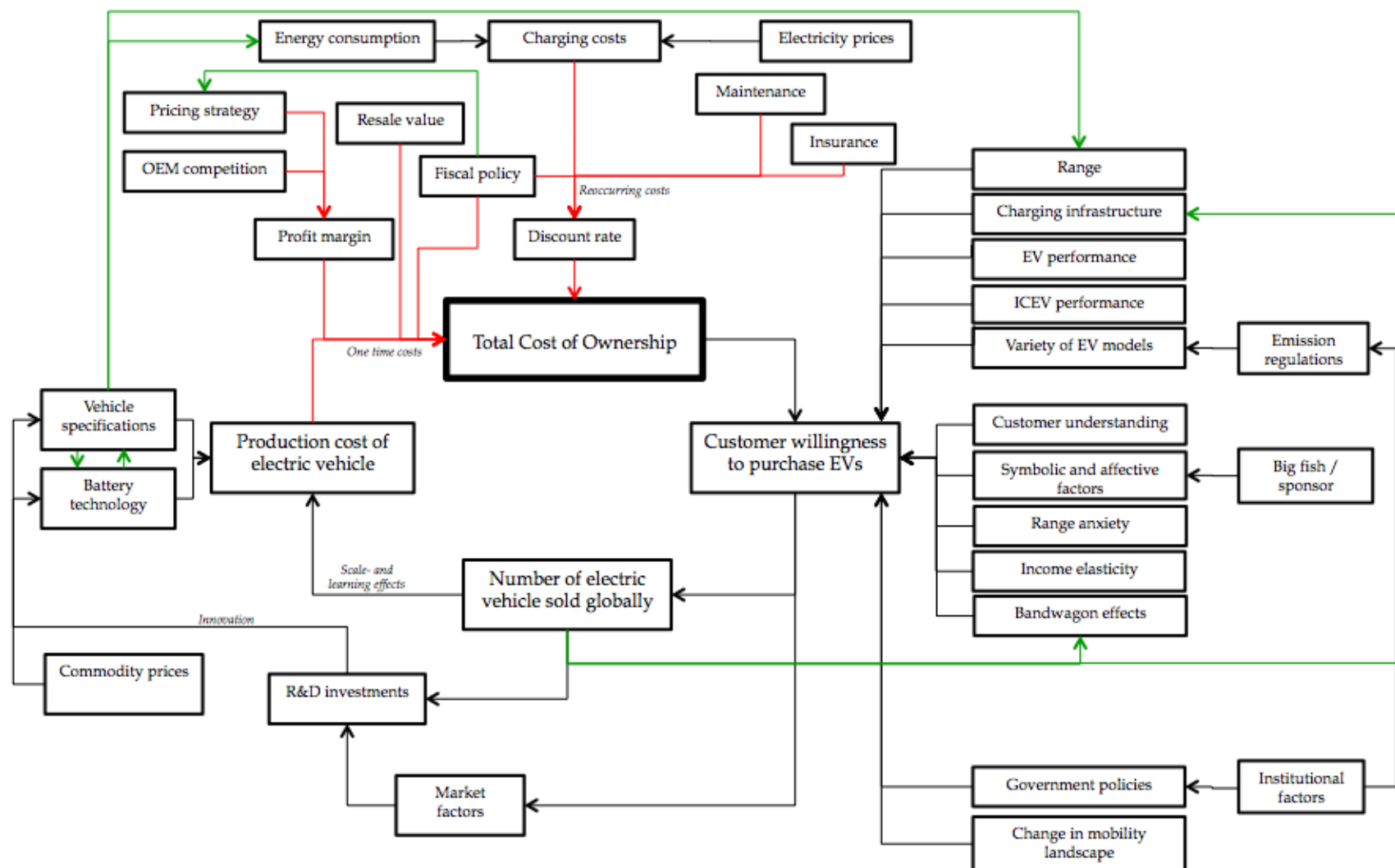


Figure 18: The detailed total cost of ownership framework for electric vehicles.

Table 6: List of factors including references.

Factor	Backed by cost literature?	Backed by technology selection literature?	Other literature	Interview references
Production costs	(Weiss, et al., 2012; Lee & Lovellette, 2011; Crist, 2012; Palencia, et al., 2014; Contestabile, et al., 2011; Wu, et al., 2015)	(Schilling, 2002; Suarez, 2004; van den Ende, et al., 2012; van de Kaa, et al., 2014; van de Kaa, et al., 2011; Schilling, 1998)	(FHA, 2009; Green, et al., 2014; Wiederer & Philip, 2010; Sierzchula, et al., 2014; CE Delft, 2011; Hill, et al., 2015; Redelbach & Friendrich, 2012; ARF & McKinsey, 2014; Thiel, et al., 2010; Windisch, 2014) and barrier literature studies in APPENDIX XIII	1-13
Profit margin	(Lee & Lovellette, 2011; Wu, et al., 2015)	(van de Kaa, et al., 2011; Suarez, 2004; van den Ende, et al., 2012)	(McKinsey, 2016)	7,10,11
Resale value	(Wu, et al., 2015)	-	(Windisch, 2014; Redelbach & Friendrich, 2012)	1-5,7,10,11,13,14
Tax/fiscal policy	(Crist, 2012; Palencia, et al., 2014; Wu, et al., 2015)	-	(Tietge, et al., 2016)	1-13
Charging costs	(Lee & Lovellette, 2011; Crist, 2012; Palencia, et al., 2014; Contestabile, et al., 2011; Wu, et al., 2015)	-	(Nemry & Brons, 2010)	3-7,10,12,13
Maintenance	(Lee & Lovellette, 2011; Crist, 2012; Palencia, et al., 2014; Wu, et al., 2015)	-	(Cleary, et al., 2010; van Vliet, et al., 2010; Windisch, 2014; CE Delft, 2011)	1,2,4,7,10,11,13,14
Insurance	(Crist, 2012; Wu, et al., 2015)	-	-	14,15
Discount rate	(Weiss, et al., 2012; Lee & Lovellette, 2011; Crist, 2012; Palencia, et al., 2014; Contestabile, et al., 2011; Wu, et al., 2015)	-	(Tsang, et al., 2012; Windisch, 2014; van Vliet, et al., 2010)	1,5,6,10,11
Range	-	See EV performance	(Perujo, et al., 2012; Cluzel & Lane, 2013; National Research Council, 2013; Steinhilber, et al., 2013; Aksen, et al., 2010; Elkind, et al., 2012; Brown, 2013; ARF & McKinsey, 2014; Nemry & Brons, 2010; Catenacci, et al., 2013) and barrier literature studies in APPENDIX XIII	1-13
Charging infrastructure	-	(Schilling, 2002; Suarez, 2004; van den Ende, et al., 2012; van de Kaa, et al., 2014; van de Kaa, et al., 2011; Schilling, 1998)	(Windisch, 2014; National Research Council, 2013; Elkind, et al., 2012; Sierzchula, et al., 2014; Tsang, et al., 2012; Boulanger, et al., 2011; Nemry & Brons, 2010; Steinhilber, et al., 2013; Green, et al., 2014) and barrier literature studies in APPENDIX XIII	1-13
EV performance	-	(van de Kaa, et al., 2011; Suarez, 2004; van den Ende, et al., 2012; van de Kaa, et al., 2014; Schilling, 2002) ¹⁹	-	1-3,6,7
ICEV performance	-	See EV performance	-	2,4,6,7,10,11
Variety of EV models	-	-	(Cluzel & Lane, 2013; Windisch, 2014)	2-4,6-10
Emission regulations	-	(van de Kaa, et al., 2011; Suarez, 2004)	-	1,7,10
Customer understanding	-	-	(Elkind, et al., 2012; Boulanger, et al., 2011; Muller-Seitz, et al., 2009; Cluzel & Lane, 2013; Aksen, et al., 2010; Tsang, et al., 2012; Brown, 2013; Windisch, 2014)	2,3,7
Symbolic and affective motives	-	(van de Kaa, et al., 2011)	(Steg, 2005)	2,3,7,10,12
Range anxiety	-	-	(Hacker, et al., 2009; Boulanger, et al., 2011; Azadfar, et al., 2015; Tsang, et al., 2012; Windisch, 2014; Cluzel & Lane, 2013; Nemry & Brons, 2010; Green, et al., 2014)	1,3,7
Income elasticity	-	-	(Geilenkirchen, et al., 2010)	1,7,10
Bandwagon effect	-	(van de Kaa, et al., 2011)	(Langezaal, 2015)	3,5,10
Government policies	-	See emission regulations	(Windisch, 2014; ARF & McKinsey, 2014)	5,6,10,11,12
Institutional barriers	-	(van de Kaa, et al., 2013)	(Tsang, et al., 2012; Stone, 2016)	1-3,7,10
Change in mobility landscape	-	-	(McKinsey, 2016)	1-3,7,9,10
R&D investments	-	-	(Orbach & Fruchter, 2011; Hacker, et al., 2009)	2-4,6-8,10
Market factors	-	(van de Kaa, et al., 2011)	-	1
Vehicle specifications	-	-	(EPA, 2013; Kay, et al., 2013; EPA, 2013; TNO, 2011; Hill, et al., 2013; Hacker, et al., 2009; Fui Tie & Wei Tan, 2013)	1-5,7,8,11
Battery technology	-	-	(Aksen, et al., 2010; Elkind, et al., 2012; ARF & McKinsey, 2014; Tsang, et al., 2012; Boulanger, et al., 2011; Brown, 2013; Cluzel & Lane, 2013; Cluzel & Douglas, 2012; Dinger, et al., 2010; Hill, et al., 2015)	1-13
Commodity prices	-	-	(Boulanger, et al., 2011; Goldman Sachs, 2015; Catenacci, et al., 2013; Hacker, et al., 2009)	-

¹⁹ The technology selection scholars do not explicitly discuss EV performance, but technological superiority in general. This is discussed in paragraph 4.5.3.

5

RESULT II: THE TCO DEVELOPMENT

In this chapter we aim to answer the second research question, which is about the actual cost development of electric vehicles in the 2015-2030 timeframe. First, the scope of the calculations is narrowed since there is a very wide spectrum of different EV types and segments. Second, right away the TCO results are presented and discussed. Third, in the subsequent five paragraphs, a detailed explanation is given how these TCO results, based on different components, came about. This concerns productions costs and resale value, but also the recurring costs involved when owning a car. In the last two paragraphs, a sensitivity analysis is executed and the limitations are clarified.

5.1 Introduction of TCO factors and EV types

The framework of the previous chapter is used to calculate the TCO development, but the scope of this research does not allow to include all factors. So first, a selection of factors is to be made. In addition, different car types can be used with different technologies and associated costs. One type and car segment is selected for this study.

5.1.1 Factors: relation to Chapter 4

The result of Chapter 4 is an extensive TCO framework that includes more factors than previous framework in literature, which makes this research unique compared to other studies (refer to 1.2). Due to the scope of this research it is necessary to limit the number of factors that are included for the TCO calculations in this chapter. The selection of which factors to include and exclude is based on two criteria. First, the direct factors are included in the TCO calculations, because they are the foundation for any TCO calculations. However, if only direct factors would be included this research would not differ from previous TCO studies. Therefore, secondly the important indirect factors are included in these TCO calculations as well. There are two selection criteria whether an indirect factor is included in the TCO calculations. First, the factors that are identified in the literature as critical (APPENDIX XIII). Second, each interviewee was asked to select his/her top 3 important factors for the TCO development (Table 4). Following Table 5, if an indirect factor is marked as critical by two independent sources (either interviews or literature), the factor is incorporated in the TCO calculations.

If the factor is quantitative it will be used in the TCO calculations directly. If the factors are qualitative it will be the basis of the scenario development. To conclude, the following factors are derived from Chapter 5 and used in this chapter:

1. Production costs;
2. Battery technology;
- 3. Profit margin;**
- 4. Resale value;**
5. Charging costs & infrastructure;
6. Maintenance;
7. Insurance;
8. Discount rate;
9. Range;
- 10. Variety of EV models (through demand);**
- 11. Customer understanding (through demand);**
- 12. Government (fiscal) policies.**

Factor 3 is neglected in other literature and new. Factor 4 is sometimes ignored and sometimes included, so in this research we test its value statistically. Factor 11 and 12 are included through demand based on the literature study, since it is not within the scope to quantify them. Finally, factor 13 is both included and excluded (in the cases) to see the difference. These five factors make this research to be different and unique, and as we argue later in this Chapter, to be more comprehensive than previous EV cost studies. An extensive list of the factors that are marked as 'more important' or 'less important' can be found in the table at the end of the Chapter 4 (Table 5).

5.1.2 Types: which EV types to incorporate

In this research three types of electric vehicles are distinguished: the plug-in hybrid, the extended range electric vehicle and the full battery electric vehicle. A more detailed discussion about the technical differences between these three can be found in the appendices (APPENDIX XIV). It is important to note that additional technologies are out there, although not included in this research (Figure 19). According to the interviews, these different versions are not necessarily competing against each other, because all enhance R&D efforts and scale- and learning effects. Nevertheless, the scope must be limited for the TCO calculations as all these differ regarding costs. The majority of the interviewees stated the BEV has to the most potential in contrast with the PHEV/EREV, given the assumption the performance will increase and the costs will go down (Interview 1-4,6,7,9,13). Since this type is apparently the most challenging regarding technology and cost, the focus will be on the BEV in this chapter.

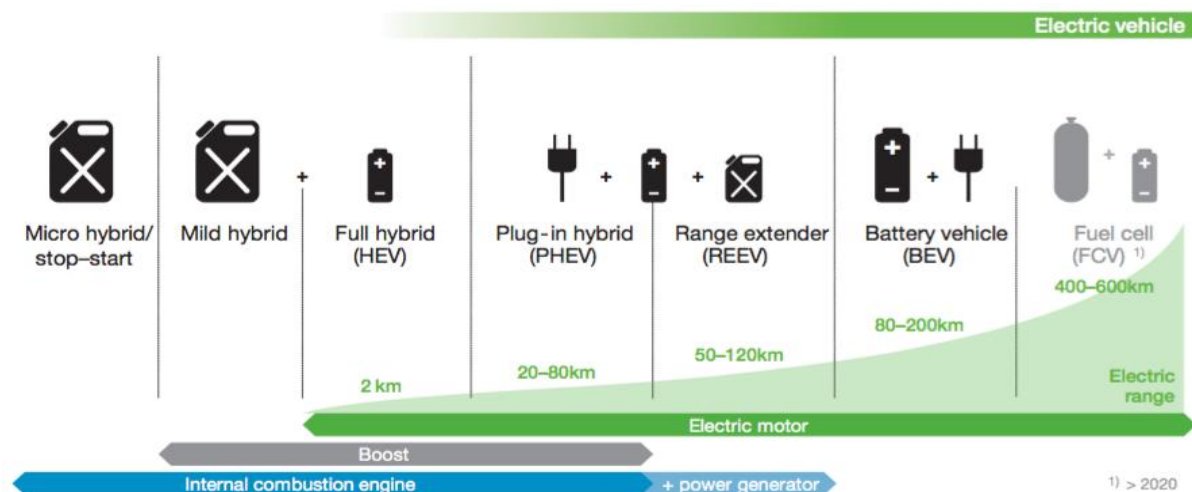


Figure 19: Different types of EVs (Kay, et al., 2013, p. 104).

But there are many types of BEV and the price range is wide. While a luxury Tesla Model S may have a sticker price above €100.000, the Renault Twizy has a price tag of less than €10.000. Since this obviously also affects the TCO results, one segment is used in this research²⁰. There is no consensus among the interviewees for the potential for BEVs in relation to the car segment. Some argue the biggest potential for the next decade is the lower segment, since these cars are generally used for short distances, they are light-weighted and sometimes households own an additional larger car (Interview 1,4,10). This is confirmed in the literature as well (Nemry & Brons, 2010). Other interviewees argue otherwise (Interview 2,3,6,7,11,13). Although there is potential for the lower segment, history tells us the first successful BEVs were of the luxury type and nowadays the focus slowly shifts to the medium size segment. This is, among others, because the additional costs are less valued in the luxury segment while the lower segment is very competitive regarding costs. Once technology matures, the costs will decline and hence the BEV can penetrate through the lower segments.

²⁰ Car segmentation differs per region across the world. The EU has set segmentation from A to J, ranging from mini cars to executive and sports cars, but there is no official definition how to categorize a car on e.g. weight or size. This is left open to the market (EC, 1999).

These two perspectives do not rule out each other by definition and nobody is able to tell whether we may see only small or luxury BEVs or both. It is however true there are small BEV (e.g. Twizy) and luxury BEVs (Model S). However, the in proportion largest medium size C-segment does not have many BEVs on its list. However, this might change in the future. At least two OEMs officially announced to produce cars for this segment (refer to Figure 31, discussed later on). Since it is a very big and economically competitive segment (TNO, 2011), we therefore choose to focus on the medium size C-segment for the TCO calculations.

In the next paragraph the TCO is calculated and the analysis is discussed. Based on the approach above, all costs involve a C-segment BEV.

5.1.3 TCO: scenarios and profiles

In the previous two paragraphs the factors were established and the type of EV was chosen. Before the total cost of ownership can be calculated, it is necessary to distinguish different methods to cope with uncertainty and assumptions. In this report, the following three concepts are used:

1. Scenarios;
2. User profiles;
3. Cases.

ad 1. Scenarios

The scenarios in this report represent the bandwidth of the TCO. For some factors, scenarios are used to account for uncertainty in the data. Take for example the electricity price: some literature argue it will increase over the course of time, while others say it remains constant or even decline. In such situations three scenarios are used. Hence, the TCO results will not display a single number, but a bandwidth with optimistic, neutral and pessimistic input data.

ad 2. User profiles

A total cost ownership is dependent on the driver characteristics, e.g. how often he/she uses the vehicle. In order to determine the TCO, a user profile has to be established with certain characteristics. It concerns the following characteristics (Table 7):

Table 7: User profile characteristics.

Characteristic	Influences the following parameters
Annual kilometres driven	Amount of required energy (kWh) Maintenance costs (€)
Proportion home/public charging (%)	Charging costs at home or public charging costs (€) Fixed charging fee per session at public stations (€)
Charging sessions a week	Fixed charging fee per session at public stations (€)
Years of ownership	Converts recurring annual costs to lifetime costs (€)
Discount rate (%)	Converts nominal lifetime costs to real lifetime costs (€)

It is impossible to establish one profile that represents all consumers. Therefore, in the next paragraph different user profiles are used to show the impact of consumer characteristics on the TCO.

ad 3. Cases

Finally, different cases are developed to show the impact on the TCO when parameters are changed. A 2x2 matrix is used, which results in four cases. The first variable is the user profile: two different consumer profiles are composed. The second variable is government influences which are either included or excluded. This allows us to see the influence of government 'interference'. Note that the different scenarios as mentioned above (e.g. different electricity prices or demand scenarios) are already incorporated in the bandwidth of the TCO graph (optimistic, neutral and pessimistic) and hence will be shown in all four cases. However, as will be addressed in the next paragraph, these four cases

may not represent a real life situation after all. Therefore, a fifth additional case is included based on a set of decision rules which may be more realistic. To conclude, there are five cases:

1. User profile 1 / excluding fiscal influences;
2. User profile 1 / including fiscal influences;
3. User profile 2 / excluding fiscal influences;
4. User profile 2 / including fiscal influences;
5. Alternative case: the interaction between TCO, range and indirect costs.

Table 8: Cases used in this research.

	Excludes government policies	Includes government policies
Profile 1	Case 1: user profile 1 / excluding fiscal influences	Case 2: user profile 1 / including fiscal influences
Profile 2	Case 3: user profile 2 / excluding fiscal influences	Case 4: user profile 2 / including fiscal influences

The factors are defined, the type of car is chosen and the method of how the TCO is calculated is explained. In the next chapter, the TCO is calculated, analysed and the results are discussed. A brief overview of the input data that is used is presented in the next paragraph. For more detailed information about the input data, please refer to the subsequent paragraph 5.3 to 5.7.

5.2 Total cost of ownership analysis

In this paragraph the total cost of ownership is calculated. The framework of Chapter 4 is the foundation of these TCO calculations. The factors that are derived from the TCO framework (Figure 18, paragraph 4.10) and included in this chapter (paragraph 5.1.1) were quantified in order to add them to the TCO tool.

In this paragraph the results are presented and discussed right away. A more detailed explanation of how these different categories are quantified and established is explained in the subsequent paragraphs 5.3 to 5.7. A summary overview of which variables are defined in these paragraphs can be found in the table below (Table 9).

First it is explained how the TCO tool is set up and what methodological choices are made. Then the results of the four cases are presented. It is however acknowledged the four cases may not represent a realistic situation of the upcoming decade. To include that as well, an alternative case is set up with different input parameters.

5.2.1 Methodology

Data for all factors that are included in the TCO calculations (refer to 5.1.1) are quantified and either part of the calculations or part of a scenario analysis. A brief overview of the quantification of these factors is shown in the table below (Table 9). A more detailed explanation of how these figures are calculated can be found in the related paragraph (see second column). These paragraphs also contain an explanation of the demand estimations and scenarios analysis.

Table 9: Nominal input data for TCO based on previous paragraphs (before actual calculations, not discounted, excluding taxes).

Category	Paragraph	Value ₂₀₁₅	Value ₂₀₃₀	Remarks
Vehicle costs	5.3			
- Vehicle technology		€15.914	€10.863 - €11.997	Decline of vehicle technology by means of experience curve in three different scenarios. Decline of powertrain by literature, no scenarios
- Powertrain		€2.992	€2.320	
Battery costs	5.3	€290 - €500 (/kWh)	€150 - €258 (/kWh)	Price per kWh. Decline based on literature study for three scenarios. Verified by other cost studies and experience curve
Resale value	5.4	€0	€0	Not included, because no significant difference between BEV and ICEV
Energy consumption	5.5	5,45 km/kWh	5,92 km/kWh	Decline based on literature studies
Charging costs	5.6			Excludes all taxes. Electricity price and public charging based on three scenarios. Home charging based on literature studies.
- Electricity		€0,06 (/kWh)	€0,024 - €0,096 (/kWh)	
- Home charging		€1.258 (once)	€1.053 (once)	
- Public charging var.		€0,107 (/kWh)	€0,052 - €0,022 (/kWh)	
- Public charging fixed		€48,81 (/year)	€48,81 (/year)	
Maintenance	5.7	€0,015 (/km)	€0,015 (/km)	Fixed based on literature studies and interviews
Insurance	5.7	€717 (/year)	€717 (/year)	Fixed based on literature studies and interviews.

The data of the table above is input data for the TCO calculations. The total cost of ownership is defined as the cumulative lifetime costs of the car in real monetary terms, so this means the nominal data in the table must be discounted first. However, there are four actions that require attention first before these calculations can be made.

1. Range vs battery costs;
2. RPE settings;
3. ICEV reference case.

ad 1. Range vs battery costs

A decline in battery costs can either lead to a lower retail price or an increase in the battery pack to increase the range while battery pack price is kept constant (as will be discussed in paragraph 5.3). Based on the interviews it is expected that an increase in range is more pressing at the moment (Table 4). Therefore, in the TCO calculations 80% of the cost reductions are allocated to the increase in range, unless otherwise stated. This is in line with the range increase of the recent car models (see Figure 31). Nevertheless, it is assumed the battery pack costs will not increase over time (range increase is not faster than the battery cost decline)²¹.

ad 2. Indirect cost settings

Part of the total retail price of a vehicle is the manufacturer's indirect costs and profits, also referred to as Retail Price Equivalent (RPE). For example, an RPE of 1,6 means that 60% of the direct manufacturing costs are indirect costs and profits. Based on the interviews it is known the RPE of BEVs is about 1,0, which means no mark-up or indirect costs are covered in the retail price. However, in the TCO results in the paragraph, indirect costs / mark-up are included in the TCO values (and hence deviate

²¹ In reality it is possible the range will increase faster than the battery cost decline to offer a more attractive product. Meanwhile the consumer might not experience a cost decline because OEMs may alter the RPE settings.

from reality). This is done because it is impossible to predict when OEMs will incorporate such expenditures in the retail price. It would be very arbitrary if we would predict when the RPE would kick-in and to what extent. It would also distort the TCO development over time. Consequently this means the current TCO calculations in this figure is higher than the actual TCO because of pricing strategy.

ad 3. ICEV reference case

This research focuses on the TCO development of EVs, not to compare EVs directly with ICEVs as that would require an extensive analyse of the ICEV development as well. However, a simplified ICEV reference case is compiled to show the relative position of EVs to ICEVs. The data and assumptions for the ICEV reference case can be found in the appendices (APPENDIX XV). Note that the goal of this research is not to compare these two directly, and therefore it would be unrealistic to use it for such purposes.

5.2.2 Case results

Regarding the user profile two cases are differentiated. In the first case a consumer buys a car to drive almost 100 kilometres each working day (excluding holidays and weekends), which results in an annual mileage of 21,655 km, which is based on CBS data from 2014 (CBS, 2015). The owners hold the vehicle for eight years. Further it is assumed he/she charges 80% of the time at home and the remaining 20% at public charging points. The car is recharged once a day on average. He/she experiences a social discount rate of 7%.

The second user drives less, just 10,754 kilometres a year, which is the average for Dutch households (CBS, 2015). He/she owns the car for five years and uses public charging half of the time, with three charging sessions a week. The discount rate is 30%.

The government influences can either be included or excluded. In the first case all financial government influences are excluded, such as VATs, energy taxes, fuel taxes and taxes when buying a car. Non-financial government incentives cannot be excluded as it would be incorporated in the EV adoption rate (following the TCO framework in Chapter 4), but are represented by the pessimistic lower bound of the graph. This shows the perspective of the pure technological cost development of EVs. The second reference case, which includes government influences, is more realistic from a consumer perspective.

Table 10: Matrix with user profiles.

	Excludes government policies		Includes government policies	
Profile 1	Annual kilometres	21.665	Annual kilometres	21.665
	Ownership years	8	Ownership years	8
	Home/public charging	80%/20%	Home/public charging	80%/20%
	# charging a week	7	# charging a week	7
	Discount rate	7%	Discount rate	7%
	BEV taxes excluded	€11.360- €15.014	BEV taxes excluded	€0
	ICEV taxes excluded	€21.795- €22.028	ICEV taxes excluded	€0
Profile 2	Annual kilometres	10.754	Annual kilometres	10.754
	Ownership years	5	Ownership years	5
	Home/public charging	50%/50%	Home/public charging	50%/50%
	# charging a week	3	# charging a week	3
	Discount rate	30%	Discount rate	30%
	BEV taxes excluded	€7.251- €10.094	BEV taxes excluded	€0
	ICEV taxes excluded	€12.956- €13.222	ICEV taxes excluded	€0

The results are shown in the figure below (Figure 20). As mentioned above, 80% of the battery cost reduction is allocated to a range increase. This results in a rise of 154 kilometres in 2015 to 292 kilometres in 2030. The results are discussed in three topics:

1. Differences between the cases
2. Differences between the scenarios
3. Differences between the BEV and ICEV reference

ad 1. Differences between the cases

As can be seen, the results vary strongly between the different cases. The influence of fiscal government policies can lead to a €15.000 increase in the TCO. This effect becomes bigger once the car is used more frequently. This is mainly because of relatively high taxes for recurring costs like electricity and petrol. The two graphs on the left side immediately show even in the most optimistic scenario the BEV will not become competitive compared to the ICEV reference between 2015 and 2030.

The one-time costs do not differ between the user profiles, but the reoccurring costs do. The figure shows the lifetime costs, which are higher for profile 1, which makes sense because it involves more kilometres. The total TCO costs per kilometre however (not presented in the figure), are way lower for profile one: €2,75/km (profile 1) compared to €4,75/km (profile 2) assuming taxes are included in 2015.

ad 2. Differences between the scenarios

The monetary differences between the upper and lower bound is up to €6.700 in the year 2015 and increases over time as uncertainty increases as well, up to €9.000 (excluding taxes) in 2030. The lower bound can be seen as the most optimistic scenario: a high adoption rate of EVs worldwide, which leads high scale- and learning effects for the battery (up to Δ€6.000 between the upper and lower bound) and the vehicle technology (up to Δ€1.100) for the one-time costs. Regarding recurring costs, the optimistic scenario assumes lower energy prices and a more efficient charging system resulting in minimal losses, leading to a price differential of €300 annually excluding taxes. When taxes are incorporated, the uncertainty is multiplied and therefore higher.

ad 3. Differences between the BEV and ICEV reference

When comparing the BEV and the ICEV reference it becomes immediately clear the 'taxes included' situation is more beneficiary for the BEV. For the one-time costs this is directly attributed to the fact BPM (a Dutch vehicle registration tax called 'Belasting van Personenauto's en Motorrijwielen') is not applicable for BEVs, which leads to a direct saving up to €5.000. This is only partially compensated by the higher production costs of BEVs, which also leads to higher VAT. The recurring taxes of petrol cars are higher as well, about 50% higher (assuming user profile 1). This is because ICEVs are less efficient and hence need relatively much energy, which is heavily taxed. Another reason is the relatively low maintenance costs of BEVs.

The ICEV reference initially becomes more expensive in one-time costs due to CO₂ reduction regulations. Over the course of time then the TCO declines again, since new car become more efficient. The BEVs main advantage is the relatively low recurring costs, which are especially beneficiary when the annual mileage is high. However, when a high discount rate is chosen, these benefits are discounted and due to the high marginal rate of time preference. The difference between the social discount rate of 7% and the private discount rate of 30% is substantial: for user profile 1 the ICEV breaks even with the BEV's lower bound in 2019 (Figure 20), but if a 30% discount rate was used these lines would not meet each other before 2022 (not presented in the figure).

To conclude: given the assumptions, the user profiles and the methodology, the BEV will most likely face a higher TCO. Government policies are of the utmost importance to increase competitiveness. The BEV however may become competitive when the mileage is high and the period of ownership is long. This is because recurring costs are competitive, while a long ownership period is required to spread out the high initial purchase price.

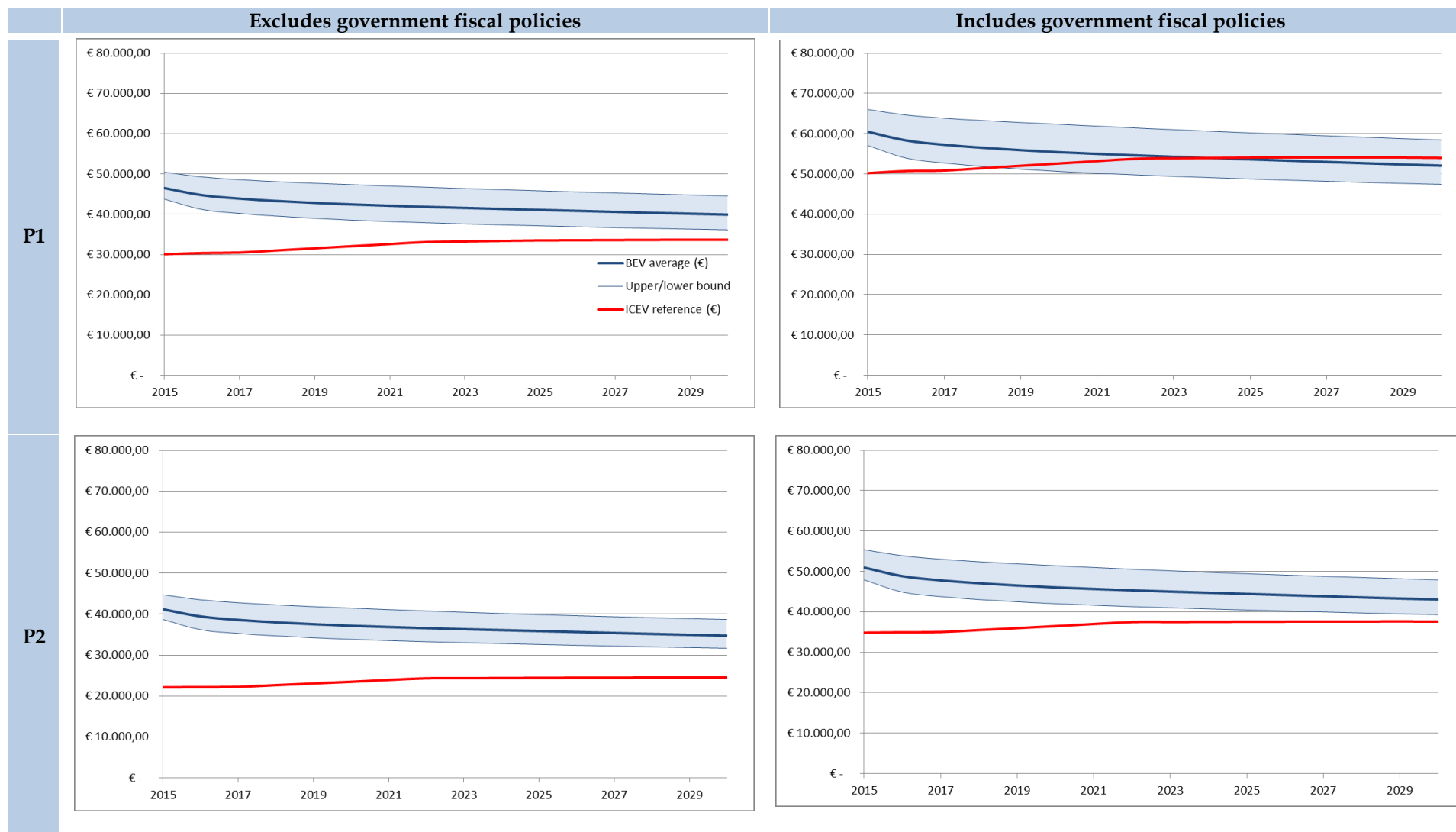


Figure 20: Lifetime TCO results for two user profiles and including/excluding governmental fiscal influence. Expressed in real €₂₀₁₅.

5.2.3 Alternative results

As discussed in the previous subparagraph, the case results are subject to two major limitations. This concerns (1) the OEM's indirect costs and profits (RPE), which is included for 100% in the results, but known to be 0% at the moment. In addition, (2) the range increase cannot be greater than the battery cost decline trend, of which 80% is attributed to range enhancement. These two parameters are shown below using these standard settings (as used in the previous subparagraph). The user profile for this graph is set to 15.000 annual kilometres, 6 years of ownership, 80%/20% home/public charging, charging once a day and a 10% discount rate (Figure 21). The cost curves are including government influences (taxes). For reasons of simplicity, only the average cost curve is drawn.

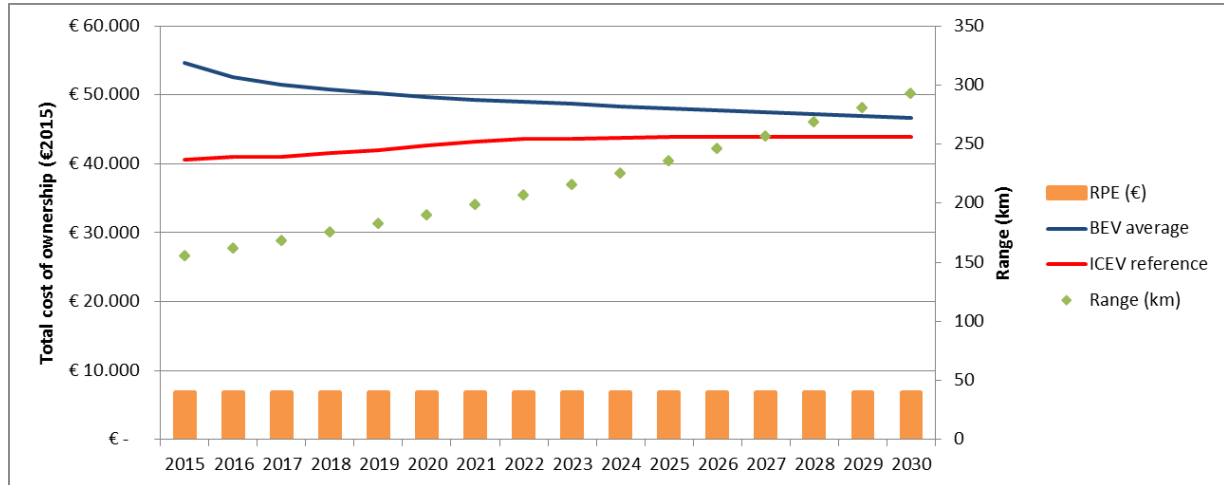


Figure 21: TCO results (real €₂₀₁₅) using 15k annual kilometres and 6 ownership years (own calculations).

In this section we attempt to draw a more realistic forecast, based on the literature, data and interview. In general we assume the majority of the stakeholders want EVs to become competitive and is willing to provide the necessary investments and/or subsidies. It is known the indirect costs/profits are zero at the moment. We assume these to be zero until the EV becomes competitive with respect to the ICEV. Regarding the second matter, the range, some new models have been announced with a much bigger range than current models (refer to Figure 11). Therefore, it looks like the range increase will be greater than the battery cost decline, at least in the short term. Subsequently, the priority settings until 250 km range are (1) range increase, (2) cost competitiveness and (3) increase of RPE. Once range becomes larger than 250 km, range and costs switch places. Based on these assumptions, the following input parameters are used:

- RPE remains zero until the BEV becomes competitive with respect to the ICEV reference;
- Once it becomes competitive, the RPE is gradually increased but the BEV remains slightly more competitive;
- The average range will increase rapidly to reach a 250 km by 2020;
- From 2020 on, the range will increase less rapidly to allow the TCO to decline, but at least reaching 300 km before 2030;
- If the range reaches 300 km before 2030, it is held constant to allow TCO to decline or RPE to kick in;
- The BEV will only become cheaper once the RPE is at the maximum level (€6.895) and the range is not below 300 km (Table 11).

Table 11: The three relating factors and their (assumed) values.

Factor	Current level	Assumed 'satisfactory' level
Cost curve	Not cost competitive	Cost competitive
Range	150 km	300 km
RPE	€0	€6.895

The rules above are applied in the tool using the same user profile as mentioned earlier in this subparagraph. The result is depicted in the figure below (Figure 22). As the figure presents, the BEV will become competitive between in 2023-2024. The RPE only kicks in by 2025 because at that point in time the cost decline becomes bigger than the range increase. The range reaches 300 kilometres by 2025 and from that moment the RPE increases more rapidly, reaching a total value of €3.103 by 2030 which is about 45% of the total required margin.

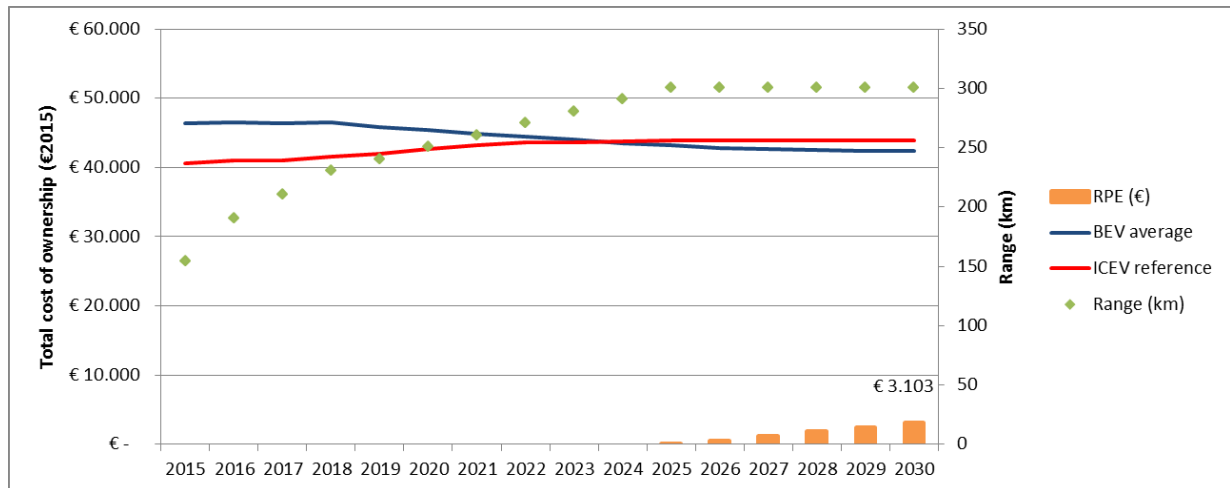


Figure 22: Alternative TCO results (real €2015) using a 'more realistic' approach (own calculations).

The alternative situation shows just one of the many possibilities as it may occur in the future. Questions may arise about the slope of the range and its maximum of 300 kilometres. It also remains unclear whether OEMs can maintain a RPE of €0 until 2025, although one can argue additional subsidies may partly compensate OEMs, eventually leading to a similar cost curve.

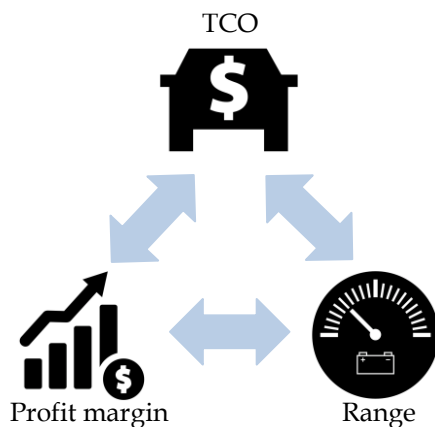


Figure 23: Relationship between TCO, profit margin and range.

Based on this alternative approach it becomes clear that the cost development, RPE and range are three critical requirements that are needed for the BEV to increase adoption and directly substitute each other (Figure 23). However, the three factors cannot all reach their 'satisfactory' value before 2030. Although not drawn in the figure because of its political uncertainty, (fiscal) subsidies is the fourth factor that directly contributes to a more smooth development of these factors.

In this paragraph we used multiple cost curves of different factors based on an extensive desk research and interviews. In addition, some assumptions and scenarios are established. In the following five paragraphs, a detailed explanation of these different cost figures is given.

5.3 Production costs

In Chapter 4 it is concluded the production costs of the electric vehicle is a major contributor to its TCO. All respondents marked production costs in their top-3 priority list of factors that are most important to increase the adoption rate of the electric vehicle (Table 4). As discussed in the previous chapter as well, the production costs is divided in the vehicle specifications and battery technology. These are influenced by both R&D and scale- and learning effects, of which the latter is highlighted as the most important factor for short- and midterm cost reductions in the interviews (Table 4). In this paragraph first the methodology of how production costs are estimated is explained. Next, based on quantitative and qualitative data we estimate the production costs of both the battery as well as the vehicle itself. This will ultimately translate in the future retail price.

5.3.1 Methodology

Following the bottom-up approach (refer to Chapter 2), we would need to identify all components in the car and then estimate their current and future costs. Following a top-down approach, we would apply a learning curve on the vehicle retail price to estimate the future retail price. While the former is beyond the scope of this research and might not incorporate scale- and learning effects, the latter is very simplistic as many different variables are forgotten. The most suitable approach for this research is to use a hybrid approach. Based on the TCO framework note both the retail price and the production cost are important for the TCO: the production cost is directly affected by R&D and scale- and learning, and the retail price is the direct input for the TCO. Also, the retail price is known but the production costs are very hard to determine. Therefore, we use the retail price to determine production costs, apply cost reductions to the production costs, and finally convert it back to the retail price.

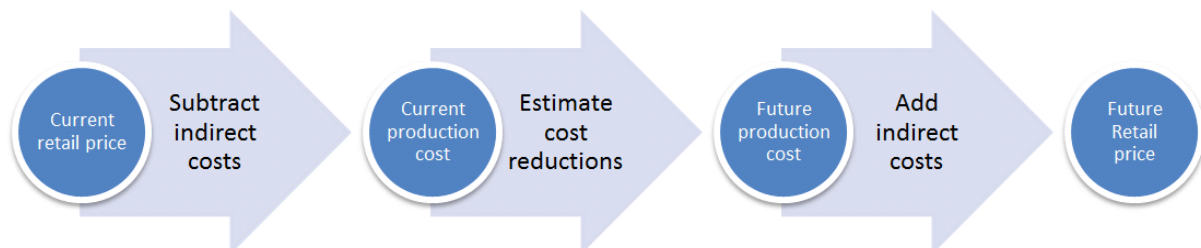


Figure 24: From current retail price to the future retail price using production costs

As visualized in the figure above (Figure 24), the starting point is the current retail price of EVs which can be found on the Internet. To determine the current production cost, a multiplier is used to estimate the difference. In the automotive literature, two types of multipliers are used. This study uses the Retail Price Equivalent (RPE) to estimate the difference, as explained in 5.2.2. A detailed explanation of the two multiplier concepts is discussed in the appendices (APPENDIX XVI). Next, the production costs are distinguished between battery pack costs and the other components of the vehicle. For the vehicle components other than the battery, cost reductions are estimated using literature and experience curves for a C-segment BEV, which is considered to be a competitive market.

For the battery technology cost development, a detailed literature study is conducted to estimate future battery costs. The future production costs can be determined and again the RPE is used to determine the future retail price.

As mentioned earlier in this report, many price differences exist among countries because of pricing strategy and taxes. In order to be consistent, we take the perspective of a Dutch consumer and hence this is based on Dutch prices, model availability and taxes.

5.3.2 Step 1: current retail price to current production cost

To determine the minimum competitive price of a car, the ICEV is used as a reference case. Therefore it is necessary to determine the average production costs of an ICEV. The average retail price of a C-segment ICEV according to BOVAG is €18.400 excluding taxes for petrol cars (Bovag, 2015). To convert this retail price to direct manufacturing costs, the Retail Price Equivalent (RPE) is used. Kolwich determined the average RPE to be 1,60 for the European market (excluding taxes). This means that 60% of the original manufacturing costs is allocated to profits and indirect costs²², such as dealer costs, transportation, R&D and corporate overhead (Kolwich, 2013). This is confirmed in the interview with the automotive consultant, which claimed there is a multiplier of 1,5-1,7 between direct production costs and the sales price (Interview 11). This would mean the production costs of an average segment C ICEV is about €11.500²³. The next step is to subtract the costs of the conventional powertrain, since this would make it possible to hypothetically ‘electrify’ the car from an ICEV to an EV. According to two studies, for an average car the powertrain costs are about 22% (McKinsey, 2012; Weiss, et al., 2012). This means the production costs of a C-segment without powertrain is about €9.000. The interviewee estimated the vehicle costs without powertrain to be more or less €10.000, which is quite consistent with the data presented above (Interview 11).

In this part the price of an EV is determined. For the C-segment in 2015 two EV models were available in the Netherlands. The average retail price of this segment is €29.500 excluding taxes, which means a premium of more than €10.000. However, the RPE is not applied for electric vehicles. In many interviews it is argued EVs are sold at or below production costs. This is a common strategy in the automotive industry, as initial investments are high. Once market share is increased by offering a low price, standardization efficiencies kick-in and this lowers the production costs (Interview 7,10,11). EVs are not subject to a competitive market and hence little to no standardization efficiencies are present at the moment. We assume a RPE of 1,0, which means the production costs of an average C-segment EV equal the selling price of €29.500. This means the production cost of an EV is almost three times that of an ICEV²⁴.

5.3.3 Step 2: current production cost to future production cost

To estimate the potential cost reduction for the upcoming 15 years (and beyond), the production process is distinguished in the two main categories just like in the TCO framework:

1. Battery technology cost reductions;
2. Vehicle technology cost reductions.

ad 1. Battery technology cost reductions

As mentioned earlier, the performance of batteries is assumed to increase in the upcoming years. This will not only result in a better performance, but also in cost reductions. Improving material choice and producing larger cells is likely to result in cost declines as well (Catenacci, et al., 2013; Hill, et al., 2015; Hacker, et al., 2009). Other factors for cost reductions are learning effects and economies of scale, as demand is likely to increase in the upcoming years (Cluzel & Douglas, 2012; Hacker, et al., 2009; Anderson, 2009).

The battery cost reduction is based on an extensive literature review (refer to paragraph 4.9). Some studies are very comprehensive, while others are relatively concise. For example the EPA (2011) has built a model with many input variables that are reviewed by multiple scientific institutions. This BatPac model is very comprehensive and also cited in other scientific references (Cluzel & Douglas,

²² In this report, the terms RPE and indirect costs are used interchangeably. In all cases it refers to the indirect costs (other than direct manufacturing costs) and profits of the OEM.

²³ Throughout this report, numbers are rounded up or down to increase the readability. In the Excel tool and appendices the numbers are not rounded up or down.

²⁴ As will be shown later in this paragraph, for the final result it does not matter whether the RPE is slightly different in reality, because long term RPE will remain 1,6.

2012; Hill, et al., 2015). On the other side, PwC (2012) and BCG (2009) do not mention their methodology, their assumptions or any references. We categorize the studies on the following criteria as discussed in the methodology part of this research (3.4). The result of applying these criteria can be found in the table below (Table 12).

Table 12: Quality categorization of battery studies.

Source (year)	Comprehensiveness	Scientific foundation	Date	Type	Concluding Quality
(Anderson, 2009)	+	-	-	+	+/-
(ARF & McKinsey, 2014)	-	+/-	+	+	+/-
(Book, et al., 2009)	--	+	-	+	+/-
(Dinger, et al., 2010)	-	+	+/-	+	+/-
(Catenacci, et al., 2013)	+	+	+	+	++
(CE Delft, 2011)	+	+/-	+/-	-	+/-
(Cluzel & Douglas, 2012)	+	+/-	+/-	+	+
(EPA, 2013)	++	+	+/-	+	++
(Gerssen-Gondelach & Faaij, 2012)	++	+	+/-	+	++
(Hill, et al., 2015)	++	+	+	-	+
(Kromer & Heywood, 2007)	+	+	-	+	+
(Lee & Lovellette, 2011)	-	-	+/-	-	--
(Hensley, et al., 2009)	-	+	-	+	+/-
(Nemry & Brons, 2010)	+/-	+/-	+/-	-	+/-
(PwC, 2012)	--	+/-	+/-	-	--
(PwC, 2013)	-	+/-	+/-	+	+/-
(TNO, 2011)	-	+/-	+/-	-	-
(Wolfram & Lutsey, 2016)	++	+	+	+	++

In Figure 25 we solely focus on the high quality studies (+ or ++) that composed battery pack prices for BEVs. Although variety amongst the studies still exists, a trend can be recognized without doubt. The variety or bandwidth is a combination of uncertainty in the estimations and prices differentials in the market (this could not exactly be extracted from the literature). The lowest predicted value for a 2030 battery is 149 €/kWh while the highest is 288 €/kWh. More information about how the battery prices are established can be found in the appendices (APPENDIX XVII).

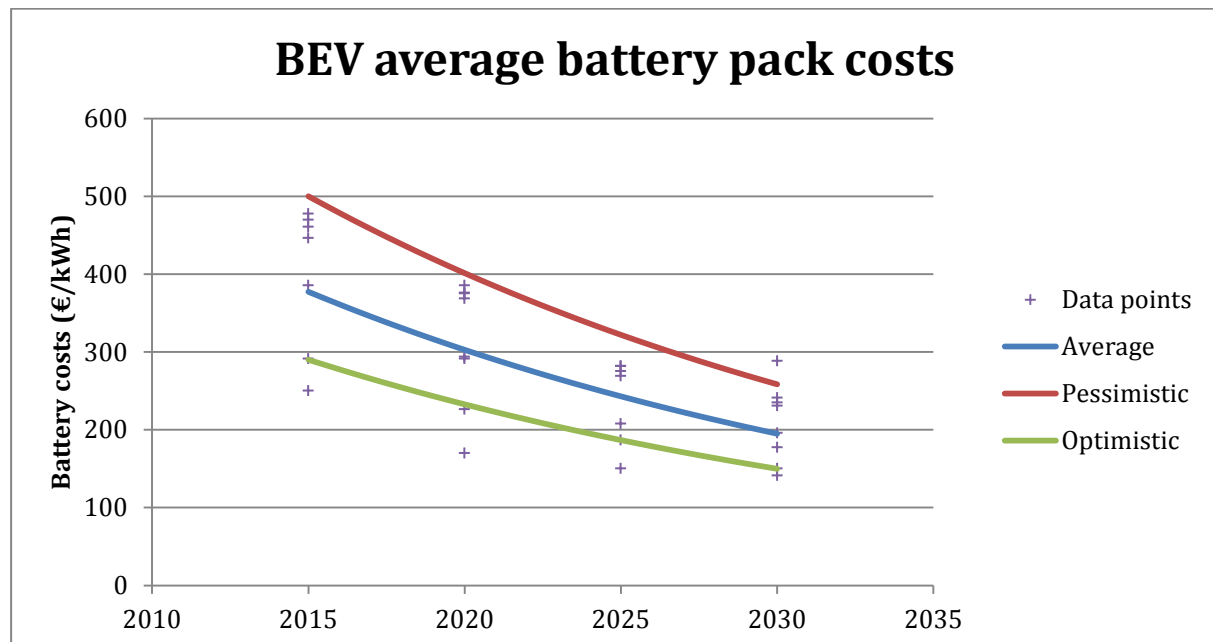


Figure 25: BEV battery price development according to high quality studies in €₂₀₁₅ (own calculations)

In general one can say bigger packages are relatively cheaper since the packing weight overhead is spread over more kWh (Cluzel & Douglas, 2012; CE Delft, 2011). Some studies (CE Delft, 2011) argue the final costs also depend on the size of the battery, since some costs are volume independent. Nevertheless, the additional costs are within the uncertainty range of the predictions anyway, so we won't

account for that in the results. Based on studies, the average curve equals the following equation:

$$y = 377,26e^{-0,22x} \quad (4)$$

So according to the average graph, the current battery costs for BEVs would be €377 per kWh. The average battery size for an C-segment BEV is 28,25 kWh. Hence, the average battery pack costs are €10.500. A pessimistic and optimistic alternative have been established as well based on the upper and lower data points according to the literature (Figure 25).

Three methods are used to verify this average trend: by the interviews, by other literature that compared different studies and by using the experience curve method. First, as will be discussed later, the cost of the battery in proportion to the total production cost is between 30% and 50%. This is in line with what the interviewees expected (Interview 4,11,14). Second, the average figure is also in line with the results from an article in Nature (Nykqvist & Nilsson, 2015), of which the results (graphs) are in line with our findings. See the appendices for the results of Nykvist & Nilsson (2015) (APPENDIX XVIII). The figure is also verified by calculating our own experience curve, as shown in the appendices. For this extrapolation three EV adoption rates are considered based on an extensive literature study: low EV adoption, medium EV adoption and high EV adoption (APPENDIX XIX). It is assumed that all EV types contribute to battery scale- and learning effects. Furthermore, the costs of materials, R&D and depreciation are not subject to economies of scale. Using a learning rate of 22%, which is in line with previous studies (Matteson & Williams, 2015; Weiss, et al., 2012), similar results show up. Most remarkable are the small differences between the different scenarios. This is because the differences between the EV adoption scenarios in cumulative stock is rather limited, especially compared to vehicle technology costs as discussed later on (refer to Figure 28)²⁵. A detailed analysis of this approach can be found in the appendices (APPENDIX XX).

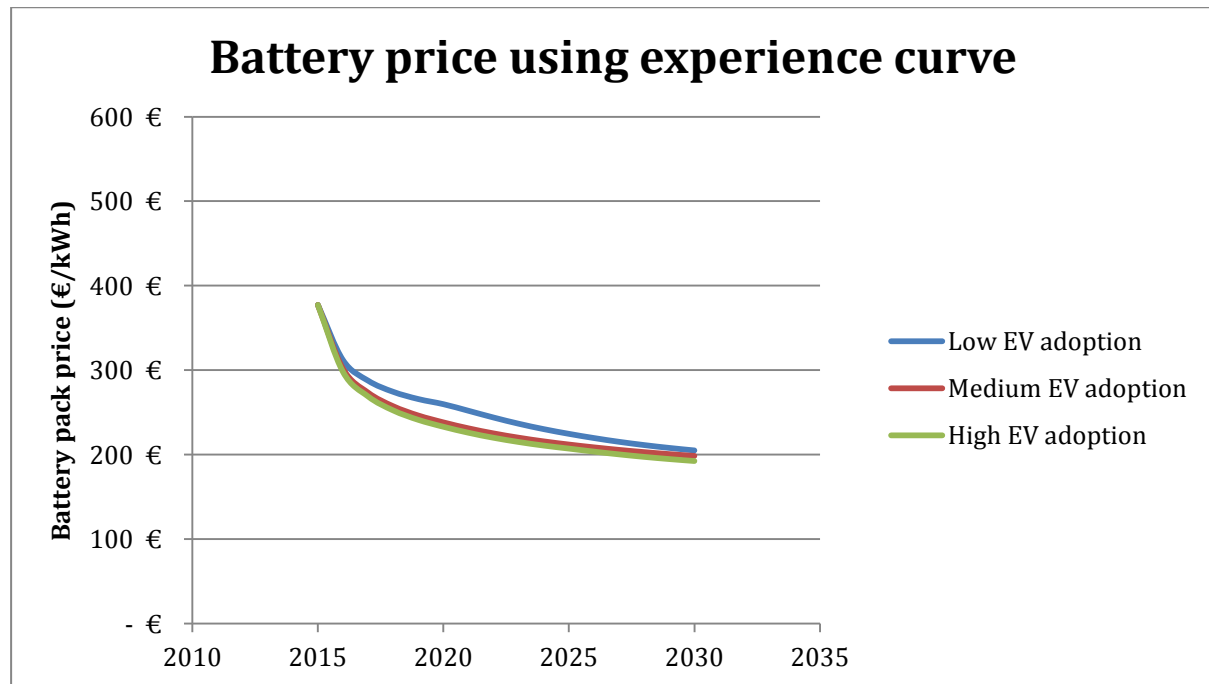


Figure 26: Verification: battery price forecast using experience curves (own calculations)

ad 2. Vehicle technology cost reductions

²⁵ The EV adoption differences between the scenarios is relatively low, while the BEV adoption differences between the scenarios is relatively high (refer to Figure 28), which explains the narrow bandwidth between the curves in Figure 25. In the author's opinion this is because BEVs are not only compared to ICEVs, but also to PHEVs and EREVs. EVs are a combination of BEVs, PHEVs and EREVs and therefore only compared to ICEVs. For BEVs, this may increase the deviation in estimations in the literature.

Currently, even if one excludes the powertrain, the costs of an EV remain higher than ICEVs. This is due to inefficiencies in the production process and (up till now) a limited scale- and learning effect. In other words, we would say the maximum potential cost reductions for EV technology equals the difference between the current vehicle technology cost of the EV and the vehicle technology costs of the ICEV, if we exclude the battery and powertrain costs (since these are fundamentally different)²⁶. This is only true assuming the current ICEV technology is highly standardized. In the textbox below an explanation of the standardization in the automotive industry is discussed.

As mentioned earlier, the automotive sector is a highly standardized and competitive market (TNO, 2011). OEMs attempt to increase economies of scale and offer different models at the same time by means of platforms and modularisation strategies. This means a common structure is shared over different types of vehicles, which makes it possible to use the same components (e.g. suspension and steering) for different vehicle models. The production platforms are flexible in order to allow for different car dimensions (e.g. wheelbase and ground clearance) (Hill, 2016). In combination with modularisation, using the same base components to assemble different end product (e.g. a 60kW or 80 kW motor), it possible to produce different models on the same production line. It is also possible to e.g. produce a petrol and EV on the same production line. According to Hill (2016), the price of a PHEV will equal the price of a conventional engine (Hill, 2016). To conclude, the automotive industry already faces an extreme form of standardization and economies of scale regarding ICEV technology and production. Given a competitive and standardized market, it is assumed the lowest production cost to produce a car without a powertrain is about €9.000.

For the ICEV, in 5.2.2 the current vehicle technology production costs were calculated for a C-segment (€9.000).

For the BEV, the estimated total production costs of an EV are €29.500. To determine the ‘vehicle technology’ production costs, the battery pack costs must be subtracted from the total production cost, using the €377 per kWh and average battery pack of 28,25 kWh for a C-segment. Next to the battery there are some additional costs attributed to the electrical powertrain of an EV, such as motor cost, inverter cost, control unit costs, etc. (TNO, 2011). Based on TNO, et al. (2011), we estimate these current total cost to be €3.000 per vehicle (APPENDIX XXI). In total, the vehicle technology costs for a C-segment BEV are on average €16.000.

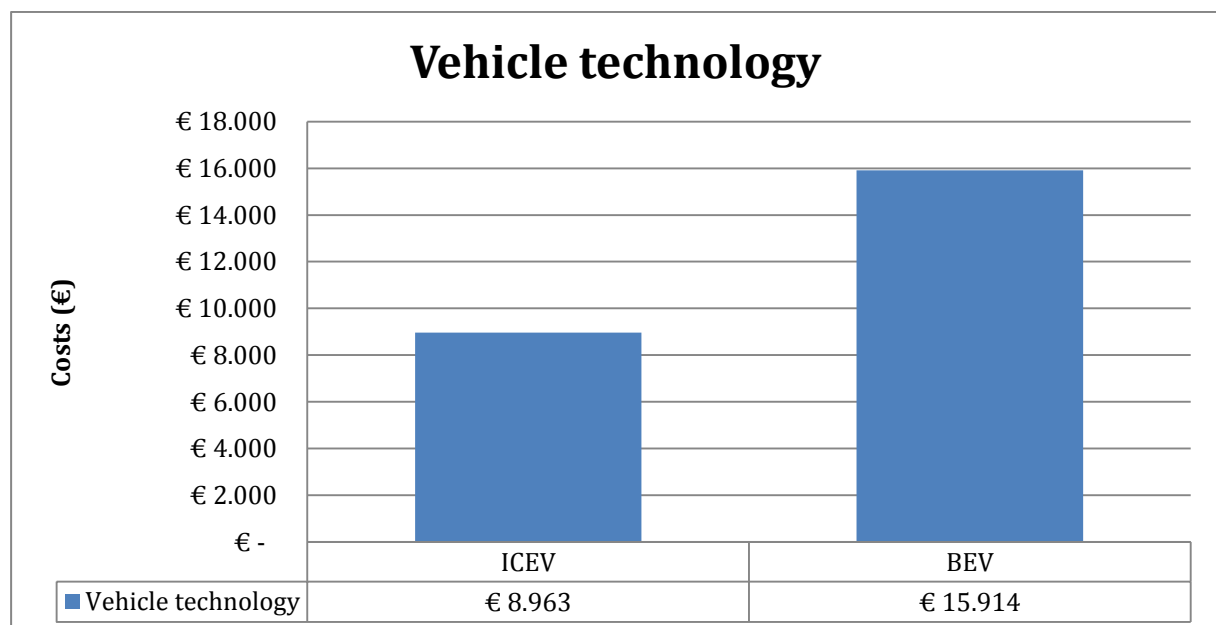


Figure 27: Current vehicle technology costs for ICEVs and BEVs (own calculations)

²⁶ ‘Vehicle technology’ costs in this report is defined as the vehicle costs excluding the ICE powertrain or BEV electrification part. So, vehicle technology costs of BEVs and ICEVs are directly comparable.

As argued above, since the ‘vehicle technology’ in the figure above is similar for ICEV and BEV, the costs can be similar as well if both benefit from scale- and learning effects. Currently, the ICEV benefits from scale- and learning but the BEV is not. Therefore, the maximum reduction potential for this average C-segment car is about €7.000 per vehicle.

This potential will take time of course. For the TCO simulations we therefore apply an experience curve depending on three BEVs adoption rate scenarios. The predicted demand is explained in the appendices (refer to APPENDIX XIX). A learning rate of 15% is assumed, as there is less development of R&D and learning progress compared to battery technology (for which a 22% rate was used), but there is definitely economies of scale potential (Matteson & Williams, 2015; Weiss, et al., 2012). The premium of €7.000 will decline to €3000-€4.500 by 2020 and €2000-€3000 by 2030. This means there is still cost reduction potential after 2030. Equation 1 of Chapter 2 is used to calculate the cost reductions (Equation 4).

$$C(x_t) = €6.951 \frac{x_t}{750.000}^{-0.2345} \quad (4)$$

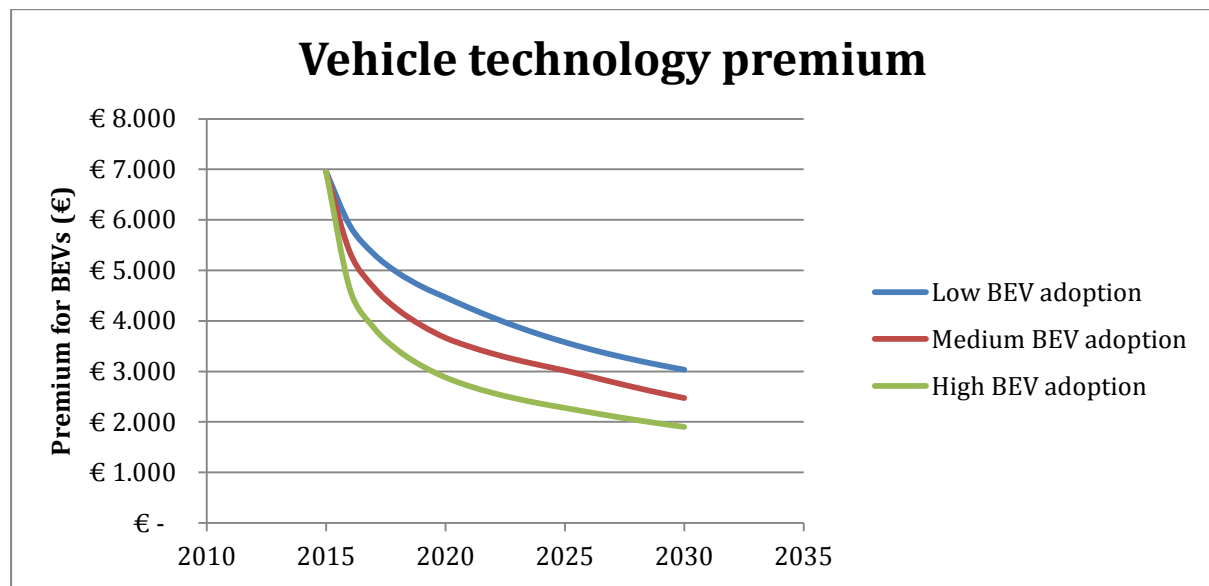


Figure 28: Economies of scale for vehicle technology premium of BEVs (own calculations)

ad 3. Total production costs

Imagine the hypothetical situation the BEV is scaled up at maximum production efficiency next to the ICEV, without physical change in the technical parameters (e.g. battery pack size). For the ICEV this would mean no change in costs²⁷. For the BEV, the battery price would fall to €195 per kWh (on average) and the efficiency gains in vehicle technology would equal the ICEV (please note figure 24 still shows a premium of at least €2.000, so it is a hypothetical situation). According to TNO, et al. (2011), the powertrain costs of a BEV will fall about 20% as well. In total, this would mean a BEV could be produced for just below €20.000. ICEV production costs, on the other hand, will increase due to more strict CO₂ emission regulations. TNO (2011) calculated the additional production costs would increase with €1923 on average to meet the 95 g/km target in 2121 (TNO, 2011).

²⁷ Obviously, many factors may influence the ICEV costs as well as discussed in Chapter 4. However, it is not within the scope of this research to account for influences of the ICEV production costs.

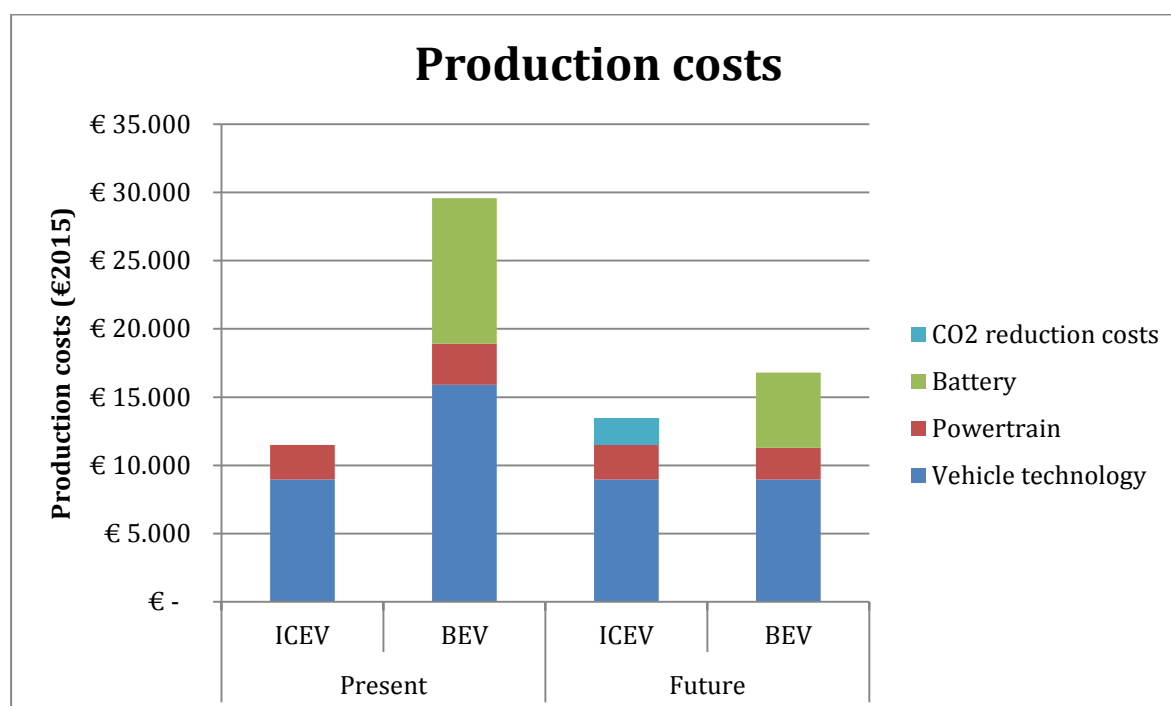


Figure 29: Production costs for BEVs and ICEVs in the present and future situation (own calculations)²⁸

5.3.4 Step 3: future production cost to future retail price

To convert future production cost to the future retail price is basically the inverse of Step 1 in this paragraph: to add the indirect costs and profit margin with the RPE multiplier. In 5.2.2 it was argued the no RPE was applied for EVs at present. It is very unlikely though that will remain the case in the future. In multiple interviews it is mentioned this cannot continue forever and there will be a moment in which producer's will sell their products above the production costs. This is verified by EPA (2013) which states that *"businesses need to be able to earn returns on their investment"* (EPA, 2013). Therefore, it is assumed the indirect costs will also apply to BEVs in the future situation.

The figure below shows the retail price for the present and future situation (Figure 30). As calculated in this paragraph the current BEV retail price is €29.500 without indirect costs. If one would include indirect costs the retail price increases to €36.500 in 2015. The future production costs decline with €13.000 from a technological perspective but due to the €7.000 mark-up the final retail price only declines €6.000.

These figures are based on the average battery price in 2030 and assume vehicle technology is as efficient and standardized as ICEV technology. In the TCO calculation in paragraph 5.2 different battery scenarios are taken into account, but based on similar fundamentals. More details about the calculations in this paragraph can be found in the appendices (APPENDIX XXII).

²⁸ Please note this is a hypothetical situation: both the ICEV and the BEV would need to be produced at maximum efficiency, which is very unlikely as they compete in the same market.

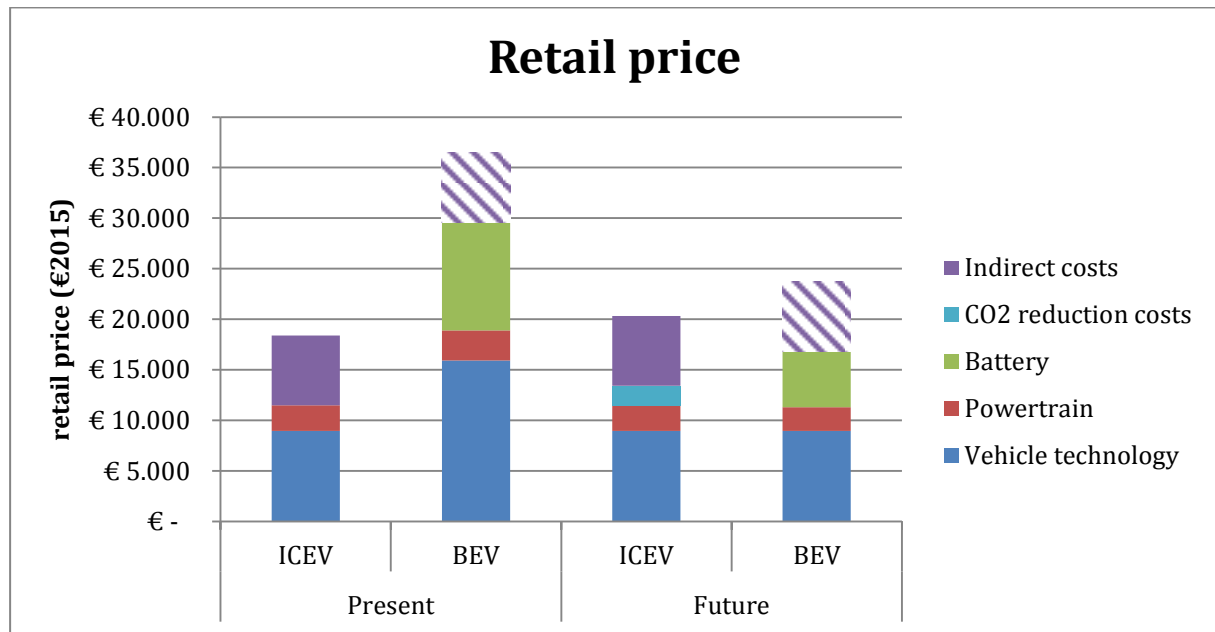


Figure 30: Theoretical retail price of ICEVs and BEVs in the current and future situation (own calculations).

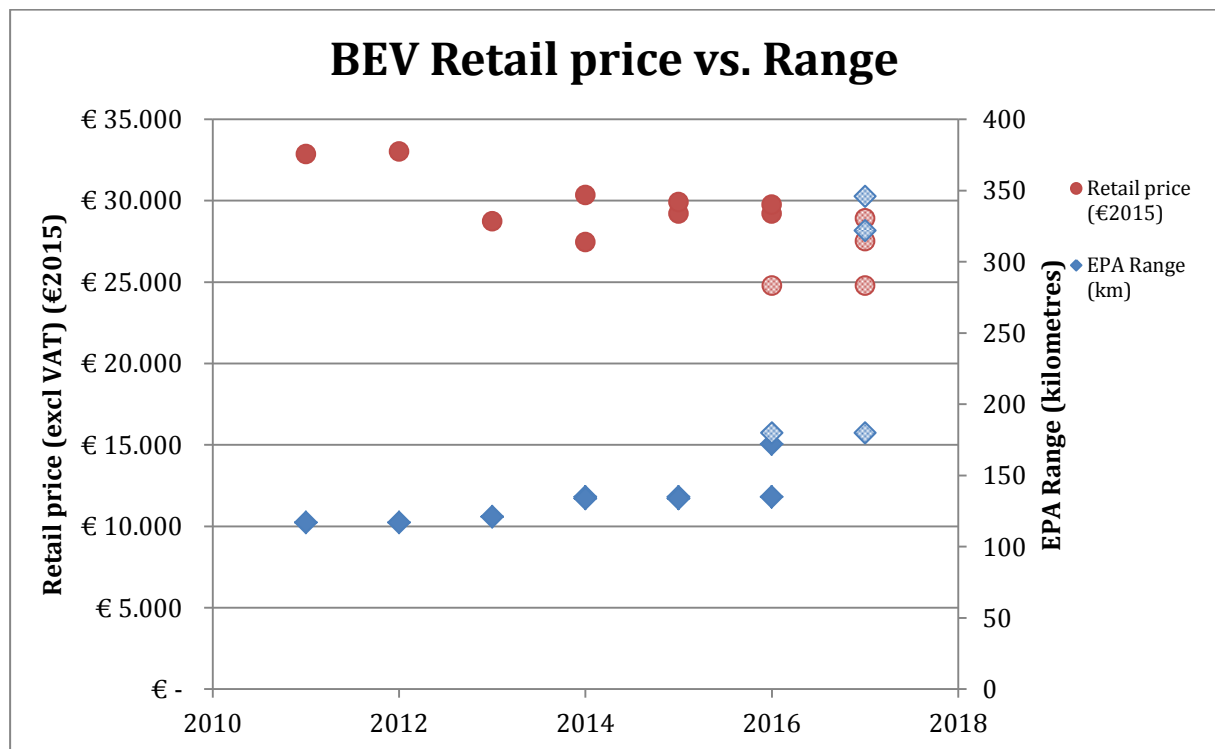


Figure 31: Retail price and range for different C-segment BEV models, including LEAF (2012-2016), e-Golf (204/2015), Bolt (2017), Model 3 (2017) and Ioniq Electric (2016/2017)

There are some side notes however. Based on the interviews, it became clear both the costs as well as the range are problematic for the introduction of EVs. Alternatively, it is possible that when battery prices declines, the battery pack size is increased to enhance the range. Although this increases the attractiveness of the EV as well, it directly substitutes the potential cost reductions with range increase and hence the cost will not fall. In the interview it is expected that range increases between 250 km and 350 km before prices will fall (Interview 7,9). This is verified by historical data, which shows range has increased substantially over the years and especially the years to come, and the real sales price declined a bit (Figure 31). Therefore, in the TCO calculation (paragraph 5.2) the range increase is taken into account at the expense of price decline in the fifth case.

5.4 Resale value

The depreciation of EVs or the resale value after a certain period of time is important in case the owner does not own the EV over the entire lifetime of the car. No previous research has been done whether the depreciation trend of EVs is similar to ICEVs, because the introduction of the EV occurred just some years ago and it takes time to enter the second hand market. In this study three reasons came up why resale value might be lower:

- Uncertainty about technological performance would increase the depreciation rate;
- Battery deterioration can suddenly decrease the value of a car;
- Rapid increase of performance leads to creative destruction.

In this paragraph the focus is on the resale value and we attempt to determine how this resale value should be included in the TCO calculations.

5.4.1 Methodology

CE Delft obtained a database with values of reused cars that are traded in the market. The database contains cross sectional data, so all data with cars for sale in November 2015 are retrieved. In order to use the data, manual information about the EVs should be entered. Therefore, we only included models that had more than nine samples and those are used to determine the depreciation over time. This includes 128 BEVs and 131.511 ICEVs. It is important to note that the price that is linked to the car is the trading price. There is no clue whether these car have been sold eventually. The retail price is not included in the database and manually entered for BEVs. For ICEVs, the average trading value for cars that is less than six months old is used to determine the retail price. In reality the depreciation rate probably declines faster than calculated using this data.

5.4.2 Visualization of the data

The 100% in the figure below (Figure 32) represents the original sticker value of the car when it was introduced. Each dot represents a unique car, of which we know the age (in months/years) and the second hand value. Each dot represents the average trading value of multiple EVs that were registered in that month. The black line represents the average ICEV depreciation over time.

Many cars with an age of three years or older were traded for just 50% of their original value. There are some exceptions: the BMW and Tesla were traded at about 100% or even more of their original value, even after more than a year. According to the interviews this may be caused by fiscal policy. Because of the lease car benefits ('Bijtelling' in Dutch) cars may be 'overvalued', even more than 100% of the original value (Interview 2).

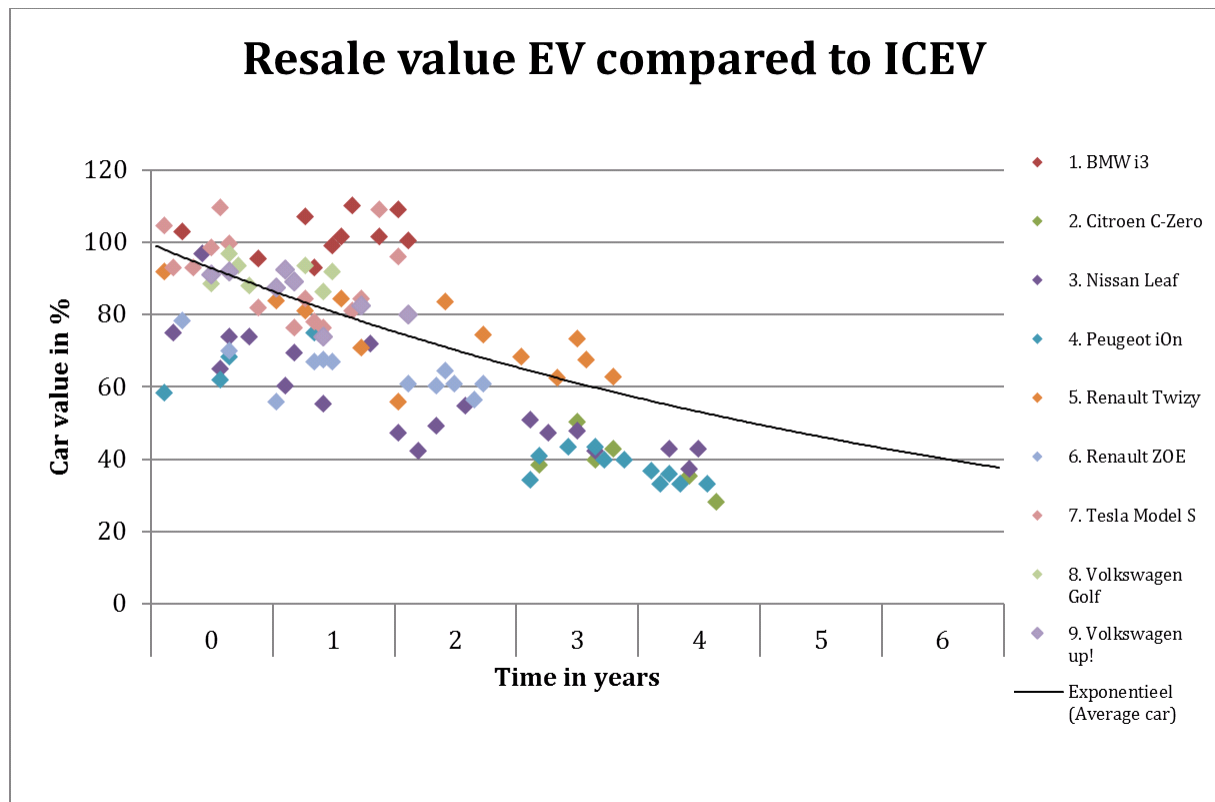


Figure 32: Depreciation of second hand BEVs over time

5.4.3 Regression analysis

A statistical regression analyses (least square method) is performed to determine the relationship of EVs and ICEVs regarding the depreciation rate. For the regression, the age of the car is accounted for.

The result of the first regression show EV has a negative but **not significant** effect on the depreciation rate. This means the depreciation rate may decline faster for EVs, but it is not a statistically significant effect ($P = 0,6612$ / Coefficient = $-0,5779$) (APPENDIX XXIII). There may be several explanations for this result. First, it could be possible the depreciation rate varies considerably among different brands (this seems to be the case based on Figure 32). Although it is possible to account for different brands, more EV data is required to do so. Second, other factors influence the outcomes. This could be fiscal policy effects, price differences between countries in Europe or the mileage of the car. Many more factors may be relevant as discussed in a previous report of CE Delft (Vanherle & Vergeer, 2016). More EVs must be traded in the second hand market to take these factors into account.

To conclude: based on the interviews, the resale value was expected to be lower for EVs. Statistically this hypothesis cannot be verified. Since there is no significant difference found between ICEV and BEVs, the resale value is not taken into account in the TCO calculations and set to €0, irrespective of the years of ownership.

5.5 Energy consumption

The total energy consumption is not only dependent on the type of car, but also on for example the driving style of the driver and whether he/she drives on the highway or in urban areas. This makes it very difficult to directly compare different vehicles.

5.5.1 Methodology

For this research we want an understanding how the literature expects the energy consumption of EVs will evolve over the course of time. Therefore, the literature is reviewed and data is extracted and

converted to one energy unit (kWh/100km) to compare the different studies. The studies will, just like the battery studies, be reviewed against the criteria of comprehensiveness, scientific foundation, date and type. If a study mentions estimations for different points in time (e.g. only for 2015 and 2025), the numbers may be extrapolated to calculate the average energy consumption for all applicable years. In addition, if a study assumes the average consumption of a New European Driving Cycle (NEDC) driving cycle, a 20% 'premium' is added to compensate for real world consumption figures as was done in another peer reviewed study as well (Wu, et al., 2015). Finally, the expected rate of energy consumption over time is applied to the current average energy consumption of the C-segment BEV.

5.5.2 Selection of studies

In total six studies are found that predicted energy consumption. Two studies are discarded right away because they do not mention future energy consumption (Lee & Lovellette, 2011; Tseng, et al., 2013). CE Delft's forecast is based on fixed improvement rates, but it is not exactly clear how the initial (high number) has come about.

Hill, et al (2015) estimates a 2013 segment C car ICEV has a energy consumption of 5,25 L/100km, a PHEV 2,22 L/100km and a BEV 1,167 L/100km. This will decline due to the weight reduction and an increase in overall energy efficiency to a energy consumption of 2,05 and 1,08 L/100km for the PHEV and BEV respectively in 2030 (Hill, et al., 2015; Hill, 2016). TNO published projections back in 2011 for the EV in 2020 and 2030. This is based on the assumptions of weight reductions.

Wu, et al. (2015) takes the NEDC values of 2014 for different BEV segments²⁹. Based on previous literature he assumes a gradual annual fuel efficiency improvement of 1,2% per year up to 2025. He also applies a real-world uplift of about 20% to correct for the fact NEDC figures are not representative for real world driving.

Table 13: Selection of studies for energy consumption.

Source (year)	Comprehensiveness	Scientific foundation	Date	Type	Concluding Quality
(TNO, 2011)	+	+	-	+	+
(Hill, et al. 2015/2016)	++	+	++	+	++
(Wu, et al., 2015)	-	++	++	+	++
(CE Delft, 2011)	-	+	-	+	+/-
(Tseng, et al. 2013)	--	+	+/-	+	+/-
(Lee & Lovellette, 2011)	--	-	-	+	--

5.5.3 Energy consumption estimation

The graph below (Figure 33) shows the average energy consumption of the high quality studies (greater than "+/-"). While Hill, et al. (2015) and TNO, et al. (2011) are quite optimistic, Wu, et al (2015) takes a more conservative approach. TNO, et al. (2011) and Hill, et al. (2015) are very optimistic regarding future energy consumption for EVs. This is because they expect innovation in the electric motor and a significant decrease in battery weight. Wu, et al (2015) takes a conservative approach.

²⁹ Although Wu, et al. (2015) also calculates PHEV segments, but crucial information is missing so we were not able to reproduce the figures. Therefore, we excluded the PHEV figures for this research.

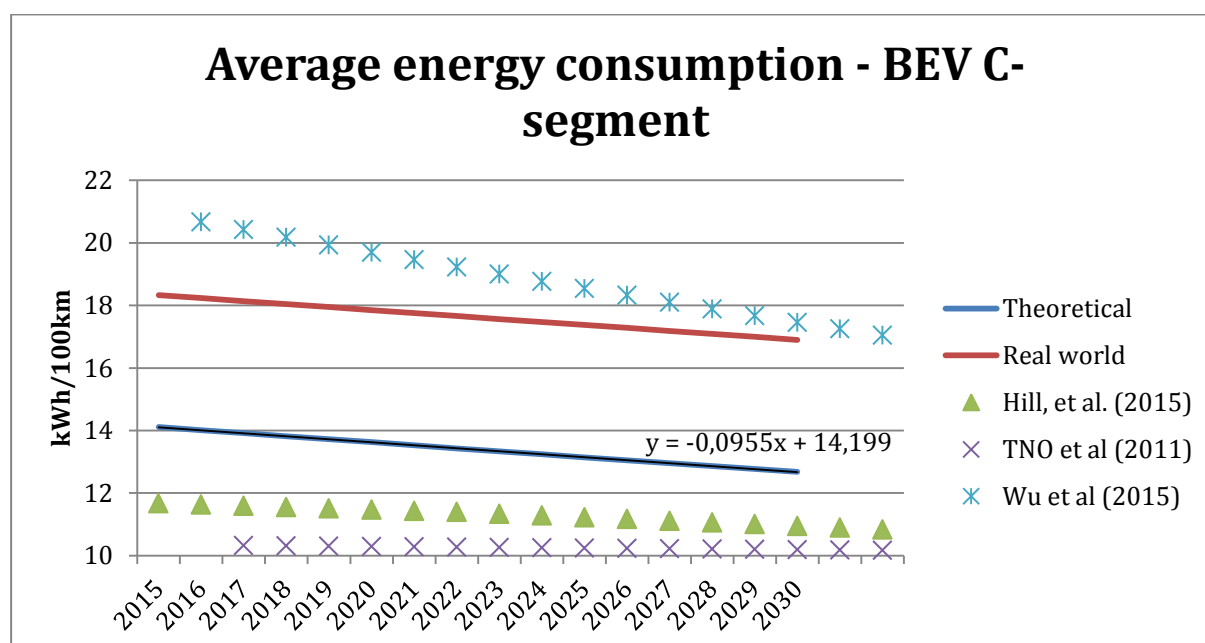


Figure 33: Average energy consumption over time for a C-segment BEV (TNO, 2011; Hill, et al., 2015; Wu, et al., 2015)

However, in reality EPA fuel efficiency numbers for different C-segment model at present are lower. The average energy consumption for the 2015 models of the LEAF and e-Golf are 18,3 kWh/100km (EPA, 2016). Therefore, the equation of the trend line is shifted until it reaches 18,3 kWh/100km, which means the corrected equation is $y = -0,0955 + 18,3$ to take into account real world driven patterns.

There is another aspect that leads to energy efficiency loss. In one interview it was brought to the attention there are some significant losses in energy efficiency during charging (Interview 14). This means there is a difference between the amount of kWh a consumer has to pay and the amount of kWh the battery is charged with. This can be caused by electrical resistance and the fact that some devices of the car are engaged during charging, such as the battery management system and fans for cooling. This energy loss is not mentioned in any study and the only information available was through general internet webpages (Nissan, 2014; Tesla Motors, 2015). These sources claim an efficiency as low as 88% although interviewee argues it is much lower (Interview 16). Based on this we assume an optimistic 95% and pessimistic 88% efficiency. It is expected these losses will be optimized in the future but cannot be eliminated entirely, leading to a 98% optimistic and 95% pessimistic efficiency (APPENDIX XXIV).

5.6 Charging costs

The previous paragraph discussed the fuel economy of the car and charging losses. Following the framework of Chapter 4, to determine the total charging costs, we also need to determine the price paid for electricity at the charging point and the price of the home charger or subscription fee when using a public charging point.

5.6.1 Methodology

The electricity prices and public charging costs may greatly influence over time and are therefore subject to many uncertainties. Multiple scenarios are developed for these two variables to account for different future situations. These scenarios are based on the discussions during the interviews and information found in the desk research.

The current and future costs of home charging are less subject to uncertainty. Quite some sources have been found that discuss future home charging costs and therefore these are used to estimate the costs.

Since the costs still vary widely, we use actual home charger cost data to exclude studies that over- or underestimated the 2015 cost values.

5.6.2 Electricity prices

Electricity prices may vary considerably over the years and are influenced by exogenous factors like government policies and commodity prices of gas and oil. CO₂ prices play a role as well, just like the development of renewable energy sources. The energy prices in other countries also influence the Dutch price (ECN, 2015). In this report three scenarios are used for the electricity price:

1. The electricity price will increase over time;
2. The electricity price will remain constant over time;
3. The electricity price will decrease over time.

ad 1. The electricity price will increase over time

ECN³⁰ estimates the electricity prices for consumers to increase from 2015 to 2020 because the wholesale price increases and the ODE tax (a tax which is used to provide sustainable energy subsidies) will increase. In total, this leads to an increase of 6 eurocents in five years time. No predication is available between 2020 and 2030 for consumer prices. A wholesale price predication has been published though. If one would assume a direct translation between wholesale prices and the electricity costs for consumers, the total electricity price will increase to €0,30 per kWh in 2030 according to ECN (ECN, 2015). A detailed description can be found in the appendices (APPENDIX XXV).

ad 2. The electricity price will remain constant over time

However, a big proportion of the electricity bill is taxes. Government policies to favour (sustainable electricity) over gas or oil may influence this trend. In addition, the fluctuations for consumers in the past remain fairly low (ECN, 2015). Therefore, it could also be possible the electricity price remains similar to the current price. Therefore, in this scenario it is assumed the 2015 prices will apply until 2030 and beyond.

ad 3. The electricity price will decrease over time

In an ultimate situation prices for EVs might actually decrease with smart grid integration (Interview 9). This is because smart grid integration can dampen big fluctuations in the energy grid. Consumers may be offered a lower price by the energy companies if other costs can be avoided, like reinforcing the grid and increasing production of power plants. According to a study by Movares (2016), this can lead to costs saving between 35% and 60% of the wholesale energy price. For consumers this could mean the current 2015 electricity price would decline from €0,22 to €0,18-€0,20 (Movares, 2016). This is represented by this scenario, assuming electricity prices will not increase. Smart grid integration is not expected before 2020, so until then the price remains constant. From 2020 on, smart grid integration kicks in leading to consumer price savings of 25%, gradually increasing to 60% savings in 2030³¹.

A visual presentation of these three scenarios can be found in the appendices (APPENDIX XXV).

5.6.3 Home charging

Ten studies are obtained that mention cost development of level 2 chargers. Many studies differentiate between acquisition costs and installation costs. It is expected the acquisition costs will decline over time due to scale and learning effects. The labour rate will remain constant, on the other hand, and since it can account for 30%-50% of the total costs, the decline is relatively low (May & Mattila, 2009; National Research Council, 2013; EPA, 2013; Hill, et al., 2013; Weeda, 2013; Madina, 2015).

³⁰ ECN and PBL published this information in the NEV ('Nationale Energie Verkenning').

³¹ Be aware the savings apply only to the consumer price (which was €0,06 in 2015), not to the taxes.

The current costs range between €600 and €2300 (Figure 55). This range is quite large. There may be some reasons why the range is quite large.

- Differences in labour rates can be used in different countries;
- Manufacturers offer chargers for a different price;
- The power output can range between 3,7-7,0kW of which the latter is more expensive.

To come up with reliable cost estimations, the studies are compared with actual 2015 home chargers costs to exclude the outliers. Using the Nissan and Tesla website, it became clear the actual home charger installation costs are between €900-1800 dependent whether the house need a utility upgrade or not (Nissan, 2016; Tesla Motors, 2016). The charging point of Renault is also sold for between €1000-€1500 (Interview 4). Therefore, all studies that are below €900 or above €1800 for their 2015 home charger cost estimations are excluded. This leaves us with five remaining studies, which are also depicted in the figure below (Figure 34).

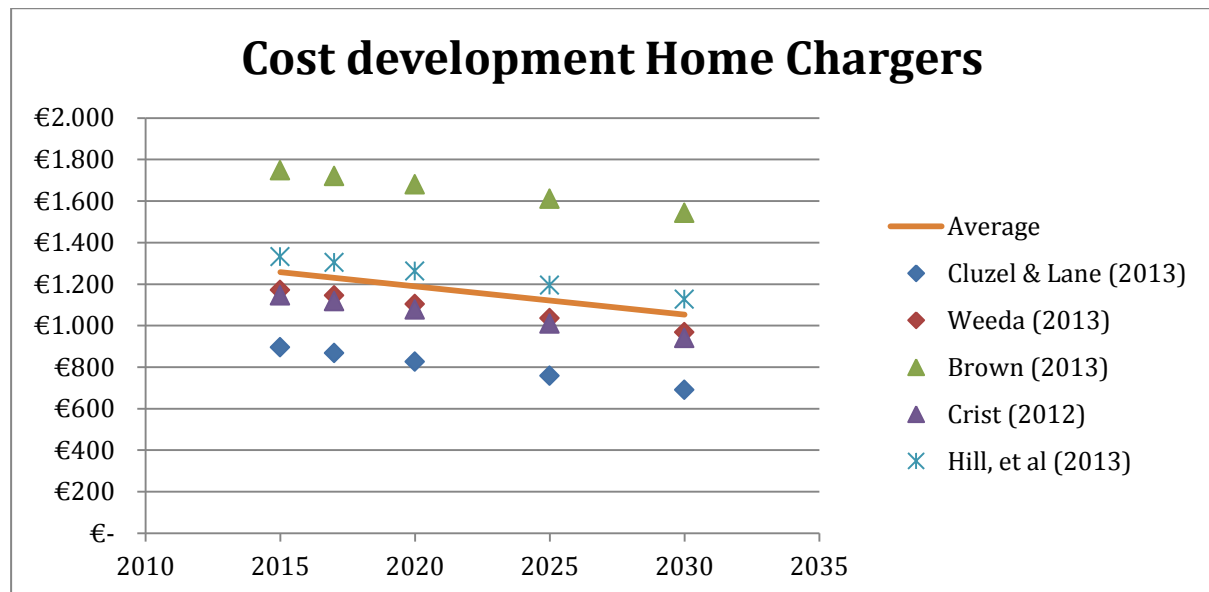


Figure 34: Cost extrapolation of level 2 home chargers (corrected for inflation and currency exchange rate if applicable €₂₀₁₅)

In order to estimate the future home charging costs, we apply the learning rate of the NRC (2013), the only study that actually applied a learning rate, to the more realistic studies (Cluzel & Lane, 2013; Weeda, 2013; Crist, 2012; Hill, et al., 2013; Brown, 2013). The result is shown in the figure above (Figure 34). Note that these numbers are not cited from the original sources, but based on the NRC (2013) learning rate with the input of the sources as mentioned in the legend. NRC learning rate is based on the following equation: $y = -27577 \ln(x) + 211717$, in which x represents the year and y the total costs in Euros₂₀₁₅. The original graph with corresponding studies can be found in the appendices, as well as a more detailed discussion of the different studies that are used in this report (APPENDIX XXVI).

5.6.4 Public charging

If the consumer wishes to use public charging infrastructure, one has to become a member of a charging provider. In the Netherlands there are ten providers that offer a subscription to charge at a public company. The charging provider can be, but is not necessarily the same as the chargepoint operators. The latter provides the actual charging station. Each charging provider has its own agreement with the charging operator which results in a complex price matrix for the consumer. This is dependent on the provider you subscribed to and the charging point you end up. Wolbertus (2016) has developed this matrix in which the actual prices are shown (Wolbertus, 2016). This does not only include the

price per kWh, but the starting fee, monthly subscription fee and one-time subscription fee as well. The matrix is enclosed in the appendices (APPENDIX XXVII).

The current public charging costs are on average €0,32 per kWh. It is very difficult to predict what the future will do. According to Hoekstra (2015) and our interviews, the business case of charging is still not viable and subsidies are distorting the cost figures (Hoekstra, 2014). Hence it is impossible to relate the investment costs to the final customer price as long as exact subsidies and its timeframe remains unclear. The uncertainty is also evident in the interviews, as one interview expects the costs for consumers to decline (Interview 3,5) and others think it will increase (Interview 12). Some even assume a different energy system will flexible prices for consumers (Interview 9,16). We therefore introduce three possibilities:

1. Prices decline to €0,27 per kWh: high utilisation rate of EVs increases efficiency (Interview 9), economies of scale in the charging technology and its installation (Interview 3,9), special energy tax for charging providers (Interview 12) and smart grid results in lower price during off-peak periods (Interview 9).
2. Prices increase to €0,37 per kWh: (local) governments retract subsidies, utilisation remains fairly low, charging companies are forced to become profitable and hourly fees are introduced (Interview 12).
3. Prices remain the same: a combination of the effects mentioned above will compensate each other.

These prices are based on the current electricity price (medium scenario in paragraph 5.6.2) and thus may alter when the electricity price changes. A combination of a pessimistic (optimistic) public costs scenario and a pessimistic (optimistic) electricity price scenario will then result in an even higher (lower) price.

5.7 Maintenance & insurance

For BEVs, there is generally consensus in the literature and interviews the maintenance costs are relatively low as was explained in the previous chapter. In this paragraph we highlight the cost expectations for BEV maintenance and repair. Insurance is discussed at the end of this paragraph

5.7.1 Methodology

As with other cost parameters, a literature study is conducted for maintenance costs. Since these costs may vary among countries, car models and segments, it is difficult to control for such factors in combination with a lack of literature studies available. Therefore, we also included CE Delft datasheets about maintenance costs of cars in the Netherlands.

For the insurance no scientific data could be obtained. As concluded from Chapter 4 (paragraph 4.4.3), there is no difference in insurance between EVs and ICEVs. Therefore, Dutch insurance websites are used to determine the price.

5.7.2 Selection of studies

Just a few studies provided detailed insight on BEV maintenance cost. CE Delft (2011) expects a 50% decline in maintenance costs for BEVs compared to ICEVs. Van Vliet (2010) and Crist (2012) use this number as well for their high scenario. Other studies did not mentioned a clear reason why costs would change or used aggregated cost categories which made it impossible to extract the real maintenance costs (Wu, et al., 2015; Lee & Lovellette, 2011; Tseng, et al., 2013; Davis, 2014).

Table 14: Selection of studies for maintenance costs.

Source (year)	Comprehensiveness	Scientific foundation	Date	Type	Concluding Quality
(CE Delft, 2011)	+	+	-	+	++
(Crist, 2012)	+	+	-	+	++
(van Vliet, et al., 2010)	+	++	--	+/-	++
(Wu, et al., 2015)	--	++	+	-	+
(Lee & Lovellette, 2011)	--	--	-	+	--
(Tseng, et al. 2013)	--	+	+/-	+	+
(Davies, 2014)	-	--	+	+	+/-

5.7.3 Results

The absolute cost figures between the studies vary as well (APPENDIX XXVIII). This could be because of different countries and whether repairs are included or not. Since this TCO focuses on Dutch households, data for The Netherlands is obtained to define the ICEV maintenance and repair costs. This is based on data of CE Delft, who participated in several transport projects with the Dutch Ministry of Infrastructure & Environment ('De Brandstofvisie'). In those projects it is determined that 3,0 eurocent/km is the most accurate average number for maintenance and repair. This number is used for all car sizes.

Although in 'De Brandstofvisie' data sheets the same number is used for maintenance and repair costs for BEV, we argue otherwise. Three relatively old studies use a 50% reduction for BEV maintenance costs compared to ICEV, either in their medium or high scenario. The majority of the interviewees stated the maintenance costs of BEVs are lower (Interview 1,2,4,7,10,13,14), therefore the low scenarios of the literature are discarded. To conclude, a 50% maintenance reduction is applied for BEV, which results in 1,5 eurocent/km. As there is no scientific evidence the gap between ICEV and BEV maintenance costs will widen in the upcoming years, it will be held constant.

For insurance, a Dutch comparing website³² for car insurance is used. Since insurances are price sensitive on many fronts, the ICEV reference and BEV car type must be almost similar. Therefore, the insurance costs for a VW Golf and a VW e-Golf are retrieved with the same input parameters (such as age, address, type of insurance, etc.). The average insurance fee of the top-3 insurance hits is used in the TCO calculations, which resulted in a monthly fee of respectively €48,70 and €58,93 for the ICEV and BEV.

5.8 Sensitivity analysis

A sensitivity analysis is conducted to see the effect of changes of the input parameters, especially those who remain uncertain. This way it is possible to determine the extent to which parameters influence the TCO. Uncertainty in battery costs, electricity prices and demand are already incorporated in the upper/lower bound of the results, so in this paragraph we rather focus on the variables that are not altered in the previous paragraphs. This includes the individual parameters that shape the user profile and cost regarding the technology.

5.8.1 User profile

There are five input parameters that determine the final user profile. In this sensitivity analysis, all the input parameters are increased proportionally to find out to what extent each individual parameter influences the final TCO (Table 15). As a reference the second user profile is used from paragraph 5.2.

³² The Dutch website independer.nl is used to compare the Dutch insurance fees. Similar input parameters are entered in order to compare the insurance fees. The average fee of the best three insurances were used (according to independer.nl).

Table 15: User profile input parameters for sensitivity analysis.

Input parameter	Reference level	20% increase level	20% decrease
Annual kilometres	10754 km	12905 km	8603 km
Proportion home charging	50%	60%	40%
Years of ownership	5 years	6 years	4 years
Charging sessions a week	3 sessions a week	3,6 sessions a week	2,4 sessions a week
Discount rate	30%	36%	24%

The financial TCO gap between the BEV average (blue line in the graph) and the ICEV reference (red line in the graph) is €19.000 in 2015 and €10.200 in 2030 for the scenario excluding government influences. In the sensitivity analysis each parameter is increased and decreased by 20% one by one. Then the difference between the original financial gap and the new gap is determined.

The results are presented in the table below (Table 16). As the two columns on the right show, the annual kilometres have the greatest effect on the TCO. A 20% increase in the annual mileage may result in a gap decline of 0,88% in 2015 and increases to a gap decline of 2,73% in 2030. The altered discount rate results in an increased TCO gap because the relatively high future ICEV recurring costs are subject to a higher discount rate. This should be handled with care as well, since discount rates in the literature fluctuate between 4% (social) and 30% (private, conservative) (refer to paragraph 4.4.5). This is way more than a 20% increase and can have a big effect, especially when government influences are included.

Table 16: Sensitivity analysis for the user profile (own calculations).

Input parameter	Original TCO gap (2015/2030)	Difference if increased (2015/2030)	Delta if decreased (2015/2030)
Annual kilometres	€19.052 / €10.216	-0,88% / -2,73%	0,86% / 2,59%
Home/public charging		-0,25% / -0,43%	0,25% / 0,43%
Years of ownership		-0,19% / -0,68%	0,24% / 0,87%
Charging sessions a week		0,08% / 0,16%	-0,08% / -0,16%
Discount rate		0,09% / 0,50%	-0,11% / -0,60%

5.8.2 Technology costs

For some technological parameters there was no data or indication to create scenarios regarding costs. This includes energy consumption, home chargers, powertrain costs and maintenance. For the first three, the costs are increased and decreased with 10% to see the effect on the TCO. The latter, maintenance, is a special case in this regard. In the TCO results the maintenance costs are assumed to be 50% of the ICEV's maintenance costs based on the literature and interview. Furthermore, it was assumed the maintenance costs of both BEVs and ICEVs remain constant over time. In reality this may not be the case, as costs can increase when the car becomes of age and there is many uncertainty regarding BEV's maintenance costs. Again, the reference case is the second user profile just like in the previous subparagraph (see Table 15, first and second column).

Table 17: Sensitivity analysis for technical parameters (own calculations).

Input parameter	Original TCO gap (2015/2030)	Delta if increased (2015/2030)	Delta if decreased (2015/2030)
Energy consumption 10% change	€19.052 / €10.216	0,29% / 0,49%	-0,29% / -0,49%
Home chargers 10% change		0,66% / 1,02%	-0,66% / -1,04%
Powertrain costs 10% change		1,55% / 2,22%	-1,60% / -2,32%
Maintenance costs are similar to ICEV		2,61% / 4,76%	N/A

The results are shown in the table above (Table 17). Out of the first three, the powertrain has the biggest effect. This is because the costs are relatively large and they are part of the acquisition price and

hence not discounted. Maintenance costs are also a big influence on the TCO. Given the uncertainty regarding the BEV's maintenance costs and lack of real life data, more research on this topic is needed to increase the accuracy of future TCO models.

5.9 Limitations

Any calculation tool is subject to assumptions about the present values and future developments. In this paragraph the assumptions and limitations of the tool are discussed, which may become a source for future research. The assumptions are distinguished in the following categories:

1. One-time costs
2. Recurring costs
3. Other influences
4. Relation between Chapter 4 and 5

ad 1. One-time costs

The productions costs are calculated based on the average Dutch retail price of different models. Data from multiple studies have been obtained to calculate production costs, but cost specifications for individual car models might differ in reality. It is assumed the Dutch retail prices of cars (excluding taxes) are a good indication of the average retail price in general. The RPE is assumed to be 1,6 for ICEVs and 1,0 for BEVs based on the data available. For the (future) cost development the absolute monetary figures are used, since it is impossible to know whether RPE multiplier will remain 1,6, both for ICEVs and EVs.

Regarding vehicle technology costs, it is assumed these costs for BEVs may ultimately reach vehicle technology costs of ICEVs, as it concerns the same components (all unique BEV/ICEV components are excluded). Using the top down experience curve method the cost decline is estimated, since it projects scale and learning benefits. The experience curve method might become less accurate once the premium declines, as it never reaches 'zero' premium. This is however post-2030 and not applicable for this research. Disruptive innovations in vehicle technology are not accounted for.

Regarding battery technology, literature data is used rather than experience curve to use a combination of top-down and bottom-up. The experience curve is used for verification, using similar learning rates as other battery studies. The literature used did account for R&D development in battery technology, but a big disruptive innovation that would commercialize before 2030 is not accounted for.

The resale value is set to zero in this research, based on the arguments that there is no statistical significance based on the data. It is not unlikely this proves to be significant in the future, as the depreciation might change once EVs become more embedded in our society.

Innovations in vehicle technology and battery technology can affect the weight for the car which on its turn affects energy consumption. Meanwhile, increasing range by a larger battery pack increases the range as well. Following the literature used, we assume a weight reduction which translates in better energy consumption, but do not adjust this when battery packs are either increased or decreased as exact figures are unknown.

In the case results, the range cannot be increased more than the maximum reduction in battery costs over time. This essentially means the battery pack size may become bigger once costs per kWh decline, but the total battery pack costs cannot increase. This may be different in reality as explained in the alternative situation (subparagraph 5.2.3).

ad 2. Recurring costs

For charging, it is assumed the consumers want to buy a home charging unit. This is included in the TCO calculations. The possibility that one may charge for 'free', e.g. at work, is not accounted for in the tool. It is also assumed the fixed charging fees (fee per session and subscription fees) remain constant over the course of time. Moreover, the public charging costs are determined from a consumer perspective, which is the basis to set up scenarios. Another method, which is not used in this research, is to take business perspective: one could research the business case of public charging and estimate which price is necessary to reach a certain company profit. Future research could incorporate this approach as well.

Regarding energy/fuels costs which occur beyond 2030 (e.g. when buying a car in 2028 and 10 years of ownership), the post 2030-costs equal the 2030-costs.

In addition, maintenance and insurance costs are also constant over time. Maintenance may in reality show a different pattern, in which the costs are low in the initial years after acquisition and increase over time. This is not included in the tool.

ad 3. Other influences

From a financial perspective, there are two assumptions as well. The consumer's perspective of owning a car is taken. This means that lease driver may experience a different situation, because they do not need to buy the car but pay a monthly premium. That leaves us with subsidies and taxes. The graphs that present cost curves with government influences represent current taxes and subsidies. As it would be very arbitrary to guess future taxes and subsidies, a 'business as usual' situation is used. The only exception is the short term energy taxes in the pessimistic scenario, as predicted by the literature. Indeed, this would mean the BPM acquisition tax for BEVs remains zero, also in 2030.

In addition, it is important to realize the focus in this research is the TCO of the EV, not the ICEVs'. As it is difficult to interpret the results without an ICEV's TCO as a reference, the costs of the conventional car are included as well. However, more assumptions are made and a less thorough research of the ICEV is conducted since it is not part of the initial research questions. A detailed explanation of the input data for the ICEV is included in the appendices (refer to APPENDIX XV).

ad 4. Relation between Chapter 4 and 5

In Chapter 4 we presented a very extensive TCO framework with various reinforcing loops and feedback relations. Subsequently, in Chapter 5 we discard many of these newly discovered factors due to the limited scope of this research. In addition, the included factors that could not be monetarized easily were used for different demand scenarios. These are two limitations for the accuracy of the TCO calculations. Monetarizing the additional factors and including all of them in the calculations could be a direction for future research and improve the TCO calculations even more. It is the author's expectation that it would not lead to a big change in the TCO curve's shape, because all discarded factors are indirectly affecting the TCO. However, it could definitely accelerate or delay the progress of the TCO development, meaning a translation over the x-as of the curve,

5.10 Conclusion

In this chapter the total cost of ownership of a C-segment BEV is calculated for multiple scenarios and cases. First, the scope is narrowed down to one car segment and one EV type. Subsequently, the costs are calculated for each category, such as production costs, charging costs and maintenance among others. Finally, the total cost of ownership is presented for multiple cases, in which two user profiles are used and government fiscal influences are both included and excluded. Finally, a sensitivity analysis is conducted to determine the most influencing factors and the assumptions are clarified to show the limitations of this tool. In this paragraph we refer back to the research question and answer the sub questions.

Question 2: *"How will the total cost of ownership of the electric vehicle develop up to 2030?"*

The following sub questions are relevant:

1. How can the TCO be calculated?
 2. What are the cost estimations of each relevant factor?
 3. What are the scenarios and assumptions in order to calculate the TCO?
 4. To what extent do the factors influence the TCO?
-

ad 1. How can the TCO be calculated?

In this research a hybrid approach is taken, based on the bottom-up and down-top methods used in cost literature (Chapter 2). Retail prices (excluding taxes) are used to derive the production costs, which is the basis of a further break down of individual components. Based on literature, (non)-

scientific data and interviews the future prices of these components is estimated. If the uncertainty of the development is high, multiple scenarios are established. This is also done for recurring factors like maintenance, energy consumption, insurance and charging. All factors are discounted and summed to calculate the total cost of ownership, either for the ownership period or the costs per kilometre.

ad 2. What are the cost estimations of each relevant factor?

In an average situation the initial purchase costs is still the main cost component of the total cost of ownership, although it is dependent on the years of ownership, annual kilometres driven and discount rate. Assuming the cases used in this chapter, the one-time costs contain 81%-91% of the average total cost of ownership (excluding taxes). This declines slightly to a 78%-90% proportion in 2030, which is still quite large. Only when the user profile is set more 'favourable', the proportion will decline significantly. The vehicle technology costs are the most expensive within the production costs and also the expected decline is largest. This however is a distorted view because battery cost reduction is for 80% attributed to a range increase. If that would be neglected, the battery costs would account for the biggest decline in production costs (up to 50%).

Within the recurring costs, insurance costs are the biggest component in absolute terms, but these are also quite high for ICEVs. Charging costs on the other hand, are significantly lower in than the average ICEV fuel costs, even in the pessimistic scenario. Maintenance costs are considered to be lower as well (50%). Finally, if accounted for, taxes are a big proportion of the recurring costs. Up to 19% in the average scenario of the BEV discounted costs are taxes, but that is still lower than the ICEV which face a percentage up to 37%.

ad 3. What are the scenarios and assumptions in order to calculate the TCO?

Three scenarios are established which resulted in the BEV's TCO range, creating an upper (optimistic) and lower (pessimistic) bound. This is done for calculations in which demand scenarios are required, such as estimating the decline of vehicle technology costs. Battery cost scenarios are applied as well, just like electricity and charging prices as it is hard to predict such prices for the upcoming 15 years. Since data about charging efficiency is very limited, scenarios are included there as well. Together this may lead to a real deviation up to 8% in 2015, which increased over time up to 11% in 2030 with respect to the average (excl. taxes).

Regarding input parameters a 2x2 matrix is compiled which consists of a case with and without government influences and two user profiles. Since the two profiles have different input values, such as annual kilometres, ownership period, discount rate and home/public charging proportions multiple perspectives are presented.

The assumptions are discussed in detail in paragraph 5.9. Important assumptions regarding Dutch retail prices, the RPE and maintenance costs must be clear to show the limitations of the cost development predictions. However, what is considered a crucial assumption is the relation between range, costs and the RPE, possibly moderated by fiscal stimulus. Once one of these variables is changed, the graph changes significantly as well. Since it is impossible to predict future pricing strategy and political willingness for fiscal policies worldwide, the relationship is elaborated on in the alternative results in paragraph 5.2.3.

ad 4. To what extent do the factors influence the TCO?

The one time costs remain the biggest factor that influence the TCO compared to the recurring costs, about 80% of the total TCO in the neutral scenario and the first user profile. The uncertainty in vehicle technology, battery costs, energy prices and charging costs are represented by the lower and upper bound. Battery technology uncertainty plays the biggest role in this, up to 63% of the price differential in 2030 between the lower and upper bound in the scenario excluding government influences. The sensitivity analysis shows that the user profile is critical as well. Especially when the annual kilometres and years of ownership are increased the TCO may alter significantly. Maintenance and power-train costs are also important factors that have a large influence on the TCO. More research into these component's cost curves could help to improve future TCO models.

6

CONCLUSION

The result of this research is twofold: Chapter 4 concluded with a new TCO framework that is more comprehensive than currently available in the literature and provides a basis for future research. In Chapter 5 the framework is used to calculate the TCO of a C-segment BEV and compared with an ICEV reference case to show the TCO of EVs up to 2030.

The first research question as defined in Chapter 1 is: *“What factors influence the total cost of ownership development of electric vehicles and what is the relationship between those factors?”*

By combining the literature streams of cost theories and technology selection literature, a list of 34 factors are identified that may directly or indirectly influence the total cost of ownership. The literature and interviews are used to draw relations between those factors and to rank their importance for the TCO development. When comparing the newly developed framework with existing TCO framework for EVs, it becomes clear the former includes many more indirect factors such as the factors influencing willingness to purchase. In addition, the profit margin is a new direct factor that is not incorporated in previous frameworks. This revised framework shows many factors and their relations play an important role regarding TCO development (Figure 18). This has not been concluded in previous research and it proves the ‘uniqueness’ of this thesis.

The newly developed framework is based on an extensive literature study and verified by interviews with more than ten national and international EV experts (Table 6). However, the framework should be regarded as an initial exploratory framework. More research can increase the robustness of identification of factors, the relationships between them and the extent to which they influence the TCO.

The second research question as defined in Chapter 1 is: *“How will the total cost of ownership of the electric vehicle develop up to 2030?”*

The framework of Chapter 4 is used as a starting point in Chapter 5. Next to all direct factors, the most important indirect factors are included (see Table 5). Using a hybrid combination of bottom-up and top-down cost estimation method, current and future production costs for a C-segment BEV are determined. Multiple scenarios are established to account for a more pessimistic or optimistic scenario, which results in an upper and lower bound in the final results. Two user profiles are established which represent different driver patterns. In addition, the TCO is calculated for both including and excluding taxes. This resulted in a 2x2 matrix.

In general it is concluded the TCO remains higher than the ICEV reference case, especially from a technological point of view. This is because the one-time costs are significantly higher and the lower recurring costs cannot compensate for these costs for both user profiles. Nonetheless, the BEV one-time costs will decline due to technological innovations and efficiencies in the production process, battery technology and powertrain. The ICEV one-time costs will to some extent increase in price due to CO₂ regulations and an increase in recurring costs. If government influences are included, the BEV may become competitive by 2024 in the average scenario using the first user profile in which the car is frequently used. The results also show an interaction between the TCO development, the RPE multiplier and range. From a consumer perspective, both the costs and range are urging drawbacks of EVs, but an increase in range leads to a direct increase in production costs. Next to that, the profit margin of OEMs may increase in the coming 15 years, but that will also lead to a direct increase in retail price. Although it cannot be predicted how these three factors will develop, a balance is necessary to keep the product attractive for both consumers and producers. Government policies could increase comfort for both parties by means of subsidies and policies that favour EV adoption.

7

DISCUSSION

In this discussion we will reflect to the scientific contributions of this research. This mainly concerns the contributions to the literature streams and interconnections between them. The limitations and work for future research is also discussed. Next, we will reflect from a managerial perspective. It is important for managers, companies and policymakers that TCO calculations have limitations, which may lead to deviations from reality. We also discuss the results of the four cases and triangular relationship between TCO, range and the OEM's profit margin. Finally, we summarize the managerial limitations and future opportunities of this tool.

7.1 Scientific contributions

Previous TCO studies (refer to 1.2) mainly focused on the factors that directly influence TCO. Following the literature stream of cost theories, this seems logical: One adopts a bottom-up and/or a top-down method to determine costs in the present and estimate the costs for the future. This also includes cost literature methods such as scale- and learning effects. However, by using such an approach, many uncertainties are created due to the same scale- and learning concepts being used. A simple framework (as shown in Figure 3) is used which excludes many other factors that may play a role as well in the cost development of EVs.

Combining two literature streams

This research used two literature streams instead of one. The literature stream of cost theory and the stream of technology selection theories are combined and applied on the case of electric vehicles. The focus of the cost theory is on factors relating to cost development, while technology selection theory's focus is on strategies to technology dominance. When combining these two streams, it becomes clear there are more factors influencing the cost development besides the conventional direct factors (such as production costs, insurance, charging, etc.). Especially the 'attractiveness of EVs' is influenced by more factors than just costs, as assumed in many cost literature. As argued in Chapter 2, network effects play an important role when one wants to reap the benefits of scale- and learning effects. In addition, other forces influence the attractiveness of a product as well, such as technological superiority, bandwagon effects, compatibility, regulations and big fish promoters. These effects are often forgotten in other studies that attempt to map EV cost development.

Contributing to the scientific literature

This study contributes to the scholars that study cost development, such as the studies that were presented in Table 1 of this research. Although only one case is investigated in this report (the case of EVs), the results would indicate that researchers who focus on cost development of technologies could improve their framework by involving technology selection theory. Studies that conducted empirical research to factors influencing technology selection could be relevant for cost development scholar as well (van de Kaa & de Vries, 2015; van de Kaa, et al., 2014b; van de Kaa, et al., 2014c). Further research is needed to point out whether that is also applicable for other cases and technologies, known as 'analytic generalization' according to Yin (1994). Future research could also focus on the effects of individual technology selection factors in this industry (van de Kaa, et al., 2014), or research how technology, strategy and network decisions are related for this automotive case (den Hartigh, et al., 2016).

The other way around, whether we could complement the list of factor of technology selection scholar, is less easy to conclude upon. Technology selection adds very broad factors like network effects and bandwagon effects (that can be applied to many technological systems). Cost literature, on the other hand, focuses more on specific factors, such as maintenance and insurance costs which are less easy to generalize (Redelbach & Friendrich, 2012; Wu, et al., 2015; Windisch, 2014). Two factors (pro-

duction costs, profit margin) are identified by both cost development literature and technology selection literature. This could prove their relevance. The other technology selection factors are identified during multiple interviews (Table 6). Another contribution to the technology selection scholars is the use of their list of factors in a new industry, namely the automotive industry. But more importantly, this list does not limit itself to researching technology selection (as it was not done in this study), but can be used for other purposes as well, such as cost development research.

Limitations and future research

It should be clear the factors and relationships between them are based on an initial desk research and interviews with a limited timeframe. Especially regarding the relations it is difficult to find convincing evidence in the literature. Therefore, we argue this is an initial framework that could be the basis for future research and adjustment, rather than claiming it is set in stone. The goal for this research is to find the effects on the TCO, but it may be used for other purposes (e.g. future demand) as well.

As such complex framework makes it difficult to predict the outcomes (van de Kaa & de Bruijn, 2015), this initial framework can also be the input for future studies that use simulation techniques to model predictions. In that case the framework may also be used for other purposes (after being adjusted), such as determine and estimate the future demand, adoption rate or market share.

Nevertheless the author acknowledges it is difficult, if not impossible, to account for all these factors in the TCO calculation, if only for the challenge to quantify and monetize all factors. Yet it is important to keep in mind TCO calculations neglect forces which may play a significant role now and in the future. Other industries may benefit from the EV as well, e.g. the electricity grid may avoid a significant cost increase when a smart grid is introduced. These cost savings are not included but might be relevant.

As mentioned in the limitations paragraph, including more factors could lead to a translation of the TCO curve along the x-axis, either accelerating or delaying the progress. If disruptive innovations (especially in battery technology) would be commercialized in the near future, the TCO may decrease drastically. On the other hand, if government policies that favour EVs are discarded, the TCO will increase. A change in adjacent technology could replace the car ownership model as we know it, making the TCO tool irrelevant.

7.2 Managerial contributions

From a managerial perspective, a new TCO is developed for the C-segment BEV, since this is the most promising but also challenging EV segment for this upcoming decade from a cost perspective. This TCO framework of Chapter 4 is used as input for the cost curves in Chapter 5.

Relating Chapter 4 and Chapter 5

The first contribution is that it is important for managers to understand cost curves may not reflect real-life situations as there are much more factors involved than included in the calculations. Due to the scope of this research, we as well only included a fraction of the factors that are identified in Chapter 4. Nevertheless, we extended the cost curves compared to previous research. The pricing strategy and range are often neglected in other cost studies (refer to Chapter 1). As pointed out in Chapter 4 and 5, these two factors are of crucial importance for the TCO development. Charging is also taken into account by the use of different scenarios. Nevertheless, the importance of a comprehensive TCO framework as presented in Chapter 4 becomes clear. Without this new framework it was impossible to reveal the relationship between TCO, range and RPE, of which the latter is a fairly unknown phenomenon. Hence, combining two literature streams resulted in a new TCO framework that on its turn improved the insights in TCO development and interpretations from a managerial perspective.

EVs remain most costly than ICEVs

A total cost of ownership range is presented based on different future scenarios, depending on the uncertainty of the data regarding EV adoption, electricity prices, etc. The upper and lower bound clearly showed a difference up to 11% in relative real costs up to 2030. In addition, four cases are developed, using two user profiles which differentiate between owner characteristics and the presence

or absence of government influences. For the owner characteristics we conclude such characteristics could be a decisive factor whether or not to switch from an ICEV to an EV, if based on a cost perspective. As recurring costs are lower, a longer ownership period and higher annual mileage positively influence the EV case. Government influences are critical as well. From a technical point of view (excluding any government influences), the EV will not become cost competitive compared to the ICEV reference case. When government influences are included (using a business-as-usual perspective), there is a possibility the BEV becomes competitive though, depending on the other variables. Finally, the discount rate chosen is an important parameter. If the 7% discount rate in user profile 1 is changed to 30%, the break even point shifts from 2024 to post-2030. Consumers may experience quite a high discount rate, so this should be handled with care. All costs in this report concern the TCO of the consumer's perspective, not from a social or well-to-wheel perspective.

Triangular relationship

As mentioned earlier, the OEMs profit margin, the EV's range and its TCO can be seen as a triangular relationship: if one is positively influenced, one of the others will be influenced negatively. The playing field can be influenced by government policies, which can stimulate the process and hence increase the attractiveness of all three factors. It is remarkable to the author this argument seems to be forgotten quite often in the literature and conversations, especially those with EV enthusiasts. Range remains a pressing issue that needs to be resolved to increase the attractiveness. Meanwhile, OEMs will need to recoup their investments, a process which cannot be delayed infinitely. Yet, it does not make sense the EV price will continue to decline rapidly as some may say. Even if OEMs can manage the EV business case without covering their indirect costs and mark-up for quite some years, the EV will probably be sold just below the ICEV retail price and we won't see a big price differential.

Implications for policymakers

Government policies may play a crucial role in the EV development and especially regarding the adoption rate. Policies limit themselves to country borders, but EV development does not, so it works on a global scale. Therefore, a change in the US policy can influence EV adoption rates in the EU. As explained in Chapter 4, policies may lead to increased attractiveness. This anticipating effect may either kick-start or severely hamper investment and hence EV adoption.

It is important to note that it is not researched whether the Dutch business-as-usual policies are sustainable from a governmental perspective. A higher EV adoption may lead to higher government expenditures or at least less tax income. Future research may research whether the governmental instruments will be affected and to what extent.

The future cannot be predicted upon

Next to government policies, it would be wise to keep in mind the possibility of a changing mobility paradigm due to connectivity and autonomous cars. Such disruptive innovations could cause a drastic change in costs. In addition, it may also affect the user profile characteristics with the introduction of e.g. car sharing. When recurring costs become lower, the use of the car potentially increases. This could also be used for future research.

The tool itself

The calculation tool can be updated at any time in the future. Scenario data can easily be updated if more accurate data becomes available. In addition, the tool can be used for other EV types and segments as well, since the data can be changed easily. Although not within the scope of this report, the appendices also include much data for PHEV, EREV and other car sizes in order to determine their TCO as well.

This research integrated cost literature with technology selection literature to shed new light on the total cost of ownership of electric vehicles. An extensive overview that shows the factors and their source (cost literature, technology selection literature, other literature or interviews) is presented in Table 6. To conclude, as the TCO shows, the cost development of EV for the upcoming decades is more complex than adding up individual components' costs or applying an experience curve. Many reinforcing cycles, feedback loops and qualitative factors play a role as well, which may tip the balance for EVs to become a mature market for the next 15 years.

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APPENDIX I. Factors influencing technology dominance

Prior interface format dominance framework		Lee et al. [9]	Schilling [5]	Suarez [4]
Factor				
Characteristics of the format supporter				
1	Financial strength			
2	Brand reputation and credibility			
3	Operational supremacy			
4	Learning orientation			
Characteristics of the format				
5	Technological superiority			
6	Compatibility			
7	Complementary goods			
8	Flexibility			
Format support strategy				
9	Pricing strategy			
10	Appropriability strategy			
11	Timing of entry			
12	Marketing Communications			
13	Pre-emption of scarce assets			
14	Distribution strategy			
15	Commitment			
Other stakeholders				
16	Current installed base			
17	Previous installed base			
18	Big Fish			
19	Regulator			
20	Antitrust laws			
21	Suppliers			
22	Effectiveness of the format development process			
23	Network of stakeholders			
Market characteristics				
24	Bandwagon effect			
25	Network externalities			
26	Number of options available			
27	Uncertainty in the market			
28	Rate of change			
29	Switching costs			

Figure 35: Factors mentioned by van de Kaa, et al. (2011) and prior studies about technology selection (van de Kaa, et al., 2011).

APPENDIX II. Search terms

The following terms were used to search for literature in the databases as explained in Chapter 3.

- Automotive technology trends
- Barriers electric car
- Barriers electric vehicle
- Battery technology electric vehicle
- Charging infrastructure electric vehicle
- Cost development electric vehicle
- Cost study electric vehicle
- Cost theory
- Electric vehicle maintenance
- Energy efficiency electric vehicle
- Fuel consumption electric vehicle
- Fuel efficiency electric vehicle
- Future cost electric vehicle
- Insurance electric vehicle
- Lithium battery technology electric vehicle
- Price electric vehicle
- Resale value electric vehicle
- Standard battles
- TCO electric vehicle
- Technology adoption
- Technology dominance
- Technology selection
- Total cost of ownership

APPENDIX III. Inflation and currency data

The figures below show the inflation and currency exchange numbers which are used to determine the cost curves of different components.

General inflation

Non-domestic output price index

Unadjusted data

Industry

GEO/TIME	European Union (28 countries)
2000	89,10
2001	90,09
2002	89,59
2003	88,87
2004	90,20
2005	92,53
2006	94,94
2007	96,16
2008	99,50
2009	96,83
2010	100,00
2011	104,41
2012	106,39
2013	106,51
2014	104,49
2015	103,18

Battery inflation

Manufacture of batteries and accumulators

Unadjusted data

GEO/TIME	European Union (28 countries)
2000	78,27
2001	78,42
2002	79,06
2003	80,60
2004	80,41
2005	80,21
2006	81,51
2007	92,08
2008	101,80
2009	97,79
2010	100,00
2011	101,72
2012	103,00
2013	104,49
2014	103,90
2015	104,26

Figure 36: Inflation data (Source: Eurostat).

Currency EUR:USD

CURRENCY	US dollar
2000	0,9236
2001	0,8956
2002	0,9456
2003	1,1312
2004	1,2439
2005	1,2441
2006	1,2556
2007	1,3705
2008	1,4708
2009	1,3948
2010	1,3257
2011	1,3920
2012	1,2848
2013	1,3281
2014	1,3285
2015	1,1095

Currency EUR:GBP

CURRENCY	Pound sterling
2000	0,60948
2001	0,62187
2002	0,62883
2003	0,69199
2004	0,67866
2005	0,68380
2006	0,68173
2007	0,68434
2008	0,79628
2009	0,89094
2010	0,85784
2011	0,86788
2012	0,81087
2013	0,84926
2014	0,80612
2015	0,72584

Figure 37: Currency exchange data (Source: Eurostat).

APPENDIX IV. Datasheet current BEV models

The table (Table 18) below shows the input data for various tables and figures in this report. The data was obtained through a variety of Internet website, as it contains general publicly available information and no academic data:

- <http://cleantechnica.com/2016/01/22/2017-volkswagen-e-golf-getting-range-boost-to-108-miles/>
- <http://electrek.co/2016/05/23/2017-vw-e-golf-186-miles-range/>
- <http://www.newcars2015-2016.com/2017-vw-up-powerup/>
- <https://www.fueleconomy.gov/feg/Find.do?action=sbs&id=36979>
- <http://electrek.co/2016/04/07/tesla-model-3-chevy-bolt/>
- <http://www.teslamodel3.nl/auto/>
- <http://www.autokopen.nl/autonieuws/2016/maart/40329-hyundai-ioniq-wordt-in-ieder-geval-goedkoper-dan-de-prius>
- https://en.wikipedia.org/wiki/BMW_i3
- <http://www.autoweek.nl/auto/74905/bmw-i3>
- <http://alle-elektrische-autos.nl/>
- <http://www.zomoto.nl/searchmycar.aspx>

Table 18: Datasheet about range and price of various BEV models.

Model	Segment	Year	Sticker price	Sticker price excl VAT	Retail price (2015)	Samen	kWh	NEDC Range	EPA Range (km)
Peugeot iOn	A	2011	29.990,00	25.201,68	28.177,19	Peugeot iOn-2i	16	100	150,00
Peugeot iOn	A	2012	29.990,00	25.201,68	27.825,64	Peugeot iOn-2i	16	100	150,00
Peugeot iOn	A	2014	29.990,00	24.785,12	25.394,59	Peugeot iOn-2i	16	100	150,00
Peugeot iOn	A	2015	29.990,00	24.785,12	24.785,12	Peugeot iOn-2i	16	100	150,00
Peugeot iOn	A	2016	21.995,00	18.177,69	18.177,69	Peugeot iOn-2i	16	100	160,00
Volkswagen up!	A	2013	25.770,00	21.297,52	22.263,77	Volkswagen up	18	160	134,00
Volkswagen up!	A	2014	25.770,00	21.297,52	21.821,23	Volkswagen up	18	160	134,00
Volkswagen up!	A	2015	25.925,00	21.425,62	21.425,62	Volkswagen up	18	160	134,00
Volkswagen up!	A	2017	26.000,00	21.487,60	21.487,60	Volkswagen up	35,8	300	201,00
BMW i3	B	2013	35.500,00	29.338,84	30.669,92	BMW i3-2013-2	22	200	130,00
BMW i3	B	2014	35.500,00	29.338,84	30.060,29	BMW i3-2014-2	22	200	130,00
BMW i3	B	2015	35.500,00	29.338,84	29.338,84	BMW i3-2015-2	22	200	130,00
BMW i3	B	2017	35.500,00	29.338,84	29.338,84	BMW i3-2017-3	33	300	194,00
Citroen C-Zero	B	2011	29.990,00	25.201,68	28.177,19	Citroen C-Zero-	16	100	150,00
Citroen C-Zero	B	2012	29.990,00	25.201,68	27.825,64	Citroen C-Zero-	16	100	150,00
Renault ZOE	B	2013	22.990,00	19.000,00	19.862,01	Renault ZOE-2i	22	210	142,00
Renault ZOE	B	2014	21.990,00	18.173,55	18.620,44	Renault ZOE-2i	22	210	142,00
Renault ZOE	B	2015	22.990,00	19.000,00	19.000,00	Renault ZOE-2i	22	240	155,00
Nissan Leaf	C	2011	34.990,00	29.403,36	32.874,96	Nissan Leaf-20	24	175	117,00
Nissan Leaf	C	2012	35.590,00	29.907,56	33.021,49	Nissan Leaf-20	24	175	117,00
Nissan Leaf	C	2013	33.270,00	27.495,87	28.743,33	Nissan Leaf-20	24	200	121,00
Nissan Leaf	C	2014	32.426,67	26.798,90	27.457,89	Nissan Leaf-20	24	200	135,00
Nissan Leaf	C	2015	35.354,29	29.218,42	29.218,42	Nissan Leaf-20	24	200	135,00
Nissan Leaf	C	2016	35.354,29	29.218,42	29.218,42	Nissan Leaf-20	24	200	135,00
Nissan Leaf	C	2016	36.000,00	29.752,07	29.752,07	Nissan Leaf-20	30	250	172,00
Volkswagen Golf	C	2014	35.950,00	29.628,10	30.356,66	Volkswagen Gc	26,5	190	134,00
Volkswagen Golf	C	2015	36.190,00	29.909,09	29.909,09	Volkswagen Gc	26,5	190	134,00
Chevrolet Bolt	C	2017	33.299,00	27.519,83	27.519,83	Chevrolet Bolt-	60		322,00
Tesla Model 3	C	2017	35.000,00	28.925,62	28.925,62	Tesla Model 3-	60		346,00
Hyundai Ioniq Ele	C	2016	30.000,00	24.793,39	24.793,39	Hyundai Ioniq	28	250	180,00
Hyundai Ioniq Ele	C	2017	30.000,00	24.793,39	24.793,39	Hyundai Ioniq	28	250	180,00
Tesla Model S	E	2013	66.200,00	54.710,74	57.192,92	Tesla Model S-	60	375	335,00
Tesla Model S	E	2013	78.600,00	64.958,68	67.905,79	Tesla Model S-	85	502	426,00
Tesla Model S	E	2014	66.200,00	54.710,74	56.056,09	Tesla Model S-	60	375	335,00
Tesla Model S	E	2014	78.600,00	64.958,68	66.556,02	Tesla Model S-	85	502	426,00
Tesla Model S	E	2015	71.900,00	59.421,49	59.421,49	Tesla Model S-	60	375	335,00
Tesla Model S	E	2015	76.000,00	62.809,92	62.809,92	Tesla Model S-	70	390	335,00
Tesla Model S	E	2015	90.600,00	74.876,03	74.876,03	Tesla Model S-	85	502	426,00
Tesla Model S	E	2015	92.100,00	76.115,70	76.115,70	Tesla Model S-	90	520	450,00
Tesla Model S	E	2016	76.000,00	62.809,92	62.809,92	Tesla Model S-	70	390	335,00
Tesla Model S	E	2016	90.600,00	74.876,03	74.876,03	Tesla Model S-	85	502	426,00
Tesla Model S	E	2016	92.100,00	76.115,70	76.115,70	Tesla Model S-	90	520	450,00
Tesla Model S	E	2017	84.100,00	69.504,13	69.504,13	Tesla Model S-	70	442	390,00
Tesla Model S	E	2017	87.500,00	72.314,05	72.314,05	Tesla Model S-	75		417,00
Tesla Model X	E	2016	84.801,00	70.083,47	70.083,47	Tesla Model X-	90		414,00
Kia Soul EV	M	2014	33.995,00	28.095,04	28.785,90	Kia Soul EV-	27		150,00
Kia Soul EV	M	2015	33.995,00	28.095,04	28.095,04	Kia Soul EV-	27		150,00
Kia Soul EV	M	2016	33.995,00	28.095,04	28.095,04	Kia Soul EV-	27		150,00
Kia Soul EV	M	2017	33.995,00	28.095,04	28.095,04	Kia Soul EV-	27		150,00

APPENDIX V. Charging specifications

In this study charging is distinguished in three functional categories:

1. Residential / workplace chargers
2. City public charging points
3. Highway public fast charging

ad 1. Residential / workplace chargers

Home chargers are divided in two categories: level 1 and level 2 stations. Level 1 charging means the 'normal' electricity socket is used to charge the vehicle. A full recharge takes up to 24 hours and power output between 1-3,7 kW. A level 2 charging point needs to be acquired and offers an output between 3,7 and 7 kW. It is mostly used for overnight charging or charging during the working day, as the charge time may take up to eight hours (Hill, et al., 2013).

Home charging requires a garage or private parking next to the house in order to plug in. About 25% of the people have a garage in Europe of which most of them live in the rural areas. In the urban areas, of which many think the EV is more attractive due to range anxiety, the figures are much lower (as low as 2,5%) (Nemry & Brons, 2010). Next to the acquisition of a charger for level 2 stations, the energy costs to charge are based on the normal household electricity price.

ad 2. City public charging points

Public charging points can be found at parking lots in cities. The level 2 station is ground mounted, offers at least two cars to be charged at a time and is faced with higher resilience and security requirements compared to residential chargers. Many public charging points allow communication between the vehicle and the station, which also enables the option for smart vehicle to grid. Public charging points offer a higher power output, between 7 and 22 kW, which can charge an EV in 2-4 hours. (Hill, et al., 2013). In order to charge at a city public charging point, one has to become a member of a charging provider. Next to fixed administrative costs, there is variable charging price which is based on the electricity price at home plus a premium.

ad. 3 Highway public fast charging

Fast charging stations have a very high power output, at least more than 22kW and up to 150 kW. This allows a vehicle to be charged in 30 minutes. (Hill, et al., 2013).

Table 19: Specifications of different charging levels based on multiple studies (Azadfar, et al., 2015; Ying Yong, et al., 2015; Theisen & Marques, 2011).

	Level 1	Level 2	Level 3
Nominal voltage	120/230V AC	208-240V AC	600V DC
Maximum current	12-15A	32A	400A
Power output	< 3,7 kW	3,7-22 kW	> 22 kW
Connector	General socket	EV supply equipment	EV supply equipment

APPENDIX VI. Standardization issues

In this section two technological standardization issues are discussed which may affect the cost development in the future:

1. Standard issues for the plugs;
2. Standard issues for the charging technology.

ad 1. Standardisation

The charging infrastructure needs to be standardised in terms of the plug types, recharging protocols and regulations for public recharging. This is necessary to ensure the compatibility between different car brands and models (Hacker, et al., 2009, p. 77) which on its turn minimises the cost for infrastructure installation.

For non-fast charging a standard has been proposed and is wide acknowledged by the industry. . The type 2 “Mennekes” has been proposed as the standard for slow charging. The main exception for new cars is the Tesla, but a converter is available to ensure compatibility.

For fast charging there is no alignment yet on one standard, meaning there are three different plug types are in circulation: the Japanese CHAdeMO, CSS “Combo” and the Tesla Supercharger.

While the number of charging points is accelerating, the costs can increase as well as long a standard is not defined and accepted by the industry. To quote Weeda (2013): *“Defining standards result in clarity for all parties – producers, investors and users – and it tends to optimize the investments, cost savings and more trust in the quality and reliability of the products. The aforementioned factors may lead to a better market acceptance and the speed of acceleration of charging infrastructure.”* (Weeda, 2013, p. 7)

Not defining standards could lead to an additional €350.000 investment ‘losses’ in The Netherlands according to the ECN study (Weeda, 2013).

While CHAdeMO is most popular right now, the EU has proposed the CSS “Combo” as the standard for fast charging. A final standardization is not expected before 2019 (ARF & McKinsey, 2014). Another standardization issue is the service system of charging points that takes care of the communication and billing. In the Netherlands EV users can use any charging point because providers agreed to use the same protocol, but this is not rolled out on a global scale (ARF & McKinsey, 2014). Many interviewees expect the costs of standardization issue are very limited, as the plugs are not very expensive (Interview 5,9)

This uncertainty is a disadvantage that hampers the rapid introduction of fast charging technology, also because the upfront investment costs are significantly higher than ‘slow’ charging. It contributes to the uncertainty whether fast charging will make it or not. This is part of a broader discussion, which questions whether fast charging will become the standard way of charging or whether it will be used in case of an emergency – as unexpectedly depleted battery. In case of the latter the major part of charging will be at home or at work, combined with a long range battery.

Research by McKinsey shows in the early adopters phase home charging is dominated with 80%. The remaining 15% and 5% are charging at the workplace and public respectively. Based on interviews, McKinsey believes this will change to a 60%-20%-20% proportion when a mass roll-out takes place. More public charging points will attract other users, such as those who do not own a garage or private parking place (ARF & McKinsey, 2014).

ad. 2 Way of charging

The methods of charging described above are all using a cable connection to charge the vehicle. However, in the past and maybe in the future different techniques might become superior: battery swapping, induction charging and the introduction of the smart grid.

- *Battery swapping:* Instead of charging a battery an alternative is to exchange the empty battery pack with a charged one at a swap station. This would take just a few minutes and drastically reduces the ‘refuelling time’. Battery swapping tests became popular around 2010, mainly because

the company BetterPlace did some pilots in different countries. However, the company filed bankruptcy in 2013 and ever since there seems little to none interest in the technology. There is no post-2013 publication that claims other companies are working on this technology (ARF & McKinsey, 2014; Windisch, 2014). According to one interviewee BetterPlace tried to solve a problem (charging took too long) that seems to resolve itself anyway (Interview 3). According to another interviewee, the compatibility issues between OEMs will never be resolved (Interview 5).

- *Induction charging*: Induction charging has been tested on a small scale. The city of Rotterdam for example started a pilot in 2016 in a consortium with universities and energy companies. Currently no car manufacturer seems to be involved in these pilots, and it is not commercially viable yet, due to energy losses and high upfront investment costs. Nevertheless some knowledge organisations remain optimistic about this technology (ARF & McKinsey, 2014; ElaadNL, 2016). One interviewee thinks the advantageous of induction charging are rather limited, while other are more optimistic (Interview 5,9)
- *Smart grid*: Sometimes it is argued the charging cost might decline in the future due to the introduction of the smart grid³³. In a smart grid the EV is connected to another vehicle (V2V), to the user its home (V2H) or to the grid (V2G). By integrating the EV – which is basically an energy storage system when connected – with the electricity grid the supply and demand of electricity can be regulated efficiently. This means the EV will be charged when electricity demand is low (or supply high) and even the EV can temporarily charge the grid when demand is high (or supply low). This can definitely be interesting, especially since the introduction of renewable energy which result in larger supply variation. When the EV owner's tariffs would be variable based on demand/supply, the TCO would decline to some extent. There are various pilots testing the technology, e.g. in Australia, Japan and the US. Currently there is no literature available that attaches a figure to the financial benefit claims (Perujo, et al., 2012; Azadfar, et al., 2015; Ying Yong, et al., 2015).

³³ A smart grid is basically an intelligent energy system in which automation improves the reliability, efficiency and sustainability of the power supply and demand (Ying Yong, et al., 2015)

APPENDIX VII. Datasheet all EV models

This table (Table 20) below shows all EV models over the course of time. The data was obtained through a variety of Internet website, as it contains general publicly available information and no academic data. The same sources as discussed in APPENDIX IV apply for this table.

Table 20: EV model over the course of time.

Model	Year	Type	Segment	Model	Year	Type	Segment
BMW i3	2013	100% elektrisch	B	Renault Twizy	2017	100% elektrisch	A
BMW i3	2014	100% elektrisch	B	Renault Zoe	2012	100% elektrisch	B
BMW i3	2015	100% elektrisch	B	Renault Zoe	2013	100% elektrisch	B
BMW i3	2016	100% elektrisch	B	Renault Zoe	2014	100% elektrisch	B
BMW i3	2017	100% elektrisch	B	Renault Zoe	2015	100% elektrisch	B
Chevrolet Bolt	2017	100% elektrisch	C	Renault Zoe	2016	100% elektrisch	B
Citroen C-Zero	2010	100% elektrisch	A	Renault Zoe	2017	100% elektrisch	B
Citroen C-Zero	2011	100% elektrisch	A	Smart Fortwo Electric Drive	2009	100% elektrisch	A
Citroen C-Zero	2012	100% elektrisch	A	Smart Fortwo Electric Drive	2010	100% elektrisch	A
Citroen C-Zero	2013	100% elektrisch	A	Smart Fortwo Electric Drive	2011	100% elektrisch	A
Citroen C-Zero	2014	100% elektrisch	A	Smart Fortwo Electric Drive	2012	100% elektrisch	A
Citroen C-Zero	2015	100% elektrisch	A	Smart Fortwo Electric Drive	2013	100% elektrisch	A
Citroen C-Zero	2016	100% elektrisch	A	Smart Fortwo Electric Drive	2014	100% elektrisch	A
Citroen C-Zero	2017	100% elektrisch	A	Smart Fortwo Electric Drive	2015	100% elektrisch	A
Ford Focus Electric	2013	100% elektrisch	C	Smart Fortwo Electric Drive	2016	100% elektrisch	A
Ford Focus Electric	2014	100% elektrisch	C	Smart Fortwo Electric Drive	2017	100% elektrisch	A
Ford Focus Electric	2015	100% elektrisch	C	Tazzari Zero	2009	100% elektrisch	A
Ford Focus Electric	2016	100% elektrisch	C	Tazzari Zero	2010	100% elektrisch	A
Ford Focus Electric	2017	100% elektrisch	C	Tazzari Zero	2011	100% elektrisch	A
Hyundai Ioniq Electric	2016	100% elektrisch	C	Tazzari Zero	2012	100% elektrisch	A
Hyundai Ioniq Electric	2017	100% elektrisch	C	Tazzari Zero	2013	100% elektrisch	A
Kia Soul EV	2014	100% elektrisch	M	Tazzari Zero	2014	100% elektrisch	A
Kia Soul EV	2015	100% elektrisch	M	Tazzari Zero	2015	100% elektrisch	A
Kia Soul EV	2016	100% elektrisch	M	Tazzari Zero	2016	100% elektrisch	A
Kia Soul EV	2017	100% elektrisch	M	Tazzari Zero	2017	100% elektrisch	A
Mercedes-Benz B Electric Drive	2015	100% elektrisch	B	Tesla Model 3	2017	100% elektrisch	C
Mercedes-Benz B Electric Drive	2016	100% elektrisch	B	Tesla Model S	2012	100% elektrisch	E
Mercedes-Benz B Electric Drive	2017	100% elektrisch	B	Tesla Model S	2013	100% elektrisch	E
Mitsubishi i-MiEV	2011	100% elektrisch	A	Tesla Model S	2014	100% elektrisch	E
Mitsubishi i-MiEV	2012	100% elektrisch	A	Tesla Model S	2015	100% elektrisch	E
Mitsubishi i-MiEV	2013	100% elektrisch	A	Tesla Model S	2016	100% elektrisch	E
Mitsubishi i-MiEV	2014	100% elektrisch	A	Tesla Model S	2017	100% elektrisch	E
Mitsubishi i-MiEV	2015	100% elektrisch	A	Tesla Model X	2016	100% elektrisch	E
Mitsubishi i-MiEV	2016	100% elektrisch	A	Tesla Model X	2017	100% elektrisch	E
Mitsubishi i-MiEV	2017	100% elektrisch	A	Tesla Roadster	2009	100% elektrisch	X
Nissan Leaf	2012	100% elektrisch	C	Tesla Roadster	2010	100% elektrisch	X
Nissan Leaf	2013	100% elektrisch	C	Tesla Roadster	2011	100% elektrisch	X
Nissan Leaf	2014	100% elektrisch	C	Tesla Roadster	2012	100% elektrisch	X
Nissan Leaf	2015	100% elektrisch	C	Think City	2007	100% elektrisch	X
Nissan Leaf	2016	100% elektrisch	C	Think City	2008	100% elektrisch	X
Nissan Leaf	2017	100% elektrisch	C	Think City	2009	100% elektrisch	X
Peugeot iOn	2010	100% elektrisch	A	Think City	2010	100% elektrisch	X
Peugeot iOn	2011	100% elektrisch	A	Think City	2011	100% elektrisch	X
Peugeot iOn	2012	100% elektrisch	A	Volkswagen e-Golf	2014	100% elektrisch	C
Peugeot iOn	2013	100% elektrisch	A	Volkswagen e-Golf	2015	100% elektrisch	C
Peugeot iOn	2014	100% elektrisch	A	Volkswagen e-Golf	2016	100% elektrisch	C
Peugeot iOn	2015	100% elektrisch	A	Volkswagen e-Golf	2017	100% elektrisch	C
Peugeot iOn	2016	100% elektrisch	A	Volkswagen e-up!	2014	100% elektrisch	A
Peugeot iOn	2017	100% elektrisch	A	Volkswagen e-up!	2015	100% elektrisch	A
Renault Fluence Z.E.	2011	100% elektrisch	X	Volkswagen e-up!	2016	100% elektrisch	A
Renault Fluence Z.E.	2012	100% elektrisch	X	Volkswagen e-up!	2017	100% elektrisch	A
Renault Fluence Z.E.	2013	100% elektrisch	X	Volvo C30 EV	2007	100% elektrisch	X
Renault Fluence Z.E.	2014	100% elektrisch	X	Volvo C30 EV	2008	100% elektrisch	X
Renault Twizy	2012	100% elektrisch	A	Volvo C30 EV	2009	100% elektrisch	X
Renault Twizy	2013	100% elektrisch	A	Volvo C30 EV	2010	100% elektrisch	X
Renault Twizy	2014	100% elektrisch	A	Volvo C30 EV	2011	100% elektrisch	X
Renault Twizy	2015	100% elektrisch	A	Volvo C30 EV	2012	100% elektrisch	X
Renault Twizy	2016	100% elektrisch	A				

APPENDIX VIII. Battery Chemistries

According to EU regulations automotive batteries can be defined as “any battery or accumulator used for automotive start, lighting or ignition power” (EU Batteries Directive, 2006). According to ACEA (2014), four main battery technologies are currently used in the automotive sector: (1) lead-based batteries are used for ICEVs to start and used as auxiliary 12V batteries. (2) Nickel metal hybrid batteries are used for HEVs. Lithium-ion batteries are used for all kind of EVs and so are (4) sodium-nickel chloride batteries (ACEA, 2014). In the table below you can see the characteristics of each chemistry type.

We review them on the following five characteristics based on multiple references (ACEA, 2014; Azadfar, et al., 2015; Manzetti & Mariasiu, 2015). *Energy density* is the amount of energy that can be stored in the battery per mass and basically determines the range, while *power density* stands for the power the battery can perform per mass and determines the acceleration of the vehicle. The *self-discharge* shows how much energy is lost when the battery is not being used. The *cycles* represent how often the battery can be recharged and hence its lifetime. The performance results are based on qualitative and relative parameters, because we used multiple sources.

Table 21: Performance of different battery chemistries. Based on: (ACEA, 2014; Azadfar, et al., 2015; Manzetti & Mariasiu, 2015; Catenacci, et al., 2013).

Chemistry	Lead-based	Nickel-based	Lithium-based	Sodium-based (ZEBRA)
Energy density	Poor performance	Medium performance	High performance	High performance
Power density	Poor performance	Medium performance	High performance	Medium performance
Self-discharge	High performance	Poor performance	Medium-high performance	Very high performance
Cycles	Poor performance	High performance	Medium performance	Unknown
Cost	Low costs	Medium costs	Medium costs	High costs

As can be seen in the overview (Table 21) only the lithium based batteries score a ‘medium’ or ‘high’ performance for each criteria. The other chemistries are less suitable for BEVs, but might still be used for HEVs or PHEVs. The sodium (also known as ‘zebra’) battery almost meet the performance criteria but has the major drawback of having an operating temperature of around 300 degrees, even when the car is not operated which requires additional safety measures. The chemistries are depicted in the figure below (Figure 38). This figure shows the performance of energy and power – which is often a trade off – and the general performance criteria for each type of EV. It shows BEVs require high performance ratios only the lithium-ion battery can meet (Hacker, et al., 2009). Although the battery performance of a PHEV is generally lower as depicted in the figure, even those cars are nowadays suited with lithium-ion batteries since the potential improvements are significantly better than nickel-based batteries (Poullikkas, 2015).

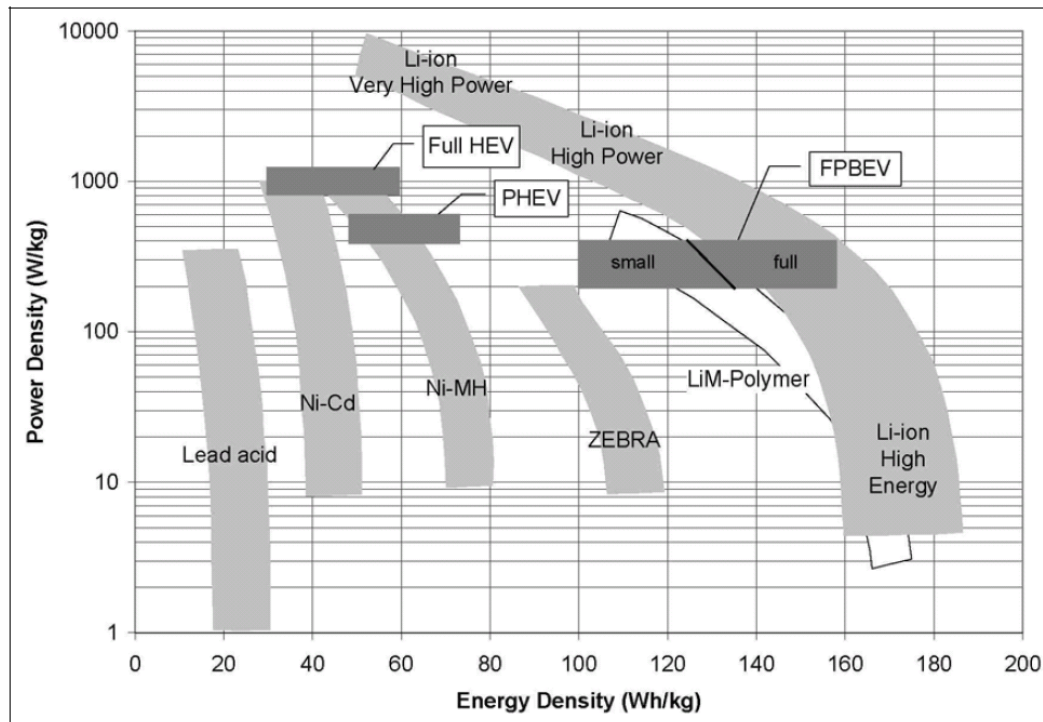


Figure 38: Power vs energy of different battery chemistries (Hacker, et al., 2009).

Lithium-ion batteries supersede other chemistries but especially nickel-based in terms of cost/performance ratio and potential cost reductions. For commercial application, lithium-based batteries are the most viable option at this point in time (ACEA, 2014; Catenacci, et al., 2013; Hacker, et al., 2009). Hence we focus on the lithium application through the remainder of this paragraph.

APPENDIX IX. Lithium-ion performance

Like most batteries, a li-ion battery converts stored chemical energy into electric energy and consists of two electrodes, an electrolyte and a fuel. The electrodes supply and collect charge and the electrolyte conduct ions that move between those electrodes. In most batteries like the lithium batteries the fuel is solid, but theoretically it could also be liquid or gaseous (Cluzel & Douglas, 2012). In this section the battery is reviewed along the following four characteristics:

1. Theory and composition
2. Chemistries

ad 1. Theory and composition

When the battery is in operation, the lithium-ions travel between the electrodes from the anode to the cathode. This initiates a flow of electrons, which can be used to for example run a motor. The material of the anode is usually graphite. The cathode material depends on the battery type. Lithium-ion batteries in the automotive sector are usually oversized. This means the total energy of the pack is higher than the usable energy and hence the window of charge is not fully used, expressed in the state of charge (SOC) (Figure 39). In short, a SOC of 100% and 0% is avoided. This is because (1) overcharging or undercharging can destroy the battery and even results in safety risks. (2) A very high or low SOC degrades battery cycle life and calendar life. (3) At a high or low SOC the battery experiences a low specific power and thus might not meet the power requirements of the vehicle. An 80% and 70% SOC window is normal for respectively a BEV and PHEV, of which the latter has higher power requirements (Cluzel & Douglas, 2012; Hacker, et al., 2009).

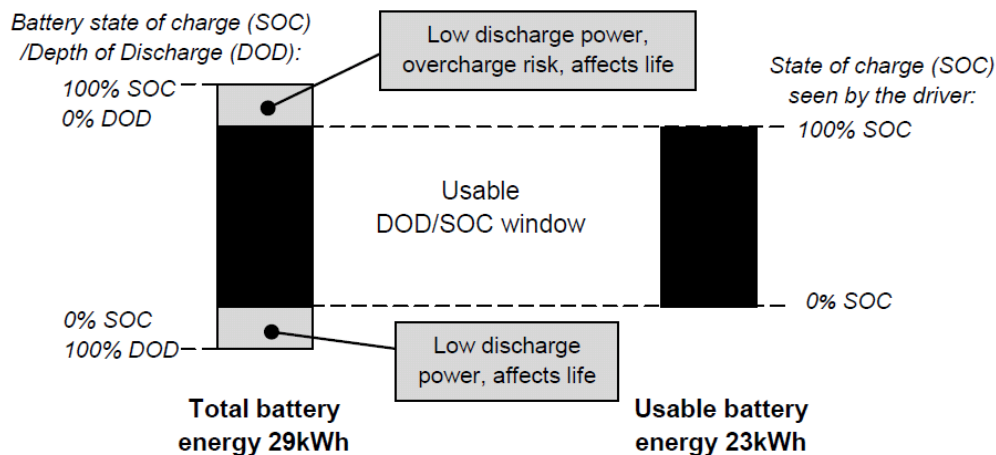


Figure 39: Battery State of Charge Window (Cluzel & Douglas, 2012).

ad 2. Chemistries

Lithium-ion is a general name for many types of lithium-based batteries. The combination of materials determine the exact name and hence the performance and associated costs. The lithium nickel cobalt aluminium oxide battery is used in the Tesla model S and has very high energy and power performance, but is also expensive. The lithium manganese oxide battery is less costly, but concerns have been raised about battery degradation in the long run and earlier versions showed poor life cycle performance. This battery is used in the Nissan LEAF, Chevrolet Volt and some other vehicles (Kay, et al., 2013). Lithium-based batteries used for electronic products like laptops and phones are generally not suitable because of their relatively low specific energy and safety risks (Young, et al., 2013). A full list of the lithium-based batteries can be found below (Figure 40).

Chemistry	Principal advantages	Principal drawbacks	Current use
Lithium–nickel cobalt aluminium oxide (NCA)	• High specific power and energy • Excellent lifespan	• Expensive • Requires careful consideration of safety aspects	Tesla Model S (longest range of current EVs – 265 miles)
Lithium–nickel manganese cobalt oxide (NMC)	• High specific energy • Good specific power • The lowest self-heating rate of Li-ion chemistries	• Designing to increase specific power reduces specific energy and vice versa • Only average lifespan	Rolls-Royce Phantom Experimental Electric (Johnson Matthey, 2013)
Lithium–manganese oxide (LMO)	• Materials are low-cost • Materials are environmentally friendly • Similar performance levels to conventional lithium-ion	• Early versions showed poor cycle life, especially at high temperatures • Reports of battery degradation concerns due to high ambient temperatures from Nissan LEAF owners in Arizona (LeSage, 2010)	Nissan LEAF, Vauxhall Ampera / Chevrolet Volt, Renault Twizy / Zoe / Fluence / Kangoo (Edison, 2011)
Lithium–titanate oxide (LTO)	• Can be fast-charged • Excellent safety • Excellent lifespan • Low-discharge characteristics	• Lower specific energy than other lithium-ion chemistries • Expensive	Honda Fit EV, Mitsubishi i-MiEV / Peugeot iOn / Citroën C-Zero
Lithium–iron phosphate (LFP)	• Thermal/chemical stability • Longer cycle life • High current rating • Lower materials cost	• Lower specific energy than other lithium-ion chemistries • High self-discharge rates • Cold temperature reduces performance • Calendar life is poor above 30°C	Smith Electric Vehicles, Fisker Karma, CODA sedan (US EV model), BYD (Chinese OEM)

Figure 40: List of different battery types (Kay, et al., 2013, p. 109).

APPENDIX X. Battery manufacturing

The manufacturing process of a lithium-ion battery involves two steps:

1. Cell production
2. Pack production

ad 1. Cell production

The first step is the manufacturing of the cell itself, assembling each cell. Currently, Tesla is the only company using small-format cells (comparable with a general 3,5V battery). All other manufacturers use large-format cells. The main advantage of the small cells is the increase in economies of scale, while the large-format cells are less sensitive to overheating (ARF & McKinsey, 2014).

ad 2. Pack production

A combination of cells together forms a module. The modules are assembled in a pack to increase the total capacity of the battery. Regardless of the pack size, each pack also has some additional components:

- Battery management system: The pack is monitored by the battery management system to protect the battery from becoming instable, e.g. in temperature or state of charge and voltage.
- Temperature control: Both cooling and heating can be needed for batteries.
- Safety devices: shunts, fuses and safety disconnects.

This is the final step of the production process. The costs of the (installation of these) component can decline by learning rates (Cluzel & Douglas, 2012). Dinger, et al (2010) estimates 75% of the involved costs is volume-dependent, while the remaining 25% is independent of the battery size. He estimated the build up of the production process in terms of costs. As can be seen (Figure 41), the material account for up to 12% of the total costs, labour up to 11% and additional parts up to 32%³⁴ (Dinger, et al., 2010).

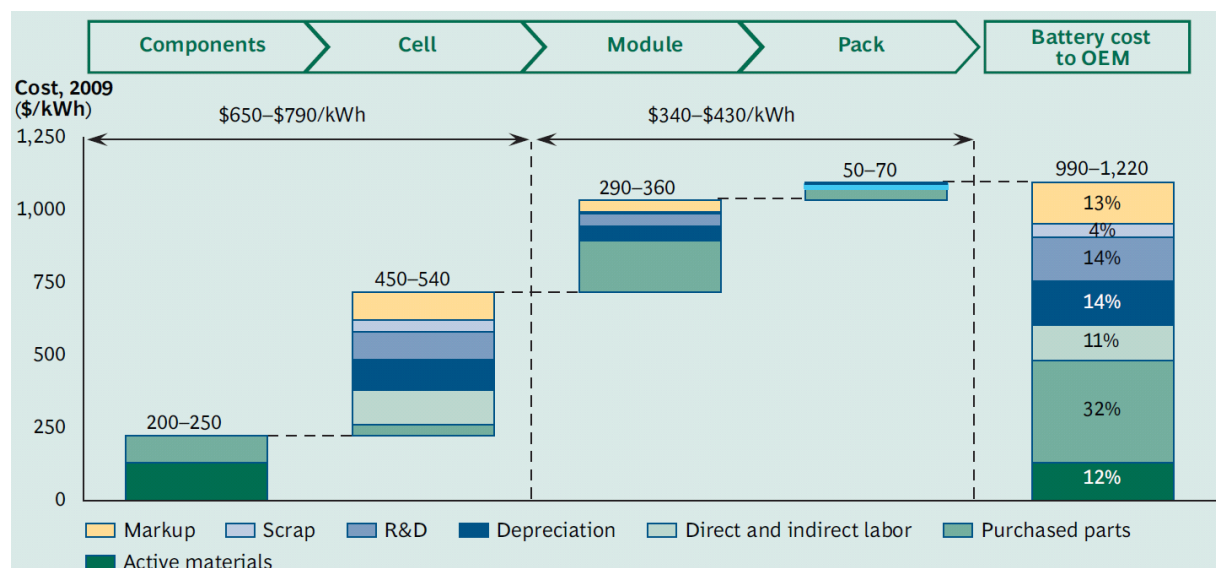


Figure 41: Cost break down of a 1.100 USD/kWh battery (Dinger, et al., 2010).

³⁴ This break down of Dinger, et al. (2010) is based on BCG's interviews and expert analysis, the underlying data has not been made public, so it is not able to verify. Also, cost reduction between the publication date and present could have changed this break down.

APPENDIX XI. Historical development time of batteries

The table depicted below shows the development time between first paper/patent and the commercial introduction of historical battery chemistries (Table 22). The delta (Δ) columns show the amount of years between the first paper/patent and respectively the first commercial cell and first use in series car (Cluzel & Douglas, 2012, p. 27).

Table 22: Development time of batteries. Source: own calculations, data retrieved from Cluzel & Douglas (2012).

Chemistry	First paper/patent	First commercial rechargeable cell	Δ (years)	First use in series car	Δ (years)
Lithium LCO	1979	1991	12	2008 (Tesla)	29
Lithium LMO	1983	1996	13	2009 (iMieV)	26
Lithium LFP	1994	2006	12	2007 (MODEC van)	13
Ni-MH	1967	1990	23	1997 (Prius)	30
<i>Average</i>			15		24,5

APPENDIX XII. Lithium prices

The figure below shows the lithium hydroxide prices in US dollars per metric tonnes over time (Figure 42). As Goldman Sachs shows, the lithium continues to be in demand (Goldman Sachs, 2015).

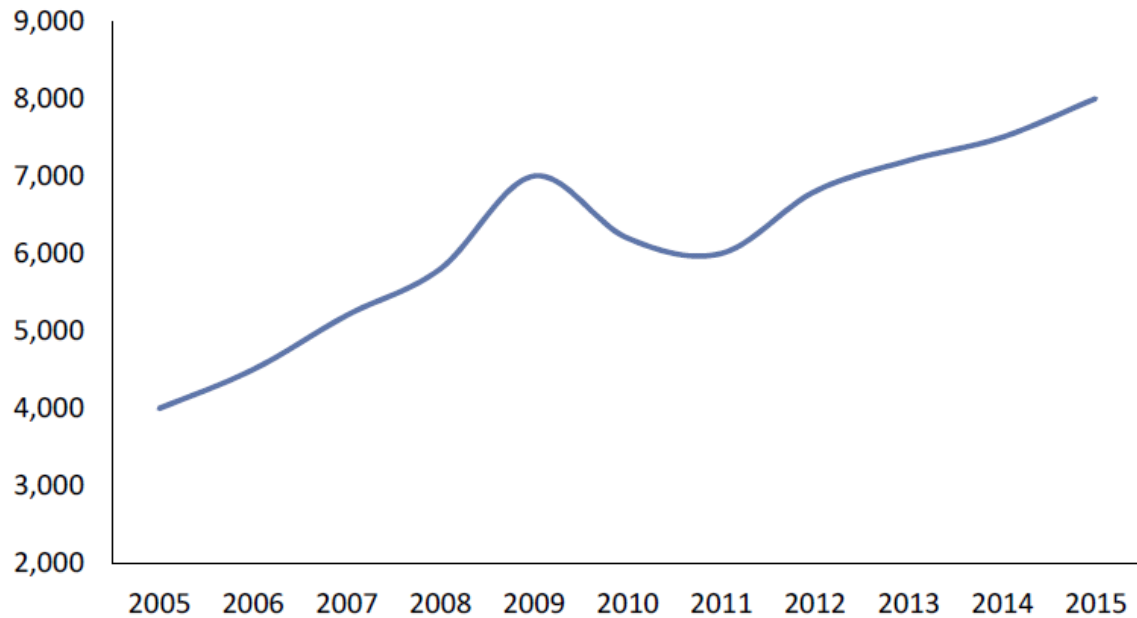


Figure 42: Price of lithium hydroxide in \$/metric tonnes over time. Source: (Goldman Sachs, 2015, p. 48).

APPENDIX XIII. Barriers to EV adoption

Based on the literature, we identified seven factors that may to a certain extent influence the TCO of EVs (Table 23). Battery technology and resale value are directly linked to EV costs and were mentioned in TCO studies as well (refer to Chapter 4). The other barriers are indirectly linked as these hamper the attractiveness for electric vehicles. When the product is less attractive, fewer products will be sold, the adoption rate may stagnate and the benefits of scale and learning effects remain absent.

Table 23: Literature that identified barriers to EV adoption. Composition based on the sources referred to in the table³⁵.

#	Source (year)	1. Battery price	2. Range	3. Charging issues	4. Consumer awareness	5. Model variety	6. Institutional barriers	7. Resale value
1	Steinhilber, et al. (2013)	✓	✓	✓				
2	Aksen, et al. (2010)	✓	✓		✓			
3	Elkind, et al. (2012)	✓	✓	✓	✓			
4	Tsang, et al. (2012)		✓	✓	✓		✓	
5	Adepetu & Keshav (2015)	✓	✓					
6	Catenacci, et al. (2013)	✓						
7	Boulanger, et al. (2011)	✓	✓	✓	✓			
8	Brown (2013)	✓	✓		✓			
9	Nemry & Brons (2010)	✓	✓	✓				
10	Perujo, et al. (2012)	✓	✓	✓				
11	Cluzel & Lane (2013)	✓	✓	✓	✓	✓		
12	Windisch (2014)	✓	✓	✓	✓	✓		✓
13	ARF & McKinsey (2014)	✓	✓					
14	National Research Council (2013)	✓	✓	✓				

³⁵ The table only shows which barriers are identified by the respective study. Vice versa, if there is no cross mark the study it does not conclude the study rejects the respective barrier.

APPENDIX XIV. Difference between PHEV/EREV/BEV

Already in the 19th century electric cars were used with a DC motor and rechargeable lead-acid battery. However the introduction of the mass-produced gasoline-powered Ford Model T challenged the early EV. The combination of low gasoline price, limited charging stations and limited range of the EV favored the ICE vehicles and thus became the dominant design (Ying Yong, et al., 2015) .

In the early 2000s days the relatively higher oil prices and emission regulations created renewed interests in the EV. As the oil prices kept increasing from 2010 on, the car manufactures were stimulated to electrify their products. New models like the Tesla Model S, Chevrolet Volt and the Nissan Leaf entered the market. By the end of 2012, EV stock is over 180.000 units globally accounting for 0,02% of the total passenger cars (IEA, 2013). This number seems to increase exponentially. The sales in 2012 compared to 2011 doubled. The EV Outlook estimates the stock unit will be more than 20 million by 2020 (IEA, 2013).

The degree of electrification of an electric vehicle is shown in the figure above (Figure 19) and is categorized in three levels in this report:

1. Combining a battery and an internal combustion engine;
2. Combining a plug-in and an internal combustion engine;
3. Full electric vehicles.

ad 1. Combining a battery and an internal combustion engine

Hybrid Electric Vehicles (HEVs) use a combination of an Internal Combustion Engine (ICE) and an electric motor. The battery for the electric motor is charged by the ICE or when the car is equipped with regenerative braking which converts and saves kinetic energy into battery pack (Tie & Tan, 2013). The combination of a small battery and a conventional ICE can result in a fuel efficiency improvement up to 30% in standard test driving cycles. These improvements can be attributed to stop-start technology, regenerative braking and electric assistance in acceleration (Hacker, et al., 2009). HEV is recognized as an incremental innovation based on ICE technology rather than a radical innovation like the BEV/PHEV/EREV and hence it is very likely the HEV technology will act as a substitute for the current ICE technology in the future (Sierzchula, et al., 2014). Therefore, the HEV is excluded in the remainder of this research.

ad 2. Combining a plug-in and an internal combustion engine

The second level of electrification is the combination of an ICE and a battery that can be connected to an external power source. We distinguish two types of EVs: the plug-in electric vehicle (PHEV) and the extended range electric vehicle (EREV).

The PHEVs are similar to HEVs, but the battery can be charged from an external source like a charging station. The configuration of PHEVs can be series, parallel or a combination series-parallel. In the series configuration the ICE is decoupled from the transmission system and can only power the car through the electric motor. In the parallel configuration the ICE is directly connected to the transmission system, just like the electric motor. The ICE and the electric motor can now complement each other, allowing city driving and highway driving. When series and parallel are combined, the vehicle can be operated in both series and parallel mode (Poullikkas, 2015). The main advantage of the parallel mode is the electric motor and combustion engine complement each other while driving. Most PHEVs with a larger battery first allows an all-electric range of about 15 kilometers. After this point the ICE will engage but the vehicle still has the advantage of a HEV (Fui Tie & Wei Tan, 2013).

In contrast to the PHEV, the extended range electric vehicle (EREV) operates in the so called charge-depleting mode. The configuration is similar to a series PHEV configuration. This means the ICE motor will only engage when the battery is below a certain level. This increases the level of electrification since the conventional motor is only used as a last resort option. The all-electric range is up to 80 kilometers (Rahman, et al., 2015).

The main advantages of PHEV/EREVs are the relatively low emissions they produce, especially when used for short journeys which allows all-electric driving. Meanwhile the ICE technology can be used for long journeys and provides short refueling capabilities just like conventional cars. The main disadvantage is the manufacturing premium up to 10.000 euros for a PHEV and 14.000 euros for an EREV according to Kay, et al. (2013). The main difference between the PHEV and the EREV is the PHEV still uses the ICE as a primary source of propulsion and the EREV has a substantial reduction in emissions, but with the main drawback of additional complexity (ARF & McKinsey, 2014).

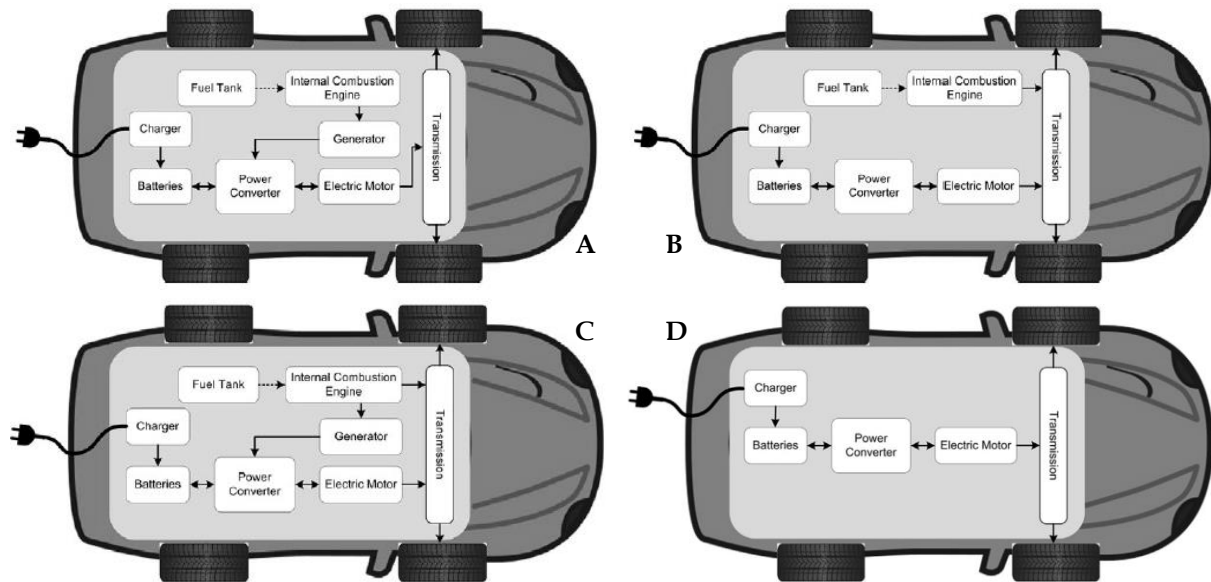


Figure 43: (a) PHEV series, (b) EREV/PHEV parallel, (c) PHEV series-parallel, (d) BEV (Ying Yong, et al., 2015).

ad 3. Battery electric vehicles

The BEV has no combustion engine and is only propelled by an electric motor that operates on battery power. Since the battery is the only power source, it is usually larger in size than the battery of a PHEV or EREV. The battery is charged by regenerative braking or external charging and is subject to high power and high energy requirements to guarantee a minimum driving range. The benefits of a BEV are zero tailpipe emissions, low running costs and less moving parts. The disadvantages are the limited range, high sticker price and relatively immature technology (Fui Tie & Wei Tan, 2013; Kay, et al., 2013).

APPENDIX XV. Datasheet ICEV reference

The vehicle productions costs of the ICEV are already discussed in paragraph 5.3, including the break down of vehicle technology costs, powertrain costs and indirect costs. The BPM is calculated using the tool of the Dutch IRS ('Belastingdienst') (Belastingdienst, 2016). The average C-segment ICEV falls into the category of 106 to 155 gram CO₂ /km. This determined using the car database which was also used for the resale value calculation (owned by CE Delft), as it also include emission data. The average CO₂ emission number (127 gram CO₂ /km) was calculated based on all C-segment ICEVs of this database which results in a BPM fee of €5.116.

Petrol prices are, just like electricity prices, based on the NEV scenario by ECN (2015), which is presented in the graph below (Figure 44).

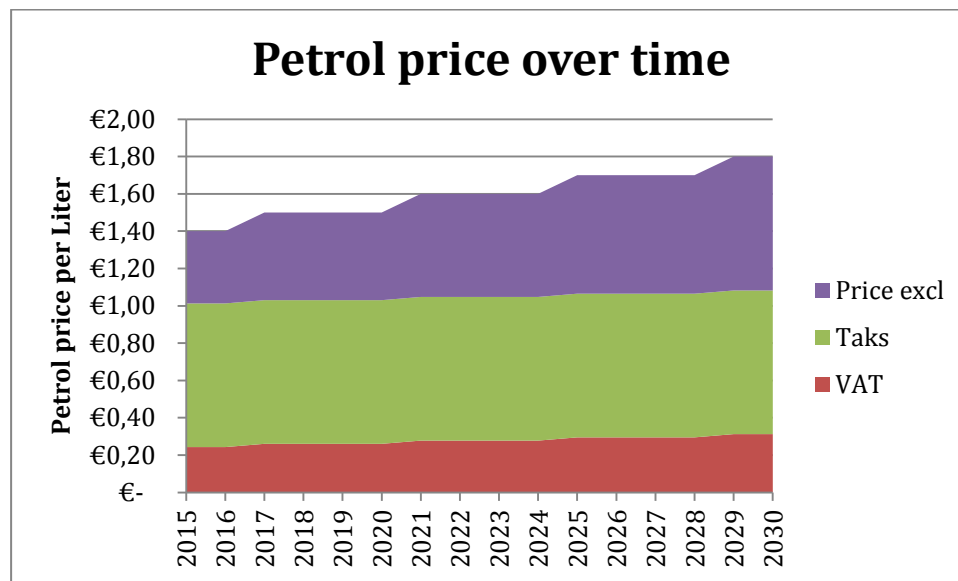


Figure 44: Petro prices over time by (ECN, 2015).

Maintenance costs are based on documents of the Dutch Ministry of Infrastructure & Environment ('De Brandstofvisie'), as explained in paragraph 5.7.3. They assume a 3,0 eurocent/km maintenance cost for ICEVs. Insurance costs were discussed in paragraph 5.7.3 as well.

The energy efficiency of the ICEV (the fuel consumption) is based on the 'De Brandstofvisie' as well. Documents of the Dutch Ministry of Infrastructure & Environment (owned by CE Delft) use fleet averages for different kind of cars for 2020 and 2030, which were extracted and interpolated for this report (Table 24).

Table 24: Fuel consumption of ICEV based on the 'Brandstofvisie' in L/km.

Year	Consumption
2015	0,06085
2016	0,06046
2017	0,06007
2018	0,05968
2019	0,05929
2020	0,0589
2021	0,05851
2022	0,05812
2023	0,05773
2024	0,05734
2025	0,05695
2026	0,05656
2027	0,05617
2028	0,05578
2029	0,05539
2030	0,055

APPENDIX XVI. Retail Price Equivalent multiplier

In the automotive industry, two methodologies are used to determine the difference between the direct manufacturing costs and the retail price. Retail Price Equivalents (RPEs) is a multiplier ($>1,0$) which stands for all indirect costs and the mark-up. This includes corporate overhead, dealer costs, transportation, marketing, etc. (Kolwich, 2013). The RPE is determined by dividing the total direct costs over the total revenues, and its value is generally between 1,5 and 2,1. The Indirect Cost Multiplier (ICM) is a relatively new alternative method to RPE since some organizations believed the RPE overestimates the actual costs and retail price. The ICM therefore differentiates between different technologies with different multipliers. For example, complex technologies like a hybrid engine system get a higher multiplier than a low-technology suspension system. This generally results in a lower overall multiplier. The ICM is criticized by organizations which favor the RPE as it would not correctly estimate the final retail price (Whinihan, et al., 2012).

Without choosing side with method is more accurate, for this research the RPE is used for two reasons. First, the RPE is generally seen as a proven method in the automotive industry while the ICM is relatively new and focused on the additional costs of the implementation of new regulations. Second, the ICM requires a break down of costs to the component level which is out of scope for this research.

Kolwich (2013) determined the RPE for different manufacturers in Europe, also using European retail prices (Kolwich, 2013). In our opinion, this table represents the best available information for this study and therefore a RPE of 1,6 is used throughout this report. There is one side note that may be more in line with the ICMs reasons to criticize the RPE. In this report, future retail prices of cars change. However, that does not necessarily mean the indirect costs change as well, following RPE methodology. Therefore, the initial RPE in absolute terms is derived and the same number is used for future costs. At first, this might seem illogical, but be aware the RPE is a multiplier used to differentiate between direct/indirect costs afterwards (based on historical data). Hence, for this report we assume the same marketing cost, transport costs and overhead costs and profits, whether a car gets more expensive or cheaper.

Table 25: RPE for nine different OEMs in Europe (Kolwich, 2013).

cost contributor	VW	PSA	Renault	GM	FORD	FIAT	BMW	Daimler	Toyota	Average	weighted Average
Cost of sales (direct manuf. costs)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Production overhead	0.28	0.16	0.23	0.20	0.15	0.23	0.27	0.19	0.22	0.21	0.22
Warranty	0.07	0.02	0.02	0.03	0.03	0.09	0.07	0.03	0.04	0.04	0.05
R&D	0.07	0.05	0.07	0.07	0.05	0.03	0.08	0.06	0.06	0.06	0.06
Depreciation and amortization	0.10	0.07	0.10	0.07	0.04	0.08	0.09	0.06	0.09	0.08	0.08
Maintenance, repair	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Corporate Overhead	0.04	0.05	0.05	0.05	0.04	0.04	0.04	0.06	0.04	0.05	0.05
Selling	0.14	0.11	0.12	0.06	0.08	0.08	0.11	0.14	0.10	0.11	0.11
Dealers	0.16	0.14	0.16	0.14	0.14	0.15	0.16	0.16	0.15	0.15	0.15
Dealer net profit	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Dealer selling cost	0.14	0.12	0.14	0.12	0.12	0.13	0.14	0.14	0.13	0.13	0.13
Net income	0.09	0.02	0.08	0.08	0.09	0.04	0.11	0.09	0.03	0.07	0.07
RPE Multiplier	1.72	1.48	1.64	1.54	1.49	1.54	1.69	1.64	1.55	1.59	1.60

APPENDIX XVII. Battery prices

The scatter plot below shows the battery pack cost estimation of all the high-quality studies. Two scenarios of one study are marked as an outlier (Gerssen-Gondelach & Faaij, 2012) and are excluded for the determination of the scenarios.

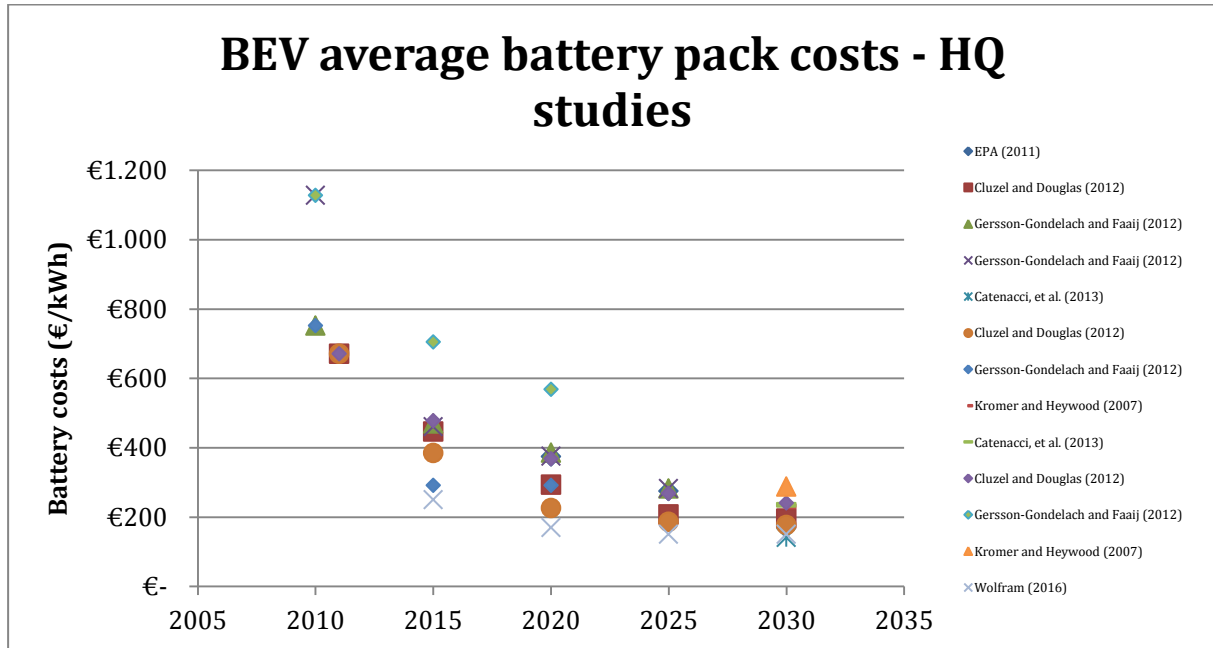


Figure 45: Battery pack estimation by different HQ sources

Using Excel an exponential trend line is derived from Figure 45, which results in the following equation: $y = 377,26e^{-0,22x}$.

APPENDIX XVIII. Verification battery costs I

The figure below shows the results of Nykvist & Nilsson (2015) which conducted a very extensive research to estimate battery costs. The results are similar with the battery costs used in this research. In the average scenario the current (2015) costs are about €400, with the lower bound (optimistic) at €250 and the upper bound (pessimistic) at €700.

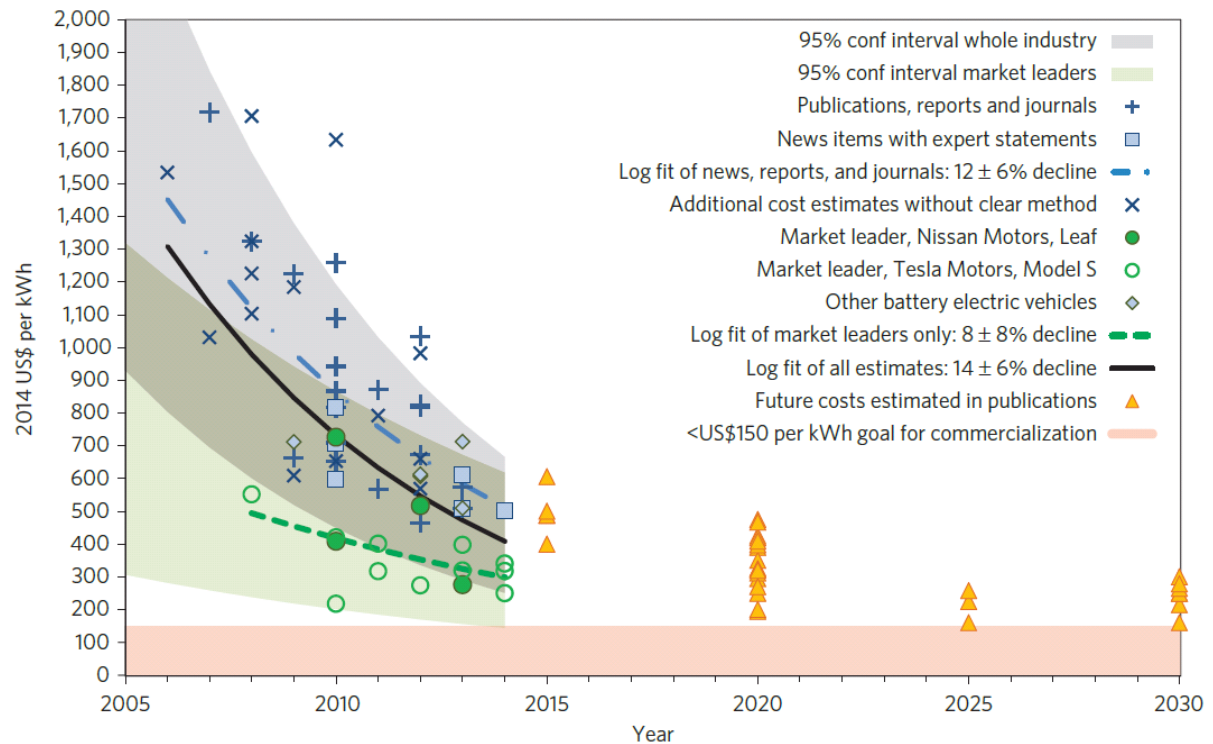


Figure 46: Estimated battery pack costs (Nykvist & Nilsson, 2015).

APPENDIX XIX. Demand scenarios

The demand of EVs, which translates in future predicted sales of such products, is relevant because it determines at what point in time scale and learning effects kick in. This can have a big influence on the price as discussed in Chapter 5, but it is also very difficult to predict the demand, as the high number of factors that influence the demand of EVs indicates (see the framework in Chapter 4). In order to determine economies of scale, we need to know the global absolute demand of EVs. This allows us calculate the total production over time, on which a learning rate can be applied.

Other studies that presented demand figures used secondary data and large differences are noted between the studies. When analysing the actual studies that compiled the (primary) data, there is rarely no explanation how the numbers are compiled. The studies that did explain their methodology either used the EV sales targets of governments or assumed a general increase in demand (e.g. 5% per year).

Global sales of all passenger vehicles

Nevertheless to compare different studies we searched for studies that compiled data. We only included data of which we could retrieve the original study (so no figures from references in other studies). Although we found 17 studies that compiled demand estimations, two issues limit the opportunity to compare these studies. First, many studies presented relative car sales to total sales. Since we need absolute number, we therefore need to determine the forecasted total car sales on a global scale, data which is generally not provided by the respective study. Five studies did estimate the global annual sales. Data from BNEF (2016) is used to determine the absolute data of the remaining studies, since it shows the average scenario (see Figure 47) and is recently published. Second, global sales data is required to compute scale effects, and many studies limit their research to a country or continent. Therefore, these are not included in the figures as presented below.

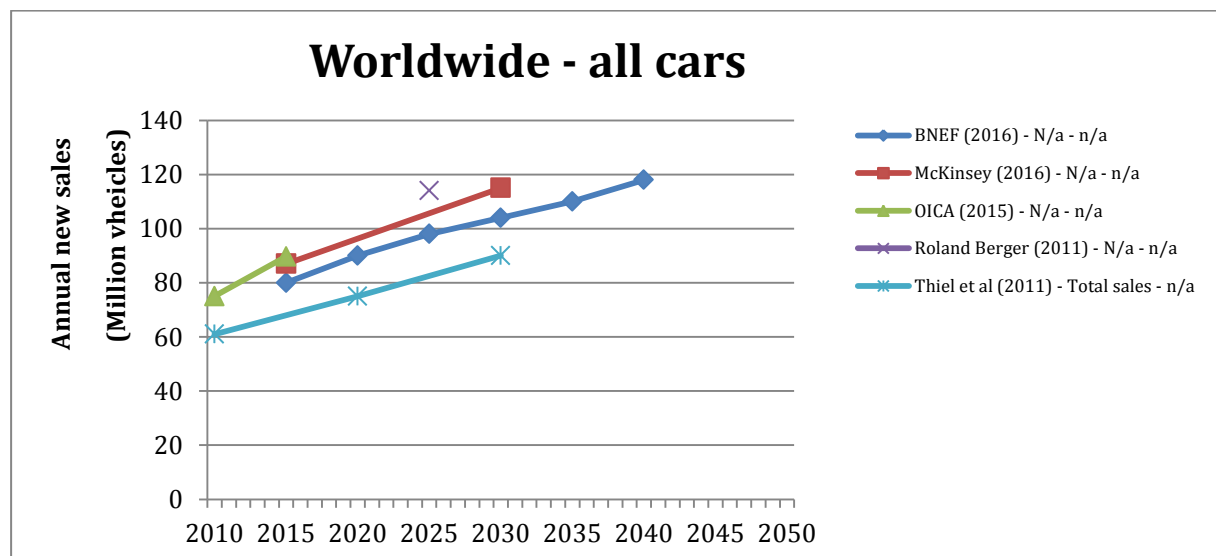


Figure 47: Worldwide annual new car sales in million of vehicles over time.

Global sales of EVs

The figure below (Figure 48) shows the annual new sales for the BEV and figure X depicts all EVs. As the figures present, some studies expect a revolution in the EV market, while others are much conservative. For the BEVs, the pessimistic scenario expects a 3% market share of BEVs in terms of annual new sales, while the average and optimistic scenario expects a respectively 9% and 25% market share. For EVs in general (includes BEV, PHEV and EREV) the market share for the three scenarios is expected to increase from 3% at present to either 16%, 21% or 42%.

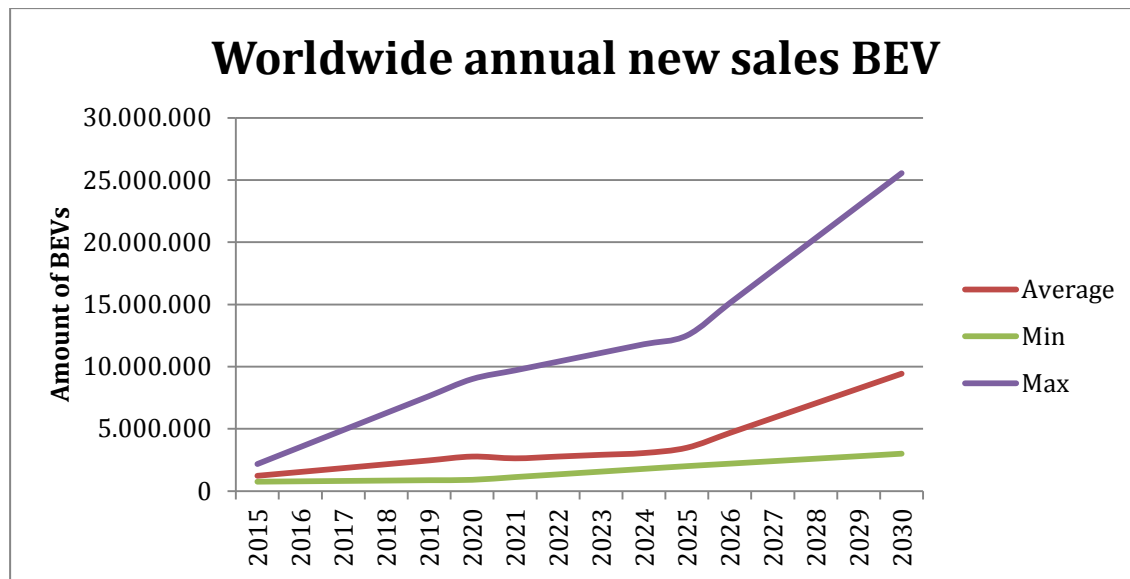


Figure 48: Worldwide annual new BEV sales in million of vehicles over time for three scenarios.

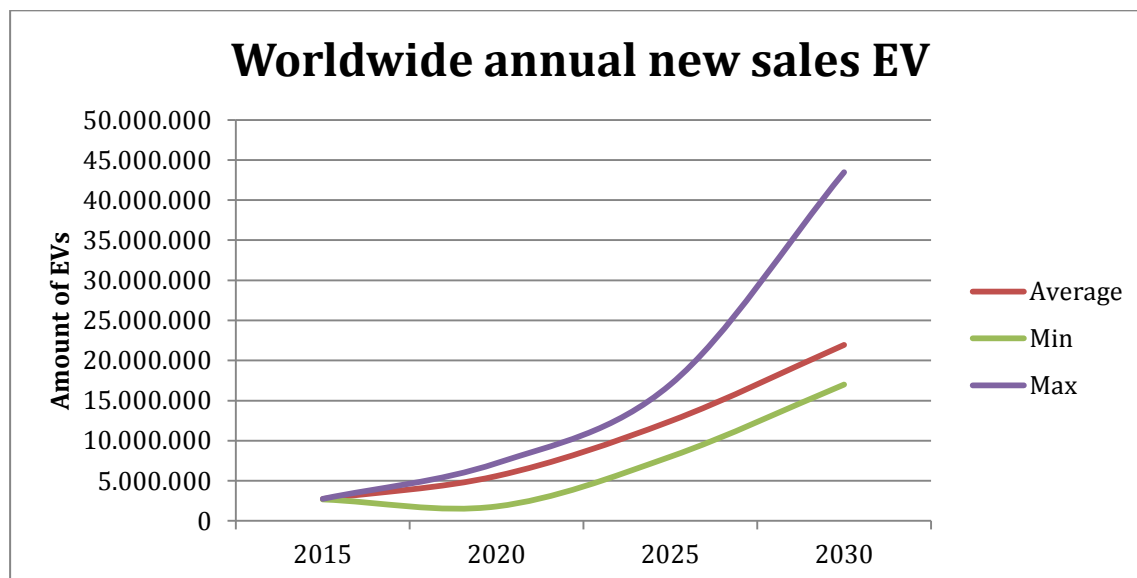


Figure 49: Worldwide annual new sales for all EVs in million of vehicles over time.

Many scenarios are collected but not presented because they only provided data for e.g. Europe, for example the scenario of CE Delft. Their most optimistic scenario expects a 10% adoption rate in 2020 which increases in ten years to an adoption rate of 84% relative to the total fleet. This would mean the market stabilisation phase would occur around 2020. More pessimistic scenarios argue the adaptation phase takes longer or the ICE technology will remain the dominant design for the upcoming 15 years (CE Delft, 2011). So when EV costs decline, the adoption rate will increase. On the other hand, when diffusion takes-off the costs will decrease as well due to the aforementioned reasons. This is a typical “chicken-and-egg” problem: cost affects adoption rate and vice versa adoption rate affects cost (Green, et al., 2014).

APPENDIX XX. Verification battery costs II

To verify the literature's expected battery pack costs from the present till 2030, we plotted the experience curve for the current average price (about €400/kWh), using three demand adoption scenarios as presented in Appendix XX: a 2030 EV market share of 16% in the pessimistic scenario, 21% in the neutral scenario or 42% in the optimistic scenario. It consists of three steps.

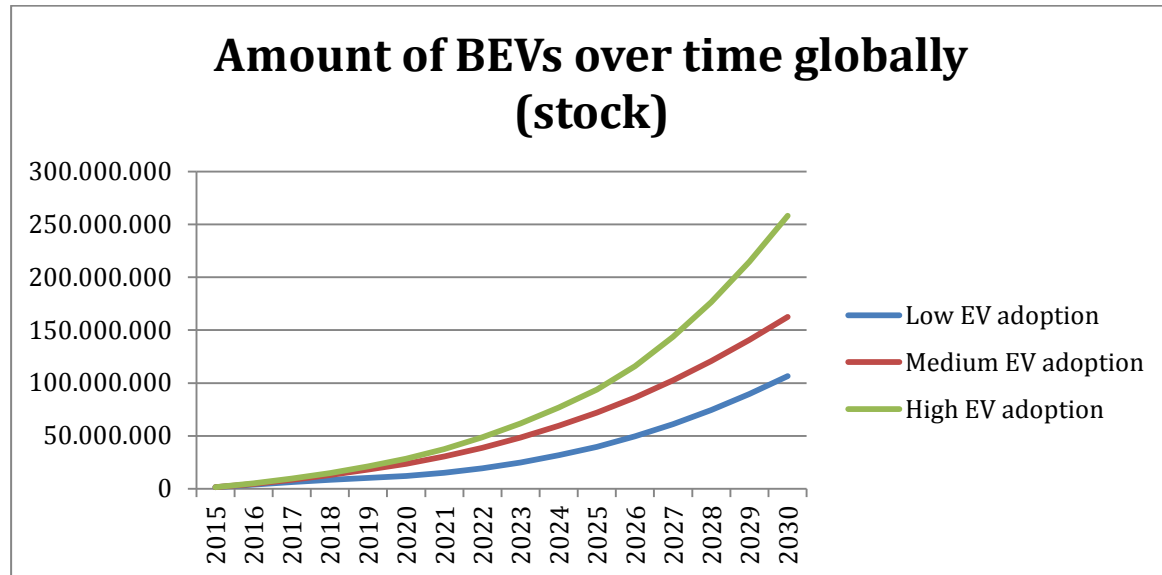


Figure 50: Number of BEV stock over time globally (source: based on data from APPENDIX XIX).

First, it is acknowledged not all costs are subject to economies of scale. The costs for raw materials for example will not change. The same applies for the proportion of R&D and financial depreciation. According to (Book, et al., 2009), is account for 40% of the total costs of the battery. Therefore, it is assumed 40% of the current costs are fixed and 60% of the costs are subject to the experience curve.

Second, the learning rate is assumed to be 22%. Other studies used a similar learning rate (Matteson & Williams, 2015; Weiss, et al., 2012).

Third, an arbitrary starting point has to be chosen. IEA (2016) expects the 2015 worldwide EV stock to be 1,26 million.

Active materials	12%	Subject to EoS	60%
Mark-up	13%	Not EoS	40%
R&D	14%		
Depreciation	14%		
Labor	11%		
Purchased parts	32%		
Scrap	4%		

Figure 51: Aspects which are (not) subject to economies-of-scale (EoS). The percentages are based on other literature (Book, et al., 2009).

Following the equation in the theory (Chapter 2, equation 1), the future costs can be calculated. The results are shown in the figure below. Although the initial slope in this graph is higher than the results from the literature, the final price in 2030 is quite similar. It is remarkable there is little difference between the adoption scenarios. This means estimating the correct battery price at present seems to be more important than the adoption estimates.

To conclude, this graph is quite similar to the graph we derived based on the literature study. In our opinion this confirms the accuracy of the data used for the TCO model.

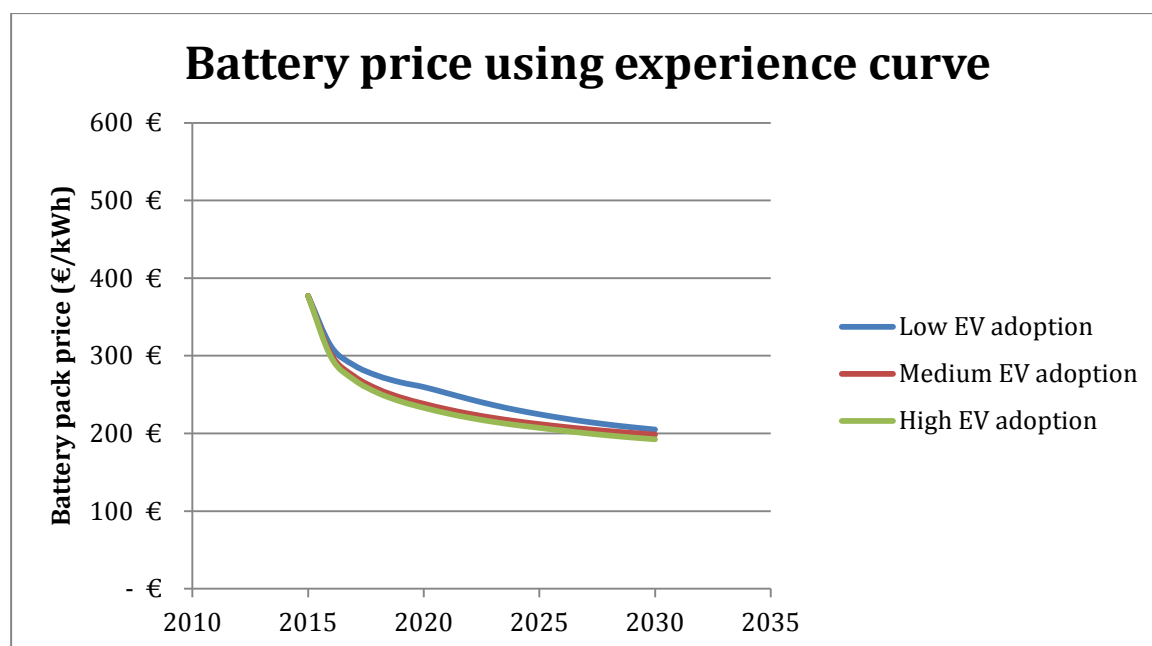


Figure 52: Battery price development using experience curves (own calculations).

APPENDIX XXI. Datasheet powertrain

The powertrain data which was used for this report can be found below and is obtained from a detailed TNO study which researched BEV powertrain costs (TNO, 2011).

Powertrain costs BEV

Type	Segment	Year	Motor	Investor	CU	HVAC	Total
BEV	B	2020	€ 463	€ 735	€ 256	€ 863	€ 2.317
BEV	C	2020	€ 587	€ 935	€ 288	€ 959	€ 2.768
BEV	D	2020	€ 620	€ 989	€ 320	€ 1.054	€ 2.983
BEV	B	2030	€ 356	€ 565	€ 256	€ 778	€ 1.953
BEV	C	2030	€ 451	€ 719	€ 288	€ 863	€ 2.320
BEV	D	2030	€ 476	€ 762	€ 320	€ 959	€ 2.516

Corrected for inflation

Figure 53: BEV powertrain costs (Retrieved from TNO and corrected for inflation (TNO, 2011)).

APPENDIX XXII. Retail price

Many input data was required to conduct the calculations of the production costs, among others the retail price, the taxes, the car's segment, the battery pack size and the estimated range. As this information could not be found in academic or semi-academic studies, regular websites were used to retrieve the data. The following information is considered to be important

- Average retail prices per segment were retrieved from an official Dutch organisation (Bovag, 2015) and are considered accurate. Retail prices for specific models however were retrieved at general website, such as autoweek.nl. Since prices vary per country, it was important to use a Dutch website;
- Regarding range, the EPA range was used because it represents a more realistic all-electric range and fuel efficiency compared to NEDC data;
- There is no official standard for the segmentation between car (A,B,C, etc.). This sometimes made it very hard to determine the correct segment. General websites were used for this process.

This following websites were used to obtain the necessary information:

- https://en.wikipedia.org/wiki/BMW_i3
- <http://www.autoweek.nl/auto/74905/bmw-i3>
- <http://cleantechnica.com/2016/01/22/2017-volkswagen-e-golf-getting-range-boost-to-108-miles/>
- <http://electrek.co/2016/05/23/2017-vw-e-golf-186-miles-range/>
- <http://www.newcars2015-2016.com/2017-vw-up-powerup/>
- <https://www.fueleconomy.gov/feg/Find.do?action=sbs&id=36979>
- <http://electrek.co/2016/04/07/tesla-model-3-chevy-bolt/>
- <http://electrek.co/2016/04/07/tesla-model-3-chevy-bolt/>
- <http://www.teslamodel3.nl/auto/>
- <http://www.autokopen.nl/autonieuws/2016/maart/40329-hyundai-ioniq-wordt-in-ieder-geval-goedkoper-dan-de-prius>
- <http://insideevs.com/global-electric-car-sales-2014-segment-leaders/>
- https://en.wikipedia.org/wiki/Vehicle_size_class#Europe
- <http://www.zomoto.nl/searchmycar.aspx>
- <http://auto-en-vervoer.infonu.nl/auto/155193-autoklassen-welke-segmenten-zijn-er-allemaal.html>

APPENDIX XXIII. Resale value regression

The results of the regression can be found below.

Dependent Variable: DEPRECIATION_RATE

Method: Least Squares

Date: 06/17/16 Time: 13:35

Sample: 1 134549 IF TYPE_TRANS="Tweedehands" AND
MK<>"Oldtimer" AND PP>0 AND PH>0 AND AGE>0 AND
KM_CLN_1000>0 AND WEIGHT>0 AND AGE<30 AND
DEPRECIATION_RATE<150

Included observations: 131639

HAC standard errors & covariance (Bartlett kernel, Newey-West fixed
bandwidth = 20.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DEPR_BENZ_FIRST_6	-0.355602	0.012951	-27.45778	0.0000
LOG(AGE_IN_MONTHS)	-25.51364	0.168906	-151.0527	0.0000
AGE_ELEK	-0.577888	1.318710	-0.438222	0.6612
C	150.7418	0.762792	197.6183	0.0000
R-squared	0.730491	Mean dependent var	47.38974	
Adjusted R-squared	0.730485	S.D. dependent var	30.66017	
S.E. of regression	15.91718	Akaike info criterion	8.372706	
Sum squared resid	33350613	Schwarz criterion	8.373003	
Log likelihood	-551083.3	Hannan-Quinn criter.	8.372795	
F-statistic	118930.0	Durbin-Watson stat	0.600899	
Prob(F-statistic)	0.000000	Wald F-statistic	7775.901	
Prob(Wald F-statistic)	0.000000			

APPENDIX XXIV. Charging losses

Based on the sources on the internet (Nissan, 2014; Tesla Motors, 2015) and interviews (Interview 14,16) we assume an charging efficiency between 95% and 88%, which increases to a 98% - 95% in 2030. This is because it is impossible to reach a 100% efficient electrical system. To illustrate the effect on the costs: If one would need 1000 kWh a year for his/her driving pattern, he/she will pay for 1053 kWh assuming a 5% charging loss (Table 26).

Table 26: Charging losses.

Charging losses			
Year	Optimistic	Neutral	Pessimistic
2015	95%	93%	88%
2016	95%	93%	88%
2017	95%	93%	89%
2018	96%	94%	89%
2019	96%	94%	90%
2020	96%	94%	90%
2021	96%	94%	91%
2022	96%	94%	91%
2023	97%	95%	92%
2024	97%	95%	92%
2025	97%	95%	93%
2026	97%	95%	93%
2027	97%	95%	94%
2028	98%	96%	94%
2029	98%	96%	95%
2030	98%	96%	95%

APPENDIX XXV. Datasheet energy prices

The scenario in which electricity prices increase over time is based on the NEV ('Nationale Energie Verkenning') of ECN (2015). Consumer prices are estimated up to 2020, but post-2020 consumer prices have to be derived based on the wholesale price. The relative increase of the wholesale price is used to calculate the increase of the consumer price, as shown in the grey cells (Table 27). The taxes are assumed to remain constant after 2020.

Table 27: Historical and future energy prices based on (ECN, 2015).

Increase in energy prices

What	2015	2020	2025	2030
Wholesale price (€/MWh)	43	50	64	69
Consumer price (€/kWh)	0,06	0,08	0,089302	0,096279
Energy tax	0,12	0,12	0,12	0,12
ODE tax	0	0,03	0,03	0,03
VAT	0,04	0,05	0,05	0,05
Total price	0,22	0,28	0,29	0,30

The figure below shows the three scenarios of electricity prices including taxes (Figure 54).

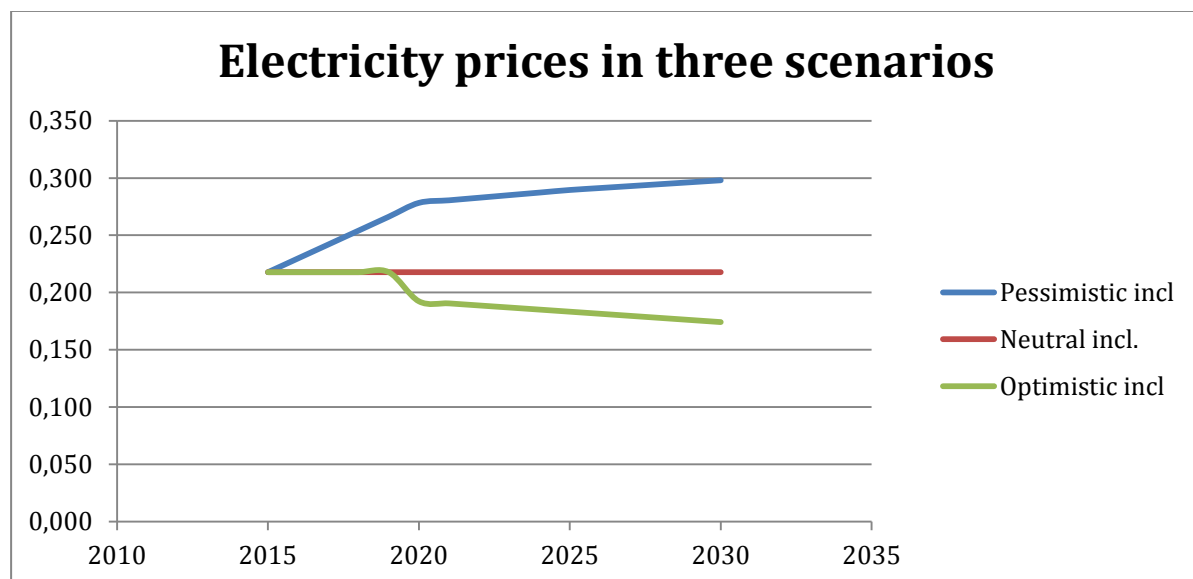


Figure 54: Electricity prices in three scenarios.

APPENDIX XXVI. Datasheet home charging

For residential or workplace chargers the current costs range between €600 and €2300 (Figure 55). Most expect the costs to be between €1000 and €2000, including installation costs. There may be some reasons why the range is quite large. First, different labour rates can be used in different countries, which is a third and sometimes half of the total costs. Second, different manufacturers offer chargers for a certain price. Third, the power output can range between 3,7-7,0kW of which the latter is more expensive. A quick look at the Nissan and Tesla website learns us the actual home charger installation costs are respectively €1800 and €900-1800 dependent whether the house need a utility upgrade or not (Nissan, 2016; Tesla Motors, 2016). Nemry & Brons (2010) ignored installation costs so is not depicted in the figure, but assumes the residential charger costs €693 (Nemry & Brons, 2010).

Since the current price is between €900-1800, some studies apparently were too conservative, at least for Dutch prices. The most realistic studies however do not extrapolate their costs.

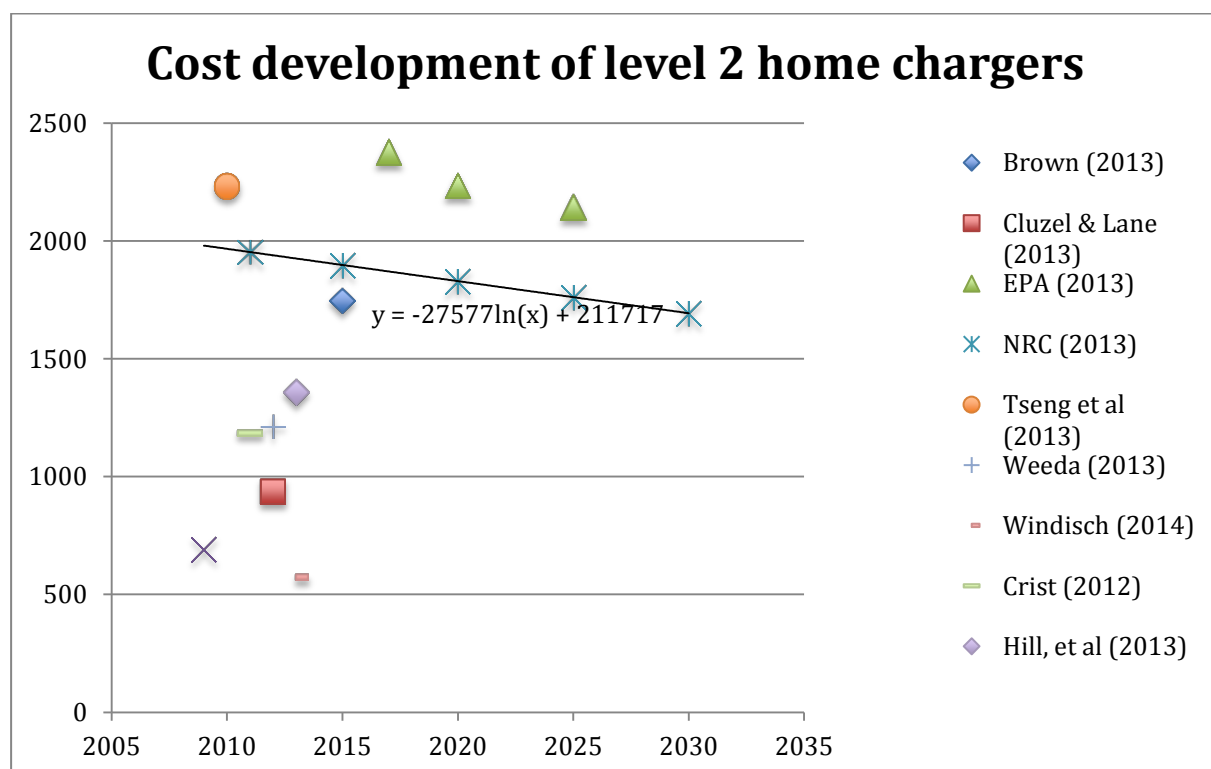


Figure 55: Cost development of level 2 home chargers (corrected for inflation and currency exchange rate if applicable €₂₀₁₅).

Most studies provided some arguments how the infrastructure cost were calculated. If so, it is explained below. If the study is not included, no arguments were provided.

May & Mattila (2009) use different retailers to determine the actual costs of a charger, which is up to \$500 for the most basic one and up to \$7000 for an advanced charging station. For this research we assume the most advanced station. They also include a \$55 to \$100 hourly rate and between half a day and two days for installation. We assume an \$85 hourly rate and one day to install the charger (May & Mattila, 2009).

ARF & McKinsey (2014) provided reliable cost data as well, but did not include maintenance costs in their calculations. In order to compare their results with the other study, we included the average labour costs for public charging to the original ARF & McKinsey numbers (ARF & McKinsey, 2014).

NRC (2011) compiled actual charger costs data from 2011 and estimated a 67% decline in equipment costs up to 2050. The installation costs (labour rate) remain the same (National Research Council, 2013, p. 336).

EPA (2013) determines future costs of EV home chargers and expects these to go down only slightly. This is because a proportionally large part of the costs are labour costs which are not subject to a learning rate and hence remain fixed (EPA, 2013).

In a study by ECN the charging point costs are determined based on literature and expert judgments. The initial costs were up to €16.000 for public charging points, €3.000 for a residential charger and €55.000-€70.000 for a fast charger.

ECN attempted to calculate the required total investment for charging infrastructure for The Netherlands. The range between the lower and upper bound varies significantly: €230 mln to €650 mln. This shows the large uncertainty regarding the charging infrastructure. It is not only affected by the cost decline estimation, but also the amount of chargers required per EV, the proportion of public and private chargers and whether fast chargers will be introduced (Weeda, 2013).

Madina (2015) estimated public charging points should have at least 3-4 charging sessions a day in order to become profitable. Once more EVs are used, the price will go down and hence the TCO will decline. The effect of technological advancement is difficult to predict. Increased battery performance or fuel consumption performance can encourage customers to either use the public charging more often or less often, because of either more EVs in general and at the same time less charging needs per EV (Madina, 2015).

APPENDIX XXVII. Public charging costs

The figure below (Figure 56) shows all applicable fees for using public charging stations in The Netherlands, depending on the charging card provider and the charging station owner (Wolbertus, 2016). All prices include VAT.

Public charging matrix																							
Laadpasprovider	EVBox			Greenflux		Nuon		Essent		The New Motion		ANWB monthly		ANWB per session		Flow Charging		Movenience		Eneco		Radiuz	
Eenmalige kosten	€		5,00	€	10,00	€	-	€	-	€	-	€	-	€	-	€	-	€	-	€	-	€	15,00
Abonnementkosten/maar	€		4,54	€	2,50	€	-	€	2,50	€	-	€	6,29	€	-	€	-	€	5,00	€	3,00	€	4,00
Chargepoint operator	Fixed fee	€/kWh	Fixed fee	€/kWh3	Fixed fee	€/kWh5	Fixed fee	€/kWh7	Fixed fee	€/kWh9	Fixed fee	€/kWh11	Fixed fee	€/kWh13	Fixed fee	€/kWh15	Fixed fee	€/kWh17	Fixed fee	€/kWh19	Fixed fee	€/kWh21	
Essent (Amsterdam)	€	-	€ 0,34	€ -	€ 0,37	€ -	€ 0,30	€ -	€ 0,32	€ 0,35	€ 0,34	€ -	€ 0,34	€ 0,34	€ 0,34	€ 0,12	€ 0,34	€ 0,30	€ 0,30	€ 0,61	€ 0,36	€ -	€ 0,34
Nuon (Amsterdam)	€	-	€ 0,34	€ -	€ 0,37	€ -	€ 0,30	€ -	€ 0,32	€ 0,35	€ 0,34	€ -	€ 0,34	€ 0,34	€ 0,34	€ 0,12	€ 0,34	€ 0,30	€ 0,30	€ 0,61	€ 0,36	€ -	€ 0,34
Cofely/EV box (Rotterdam)	€	-	€ 0,29	€ -	€ 0,32	€ -	€ 0,30	€ 0,61	€ 0,36	€ 0,35	€ 0,29	€ -	€ 0,29	€ 0,34	€ 0,29	€ 0,12	€ 0,29	€ 0,30	€ 0,26	€ 0,61	€ 0,36	€ -	€ 0,29
Ballast Nedam (Utrecht)	€	-	€ 0,29	€ -	€ 0,32	€ -	€ 0,30	€ 0,61	€ 0,36	€ 0,35	€ 0,29	€ -	€ 0,29	€ 0,34	€ 0,29	€ 0,12	€ 0,29	unknown	unknown	€ 0,61	€ 0,36	€ -	€ 0,29
Alfen (Den Haag)	€	-	€ 0,25	€ -	€ 0,28	€ -	€ 0,30	€ 0,61	€ 0,36	€ 0,35	€ 0,25	€ -	€ 0,30	€ 0,34	€ 0,25	€ 0,12	€ 0,25	unknown	unknown	€ 0,61	€ 0,36	€ -	€ 0,25
EVnetNL	€	0,61	€ 0,35	€ 0,64	€ 0,38	€ 0,61	€ 0,35	€ 0,61	€ 0,36	€ 0,96	€ 0,35	€ 0,61	€ 0,35	€ 0,95	€ 0,35	€ 0,73	€ 0,35	€ 0,30	unknown	€ 0,61	€ 0,36	€ 0,61	€ 0,35
Essent	€	-	€ 0,36	€ -	€ 0,37	€ -	€ 0,30	€ 0,61	€ 0,36	€ 0,35	€ 0,36	€ -	€ 0,36	€ 0,34	€ 0,36	€ 0,12	€ 0,36	€ 0,30	€ 0,30	€ 0,61	€ 0,36	€ -	€ 0,36
Nuon	€	-	€ 0,34	€ -	€ 0,37	€ -	€ 0,30	€ 0,61	€ 0,36	€ 0,35	€ 0,34	€ -	€ 0,34	€ 0,34	€ 0,34	€ 0,12	€ 0,34	€ 0,30	€ 0,30	€ 0,61	€ 0,36	€ -	€ 0,34
The New Motion	€	-	unknown	€ -	unknown	€ -	€ 0,30	€ 0,61	€ 0,36	€ 0,35	unknown	€ -	unknown	€ 0,34	unknown	€ 0,12	unknown	€ 0,30	unknown	€ 0,61	€ 0,36	€ -	unknown
EVBox	€	-	€ 0,29	€ -	€ 0,32	€ -	€ 0,30	€ 0,61	€ 0,36	€ 0,35	€ 0,29	€ -	€ 0,29	€ 0,34	€ 0,29	€ 0,12	€ 0,29	€ 0,30	unknown	€ 0,61	€ 0,36	€ -	€ 0,29
Eneco	€	-	€ 0,29	€ -	€ 0,32	€ -	€ 0,30	€ 0,61	€ 0,36	€ 0,35	€ 0,29	€ -	€ 0,29	€ 0,34	€ 0,29	€ 0,12	€ 0,29	€ 0,30	€ 0,26	€ 0,61	€ 0,19	€ -	€ 0,29
Ecotap	€	-	€ 0,30	€ -	€ 0,33	€ -	€ 0,30	€ 0,61	€ 0,36	€ 0,35	€ 0,30	€ -	€ 0,30	€ 0,34	€ 0,30	€ 0,12	€ 0,30	€ 0,30	€ 0,27	€ 0,61	€ 0,36	€ -	€ 0,30
ANWB	€	-	€ 0,29	€ -	€ 0,32	€ -	€ 0,30	€ 0,61	€ 0,36	€ 0,35	€ 0,29	€ -	€ 0,29	€ 0,34	€ 0,29	€ 0,12	€ 0,29	€ 0,30	€ 0,27	€ 0,61	€ 0,36	€ -	€ 0,29
Allego tot 3,8KW	€	0,50	€ 0,32	€ 0,53	€ 0,35	€ 0,61	€ 0,35	€ 0,61	€ 0,36	€ 0,85	€ 0,32	€ 0,50	€ 0,32	€ 0,84	€ 0,32	€ 0,62	€ 0,32	€ 0,80	€ 0,29	€ 0,61	€ 0,36	€ 0,50	€ 0,32
Allego tot 7,6KW	€	0,50	€ 0,32	€ 0,53	€ 0,35	€ 0,61	€ 0,35	€ 0,61	€ 0,36	€ 0,85	€ 0,32	€ 0,50	€ 0,32	€ 0,84	€ 0,32	€ 0,62	€ 0,32	€ 0,80	€ 0,29	€ 0,61	€ 0,36	€ 0,50	€ 0,32
Allego tot 11KW	€	0,50	€ 0,33	€ 0,53	€ 0,36	€ 0,61	€ 0,35	€ 0,61	€ 0,36	€ 0,85	€ 0,33	€ 0,50	€ 0,33	€ 0,84	€ 0,33	€ 0,62	€ 0,33	€ 0,80	€ 0,30	€ 0,61	€ 0,36	€ 0,50	€ 0,33
Allego tot 23KW	€	0,50	€ 0,31	€ 0,53	€ 0,36	€ 0,61	€ 0,35	€ 0,61	€ 0,36	€ 0,85	€ 0,31	€ 0,50	€ 0,31	€ 0,84	€ 0,31	€ 0,62	€ 0,31	€ 0,80	€ 0,28	€ 0,61	€ 0,36	€ 0,50	€ 0,31
Flow	€	-	€ 0,29	€ -	€ 0,32	€ -	€ 0,30	€ 0,61	€ 0,36	€ 0,35	€ 0,29	€ -	€ 0,29	€ 0,34	€ 0,29	€ 0,12	€ 0,29	€ 0,30	€ 0,27	€ 0,61	€ 0,36	€ -	€ 0,29
Greenflux	€	-	€ 0,35	€ 0,64	€ 0,38	€ 0,61	€ 0,35	unknown	unknown	€ 0,35	€ 0,35	€ -	€ 0,35	€ 0,34	€ 0,35	€ 0,12	€ 0,35	€ 0,30	€ 0,32	€ 0,61	€ 0,36	€ -	€ 0,35
ANWB/Greenflux A-locatie	€	1,98	€ 0,25	€ 2,01	€ 0,28	€ -	unknown	unknown	unknown	€ 2,33	€ 0,25	€ 1,98	€ 0,25	€ 2,32	€ 0,25	€ 2,10	€ 0,25	€ 2,28	€ 0,23	€ 0,61	€ 0,36	€ 1,98	€ 0,25
Average	€	0,23	€ 0,31	€ 0,27	€ 0,34	€ 0,18	€ 0,32	€ 0,54	€ 0,36	€ 0,58	€ 0,31	€ 0,23	€ 0,31	€ 0,57	€ 0,31	€ 0,35	€ 0,31	€ 0,52	€ 0,28	€ 0,61	€ 0,35	€ 0,23	€ 0,31

* All prices are including VAT

Figure 56: Public charging costs matrix (Wolbertus, 2016).

APPENDIX XXVIII. Input data maintenance costs

The data is based on the following studies:

- CE Delft's study argues the alternative components of the EV compared to ICEVs are all maintenance free and scheduled maintenance is not required. The only concern raised by CE Delft is battery deterioration after about 200.000 kilometres. Hence, they assume the BEV's maintenance costs to be half of the ICEV costs. The cost to maintain a PHEV are similar to the ICEV cost (CE Delft, 2011).
- Davis (2014) used maintenance cost calculations based on OEM recommendations for different EV models relative to comparable conventional cars (Davis, 2014).
- Lee and Lovellette (2011) take into account maintenance costs as well, but does not mention how the numbers are determined (Lee & Lovellette, 2011). Therefore, their results are excluded for this research.
- Propfe, et al. (2012) used historical data of the mean times between failure (MTBF) of various component.

The data is presented in the table below (Table 28).

Table 28: Datasheet maintenance costs.

Source (year)	Base year price	EV type	Size	Value origin	Unit	Real EUR	Value	Lifetime	VMT	Unit2	Relative c.t. ICEV
Cleary, et al. (2010)	2009	ICE	Medium	\$ 6.957,58	Total costs USD	€ 6.685,81	€ 0,026929	10	154.270	Miles	#N/B
Cleary, et al. (2010)	2009	PHEV	Medium	\$ 5.151,14	Total costs USD	€ 4.949,93	€ 0,019937	10	154.270	Miles	25,96
CE Delft (2011)	2009	ICE	Medium	€ 914,00	Yearly costs EUR	€ 974,47	€ 0,092922	14	10.487	km/year	#N/B
CE Delft (2011)	2009	PHEV	Medium	€ 914,00	Yearly costs EUR	€ 974,47	€ 0,092922	13	10.487	km/year	0,00
CE Delft (2011)	2010	EREV	Medium	€ 418,00	Yearly costs EUR	€ 435,81	€ 0,041557	11	10.487	km/year	55,28
CE Delft (2011)	2010	BEV	Medium	€ 418,00	Yearly costs EUR	€ 435,81	€ 0,041557	11	10.487	km/year	55,28
Propfe (2012)	2011	ICE	Medium	€ 0,072000	Ct/km EUR	€ 0,073798	€ 0,073798	#N/B	#N/B	#N/B	#N/B
Propfe (2012)	2011	PHEV	Medium	€ 0,070000	Ct/km EUR	€ 0,071748	€ 0,071748	#N/B	#N/B	#N/B	2,78
Propfe (2012)	2011	EREV	Medium	€ 0,053000	Ct/km EUR	€ 0,054323	€ 0,054323	#N/B	#N/B	#N/B	26,39
Propfe (2012)	2011	BEV	Medium	€ 0,059500	Ct/km EUR	€ 0,060986	€ 0,060986	#N/B	#N/B	#N/B	17,36
Davis (2014)	2013	ICE	Medium	\$ 3.909,00	Total costs USD	€ 3.515,45	€ 0,014563	#N/B	150.000	miles	#N/B
Davis (2014)	2013	EREV	Medium	\$ 2.151,00	Total costs USD	€ 1.934,44	€ 0,008013	#N/B	150.000	miles	44,97
Davis (2014)	2013	PHEV	Medium	\$ 1.827,00	Total costs USD	€ 1.643,06	€ 0,006806	#N/B	150.000	miles	53,26
Davis (2014)	2013	BEV	Medium	\$ 793,00	Total costs USD	€ 713,16	€ 0,002954	#N/B	150.000	miles	79,71

This results in the following graph (Figure 57).

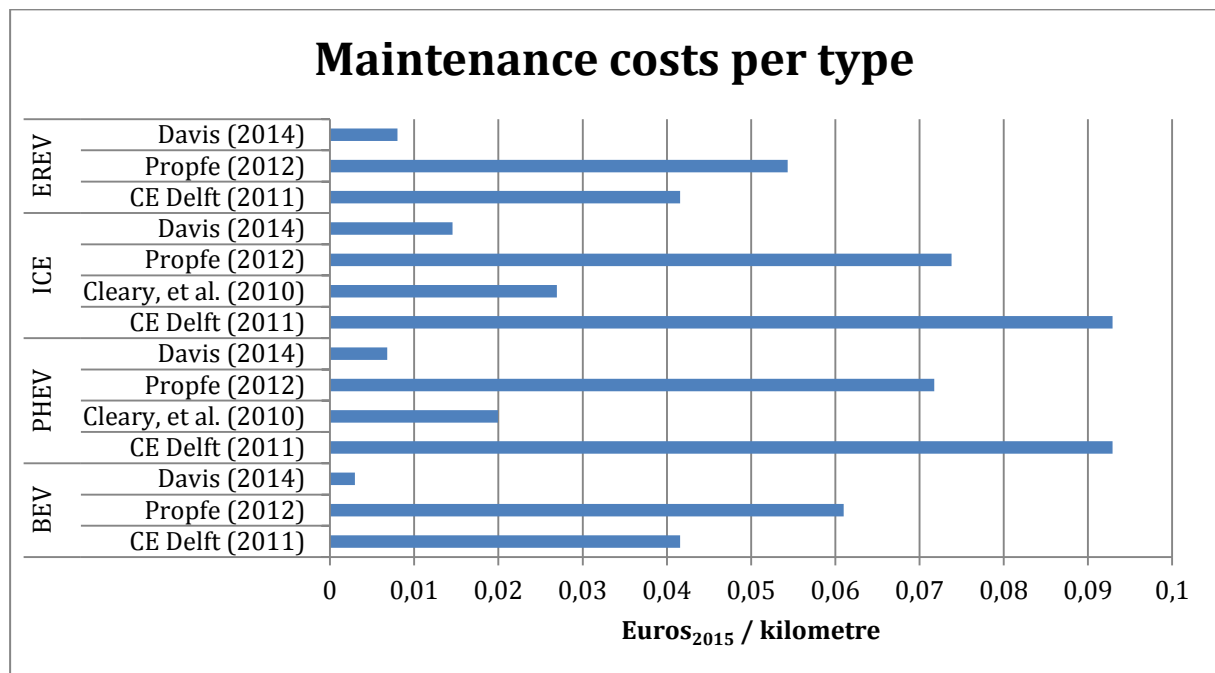


Figure 57: Maintenance cost overview.

Interview 1. Bert van Wee

Algemene informatie

Naam	: Bert van Wee
Organisatie	: Technische Universiteit Delft
Functie	: Professor Transport Policy
Datum interview	: Woensdag 18 mei 2016
Tijd	: 09.00 – 10.00 uur

Algemene vragen

1. Is het model begrijpelijk? *Om te verifiëren of de geïnterviewde het heeft begrepen.*
 - De geïnterviewde geeft aan dat het model begrijpelijk is.
2. Zijn er nog factoren (blokjes) die niet op de goede plek staan, missen of juist verwijderd moeten worden?
3. Zijn er nog relaties (pijltes) die niet op de goede plek staan, missen of juist verwijderd moeten worden?

Uitleg vereenvoudigde model. De geïnterviewde heeft de volgende opmerkingen:

- De geïnterviewde geeft aan dat financiële prikkels (bijvoorbeeld invloed van GDP op R&D) niet is weergegeven in slide 4.
- De geïnterviewde is het voor de rest eens met het schema zoals het is weergegeven in slide 4.
- De geïnterviewde geeft wel aan dat het belangrijk is om duidelijk onderscheid te maken tussen one-time cost en reoccurring costs

Uitleg gedetailleerde model. De geïnterviewde heeft de volgende opmerkingen:

- Zitten reparatiekosten er ook bij? Neem dit mee. De verwachting is dat de totale onderhoud en reparatiekosten lager zijn, omdat er minder componenten op zitten en dat er minder bewegende delen opzitten.
- De geïnterviewde geeft aan dat het aannemelijk is dat standard battles direct charging beïnvloed, en dat in dat geval het een niveau 'terug' moet. Wel zelf uitzoeken.
- De geïnterviewde geeft aan dat het rijtje factoren (rechts) die 'customer willingness to purchase EVs' beschrijft nogal in willekeurige volgorde wordt gepresenteerd. Het advies is om het op te delen in subcategorieën:
 - Charging gerelateerde onderwerpen
 - Voertuig performance
 - Imago (ipv environmental awareness)
 - Overig
- Sommige voertuig specs missen: hoeveel bagage past erin, hoe snel trekt de auto op, topsnelheid. Dit heeft ook invloed op de WTP
- 'Imago' in plaats van 'Environmental awareness' is misschien beter en breder: het kan immers ook om het promoten van hightech gaan
- Variety of EV models wordt vaak over het hoofd gezien in de literatuur
- Change in mobility landscape kan ook zeker invloed hebben op WTP. Denk aan Uber toestaan, promoten van delen van auto's.
- Range en Range anxiety zijn niet hetzelfde: de eerste is onderdeel van de performance van het voertuig en de tweede is de perceptie.
- Range is een hele belangrijke voor het wel/niet kiezen van een EV
- De geïnterviewde geeft aan dat 'government' op verschillende plaatsen in het model terugkomt. Het staat er nu erg algemeen, wat voor verwarring kan zorgen. Bedenk waar het terug moet komen of maak het specifieker.

- Government policies moet een niveau terug. Heeft invloed op veel zaken, maar pak de dominante. Als bijvoorbeeld in grote steden alleen nog maar EVs mogen rijden, dan geeft dat een enorme impuls aan de EV industrie. Meeste invloed op charging, fiscale voordelen (en nadelen) en mobility landscape. Stel dat de EV hard gaat, dan is het goed mogelijk dat bijvoorbeeld kilometerrijden wordt ingevoerd om te compenseren voor de 'verloren' accijns uit benzine.
 - Denk goed na over de rol van de overheid. Je kunt prima beargumenteren waarom je het op slechts een paar dingen toegepast is. Dit is een afweging tussen compleetheid of leesbaarheid. Je kunt bijvoorbeeld ook met kleuren werken.
 - Institutional barriers zou Institutional factors moeten zijn. Gebeurt inderdaad op wereldwijde schaal. Maar bedenk wel dat niet elke fabrikant per se tegen emission regulations is.
 - Revenues zijn inderdaad een bodem voor R&D investment, maar er is ook een anticiperende werking. Als men een groei verwacht, of policies, wordt er al geïnvesteerd.
 - Het is misschien beter om market factors te maken van wat nu market confidence heet. Dan kan er een pijl van policies naar market factoren. Interviewer: Is dat belangrijk? Geïnterviewde: Ja, het overheidsbeleid werkt door naar R&D via market factors.
 - Interviewer: Een pijl van willingness to purchase naar market factors? Ja dat kan. Kies bewust voor een aggregatieniveau
 - GDP growth: ik mis een blok sociaal economisch demografische factoren. Als het inkomen hoger wordt, dan wordt de willingness to purchase ook hoger. Inkomen speelt een rol. GDP is lastiger te bewijzen en is minder relevant voor jou onderwerp. Ik zou het bij inkomen houden.
 - Scheidt kenmerken van EVs en kenmerken van consument. Samen bepaalt dat de WTP. De interactie tussen die twee zijn de mobilitateitskenmerken van de consument en de charging infrastructuur.
 - Commodity prices worden inderdaad beïnvloed door het GDP
 - Maak een gestript model waar je je richt op de kern van de zaak, bijvoorbeeld met kleuren.
 - Verander vehicle performance in vehicle specifications
 - Battery technology and vehicles specifications hebben een wisselwerking. Als je bijvoorbeeld minder batterijen nodig hebt, kunnen de remmen ook lichter gemaakt worden in verband met het lagere gewicht.
 - OEM competition en Pricing strategy staat goed.
 - Subsidies on EV worden deels weggesnoept door de fabrikanten. Onderzoek wijst uit dat de kale autoprijzen in landen met fiscale subsidies namelijk hoger is, wat zou betekenen dat fabrikanten een deel van de subsidie 'opeten'. Die zou er nog bij kunnen.
 - Fiscal policy heeft invloed op zowel one-time costs als reoccurring costs. En dus ook op pricing strategy in verband met het vorige punt.
 - Depreciation moet resale value worden, aangezien het om de tweede hands waarde gaat.
 - Bedenk ook dat de onzekerheid over de restwaarde barrière om EVs aan te schaffen
 - Ik mis het onderscheid tussen zakelijk en prive: onzekerheid over restwaarde is niet van toepassing op zakelijk.
 - Discontovoet: consumenten hanteren een hogere discontovoet dan de overheid. Break-even na 10 jaar is niet nuttig voor consumenten. Interviewer: Hoe zou u dat toevoegen? Geïnterviewde: toevoegen bij one time costs and reoccurring costs.
 - Heffingen per km: inkomstenderving uit brandstof wil overheid niet kwijtraken, dus wordt gecompenseerd
 - Denk ook aan Dedicated EVs: niet gewone auto's elektrisch maken zoals Tesla, maar speciaal voor EVs. Veel lichter, veel kleiner. Bijvoorbeeld Twizy. Dit verandert ook de manier hoe we mobiliteit gebruiken.
 - Het is een goed model, ziet er compleet uit. Met eerdergenoemde tips kun je het nog verder uitbreiden, maar voorkom dat het onleesbaar wordt.
4. Wat zijn de TOP-3 factoren die volgens het meest belangrijk zijn voor een verdere introductie van EVs in de maatschappij?
- De top 3 belangrijkste factoren is denk ik:

- Batterijprijs: Aanschafprijs welke gevoed is door schaal- en leereffecten in de batterij
 - Overheidsbeleid: ambities, maar ook extra heffingen
 - Range en laadinfrastructuur is de belangrijkste indirecte die op schaaleffecten
5. Binnen welk auto segment ziet u het meeste kans voor EVs om zich te ontwikkelen, en waarom?
- Segmenten: Met name een focus op kleine klasse (Twizy). Kan een extra auto worden (aanpassing van het wagenpark in huishoudens).
6. Welk type EV (BEV/PHEV/EREV) heeft het meeste kans voor ontwikkelen volgens u, en waarom? En op welke termijn?
- Type EV: BEV, PHEV of EREV: Hangt ook sterk af van kostprijs batterij en actieradius: men gaat geen PHEV kopen als de batterijprijs (en dus de BEV prijs) heel laag is. PHEV en EREV is alternatief om slechte eigenschappen BEV te maskeren. Gaat evolutionair over de tijd spelen. Voordeel PHEV gaat afnemen als batterijkosten lager worden en snelladen aantrekkelijker wordt.
 - Interviewer: *Is (snel)laden vs batterij supplementair?* Ja dat is zo. Bepaalt het dichtheid van je netwerk. Als je 1000km range hebt, heb je een veel minder dicht netwerk nodig dan wanneer je 100km range hebt.

Specifieke vragen

Depreciation

7. In de literatuur wordt de restwaarde vaak op nul gezet. Dit impliceert dat de restwaarde of heel onduidelijk is, maar in ieder geval niet meer waard is dan een ICEV. Bent u het daarmee eens en wat zouden redenen kunnen zijn?
8. Zou het aannemelijk zijn dat het restwaarde patroon veranderd in de toekomst? Waarom? En vanaf wanneer dan?
9. Wat zou een verklaring kunnen zijn dat sommige merken hun waarde wel behouden en andere niet?
- De negatief exponentiele trendlijst is inderdaad gebruikelijk. De waarde-vastheid van BMW en Tesla is ongebruikelijk. EV lijkt dus sneller af te nemen dan ICEV. Dit kan verklaart worden door het feit dat wellicht het accupakket moet worden vervangen en de range neemt af naarmate de auto ouder wordt. Als je batterij goedkoper wordt, maakt het minder uit.
 - Interviewer: zou de theorie van creative destruction ook een verklaring kunnen zijn? Geïnterviewde: ja klopt, maar ook hier is de actieradius is weer het sleutelwoord
 - Interviewer: Kan het in de toekomst een gelijkwaardig patroon volgen? Geïnterviewde: Ja, het is zelfs denkbaar dat in de toekomst die EVs waardevaster zijn, vanwege maintenance kosten.

Maintenance

10. *Plaetje onderhoudskosten laten zien.* De kostenschattingen van onderhoud lopen erg uiteen. Wat zou een verklaring kunnen zijn?
11. Welke trend verwacht u wat betreft de kostenontwikkelingen voor onderhoud van EVs ten opzichte van ICEVs? Waarom zijn deze kosten hoger/lager dan bij ICEVs?

- De verwachting is dat de totale onderhoud en reparatiekosten lager zijn, omdat er minder componenten op zitten en dat er minder bewegende delen opzitten. Over de toekomst kan ik weinig zeggen.

- Einde -

Interview 2. Frank Rieck

Algemene informatie

Naam : Frank Rieck
Organisatie : Hogeschool Rotterdam
Functie : Lector Future Mobility
Datum interview : Dinsdag 24 mei 2016
Tijd : 10.00 – 11.00 uur

Algemene vragen

1. Wat is uw functie en hoe verhoudt zich dat tot EVs?
 - Ik ben lector future mobility aan de Hogeschool Rotterdam en leid het onderzoek naar de EVs, autonoom rijden, etc. Dit beperkt zich niet tot personenauto's. Ik heb zelf ook in de industrie gewerkt. Frank heeft ook onderzoek gedaan naar kosten van EVs in het E-mobility lab.
 - Eigenlijk is Total Cost of Ownership (TCO) geen geschikte term als we in de toekomst geen auto meer bezitten omdat we deze delen. Veel bedrijven leasen auto's al en de vraag is hoe lang de particulier nog een auto zelf wil bezitten wilt. Total Cost of Operation zal dan toepaslijker zijn.
2. Is het model begrijpelijk?
 - De geïnterviewde geeft aan dat het begrijpelijk is.
3. Zijn er nog factoren (blokjes) die niet op de goede plek staan, missen of juist verwijderd moeten worden?
4. Zijn er nog relaties (pijltjes) die niet op de goede plek staan, missen of juist verwijderd moeten worden?

Uitleg gedetailleerde model. De geïnterviewde heeft de volgende opmerkingen:

- Fuel consumption zou energy consumption moeten zijn als je over EV's spreekt.
- Pricing strategy: EVs worden met verlies verkocht, omdat de volle ontwikkelingskosten nog niet terug gewonnen kunnen worden. Tesla bijvoorbeeld maakt verlies op iedere auto maar ze groeien enorm. Wat neem je wel / niet mee in de kostprijs is natuurlijk de vraag: direct/indirecte kosten. Desondanks kun je wel zeggen op basis van de prijzen dat ze eigenlijk geen winstmarge kunnen maken. Dat doen ze om marktaandeel te winnen. Zodra ze dat hebben bereikt zal door verhoogde Economies of Scale wel degelijk winst gemaakt kunnen worden.
- OEM competition: Meer competitie van Apple, Google en andere zouden het speelveld kunnen veranderen. Mee eens.
- Punten die WTP (Willingness to Pay) beïnvloeden: mee-eens. Wel de volgende opmerkingen:
- Imago: is een belangrijke naast environmental awareness
- Standard battles: Ja, maar alleen van toepassing op fast charging, niet op normaal laden (dat is Mennekes geworden). Valt erg mee, denk dat de DC fast charging snel opgelost gaat worden. Er zijn er nog meer twee in de running: Japanse en Europese.
- EV supply models: Ja, dit is ook een hele belangrijke geworden. Mensen willen keuze uit meerdere modellen.
- Change in mobility landscape: Ja, mee eens. Zie ook de motie Groot. Sommige vinden EV een gedoe: ik moet een laadpaal zoeken, hoe doe ik dat met vakantie, hoe moet ik een paal installeren bij mijn huis. Customer understanding is daarom belangrijk: er is ook minder gedoe, het rijdt beter, je kunt laden als de auto niet nodig is etc. Eerlijke voorlichting is belangrijk, bij-

voorbeeld via die EPA ratings zoals in de VS. TCO wordt ook gegeven t.o.v. een gemiddelde. Transparantie is key.

- Institution barriers: Sommige grote autobedrijven zijn slapende reuzen geworden, zijn niet voorbereid op verandering en zien hun usual business case verdwijnen. Ze gaan liever veilig achter een barrière zitten. Men gebruikt bijvoorbeeld waterstof-auto's om anderen te overtuigen dat EV niks worden.
 - Toekomstig beleid: De misgelopen accijns op benzine kan in de toekomst een probleem worden. Overigens wordt er op elektriciteit per energie-inhoud meer energiebelasting geheven dan op brandstof, maar EV gaan extreem zuinig met energie om. Dat laatste is juist een economisch voordeel. Het overheidsbeleid in NL is ook niet consistent maar heel turbulent. Je moet maatregelen op tijd aankondigen en een vast patroon aanhouden.
5. Wat zijn de TOP-3 factoren die volgens het meest belangrijk zijn voor een verdere introductie van EVs in de maatschappij?
- Economies of scale is de belangrijkste: en dan met name de batterijen en in mindere mate het voertuig. Sommige gebruiken bijna hetzelfde platform (Volt, e-Golf), terwijl voor een Model S/Leaf een heel nieuw platform nodig is. Deze worden dus gevoed door die attractiveness.
 - Innovatie is ook van belang, bijvoorbeeld product of proces optimalisatie. Maar ik verwacht geen fundamenteel nieuwe batterijtype in de komende 15 jaar, want dat is allemaal nog in lab-stadium
 - Charging is ook een probleem/kans. Goede infrastructuur is nodig.
6. Binnen welk auto segment ziet u het meeste kans voor EVs om zich te ontwikkelen, en waarom?
- Iedereen dacht in het verleden dat het zou beginnen met het kleinere segment, maar het tegenovergestelde blijkt waar. Dit komt vanwege de marge in de kostprijs, en ook marketing technisch. Het is makkelijker wat extra te vragen voor een dure auto, dan voor een goedkope auto. Het is ook een ander type klant. Puur rationeel (kleine auto = korte afstanden) klopt het wel om met een kleine auto te beginnen, maar het werkt niet in de praktijk.
7. Welk type EV (BEV/PHEV/EREV) heeft het meeste kans voor ontwikkelen volgens u, en waarom? En op welke termijn?
- Voor de personenauto denk ik dat de PHEV/EREV cruciaal is tot 2025, door de beperkingen van infrastructuur en range. Maar tegen 2030 verwacht ik dat we helemaal voor BEV gaan. Desondanks kunnen alle types een bijdrage leveren aan schaal en leereffecten en customer understanding.
 - Dit gaat ook op zakelijk / OV gebied gebeuren, maar buiten de scope van dit onderzoek. Waterstofauto's zijn ook een optie, maar dat is niet perse concurrerend. Een waterstof fuel cell kan zal als range extender worden ingezet.

Specifieke vragen

Demand

8. Wat is uw verwachting van de te verwachte vraag wereldwijd? Wat zijn de belangrijkste factoren waarvan deze vraag afhangt?
9. Verwacht u dat EVs een niche blijven tot 2025, en waarom?

- In 2020 is het sowieso nog een niche, omdat de omloop snelheid beperkt is. Maar ik denk dat na 2020 het storm gaat lopen. Rond de 25% van annual new sales. Tegen de 2030 aan wordt 50% makkelijk gehaald. Dat zie je nu al gebeuren, het aantal EVs groeit hard en ik zie dat niet veranderen.
- Interessant is dat vroeger er veel zorgen waren over veiligheid. Dit is allemaal vrij snel opgelost. Ook wat betreft de afwezigheid van geluid is vrij snel overgewaaid. Dit geeft een signaal dat EVs meer geaccepteerd worden.

Depreciation

10. In de literatuur wordt de restwaarde vaak op nul gezet. Dit impliceert dat de restwaarde of heel onduidelijk is, maar in ieder geval niet meer waard is dan een ICEV. Bent u het daarmee eens en wat zouden redenen kunnen zijn?
11. Zou het aannemelijk zijn dat het restwaarde patroon veranderd in de toekomst? Waarom? En vanaf wanneer dan?
12. Wat zou een verklaring kunnen zijn dat sommige merken hun waarde wel behouden en andere niet?
 - De reden dat sommige merken wel hun waarde behouden komt door de fiscale voordelen er nog opzitten. Dus dit is totaal fiscaal gestuurd, want er zit wellicht 0% bijtelling op.
 - Dat sommige auto's die heel hard afschrijven is wel logisch: de performance is een stuk beter geworden in de afgelopen jaren. Zodra het nieuwe model een hogere range heeft is de oude minder waard. Dit zal stabiliseren. Hier kan je dus geen conclusies uithalen voor de toekomst.
 - Als de accu's niet zou slijten, dan zou je technisch gezien zeggen dat de EV waardevaster is doordat er minder onderhoud nodig is en de slijtage minimaal is. Economisch gezien heb je een probleem door de accu en elektronica, daar zie je dat de ontwikkeling heel snel gaat. Een EV van drie jaar geleden is nu al minder waard doordat de ontwikkeling snel gaat. In de toekomst verwacht ik dat ze waardevaster worden dan conventionele auto's. Maar niemand weet wat ze gaan doen, en dat is wel uniek in deze markt, aangezien het normaal heel goed te voorspellen is. Dit creëert veel onzekerheid en leidt tot een grotere afschrijving. Dit is in de TCO ook het meest onzekere punt. Het wordt beter, maar niemand weet wanneer. Zakelijk gezien is dit ook een punt: afschrijving van bussen is nu relatief laag omdat de emissieregels steeds omhoog gaan. Voor een EV bus kan een langere afschrijving worden gehanteerd. Dit kan ook particulier gaan komen: waarom zou je een goede EV wegdoen? Dat heb je nu wel met ICEVs.

Interviewer: zou het kunnen dat de huidige kopers van de EV simpelweg geen 2^e hands kopen? Lastig punt. Er zijn weinig mensen die een EV kopen zonder dat het goedkoop is (bijvoorbeeld zonder fiscale voordelen). Initieel is het een zaak om geld. Nu het wat begint te lopen worden mensen ook enthousiast om de performance van de auto. Maar de tweedehands markt blijft een issue omdat ze risico's willen mijden. De overheid zou dus die tweedehands markt moeten steunen om die ook aantrekkelijk te maken.

 - De overheid zou eigenlijk fiscale voordelen moeten geven aan tweedehands EV-kopers.

Maintenance

13. De kostenschattingen van onderhoud lopen erg uiteen. Wat zou een verklaring kunnen zijn?
14. Welke trend verwacht u wat betreft de kostenontwikkelingen voor onderhoud van EVs ten opzichte van ICEVs? Waarom zijn deze kosten hoger/lager dan bij ICEVs?
 - Op gebied van onderhoud was het heel lastig om de werkelijke cijfers te krijgen: leasemaatschappijen en garages willen er niet over praten. Maar de informatie die binnenkomen gaven aan dat er eigenlijk heel weinig onderhoud was: zelden claims over het elektrische gedeelte. De meeste zaken waren de 'normale' onderdelen die ook in een conventionele auto zitten. Ei-

genlijk is het een kwestie van ruitenwissers en banden. Het is zoveel goedkoper omdat er weinig bewegende slijtagegevoelige onderdelen inzitten. Hoeveel goedkoper het is ten opzichte van een ICEV hebben we niet kunnen vaststellen. We hebben wel gekeken welke onderdelen niet meer toepasbaar zijn voor een EV (e.g. distributieriem). Op die manier kom je erachter dat je nog maar op een kwart van de onderhoudskosten zit (exclusief het accugedeelte). We verwachten dat dat in de toekomst nog goedkoper wordt, doordat er kinderziekten uitgehaald worden en door verdere optimalisatie.

- Einde -

Interview 3. Auke Hoekstra

Algemene informatie

Naam : Auke Hoekstra
Organisatie : TU Eindhoven
Functie : Senior Advisor Electric Mobility
Datum interview : Dinsdag 24 mei 2016
Tijd : 16.00 – 17.30 uur

Algemene vragen

1. Wat is uw functie en hoe verhoudt zich dat tot EVs?
 - Ik ben adviseur bij de TU Eindhoven. Daarnaast heb ik nog een aantal andere functies zoals bij een netbeheerder en Stichting E-laad. Meer de technische kant van EV, wat minder aan de milieukant van dit onderwerp.
2. Is het model begrijpelijk?
 - De geïnterviewde geeft aan dat het model begrijpelijk is.
3. Zijn er nog factoren (blokjes) die niet op de goede plek staan, missen of juist verwijderd moeten worden?
4. Zijn er nog relaties (pijltes) die niet op de goede plek staan, missen of juist verwijderd moeten worden?

Uitleg gedetailleerde model. De geïnterviewde heeft de volgende opmerkingen:

- De introductie van de EV is enorm belangrijk voor het 2-graden scenario, anders wordt het heel lastig om dat te halen. Andere energiebesparingen (e.g. isolatie) zijn ook belangrijk, maar EV heeft een veel grotere bijdrage.
- Imago is heel belangrijk voor auto's. De duurste KIA is nog steeds minder waard als een goedkope Mercedes, terwijl veel specs wel gelijk zijn. Het gaat om het imago waar mensen bereid zijn voor te betalen. Tegenwoordig zie je dat ook voor EVs: die hebben nu een goed imago. Dat bepaalt de WTP.
- Imago is wat anders dan betrokkenheid bij het milieu en dat is weer wat anders dat je gewoon enthousiast wordt van zo'n auto.
- Ik denk dat dat die environmental awareness minder belangrijk is dan van tevoren gedacht, terwijl imago en enthousiastelingen juist de reden is. Het is een beetje als een Apple product.
- Ik mis de viral effecten: als je buurman er eentje koopt, wil je er ook een. Dit zijn nu transaction costs, maar straks hoeft je die niet meer te maken. Dit hangt ook samen met customer understanding: iedereen begrijpt een brandstofmotor, maar in feite is het veel ingewikkelder. Terwijl niemand nu een EV begrijpt. Ik denk dat dit om gaat draaien in de komende jaren als er meer auto's worden verkocht.
- Het imago van EVs is nu heel hoog. Voor Tesla was het heel laag en door Tesla is het helemaal gekeerd, het is heel positief nu. Ik kan het niet met zekerheid zeggen, maar ik verwacht dat dit doorgaat.
- Denk ook aan schaal- en leereffecten voor toeleveranciers. Nu is het allemaal nog heel ingewikkeld, zo'n laadpaal plaatsen. Maar straks weet gewoon iedereen hoe het zit.
- Standard battles: ik verwacht dat het wel de Mennekes stekker wordt voor normaal laden, die 'oorlog' is bijna over. Voor snelladen is het nog wel gaande, maar niet erg duur, want ze bieden gewoon meerdere stekkers aan bij die laadstations. Dat kost wat wel, maar het is niet heel duur. Niet een hele grote invloed op de kosten.

- Range anxiety is heel wat anders dan de range. Mensen die veel rijden hebben niet perse last van anxiety, terwijl iemand die 99% korte ritjes rijdt het wel kan ervaren omdat hij/zij 1x 1200 km moet afleggen.
 - Desondanks is innovatie ook enorm belangrijk. Tegenwoordig is het zelfs mogelijk om nieuwe materialen in batterijen te simuleren in computermodellen. Ook dat kan heel veel kosten besparen. Nieuwe materialen en chemistries heeft zeker wel potentie, maar het zit nog in het vat (science-fase). Ook dat gaat de komende 15 wel commercialiseren (ongeveer 10 jaar).
 - Beleid: de snelheid van adoptie valt of staat met beleid.
 - Performance: iedereen uit mijn enquête vindt een elektrische auto beter rijden dan ICEV. Dit is nog een belangrijk punt. De beste manier om iemand te overtuigen een EV te kopen is door hem/haar een proefrit te laten maken. Dit zijn de onverwachte extra voordelen waar weinig mensen aan gedacht hadden.
 - Change in mobility: de toekomst van een auto, wordt geen auto. Die opgewerkte koets voor vijf personen, dat gaat het niet worden. Het delen van auto's, zoals car2go. Jongere mensen identificeren zich niet perse meer met het soort auto, wat de oudere generatie nog wel doen. Het is gewoon een vorm van vervoer. Een een- of tweepersoons auto is heel logisch. De meest gebruikte auto (>1 in een gezin) elektrisch is een fantastische nieuws. De luxe van een Tesla gecombineerd met de grootte van een Twizy. Een auto delen in 2030 lijkt me niet onlogisch.
5. Wat zijn de TOP-3 factoren die volgens het meest belangrijk zijn voor een verdere introductie van EVs in de maatschappij?
- Het belangrijkste is op dit moment zeker de batterijkosten, zeker voor 50%. Daarin onderverdeeld zit R&D en productinnovatie
 - Algemene Economies of Scale voor volledig elektrisch: als straks alles BEV is, dan kan je alle kosten voor verbrandingsmotoren (qua productiekosten) eruit halen. Ook omdat er dan een productielijn gebruikt kan worden. Dit is wel tijdelijk: over vier jaar is dat effect weg. Dat geldt niet voor batterijdaling, dat gaat nog 20 jaar door.
 - Nieuwe systemen: bijvoorbeeld een motor in elk wiel, waardoor de prestaties nog veel beter worden. Dat wordt in de toekomst denk ik de standaard. De performance eisen gaan gewoon omhoog: sneller optrekken, goede besturing, etc.
 - Laadinfrastructuur: is ook een belangrijke voor grootschalige adoptie. Hier gaat nog veel gebeuren door de standard battles, en het verhogen van het vermogen van (snel)laders.
 - Ik verwacht dat de ontwerpkosten ook omlaag gaan als er meer EVs worden verkocht, eigenlijk leer effecten. Een hybride is eigenlijk veel complexer omdat beide systemen moeten worden ontworpen en gemaakt. Een groot gedeelte van de kosten is ontwerp. Dat kan snel kleiner worden als we opschalen.
6. Waar verwacht u dat de EV zich nog in zal ontwikkelen op technisch gebied? En op welke termijn dan?
- Optimalisatie in de bestaande systemen. Bijvoorbeeld het actief balanceren van de batterijcellen, om het maximale eruit halen. Dit gaat zorgen dat batterijen minder snel slijten bijvoorbeeld. Het monitoren kan nog veel beter.
 - De focus zal eerste liggen (vermoed ik) op het vergroten van de range, daarna pas een kostendaling. Dat komt omdat die range echt acceptabel moet worden.
 - Als zo'n auto lichter wordt, dan kunnen ook andere dingen lichter: denk aan batterijen en remmen.
7. Binnen welk auto segment ziet u het meeste kans voor EVs om zich te ontwikkelen, en waarom?

- Wat betreft de klassen, verwacht ik dat het ontwikkelingspatroon van duur naar goedkoop gaat. Dus groot naar klein. Dat is ook normaal in de auto-industrie. Het idee van klein naar groot was inderdaad in het verleden zo, maar toen hield men nog geen rekening met de batterijontwikkeling. Er zit gewoon wat meer marge in de duurdere auto's voor die dure batterij. Een kleine auto is simpelweg te duur voor de batterijen.
- 8. Welk type EV (BEV/PHEV/EREV) heeft het meeste kans voor ontwikkelen volgens u, en waarom? En op welke termijn?
- Ik verwacht dat de plug in varianten (PHEV/EREV) een tussenoplossing zijn en op ten duur worden vervangen door BEVs. Als de range groter wordt i.c.m. snelladers, gebeurt hetzelfde als met Betterplace (*zie verderop*). Ook psychologische factoren spelen mee: mensen willen misschien geen verbrandingsmotor meer. De PHEV/EREV kan wel bijdragen aan de schaal- en leereffecten van de EV als geheel.

Specifieke vragen

Demand

9. Wat is uw verwachting van de te verwachte vraag wereldwijd? Wat zijn de belangrijkste factoren waarvan deze vraag afhangt?
 10. Verwacht u dat EVs een niche blijven tot 2025, en waarom?
 11. Verwacht u dat ICEVs nog steeds geproduceerd worden in 2030, en waarom?
- Nee, in 2025 is de EV qua nieuwverkopen geen niche meer. Daar durf ik wel op te wedden. Mijn intuïtie zou zeggen (heel grofweg) tussen de 40% - 60% van de nieuw verkopen in NL in EV. Wereldwijd zal het wat lager liggen, tussen de 30% - 50%.
 - Ja, in 2030 worden nog steeds ICEVs verkocht, maar dan is dat een niche.
 - Volgens innovatiewetenschappers is de energie transitie toch wel echt een transitie. Maar de huidige 'experts' komen voornamelijk vanuit de huidige grote corporates. Veel transities (IT, vliegverkeer, digitale fotografie) zijn zelden voorspeld door de bestaande spelers.
 - Ik heb zelf een keer het sommetje gemaakt voor zonnepanelen: en daaruit bleek dat organisaties (bijv. IEA) hun voorspellingen veel te conservatief waren. Alle voorspellingen uit de automotive branch zijn conservatief.
 - Je wordt natuurlijk wel beperkt door de ontwikkeltijd van auto's, doorgaans 7 jaar. Maar wellicht kan dat teruglopen: als een aandrijflijn / productielijn meerdere auto's maken. Bijvoorbeeld van de Golf naar de e-Golf.
 - Tesla hergebruikt meer componenten voor haar nieuwe modellen. Dus wellicht wordt het 3 tot 4 jaar in plaats van 7.
 - Omdat de binnenkant simpeler is, kan het sneller.
 - Ik denk dat 100% in 2025 technisch niet onmogelijk is, maar dat is sociaal lastig te accepteren. Dan worden de veranderingen heel groot.
 - Over 20 jaar is gewoonweg niet meer acceptabel om in een ICEV te rijden. Misschien wel over 10 jaar.
 - Het 'gezeur' dat ze geen geluid maken (die EVs), dat hoor je van niemand meer. Dit lijkt dus op een verandering in hoe mensen tegen EVs aankijken. Maarten Steinbuch doet onderzoek naar autonoom rijden en dat autonoom rijden wordt steeds meer als disruptief gezien.
 - Belastingtarieven zullen in de toekomst ook anders ingericht moeten worden. Dat hoeft niet perse uit de brandstof te halen. Kan bijvoorbeeld ook wegenbelasting zijn. Kilometerrijden is ook zeer aannemelijk. Het is alleen niet realistisch om dat eenzijdig op EVs te doen, dan vallen ICEVs daar ook onder. Ja, kilometerheffing.

- Het is oneerlijk om te zeggen dat de accijns per km voor EVs goedkoper is. Dat komt namelijk omdat een EV veel efficiënter is. Als er een nieuwe auto op de markt komt die heel efficiënt is, ga je toch ook geen accijns verhogen. Als je kijkt naar accijns per energieeenheid (kwh of J) dan is de belasting van EV hoger.

Depreciation

12. In de literatuur wordt de restwaarde vaak op nul gezet. Dit impliceert dat de restwaarde of heel onduidelijk is, maar in ieder geval niet meer waard is dan een ICEV. Bent u het daarmee eens en wat zouden redenen kunnen zijn?
 13. Zou de batterij een invloed kunnen hebben op deze restwaarde, en waarom?
 14. Zou het aannemelijk zijn dat het restwaarde patroon veranderd in de toekomst? Waarom? En vanaf wanneer dan?
 15. Wat zou een verklaring kunnen zijn dat sommige merken hun waarde wel behouden en andere niet?
- Interessante grafiek. Ik denk dat het wel erg bijtrekt in de toekomst, richting de conventionele auto's. Dit is deels omdat het met belastingvoordelen is verkocht en de grote onzekerheid, en het feit dat mensen het simpelweg niet snappen.
 - Het waardeverval van de Tesla / BMW kan inderdaad door de bijtelling komen.
 - *Interviewer: Kan het komen doordat het huidige type mensen gewoon geen tweedehands auto koopt? Ja, mee eens.*
 - *Interviewer: Kan het ook komen door obsoleete destructie, het feit dat deze producten in korte tijd steeds beter worden? Ja, mee eens.*
 - Desondanks denk ik dat de onzekerheid over batterij is misschien wel de belangrijkste

Battery technology

16. Op het gebied van batterijtechnologie verwacht de literatuur dat de kosten verder zullen dalen. Bent u het daarmee eens?
- Het plaatje ziet er goed uit, dat komt overeen met mijn verwachtingen.

Charging

17. Wat zijn volgens u de grootste onzekerheden op het gebied van charging?
 18. Hoe heeft dat invloed op de kosten?
 19. Hoe ziet u het thuisladen en publiek laden in de toekomst voor zich? Zal die verhouding gaan veranderen? En verhouding 'normaal laden' en 'snel laden'?
- Uiteindelijk is het gebruikerspatroon belangrijk: op je werk heb je bijvoorbeeld een heel goedkoop tarief, en thuis betaal je de normale prijs. Publiek is het natuurlijk weer duurder. Dus dat heeft veel invloed.
 - Meer range heeft wel tot gevolg dat de dichtheid van laadinfrastructuur minder groot wordt. Dus dat substitueert deels. Maar de substitutie ligt met name op destination charging, dat is vaak lastig. Tenzij het heel makkelijk geregeld is (bijvoorbeeld bij een bedrijf).
 - Vroeger dacht ik dat overal laadpunten moesten komen, maar daar kom ik een beetje op terug omdat het ingewikkeld is. Dan is snelladen wel echt een optie.
 - Desondanks denk ik niet dat mensen hun thuisoplaadpunt op gaan geven. Als je momenteel geen thuisoplaadpunt heb, heb je geen elektrische auto. Uit een enquête blijkt dat zonder thuisladen het heel onaantrekkelijk is om een EV te komen.

20. Wat verwacht u van de kostenontwikkeling van publiekladen? Zowel qua omvang als qua timing.
- Een publiek laadpunt kost met installatie nu misschien 5.000 euro, over tien jaar misschien 3.000 euro. Maar dat zijn nog steeds beperkte kosten ten opzichte van de 'auto'- productie kosten. Maar desondanks is het wel belangrijk om die auto's te verkopen. Over tien jaar is het gewoon geregeld, maar tot die tijd is het lastig.
21. Wat verwacht u aan kostenontwikkeling voor de consument wat betreft publiek laden?
- Ik verwacht dat de tarieven voor publiek laden wel goedkoper worden. Maar hier zit heel veel beleid in, dus dat is een lastig punt. Voor thuisladen is de energiebelasting relatief hoog. Dit is het punt waar de overheid moet beslissen waar hun ambities liggen. Desondanks verwacht ik dat het wel wat goedkoper wordt.
22. Verwachten jullie dat wanneer er een doorbraak komt in de batterijtechnologie die negatieve of juist positieve impact kan hebben op het aantal oplaadpunten?
- Snelladen als substitutie van thuisladen? Ik zie het niet gebeuren. Het kan wel, maar het is gedoe voor de consument (mentaal een barrière). Als je dat in geld gaat uitdrukken, dan zou de TCO hoger worden.
 - Betterplace loste een probleem op dat er niet was, vooral naarmate de tijd vorderde. Het feit dat OEMs niet wilde meewerken was overigens ook een probleem. Een snellader is niet ideaal, want het is nog steeds langzamer dan battery swapping. Maar het is ook geen eindeloos groot probleem. Daar is Betterplace op geknapt: het probleem was steeds minder groot.

- Einde -

Interview 4. Jaap van Tiggelen

Algemene informatie

Naam : Jaap van Tiggelen
Organisatie : Renault Nederland
Functie : Manager Public Affairs
Datum interview : Woensdag 25 mei 2016
Tijd : 14.00 – 15.00 uur (telefonisch)

Algemene vragen

1. Wat is uw functie en hoe verhoudt zich dat tot EVs?
 - Ik ben Manager Public Affairs bij Renault Nederland, zowel voor producten en services. Met name bezig met externe contacten zoals overheden en NGOs. Zero-emission vehicles is een strategische pijler bij Renault.
2. Is het model begrijpelijk?
 - De geïnterviewde geeft aan dat het model begrijpelijk is. *(Alleen de eenvoudige versie is uitgelegd i.v.m. de focus op de HOE-vraag en de tijd)* en vindt het model logisch.
3. Geeft dit model in uw ogen weer hoe de ontwikkeling van de TCO voor EVs verloopt?

Uitleg eenvoudige model. De geïnterviewde heeft de volgende opmerkingen:

- De grootste factor waardoor een EV hogere TCO heeft is toch nog de batterijprijs. Het grootste prijsverschil tussen een ZOE (EV) en een Clio (ICEV) is toch de batterij. Dit komt omdat we de schaalvoordelen nog niet zien tot nu toe. Economies of scale is een heel belangrijk mechanisme. Dit is ook een kip-ei effect natuurlijk.
 - Het aandeel batterij t.o.v. van de totale productiekosten kan inderdaad oplopen tot 50%, hoewel 50% wel aan de hoge kant is. Het kan in de toekomst zo zijn (kan het niet hardmaken) dat een EV goedkoper wordt door de complexe onderdelen van een ICEV.
 - Het ontzorgen van de klant (bijvoorbeeld qua laadinfrastructuur) is een belangrijk aspect. En je ziet dat dat ook belangrijk is of de klant voor elektrisch gaat kiezen.
4. Wat zijn de TOP-3 factoren die volgens het meest belangrijk zijn voor een verdere introductie van EVs in de maatschappij?
 - Los van de auto (economies of scale / productie): het is belangrijk de markt zover te krijgen voor de introductie van EVs
 - Denk hierbij bijvoorbeeld aan laadinfrastructuur
 - Denk ook aan overheidsbeleid. De zakelijke markt krijgt wel veel aandacht, maar de private markt nog niet in Nederland. Het mooiste zou zijn als hier een Europese gedachte inzit.
 5. Binnen welk auto segment ziet u het meeste kans voor EVs om zich te ontwikkelen, en waarom?
 - Qua segment is lastig, dat hangt ook af van hoe het in toekomst ontwikkelt. Misschien wordt de focus wel op de kleinere auto's. Een grotere auto (zoals Tesla) kan wel, maar dan wordt het ook weer duurder. Het lijkt niet zo logisch om een grote auto elektrisch te maken, want dan heb je ook weer meer batterijen nodig, wat de auto weer duurder maakt.

6. Welk type EV (BEV/PHEV/EREV) heeft het meeste kans voor ontwikkelen volgens u, en waarom? En op welke termijn?
- Qua type EV (BEV/PHEV/EREV): de komende tien jaar is een transitie, dus er is nog ruimte voor de EREV. De PHEV wat minder, omdat het nog niet lekker loopt in de huidige vorm. Deze heeft namelijk te weinig batterijcapaciteit. Ik denk dat bijvoorbeeld de Duitse automarkt zich zal focussen op de EREV. We groeien langzaam naar BEV, maar door de barrières (range, range anxiety) is de EREV nodig. Maar uiteindelijk wordt de auto-industrie ook geforceerd door de EU emissie regels. Dit is ook in het voordeel voor de EREV t.o.v. de PHEV i.v.m. uitstoot.

Specifieke vragen

Vehicle technology

1. Het is de verwachting dat ICEV technology nog zuiniger zal worden. Verwacht u dat ook voor EVs?
 2. Waar valt op productiekosten nog veel te besparen?
- Ik denk dat je het in eerste instantie toch in de opschaling (economies of scale) moet zien, en wat minder aan de innovatie kant.
 - Ja er zijn ook kansen om productiekosten te besparen. Bijvoorbeeld ander materiaalgebruik kan auto's lichter maken. Ik denk dat we steeds meer naar de 'dedicated' EV gaan qua productie dan een ICEV ombouwen naar een EV. Dat brengt voordelen met zich mee, zoals bijvoorbeeld gewicht.
 - Op component niveau probeert Renault een productielijn te hebben voor meerdere modellen, het modulaair bouwen. Het platform van een nieuwe EV is in het begin uniek, dus vraagt hoge investeringen. Als er meerdere EV modellen zou zijn, dan lijkt het theoretisch logisch dat diezelfde platforms gebruikt kunnen worden, hetgeen de productiekosten verlaagd. Op die manier kan je ook sneller nieuwe modellen op de markt brengen.
 - Economies of scale wordt gedeeld door verschillende varianten. Elke batterijcel is er eentje, dus dat helpt.

Battery technology

3. Op het gebied van batterijtechnologie verwacht de literatuur dat de kosten verder zullen dalen. Bent u het daarmee eens?
 4. Wat is de oorzaak van deze daling?
- De grafiek ligt wel in lijn met mijn verwachtingen. Ik denk dat er steeds meer productielocaties voor batterijen gaan clusteren, waardoor economies of scale worden gerealiseerd.

Maintenance

5. De kostenschattingen van onderhoud lopen erg uiteen. Wat zou een verklaring kunnen zijn?
 6. Welke trend verwacht u wat betreft de kostenontwikkelingen voor onderhoud van EVs ten opzichte van ICEVs? Waarom zijn deze kosten hoger/lager dan bij ICEVs? Hoeveel dan? En nu al, of is dat iets dat in de toekomst zo gaat zijn (en wanneer dan)?
- Het zou goed kunnen dat de onderhoudskosten toch snel 30% lager zijn voor EV t.o.v. ICEV. Dat komt door minder draaiende delen, geen olie, minder componenten. Je ziet misschien een

lichte toename bij banden doordat ze wat harder optrekken/de hoek omgaan (maar geen harde data nog).

- Ik verwacht dat de onderhoudskosten in de toekomst misschien nog wat dalen door marktwerking, wat nu vooral bij de merkdealer ligt. Maar er is nog weinig data van componenten door de korte looptijd.
- Wat betreft degradatie aan de batterij: Renault verhuurt de batterij, onder de 80% capaciteit krijgt de klant een nieuwe batterij. We willen deze producten een tweede leven geven aangezien we eigenaar blijven van de batterij.

Charging

7. Wat verwacht u van de kostenontwikkeling van thuisladen?

- Renault biedt ook oplaadpunten voor thuis of werk. Zo'n 1000 tot 1500 euro voor een oplaadpunt is een beetje de range. Dit kan in de toekomst nog goedkoper worden, daar is al veel gebeurd overigens.

8. Wat verwacht u van de kostenontwikkeling van publiekladen?

- Publiek laden is het lastiger te dalen, omdat er exogene ontwikkelingen zijn als aansluiting, operationele kosten, belastingen, aansluitkosten, etc. Publiek is veel complexer dan een thuislaadpunt. Dit beperkt het aantal publieke palen, de kWh prijs is gewoon te hoog, met name omdat ze in het kleinverbruikerstarief zitten.

Demand

9. Wat is uw verwachting van de te verwachte vraag wereldwijd? Wat zijn de belangrijkste factoren waarvan deze vraag afhangt?

10. Verwacht u dat EVs een niche blijven tot 2025, en waarom?

11. Verwacht u dat ICEVs nog steeds geproduceerd worden in 2030, en waarom?

12. Hebben zij waarden die ze kunnen delen?

- Ik denk dat gedreven door milieu, wetgeving etc dat we steeds meer PHEV/EREV gaan zien, dus dat telt aardig. Dus dat kan een ruim deel worden van het totaal aantal verkochte auto's.
- Ik denk dat het nu een niche is. Ik denk dat in 2025 het geen niche meer is. *Interviewer: is 50% een optie?* Wellicht, er worden ongeveer 450.000 auto's per jaar in NL verkocht. Ik denk dat 10% nieuwverkoop wel mogelijk is. Dan zou een totaal wagenpark van 200.000 EVs in NL wel mogelijk is.
- Er worden in 2030 zeker nog ICEVs geproduceerd, zeker ook voor andere markten dan de EU.

Depreciation

13. In de literatuur wordt de restwaarde vaak op nul gezet. Dit impliceert dat de restwaarde of heel onduidelijk is, maar in ieder geval niet meer waard is dan een ICEV. Bent u het daarmee eens en wat zouden redenen kunnen zijn?

14. Zou het aannemelijk zijn dat het restwaarde patroon veranderd in de toekomst?

15. Wat zou een verklaring kunnen zijn dat sommige merken hun waarde wel behouden en andere niet?

- De snelle afschrijving is met name het onderbuik gevoel van de batterijdegradatie. Het gevoel dat de auto veel sneller afschrijft tekent dit. Aan de andere kant zitten er ook veel minder gesleten delen in dan een ICEV, dus dat zou je moeten kunnen compenseren. Dit zit ook in customer understanding en vandaar dat wij de batterij leasen. Daarnaast zijn het waarschijnlijk met name leasemaatschappijen, die snel afschrijven en conservatief zijn met nieuwere producten. Dus dit is niet gek. Dit moet zich bewijzen.
- In de toekomst kan de EV een vergelijkbare trend vertonen als de ICEV, en misschien wel beter.

- Einde -

Interview 5. Pepijn Vloemans

Algemene informatie

Naam : Pepijn Vloemans
Organisatie : Fastned
Functie : Investor Relations & Communication
Datum interview : Vrijdag 27 mei 2016
Tijd : 10.00 – 11.00 uur

Algemene vragen

1. Wat is uw functie en hoe verhoudt zich dat tot EVs?
 - Ik was betrokken bij de beursgang van Fastned. Inmiddels meer naar de policy kant verschoven, dus alles wat te maken heeft met overheid, lobby's, politiek en andere belangrijke spelers.
2. Is het model begrijpelijk?
 - De geïnterviewde geeft aan dat het model begrijpelijk is. *(Alleen de eenvoudige versie is uitgelegd i.v.m. de focus op de HOE-vraag en de tijd)* en vindt het model logisch, hoewel het alleen in grote lijnen uitgelegd is.
3. Zijn er nog factoren (blokjes) die niet op de goede plek staan, maar missen of juist verwijderd moeten worden?
4. Zijn er nog relaties (pijltes) die niet op de goede plek staan, maar missen of juist verwijderd moeten worden?
 - De wetenschap kijkt vooral naar het verleden, en wat minder naar de toekomst.
 - Laadinfrastructuur is een belangrijk aspect voor de willingness to purchase.
 - De tweede hands waarde is een grote onzekerheid momenteel voor EVs.
 - Er is nog een belangrijk effect dat je mee kunt nemen: het rook-effect. Vandaag de dag is roken in openbare ruimtes niet meer geaccepteerd. Die omslag is heel snel gegaan. Wij denken dat er ook zo'n omslag komt met auto. Het wordt straks asociaal om een conventionele auto te rijden. Dit leidt tot een S-curve: een hele lange aanloop naar 1%, maar daarna gaat het veel sneller (zie ook www.fastned.nl/autowende).
 - Schaaleffecten zijn enorm belangrijk voor de TCO. Dat zag je in andere technologieën ook: windmolen en zonnecellen. Dat geldt ook voor batterijcellen en auto's.
 - Er zitten ook minder componenten in een EVs, dus het is minder complex. GM doet dat al: die koop van LG niet meer alleen de batterij, maar een groot deel van het elektrisch systeem.
 - Voor consumenten is de sticker price is het belangrijkste. Verbruikskosten zijn minder belangrijk. Bedrijven doen dat wel, die kijken meer naar de TCO. Er is dus eigenlijk een hogere discontovoet voor consumenten.
 - EVs zijn de toekomst, maar de snelheid is afhankelijk van o.a. beleid. De hele sector wil duidelijkheid, minder onzekerheid, zodat men durft te investeren. Daarmee verlaag je de kosten van kapitaal, zijn banken eerder geneigd om te financieren. Hier is beleid heel belangrijk.
 - Er komt wel steeds meer zekerheid: Klimaat conferentie in Parijs, de motie Vos is aangenomen.
5. Wat zijn de TOP-3 factoren die volgens het meest belangrijk zijn voor een verdere introductie van EVs in de maatschappij?

- Wij erkennen drie belangrijke punten bij Fastned: prijs, performance en regulations. Dat zien de drie drijvende factoren achter de acceptatie van EVs.
 - Prijs: schaaleffecten in auto platforms en batterij packs. De cellen worden niet alleen voor automotive toegepast, maar bijvoorbeeld ook voor de powerwall. Dit brengt additionele economies-of-scale met zich mee.
 - Performance: de prestaties van een EV zijn veel beter. Het geeft minder geluidsoverlast. Ook is de acceleratie van een EV veel beter dan een ICEV.
 - Regulation: de regels worden steeds strenger in Europa. De volgende stap is dat we teruggaan naar 95 gram CO₂ /km. Dit is echt heel erg laag. Dit is een drijver voor OEMs om in actie te komen en meer EV modellen aan te bieden.

Specifieke vragen

Charging

6. Hoe ziet u het thuisladen en publiek laden in de toekomst voor zich? Zal die verhouding gaan veranderen? En verhouding 'normaal laden' en 'snel laden'?
 - De eerste mensen die een EV kochten zijn mensen met een eigen oprit, omdat de publieke infrastructuur ontbrak. Ongeveer 25% van een huishoudens heeft een eigen oprit in Nederland. Wij denken dat het meest efficiënte manier is via fast charging en dat dat aandeel dus groter wordt.
 - Momenteel zitten we op 50 KW laden. Volgend jaar gaan we naar 150 KW. Rond 2020 willen we naar 350 KW. Straks heb je in een paar minuten je batterij weer vol. Meer informatie hierover is te vinden op de website van CharIN.
 - De Duitse automotive industrie verwacht dat fast charging echt heel belangrijk is voor de acceptatie.
 - Wij verwachten dat men dus straks elektriciteit gaat 'tanken'

Interviewer: Kun je uitleggen waarom je deze trend verwacht en wat de invloed op de kosten is?

- Fast charging is heel efficiënt: je bundelt de relatief dure laadinfrastructuur op een aantal vaste plekken waar vervolgens veel mensen langskomen. Door het te delen met heel veel auto's kan je naar hoge bezettingsgraden. Mensen blijven niet lang hangen zoals nu in de publieke locaties gebeurt. Dit is ook efficiënt voor bijvoorbeeld onderhoud.
- Wij verwachten dat de publieke punten op termijn deels weer zullen verdwijnen. Op korte termijn is het een mix van verschillende infrastructuur. Op de lange termijn (15 jaar) verwachten we dat er 'tankstations' komen en langzaam laden verdwenen is.
- We hebben nu 15 stations, en concessies voor 200 stations langs de snelweg. We willen uitbreiden naar steden, bijvoorbeeld Amsterdam en Rotterdam. Er zijn nu 4200 benzinstations. Er zijn misschien wat minder stations door thuisladen en werkladen, maar doordat je gemiddeld iets langer bezig bent verwachten we ongeveer 4000 fast charging stations.

7. Wat verwacht u van de kostenontwikkeling van snelladen?

- Of de kosten zullen toe- of afnemen in de toekomst, daar durf ik niks over te zeggen.
- We verwachten eerder een toename van de kosten qua investering, doordat we omhoog gaan in vermogen. Dat gaat de consument niet voelen, want omdat er meer EVs op de weg komen kan het worden verspreid over meerdere gebruikers.
- Door de hoge bezettingsgraad verwachten we dat onze overhead relatief steeds een kleiner aandeel wordt, en de kosten voor de consument dus zullen dalen.

8. Wat verwacht u aan kostenontwikkeling voor de consument wat betreft charging?

- De elektriciteitsprijs is erg aan het dalen de laatste jaren. Dus wellicht wordt het nog goedkoper. Daarnaast verwachten we grote volumes, waardoor we in het zakelijke tarief komen.
 - Per station geldt er een netaansluiting, dus we kunnen niet alle stations bij elkaar 'optellen' voor het in aanmerking komen van het zakelijke tarief. Maar er zou beleid moeten komen wat betreft laadpaal belastingen
9. Verwachten jullie dat wanneer er een doorbraak komt in de batterijtechnologie die negatieve of juist positieve impact kan hebben op het aantal oplaadpunten?
- Wij verwachten geen substitutie. Als de range beter wordt, worden EVs definitief de toekomst. Daarnaast is een grote range gecombineerd met snelladen zorgt dat voor een ander type autogebruik. Bij lage range ben je altijd bezig met 100% opgeladen is. Bij een grotere range en een goed netwerk, ben je daar niet meer mee bezig. Eens in de 10 dagen laad je tot 80%.
 - Een grotere range vervangt dus eerder de slow charging en is op termijn aantrekkelijk voor fast charging.
10. Vragen additionele kosten: belastingen, vergunningen, netverzwaring, grootverbruikstarief?
- De kosten voor vergunningen etc. liggen met name bij langzaam laden, omdat er enorm veel punten nodig zijn. Wij vragen een forse netaansluiting aan langs de snelweg. Dat kost wat, maar het is er maar een.
11. Introductie van nieuwe technieken. Wat verwachten jullie van deze technieken?
- a. Battery swap
 - b. Induction charging
- Battery swapping geloven we niet in. De batterijen moeten namelijk compatible zijn tussen verschillende OEMs. We verwachten dat dat niet lukt. Daarnaast moet je de lege batterijen ook weer snel opladen, anders heb je enorm veel voorraad. Dus het is niet de oplossing.
 - Inductie laden: er gaat zoveel stroom door zo'n kabel heen, dat is nu nog niet mogelijk. We staan er zeker voor open, maar wij zien niet enorm veel voordelen.
12. Standard battles: verschillende soorten in omloop, wat is de invloed op de kosten
- Stekker standaarden: bij slow charging is het de mennekes. Bij FC is de strijd nog gaande: wij bieden meerdere stekkers aan. De kosten zijn wel wat, maar niet heel veel. Uiteindelijk is het alleen drie kabels in plaats van een. Wij verwachten dat CCS de toekomst wordt, in ieder geval in Europa. Dan is er ook een stekker voor alle soorten laadpalen.
 - Maar de additionele kosten zijn verwaarloosbaar

Demand

13. Wat is uw verwachting van de te verwachte vraag wereldwijd? Wat zijn de belangrijkste factoren waarvan deze vraag afhangt?
- Lastig om te zeggen voor de hele wereld, ik kan er geen uitspraak over doen. In China gaat het nu echt hard, ook omdat de noodzaak groot is i.v.m. vervuiling. Daarnaast willen ze ook eigenaar worden van de hele waardeketen van de productie van auto's. Dus ze hebben ook zakelijke motieven. Ze zien dat de Duitse/Amerikaanse markt hier nog niet instappen en zij willen dus de auto opnieuw uitvinden. Voor hun een mega kans.

Depreciation

14. In de literatuur wordt de restwaarde vaak op nul gezet. Dit impliceert dat de restwaarde of heel onduidelijk is, maar in ieder geval niet meer waard is dan een ICEV. Bent u het daarmee eens en wat zouden redenen kunnen zijn?
15. Zou het aannemelijk zijn dat het restwaarde patroon veranderd in de toekomst? Waarom? En vanaf wanneer dan?
- De batterij is hierin de grootste factor. Als de fabrikant gewoon 8-10 jaar garantie geeft en garantie geeft dat je over 10 jaar die batterij kan laten vervangen, dan kan je zo'n auto misschien wel een tweede leven geven. Het probleem lost zichzelf wellicht op.

- Einde -

Interview 6. Art van der Giessen

Algemene informatie

Naam : Art van der Giessen
Organisatie : Gemeente Amsterdam
Functie : Projectmanager Electric Vehicles
Datum interview : Maandag 30 mei 2016
Tijd : 16.00 – 17.00 uur

Algemene vragen

1. Wat is uw functie en hoe verhoudt zich dat tot EVs?
 - Ik werk voor dienst Ruimte & Duurzaamheid op gebied van elektrische vervoer. Het doel van mijn afdeling is het mogelijk maken van elektrisch vervoer binnen Amsterdam. Denk het aan faciliteren door infrastructuur te plaatsen, stimuleren door middel van subsidies (meestal zakelijk) en reguleren van 'vieze' voertuigen door middel van bijvoorbeeld milieuzones.
2. Is het model begrijpelijk?
 - De geïnterviewde geeft aan dat het model begrijpelijk is. *(Alleen de eenvoudige versie is uitgelegd i.v.m. de focus op de HOE-vraag en de tijd)* en vindt het model logisch, hoewel het alleen in grote lijnen uitgelegd is.
3. Zijn er nog factoren (blokjes) die niet op de goede plek staan, maar missen of juist verwijderd moeten worden?
4. Zijn er nog relaties (pijltes) die niet op de goede plek staan, maar missen of juist verwijderd moeten worden?

Uitleg eenvoudige model. De geïnterviewde heeft de volgende opmerkingen:

- Wat je nog zou kunnen toevoegen is dat er een extra heffing komt voor ICEVs: denk aan een milieuzone waar je met een ICEV voor moet betalen.
 - Het aanbod van modellen is nu redelijk beperkt. Dat moet toenemen, dat is een belangrijke prikkel. Mensen willen keuze, kijk maar naar ICEVs: het aantal modellen is echt enorm. Als het aanbod groter wordt, met een range die groter is,
 - Het gaat nu echt wel hard en ik denk dat de range nu snel omhoog gaat. OEMs kondigen kort van tevoren hun nieuwe technologieën aan, want anders verkopen ze minder van hun oudere modellen.
 - Er is overheidsbeleid nodig om EVs verder te introduceren
 - Belastingmaatregelen hebben vaak een heel groot bereik en zet elke automobilist aan het denken. Bij subsidies heb je dat minder.
 - *Interviewer: Waar in het model is beleid het belangrijkste?* Onderzoek weet ik niet zo goed. In Duitsland is veel geld gestopt in R&D, maar je ziet dat de markt daar niet op gang komt. Het meest effectief zijn fiscale voordelen op rijksniveau. De niet monetaire voordelen zit wat meer lokaal beleid en biedt ook extra's.
5. Wat zijn de TOP-3 factoren die volgens het meest belangrijk zijn voor een verdere introductie van EVs in de maatschappij?
 - Prijs en Range zijn de belangrijkste factoren. In mindere mate het aanbod modellen wat er is.

- Die range is niet te overkomen met alleen maar meer laadpalen neer te zetten. Mensen willen er gewoon lekker mee kunnen rijden.
 - Voor de 'gewone' consument is het simpelweg te duur. Het voordeel is momenteel voor de leaserijder.
 - Men koopt de auto voor het ene ritje naar Frankrijk of Spanje.
 - De grootste hobbel is de range. Als er een auto is die betaalbaar is en 250 km range hebt, dan wordt het aantrekkelijk.
6. Wat doet de gemeente Amsterdam nu aan beleid? (*extra vraag*)
- Elektrische taxi's in Amsterdam krijgen voorrang bij de taxistandplaatsen. Zo verhoog je ook de inkomstenkant van een taxi eigenaar.
 - In 2021 zijn alleen nog maar emissievrije taxi welkom op Amsterdam Centraal Station.
 - Wellicht komen er meer maatregelen in de toekomst. Denk bijvoorbeeld aan het gebruik van bus- en trambaan alleen voor emissie loze taxi's.
 - Er komen ook meer milieuzones voor Amsterdam, maar nog niet voor personenauto's
 - Parkeervergunningen: voor oudere auto's krijg je op termijn geen verkeervergunning meer.
 - Beleid voor personenauto's richt zich momenteel met name op laadpaal infrastructuur. Daarnaast krijg je voorrang op de parkeervergunning. Dat scheelt een paar jaar.
7. Binnen welk auto segment ziet u het meeste kans voor EVs om zich te ontwikkelen, en waarom?
- Kleine auto's zijn doorgaans goedkoper en de marges zijn kleiner voor de OEMs, dus het is lastiger om die batterij mee te verkopen. Grotere auto's hebben daar minder last van relatief gezien, dus ik denk dat die eerst bediend zal worden.
 - Als je een aantrekkelijk aanbod hebt in het middenklas segment, de C-klasse, dan kan daarna de B-klasse volgen. Hogere klassen zoals de Tesla kan natuurlijk ook.
 - Het idee van de EV als kleine tweede auto is lastig uitvoerbaar. Je zal de prijs dan heel aantrekkelijk moeten maken en daarvoor moet de prijs voor de batterij naar beneden. De meeste kansen liggen in de segmenten waar je de auto zakelijk kan gebruiken (leaseauto's).
 - Een consument kijkt waarschijnlijk ook minder naar de Total Cost of Ownership en meer naar de aanschafwaarde. Daar heb ik geen onderzoek naar gedaan, maar dat denk ik.
8. Welk type EV (BEV/PHEV/EREV) heeft het meeste kans voor ontwikkelen volgens u, en waarom? En op welke termijn?
- Als er een accuprijs doorbraak komt i.c.m. goede laadinfrastructuur dan denk ik dat we naar BEV gaat. PHEV / EREV is dan onlogisch omdat er twee typen aandrijving in zitten. Dat hebben we omdat BEV nog niet aantrekkelijk is qua range.

Specifieke vragen

Charging

9. Hoe ziet u het thuisladen en publiek laden in de toekomst voor zich? Zal die verhouding gaan veranderen? En verhouding 'normaal laden' en 'snel laden'?
- Veel mensen in Amsterdam hebben geen eigen oprit. Thuisladen en publiek laden loopt hier dus door elkaar heen. We hebben dus ook bewust een maximum tarief (ongeveer 28 ct/kWh) afgesproken met de exploitant die de laadpalen beheerd. Per maand hebben we ongeveer 10.000 unieke gebruikers, met in totaal 60.000 charging sessions op 2000 punten. We gaan in de toekomst naar 4000 in 2018 als ambitie.

- Maar er is dus wel degelijk een groep mensen in Amsterdam die regelmatig gebruik maakt van deze infrastructuur.
 - Fast charging is ook interessant, maar wat je ziet is dat veel mensen toch overnight charging. Veel EVs kunnen ook (nog) niet snelladen, zeker plug-in varianten gaan niet naar snelladen toe. Als je gewoon verder kunt rijden, doe je dat. Dus zolang er beschikking is over de infrastructuur, thuis, publiek of op z'n werk zal diegene dat doen. Ook zien we dat ze lang genoeg aan de paal staan om helemaal op te laden. Daarnaast heeft het de voordelen van smart grid.
 - Ik denk dat beide systemen in de toekomst gebruikt zullen worden. Maar ik denk niet dat we allemaal massaal gaan 'tanken'. Een van de voordelen van een EV is juist dat je niet langs een tankstation hoeft.
 - Maar de beperking is wel dat er waarschijnlijk geen 200.000 laadpalen komen (aantal parkeerplaatsen in A'dam), dus dat is nu wel een punt voor de toekomst.
 - Ik denk niet we bij elke parkeerplek een lader zal krijgen.
10. Wat verwacht u van de kostenontwikkeling van publiekladen? Zowel qua omvang als qua timing.
- De palen worden bekostigd door de gemeente en wij zijn dus ook eigenaar van de palen. De prijzen van de palen zijn wel flink naar beneden gegaan de afgelopen jaren. De aansluitkosten zijn deels wettelijk en arbeid, en dalen dus niet.
 - De kosten voor aanschaf- en installeren van een paal is voor Amsterdam lager dan wat het plaatje aangeeft. Maar de ene gemeente is de andere niet. Omdat wij zoveel palen kopen hebben we een lagere prijs. Het onderhoud is ook relatief efficiënt omdat er zoveel palen zijn.
 - Dit soort palen zitten op het klein verbruikstarief, elke paal is een apart object. Als je het als een netwerk zou zien, zou de business case in een klap omslaan
 - Maar de politiek wil nu een soort tussen variant: een speciaal tarief voor laadinfrastructuur die tussen groot en klein inzit.
 - Qua beleid denk ik dat een 'de vervuiler betaalt' een goede methode is.
 - Inductie is wel een interessant systeem, maar wat doet het met de aanschaf en vooral onderhoudskosten? Lijkt me voor nu nogal kostbaar.
11. Sommige stakeholders geven aan dat er hoge administratieve/overige kosten zijn voor laadinfrastructuur, zoals belastingen, vergunningen, netverzwaring en grootverbruikstarief. Kunt u hier een inschatting van geven?
- Dat is in Amsterdam geen probleem, omdat we hier stimuleren. Er zijn natuurlijk wel aansluitkosten. Afhankelijk van de grootte van de aansluiting betaal je een bedrag aan de netbeheerder. Voor palen in Amsterdam geldt het gelijke tarief als voor een woning.

Demand

12. Wat is uw verwachting van de te verwachte vraag wereldwijd?
13. Verwacht u dat EVs een niche blijven tot 2025, en waarom?
- Ik denk dat het in 2025 geen niche meer is, maar wel meer naar de hoge grens van de grafiek. Het gaat echt rollen nu, als je ook kijkt naar bijvoorbeeld Tesla. Andere OEMs gaan nu mee verwacht ik, dan komen er aantrekkelijke auto's. Samen met een lage batterijprijs wordt het aantrekkelijk.
14. Verwacht u dat ICEVs nog steeds geproduceerd worden in 2030, en waarom? *(doorvragen indien ja)*

- Ja, er worden in 2030 in de wereld nog wel normale auto's verkocht. Maar het grootste gedeelte heeft een elektrische aandrijving.

Interview 7. Huib van Essen

Algemene informatie

Naam : Huib van Essen
Organisatie : CE Delft
Functie : Manager Verkeer & Vervoer
Datum interview : Dinsdag 31 mei 2016
Tijd : 10.00 – 11.30 uur

Algemene vragen

1. Wat is uw functie en hoe verhoudt zich dat tot EVs?
 - Ik ben Manager Verkeer & Vervoer bij CE Delft.
2. Is het model begrijpelijk?
 - De geïnterviewde geeft aan dat het begrijpelijk is.
3. Zijn er nog factoren (blokjes) die niet op de goede plek staan, maar missen of juist verwijderd moeten worden?
4. Zijn er nog relaties (pijltjes) die niet op de goede plek staan, maar missen of juist verwijderd moeten worden?

Uitleg gedetailleerde model. De geïnterviewde heeft de volgende opmerkingen:

- De levertijd zou ook nog wel eens een probleem kunnen worden, als het heel hard loopt en autofabrikanten reageren niet snel genoeg
 - De reliability van de technologie is belangrijk. Dat komt terug in de technische parameters.
 - Het imago van de EV is ook van belang.
 - De vehicle performance is ook bepalend: het product EV t.o.v. het product ICEV in imago, performance, customer understanding.
 - De range is belangrijk, maar is iets anders dan de range perceptie (range anxiety). Die zou ik apart neerzetten.
 - De inkomenselasticiteit speelt mee, maar in mindere mate. Ik verwacht weinig verschil voor de komende 15 jaar. Consumentenvertrouwen heeft natuurlijk ook invloed.
 - Er is ook een relatie tussen market confidence and WTP. Hogere aantrekkelijkheid zorgt voor meer market confidence.
 - Grondstoffen kunnen duurder worden als er wordt opgeschaald, hoewel er dan ook weer innovatie kan plaatsvinden.
 - De emission regulations hebben ook invloed op de pricing strategy, omdat auto misschien goedkoper/duurder in de markt moeten worden gezet om te zorgen dat OEMs de eisen halen.
 - Wat meer groeperen, bijvoorbeeld: production, consumenten, exogene factoren
 - Als de verdeling van de TCO (one time cost vs reoccurring cost) verandert, kan ook het gebruik ook veranderen. Gaan mensen met een EV meer rijden omdat de gebruikskosten laag zijn, of gaan ze juist minder rijden omdat je beperkt wordt door de range.
 - Het zou goed kunnen dat de producten nog onder kostprijs wordt verkocht om marktaandeel te vergroten.
5. Wat zijn de TOP-3 factoren die het meest belangrijk zijn voor een verdere introductie van EVs in de maatschappij?

- De aanschaffkosten en daaruit volgt de batterijprijs is de grootste factor. Andere factoren zoals goedkoop laden scheelt wel, maar het grootste aandeel is toch de aanschafprijs. Dat hangt samen met de economies of scale.
 - Een grotere range is echt belangrijk. Als de batterijprijs omlaag gaat, zal eerst de range omhoog gaan. Dat beperkt nu nog het marktaandeel van EVs, samen met het aanbod in modellen. Als je een range hebt van 350 km dan spreek je een nieuwe groep mensen aan. Dan wordt charging ook belangrijker, omdat er dan misschien een tekort staat.
 - Op termijn wordt het een beter product, speciaal voor EVs. Maar het een grote investering op dit moment voor OEMs
 - Economies of scale in de productlijnen is mogelijk. De auto-industrie is heel erg gestandaardiseerd de afgelopen jaren om kostenvoordeel te maken. Nu komt er een EV, en dan gaat het gedeeltelijk niet meer op. Men wil proberen hierop voort te bouwen, als dat mogelijk is. Dat is het lastige voor bestaande fabrikanten
 - In de toekomst wordt een auto herontworpen voor een EV (zoals Tesla nu al doet).
6. Binnen welk auto segment ziet u het meeste kans voor EVs om zich te ontwikkelen, en waarom?
- Ik denk dat het vanuit de luxere begint. Daarna zal het naar beneden gaan als de prijs goedkoper wordt. Je ziet meer de C/D segment nu opkomen: de Bolt, Tesla Model 3, etc. Voor het A/B segment is het heel moeilijk om het nu concurrerend te maken.
7. Welk type EV (BEV/PHEV/EREV) heeft het meeste kans voor ontwikkelen volgens u, en waarom? En op welke termijn?
- Fiscale voordelen stimuleren vooral BEVs. De PHEV/EREV blijven wel, maar zullen wat verschuiven naar een EREV met grotere electric range (e.g. 80 kilometer). De barrières maken BEVs minder aantrekkelijk, en de PHEV/EREV zijn voor fabrikanten een mooie overgang om de technologie te ontwikkelen
 - Hangt ook van CO₂ regels af. Dus wordt erg bepaald door beleid.
8. Hoe zie je de toekomst van EVs als je kijkt vanuit een beleidsoogpunt. Wat zou er moeten veranderen? (*extra vraag*)
- Rekeningrijden is een optie als EVs een groter aandeel gaat krijgen. Anders gaat het totaal aantal autokilometers wellicht ook toenemen, de overheid raakt het sturingsmechanisme kwijt. Het alternatief is dat je een stuk belastinginkomsten kwijtraakt (gaat om 8 miljard euro).
 - Het vermogen dat nodig is om heel veel auto's op te laden is gigantisch. Zonder laadsturing is dat niet makkelijk op te vangen voor netbeheerders. Je krijgt enorme pieken en dalen. Laadsturing wordt daarom belangrijk. Variabele elektriciteitsprijzen zijn een mogelijkheid om vraag en aanbod in elektriciteitsmarkt op elkaar af te stemmen, afhankelijk van het aanbod i.c.m. smart grid.

Specifieke vragen

Charging

9. Hoe ziet u het thuisladen en publiek laden in de toekomst voor zich? Zal die verhouding gaan veranderen? En verhouding 'normaal laden' en 'snel laden'?
- Ik denk dat het aandeel van snelladen beperkt zal zijn. Dat komt ook omdat de kwaliteit van de batterij erdoor afneemt. Daarnaast omdat het simpelweg duur is.

- Ik denk dat als de auto stilstaat je gaat laden, niet dat we met z'n allen gaan tanken. Het klinkt in ieder geval waarschijnlijker.
- Ik betwijfel of FC de dominante manier van charging wordt. De kosten om zoveel stroom te leveren zijn enorm hoog, zeker in combinatie van hernieuwbare energie.
- Overigens heb ik zelf een PHEV/EREV en lijkt het erop dat er wel wat verliezen zijn tijdens het laden. Wellicht nuttig om dat mee te nemen in de TCO berekeningen.

10. Wat verwacht u van de kostenontwikkeling van thuisladen?

- De plaatjes zien er aannemelijk uit.

Demand

11. *Uitleg van de demand ontwikkeling volgens de literatuur.* Wat is uw verwachting van de te verwachten vraag wereldwijd? Wat zijn de belangrijkste factoren waarvan deze vraag afhangt?

12. Verwacht u dat EVs een niche blijven tot 2025, en waarom? (*doorvragen indien nee*)

- De schaafeffecten zijn natuurlijk wel afnemend. In de eerste paar miljoen auto's heb je nog veel reductie, maar vanaf een bepaald punt is het effect minder.
- 4 miljoen in 2030 lijkt me onrealistisch laag. Ik verwacht dat tot 2020 zal het toenemen maar nog niet heel erg enorm. Maar vanaf 2020 heb je meer modellen en dan gaat het hard. Dus in 2025 is het geen niche meer, maar kan het tot tientallen procenten marktaandeel.

Depreciation

13. In de literatuur wordt de restwaarde vaak op nul gezet. Dit impliceert dat de restwaarde of heel onduidelijk is, maar in ieder geval niet meer waard is dan een ICEV. Bent u het daarmee eens en wat zouden redenen kunnen zijn?

14. Zou het aannemelijk zijn dat het restwaarde patroon veranderd in de toekomst? Waarom? En vanaf wanneer dan?

15. Wat zou een verklaring kunnen zijn dat sommige merken hun waarde wel behouden en andere niet?

- Let op dat je gelijk wat van je waarde van je auto kwijt bent zodra je de auto aanschaft.
- Dit zegt niks over de afschrijving in de toekomst, want dit kan heel goed nog veranderen.
- Wat speelt is de betrouwbaarheid van het product, de snelheid van de verbeterde technieken en producten, en de nieuwere producten worden ook goedkoper. Dat zie je bij een nieuwe Golf niet.
- De Tesla zijn misschien waardeverlozen omdat er een hoge vraag naar is.
- In de toekomst misschien nog wel waardeverlozen omdat de onderhoudskosten lager zijn. Het hangt wel af van hoelang de batterij meegaat.

Battery technology

16. Op het gebied van batterijtechnologie verwacht de literatuur dat de kosten verder zullen dalen. Bent u het daarmee eens?

17. Wat is de oorzaak van deze daling? (uitsluiten innovatie / schaafeffecten). Wat zijn mogelijke barrières voor deze kostendaling?

18. *Plaatje kostenontwikkeling laten zien.* Hoe denkt u dat de kostenontwikkeling van de batterij zal verlopen? Zowel qua omvang van de kosten als qua timing van de kostendaling.

- De kwaliteit van een batterij speelt ook een rol (degradatie).
- Zowel schaafeffecten en innovatie zijn van belang. Enerzijds geheel nieuwe batterijconcepten (radicaal). Maar op kortere termijn optimalisatie van de huidige concepten, bijvoorbeeld de state of charge limieten, balans van de cellen, etc (incrementeel). Kortom: levensduur en gebruik van batterij.
- Maar mijn contacten bij Toyota zeggen dat er vrijwel nooit problemen zijn met die batterijen, nooit vervanging nodig.
- Bij bussen bijvoorbeeld worden die batterijen na 5-7 jaar afgeschreven, maar die hebben ook een heel ander gebruiksprofiel.
- Kijk ook waar de kosten van het produceren van een battery pack uit bestaan. Als het puur in de materialen ziet, dan heeft economies of scale minder effect natuurlijk
- Richting de 150 tot 200 euro per kWh lijkt me wel aannemelijk, maar dat blijft 10.000 euro voor een batterij als je een behoorlijke range wilt hebben van ca. 250 km of meer.

Maintenance

19. *Plaatje onderhoudskosten laten zien.* De kostenschattingen van onderhoud lopen erg uiteen. Wat zou een verklaring kunnen zijn?

- Ik vind 1 cent per km wel erg laag, daar koop je amper banden voor. ICEV is voor normaal onderhoud ongeveer 3 cent/km. EVs kunnen wel wat goedkoper, tussen 1 en 2 cent. Het motoronderhoud valt natuurlijk weg, je hoeft minder te vervangen en verversen.

- Einde -

Interview 8. Paul Wolfram

General information

Name : Paul Wolfram
Organisation : International Council on Clean Transportation
Position : Research Associate
Date : Tuesday May 31, 2016
Time : 14.30 – 15.30 PM (UTC+2, conference call)

General Questions

1. What's your position and how is it related to EVs?
 - I work for the ICCT on Electric Vehicles as a research associate. I conducted research on the cost of EVs from a production point of view and on well-to-wheel CO₂ emissions and energy demand. I might be able to send you the manuscript of my study on EV costs and carbon emissions. Once it's officially published, you can use it.
 - My expertise is mainly from the production perspective. Therefore, depreciation, maintenance and charging are not really my expertise.
2. Do you understand the model?
 - The interviewee says he understands the model.
 - You might want to put arrows in both directions, for example between the number of cars sold and the R&D opportunities.
3. Which TOP3 factors in your opinion hamper the introduction of EVs?
 - I'm working more on the component level. But I think the battery is one of the most influencing factors. For battery EVs with a 100 miles range the cost of the battery is responsible for about 60% of the whole cost increment over a comparable ICEV. That's why an EV costs more than a conventional vehicle. For a 300 miles range car the cost increment of the battery is even bigger.
 - Once the batteries become cheaper, both the range will increase and the EV sticker price becomes cheaper. By 2030, a 100 mile EV might be cheaper than an ICEV. But a 300 mile EV will take longer to compete with an ICEV. *Interviewer: Why will the price decline?* Energy density of the lithium-ion battery will go up considerably. Also the lithium-air battery is a promising concept. Right now they are very far from commercialization. *Interviewer: Could EVs be a viable alternative to ICEVs by 2030?* Yes, why not. It could be. Research suggests that there's progress.

Specific questions

Vehicle technology

4. The literature expects ICEV technology will become more efficient over time. Do you think EV will become more efficient as well?
5. How can the production costs be lowered in the future?
 - There's always room for improvement, but this is not my expertise.
 - Regarding production lines, many components can be the same for a normal Golf and an e-Golf. Take for example the tires, wheels, chassis, they are all the same. The electric part is obviously different. But I don't know for sure how producer's will make these arrangements, if they use the same production lines.

- Batteries are probably produced by the battery manufacturer. There are many alliances between battery suppliers and car manufacturers.

Battery technology

6. The literature expects battery costs to decline as well. How will this cost reduction be achieved?
 - I think it's probably a combination of economies of scale and innovation. Economies of scale might be the biggest factor. But also high cost materials will be replaced by low cost materials. More efficient techniques with reduced wastage will also contribute.
 - I haven't looked into battery deterioration. Some literature claims that the vehicle lifetime is currently longer than the battery lifetime (like 2 or 3 times). But the battery life already increased in recent years and will further increase.
7. How do you think the cost development of batteries will develop? Is that in line with the graph?
 - The graphs in my research look similar.
 - Increasing production capacity is very closely related to the economies of scale effect. Tesla aims a 30% battery cost reduction by building the Gigafactory. However, the biggest economies of scale may have already occurred. My estimation is that the current battery price (rough estimate) is about 250 € per kWh at pack level. That is for market leaders. The average battery price for the whole industry is higher.

Demand

8. What is your expectation on the estimated demand over time? What are important factors resulting in a higher/lower demand?
9. Do you expect the EVs to remain a niche until 2025, and why?
 - The question is how do you define a niche? Currently the sales of EVs are below or at 1%. It's very difficult to give an outlook. I know there are some scenarios in which EVs will take up considerably. But I honestly don't know what the future will do.
10. Do you expect ICEVs still to be produced in 2030, and why?
 - It depends on how strict the CO₂ standard in the European Union, the U.S. and in other regions will be. The 2021 target of 95 g CO₂ /km in the EU is not strict enough to force manufacturers into EV production at a significant scale. A 2030 target in the range of roughly 70 g CO₂ /km (as currently under discussion) will require higher EV sales but substantial amounts of ICEVs will definitely still be produced and sold. Most other regions have less strict CO₂ targets than the EU.

- End -

Interview 9. Joris Hupperets

Algemene informatie

Naam : Joris Hupperets
Organisatie : Vattenfall
Functie : Director New Operating Models
Datum interview : Donderdag 2 juni 2016
Tijd : 18.00 – 19.00 uur (telefonisch)

Algemene vragen

1. Wat is uw functie en hoe verhoudt zich dat tot EVs?
 - Nuon/Vattenfall levert laadoplossingen bij mensen thuis, bij bedrijven en ook publieke oplaadpunten. We werken intensief samen met autofabrikanten, overheden en andere bedrijven. Wij nemen de verantwoordelijkheid voor het plaatsen en de operatie van de laadpaal. We bieden een totaaloplossing.
2. Wat zijn de TOP-3 factoren die volgens het meest belangrijk zijn voor een verdere introductie van EVs in de maatschappij?
 - Het belangrijkste aspect voor de introductie van EV is de prijs van batterijen. Op basis wat ik heb gehoord, o.a. speeches van Tony Seba. Hij zegt: vanaf 2020 is een middenklasse auto van 30.000 USD in de aanschaf (of TCO, onbekend) vergelijkbaar met de normale auto. Vanaf 2025 zijn zelfs kleine auto's zijn goedkoper in de EV vorm dan in de conventionele vorm.
 - Dit komt omdat de batterijprijzen gewoon dalen, net als zonnepanelen. Dan gaat de range ook omhoog, want dat is nu onacceptabel. En dan wordt het geschikt voor de massa (vanaf 250 kilometer range).
3. Welk type EV (BEV/PHEV/EREV) heeft het meeste kans voor ontwikkelen volgens u, en waarom? En op welke termijn?
 - PHEV is een tussenoplossing, mits de batterijverlaging gewoon doorzet. Als de range straks omhoog gaat, gaat die introductie van EV wel door. Het wordt allemaal BEV uiteindelijk. Het range probleem bestaat niet meer vanaf 250 km range.
 - Zowel de prijs gaat naar beneden als de range omhoog. Maar 250 km is wel een must, dit is het grootste probleem voor de introductie van EVs.

Specifieke vragen

Charging

4. Hoe ziet u het thuisladen en publiek laden in de toekomst voor zich? Zal die verhouding gaan veranderen? En verhouding 'normaal laden' en 'snel laden'?
 - Uit ons klantenonderzoek in NL komt dat 80% thuis laadt (dit kan zowel een home charger als een public charging point zijn), 15% op het werk en nog geen 5% aan de snellader. Voor sommige doelgroepen is snelladen natuurlijk wel interessant, bijvoorbeeld een taxi. Voor een 'normale' rijder heb je geen snellader nodig, maar kan je prima 's nachts laden. Zeker als straks de range ook nog wat omhoog gaat.

- Een voordeel van een EV is dat je elke dag kunt beginnen met een volle accu. Snelladen gaat wel gebruikt worden, maar niet als hoofd methode. Het kost gewoon tijd en meer geld. Het tanken in tankstations is denken in het oude systeem.
 - *Interviewer schetst de situatie dat er wellicht te weinig laadinfrastructuur is als iedereen een EV zou hebben.* Niet iedereen hoeft elke dag te laden als je range acceptabel is, dus het aantal laadpalen per EV zal dalen. Daarnaast is het niet onmogelijk om een heel significant deel van de parkeerplekken uit te rusten met laadpalen. Ik zie het probleem niet.
 - In het ideale geval heb je zelfrijdende auto's i.c.m. inductieladen. Dan kunnen ze zelf verwisselen. 's Nachts is het meest geschikte moment om te laden.
 - De huidige proporties zijn 80:15:5. In de komende jaren verwacht ik dat thuis de belangrijkste locatie blijft.
5. Wat verwacht u van de kostenontwikkeling van thuisladen?
- Een laadpunt thuis kost ongeveer 600-700 euro in aanschaf. Dan nog eens 600 euro aan installatie, maakt samen 1200 euro. Er kan nog wel 10-20% in installatie door efficiëntie. De aanschaf zou door de helft kunnen als we dat grootschalig gaan doen. Dit is een grove inschatting.
6. Verwachten jullie dat wanneer er een doorbraak komt in de batterijtechnologie die negatieve of juist positieve impact kan hebben op het aantal oplaadpunten?
- Een hogere range leidt niet tot minder kilometers in totaal. Dus de behoefte aan kWh's blijft gelijk. Maar er is inderdaad een substituut risico wat betreft de verdeling van thuisladen.
 - Wat gaat veranderen is dat in de huidige situatie je altijd wilt laden. Als de range groter wordt is er minder behoefte aan aantal palen, maar dan gaat het gebruik per punt dus omhoog.
7. Wat verwacht u van de kostenontwikkeling van publiekladen?
- Het laden in Amsterdam aan de palen overtreft al onze verwachtingen.
 - Vanuit de laadkant is schaal ook belangrijk. Wat betreft de productiekosten kan er nog wel 20-30% omlaag. Wat betreft installatie zit er een groot gedeelte manuren in, dus daar kan minder vanaf. De installatie is ongeveer 1/3 van de kosten.
 - Een paal kost nu ongeveer 4000 euro voor aanschaf- en installatiekosten (excl. operationele kosten). Een deel is een vast tarief, zoals manuren installatie en netwerkkosten. Dus de kansen hierin zit in het verhogen van het verbruik van de paal. Daardoor zouden de kosten van de eindgebruiker omlaag kunnen. Het effectief rendement is slechts 10%. Dat betekent dat het totale vermogen per etmaal maar voor 10% benut wordt. 100% is niet haalbaar zonder zelfrijdende auto's (dat is toekomstmuziek). Maar het moet wel omhoog kunnen.
 - Huidige kosten voor de consumenten is 33 ct per kWh (28 cent exclusief BTW). De kosten thuis zijn ongeveer 20 ct per kWh. Als het verbruik omhoog gaat (bezettingsgraad) kunnen de publieke kosten omlaag. Indien belastingvoordelen komen zou het zelfs lager dan thuis kunnen worden, maar dit verwacht ik niet. Een publieke paal heeft ook operationele kosten.
 - Van de 20 ct is ongeveer 13 ct belasting. Er ligt nu een voorstel om die belasting te halveren in de periode 2017 – 2020.
 - Nu is de business case van publieke palen niet mogelijk zonder subsidie van de gemeente.
 - 8 ct marge (28 cent – 20 cent) kan voldoende zijn in de toekomst als de bezettingsgraad hoger wordt.
 - Tegelijkertijd moet je bedenken dat je ook een thuislader aan moet schaffen als je kiest voor een home charger. Dat kost ook zo'n 8 cent per kWh: Als je 1200 euro voor een laadpunt betaald, deel je door 3000 kWh (15k km) en delen door 5 jaar afschrijving is ongeveer 8 cent.

- *Interviewer: zouden de publieke palen ook in het zakelijk tarief kunnen komen?* Om in het zakelijk tarief te komen moet je wel echt veel laden. Dat is wel mogelijk bij bijvoorbeeld taxistandplaatsen, maar bij heel veel palen zie ik dat niet zo heel snel gebeuren.
8. Introductie van nieuwe technieken. Wat verwachten jullie van deze technieken?
- c. Battery swap
 - d. Induction charging
 - e. Smart grid
- Inductieladen lijkt me zeer praktisch. Voor 2030 kan het denk ik wel, vooral bij mensen thuis. Het probleem is de standaardisatie: je moet met verschillende auto's kunnen laden. Voor thuisladen is het ideaal. Dat maakt het voor werk/publiek lastig voor 2030.
 - De battery swap is dood. Ook hier is standaardisatie een probleem. Men gaat niet accepteren dat een battery pack wordt verwisseld tussen verschillende soorten auto's. Met stekkers was het al een probleem.
 - Smart grid: er zijn voor- en nadelen. Technisch kan het, maar of het economisch kan is belangrijker de komende jaren. Juridisch is het ook een punt: wat doet het op- en ontladen van de degradatie van de batterij. En wat als het mis gaat? Het is nu nog te onzeker om er iets van te zeggen. In de toekomst kan laden zo wel goedkoper worden als de prijs voor elektriciteit laag is. Exclusief energiebelasting en BTW zit er zo 2/3 cent verschil in per kWh. Voor de consument is dat niet schokkend in verband met belastingen, relatief gezien.
9. Standard battles: verschillende soorten in omloop, wat is de invloed op de kosten? (*Extra vraag aangezien model niet is behandeld*)
- Met normaal laden is het wel opgelost. Met snelladen loopt het nog, drie mogelijkheden: de Tesla's variant, de CHAdeMO variant en de CSS variant. In de EU kiest men voornamelijk voor de laatste. Maar in Japan zal men denk ik de CHAdeMO kiezen. Maar dat houdt de ontwikkeling niet tegen verwacht ik. Dat is geen probleem.

Demand

10. Wat is uw verwachting van de te verwachte vraag wereldwijd? Wat zijn de belangrijkste factoren waarvan deze vraag afhangt?
11. Verwacht u dat EVs een niche blijven tot 2025, en waarom?
- Daar waar de elektriciteitsprijs relatief laag is, dan heeft de EV alle potentie om mainstream te gaan. Vanaf 2025 heb je zo goed als zeker voldoende aanbod aan modellen met 250 km range voor een goede prijs.
 - Lastig om te zeggen of de helft van de nieuw verkopen een EV is. Maar 1 miljoen EVs in 2025 moet wel haalbaar zijn. Maar als het goed is wordt het gewoon goedkoper dan een normale auto: kijk naar het aantal bewegende delen en de complexiteit van een normale auto. Bij een EV heb je dat gewoon niet.

- Einde -

Interview 10. Anco Hoen

Algemene informatie

Naam : Anco Hoen
Organisatie : Planbureau voor de Leefomgeving
Functie : Senior Researcher
Datum interview : Maandag 6 juni 2016
Tijd : 13.30 – 15.00 uur

Algemene vragen

1. Wat is uw functie en hoe verhoudt zich dat tot EVs?
 - Ik werkte 14 jaar voor PBL en deed daar onderzoek naar milieu en mobiliteit. Ik ben me in de loop der tijd gaan verdiepen in elektrische mobiliteit. Ik ben ook de tweede auteur van ‘Nijland, 2012’.
 - Uit eerder stated preference analysis onderzoek (2012) dat ik gedaan heb blijkt dat kosten heel belangrijk is voor het aanschafgedrag van de ‘normale consument’. Dan bedoel ik dus niet de early adopter. De aanschafprijs is echt belangrijk, daarna komt de range. Zelfs als deze problemen opgelost zouden worden kwam er nog niet uit dat EVs per definitie aantrekkelijker waren, integendeel. We noemden dit een ‘intrinsiek negatieve waardering’.
2. Is het model begrijpelijk?
 - De geïnterviewde geeft aan dat het model begrijpelijk is.
3. Zijn er nog factoren (blokjes) die niet op de goede plek staan, missen of juist verwijderd moeten worden?
4. Zijn er nog relaties (pijltjes) die niet op de goede plek staan, missen of juist verwijderd moeten worden?

Uitleg gedetailleerde model. De geïnterviewde heeft de volgende opmerkingen:

- Range anxiety is het psychologische aspect en range is de fysieke range (beperking)
- Imago (gebaseerd op environment awareness) is een dubbele. Er zijn mensen die imago als status zien maar niet milieubewust zijn. Die mensen willen bijvoorbeeld een hummer. En er zijn mensen die status belangrijk vinden en wel milieubewust zijn. Als je het verandert in imago zou ik het combineren met high environment awareness.
- Een auto kopen vanwege het high-tech zijn eigenlijk technofielen. Die mensen hebben affiniteit met het aanschaffen van innovatieve producten
- Eigenlijk moet je het symbolisch- affectieve factoren noemen: daar zit imago in, daar zitten fun in, daar zit environment in. Zie ook de studie ‘lust and must’ van Linda Steg uit 2005 van de RUG.
- De relatie tussen inkomensgroei en het verkoop van auto’s is er wel, de aanschaf barrière wordt lager.
- Als er dan steeds meer EVs op straat komen dan zijn andere mensen ook weer eerder bereid een EV te kopen.
- Het kan bijna niet anders dan dat de elektrische auto’s op dit moment tegen kostprijs (of minder) verkocht worden. Het zou interessant zijn als je daar ook aanwijzingen voor kunt vinden. Maar als het marktaandeel omhoog gaat, zullen ze meer winst moeten maken.
- *Interviewer: kan het zijn dat de aanschafprijs gelijk blijft bij lagere productiekosten?* Ja dat zou goed kunnen. Of de aanschafprijs moet omhoog.

- Maar dat aanschafmoment is heel belangrijk. Consumenten hebben in dat geval dus een bepaalde discontovoet. Er is ook literatuur die zegt dat consumenten geen discovoet hebben, maar ik ben er wel van overtuigd dat aanschaf 'nu' belangrijker is dan brandstofkostenbesparingen in de 'toekomst'.
 - Het beleid van de overheid speelt overal in dat model een rol. Overweeg een apart blokje met overheid beleid.
5. Wat zijn de TOP-3 factoren die volgens het meest belangrijk zijn voor een verdere introductie van EVs in de maatschappij?
- De batterijprijs is verreweg de grootste factor (euro/kWh), die heeft het meeste invloed op de TCO, in combinatie met de afschrijving. Wat ik in de literatuur lees is dat de kostenreductie tot 150-250 dollar/kWh kunnen gaan. Maar hoe verhoudt dat zich tot conventioneel? De conclusie die ik dan trek is dat zo'n EV toch duurder zijn en blijft (puur op aanschaf). Je kunt natuurlijk nog wat terugwinnen op je variabele kosten.
 - Een andere mogelijkheid is het direct verlagen van de energiebelasting waardoor de elektriciteitsprijs lager wordt. Dat hangt nauw samen met politieke keuzes. Als de prijs van elektriciteit (of brandstof) afhangt van de CO₂ uitstoot en een EV stoot minder CO₂ uit, dan betalen we in de toekomst minder. Maar dan loopt de overheid dus ook belastinginkomsten mis. Nu is dat niet zo geregeld in de elektriciteitsprijs, maar als je naar een emissiehandelsstelsel gaat, dan zou je dat wel hebben.
 - Het is een duurder product, en het voldoet nog niet aan de prestaties van een ICEV. Denk bijvoorbeeld aan de range, de oplaadtijd, het zoeken naar een oplaadpunt. Dat zijn de belangrijkste. Het aantal modellen speelt ook mee, maar is minder van belang.
6. Binnen welk auto segment ziet u het meeste kans voor EVs om zich te ontwikkelen, en waarom?
- Vooral de mensen die weinig km's rijden vonden een EV interessant bleek uit mijn onderzoek. Dus de wat kleinere auto's hebben het meeste potentie.
 - *Interviewer: nu zie je ze vooral in de hogere klassen.* Klopt, het betekent ook niet dat er geen vraag naar is in het hoge segment. Ik denk alleen dat het potentieel voor de lage klasse groter is. En daarnaast heb je voor een kleinere auto ook minder batterijen nodig. Het blijft lastig. De grote auto's die nu verkocht worden daar zit ook veel subsidie op. Op een Tesla kan je enorm veel 'korting' krijgen. Maar ik verwacht dat het in een kleine segment interessant is.
7. Welk type EV (BEV/PHEV/EREV) heeft het meeste kans voor ontwikkelen volgens u, en waarom? En op welke termijn?
- Een PHEV/EREV is geen oplossing voor het probleem dat we CO₂ moeten terugdringen tot bijna nul. Maar als je niet vanuit een milieuperspectief kijkt, dan haalt een PHEV/EREV een hoop bezwaren weg en is er zekere en plek voor. *Interviewer: wat bepaalt welke weg er wordt genomen?* De vraag is of de consument bereid is te switchen voor het milieu. Als de overheid bepaalt dat ICEV rijden extreem duur wordt, maar dan wordt mobiliteit ook heel duur. Ik betwijfel of dat politiek haalbaar is. Dus ik denk dat PHEV/EREV dan een behoorlijk aandeel zal hebben in de komende jaren.

Specifieke vragen

Demand

8. Wat is uw verwachting van de te verwachte vraag wereldwijd? Wat zijn de belangrijkste factoren waarvan deze vraag afhangt?

- Ik verwacht dat als de overheid niks meer doet dan dat ze nu doen, dan verwacht ik nog steeds niet dat er in 2030 50% van het aantal nieuw verkochte auto's een EV kopen. Je zit je vast in het kip-ei effect, en beleid zal de EV dus aantrekkelijk moeten maken om te compenseren voor de hogere TCO. Het enige wat ik nog kan bedenken is dat bijvoorbeeld China beleid doordrukt waardoor het aantal verkopen omhoog schiet en dus opschaling nodig is.
- *Interviewer: andere mensen hebben het over een omslag in imago en rookeffect.* Het is een interessant scenario en ik zou het zeker niet afschrijven. Maar belangengroepen voor EVs hameren er voortdurend op dat er meer geld/beleid voor EVs moet komen. Dat is voor mij een aanwijzing dat er het nog niet zelfstandig lukt. Tegelijkertijd beloven enthousiastelingen dat over een paar jaar er een grote omslag naar EVs komt. Ik vraag me dan af wat de grote game-changer is die dat wel mogelijk maakt. Dat wordt vaak op batterijkosten gegooid, maar zoals je zelf ziet, is er wel daling maar niet extreem.
- Desondanks wordt de Model 3 van Tesla een heel interessante auto. Een gedeelte van de consumenten is best bereid meer te betalen voor een gelijkwaardig alternatief. Maar niet iedereen is bereid een meerprijs te betalen om in een Model 3 te rijden. Een grote groep koopt tweedehands auto's en interesseert EVs helemaal niks. Vergeet die groep niet.
- Als er meer EVs komen is rekeningrijden is wel een hele logische stap zou je denken en een prima alternatief. Of je moet naar een CO₂-betaalsysteem. Dat neemt alleen wel af (de inkomsten) naarmate er meer emissie loze auto's op de weg komen.

Depreciation

9. In de literatuur wordt de restwaarde vaak op nul gezet. Dit impliceert dat de restwaarde of heel onduidelijk is, maar in ieder geval niet meer waard is dan een ICEV. Bent u het daarmee eens en wat zouden redenen kunnen zijn?
10. Zou het aannemelijk zijn dat het restwaarde patroon veranderd in de toekomst? Waarom? En vanaf wanneer dan?
11. Wat zou een verklaring kunnen zijn dat sommige merken hun waarde wel behouden en andere niet?
 - Het figuur is interessant en nieuw. Maar ik weet niet of je er direct conclusies uit kan trekken, zeker voor de toekomst. Fiscale effecten kunnen voor vreemde effecten in dit plaatje zorgen.
 - Fiscale effecten zoals bijtelling kan er inderdaad voor zorgen dat sommige auto's extreem waardevast zoals je in de grafiek ziet.
 - De voornaamste reden voor de relatief hoge afschrijving is de onzekerheid van de batterij. Het is onderdeel van een opstartprobleem. Het feit dat mensen die een EV kopen liever een nieuwe willen en 'obsolete destruction' is ook mogelijk.

Battery technology

12. Op het gebied van batterijtechnologie verwacht de literatuur dat de kosten verder zullen dalen. Bent u het daarmee eens?
13. Wat is de oorzaak van deze daling?
 - Volgens mij berekenen de studies de kostendaling op basis van schaaieconomie, maar dat is natuurlijk een kip-ei effect. Er zijn mensen die beweren dat een EV ergens kort na 2020 al concurrerend is met een ICEV in aanschaf. Dat lijkt mij sterk. En zelfs als er schaaieffecten optreden, dan denk ik nog dat de aanschafprijs hoger is.
 - Volgens mij zit het in de literatuur alleen in schaalvoordelen. Misschien ook wel wat in innovatie, maar de bulk zit in de schaal.

- Er wordt natuurlijk weleens gesproken over lithium-air batterijen. Die worden doorgaans niet meegenomen in kostenstudies, dat is enorm revolutionair. Ik zou daar nu geen rekening mee houden. Zulke systeemverandering zou ik niet meenemen, dat gaat over tientallen jaren, als ze al überhaupt ooit levensvatbaar worden.
14. Hoe denkt u dat de kostenontwikkeling van de batterij zal verlopen? Zowel qua omvang van de kosten als qua timing van de kostendaling.
- Dit figuur is heel erg in lijn met wat wij destijds vonden. Het viel mij destijds op dat er weinig 'high-quality' papers naar kosten van batterijen. De onderbouwing is best matig in de literatuur.

Maintenance

15. De kostenschattingen van onderhoud lopen erg uiteen. Wat zou een verklaring kunnen zijn?
16. Welke trend verwacht u wat betreft de kostenontwikkelingen voor onderhoud van EVs ten opzichte van ICEVs? Waarom zijn deze kosten hoger/lager dan bij ICEVs? Hoeveel dan? En nu al, of is dat iets dat in de toekomst zo gaat zijn (en wanneer dan)?
- Er zitten meer bewegende delen in een ICEV, dus het zou logisch zijn als de onderhoudskosten voor een EV lager zijn. Hier is ook heel weinig over te vinden. Er zijn weinig ervaringen mee, maar het is wel plausibel dat de kosten lager zijn. Maar houd een behoorlijke bandbreedte aan omdat er veel onzekerheid/weinig ervaring mee is. Besef wel dat de onderhoudskosten maar een fractie zijn van de TCO kosten. Dit speelt nauwelijks een rol voor consumenten. Wat de toekomst gaat doen durf ik niet te zeggen.

Charging

17. Wat zijn volgens u de grootste onzekerheden op het gebied van charging?
18. Hoe ziet u het thuisladen en publiek laden in de toekomst voor zich? Zal die verhouding gaan veranderen? En verhouding 'normaal laden' en 'snel laden'?
- Ik denk dat de meerderheid van de mensen thuis blijft laden en daarmee bedoel ik mensen die voor de deur laden (kan dus ook publiek zijn). Dat is een voordeel. Het publieke laden, ik verwacht dat daar niet zoveel groei meer in zit. Het snelladen zit misschien nog wel wat groei in. Dus thuisladen blijft 80/70%.
 - *Interviewer legt visie van veel snelladen vs veel publiek slow-charging uit. Hoe sta jij daarin?* Ik kan me bij beide scenario's wel wat voorstellen. Ik weet niet of er technische barrières zijn voor snelladen. Als je straks in 6 minuten kan laden, klinkt het wel als een plausibel verhaal. Maar ik heb me er nooit echt in verdiept.
19. Wat verwacht u van de kostenontwikkeling van thuisladen? Zowel qua omvang als qua timing.
20. Wat verwacht u van de kostenontwikkeling van publiekladen? Zowel qua omvang als qua timing.
21. Wat verwacht u van de kostenontwikkeling van snelladen? Zowel qua omvang als qua timing.
- In mijn onderzoek hebben we heel summier gezocht naar kosten van laadinfrastructuur. Mijn gevoel zegt dat de kosten niet heel veel zullen dalen. Ik denk dat het redelijk uit geëvalueerd is. De meeste kosten zijn materiaal en installatie. Dus het gaat wel iets naar beneden, maar

niet met dezelfde sprongen als een batterijkosten daling. Ik denk ook dat veel kostendalingen al gedaan zijn. Maar het kan ook een misvatting zijn.

- Einde -

Interview 11. Gopal Duleep

General information

Name : Gopal Duleep
Organisation : H-D Systems
Position : President
Date : Monday June 6, 2016
Time : 15.00 – 16.00 PM (UTC+2, conference call)

General Questions

1. What's your position and how is it related to EVs?
 - I'm with a consulting firm called H-D Systems. I'm in the consulting for more than 30 years now, among other with ICF International, mainly in the automotive sector. I covered the technology part, the economic part and the cost part. Our customers are NGOs, governments and automotive companies.
2. Do you understand the model?
 - The model is clear and represents the TCO development. *Only the basic version of the model is explained in this interview.*

Explanation of the simplified model. The interviewee has the following comments:

- The production cost does not equal the retail price. Currently they're selling at or below the production cost on EVs.
 - A normal range between production cost and retail price for normal vehicles is between 1,5 and 1,7. With production costs I then mean the costs without R&D, overhead, marketing, transport cost, etc.
 - The resale value is uncertain and that makes it important
 - Also look into the discount rate to calculate the present value. Some studies argue customers have a very high discount rate, like 20% discount rate. Large uncertainty results in an increasing discount rate. It may decline in the future when uncertainty is taken away.
3. Which TOP3 factors in your opinion hamper the introduction of EVs?
 - The retail price is very high, mainly because of the battery. The battery price will see the most decline in costs I think.
 - The range is limited. A 100-miles range is not very useful because one needs a second car.
 - Technological uncertainty about the battery, which translates in the resale value.
 - In most countries it is not a self-supporting business right now, so government policies are needed.
 4. Which car segment has the most potential for EVs and why?
 - People used to think it was the A and B segment. But I think Tesla used to prove this is wrong. The near-luxury segment can absorb the initial higher price without strongly affecting the market. The low segments are very price sensitive markets. For luxury cars there's much more room to recover the price.

- Whether A/B segments will switch to EVs remains to be seen. ICEVs are also improving, so it could be that the battery price will never catch up with ICEVs until 2030. If fuel consumption is good enough it may compete with EVs.
5. Which type of EV (BEV/PHEV/EREV) has the greatest chance to develop and why?
- I suspect that all three versions will be on the market. Whether PHEV/EREV are still produced in 15 years, is dependent on the performance of the batteries for EVs. If there's no battery breakthrough I think PHEV/EREVs remain important.

Specific questions

Vehicle technology

6. The literature expects ICEV technology will become more efficient over time. Do you think EV will become more efficient as well?
7. How can the production costs be lowered in the future?
- ICEVs may compete with EVs until 2030. *Interviewer: some other interviewees said EVs are less complex and therefore easier to produce.* No that's not true. Producing an ICEV is much less expensive, even if you compensate for economies of scale. Besides the battery, other electrification parts like the electric motor and power control are very expensive as well.
 - Production costs of EVs can be lowered, but no major innovations in the vehicle technology are expected. Let's say a 1% cost reduction a year on average for the upcoming 15% year. But that also applies to ICEVs.
 - Right now many EVs use a derived platform, so there's no very big potential in cost reductions on the chassis side. For e.g. the LEAF which has a unique platform there is more potential. But for the others the cost reduction is very minor.
 - The technology improvements in e.g. the electric motors will be there in the next 15 years, but it is almost insignificant.
 - Range is more valuable especially in the near-luxury markets.

Battery technology

8. The literature expects battery costs to decline as well. Do you agree?
9. How will this cost reduction be achieved?
10. How do you think the cost development of batteries will develop? Is that in line with the graph?
- The potential energy density of lithium-ion is not enough for long range EVs, so a battery breakthrough is required for large scale EV adoption.
 - Comment on the graph: I think the costs can be right, but some are on the low end and I think that is because they represent the cell costs. The pack is more expensive. The 350 EUR/kWh for 2015 is correct for the cell. The pack is about 500 EUR/kWh. The typical battery pack is about 60% more than the cell. That's labor, safety systems, fusing and other components. I think this remains roughly the same.
 - On the cell cost level I expect 150-180 EUR/kWh for 2025. From there on it will be pretty flat I think.

- Up until now, the cost reductions took place because of learning and technology improvements (innovations), not because of economies of scale. That resulted in a improved energy density and hence a reduction in EUR/kWh.
- In the 2020 – 2025 timeframe the economies of scale effect might kick-in, although that's very difficult to predict. Many have been wrong in the past. But I don't expect major innovations in lithium-ion anymore.
- Regarding battery deterioration, it is safe to say that the battery lasts about 10-12 years on average (if 80% capacity is the minimum). The influence of fast charging is negative, but how much is open to question.
- A C-class vehicle costs about 11.000 EURO without the electrification part / engine part. A typical 80 KW motor and power electronics would be about 2500-3000 EURO. If you include battery costs, you can calculate the total production costs.
- Regarding economies of scale: there are about 8-10 battery producers. If the markets growth, more companies will jump in.
- *Interviewer: the literature mentioned the use of ultra-capacitors. What's your opinion on that?* Current hybrid batteries do not seem to be power limited and the battery + ultra-capacitor is far more expensive. I think it is a solution looking for a problem where none exists.

Maintenance

11. The estimations of costs for maintenance vary considerably. What do you think could be an explanation for these differences?
- The costs of EVs may be lower if you own the car for a long time. But in the initial years of ownership, ICEVs have become very reliable now, so there's no much maintenance for ICEVs in the first 4-5 years. Once the cars becomes older, it is an advantage for EVs in terms of maintenance costs.

Demand

12. What is your expectation on the estimated demand over time? What are important factors resulting in a higher/lower demand?
 13. Do you expect the EVs to remain a niche until 2025, and why?
- It don't see it happening EVs will be competing with ICEVs in the next 15 years if there's no battery breakthrough. But a breakthrough is not impossible until 2030. But I don't dare to give you a percentage of the likelihood.

Depreciation

14. In other cost studies the resale value is often not included or set to zero on purpose. This implies the resale value is vary uncertain, but at least not worth more than an ICEV. Do you agree and what would be the reasons for this uncertainty?
 15. Is it reasonable to think this pattern will change in the future? Why? And from which point in time?
- Depreciation is caused by the battery uncertainty. Once people are more confident about the battery and maybe EVs in general, the resale value will be similar to ICEVs.

- End -

Interview 12. Robert van den Hoed

Algemene informatie

Naam : Robert van den Hoed
Organisatie : Hogeschool van Amsterdam
Functie : Lector/Professor Energy and Innovation
Datum interview : Maandag 6 juni 2016
Tijd : 14.00 – 15.00 uur (telefonisch)

Algemene vragen

1. Wat is uw functie en hoe verhoudt zich dat tot EVs?
 - Ik ben Lector Energie en Innovatie aan de HvA. Hiervoor heb ik bij Ecofys gewerkt. Met name de infrastructuur kant pak ik op bij de HvA. We doen ook veel data-analyses naar de laadsystemen voor het maken van monitoringtools en voorspellingen.
2. Is het model begrijpelijk? *Om te verifiëren of de geïnterviewde het heeft begrepen.*
 - De geïnterviewde geeft aan dat het model begrijpelijk is en vindt het model logisch.
3. Zijn er nog factoren (blokjes) die niet op de goede plek staan, missen of juist verwijderd moeten worden?
4. Zijn er nog relaties (pijltjes) die niet op de goede plek staan, missen of juist verwijderd moeten worden?

Uitleg eenvoudige model. De geïnterviewde heeft de volgende opmerkingen:

- Kijk goed hoe je laadinfrastructuur wel/niet meeneemt in je TCO model, aangezien niet alle kosten direct bij de consument komen maar uiteindelijk misschien wel.
5. Wat zijn de TOP-3 factoren die volgens het meest belangrijk zijn voor een verdere introductie van EVs in de maatschappij?
 - Productiekosten springen het meest in het oog i.v.m. de batterijprijs. Schaaieconomie is belangrijk maar dat loopt nog niet echt hard.
 - De range zal omhoog moeten om het product aantrekkelijker te maken.
 - De laadinfrastructuur is een beperkte factor, zeker de onzekerheid over hoe dit systeem eruit ziet over 15 jaar. Daardoor durven veel minder mensen te investeren.
 - Fiscale voordelen is echt belangrijk geweest voor het introduceren van EVs.

Specifieke vragen

Demand

6. Wat is uw verwachting van de te verwachte vraag wereldwijd? Wat zijn de belangrijkste factoren waarvan deze vraag afhangt?
7. Verwacht u dat EVs een niche blijven tot 2025, en waarom?

8. Verwacht u dat ICEVs nog steeds geproduceerd worden in 2030, en waarom?

- Ik denk dat het geen niche meer is in 2025. In Noorwegen gaat het nu al heel hard. De nieuwe Tesla is ook een belangrijke. Zij hebben zo'n belangrijke rol om credibility te geven aan EVs. Tesla heeft deze hele markt op z'n kop gezet.
- Tesla heeft zo'n belangrijke rol. Elektrische auto's waren vroeger gewoon invalide autootjes 20 jaar geleden. Het sex appeal is zo duidelijk door hun omhoog gegaan. Nu komen er ook concurrenten, Google en Apple. Dan wordt het echt credible. Dan is het geen niche-markt meer, maar een serieus marktsegment.
- Tot 3-5 jaar geleden kon me nauwelijks voorstellen dat 1 op de 10 auto's elektrisch zou worden. Dat is nu gewoon gelukt in sommige landen. Meer dan 50% van de nieuwverkopen in 2025 in veel landen in Europa zou gewoon mogelijk moeten zijn.
- Uiteindelijk denk ik dat de EV ook qua kosten wel concurrerend is met de ICEV. Maar ik kan me niet voorstellen dat het veel goedkoper wordt: een verbrandingsmotor is zo ongelofelijk goedkoop. Maar het zal wel in dezelfde prijsrange komen.

Charging

9. Wat zijn volgens u de grootste onzekerheden op het gebied van charging?

10. Hoe heeft dat invloed op de kosten?

11. Hoe ziet u het thuisladen en publiek laden in de toekomst voor zich? Zal die verhouding gaan veranderen? En verhouding 'normaal laden' en 'snel laden'?

- Momenteel lijkt het me logisch dat de meeste mensen met een EV toch thuis kunnen laden (ofwel home charger ofwel een publiek punt).
- Als je Tesla vraagt waar mensen gaan laden, dan zeggen ze dat dat thuis gaat gebeuren. In de US hebben ook veel meer mensen een eigen oprit. De verhouding privaat/publiek wisselt dus per land.
- Het idee dat we meer gaan snelladen lijkt me logisch. De eerste 4000 palen in Amsterdam dat kan allemaal nog wel. Maar doorgroeien naar 10.000-20.000 palen wordt veel lastiger.
- *Interviewer: sommige geïnterviewde denken dat we naar een smart grid met overnight charging gaan terwijl andere aan fastcharging denken.* Thuisladen zal altijd blijven. Maar inderdaad, ik zie het niet gebeuren dat we naar zoveel laadpalen gaan. De capaciteit van de paal zelf is goed, maar de investeringen zijn enorm. Dus dat pleit eigenlijk voor meer snelladers, maar wel complementair aan elkaar. Dus laadpleinen, fast charging stations. Maar we gaan ook niet allemaal snelladen. Dus het wordt niet dominant.

12. Wat verwacht u van de kostenontwikkeling van thuisladen? Zowel qua omvang als qua timing.

- Ja dat klopt wel. Op basis van andere studies hoorde ik dat het wel onder 1000 euro kan. Andere zeggen juist dat de rek er nu al uit is. Maar ik denk dat er nog wel wat schaal en leereffecten toepasbaar zijn.
- Voor nieuwbouw huizen zijn hier ook kansen. Als je nu al de goede kabels heb liggen, dan hoef je niet meer te graven zoals het soms nu het geval is en dat drukt de kosten.

13. Wat verwacht u van de kostenontwikkeling van publiekladen? Zowel qua omvang als qua timing.

- Reducties zijn nog wel mogelijk in de voorbereidingen. Bij het installeren van een laadpaal komen verschillen partijen in beeld: gemeente, energiemaatschappij, aannemer, etc. Dat is nu nog wat nieuw, maar kan allemaal nog wel efficiënter. Zie ook publicatie van Hoekstra.
- De kosten hiervoor komen we wel bekend voor, ziet er goed uit. Maar zoek dat op in de literatuur.
- 70% van de mensen heeft geen oprit en is dus afhankelijk van een publieke laadpaal. Nu wordt bijvoorbeeld in Amsterdam alles nog gefinancierd, maar ik kan me voorstellen dat je in de toekomst gewoon mee moet betalen.

14. Kunt u iets vertellen over gridkosten en de piekbelasting voor netbeheerders?

- De gridkosten zijn nog een belangrijke. $3 \times 25A = 400$ euro per jaar. $3 \times 35A = 1100$ euro jaar. Dan heb je alleen nog maar de aansluiting. Het verlagen van deze prijs is enorm belangrijk. In Amsterdam hebben ze besloten om de aansluiting van de meeste laadpunten terug te schroeven naar $3 \times 25A$ (laadpunten daar gelaten die veel Tesla rijders hebben; veel in Nieuw West wegens de Tesla taxi's die daar veel laden), omdat je nog steeds 99% van de gebruikers van voldoende stroom kan voorzien met die lagere aansluiting. Misschien is een flexibele aansluiting wel een beter idee. Zie publicatie van PWC / Auke Hoekstra. Momenteel maakt de gemeente deze kosten.
- In onze database hebben we meer dan 17k unieke gebruikers (die regelmatig bij een publiek laadpunt laden), dus dat is in ieder geval 15% als je uitgaat van 100k EVs.
- Inductieladen kan handig zijn, maar ik zie wel problemen. Grote kosten nu nog, lastig communiceren met auto OEMs. Er zijn standardisatieproblemen. Dan moet er nog wel heel veel gebeuren.
- Het nadeel is de piekbelasting. Smart charging biedt daarvoor een oplossing denk ik. Daar verwacht ik wel veel van.
- Snelladen: piekbelasting hoeft geen groot probleem te worden. Misschien komen er wel bufferbatterijen bij zulke plekken.

15. Wat verwacht u aan kostenontwikkeling voor de consument wat betreft publiek laden?

- Ik verwacht dat publieke laadkosten EUR/kWh omhoog gaan voor gebruikers. Je betaalt nu al per paal verschillende kosten. Je hebt eigenlijk als gebruiker geen idee wat je gaat betalen. Per pas verschilt het ook nog eens. Sommige provider hebben een starttarief ingevoerd, omdat ze gewoon niet uitkomen. Een andere provider rekent een uurtarief. Dat is heel logisch als straks de bezettingsgraad omhoog moet. In die tarieven gaat er dus wel veel veranderen denk ik. De start- en uurtarieven worden meer ingevoerd en de gridkosten worden verdisconteerd in de tarieven.
- De rol van de nationale overheid is ook belangrijk. Denk bijvoorbeeld aan de bijtelling, daarvoor is het zo'n enorm succes geworden in aantallen EVs. Het terugdringen van die energiebelastingen is een belangrijke voor het aanjagen van EVs.

- Einde -

Interview 13. Marco van Eenennaam

Algemene informatie

Naam : Marco van Eenennaam
Organisatie : ANWB
Functie : Adviseur Public Affairs
Datum interview : Maandag 6 juni 2016
Tijd : 15.00 – 15.30 uur (telefonisch)

Algemene vragen

1. Wat is uw functie en hoe verhoudt zich dat tot EVs?
 - Ik werk bij de afdeling Belangenbehartiging aan de Verenigingskant van de ANWB. Ik houd me bezig met de development van EVs namens de ANWB. De kennis op gebied van TCO zit met name op gebied van de consument, op individueel niveau.
2. Is het model begrijpelijk?
 - De geïnterviewde geeft aan dat het model begrijpelijk is. *(Alleen de eenvoudige versie is uitgelegd i.v.m. de focus op de HOE-vraag en de tijd)* en vindt het model logisch, hoewel het alleen in grote lijnen uitgelegd is.
3. Zijn er nog factoren (blokjes) die niet op de goede plek staan, maar missen of juist verwijderd moeten worden?
4. Zijn er nog relaties (pijltes) die niet op de goede plek staan, maar missen of juist verwijderd moeten worden?
 - Geen opmerkingen.
5. Wat zijn de TOP-3 factoren die volgens het meest belangrijk zijn voor een verdere introductie van EVs in de maatschappij?
 - In de aanschaf verwachten wij dat de EV nog wel duurder zal zijn (tot over 5 jaar). Terugkerende kosten zijn aanzienlijk lager. Hoewel de prijzen van laden in de publieke ruimte ook steeds hoger zijn geworden de afgelopen jaren. Wij informeren de consument dus op de TCO voor 4 jaar gebruik en dan denken we dat het ongeveer 4000-5000 euro duurder uit komt met 15k per jaar. Een breakeven ligt ongeveer op 7-8 jaar volgens onze schattingen.
 - De batterijprijs moet naar beneden voor de aanschafprijs
 - Het gemak: zoeken naar paal, met een stekker rondlopen, het imago
 - Maar: gaat die auto op TCO niveau financieel interessant worden, dan gaan veel meer mensen over 'die ellende' heen kunnen stappen. Dan gaan de bezwaren dus minder spelen.
 - Interviewer: is dat ongemak weg te nemen? Deels zal dat blijven: je blijft een actieradius hebben die niet in 2-3 minuten is op te laden. Tegelijkertijd zie je concepten ontstaan die zorgen weg kunnen nemen. Wij zijn groot voorstander van een mobiliteitsabonnement: een contract waarin je een EV hebt, maar ook 40% kosten op treinreizen in de daluren, een vervangende ICEV als je toch op vakantie gaat, een zonnepanelen of een aandeel in de windmolen. Zo haal je die pijnpunten weg.
 - Desondanks zal men een premium betalen.

6. Binnen welk auto segment ziet u het meeste kans voor EVs om zich te ontwikkelen, en waarom?
 - Ik verwacht dat het vanuit het hogere segment begint, zoals je nu ziet. Of die auto naar 80k of 82k kost dat maakt niet zoveel uit. We verwachten vervolgens voor de komende jaren vooral in het B/C-segment de BEVs. Omdat die markt het grootst is en omdat we denken dat de EV het als gezinsauto erg goed kan doen. Tesla Model 3, ZOE, LEAF, VW e-Golf, BMW i3.
 - *Interviewer: En het beeld van een dedicated kleine EV als tweede auto?* Ja, kan, maar dan is het meer een niche product. Het kan zeker een tweede auto zijn, maar er wordt nu weinig ontwikkelt in het A-segment. Het verschil in prijs tussen een Up! en een e-UP! is nog zo groot, dat is niet concurrerend. Als 2^e auto zie je vaak een kleine tweedehands. Daar kan een dure EV momenteel nog bij lange na niet concurreren. Dus qua gebruiksmogelijkheden een ideale 2^e auto maar qua prijs nog niet.
7. Welk type EV (BEV/PHEV/EREV) heeft het meeste kans voor ontwikkelen volgens u, en waarom? En op welke termijn?
 - Wereldwijd denk ik dat BEV en PHEV/EREV naast elkaar blijft bestaan, wellicht voor de PHEV/EREV met een brandstofcel. In NL gaat PHEV de komende jaren in aantallen naar beneden in verband met fiscale voordelen. Dus hier zal het moeten komen van de BEV.

Specifieke vragen

Demand

8. Verwacht u dat EVs een niche blijven tot 2025, en waarom? (*doorvragen indien nee*)
 - Ik denk dat het geen niche meer is. Aan de ene kant zijn er hele hoge ambities en aan de andere kant de technisch-economische realiteit. In 2025 alle nieuwverkopen een EV lijkt me niet realistisch. 2035 zou dat wel zo kunnen zijn (zie afspraken SER energie-akkoord)

Depreciation

9. In de literatuur wordt de restwaarde vaak op nul gezet. Dit impliceert dat de restwaarde of heel onduidelijk is, maar in ieder geval niet meer waard is dan een ICEV. Bent u het daarmee eens en wat zouden redenen kunnen zijn?
10. Zou het aannemelijk zijn dat het restwaarde patroon veranderd in de toekomst? Waarom? En vanaf wanneer dan?
11. Wat zou een verklaring kunnen zijn dat sommige merken hun waarde wel behouden en andere niet?
 - Door de fiscale bijtellingen zijn de grafieken moeilijk te maken. Daarnaast door automatische updates (neem de Tesla), wordt die auto feitelijk 'beter' door de updates. De vraag is of de huidige tabellen dan nog realistisch zijn.
 - De grote afschrijving komt met name door de onzekerheid over de batterij en de verwachte verbeterde modellen de komende jaren
 - Voor de toekomst verwacht ik dat de EVs wel iets waardevaster worden. Dat heeft voornamelijk te maken met de garantie dat die batterij betrouwbaar is of dat er een goede tweedehands markt voor EVs is. Als die batterij dan nog 4000-5000 euro waard is, dan zal de afschrijving daar stoppen.

- Tot nu toe lijkt de afwaardering van de batterij mee te vallen, maar dat is alleen wat ik hoor. Bij de Tesla valt het erg mee, hetzelfde geldt eigenlijk voor de Prius. Er zijn gewoon prima Prius auto's die prima functioneren met 5 ton op de teller. Als je dan weer kijkt naar de garanties van de fabrikant dan ga je weer twijfelen. Zij lijken dus ook niet zeker van hun zaak.

Maintenance

12. *Plaatje onderhoudskosten laten zien.* De kostenschattingen van onderhoud lopen erg uiteen. Wat zou een verklaring kunnen zijn?
13. Welke trend verwacht u wat betreft de kostenontwikkelingen voor onderhoud van EVs ten opzichte van ICEVs? Waarom zijn deze kosten hoger/lager dan bij ICEVs? Hoeveel dan? En nu al, of is dat iets dat in de toekomst zo gaat zijn (en wanneer dan)?
 - Wij gaan uit van 40% onderhoudskosten voor een BEV t.o.v. een ICEV, en voor een PHEV gaan we uit van 70%. Zo wordt het ook in het document "maak elektrisch rijden groot" n.a.v. de motie Groot in het parlement gehanteerd.
 - Wel zie je ook weer nieuwe onderhoudszaken erbij komen. Bijvoorbeeld een doormeting van de accu waardoor je als klant inzicht krijgt in de huidige batterijprestaties.
 - Ik denk dat de 40% / 70% zo blijft de komende 5 jaar.
 - *Interviewer: in een ander interview werd aangegeven dat het voor de eerste 4 jaar niet zoveel uitmaakt tussen een EV of ICEV.* Ja, feitelijk is dat natuurlijk wel zo. Maar normaal rijd je een auto natuurlijk voor meer dan vier jaar.

- Einde -

Interview 14. Winstone Jordaan

General information

Name : Winstone Jordaan
Organisation : GridCars, South Africa
Position : Director
Date : Thursday June 16, 2016
Time : 14.30 – 15.00 PM (UTC+2, conference call)

General Questions

1. What's your position and how is it related to EVs?
 - I'm the owner of a company called GridCars and we develop small commuter cars. We develop our first car, which will take another year. We work with Nissan for charging infrastructure in South Africa as well. We develop EV charging systems ourselves.
2. Which TOP3 factors in your opinion hamper the introduction of EVs?
 - In South Africa the biggest problem is the taxes: about double the taxes of a normal car. A 30k euro car will cost an additional 28k of taxes. The same applies for the battery. We've been fighting about it with the government, so hopefully it will change in the future.
 - EV haven't scaled up enough yet. The price will go down as demand grows. This applies to the battery and electronic motors and power controllers.

Specific questions

Vehicle technology

3. The literature expects ICEV technology will become more efficient over time. Do you think EV will become more efficient as well?
4. How can the production costs be lowered in the future?
 - The automotive industry has been standardizing over the years to increase efficiency and lower production costs, so there's less room to reduce costs for the chassis. Take e.g. the LEAF, the chassis is comparable to a normal ICEV. Just a new model.

Battery technology

5. The literature expects battery costs to decline as well. Do you agree?
6. How will this cost reduction be achieved?
7. How do you think the cost development of batteries will develop? Is that in line with the graph?
 - The figures you presented look familiar to me, I think that's where we're heading. But that is on the cell level. But the incremental costs for the pack can be lowered as well. A pack price is 1,5 to 2,0 times the cell costs.
 - The proportion of the battery costs about half of the total production costs. The other electrification part (motor, controller) is about 20-25%. And the rest of the vehicle is about 25% as well.

- I expect a 30-35% reduction of EV costs over the next 15 years. But, you won't see that directly in the retail price since they'll put more batteries in. Over the next 15 year you'll see the battery about triple in range. Note: the 30% reduction might be different in Europe because of the South African tax system.
- There'll be new innovations in the battery chemistry. A battery with a range of 1000 km within 15 years is not impossible.
- About battery degradation: some unofficial information tell us the degradation is slightly more than expected. However, I'm not in the position to tell, since it's not my expertise.

Maintenance

8. The estimations of costs for maintenance vary considerably. What do you think could be an explanation for these differences?
 9. What do you think will happen regarding maintenance costs compared to ICEV now and in the future? Why are these costs lower/higher than ICEVs? Why will it (not) be different in the future?
- I think maintenance costs will be eventually settling at 20-30% of the ICEV. Currently because of the technological uncertainty they double check the car. Also by monitoring the car live the maintenance costs can be reduced.

Charging

10. How will charging at home and in public relate to each other in the future? Will the proportion between these change over the course of time? And the proportion 'slow public charging' and 'fast charging'?
 11. What do you expect about the cost development of home charging?
 12. In case battery becomes much cheaper in the future, will that have a positive or negative effect on public charging? And why?
 13. What do you expect about the cost development of slow public charging?
 14. What do you expect about the cost development of fast charging?
- There are about 70 charging points (public) in SA, of which we installed half.
 - I think there'll be a mix between fast and slow charging. People will charge at home, work, shopping malls. But there's a market for fast charging as well.
 - My concerns with fast charging is the thickness of the cables as power output increases. That's the bottleneck of the process. The battery is not the bottleneck, but whether you can get the amps to fast charge.
 - There are some losses during charging. I'll send you some more information about it via email.
 - We sell a home charging unit for about 9000 ZAR (537 EUR³⁶).
 - The simple units for 18.000 ZAR (1073 EUR) and the most advanced for 38.000 ZAR (2266 EUR). That's excluding the installation price, which is about 5000 ZAR (298 EUR) in South Africa.

³⁶ Exchange rate of June 20, 2016: EUR/ZAR 16,775

- Yes, we are developing a fast charging system as well. The cost development of fast charging is about 400.000 ZAR (23.848 EUR) and 600.000 ZAR (35.773 EUR). We focus on 380.000 ZAR (22.656 EUR).

Depreciation

15. In other cost studies the resale value is often not included or set to zero on purpose. This implies the resale value is vary uncertain, but at least not worth more than an ICEV. Do you agree and what would be the reasons for this uncertainty?
 16. Is it reasonable to think this pattern will change in the future? Why? And from which point in time?
- I don't think we have enough EVs in the second hand market in South Africa. I would think the depreciation is higher right now, because they don't have confidence. It's a trust issue. Producers should guarantee the battery.
 - In the future I expect the depreciation to be less. The car itself experience less stress, so the technical state of the car is better compared to an ICEV.

- End -

Interview 15. Zoey Planjer

Algemene informatie

Naam : Zoey Planjer
Organisatie : Achmea
Functie : Productmanager Mobiliteit
Datum interview : Dinsdag 21 juni 2016
Tijd : 17.10 – 17.30 uur

1. Hoe wordt jullie premie voor EVs bepaald?
 - De premie is niet alleen afhankelijk van de cataloguswaarde, maar ook bijvoorbeeld van het gewicht van de auto, vermogen van een auto en de kenmerken van de klant. Het gewicht is belangrijk omdat het de impact van de (letsel)schade kan bepalen. Over het algemeen zijn zwaardere auto's onderhevig aan een hogere premie, maar dat hoeft niet altijd het geval te zijn.
 - Aangezien de cataloguswaarde van een EV doorgaans hoger is, in combinatie met een hoger gewicht door de batterij, is de premie van een EV dus over het algemeen ook hoger.
2. Nemen jullie EVs op een andere manier mee omdat het nog een onzekere markt is bijvoorbeeld?
 - Nee, EVs zijn nog een aparte categorie. Dat is ook omdat er maar een heel klein deel EV is en we hebben dus weinig data om daar iets over te zeggen. We hanteren dus dezelfde spelregels als een ICEV. Tesla's zijn hier wel de uitzondering. Hier hebben we in korte tijd geleerd dat de schadelast gemiddeld gezien erg hoog kan uitvallen.
3. Hoe zit dat dan met een Tesla?
 - De schadelasten van een Tesla zijn over het algemeen hoger. Dat komt omdat men grotere schades alleen bij de Tesla dealer kan repareren. Daarnaast zijn de kosten ook hoger omdat de batterij vaak beschadigt is, hetgeen het duurste onderdeel is van die auto. Je kunt die auto dan bijna afschrijven. Hier zijn wel positieve ontwikkelingen in gaande: reparatie van Tesla's wordt steeds goedkoper en ligt niet alleen meer bij de Tesla Shops.
4. Hoe zie je toekomst voor je wat betreft deze spelregels voor de komende 15 jaar?
 - Dat ligt natuurlijk ook aan hoe de auto's zich ontwikkelen. Ik denk zelf dat het samenhangt met zelfrijdende auto's. Ik denk dat puur het elektrische gedeelte niet veel zal veranderen vanuit de verzekeringskant. De verzekeringswaarde zit niet per definitie in een verbrandingsmotor, maar eerder in de opties. Dat is bij elektrische auto's niet anders.

Interview 16. Harold Breet

Algemene informatie

Naam : Harold Breet
Organisatie : Meeus
Functie : N/A
Datum interview : N/A: per e-mail
Tijd : N/A: per e-mail

The statement of the interviewee is presented below.

Van: Breet, HP (Harold)
Verzonden: woensdag 8 juni 2016 12:59
Onderwerp: RE: TU Delft vraag verzekering EVs - follow up

Paul-Jan,

Een interessante case waar deze student (?) mee bezig is. Mogelijk komen hier resultaten uit die ook voor ons interessant zijn (en gedeeld worden?).
Algemene informatie (wellicht al bekend) is terug te vinden op: <http://www.rvo.nl/onderwerpen/duurzaam-ondernemen/energie-en-milieu-innovaties/elektrisch-rijden/stand-van-zaken/cijfers>

V.w.b. onze verzekeringen zit er geen verschil in tarifiering elektrische-, hybride, of voertuigen op de reguliere brandstoffen.
Wij hebben geen premiefactor o.b.v. brandstof, maar o.b.v. het jaarkilometrage, het (leeg)gewicht van de auto en de cataloguswaarde (indien volledig casco).
Er zijn verzekeraars die de brandstof wél als premiefactor gebruiken, maar dan ligt hybride en elektrisch m.i. op het niveau benzine en niet op de (hogere) factor diesel of gas.

Verder zijn er verzekeraars die zeggen een specifiek product voor elektrische auto's te hebben (bijv. Allianz), maar in de praktijk betekent dit een aanvulling op de reguliere voorwaarden d.m.v. clausules.
(voor Tesla's) Hierin wordt bijv. secundaire dekking verleend voor de laadpaal en wordt ook dekking geboden voor pechhulp als de accu onderweg is leeggemaakt. Zie bijgevoegde clausules.
Ook Centraal Beheer en Delta Lloyd zeggen een apart product te hebben voor specifiek Tesla's, maar volgens mij richt zich dat meer op een aparte (vaste en lagere) premie.
Of dit nog steeds zo is, weet ik niet, gezien ook het volgende bericht: <http://www.smartdriving.nl/centraal-beheer-dumpt-tesla-rijders-met-premiestijging/>

Wél weet ik van verzekeraar Reaal dat zij juist geen Tesla's meer accepteren. Dit vanwege het feit dat reparatie alleen bij Tesla en niet bij universele reparatiebedrijven kan plaatsvinden, de reparatiekosten relatief hoog zijn (import onderdelen uit Amerika) en zij ook geen goede inzage krijgen in de juistheid van het reparatiebedrag. Dit heeft dus niet alleen te maken met de elektrische aandrijving.

Verder is er een bijzonderheid bij bijv. het merk Renault, waar het accupack géén eigendom wordt van de koper, maar geleased moet worden. De consumentenprijs lijkt dus een stuk lager en wordt ook tegen die lagere waarde (casco) verzekerd, maar dan valt de accu ook niet binnen de dekking. Renault staat garant voor de accu, maar ik vraag me af of dat ook i.g.v. schade door een van buiten komend onheil (bijv. aanrijding of diefstal hele voertuig) is en niet uitsluitend is beperkt tot "eigen gebrek". Dat heb ik nog niet uitgezocht. Zie: <https://www.renault.nl/showroom/elektrische-auto/zoe/zoe/ze-batterij/>

Resumerend:

- Bij ons zit er geen premieverschil in auto's met verschillende brandstoffen, maar met dezelfde cataloguswaarde/consumentenprijs.
- Als het accupack in de consumentenprijs is opgenomen (en eigendom van koper), is deze in het verzekerde bedrag opgenomen.
- Er zijn verzekeraars die een voordeliger tarief aanbieden voor Tesla's, maar ik weet niet of dat ook voor andere modellen zoals bijv. Opel Ampera van toepassing is.

Persoonlijk denk ik niet dat de (overgang naar) elektrisch aangedreven auto's een significant verschil in premietarifiering gaat veroorzaken, maar dat de ontwikkeling van autonoom rijden en gedeeld autogebruik daar een grotere invloed op zullen hebben.

Wat mij betreft mag je dit bericht integraal doorsturen, maar dat laat ik aan jou over.

Met hartelijke groet,
Harold Breet

Interview 17. Sander Ouwerkerk

Algemene informatie

Naam : Sander Ouwerkerk
Organisatie : The New Motion
Functie : Director Business Development
Datum interview : N/A: per e-mail
Tijd : N/A: per e-mail

Specifieke vragen

Charging

1. Wat zijn volgens u de grootste onzekerheden op het gebied van charging?
 - overheidsregulering en bemoeienis m.b.t.
 - A. belastingen (grootverbruikerstarief, energiebelasting)
 - B. verplichtingen (al dan niet een centrale data hub, verplichtingen t.a.v. functionaliteiten)
 - C. maximeren en bepalen van tarifiering
 - M.a.w., wij vinden de overheid nogal bemoeierig, en niet altijd ten goede. In plaats van randvoorwaarden te scheppen gaat ze invullen. In onze ogen gaat het om randvoorwaarden (level playing field) waarbinnen ondernemers de invulling doen.
 - Met name de onzekerheden in fiscaliteit remmen de groei. Stroom kost maar 5 cent, of minder, maar de overheid doet er thuis 16 cent belasting op, maar bij een bedrijf maar 6 cent. Dat geeft hele vreemde gevolgen dat thuis laden duur is en zakelijk laden goedkoop.
 - De regelgeving is er niet klaar voor dat iedereen aan iedereen stroom moet kunnen verkopen, en dat is noodzakelijk voor de doorbraak van EVs.
2. Hoe heeft dat invloed op de kosten?
 - Met name op de opbrengsten - die staan daardoor onder druk.
3. Hoe ziet u het thuisladen en publiek laden in de toekomst voor zich? Zal die verhouding gaan veranderen? En verhouding 'normaal laden' en 'snel laden'?
 - Beiden hebben een grote toekomst. Thuisladen doe je als je kan, dat is ideaal en zal iedereen met een oprit doen. Publiek laden is eigenlijk ook thuis laden, voor mensen zonder oprit.
 - Normaal laden zal steeds sneller gaan, 11kw in thuissituatie is geen probleem en voldoende, en is ook voor publiek laden prima.
 - Wij geloven niet in snelladen anders dan dat je dan voor minder dan 5% van je laadbehoefte doet. Namelijk als je op vakantie gaat, en die hele enkele keer dat je je dag niet goed gepland hebt. Wat nu snelladen heet, 50kw, is eigenlijk traag en doet niemand. Snelladen wordt pas zinvol vanaf 150KW. Tesla is met 120KW min of meer ok.
4. In de bijlage vindt u een plaatje van de aanschaf en installatiekosten van een publieke laadpaal. Komt dat ongeveer overeen met wat jullie verwachten? Zo nee, wat verwacht u van de kostenontwikkeling van publiekladen?
 - Ik kan er niet veel over zeggen i.v.m. bedrijfsgevoeligheid, maar iemand die vandaag de dag EUR 4000 voor een publieke laadpaal betaalt, betaalt heel erg veel teveel. Maar wij lopen ver

voorop de competitie daarin. Met name ook de efficiëntie in installatie is een belangrijk punt daarin. Omdat dit zo competitief gevoelig is, kan ik helaas niet concreter zijn. Maar wel dat we jouw kostencurve al minstens gehalveerd hebben, vandaag.

5. Momenteel bestaan er verschillende soorten abonnementen voor publiek laden. Kunt u iets vertellen over de kosten voor de consument in de toekomst: nemen die toe/af? Waarom?
 - Wij denken dat die rond de 25-35ct blijven omdat anders de business case van een laadpaal niet draait. En wederom, omdat de belasting zo een grote component is, is de grootste onzekerheid de overheid.
 - Energie wordt spotgoedkoop op termijn. Zonne-energie wordt de dominante energiebron en steeds goedkoper, en dat zal in steeds sneller tempo gaan.
 - Wat wij verwachten op termijn is dat het veel meer gaat om de spotmarket prijzen, dus real-time vraag en aanbod van energie gaat de prijs van stroom bepalen, en daarop gaan mensen hun oplaadgedrag afstemmen. Duurt nog wel een paar jaar, maar dat is waar wij ook naar kijken voor de toekomst.
6. Er zijn andere partijen die verwachten dat er naast het standaard kWh-tarief ook een start tarief en een uurtarief ontstaan (sommige doen dit al). Hoe staat TheNewMotion hierin?
 - Zeker wij denken dat ook en doen dat ook. Let op: wij bepalen de prijzen niet, dan doen de partijen die de laadpaal in bezig hebben (gemeentes, bedrijven). Die bepalen zelf wat voor tarief ze willen per starttik/uurtarief/kwh, en wij publiceren die prijzen in onze app. Wij rekenen die 1-op-1 door aan eindklanten.
7. Ik begreep dat er verliezen ontstaan bij het laden van een EV, tot ongeveer 12% tussen waarvoor men 'betaalt' en de daadwerkelijke energie in de accu (door bijv. kabelverliezen). Komt dat overeen met jullie beeld?
 - Die vraag zou je aan OEMs moeten stellen. Ik herken dit getal overigens niet en komt mij als hoog over. Uiteraard is er omzettingsverlies (warmte), en dat merk je vooral als je met lege accu na hard rijden over de autobaan gaat snelladen, dan staan de ventilatoren van de tesla op volle toeren te blazen om te koelen.
 - Wat me wel bekend is, is dat het koelen van het opladen bij hogere vermogens (150-300kw) een ding is, en daar kan ik het getal 12% wel goed plaatsen. Wel een interessante vraag trouwens, ik hoor deze niet vaak. Bij normaal laden zouden de verliezen heel gering moeten zijn, omdat het laden in een relatief rustig tempo gaat met minder weerstand. Met meer vermogen laden is ook met meer weerstand, vandaar.

- Einde -