Eindhoven University of Technology

MASTER

Why wait?
timing the moment of entry into the e-mobility market

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Why Wait?

**Timing the moment of entry into the
e-mobility market**

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in partial fulfilment of the requirements for the degree of

**Master of Science
in Innovation Management**

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"...the Stone Age ended, not because we ran out of stones. It's ideas, it's innovation, it's technology that will end the Age of Oil before we run out of oil."

<div align="right">
Prof. Richard Sears, former Vice President of Shell
TED conference, April 2010
</div>

Preface & Acknowledgements

After an intensive period of analyzing, writing and researching, my master thesis report is a fact. This report is the final assignment for my master Innovation Management at the Eindhoven, University of Technology.

I would like to thank my first supervisor from the university, Prof. Dr. Nijssen, for his guidance and enthusiasm during this project. I also like to thank him for fulfilling the role of first supervisor after my initial supervisor left the university. Furthermore, I like to thank my second supervisor from the University, Bob Walrave, for his help and guidance during the modeling process which gave me new ideas about how to implement certain aspects in the model. I wish him the best of luck with the final stages of his dissertation.

From Ballast Nedam I would like to thank Ruud Kos for the discussions and help during this project and to encourage and keep faith in me even when things didn't always worked out like they should. I wish him the best of luck with his new company, Bough Bikes. I also would like to thank Erik Kemink for giving me the opportunity to do my master thesis project at Ballast Nedam and to support me when needed.

Last but not least I would like to show my gratitude to my parents, family and friends for their support and encouragements during my studies and thesis project.

Thomas Wijtvliet

January 2012

Management Summary

Introduction

At the moment the Battery Electric Vehicle (BEV) receives a lot of attention from governments, carmakers and infrastructure providers as it is a possible solution to reduce the pollution and high dependency on fossil fuels. The first BEVs are introduced onto the market and predictions about future sales are positive but vary substantially. As BEV drivers are depended on recharge infrastructure to recharge their batteries, the need for recharge stations creates opportunities for companies such as Ballast Nedam.

Research questions

There are, however, a lot of uncertainties about the future of e-mobility and management is therefore looking for ways to reduce this uncertainty. The challenge is to turn this market opportunity into a business opportunity for Ballast Nedam. One of the questions Ballast Nedam has is when to enter the e-mobility market; should they be a pioneer or a follower? This thesis analyzes what moment of entry strategy is most suitable for Ballast Nedam. The appropriate moment of entry into a market is a crucial strategic choice and is one of the main reasons for new product success or failure; it is a "critical decision, involving the need to balance the risk of premature entry (entry to early) with the problems of missed opportunities as a result of late entry" (Sinha and Noble, 2005). Therefore, the following research question has been investigated

> *"What is for Ballast Nedam, as a provider of recharge infrastructure, the most suitable moment of entry into the electric mobility market?"*

Whether a firm should enter a market as a pioneer or as a follower depends on first-mover-advantages (FMAs). FMAs stem from mechanisms and the effectiveness of these mechanisms in creating FMAs are moderated by the product-market characteristics (macro side) and the resources and capabilities of a firm (micro side). Hence, two sub-questions were proposed and further investigated:

RQ1:   *"How will the technological transition from fossil-fuel driven vehicles towards battery electric vehicles develop?"*

RQ2:   *"What are the strengths and weaknesses of the resources and capabilities of Ballast Nedam compared to other players in the market?"*

Research methodologies

To analyze and answer the first research question, a system dynamics model has been developed. The model incorporates findings from literature on transition dynamics, survey data of consumers' willingness to adopt a BEV and (technical) developments of the BEV platform. It includes the three central actors who are active in the transition; consumers, automotive and

infrastructure providers as well as the ability to include governmental policies. In the model, the BEV is compared with the Internal Combustion Engine (ICE) platform on four attributes; price, driving range, recharge infrastructure and recharge time. How important each attribute is perceived by drivers was determined by surveys conducted earlier by Ballast Nedam and Ecomobiel. To answer the second research question, a small survey was held under employees of Ballast Nedam who have knowledge of the e-mobility market and the players involved in this market to identify the resources and capabilities of Ballast Nedam and other players.

Results and recommendation

After the model was developed, the transition from ICE vehicles towards BEVs was simulated. From the base run, shown in Figure 0.1, it became clear that the transition towards BEVs is slow; in the year 2020, only about 140.000 BEVs are expected to be on the road, which is about 1.8% of the total number of passenger vehicles in the Netherlands. The reason for this low number is that first of all, attractiveness of the BEV (based on the four attributes) will not become more attractive than the ICE before the year 2025. Second, consumers need to become familiar with the BEV. The BEV might be a very good alternative and can compete with the ICE, for a potential adopter to consider the platform it requires more knowledge, experience and exposure about and to the BEV platform as the ICE platform is a more familiar and trusted technology than the BEV and thus, people are more inclined to repurchase an ICE again rather than to purchase a BEV; they need time to perceive the attractiveness of the BEV. Looking at the right graph, the attractiveness of the BEV (red line) exceeds the ICE in the year 2025. This is however not perceived by the driver population until 2037 (green line) which is caused by the slow gain in familiarity with the BEV under potential adopters (blue line) and therefore take-off in sales is likely to occur between 2025 and 2030, as can be seen in the left graph (green line).

In the bottom graph the implications on the infrastructure is shown. Before ~2027, the construction rate of recharge stations stays more or less constant with about 12.000 units per year. However, after 2027 a large increase in the construction rate (red line) can be seen with a maximum of about 95.000 stations a year (~430 stations/day). Based on these simulation results, FMAs are primarily present in the ability to preempt important space such as attractive locations but more importantly, the ability to create a large network of charging stations and by doing so create an important competitive advantage through network effects. However, when take-off occurs in BEVs and the construction rate of recharge stations growths significantly, it will be difficult to keep up with demand and other players are likely to enter the market and could reduce the FMAs build up by the pioneer relatively quick due to rapid growth in construction rate. Furthermore, the pioneer will face high risks, as utilization rates of the recharge stations will initially be low due to low amount of BEVs on the road and the possibility that the market won't take off. Also, followers can learn from the pioneer and consumer behavior can easily be observed reducing the learning costs of followers.

The result of the second research question indicated that Ballast Nedam scores ███████ ██ but does not score well on ███████████████████████████████ resources. Also, ████████ ██████████████████████████████████ is relatively low. For a pioneer to enter the e-mobility market, large financial resources and a large direct sales force (marketing resource) are important. Based on the firm resources and the simulation results, it is suggested that Ballast Nedam should be a follower instead of a pioneer and enter the e-mobility market not before 2020 as the risks of failure is very high. After 2020, take-off becomes more likely as the attractiveness of the BEV increases and people become more familiar with the BEV platform. It is therefore suggested that Ballast Nedam enters in the timeframe 2020-2025, just before take-off is expected to occur. Also, consumer behavior will be better understood concerning recharge needs reducing the risks of failure.
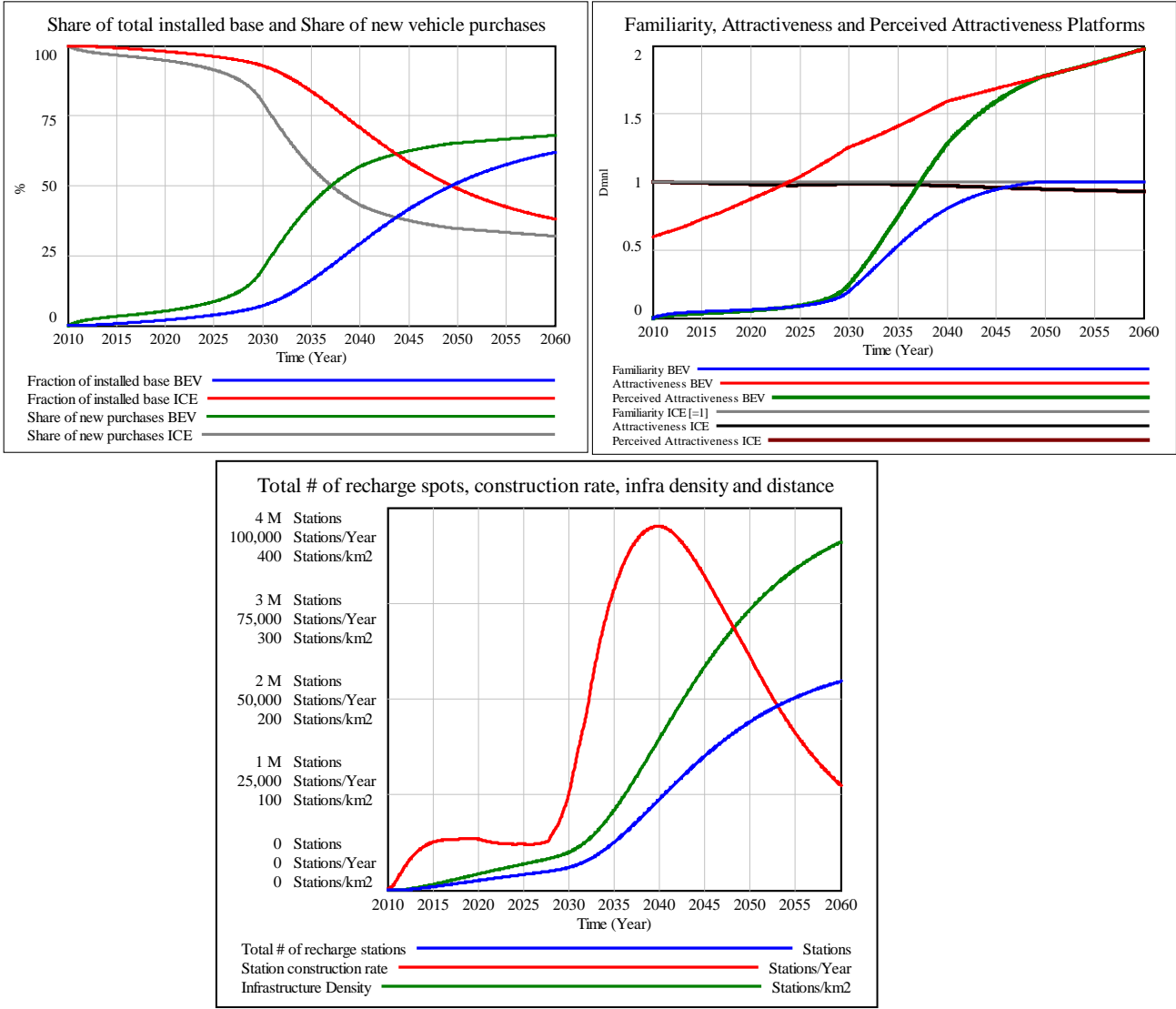

Figure 0.1 – Results base run

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List of Abbreviations

ATR	Attribute
BEV	Battery Electric Vehicle *(also called FEV)*
BN	Ballast Nedam
BPM	Tax for passenger cars and motorcycles *(Belasting Personenauto's en Motorrijwielen)*
CBS	Statistics Netherlands *(Centraal Bureau voor de Statistiek)*
CLD	Causal Loop Diagram
CNG	Compressed Natural Gas
CO_2	Carbon-di-Oxide
EEA	European Environment Agency
EPA	Environmental Protection Agency
FEV	Full Electric Vehicle *(also called BEV)*
FMA	First-Mover-Advantage
GHG	GreenHouse Gas
GM	General Motors
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
IEA	International Energy Agency
MLP	Multi-Level-Perspective
NGOs	Non-Governmental Organizations
NO_x	Nitrogen Oxides
PHEV	Plug-In Hybrid Electric Vehicle
PM	Particulate Matter
PPP	Public-Private-Partnerships
RDW	Government department for roadtraffic *((Rijks)Dienst voor het Wegverkeer)*
SD	System Dynamics
SFD	Stock-and-Flow Diagram
SHEV	Series Hybrid Electric Vehicle
SoC	State-of-Charge
ST-system	Socio-Technical system
TCO	Total Cost of Ownership
TT	Technological Transition
TtW	Tank-to-Wheel
VAT	Value Added Tax
VW	Volkswagen
WF	Weight Factor
WoM	Word of Mouth
WoT	Word of Town
WtW	Well-to-Wheel

1 Introduction

Since the beginning of the industrial revolution, the need for fossil fuels has increased dramatically and has been increasing ever since. According to the International Energy Agency (IEA), the global consumption of oil has increased from 2.500.000.000 tons per year in 1972 to 4.000.000.000 tons in 2008[1]. 60% of the global oil consumption is used to fulfill society's transportation needs and more than 90% of the transportation sector worldwide is powered by fossil fuels. The high consumption of fossil fuels in society and in transport is problematic; first of all, due to its impact on the climate and pollution[2]. Transport accounts for almost 30% of the global CO_2 emissions[3] and is a large contributor to other pollutants such as Nitrous Oxides (NO_x) and Particulate Matter (PM). Furthermore, oil reserves are shrinking, there is uncertainty about the security of oil supplies and fuel prices are rising (van Vliet *et al.*, 2011).

To reduce this high dependency on fossil fuel and its negative side effects, stakeholders such as governments, carmakers, infrastructure providers and research institutes are exploring the possibilities to change from conventional fossil fuel driven vehicles towards alternative fuel driven vehicles such as fuel-cell vehicles and Battery Electric Vehicles (BEVs). Especially the BEV receives a lot of interest at the moment as it is in a stage that it is far enough developed to be introduced onto the market. Several pilot projects are carried out at the moment concerning the BEV to gain experience in the field (Narich *et al.*, 2011) and some vehicle manufacturers such as Nissan and Renault have introduced a BEV on the market and more are expected to follow (Winckens, 2010) [4].

1.1 Challenges e-mobility

A successful transition towards e-mobility could create opportunities for companies, reduce the dependency on foreign fossil fuels and reduce GreenHouse Gas (GHG) and local emissions[5]. However, the transition towards BEVs is complex and difficult and many challenges need to be overcome before the BEV will become accepted. Drivers base their decision to purchase a certain vehicle platform on various attributes. The four most important attributes are (i) price, (ii) driving range, (iii) infrastructure density and (iv) recharge time (Gärling and Thøgersen, 2001)[6]. At the moment, the BEV scores relatively low on these four attributes compared to the ICE. Furthermore, whether a driver will consider a certain platform depends on how familiar

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[1] See also IEA

[2] Road transport is by far the most polluting form of passenger transport (see also eea.europa.eu)

[3] See also IEA

[4] Only the BEV is considered. See appendix C2 for a discussion of the different electric vehicle types.

[5] The advantages of the BEV compared to the fossil-fuel driven vehicles are discussed in appendix C4.

[6] Surveys held by Ballast Nedam and Ecomobiel also indicated that these four attributes are considered most important. For an overview of the survey results see appendix D1 & D2.

he or she is with that particular platform. If a driver has not enough knowledge about the platform, he or she will be reluctant to consider purchasing it and will rather repurchase the platform he or she is already familiar with, the ICE platform.

Whether the transition towards BEVs will become a success depends on what the value of these four attributes and customer familiarity is going to be in the future. The future price of the BEV depends for instance on the developments in battery technology. Also the government can play a role in the price of the BEV by giving subsidies. Battery developments also influence the future driving range of the BEV which again influences the need for infrastructure. A larger driving range will decrease the need for infrastructure for instance while an increase in recharge time will increase the need for infrastructure. The developments of the four attributes and consumer familiarity are interrelated. This proposes several challenges on for instance the technological, consumer and political level. The challenges will shortly be discussed in the next sections.

1.1.1 The chicken-and-egg problem

There is a so called chicken-egg problem between fuel providers, carmakers and consumers. It requires substantial infrastructure investments to enable the transition towards e-mobility. Infrastructure investments are, however, not only costly but also risky as it is uncertain the utilization-rate of the new infrastructure will be high enough to recover the costs made (Philip and Wiederer, 2010). In order to have a high utilization rate, large numbers of electric vehicles need to be available for the consumers. This in turn requires large investments of carmakers in R&D and capital goods to enable mass production. These investments are risky as well if the infrastructure that is required to use an electric car is not in place yet and customers are reluctant to purchase an electric vehicle. Furthermore, the automotive industry such as manufacturers of combustion engines and transmissions has invested heavily in the conventional platform and factories which make them reluctant to change.

Infrastructure and electric cars are complementary goods (Hellman and van den Hoed, 2007; Struben and Sterman, 2008; Meyer and Winebrake, 2009); goods that operate in a system and must be consumed together (Katz and Shapiro, 1994; Welch, 2006; Schilling, 2008). Other examples of complementary goods are for example DVD players and the DVDs or computer hardware and its complementary software. Without the sufficient penetration of both goods the purchase and use of complementary goods becomes highly inconvenient (Golder and Tellis, 1993; Meyer and Winebrake, 2009). This inconvenience introduces a new set of costs to the consumer known as "convenience costs". Charge stations must be conveniently located to reduce convenience costs associated with recharging. This mechanism prevents the transition to e-mobility; only when both investments are made, in infrastructure as well as in the vehicles, the risks of failure can be reduced and a transition possible.

1.1.2   Consumer behavior

Many consumers are reluctant to purchase an electric car due to so called "range anxiety". Although this relates mainly to battery technology and the driving range possible on one charge, it was found that infrastructure could help to reduce the fear of potential EV drivers (Watson, 2010). Also the consumer preference for long range, versatile vehicles in combination with the limitations of the electric vehicle in terms of range and recharge time form a problem as well as the high purchase price and consumers perceptions of safety with respect to fire and other hazards (Gott and De Vleesschauwer, 2010). It is important to know what the consumer requirements are and what trade-offs they may want to make. Also consumers need to be educated in order to better understand the functionality of electric cars and what its benefits are; they have to become more familiar with the electric car (Montaguti *et al.*, 2002; Struben and Sterman, 2008). This also imposes a chicken-and-egg problem; as long as customers are not familiar with the electric vehicle and are not certain concerning their knowledge about the electric vehicle, they will not consider buying one. However, when no electric vehicles are bought, the diffusion of information about the vehicle through word of mouth and driver experiences will stay low and in consequence the purchase rate of the electric vehicle. Thus familiarity of the consumer with the electric vehicle influences the transition speed and its outcome.

1.1.3   Technological challenges

One of the main barriers Farla et al. (2010) identified to sustainable transportation were barriers related to technological components and vehicles. For instance battery costs are still very high and there is uncertainty about the future developments of battery capacity which influence the driving range of the vehicle. At the moment the BEV has a relative short driving range compared to the ICE platform. Other uncertainties lie in battery lifetime and the amount of recharges possible during the lifetime of a battery (Gott and De Vleesschauwer, 2010). Also the uncertainty about the availability of car models in the future forms a barrier although more electric cars will be introduced in the market in 2012 (Winckens, 2010). The strength of these barriers will change over time and influences the speed and outcome of the transition; the higher the adoption rate, the lower the cost of the battery will be for instance.

Another uncertainty is which way of charging will become dominant; slow-, fast- or inductive charging, battery swap or a combination of these. Other technologies that need to be developed are for instance the development of back-office support functions to conduct the various commercial and operational transaction requirements to operate the e-mobility market (for instance the development of software to handle and settle roaming transactions between providers of charge stations) (Narich *et al.*, 2011). Although not a problem for the near future, the impact on the grid could also be a concern; the capacity has to be increased and intelligent grids ('smart grids') will be necessary (Electrification-Coalition, 2009; Rijkswaterstaat, 2010).

1.1.4   Political challenges

The transition towards BEV takes many years. In order to make the transition successful, political commitment, for instance through subsidies, is important as it can change for instance the speed of the transition (Watson, 2010). However, it is difficult to build and sustain national consensus on energy policy priorities, especially for longer periods of time. This introduces extra uncertainty about future market developments and could influence the transition speed and its outcome. As will be discussed later on, there is a relation with the transition and the moment of entry; therefore, changes in how the transition takes place will have impact on the moment of entry and vice versa. Other challenges that influence the speed of the transition are for instance the ease of getting permits and if markets are heavily regulated or not.

1.1.5   Standardization and interoperability challenges

In the Netherlands there is now a standard for public charging, namely the type 2 – mode 3 standard[7]. Also in Germany, Belgium, Ireland, the United Kingdom and the Scandinavian countries this standard is used[8]. However, other standards such as connectivity to electricity networks and cyber security as well as the security of communications to provide interoperability within and across markets to provide customers with security, ease and flexibility still need to be set (Narich *et al.*, 2011). Often different formats compete with each other for a period of time until one format becomes the dominant design and sets the standard. Examples are for instance the battles between VHS and Betamax and recently between Blu-ray and HD-DVD. Which technology will become the standard is hard to tell in the beginning but will become clearer after a certain amount of time which influences the decision on the moment of entry for a company. A company would like to know it supports the 'right' standard (Katz and Shapiro, 1994).

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[7] See appendix C3 for an overview of standards and recharge technologies.

[8] European standard (Dutch)

1.2 Problem Statement

1.2.1 Background

The predictions about future BEV sales are positive but vary substantial; the Dutch government for instance estimated 1.000.000 BEVs in 2020[9] (Berg *et al.*, 2009) while ING estimates about 140.000 BEVs in 2020 (ING-Economisch-Bureau, 2011) and BOVAG around 200.000 BEVs in 2020 (Tankpro and Aarts, 2011). The successful introduction of the BEV depends, among other things, on the availability of recharge stations. Several researchers indicate the importance of infrastructure for the successful diffusion of electric vehicles (Welch, 2006; van Bree *et al.*, 2010; Watson, 2010; Narich *et al.*, 2011).

The need for recharge stations creates opportunities for companies such as Ballast Nedam. One of the core activities of Ballast Nedam Concessions is mobility. At the moment Ballast Nedam Concessions is already active in the market of alternative fuel driven vehicles, namely through CNGnet. CNGnet is a network of Compressed Natural Gas (CNG) stations across the Netherlands where cars running on CNG can refuel. These stations are developed, constructed and managed by Ballast Nedam Concessions which is in line with the integral solutions they offer. Developing, constructing and managing a nationwide recharge network for BEVs could be an interesting opportunity for Ballast Nedam concessions[10]. There is however a lot of uncertainty about the future of e-mobility and management is therefore looking for ways to reduce this uncertainty.

1.2.2 Management dilemma

At the moment there is still a lot of uncertainty about the e-mobility market and if Ballast Nedam should enter this market in the near future or wait until uncertainty is resolved. The construction of the needed infrastructure requires large upfront investments while the risks are high. The future market size is uncertain and depends partly on the available infrastructure which imposes a "chicken and egg problem" as discussed in Paragraph 1.1.1.

The uncertainty about the e-mobility market complicates the decision for Ballast Nedam on when to enter the market; a management dilemma. Is it better to wait until the market uncertainty is reduced but run the risk to lose crucial time or enter early, take a head start on competitors and capture possible first-mover advantages?

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[9] The government recently lowered their expectations to 700.000 BEVs in 2025 (Inia, 2011)

[10] More information concerning the company Ballast Nedam can be found in Appendix A

> **Problem statement:**
>
> *"Ballast Nedam would like to have a better understanding of how the e-mobility market is going to develop and what the most appropriate moment of entry is for them as a provider of recharge infrastructure"*

1.3 Research Questions

From the problem statement it became clear that Ballast Nedam likes to better understand what the most suitable moment of entry is into the electric mobility market as an infrastructure provider. According to Sinha and Noble (2005), the moment of market entry is *"a critical decision, involving the need to balance the risk of premature entry (entry to early) with the problems of missed opportunities as a result of late entry"*. This thesis will focus on this moment of entry decision to determine what the most suitable moment of entry is for Ballast Nedam. Hence, the main research question that this thesis explores is as follow:

> Main research question:
>
> *"What is for Ballast Nedam, as a provider of recharge infrastructure, the most suitable moment of entry into the electric mobility market?"*

The moment of entry depends on whether there are First-Mover-Advantages (FMAs) and if these FMAs are durable and can be maintained by the pioneer. FMAs are the advantages that can be gained by a pioneer that enters a market. These FMAs arise from isolating mechanisms such as buyer switching costs, economies of scale, preemption of scarce resources and network effects. They can result in dominant, enduring market shares and abnormal financial returns which can be difficult to match or obtain by following firms (Kerin *et al.*, 1992).

However, being a pioneer also has several disadvantages; they face higher levels of market, technological and competitive uncertainty compared to following firms which makes being the pioneer more risky (Calantone *et al.*, 2010). They might have to invest heavily in R&D, market education and infrastructure development for instance. Following firms can have several advantages such as the ability to 'free-ride' on the investments made by the pioneer or wait until market- and technology uncertainties are resolved (Lieberman and Montgomery, 1988; Golder and Tellis, 1993).

The effectiveness of the isolating mechanisms in creating FMAs is moderated by a firm's resources and capabilities (micro side) and the product-market characteristics (macro side) (Suarez and Lanzolla, 2007). If for instance the pace of the market evolution is high (i.e. take-

off occurs shortly after the introduction of the product) it will affect the ability of the firm to preempt all scarce resources as the time to do so will be shorter then when the pace of the market evolution is slow. Also, when market growth is high, at any point in time there will be enough buyers on the market that following firms can capture.

When take-off in sales occurs is an important issue for managers; firms need to know when to invest in resources such as manufacturing, inventory, distribution and sales staff. However, Golder and Tellis (1997) also note that the average time to take-off is six years which means that it requires patience and careful planning on the part of managers. Companies need to be cautious about committing too many resources when they enter the market and expectations of investors should be managed. To answer the main research question, more information about the macro and micro side is needed which, at the moment, is not sufficiently present at Ballast Nedam.

1.3.1   Research Question 1 – Macro side

The product-market characteristics (macro side) moderate the effectiveness of the isolating mechanisms in creating FMAs. The change from fossil-fuel driven vehicles towards BEVs is called a technological transition. Due to the complexity of a technological transition it is difficult to determine what the best moment of entry is as many actors influence the direction and speed with which the transition is evolving.

A good understanding of the technological transition gives Ballast Nedam a better understanding of how the market is going to develop which results in a better assessment on the product-market characteristics, how it could affect the FMAs and which resources would be necessary to capitalize and exploit these FMAs. If Ballast Nedam lacks the right resources it could delay its entry, form partnerships with firms that possess the resources that Ballast Nedam lacks or not enter at all. The first research question is as follow:

Research Question 1:

> *"How will the technological transition from fossil-fuel driven vehicles towards battery electric vehicles develop?"*

A system dynamics approach will be used to get a better insight in how the installed base of the BEV is going to develop, when take-off occurs, how infrastructure is co-evolving over time and what the key variables are that influence the transition dynamics. The system dynamics methodology will be discussed in more detail in Paragraph 1.4.

1.3.2   Research Question 2 – Micro side

The characteristics of a firm also determine whether or not it will be able to exploit FMAs. Certain resources may make it possible for the firm to enter the market quickly and capitalize FMAs while firms who lack these resources may not be able to capitalize, regardless of their desire to do so. Therefore, an analysis of the resources and skills of Ballast Nedam is made to determine the relative strength and weaknesses compared to other players in the market. Also the resources of possible partners are assessed; when Ballast Nedam lacks certain resources it can decide to form a partnership with a firm that has the required resources and in that way may be better able to compete. The research question for this stage is as follow:

> Research Question 2:
>
> *"What are the strengths and weaknesses of the resources and capabilities of Ballast Nedam and other players in the market?"*

1.3.3 Determine suitable moment of entry for Ballast Nedam

After answering research question 1 and 2, the results will be combined to give Ballast Nedam recommendations on what moment of entry is most suitable for them; should Ballast Nedam be a pioneer or is a follower strategy more suitable. By combining the results of question one and two, the main research question can be answered: *"What is for Ballast Nedam, as a provider of recharge infrastructure, the most suitable moment of entry into the electric mobility market?"*

1.4 Research methodologies

To analyze and answer the first research question, a system dynamics approach has been chosen. This approach has been chosen above other approaches as it enables the researcher to analyze the complex and dynamic behavior of the technological transition. Most statistical methods are based on one-way causal relationships where independent variables influence a dependent variable. The system dynamics approach, however, includes a series of processes with circular causality (e.g. variable A influences variable B, which influences variable A). While each process might be understood very well, their interactions are often much more difficult to predict and behave non-linear (Davis *et al.*, 2007). These non-linear relationships are often difficult to explore with traditional statistical techniques but can offer surprising results.

In case of the transition, many actors are active in the system that can influence the direction and speed of the transition. System dynamics is a powerful method to understand and explore this dynamic behavior of the transition. It helps to understand why factors in a system behave as they do, what the trade-offs are and when tipping points occur. By simulating different scenarios, the impact on the transition dynamics over time can be explored. What is for instance the influence of word of mouth, battery improvements or infrastructure density on the transition? When does the transition become self-sustaining?

Although there is no best practice for the system dynamics modeling process, the process proposed by Sterman (2000) is widely used and will be used during this research. In Figure 1.1 the modeling process is shown and will be briefly explained:

1. *Problem Articulation:* determining the boundaries of the system, collect preliminary data.
2. *Dynamic Hypothesis:* identify main variables, develop causal loop diagram, analyze loop behavior over time
3. *Formulation:* construct stock-flow diagrams, collect detailed data, develop a model with equations and initial conditions
4. *Testing:* validate the model through sensitivity analysis and extreme conditions to discover flaws
5. *Policy Formulation & Evaluation:* Develop and simulate alternative scenarios, evaluate robustness, compare results, report and present results to stakeholders, develop a 'management flight simulator' to facilitate learning in the organization

Note that the modeling process is iterative. Results of any step can yield insights that lead to revisions in any earlier step (indicated by the links in the center of the diagram). The modeling is carried out in 'Vensim', a system dynamics program. As a starting point, the paper written by Struben (2006) is used who developed a system dynamic model that simulates the transition towards hydrogen fuel cell vehicles. This model is adjusted in order to be able to answer the proposed research questions.
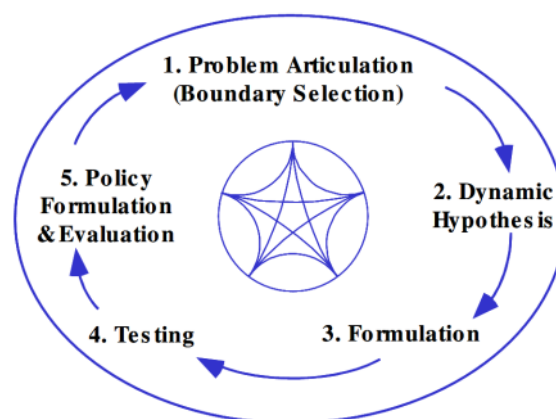
Figure 1.1 - System dynamics modeling process

The model incorporates findings from literature on transition dynamics and moment of entry decisions, survey data of consumers' willingness to adopt a BEV conducted earlier by Ballast Nedam and Ecomobiel and (technical) developments of the BEV and ICE platform.

To answer the second research question, first literature concerning moment of entry decision and the resource-based view has been consulted. To identify the resources and capabilities of Ballast Nedam as well as other players in the e-mobility market, a small survey was filled in by employees of Ballast Nedam who are well familiar with the e-mobility market. The results of this survey can be found in Appendix F. The questions of the survey were grouped into six groups of resources and capabilities; technical, marketing and sales, finance, ability to cooperate in partnerships, flexibility and risk behavior and cooperate priority towards e-mobility. The companies that were rated in the survey were divided into four groups; energy, construction, hardware suppliers and fleet owners.

1.5   Outline of the thesis

The thesis is structured as follow. In chapter two the theoretical background of this research will be discussed. Literature concerning the moment of entry, resource-based view and technological transitions will be discussed. In chapter three the causal loop diagram is discussed. The causal loop diagram is an important tool for representing the feedback structures of the system. In chapter four the behavior of the transition towards the BEV will be discussed by means of the base run and several scenarios. In chapter five, based on the transition behavior, it is argued whether first-mover-advantages are present and durable. In this chapter also the resources and capabilities of Ballast-Nedam and other companies active in the market will be discussed and an advice is given to Ballast Nedam whether they should follow a pioneer or follower strategy. Finally, chapter six will present the conclusion of the research including recommendations for Ballast Nedam, limitations and directions for future research.

2 Theoretical Background

From the problem statement and research questions it became clear that Ballast Nedam would like to have a better understanding about what an appropriate moment of entry is into the e-mobility market as an infrastructure provider. This chapter provides the theoretical background for the thesis project and literature concerning the moment of entry decision will be discussed. The moment of entry decision, which is part of the market entry strategy of a company, is a crucial strategic choice for a company and one of the main determinants of product success. The aim of this chapter is to give the reader insight in the moment of entry decision and it provides a background for the further research conducted in this thesis.

The chapter starts with an introduction on the moment of entry decision followed by a framework about First-Mover-Advantages (FMAs). FMAs stem from mechanisms and the effectiveness of these mechanisms in creating FMAs are moderated by the resources of a firm (micro side) and the product-market characteristics (macro side). These mechanisms as well as the micro- and macro side will be discussed in more detail. Extra emphasis will be given to the macro side as the product-market characteristics of the e-mobility market are complex and important for the moment of entry decision.

2.1 Moment of entry

The appropriate moment of entry into a market is a crucial strategic choice (Porter, 1998; Di Benedetto, 1999) and is one of the main reasons for new product success or failure (Lilien and Yoon, 1990). The first mover usually requires considerable investment in innovation, has greater risk of exposure and may run the risk that the return on investment comes too late to recover the entry costs, but potentially captures a leadership position and could achieve sustainable competitive advantage (Calantone *et al.*, 2010). Late entrants face other risks but may learn from the first mover mistakes resulting in lower entry costs or have the possibility to not enter if market prospects don't look attractive (Shen and Villas-Boas, 2010). According to Sinha and Noble (2005) the moment of market entry is "a critical decision, involving the need to balance the risk of premature entry (entry to early) with the problems of missed opportunities as a result of late entry".

First-mover advantages (FMAs) are the advantages that can be gained by a pioneer or first-mover that enters a market. Lieberman and Montgomery (1988) define first-mover advantages in terms of: "the ability of pioneering firms to earn positive economic profits (i.e. profits in excess of the cost of capital)". These FMAs include for instance opportunities to create a sustainable leadership in technology, pre-empting of scarce assets, profit from customer switching costs and gaining added sales associated with buyers' greater knowledge of pioneering brands (Szymanski *et al.*, 1995). These FMAs can result in dominant, enduring market shares

and abnormal financial returns which can be difficult to match or obtain by following firms (Kerin *et al.*, 1992).

However, being a pioneer also has several disadvantages; they face higher levels of market, technological and competitive uncertainty compared to following firms which makes being the pioneer more risky (Calantone *et al.*, 2010). They have to invest in R&D, market education and infrastructure development for instance. Following firms can have several advantages such as the ability to 'free-ride' on the investments made by the pioneer or wait until market- and technology uncertainties are resolved (Lieberman and Montgomery, 1988; Golder and Tellis, 1993).

So what is a better timing strategy; to be a pioneer or a follower? This question is not easily answered; in the literature many conflicting findings are found concerning this issue (Golder and Tellis, 1993). Research that focused mainly on the possibility that order of entry exerts a direct effect on business performance, offered only mixed results (Szymanski *et al.*, 1995). A second stream of research therefore focused on the contingent nature of FMAs, or conditions under which firms may or may not gain advantage from early entry (Eggers *et al.*, 2011). Findings from this contingency perspective provide evidence that the contingency perspective is a more valid perspective (Szymanski *et al.*, 1995) or as Kerin *et al.* (1992) put it "...the factors involved in achieving and sustaining first-mover advantages are considerably more complex than a simple order of entry effect".

Research concerning FMAs has developed in three conceptual categories (Suarez and Lanzolla, 2007); (i) the drivers or "isolating mechanisms" that provide certain advantages and disadvantages for pioneers (Lieberman and Montgomery, 1988; Kerin *et al.*, 1992), (ii) the "micro" side that focused on firm-characteristics such as firm-resources and skills (Kerin *et al.*, 1992; Lieberman and Montgomery, 1998; Schoenecker and Cooper, 1998; Suarez and Lanzolla, 2005) and (iii) the "macro" side which focused on the product-market characteristics (Kerin *et al.*, 1992; Szymanski *et al.*, 1995; Suarez and Lanzolla, 2007).

2.2   FMA framework

In Figure 2.1 the relations between the three categories are shown. In the middle, the "isolating mechanisms" are shown. These mechanisms can generate FMAs for a firm. However, the effectiveness of these isolating mechanisms in creating FMAs depends on both firm-characteristics (*'micro-side'*) and product-market characteristics (*'macro-side'*). The mechanisms can be clustered into economic factors, preemption factors, technological factors and behavioral factors. Whether a firm is able to exploit these FMA creating mechanisms and capitalize the opportunity depends on its resources and characteristics. A pioneer that cannot capitalize the first-mover advantages will run the risk that a follower will take the leadership position in the market. However, the effectiveness of these mechanisms is not only moderated

by a firm's resources but also moderated by product-market characteristics (Kerin *et al.*, 1992; Szymanski *et al.*, 1995; Suarez and Lanzolla, 2007). FMAs can for instance be affected by the degree of competition, market structure, time elapsed between the entry of the first and second mover and the pace of technology and market evolution (Suarez and Lanzolla, 2007). In the next paragraphs, these isolating mechanisms and the micro- and macro side are discussed in more detail.

Once the firm has made an assessment on the factors of the micro- and macro side it can make a choice about the strategic moment of entry. If there are for instance FMAs but the firm doesn't possess the right resources it might be better to wait and enter as a follower. It could also try to obtain the necessary resources by forming a partnership with a firm that does have those resources.
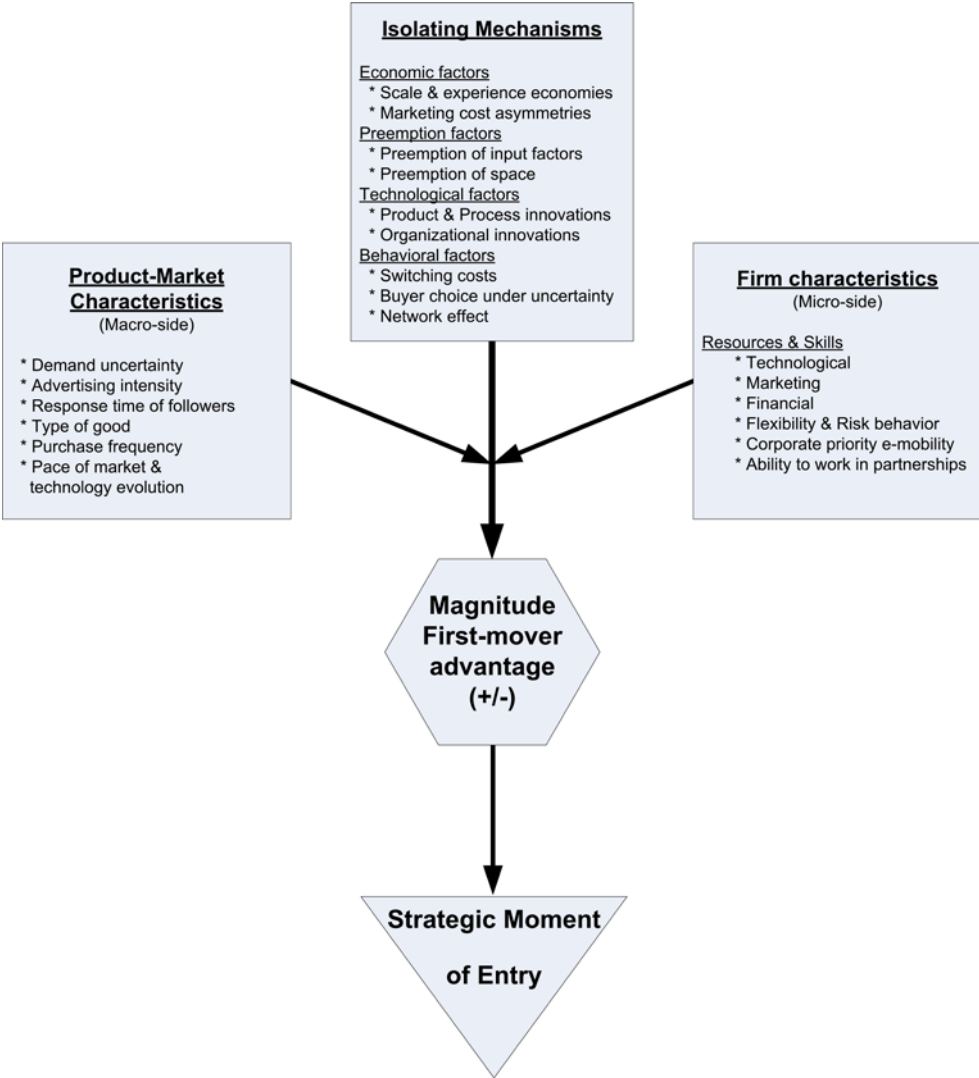

Figure 2.1 - First-Mover-Advantage framework
Based on: (Lieberman and Montgomery, 1988; Kerin *et al.*, 1992; Szymanski *et al.*, 1995; Suarez and Lanzolla, 2007)

2.2.1   Isolating Mechanisms – drivers of FMAs

First-Mover-Advantages can arise from four different sources; economic factors, preemptive factors, technological factors and behavioral factors (Kerin *et al.*, 1992). Within each source there are a number of mechanisms or drivers that create and enhance first-mover-advantages. These mechanisms are called "isolating mechanisms" as they protect a firm from imitative competition (Lieberman and Montgomery, 1988). In this paragraph, these isolating mechanisms will be discussed.

Economic factors

There are two mechanisms that create FMAs in the form of cost advantages: (i) scale and experience economies and (ii) marketing cost asymmetries (Kerin *et al.*, 1992).

Scale and experience economies: Refers to decline in unit costs of a product (or operation or function that goes into producing a product) as the cumulative output per period increases (Lieberman and Montgomery, 1988). A pioneer will have the highest cumulative experience which creates a cost-advantage over following firms (Kerin *et al.*, 1992). This cost-advantage based on cumulative experience can be difficult to overcome by followers if the pioneer is able to maintain its leadership position in market share. In nearly every function of a company economies of scale can be present such as manufacturing, R&D, purchasing, marketing, distribution and sales force (Porter, 1998). These economies of scale create entry barriers for potential followers.

Marketing cost asymmetries: When a pioneer is the only firm in the market (monopoly), their marketing messages will be much more effective in reaching potential customers. Once followers start entering the market, multiple messages will be send out to potential customers which will reduce the effectiveness of the messages in total. This could mean that followers have a cost-disadvantage as they have to advertise more to attract customers to their product and away from the pioneer while the pioneer already created brand awareness and thus can direct its marketing efforts towards its installed base (Kerin *et al.*, 1992).

Preemption factors

A first mover may be able to gain a competitive advantage by preemption competitors in the acquisition of scarce assets such as government permits, key locations, relationships with key suppliers and access to distribution channels (Lieberman and Montgomery, 1988; Schilling, 2008). Preemption factors can, in contrast to economic factors, provide a basis for a first-mover to achieve *absolute* cost advantages (for instance through procurement contracts that ensure supply of materials at a price that will be lower than incurred by followers) or differentiation advantages (for instance by preemption of geographic space or marketing channels) (Kerin *et al.*, 1992)

Preemption of input factors: A pioneer that has superior information may be able to purchase assets at market prices below those that will prevail later in the evolution of the market. Assets

are for instance natural resource deposits and manufacturing locations. Also assets such as skilled employees can create an advantage (Lieberman and Montgomery, 1988).

Preemption of space: In most markets there is only room for a certain amount of profitable firms. The pioneer may gain a differentiation advantage through spatial preemption. A pioneer is able to select the most profitable niches in terms of geographical space (locations), perceptual space (product attributes), distribution space (shelf space) and market segments (selecting most profitable or largest). The pioneer can limit the spatial space and/or options available for the follower by taking strategic actions. This makes the pioneer a more favorable position (Kerin *et al.*, 1992; Schilling, 2008)

Technological factors

Technological factors can produce a cost and/or differentiation advantage through innovations in product, process and organization (Kerin *et al.*, 1992).
Product and process innovations: Innovations in product and process technologies can create a differentiation advantage (e.g. through better product performance) and/or cost advantages (e.g. by lowering the production costs). A pioneer can take advantage by creating a sustainable leadership in technology; for instance by a breakthrough in technology by its R&D department. By introducing a new technology first, the pioneer can generate a long-lasting reputation as a leader in that technology domain. This reputation can help the pioneer to sustain brand loyalty and market share even after competitors have introduced comparable products (Schilling, 2008).

Organization innovations: Innovations in organizations can create cost advantages (e.g. through improvements in productivity of the workforce) and differentiation advantages (e.g. through creative execution of marketing programs) (Kerin *et al.*, 1992). Organizational innovations often diffuse more slowly through an industry or between firms compared to product or process innovation and thus may create a prolonged first-mover advantage (Lieberman and Montgomery, 1988).

Behavioral factors

Behavioral factors may provide a pioneer with opportunities to *achieve* differentiation advantage (e.g. switching costs) or for a differentiation advantage to be *provided* to the pioneer by the marketplace (e.g. complementary goods) (Kerin *et al.*, 1992).
Switching costs: Once buyers have adopted a good, they often face costs to switch to another good (Schilling, 2008). High switching costs can be beneficial for the pioneer as they prevent adopters to switch to another brand or firm. Switching costs can be divided into two types: contractual and non-contractual switching costs (Kerin *et al.*, 1992). Contractual switching costs are imposed onto the buyers by the pioneer. They may be created on purpose by the pioneer such as contracts with a minimum term, for instance mobile phone contracts, or

created incentives for repeated purchase such as "buy two and get one extra for free". Non-contractual switching costs can originate from the initial investment a buyer makes to adopt the company's product; for instance time and money spent in selecting a supplier, costs made to acquire complementary goods such as software and the training of employees to become familiar with its operation (Lieberman and Montgomery, 1988). If buyers face switching costs, the pioneer that captures customers early, may be able to keep those customers even if technologies with a superior value proposition are introduced later (Schilling, 2008). For instance the QWERTY keyboard is, although inferior to the later developed DVORAK keyboard, still the dominant design. Switching to the latter keyboard would mean high costs for companies as tens of millions of people need to have training in the new keyboard layout. Other non-contractual switching cost can arise due to supplier-specific learning by the buyer. A buyer can get used to certain characteristics of the pioneer and its product and therefore the buyer may hesitate to switch to a follower.

Buyer choice under uncertainty: In early stages of the market, buyers are faced with imperfect information regarding product quality. Buyers may stick with the first product-brand that can perform its job satisfactory; it creates brand loyalty. This is especially present in low cost goods where finding a new superior product doesn't justify the search costs (Lieberman and Montgomery, 1988). A pioneer can create a reputation for a certain quality which can also be used for other additional products. Furthermore, the pioneer can influence how customers evaluate attributes in the product category and the pioneer's product may become the standard for the product category (Golder and Tellis, 1993).

Network effect: Certain products have besides their intrinsic value, which refers to the features or attributes designed into the product sold, also extrinsic value. Extrinsic value is the set of benefits derived from outside the product itself such as size of the installed base and the availability of complementary products (Lee and O'Connor, 2003). Complementary products influence the value of the base product. An increase in installed base or in complementary goods will increase the product's value; the value of a telephone increases when more people have a telephone (increase in installed base) and the value of a PC increases when more software programs are available (increase in complementary goods). A pioneer has more time to establish a larger installed base which could result in a higher perceived value of the product compared to followers with a smaller installed base. Also, the product of the pioneer could become the standard and a benchmark for complementary goods which will result in a differentiation advantage for the pioneer (Kerin *et al.*, 1992). However, Srinivasan *et al.* (2004) found that network effects have a negative effect on the survival duration of pioneers and argue that firms contemplating to enter such markets should take a wait-and-see approach.

Now that the isolating mechanisms have been discussed in detail, the next two sections will discuss how the effectiveness of these mechanisms in creating FMAs is moderated. As discussed

in Paragraph 2.2 and shown in Figure 2.1, there are two sources that influence the effectiveness of the mechanisms discussed; the firm characteristics (*'micro-side'*) and product-market characteristics (*'macro-side'*).

2.2.2   Firm Characteristics

Lieberman and Montgomery (1998) argue that resources and timing of entry interact with each other and that the optimal timing often depends on the strengths and weaknesses of the firm's resources. In another article of Lieberman and Montgomery (1988) they note that:

> "…for any given firm, the question of whether early or late entry is more advantageous depends on the firm's particular characteristics. If one firm has unique R&D capabilities while the other has strong marketing skills, it is in the interest of the first firm to pioneer and the second firm to enter at a later date. Both may earn significant profits entering in this sequence, but neither would gain if the (attempted) order of entry were reversed."

Several studies investigated the effect of firm's characteristics on their moment of entry in the market (Suarez and Lanzolla, 2007). Most of these studies are based on the resource-based view of the firm which focuses on the relationship between firm-specific factors and the pursuit of competitive success (Sinha and Noble, 2005). In the resource-based view, a firm's ability to derive FMAs should be assessed "with reference to the competence and capabilities which new entrants have, relative to the competitors" (Suarez and Lanzolla, 2007). The characteristics of a firm (e.g. resources and skills) determine whether or not it will be able to exploit FMAs. Certain resources may make it possible for the firm to enter the market quickly and capitalize FMAs while firms who lack these resources may not be able to capitalize, regardless of their desire to do so (Schoenecker and Cooper, 1998). Also, if a firm has resources that make it possible to capitalize FMAs it will have a greater incentive to enter the market early. Research further showed that pioneers, early followers and late entrant tend to deploy different skills and resources (Suarez and Lanzolla, 2007).

Larger firms tend to be early market entrants due to their more complex and diverse web of resources (Schoenecker and Cooper, 1998). Unused resources and excess capacity represent a significant dilemma; their lack of assimilation or utilization creates pressures within the organization (Sinha and Noble, 2005). This pressure is relieved through organizational diversification actions such as entry into emerging markets. This phenomenon, combined with the fewer resource constraints inherent in larger firms, suggests that larger firms (both in absolute and relative share terms) will tend to be earlier entrants into emerging markets. Furthermore, firms tend to enter a market earlier when the emerging market more closely relates to the firm's existing strategic focus (Sinha and Noble, 2005).

Schoenecker and Cooper (1998) found that firms with larger R&D intensity (technological resource) will enter early; a firm that makes a significant, consistent investment in R&D has the capability to create a product or process innovation. Furthermore, firms with large internal financial resources and firms who possess a direct sales force (marketing resource) will enter earlier as they can play a role in market education, especially when the products are complex. Also, when the new market relates to the other markets of the firm, using the already established sales force can be a good way to increase productivity of that resource. Firms with strong marketing and a significant brand name tend to enter later into a market. Whether a firm with greater financial resources will lead to pioneering is not clear as research gave conflicting findings.

2.2.3 Product-Market Characteristics

The isolating mechanisms discussed provide opportunities for firms with the right resources to capitalize them. However, the effectiveness of the mechanisms is not only moderated by the firm's resources but also moderated by product-market characteristics (Kerin *et al.*, 1992; Szymanski *et al.*, 1995; Suarez and Lanzolla, 2007). FMAs can for instance be affected by the degree of competition, market structure and time elapsed between the entry of the first and second mover (Suarez and Lanzolla, 2007).

The before mentioned *economic factors* that create FMAs are moderated by demand uncertainty, advertising intensity and response time. Demand uncertainty implies that, when there is a greater uncertainty in demand, a pioneer will be unwilling to commit substantial resources or enter in small scale. The scale dependent cost advantage will in consequence also be lower. Also if market demand is too small, no large scale effects can be achieved by the pioneer which reduces the cost advantages through scale. Another moderator is that, in a market characterized by low advertising-to-sales ratio, cost advantages gained by the pioneer due to marketing cost asymmetries will be lower than in markets characterized by high advertising-to-sales ratios. The time elapsed between the pioneer and the follower is another moderator. If the time between the two is short, the pioneer will have less time to gain cost- and differentiation advantages through scale- and experience economies and marketing asymmetries (Kerin *et al.*, 1992).

Moderators of *preemption factors* are for instance the preemptive investments under demand uncertainty and the pace of market evolution. When demand is highly uncertain, the pioneer will be reluctant to secure long-term contracts with suppliers and won't commit large resources in building plants and equipment (Kerin *et al.*, 1992). The pace of market evolution also affects FMAs. Market evolution of innovations is generally characterized by an initial period of slow growth and eventually followed by a sharp increase (i.e. take-off) (Golder and Tellis, 1993; 1997; Suarez and Lanzolla, 2007). If this take-off occurs relatively fast after product introduction (i.e. pace of market evolution is high), it will affect the ability of the firm to

preempt resources. When market growth is high, at any point in time there will be enough buyers to be captured by followers. Figure E.1 in appendix E1 gives a further understanding of the role played by the pace of market evolution.

The pace at which technology evolves directly affects the possibility of deriving FMA through *technological factors* (Suarez and Lanzolla, 2007). Technology evolution might render the pioneers knowledge obsolete, destroy existing competences and minimize possible experience curve advantages. A faster pace in technology evolution may also render patents and other forms of intellectual property fast obsolete or companies invent around the patent as the fast change in technology gives followers plenty of opportunities to do so (Golder and Tellis, 1993; Hauser *et al.*, 2006).

Moderators of *behavioral factors* can be type of good, purchase frequency and the pace of market evolution. If a product is an experience good, a good from which the benefits can only be determined after the buyer purchased and used it, the buyer uncertainty will be higher than for search goods, a good from which buyers can easily determine the benefits before they purchase it. An experience good has higher switching costs in comparison with a search good and therefore the FMA is higher when the product is an experience good. Purchase frequency affects a pioneer's differentiation advantage; when purchase frequency is high, the perceived risk of product trail is low. Also when frequency is very low, the pioneer's advantage will be low as it minimizes consumption experience asymmetries. With moderate purchase frequency the pioneer's advantage will be the highest (Kerin *et al.*, 1992). Also here the pace of market evolution can affect the pioneer's advantages. If the market growth is high, it can minimize the advantage a pioneer might have due to network effects as there will be enough buyers available for followers as well and it is argued that a fast pace in market evolution is crucial to overcome network effects (Suarez and Lanzolla, 2007).

Suarez and Lanzolla (2005, 2007) also researched the combined effect of pace of market and technology evolution on the overall effectiveness of the FMA isolating mechanisms. They constructed a matrix which has four possible scenarios (see Figure 2.2). The first scenario (Quadrant 1) is a scenario where both pace of market and technology evolution are smooth. Such a scenario is a strong enabler of FMAs; it allows pioneers to create a dominant position and followers have difficulty to differentiate their products from the pioneer due to the slow pace of technology evolution. In quadrant two, the pace of technology is still smooth but the market evolves abrupt; in such a scenario only a weak and short effect of FMAs is expected. Due to the abrupt pace of market evolution, pioneers need many resources in terms of manufacturing, inventory, distribution and sales staff to be able to keep up with customer demand and target all market segments. The third quadrant shows the reverse situation; fast pace of technology evolution but the market evolves slowly. Also in this scenario FMAs are expected to be weak. The pioneer's technology becomes obsolete quickly; it should have

substantial resources in R&D and finance to survive. In the last scenario, quadrant four, both the pace of technology and market evolution is fast; in this scenario FMAs are very unlikely. Products of the pioneer become quickly obsolete and are often overtaken by product improvements of followers and due to the high pace of market, followers can target unused spaces. In appendix E2 examples are given of products and companies that operate in one of these four scenarios.
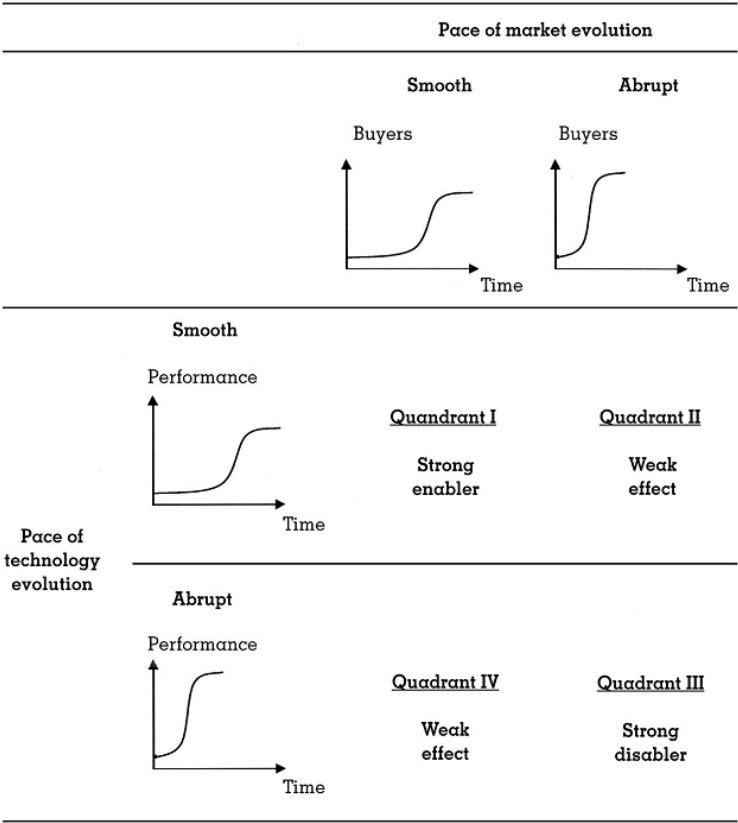
Figure 2.2 - Effect pace of market and technology evolution on FMAs
Source: (Suarez and Lanzolla, 2007)

2.3   Product-market characteristics e-mobility market

How the e-mobility market is going to develop is very complex as many different stakeholders are involved who influence the development of the market. This makes it difficult to assess the moderating effect of the macro level on the mechanisms that create FMAs. The possible change in the transportation sector from fossil fuel driven vehicles towards the battery electric driven vehicles is called a Technological Transition (TT). A TT can be defined as large changes in the way societal functions, such as transportation, communication, housing, feeding, are fulfilled. These societal functions are fulfilled by Socio-Technical systems (ST-systems), which consist of a cluster of aligned elements, e.g. knowledge, user practices and markets, regulation, cultural meaning, infrastructure, maintenance networks and supply networks (Geels, 2005). According to Geels (2002) a "technological transitions consist of a change from one socio-technical system to another, involving substitution of technology, as well as changes in other elements".

Understanding the factors that are involved in a technological transition can help to understand the developments and speed of a transition; it gives a better understanding of the product-market characteristics and thus a better assessment on the moment of entry decision.

2.3.1   Technological Transitions

Technological transitions do not occur easily because the elements in a socio-technical system are linked and aligned to each other (Verbong and Geels, 2010). New technologies have a hard time to break through because regulations, infrastructure, user practices, maintenance networks are aligned to the existing technology which gives the current socio-technical system a high stability. New technologies often face a miss-match with the established socio-technical system. However, ST-systems rarely remain 'closed' for good (Geels, 2002). Pressures create tension on the ST-system which forces people within the system to search for alternative technologies.

To analyze the dynamics of technological transitions, how the change from one ST-system to another occurs, Geels (2002; 2005) developed the Multi-Level-Perspective (MLP). In the MLP, three conceptual levels are distinguished: the socio-technical regime, the socio-technical landscape and the technological niches (Figure 2.6).

2.3.2   Meso level - socio-technical regime

On the meso level, three interrelated dimensions are important: (i) the social-technical system, i.e. the tangible elements that are needed to fulfill societal functions, (ii) the actors in social groups who maintain and reproduce the elements and linkages of the socio-technical system, and (iii) the rules which guide and orient activities of actors and social groups (Geels, 2004; 2005; Verbong and Geels, 2010). In Figure 2.3 the interrelation between these three dimensions are shown including their interactions (Geels, 2004). These interactions account for the stability of existing ST-systems, for instance through contracts, cognitive routines, core capabilities and competences, user practices and regulations. Also, powerful actors may try to suppress innovations through market control or political lobbying (Geels, 2005). Also due to the material and economic nature of ST-systems they tend to have a certain 'hardness' which makes them hard to change (Geels, 2004). For these reasons, existing ST-systems are characterized by stability.
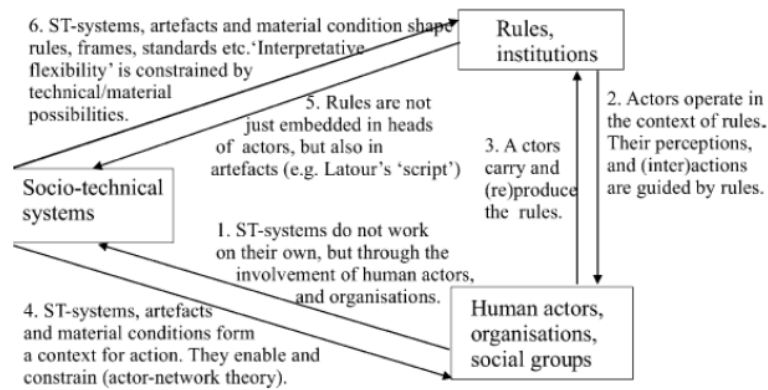
Figure 2.3 - The three interrelated dimensions of a socio-technical regime
Source: (Geels, 2004)

Socio-technical regime of land-based road transportation

The automobile is part of the socio-technical regime of land-based road transportation. In Figure 2.4 the socio-technical system of land-based road transportation including its elements is shown. These elements and linkages are the result of activities of actors within the regime. Road infrastructures and car regulations, for instance, are built and maintained by transportation ministries. Cultural and symbolic meanings of cars are produced in the interaction between users, media and societal groups. User practices and mobility patterns emerge from the daily use of cars by user groups. Industry structures are the outcome of mutual positioning and strategies of car manufacturers and their suppliers. The technological knowledge embodied in cars is created by car designers and engineers, while cars as artifacts are produced by car manufacturing firms. The activities of these different actors are aligned to each other and coordinated and due to this, the transportation function is fulfilled (Geels, 2002).

The three central actors in the regime, which are shown in Figure 2.5, are the fuel providers, carmakers and consumers while other groups, such as governmental organizations, NGO's, support- and environmental groups, influence the central actors and the system (van Bree *et al.*, 2010). The interaction between carmakers and consumers consists out of the product offering of the carmakers to the consumer which are accepted to a certain degree by the consumers. The carmakers try to match their product offerings to the preferences of the consumers although carmakers also try to influence these preferences. The consumers in turn influence the carmakers by expressing their preferences. The interaction between fuel providers and the consumers is based on the offering and purchase of the fuel. Like the interaction between carmakers and consumers, fuel providers and consumers influence each other. There is also an interaction between the fuel providers and the carmakers. This interaction consists out of co-optimization of fuel, lubes and engines and monitoring each other's activities. The

interactions of these three actors determine for a large part the role of the automobile in the regime.
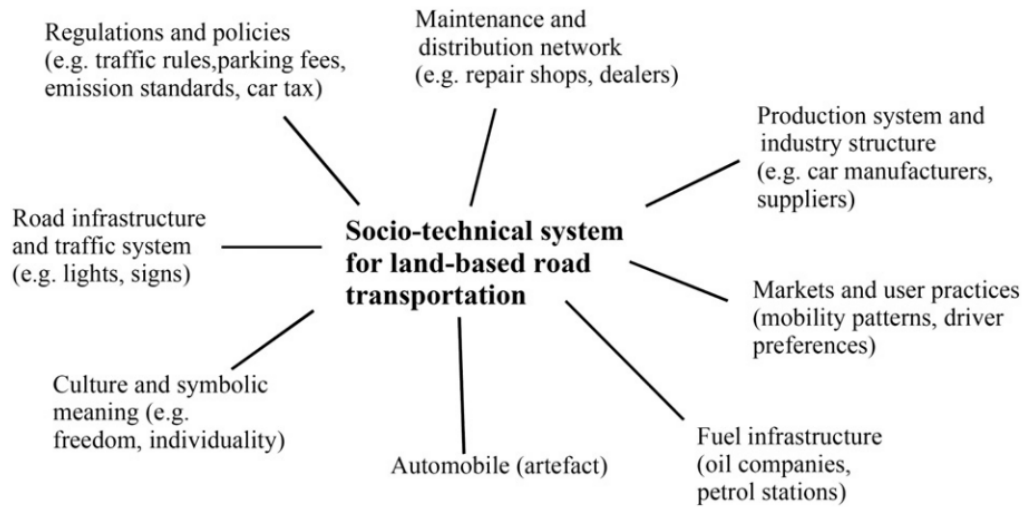
Figure 2.4 - The Socio-Technical System for land-based road transportation
Source: (Geels, 2005)

The three central actors are influenced by other actors such as governmental organizations, NGO's, support- and environmental groups (van Bree *et al.*, 2010). Governmental organizations for instance through policies such as tax on cars and fuel, (emission) regulations and subsidies. Consumers in turn also influence the government through voting for instance and the industry tries to influence the government through lobbying. Also NGO's such as environmental and support groups for certain technologies and the industry influence each other. It is important to note that all these different actors might not have the same goals and can even conflict with each other and influence the transition, its duration, speed and the outcome.
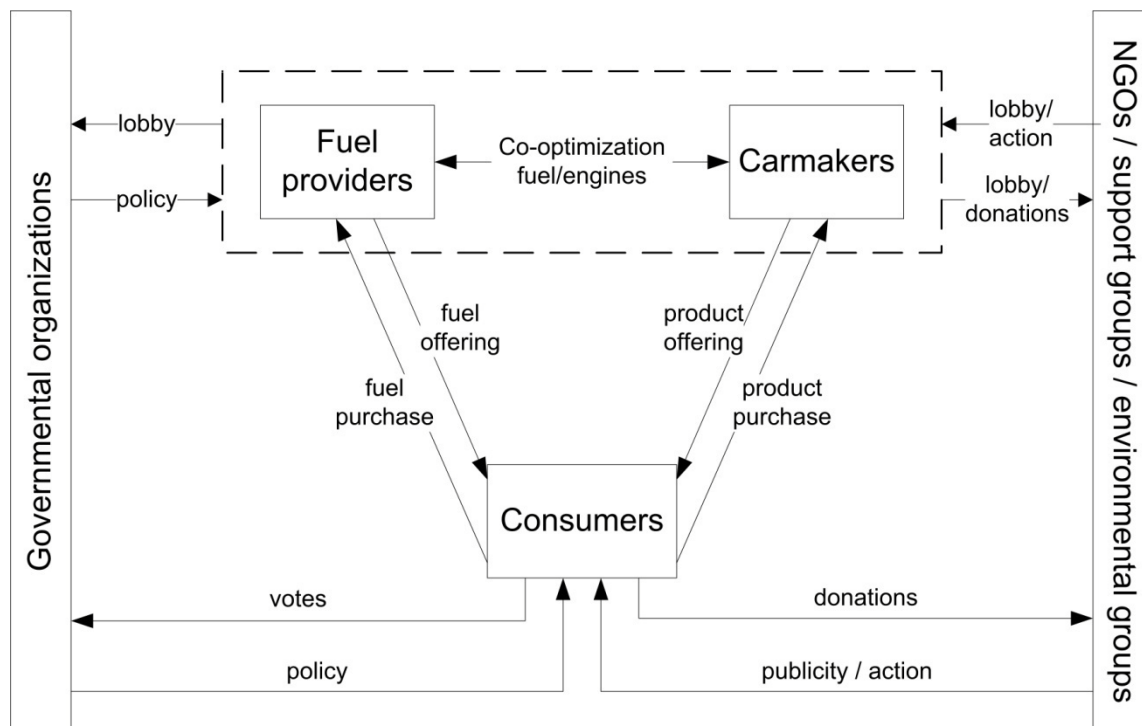
Figure 2.5 - Actors in the current socio-technical regime of car-based transportation
Source: (van Bree *et al.*, 2010)

2.3.3   Macro level - landscape developments

The developments in the landscape, the macro level, are situated outside the sphere of influence of the actors in the regime. Physical constraints are part of this level but also less tangible aspects such as shared (cultural) beliefs, public opinion, globalization and environmental issues (van Bree *et al.*, 2010). The landscape developments can exercise pressure on and create tension between elements in the socio-technical regime (Geels, 2004). In case of the transportation sector these pressures, as discussed in Chapter 1, stem from climate-change and environmental problems, fossil fuel depletion and rising fuel prices (Struben, 2006; Farla *et al.*, 2010; van Bree *et al.*, 2010). Due to these pressures and tensions between the elements it is possible that a "window of opportunity" emerges which gives room for the introduction of new technologies, such as the BEV, which have been developed in the lowest level of the multi-level-perspective; the technological niches (Geels, 2002).

2.3.4   Micro level - technical niches

Small market niches or technical niches act as 'incubation rooms', shielding new technologies from mainstream market selection. Such protection is needed because new technologies initially have a low price/performance ratio (Geels, 2005). Protection comes from small networks of actors who are willing to invest in the development of new technologies; the drawbacks of the new technology such as high costs are compensated by other favorable characteristics for instance in reliability (Verbong and Geels, 2010). Niches provide a location for learning, not only on the technology but also domains such as regulations, user preferences, production

systems and infrastructure. A new technology can, after continuous development, compete with and maybe replace the technologies of the current ST-system. In case of the transportation sector, the landscape pressures described above triggered some actors, for instance universities, to start developing technologies to enable alternatives such as the BEV. Actors now get more experience for instance with the BEV through several pilot projects around the world (Narich *et al.*, 2011) which creates pressures on the current regime in place. It should be noted that both sources of pressure, from the macro level as well as the micro level, are important for the wider breakthrough and diffusion of the new technologies (Geels, 2005)
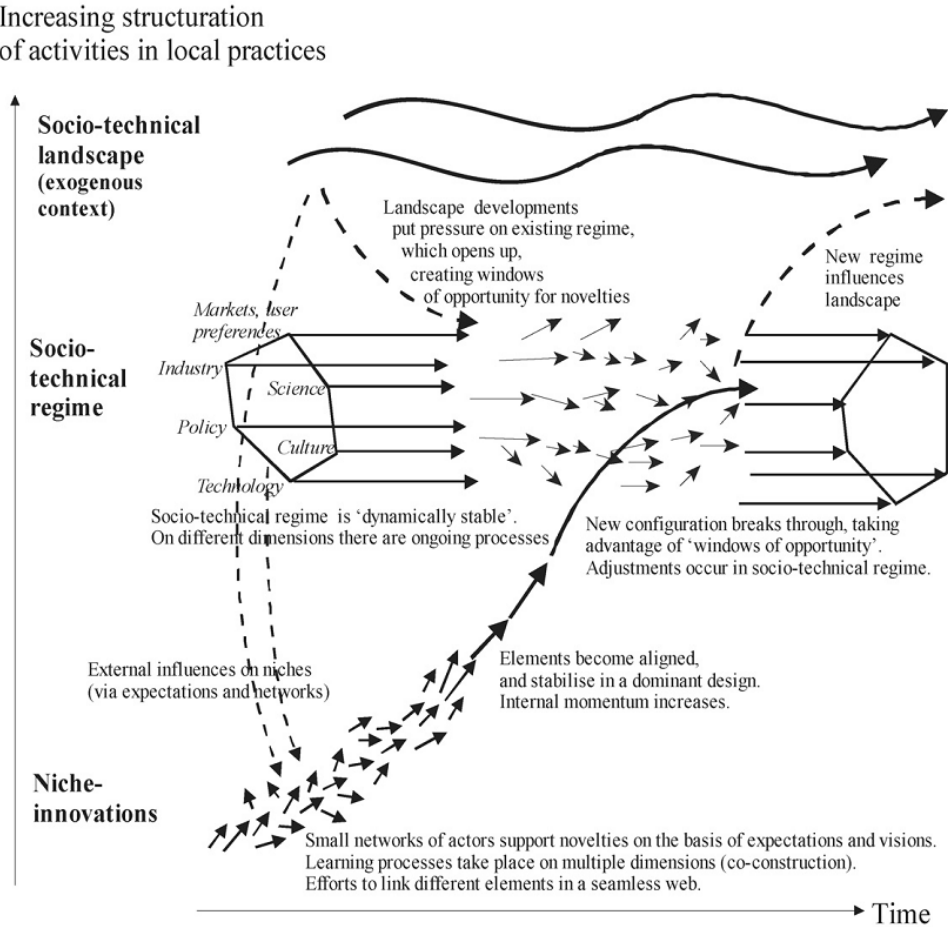

Figure 2.6 - Multi Level Perspective (MLP)
Source: (van Bree *et al.*, 2010)

2.4   Conclusions

The moment of entry into a market is a crucial strategic choice and is one of the main reasons of product success or failure (Kerin *et al.*, 1992). The decision to enter the market as a pioneer or as a follower depends on whether there are FMAs and if a firm is able to capture these FMAs. FMAs arise from 'isolating mechanisms' and can be grouped into four different categories; economic factors, preemption factors, technological factors and behavioral factors. The effectiveness of these mechanisms in creating FMAs for a specific firm is moderated by the firm characteristics ('micro side') and product-market characteristics ('macro-side').

The firm-characteristics (micro-side) determine whether or not the firm will be able to exploit FMAs. Certain resources may make it possible for the firm to enter the market quickly and capitalize FMAs while firms who lack these resources may not be able to capitalize, regardless of their desire to do so (Schoenecker and Cooper, 1998). Product-market characteristics (macro-side) that influence FMAs are for instance the pace of the market and technology evolution, type of good, response time of followers and purchase frequency. Once a firm has made an assessment of the micro- and macro side it can make a decision about whether a pioneer or follower strategy is more suitable.

However, the product-market characteristics of the e-mobility market are very complex due to the many actors involved in the transition towards BEVs. In the literature, the change from fossil-fuel driven vehicles towards BEVs is called a technological transition; a shift from one socio-technical system to another. A technological transition is often explained by means of the Multi-Level-Perspective (MLP) in which three levels can be distinguished; (i) socio-technical landscape (ii) socio-technical regime and (iii) technological niches. Pressures occurring from the landscape and niche level create a window of opportunity for new technologies such as the BEV.

Although the MLP explains how transitions of technologies in complex systems occur, it does not provide an answer to how the e-mobility market specifically is going to develop. This makes it difficult to make a good assessment on the product-market characteristics and the effectiveness of the mechanisms in creating FMAs. Hence, the research questions proposed in Paragraph 1.3 can't be answered based on the literature alone. In the next chapter a system dynamics model is therefore discussed that can give a better insight into the product-market characteristics. Together with data on the firm-characteristics, the main research question can be answered.

3 Causal Loop Diagram

In this chapter the Causal Loop Diagram (CLD) of the model will be discussed. The model is used to assess how the transition towards the BEV is going to develop. In system dynamics modeling process, there are two important modeling approaches; causal loop diagrams and Stock-and-Flow Diagrams (SFD). In this chapter the causal loop diagram will be discussed. The advantage of the CLD is the limited use of symbols and the focus on loop structure which makes it more understandable for non-technical people and it is easier to communicate the structure of the model than a SFD. Therefore, the model will be explained by means of the CLD. The SFDs are discussed in Appendix B. Stocks and flows, along with feedback, are the two central concepts of system dynamics (Sterman, 2000). They present the conceptual and mathematical definition of stocks and flows and give generally a more detailed specification of what is believed to be happening.

The chapter starts with the general concepts of CLDs. After this introduction to CLDs, the CLD developed in this thesis will be discussed. The model is divided into three different sections with each section resembling one of three central players; (i) consumers, (ii) automotive industry and (iii) fuel providers[11].

3.1   CLD - Modeling process

A CLD is an important tool for representing the feedback structures of systems (Sterman, 2000). Figure 3.1 gives an example of the feedback structures and shows the often cited barrier for the introduction of the BEV; the chicken-egg-dynamic[12]. The CLD consists of variables which are connected by arrows denoting the causal relationships called causal links. Each causal link is assigned a polarity, either positive (+) or negative (-) and indicates whether the relationship is positive or negative. A positive link indicates that if the variable at the origin of the arrow increases, then the dependent variable will increase above what it would otherwise have been. When the variable at the origin of the arrow decreases, then the dependent variable will decrease below what it would have been (Sterman, 2000). In Figure 3.1 for instance, an increase in the attractiveness of the BEV will result in a larger installed base; a decrease in attractiveness will result in smaller installed base. A negative link indicates that if the variable at the origin of the arrow increases (decreases), the dependent variable will decrease (increase) below (above) what it would have been otherwise. In the figure for instance an increase in the actual number of stations will decrease the station shortfall.

In the figure also loop identifiers are placed in the center of a loop which indicate whether an entire loop is positive (reinforcing) or negative (balancing). The behavior of a positive,

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[11] As discussed in Paragraph 2.3.2 and shown in Figure 2.5

[12] As discussed in Paragraph 1.1.1

reinforcing feedback loop is exponential growth. In the example, if the installed base of the BEV increases, more people will need to recharge and thus more stations are desired. This will result in a discrepancy between the desired and actual number of stations. Stations need to be constructed (corrective action) to reduce this discrepancy. When the number of stations increases, the attractiveness of the BEV will increase as more infrastructure is available for BEV drivers which will result in even a higher installed base of BEVs. Hence, this loop is reinforcing. This positive, reinforcing loop also works in the other direction. In the example also a negative, balancing loop is present; when the shortfall in recharge stations increases, more stations will be constructed (more corrective actions are taken) which will reduce the discrepancy between the actual and desired number of stations.
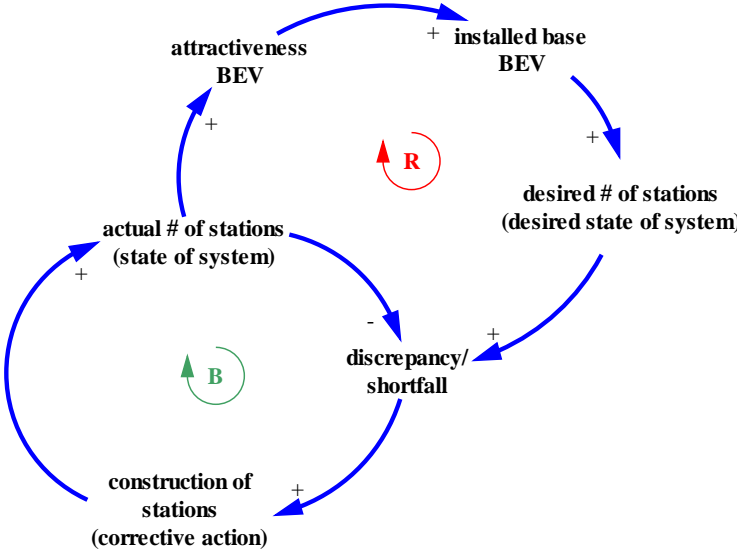
Figure 3.1 - Causal Loop Diagram Example

Now that the CLD modeling approach has been discussed, the transition model used in this thesis will be explained. The model is partially based on the transition model of Struben (2006) who modeled the transition towards fuel cell vehicles. The model is divided into three different sections with each section resembling one of three central players; (i) consumers, (ii) automotive industry and (iii) fuel providers. Before the three sections are discussed, however, the Bass diffusion model will be explained.

3.2   Bass diffusion model

The adoption of new products is often explained by means of the diffusion curve which shows an s-shaped curve in which adoption over time is shown (Tidd, 2010) (Figure 3.3, left). Managers often have little idea about the s-shaped behavior; their sales forecast often show linear growth (Golder and Tellis, 1997). However, the diffusion of products often has a distinct s-shape pattern with distinct takeoff moment. Although there are several models that simulate the diffusion of a product, one of the most popular models to simulate new product growth and diffusion is the Bass diffusion model developed by Frank Bass (Sterman, 2000). It is used in

many fields such as marketing strategy and management of technology. The Bass diffusion model solves the startup problem logistic- and many other models have. A logistic model is in equilibrium when there are no adopters and hence it cannot explain the genesis of the initial adopters. Bass solved these start up problems by assuming that potential adopters become aware of a new product innovation not only through word of mouth of initial adopters but also through external information sources such as advertising and media attention (Sterman, 2000). The consumer section of the model is based on the bass-diffusion model although important revisions have been made. These improvements are based on the work of Struben (2006) who modeled the transition towards hydrogen vehicles in the US.

In Figure 3.2 the Bass diffusion model is shown. The total adoption rate is the sum of adoptions resulting from advertising (loop B) and adoptions arising from Word of Mouth (loop R). In the beginning, when the product is introduced and the adopter population A is zero, the only loop that will be active is loop B; adoption only occurs through the external influence of advertising. The effect of advertising (blue line in Figure 3.3, right) will be the largest at the beginning of the diffusion and diminishes over time when the number of potential adopters P reduces (Sterman, 2000). The effect of loop R will increase when more people adopt the product, hence it is reinforcing. The higher the number of adopters A, the more Word of Mouth (WoM) is generated and the more potential adopters P become aware of the product and will adopt the product even further increase WoM (red line). Once more than half of the potential adopters have adopted the product (i.e. they became Adopters A), the market gets saturated (as the number of Potential Adopters P left is reducing) and hence the adoption rate will decrease, which can be seen in Figure 3.3, right (green line).

In the dynamics of a bass diffusion curve there is a point where the increase in adopters A is self-sustaining. This point is called the *tipping point.* At the tipping point, reinforcing, positive feedback loops within the system dominate the negative balancing feedback loops; the adopters A population becomes dominant (Sterman, 2000).
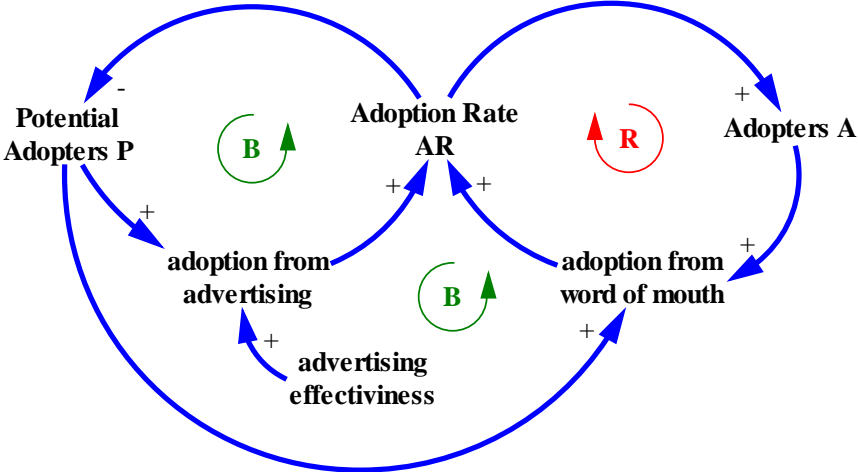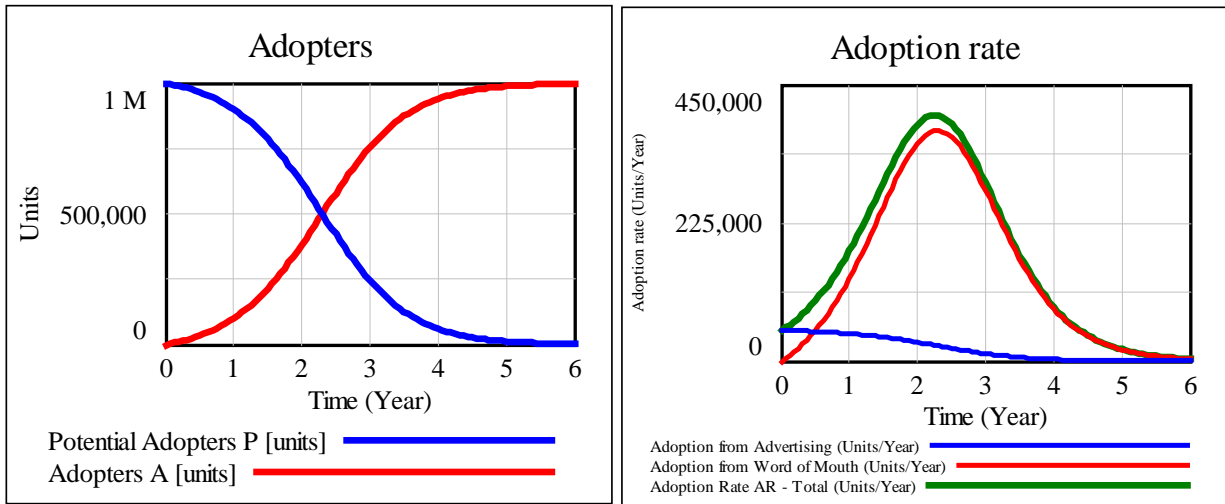

Figure 3.2 - Bass diffusion model

Figure 3.3 - (Potential) adopters (left) and adoption rate (right) over time

However, the Bass diffusion model has some limitations; the adoption in the original model only occurs through advertising and WoM. However, potential adopters do not adopt a product solely due to these two influences; the product characteristics are just as important. What is the attractiveness of the product compared with similar products on the market? What is for instance the attractiveness of the BEV platform when it is compared to other platforms such as the ICE platform? Potential adopters will look at the price, performance, driving range, operational costs and availability of complementary goods such as fuel infrastructure. In the original Bass diffusion model these influences are omitted and assumed to be zero while the importance of WoM is greatly overestimated (Sterman, 2000). Also, the bass diffusion model assumes a uniform communication flow; i.e. contact effectiveness or the strength of WoM is a constant for the entire population (Dattée and Weil, 2007). Another limitation of the bass diffusion model is that the population that adopted the product does not decrease, i.e. they never abandon the product nor do they repurchase it.

3.3   CLD - Consumer section

The model in this thesis solves several of the limitations discussed in previous section; the BEV platform will be compared with the dominant platform, the ICE, introducing competeiveness between the two platforms. The decision to adopt a platform is no longer based solely on WoM and advertising but depends on the 'perceived attractiveness' of each platform. The perceived attractiveness of the platform is determined by two main variables; (a) the 'real attractiveness' of the BEV platform compared to the ICE platform and (b) the 'familiarity' potential adopters have with the particular platform. The attractiveness of a platform depends on four attributes which are considered most important; (i) price, (ii) driving range, (iii) infrastructure density

and (iv) refuel/recharge time (Gärling and Thøgersen, 2001)[13]. Each attribute of a platform is compared with the attributes of the other platform to determine its relative attractiveness. How potential adopters perceive this attractiveness and are willing to consider a platform depends, however, not only on the real attractiveness of each platform but also on how familiar the person is with the platform (Montaguti *et al.*, 2002; Struben, 2006; Dattée and Weil, 2007).

The BEV might be a very good alternative and can compete with the ICE, for a potential adopter to consider the platform it requires more knowledge, experience and exposure about and to the BEV platform as the ICE platform is a more familiar and trusted technology than the BEV and thus, people are more inclined to repurchase an ICE again rather than to purchase a BEV; they have more experience with the ICE platform and know what they "get"(Struben, 2006). Potential buyers face uncertainty, especially in the beginning and therefore are more inclined to stick with the product that can perform its job satisfactory, i.e. the ICE (Lieberman and Montgomery, 1988). Over time, when more information becomes available to the consumer, this uncertainty will reduce (Montaguti *et al.*, 2002).

In Figure 3.4 the CLD of the consumer section is given. The *'share of purchase BEV'* (i.e. the share of total vehicle purchases being a BEV) depends thus on how the attractiveness of the BEV is perceived. This *'perceived attractiveness'* variable depends on two variables; the attractiveness of the BEV compared to the ICE and the familiarity potential adopters have with the BEV platform. The first variable indicates how well the BEV platform scores compared to the incumbent platform, the ICE. The attractiveness of the BEV platform depends on its price, the operating costs, performance in terms of driving range and the availability of fuel infrastructure. The attractiveness of the BEV is determined by the supply side of the model, the automotive industry and infrastructure. These will be discussed in Paragraphs 3.4 and 3.5.

The other variable that influences the sales of the BEV platform is whether someone is familiar with the platform and is willing to consider it. The BEV might be very competitive and a good alternative for a group of drivers who are currently driving an ICE but if the BEV is not familiar and not in their consideration set the BEV will still not be sold regardless of its attractiveness. Vehicles are complex products and involve many experience attributes such as performance, comfort, reliability, fuel and operating costs. These attributes are often ambiguous and disputed in the beginning and the general public opinion is an important factor that can delay or fail the diffusion of the technology (Montaguti *et al.*, 2002; Struben, 2006; Dattée and Weil, 2007; Tidd, 2010). Consumers need to be educated and need to learn about and become aware of the existence of new technologies, its relevance and understand its

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[13] Surveys held by Ballast Nedam (Bongard, 2011) and Ecomobiel (2011) also indicated that these four attributes are considered most important. For an overview of the survey results see appendix D1&D2

functionality; they have to become familiar with the product and its technology (Struben, 2006).

When someone is exposed to the platform they will get more familiar with it and the more they get familiar with the platform the more they will take it into their consideration set the next time they will purchase a vehicle. This process of getting familiar with the BEV platform is slow, however, as vehicles can be considered durable goods, having long periods of time between successive purchases (Dattée and Weil, 2007)[14]. A survey held in 2010 by Ecomobiel (2011)[15] showed for instance that 53% of the Dutch population is still unfamiliar with the term *'hybrid'* although commercially available hybrids are on the market since 2000.

People who are not familiar enough with the BEV platform will rather (re-)purchase an ICE, the platform that has proven its value and that is familiar to the customer and population; i.e. buyer choice under uncertainty (Lieberman and Montgomery, 1988). For instance, the Compressed Natural Gas (CNG) vehicle is popular in Argentina, Brazil and Pakistan but failed to get a foothold in the rest of the world despite its benefits compared with gasoline and diesel engines. People in the rest of the world are not familiar enough about its benefits and thus don't include it in their set of possible options when they are going to purchase a new vehicle (Collantes and Melaina, 2011). When familiarity of the BEV increases, the potential adopters will become more confident and more potential adopters are willing to consider the product and will include it into their consideration set (Montaguti *et al.*, 2002).

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[14] See also 12manage

[15] Sample population was the Dutch driver population with a sample size of 10.000. For the survey results see appendix D2.
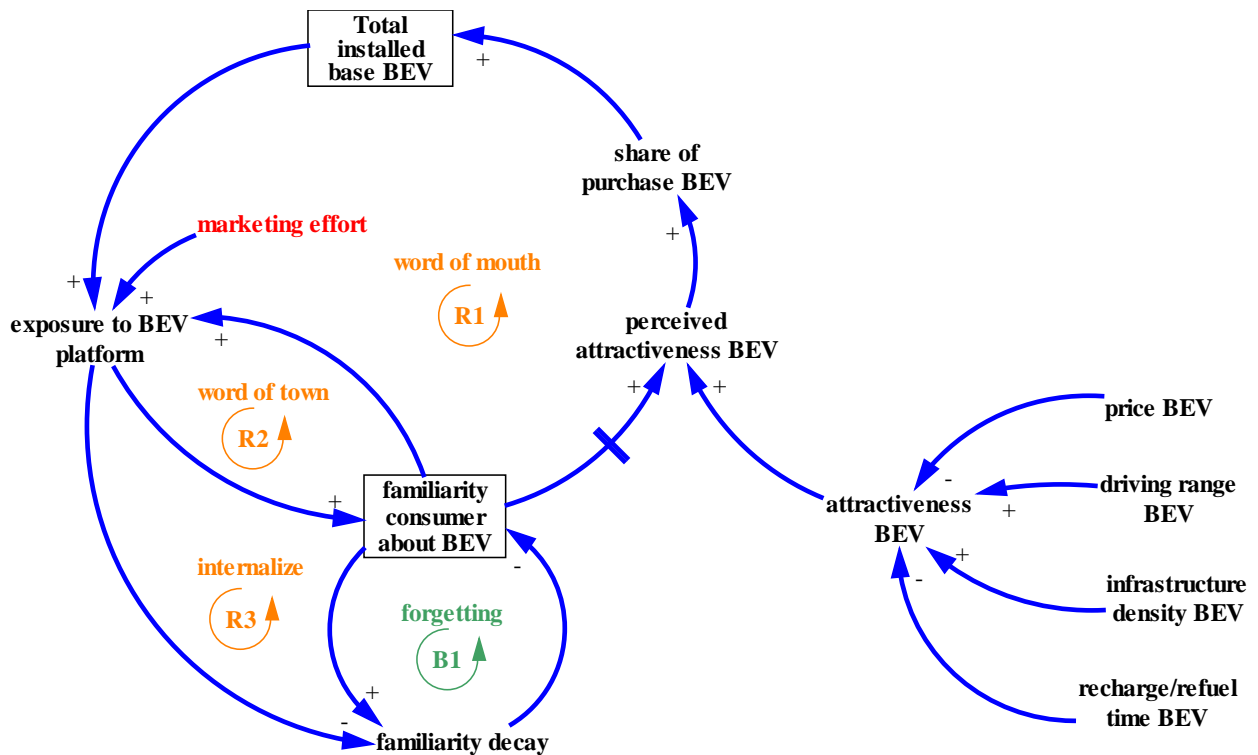
Figure 3.4 - CLD Consumer section

In the consumer section, this process of becoming more familiar with the BEV platform is captured. The stock *'familiarity consumer about BEV platform'* captures the cognitive and emotional processes through which non-BEV drivers gain enough information about, understanding of, and emotional attachment to the BEV platform for it to enter their consideration set (Struben, 2006). Familiarity increases through exposure the driver population has to the BEV platform and this exposure originates from several sources (Sterman, 2000)[16]. First, when the installed base of the BEV platform increases, it will result in more direct exposure to the BEV platform. For instance by seeing the BEV driving on the street, by test-driving the vehicle, information and experiences shared by BEV drivers, etc. This will lead to more familiarity of the platform and increases a person's willingness to consider the BEV platform and eventually will lead to more sales and a higher installed base of the BEV and thus even more direct exposure to the BEV platform. This dynamic is captured in the reinforcing loop R1, the *'word of mouth'* loop.

Another reinforcing feedback loop that can be identified is loop R2, the *'word of town'* loop. Vehicles are emotional and visible products and familiarity of the BEV platform will also increase through interaction between nonBEV drivers. When familiarity about the BEV increases, people will talk more about the product and by doing so, more exposure to the BEV platform is created increasing its familiarity further. It is assumed that WoM from a BEV

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driver has more strength as they share more information about the BEV and the information is considered to be more creditable compared to WoM of nonBEV drivers (Dattée and Weil, 2007; Struben and Sterman, 2008).

Familiarity can not only increase, it can also decrease as it takes effort to gain attention and other platforms such as the ICE are competing for attention of the potential adopters. People can thus lose interest and 'forget' about a product. This behavior is captured in the balancing loop B1, the *'forgetting loop'* [17]. However, when exposure is sufficiently intense, people start to accept this new technology into their daily lives and the platform becomes internalized which means that the platform becomes embedded in their minds, reducing the influence of balancing loop B1 which captures forgetting (Struben, 2006). In the beginning, when exposure to the BEV platform is low and infrequent, the decay of familiarity will be high; hence, the increase of familiarity due to exposure will be decreased due to familiarity loss. For consumers to adopt a BEV, familiarity increase should exceed familiarity decrease due to forgetting. Once more consumers have adopted the platform and the total exposure to the BEV platform increases sufficiently, the familiarity loss will become zero (loop R3; *'internalize loop'*).

Besides loop R1 and R2, also an external variable influences the total exposure the population has with the BEV, namely the marketing effort. This exogenous variable is important as it generates the first exposure the population has to the BEV platform (Sterman, 2000); it starts the initial gain in familiarity of the BEV platform and thus its sales (given that the BEV platform is sufficiently competitive). The effect of marketing will be largest at the beginning and will diminish over time once more people have adopted the BEV.

3.4   CLD - Automotive section

The attractiveness of a platform is determined by four attributes; (i) price, (ii) driving range, (iii) infrastructure density and (iv) refuel/recharge time. In the automotive section the price of a platform is determined while the other three attributes are determined in the infrastructure section. In Figure 3.5 the CLD of the automotive section is shown. Price is an important attribute as a new (higher quality) technology will not displace an old (lower quality) technology if there is a significant price difference (Windrum and Birchenhall, 2004). Even if the BEV scores very good on the other quality attributes, if the price is too high consumers will not purchase it. According to Golder and Tellis (1997) it's also the single most important attribute to determine the take-off in sales.

There is one reinforcing feedback loop R4 which resembles the reduction in platform price through scale effects. When vehicle sales of a platform increase, a company gains more experience in producing the particular platform which will decrease the cost of producing a unit

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[17] In appendix B2.4 the behavior of the forgetting loop is discussed in more detail.

(Lieberman and Montgomery, 1988) and the price a potential customer has to pay. When the purchase price drops, the vehicle platform will become more attractive (given the attractiveness of the other platform remains the same) and more vehicles of the platform will be sold. This in turn will even further decrease the unit cost due to more cumulative sales.

Besides the unit cost of a vehicle, also other costs should be taken into consideration. Especially for the BEV, the batteries make up a large part of the total purchase price (Electrification-Coalition, 2009; Offer *et al.*, 2010; ING-Economisch-Bureau, 2011; van Vliet *et al.*, 2011). Although it would be possible to model the reduction in battery costs endogenously within the model, it would be less accurate as battery improvements and cost reductions are not only made in the automobile industry but also in several other industries (e.g. computer industry) and thus the reduction of the battery price through scale effects would be less accurate. Therefore the battery cost reduction is modeled exogenously on the basis of predictions made by other researchers (Electrification-Coalition, 2009; Offer *et al.*, 2010; ING-Economisch-Bureau, 2011; van Vliet *et al.*, 2011). However, as Windrum and Birchenhall (2004) noted, the entrance of new technologies stimulates the old technology firms to innovate and to improve the quality of their products. In the model, therefore, an increase in fuel efficiency of the ICE was included which reduces the price of the ICE over time making it more attractive.

Besides the purchase price, also operating costs influence the attractiveness of a vehicle platform. However, consumers often don't consider the Total Cost of Ownership (TCO) but consider the operating costs for the time they will drive the vehicle which is for the majority of people about four years[18]. Therefore, only the costs made in the first four years are considered in the model.
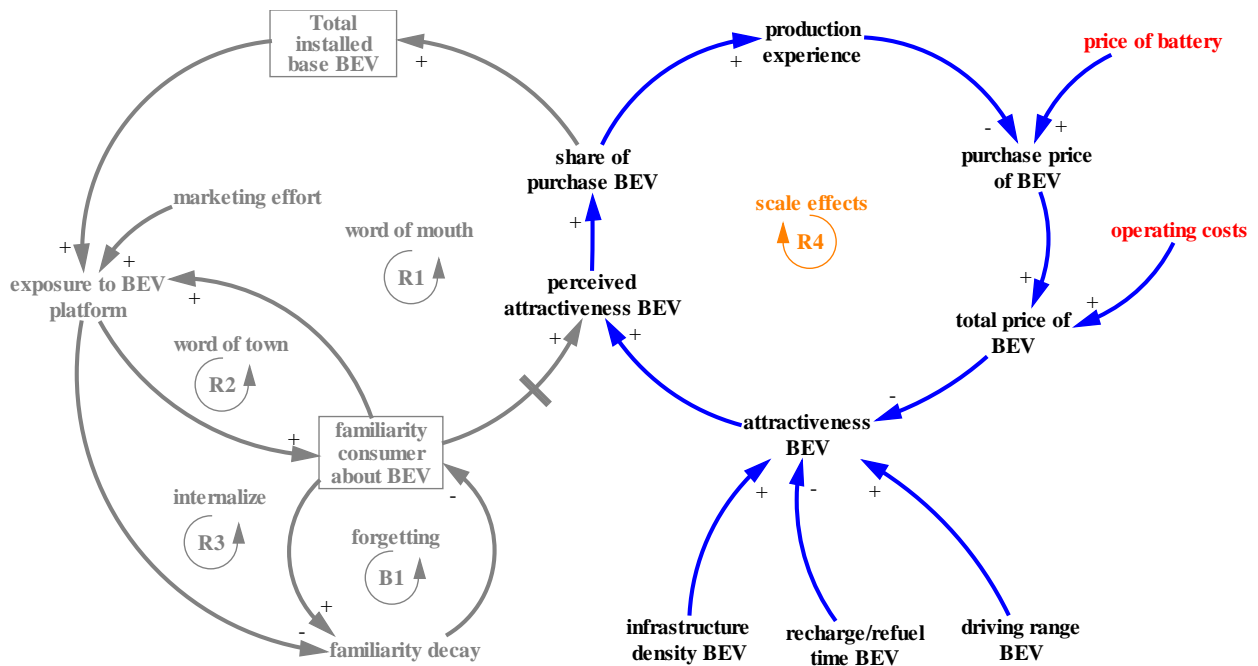
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[18] See also autotrack

Figure 3.5 - CLD Automotive section

3.5 CLD - Infrastructure section

In the infrastructure section the other three attributes are modeled (see Figure 3.6). A vehicle platform might be very attractive in terms of price, if the platform can only be refueled in a few places it is still unattractive to purchase. Likewise for attributes such as driving range; a short driving range will result in more detours to a recharge/fuel station and more inconvenience. The infrastructure section simulates the endogenous growth of the fuel infrastructure satisfying one of the criteria stated by Welch (2006); a transition model should contain endogenous vehicle demand and refueling infrastructure growth. This chicken-egg dynamic, which was discussed in Paragraph 1.1.1, is captured by the reinforcing feedback loop R5 (*chicken-egg-dynamic)*. When the number of BEVs increases (installed base), the recharge demand will increase which in turn will increase the number of stations needed (goal). This in turn will increase the station density which makes it easier for drivers to find a recharge spot and hence the attractiveness to drive a BEV. The BEV becomes more attractive which increases the attractiveness of the BEV platform (given the attractiveness of the ICE platform remains the same) more BEV sales will be made resulting in a larger installed base and recharge demand.

Besides the reinforcing feedback loop R5, there is also a balancing loop (B2) which captures the action of companies to construct recharge stations. When the number of stations desired increases, a station shortfall (gap) will occur between the desired and actual number of stations. Companies will try to close this gap and the larger this gap becomes the more effort they will put in the construction of new recharge stations as the business opportunity becomes more visible and companies will take actions to capture this opportunity by constructing more

recharge stations. The number of stations needed depends on two variables; the size of the installed base and the number of stations needed per vehicle. The number of stations needed per vehicle is depended on the driving range; when vehicles can drive further, less recharge moments are needed which reduces the number of stations needed per vehicle (Electrification-Coalition, 2009).

Driving range also has a direct effect on attractiveness; not only reduces it the need for recharge stations, it also means less refuel effort due to a lower refuel interval. Another exogenous variable is the recharge time; the shorter the time to refuel, the higher the attractiveness for this attribute. Slow recharging has the disadvantage that it can take a long time, up to 8 hours depending on the state of charge of the battery. This is less of a problem when the driving range of the vehicle is sufficient to suffice in the daily driving need and the vehicle can recharge overnight. However, if the driving range isn't sufficient during the day, recharging along the way is necessary. In this case it would be highly inconvenient when the vehicle needs to be recharged for many hours before the driver can continue its journey. Therefore, the attractiveness of the vehicle is depended on the driving need of the driver and the recharge technology employed.

Figure 3.6 - CLD Infrastructure section

4 Results

In this chapter the results from the base run will be presented. The settings and rationale for the base run can be found in appendix B2 & B3. Furthermore, this chapter discusses several scenarios. These scenarios show the effect of different values for familiarity and platform attributes on the dynamics of the technological transition.

4.1 Base run

The transition model is used to see the behavior of transition over time. The base case functions furthermore as a comparison to other scenarios; what happens compared to the base run when other parameter values are used. On page 42 several graphs are plotted that show the behavior of key variables in the system. The duration of the simulation is 50 years to show the full behavior of the model and transition. In graph A the fraction of the total installed base is shown (blue and red line). Remember that the total installed base of all platforms is considered a constant as the number of new vehicle sold every year is about the same amount of yearly discards (~510.000). The graph shows that only after 40 years, in 2050, there will be more BEVs on the road then ICE vehicles; the BEV fraction of the total installed base is growing slowly. In graph A also the share of purchase of each platform is shown (green and grey line). The share of purchase growths faster than the fraction of installed base of the BEV; in ~2037, 50% of the new vehicles sold will be a BEV. These new vehicles sold will enter the aging chain[19]. This aging chain accumulates new vehicles and discards the vehicles that are being scraped. This explains the difference between share of purchase and fraction of installed base; as vehicles in the Netherlands have an average lifespan of about 16.4 years[20] it takes considerable amount of time before the whole car park changes platform.

The share of purchase depends on the perceived attractiveness of each platform which is again depended on the familiarity and actual attractiveness of the platform[21]. In graph B the attractiveness of the different BEV attributes is given as well as the overall attractiveness of the BEV and ICE platform (blue and red line respectively). The graph shows that the attractiveness of the ICE platform remains almost constant with a small decrease at the end of the simulation which is caused by a decrease in fuel stations. And although the fuel price rises every year with 3.68 eurocents/liter, the increase in fuel efficiency and decrease in purchase price of the ICE platform compensate the extra costs due to increasing fuel prices. The total price of a platform (purchase price + 4 year operating costs) thus remains more or less around the total price of the ICE at t_0. In the graph it can be seen that around ~2025 the BEV

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[19] See appendix B2.2.

[20] See appendix C7

[21] As discussed in Paragraph 3.3. See also formulas 4 and 5 in appendix B2.3

becomes more attractive then the ICE although, due to the lack of familiarity, the share of purchase needs another 10 years to become more then 50%. Looking at each attribute in detail it can be seen that the total price of the BEV is expected to be lower than the total cost of the ICE platform. At this moment (t_0), the TCO of the BEV is still about 1.2 times more expensive which corresponds with findings of others[22]. When looking just at the purchase price of both platforms and thus neglecting operating costs, however, it takes considerably more time before the BEV becomes cheaper, namely only after 2025 the purchase price of the BEV becomes lower than that of the ICE platform. The operating costs of the BEV are lower but these benefits are initially cancelled out by the higher purchase price of the BEV.

The driving range increases over the course of the simulation, increasing the attractiveness of this attribute. In the year 2040 the attractiveness of this attribute becomes equal to the attractiveness of the ICE driving range. The attractiveness from infrastructure density increases steadily as stations can be build fast and, due to an initially low amount of BEV vehicles, utilization and crowding at station stay initially low. Also, due to the increase in driving range, less recharges are needed and station density becomes less an issue. Recharge time however remains low for a long period of time but, due to the low weight given to this attribute, it has less impact on overall attractiveness of the platform. Furthermore the car can be recharged in less than 2 hours for 65% of the population[23].

Besides attractiveness of a platform, also familiarity influences how the attractiveness of the platform is perceived. Familiarity can be gained by the three sources; Word of Mouth from nonBEV drivers (word of town loop), Word of Mouth from BEV drivers and marketing[24]. The influences of these three loops can be seen in graph C, which plots the exposure created by these loops. As can be seen in the graph, the exposure initially is almost entirely generated by the marketing effort. As the average familiarity increases under ICE drivers, the word of town loop starts to go gain power; people still own an ICE but are getting more familiar and thus more exposure to the platform is generated. Later, when more people start to switch to the BEV platform, the word of mouth loop of BEV drivers starts to gain power while the word of town loop reduces again. This is caused by people who switch to the BEV platform and thus less people can generate exposure through the word of town loop. Also, people who switch to the BEV platform take their familiarity about the platform with them.

In graph D the dependency of perceived attractiveness on the familiarity and real attractiveness is shown. Although the BEV becomes more attractive in 2025, this is only perceived as such later on, due to the low initial familiarity of the platform. In 2037 the

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[22] See appendix C11

[23] See appendix B2.5.4

[24] See also formulas 6 and 7 in appendix B2.4

perceived attractiveness of the platform becomes higher than the perceived attractiveness of the ICE platform and hence the share of purchase being a BEV becomes higher than 50% (as can be seen in graph A). Between 2030 and 2050 the perceived attractiveness increases considerably; the real attractiveness of the BEV is already above that of the ICE platform and once familiarity starts to increase this has a major effect on the perceived attractiveness of the platform. The influence of different levels of familiarity on the transition will be explored in more detail in the next section.

In graph E the number of recharge stations over time (blue), the infrastructure density (green), construction rate (red) and distance between recharge stations (grey) are shown. Initially the number of recharge stations remains relatively low due to the small installed base of the BEV. From 2030 on, an increase in stations can be seen and in the end, in 2060, 2.1 million stations are being built which is half the amount of BEVs on the road around that time (every charge station is considered to have two charge spots). Looking at the construction rate it can be seen that, after an initial increase, the construction rate remains constant between 2015-2025. This is caused by the increase in driving range of the BEV which reduces the number of recharge stations needed per vehicle. However, between 2025 and 2030 the construction rate increases sharply due to the increase in BEVs and at the top of the growth rate, about 95.000 stations need to be build per year to keep up with recharge demand. This means that per day, about 430 stations need to be built which is a huge amount and it is the question if this construction rate is possible to be achieved[25]. It must also be noted that these are all slow recharge stations and hence, quick recharge stations could replace a multitude of these recharge stations due to the higher carrying capacity of such stations. However, fast recharge stations are more expensive compared to slow recharge stations and have a negative effect on the lifespan of the battery.

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[25] Considering there are 220 working days in a year

A — Share of total installed base and Share of new vehicle purchases

Fraction of installed base BEV
Fraction of installed base ICE
Share of new purchases BEV
Share of new purchases ICE

B — Attractiveness of attributes BEV

Overall attractiveness BEV
Overall attractiveness ICE
Attractiveness from Infrastructure Density
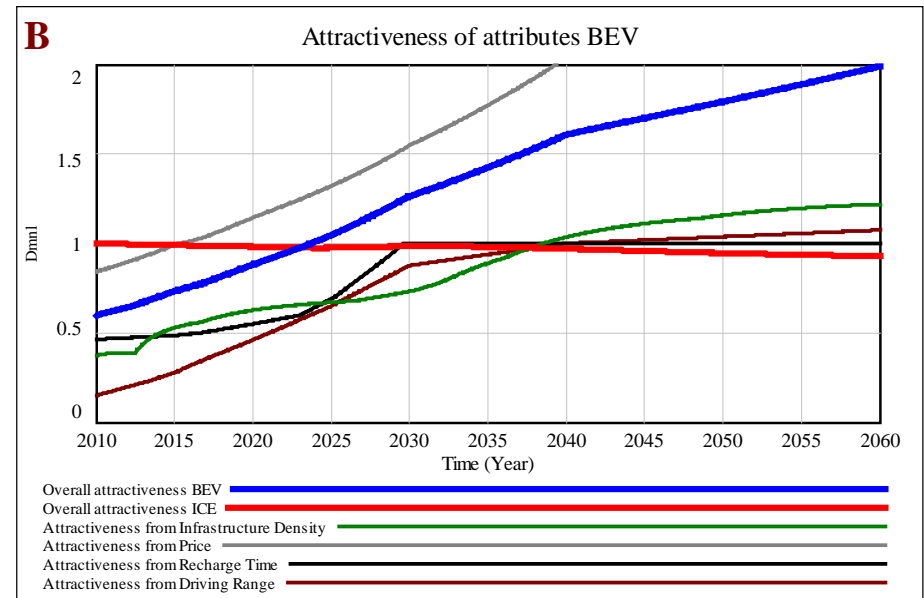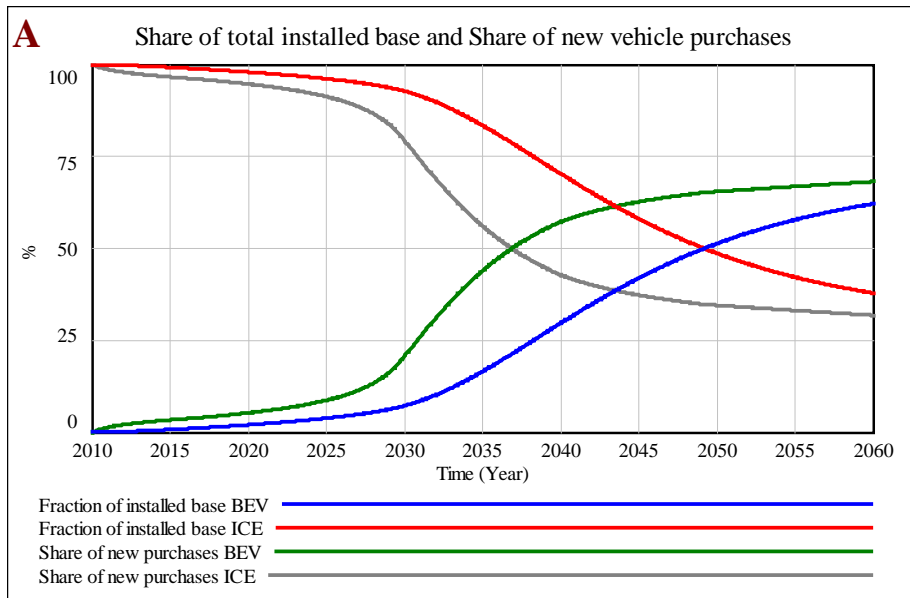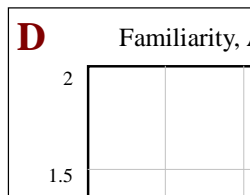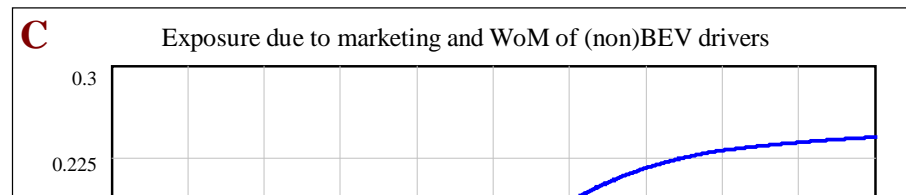Attractiveness from Price
Attractiveness from Recharge Time
Attractiveness from Driving Range

Figure 4.1 - Base run – graphs A-D

C — Exposure due to marketing and WoM of (non)BEV drivers
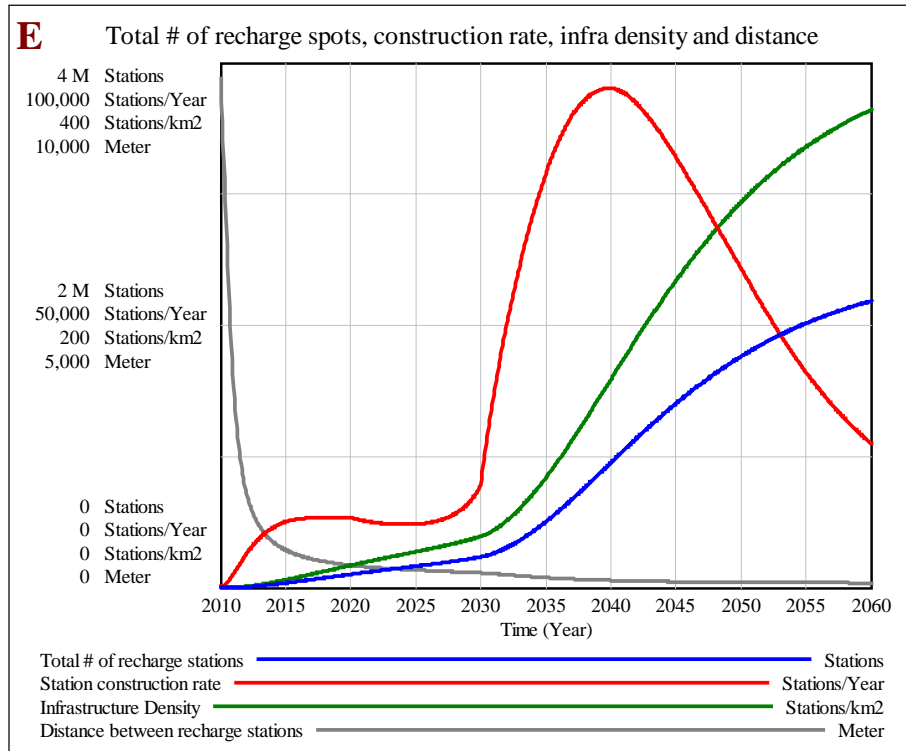
D — Familiarity, A

Figure 4.1 - Base run – graph E

4.2 Familiarity with BEV

As discussed before, the familiarity drivers have with the BEV influences how the attractiveness of the BEV is perceived which in consequence determines the share of purchase of the BEV. Initially, the adoption rate of the BEV is very low due to low familiarity of the platform compared to the ICE platform. Even when the BEV becomes more attractive, diffusion speed initially stays low due to the low familiarity. To accelerate the diffusion of the BEV, a higher exposure to the platform could be beneficial as it directly influences the familiarity potential adopters have with the platform. Exposure to the platform is generated by three variables: WoM BEV drivers, WoM non-BEV drivers and marketing effectiveness. To see the effect of marketing on familiarity generation; the marketing effectiveness in terms of strength and duration is tested.

In Figure 4.2 (left graph) the duration of the marketing campaign is changed while the strength is unaltered. In the figure, two different patterns are visible after the marketing campaign is ended; or familiarity stagnates and decreases again or familiarity about the BEV platform increases further. This behavior is caused by the tipping point in the system as discussed in Paragraph 3.3. When the market duration is shorter than 22 years, the WoM loops are too weak to generate enough exposure to the platform. The balancing loop (*'forgetting'*) is still dominant and hence familiarity will decrease after the marketing campaign has ended. A marketing campaign longer than 22 years will result in further growth in familiarity. As can be seen in the graph, the increase in familiarity after 22 years is mainly generated by the WoM

loops as the impact on familiarity increase due to a longer marketing duration is minimal (compare for instance the impact of the 24 and 50 year marketing campaign on familiarity increase). This result indicates that marketing duration should be long enough in order to reach the tipping point of the system but once the system has passed the tipping point, the influence of marketing reduces.

In Figure 4.2 (right graph) the impact of different marketing strengths and/or marketing durations are shown. Here it can be seen that that the impact of marketing strength on familiarity increase is substantial. Also, with an increased marketing strength, the duration of the marketing campaign can be shortened; with a marketing strength of 0.04 (0.05) the tipping point is already reached after 12 (8) years instead of 22 years when marketing strength is 0.03. This could be important as it might be cheaper to invest heavily in marketing for a short period of time in the beginning to initiate the word of mouth loops then to invest moderate in marketing for a longer period.
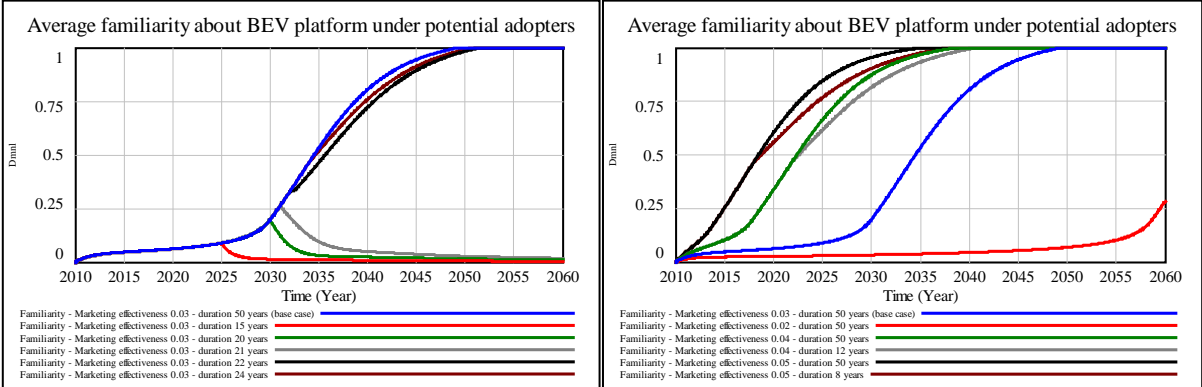

Figure 4.2 – Familiarity – different durations (left) and effectiveness (right)

The effect of marketing strength and duration on familiarity increase has to do with the balancing loop B1 (= *'forgetting loop')*. The rate of '*familiarity decay'* depends on the total exposure the platform receives[26]. Above a certain exposure, familiarity decay becomes zero. In Figure 4.3 the familiarity decay rate is shown. The red lines show that, when the marketing campaign is ended too early and the WoM loops are not dominant yet in creating sufficient exposure, familiarity decay will increase again after the marketing campaign is ended. The total exposure to the platform is, due to ending of the marketing campaign, reduced and too low to shut down the balancing loop ('*forgetting loop'*). Look for instance at the grey lines of both graphs; due to the low marketing strength, familiarity is only gained slowly (right graph) as not enough exposure is generated to close the forgetting loop. Only at the end of the simulation, enough exposure is generated and the familiarity decay rate becomes zero (left

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[26] See also appendix B2.4

graph). The outcome of Figure 4.3 shows that familiarity with the BEV platform can be lost quickly if the marketing campaign is ended to soon.
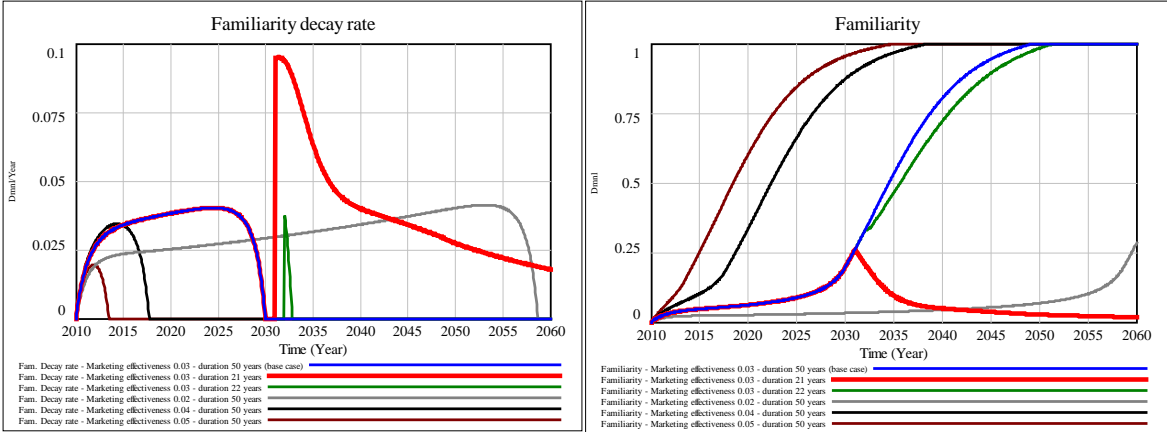

Figure 4.3 - Decay of familiarity at different marketing effort/durations

In Figure 4.4 the share of purchase for different advertising efforts is shown. It can be seen that the impact of familiarity on the market share of the platform is substantial. In the base case (blue line), a share of purchase of 20% of the total sales (≈ 110.000 vehicles) is achieved just after 2030 while when the marketing effort is 0.04 or 0.05, 20% share of purchase is already reached in 2019 and 2017 respectively. These results also show that marketing greatly influences the share of purchase of the BEV and greatly influences the transition.
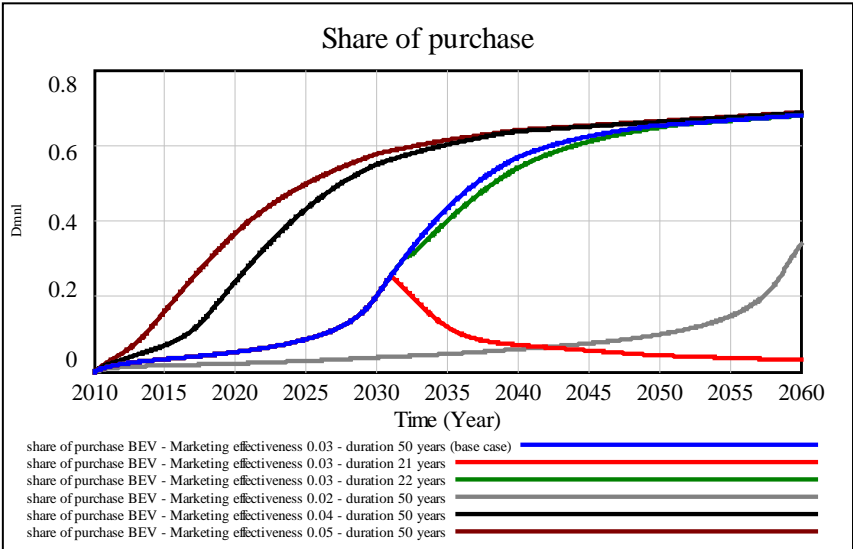

Figure 4.4 - Share of purchase with different marketing effort/durations

4.3   Price

According to the literature (Golder and Tellis, 1997; Gärling and Thøgersen, 2001) and surveys conducted, the most important attribute of a vehicle platform is the price. In this section, therefore, different price scenarios are discussed to see what the effect is on the dynamics of the transition.

4.3.1   Including different TCO calculations

In the base run the assumption is made that drivers consider, besides the purchase price of the vehicle, also the operating cost for four years. In case of the BEV, looking at the total costs (= purchase price + operating costs[27]) is beneficial as the purchase price of the BEV at t_0 is much higher than the ICE due to the high battery price. The lower operating costs of the BEV, however, partially compensate this higher purchase price. But what happens when potential consumers only look at the purchase price and neglect the operating costs? Or when they look at operating cost over a shorter or longer period of time?

In Figure 4.5 the impact of the BEV price on share of purchase (left) and construction rate of recharge stations (right) are shown. The blue lines indicate the base case in which purchase price (PP) and the operating costs (OC) for four years in total are considered. It is clearly visible that, when customers only consider the purchase price (red line), the takeoff moment is delayed with about 5 years. This is caused because the initial purchase price of the BEV is much higher than that of an ICE and thus the attractiveness of the price attribute of the BEV is lower, meaning that the overall attractiveness of the BEV is lower as well. When the operating costs over a longer period than 4 years are considered (black and brown line), take-off occurs earlier. This has implications also on the construction rate as can be seen in the graph on the right. For all scenarios, take-off in construction rate occurs around 2025-2030, but depending on the scenario the slope of the take-off curve is steeper. In light of these scenarios in can be important for stakeholders in the e-mobility market to emphasize that customers should consider TCO instead of just looking at the purchase price. Furthermore, infrastructure providers should be aware that the slope of the construction rate becomes higher when people are considering TCO instead of just purchase price, meaning they have less time to scale up their production/construction rate. Consider the time to go from a construction rate of 25.000 stations/year to 90.000 stations/year; in case of the red line companies have 9 years to scale up while in case of the brown line this is just 7 years.

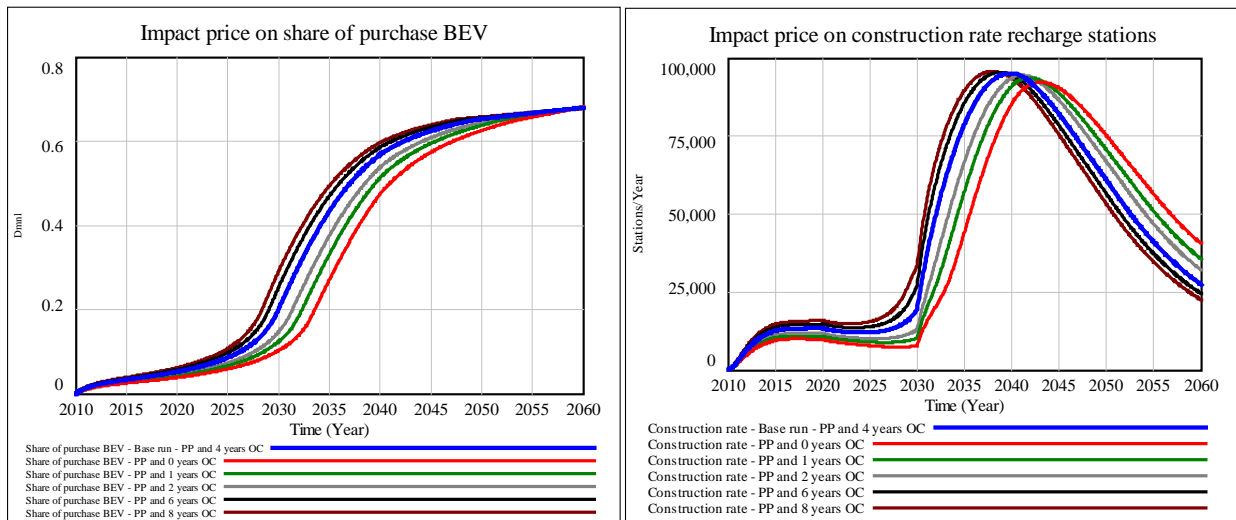[27] See also formula 13 in appendix B2.5.1

Figure 4.5 - Effect of different TCO calculations on share of purchase and construction rate

4.3.2   Subsidy

The government can, besides the tree central actors, also influence the transition. For instance by providing subsidies on BEVs, lower taxes for the BEV or increase taxes for the ICE. To see the implications of different government policies on the transition, several scenarios are simulated which are shown in Figure 4.6. First, consider the scenario where the government decides to give a subsidy of 5000 euro on the purchase price of the vehicle. When the subsidy is given for the whole simulation period (red line), which is highly unlikely, it would result in considerably more sales after the year 2025. However, for a more realistic scenario also durations of 10 (green line) and 15 years (gray line) are simulated. The effect of the subsidies on BEV sales can be seen even after the subsidy has stopped (2020 and 2025 respectively) but eventually, on the long run, the effect of the subsidies will wear off. In the figure also the impact of extra taxes on ICE platform is shown. In one case, a BPM tax of 40% is charged instead of 27.7% (black line) and in the other case, the BPM tax increases with 1 percentage point per year starting with 27.7% at t_0 (brown line). As can be seen in the graph, extra tax for the ICE has less effect then giving a subsidy on the BEV. Overall, it can be concluded that the government, by giving subsidies or increasing taxes, can influence share of purchase for the BEV platform in a positive way although the effect is minimal. In the beginning, the purchase price of the BEV is high, even when a subsidy of 5000 euro is given. This means that the attractiveness of the BEV price is still inferior to the ICE price. As subsidy is only given the first 10-15 years and familiarity in the first period is low, the impact is minimal. Also, the attractiveness depends not only on the price attribute but also on the other three, which are also low in the first 15 years of the simulation.
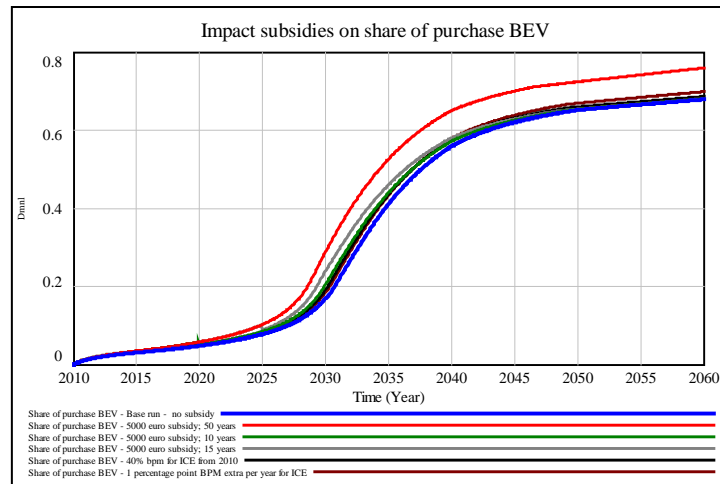
Figure 4.6 - Impact subsidies on share of purchase BEV

4.3.3   Impact different payment structures (subscription or pay per kWh)

There are two basic pricing strategies to generate revenue from public recharge stations[28]. However, it is unclear if consumers are willing to pay a premium on top of the normal kWh price or if they are willing to subscribe to a contract of a service provider (when they are able to charge at home or at the office). In the base-run the "fuel costs" of the BEV are calculated by using the standard kWh price for households (0.25 euro/kWh). However, people who need to charge in the (semi-) public domain need to pay more. To see the difference in adoption, two payment strategies are simulated; one scenario where infrastructure providers add a margin of 50% to the kWh price (which means that users pay about ~270 euro extra per year) and one scenario where consumers pay a subscription fee of 100 euro per month (about ~665 euro extra per year)[29].

In Figure 4.7 the results are shown. As the costs for consumers in the subscription strategy are higher, the share of purchase lacks behind that of the other two strategies. The TCO will be higher and thus attractiveness of the BEV is lower. The same accounts for the pay-per-kWh strategy, albeit less than in the subscription strategy. The effect of different payment structures is however minimal on share of purchase and construction rate as the effect on the total cost of ownership is, due to the high purchase price of the BEV, minimal.

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[28] See appendix C3.2

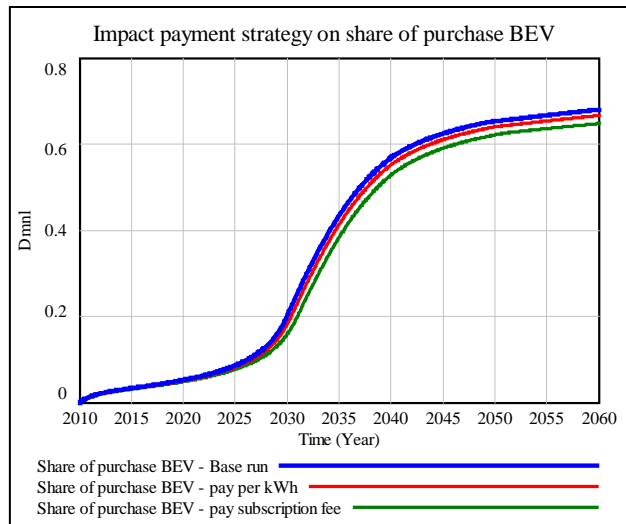[29] Fees are fixed over the whole simulation period

Figure 4.7 - Impact pricing strategies

4.4   Driving Range

The driving range of a BEV depends for the largest part on the battery capacity. What will happen when the battery technology improves faster or slower than predicted in the base case scenario? A scenario with different driving ranges due to battery technology is therefore simulated to see the impact on share of purchase and construction effort for infrastructure providers. Figure 4.8 shows the impact of different driving ranges due to battery technology on share of purchase and construction rate. The driving range is increased/reduced with fixed percentages (-50%, -25%, +25% and +50%). Looking at the share of purchase between the worst case (-50% driving range, black line) and the best case scenario (+50% driving range, green line), a maximum difference of about 15% in share of BEV purchases can be seen or, in absolute numbers, an extra ~77000 BEVs per year will be sold.

Looking at the construction rate, in case of the worst case scenario, a higher amount of stations will need to be constructed due to the lower driving range of the BEVs. In the best case scenario, the construction rate initially decreases. However, due to a higher overall attractiveness of the BEV, the share of BEV purchases increases more rapidly increasing the number of BEVs on the road and thus construction rate increases again after the initial decrease. If the worst case (-50%) is left out, the impact on construction rate is minimal.
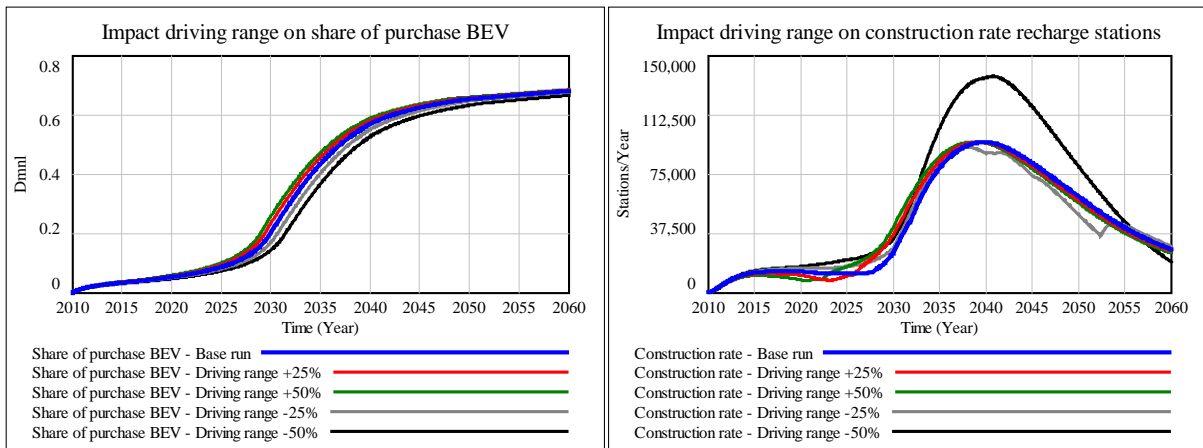
Figure 4.8 - Impact driving range on share of purchase (left) and construction rate

4.5 Infrastructure density

The number of stations that are needed per vehicle depends on the driving range of the vehicle. In the base case the station per vehicle ratio starts with 2 and decreases to 1 station/vehicle in the long run[30]. This ratio, however, is an assumption as it is unclear how many stations per vehicle are really needed. To see the implications of higher or lower station to vehicle ratios, two scenarios are plotted; One where the ratio goes from 2.5 at t_0 to 1.5 station/vehicle and one scenario where the ratio is 1.5 to 0.5 station/vehicle. In Figure 4.9 the results are shown; in the high ratio scenario, ~150.000 stations need to be build per year on its peak while in the low ratio scenario ~50.000 stations per year need to be constructed. Also, the growth in construction rate is much higher for the high station to vehicle ratio as take-off in BEV sales occurs more or less at the same time for all three scenarios. In the period 2027-2040 this would mean a growth of ~121.000 stations/year in the high ratio scenario while in the low ratio scenario the growth in construction rate is 'only' 44.000 stations/year, a considerable difference. In the long run, this means a difference in total number of stations of two million. Till 2025, however, the difference in construction rate is small. From this scenario it can be concluded that it is important to keep track of the station to vehicle ratio, especially when take-off is about to occur as large differences in construction rate can be expected depending on the station/vehicle ratio. By the time take-off will occur, it is likely that more is known about consumer recharge behavior and in consequence the appropriate ratio.
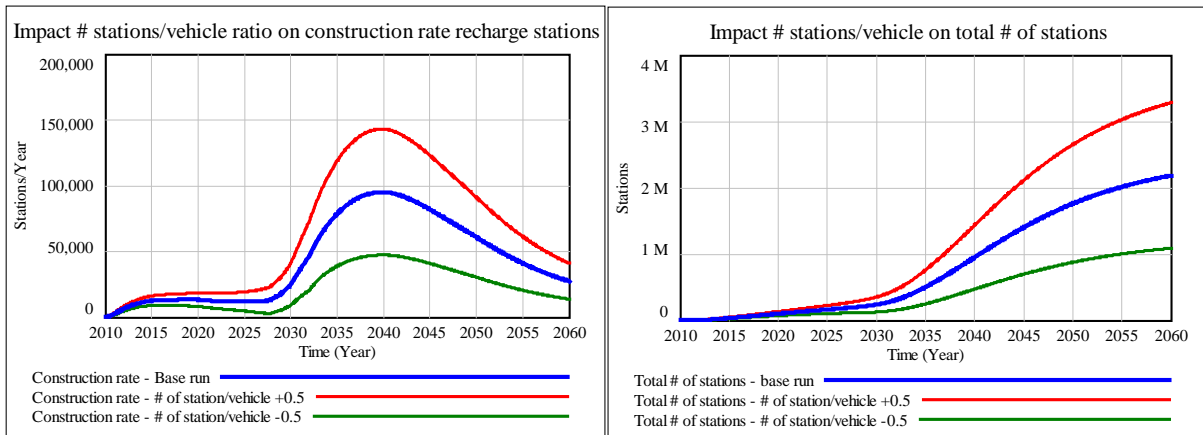
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[30] See also appendix B2.5.3

Figure 4.9 - Impact # stations/vehicle on construction rate and # of stations

4.6   Overview results

In Table 4.1 below an overview of the simulation results is given. The variables that influence familiarity have a large effect on the transition. For the transition to become self sustaining, marketing duration should be long enough in order to reach the tipping point of the system. Once the system has passed the tipping point, the influence of marketing reduces. The large effect on share of purchase also has implications for the construction rate of the needed infrastructure. Therefore, it is important to closely monitor the familiarity customers have with the BEV platform.

Looking at the price scenarios, TCO has a moderate influence on share of purchase and construction rate while subsidies and different payment schemes have a small effect. To stimulate adoption, stakeholders should emphasize customers to consider TCO instead of just looking at the purchase price.

Driving range has a moderate effect on the share of purchase which is as expected as driving range is an important attribute of a platform. The impact on the construction rate is however small. A lower driving range indicates that more stations will be needed. However, due to the lower attractiveness of the BEV, the share of purchases will be lower and thus the amount of stations that need to be build. The reverse accounts for the scenario when driving range is higher; higher driving range means less recharge stations but due to the higher attractiveness, more BEVs enter the road.

The number of stations needed per vehicle has obviously a large impact on the station construction rate. However, as discussed, before take-off (<2027) the difference in construction rate is smaller. Once take-off occurs however large differences can be expected.

Table 4.1 - Summary simulation results

Type of simulation	Share of purchase			Construction rate		
	Small	Moderate	Large	Small	Moderate	Large

		effect	effect	effect	effect	effect	effect
Familiarity	Advertising			x			x
	WoM			x			x
	WoT			x			x
Price	TCO		x			x	
	Subsidies	x			x		
	Payment	x			x		
	Driving range		x		x		
	Stations/Vehicle		x				x

5 Discussion

In this chapter it is argued whether first-mover-advantages are present in the e-mobility market and if Ballast Nedam has the resources to be able to capture FMAs. Based on the base run, the effectiveness of the mechanisms in creating possible FMAs are evaluated and it is argued whether there are FMAs in the e-mobility market for an infrastructure provider. After the evaluation of the e-mobility market (macro side), the firm resources and capabilities are evaluated and argued whether FMAs, based on resources and capabilities, can be captured. Finally, an advice to Ballast Nedam is given whether they should follow a pioneer or a follower strategy and if so, which timeframe would be most suitable.

5.1   First-Mover-Advantages based on product-market characteristics

In this part the influence of the product-market characteristics on the effectiveness of the isolating mechanisms in creating first-mover-advantages is discussed. To recall, there are four broad categories of mechanisms; (i) economic factors (ii) preemption factors (iii) technological factors and (iv) behavioral factors.

5.1.1   Economic factors

Scale and experience economies: Looking at the base run it can be seen that the moment of take-off in sales occurs relatively late, around 2025-2030. The same accounts for the construction rate and number of recharge stations. This indicates that there is considerable amount of time to buildup scale economies for the pioneer. However, although the technology is relatively new and recharge stations are not yet produced on a large scale, scale effects are unlikely; recharge stations consist mainly out of low tech electronics in which cost reductions through scale effects are marginal. Also, a large share of the investment will go to labor costs such as constructing and installing the stations and arranging permits which is relative insensitive to cost reduction through scale effects (Philip and Wiederer, 2010). Furthermore the construction rate initially remains low meaning the magnitude of possible cost reductions through scale effects won't be high and the pioneer will likely, due to the unpredictable future, not deploy all its resources reducing the advantage. Furthermore, once take-off occurs, construction rate increases considerably in a short time period; the cost advantage a pioneer may have build up due to scale effects will be reduced as followers can also gain considerable cost reductions due to scale effects in that period as the pioneer won't be able to control the whole market. The entry barrier for followers due to scale economies of the pioneer will erode in this period and companies are likely to enter the market.

Marketing cost asymmetries: The first infrastructure provider has the advantage that his marketing messages are more effective in reaching potential customers (BEV drivers) and can create brand awareness for its charge stations. When the market growths, it has the advantage that, due to its created brand image, more people will know about its product creating a

possible larger market share compared to its followers. However, in the beginning, when the number of BEV drivers is still low, the number of potential customers (=BEV drivers) will be low and it will be questionable that people that don't have a BEV yet will even pay attention to the advertising campaign of an infrastructure provider (effectiveness of marketing message will be low).

5.1.2 Preemption factors

Preemption of input factors: The materials used for the recharge stations are not rare and it is not expected that being a pioneer has an advantage in this respect.

Preemption of space: The pioneer could be able to create FMAs and thus entry barriers for followers by preempting precious space; the pioneer is able to select the most attractive charge locations. When more stations are placed it will be harder to find an attractive charge location and thus it could pay of to be the pioneer. In case of fast charging this could be advantageous as it is preferred to place theses stations at places where traffic intensity is high such as highways and traffic hubs. However in case of slow charging, which is considered in this model, this is of less importance as the throughput time and thus utilization rate of a slow charge stations is very low as only one to two vehicles a day can be charged. It is thus less important to have attractive locations in terms of busy traffic throughput. Instead, it is more important that stations are close to where a driver wants to be; at work or in the street where they live. Entering too late could diminish the possibilities to find such places. It is therefore advisable to enter not too late although it is not per definition necessary to enter very early; a follower with many resources can still have attractive locations when he builds the majority of the stations between 2025-2035, before take-off. Also, when the market growth is high, at any point in time there will be enough buyers for the followers.

5.1.3 Technology factors

Innovations in product and process technologies can create a differentiation advantage and/or cost advantages. However, as discussed, the technology of recharge stations is not high-tech as it consists mainly out of ordinary low tech components. The technology used can, if necessary, be easily imitated and therefore in this respect there is no advantage in entering early.

5.1.4 Behavioral factors

Switching costs: Switching costs can be beneficial for a pioneer as they prevent the customers to switch to another brand or firm. There are two types; contractual and non-contractual switching costs. An infrastructure provider can impose contracts to the customers which makes it difficult for them to switch providers for a certain amount of time. These customers are then bounded which prevent other providers to capture these customers. However, once the contract is over customers are free to choose any provider they want. If a pioneer is able to capture most customers in the growth phase this could be a potential advantage. Looking at possible

advantages due to non-contractual switching costs, it can be concluded that there are none. People can charge wherever they want, due to standardization of the cables and plugs and thus can easily switch between providers in this respect. In the growth phase also the consumer power will increase as consumers have more choice in service providers.

The BEV is an experience good; the majority of its benefits can only be determined after it has been purchased. It also creates buyer switching costs as customers get used to the BEV and will be reluctant to switch. For the infrastructure this is less of an issue; the benefit of one recharge provider to another can be determined often before hand; it is more of a search good and hence, it will be difficult to build an entry barrier by the pioneer in this respect.

Network effects: In the e-mobility markets network effects are present. The value of the BEV rises when more infrastructure is present (indirect network effect). An infrastructure provider can also benefit from network effects. A pioneer can build a large network of recharge stations and by doing so create a higher perceived value compared to followers who don't have such an elaborate network. This advantage can be hard to overcome by following firms; only when market growth is high, competitors might be able to overcome this advantage. A pioneer can also create an advantage by having more attractive locations, although for slow recharging it is less important to be located at a busy traffic hub; it is more important to have many stations. Looking at the pace of the market evolution it can be seen that it takes quite some time before takeoff occurs and thus time for a pioneer to build up a large network of recharge stations. However, due to the low amounts of BEVs on the road before take-off, the revenues of the pioneer generated by these BEVs will probably not be enough to recover the costs he has made to install the network. Furthermore, as the moment of take-off is not expected in the coming 15 years, a pioneer might not have enough resources left when the moment of take-off does occur; if the pioneer can't keep up with demand the quality of the network will go down as more people need to charge on the same amount of charge stations; the probability that a BEV driver can find an empty spot will go down (blocking probability). Also, as the growth in construction rate is very high when take-off occurs, followers can build up their own installed base of recharge stations as well as there will always be a market with potential clients and thus can potentially overcome the advantage the pioneer created.

5.1.5 Pace of market and technology evolution

Comparing the base run with the scenarios of Suarez and Lanzolla discussed in Paragraph 2.2.3, the most likely scenario for infrastructure providers is situated in quadrant 1 and 2 (see also Figure 2.2). The pace of technology evolution for recharge infrastructure is not considered to be fast and thus excludes quadrant 3 and 4. Whether the pace of market evolution is fast or slow is less clear. The simulation results showed that the extent to which ICE drivers are familiar with the BEV is very important on the transition speed. Based on the simulation, the BEV is likely to become competitive in 10 to 15 years. However, the gain in familiarity of the

product is slower; people will be uncertain about the performance, safety and other attributes of the BEV and confidence in the platform only growths slowly. The pace of the market evolution in the base case is thus expected to be initially slow but at the take-off phase, the growth curve is very steep for infrastructure providers which indicates that possible created FMAs will erode fast in this period.

5.1.6   Evaluation FMAs based on product-market characteristics

In Table 5.1 below, an overview of the mechanisms and their ability to generate possible FMAs based on the product-market characteristics is given. Possible FMAs for the pioneer are primarily present in the ability to preempt important space such as attractive locations but more importantly, the ability to create a large network of charging stations and by doing so create an important competitive advantage through network effects. This competitive advantage could be durable if the pioneer is able to keep up with demand when take-off occurs and can withstand low utilization rates in the beginning. Switching cost and economies of scale are expected to create medium FMAs while all other mechanisms don't succeed in generating durable FMAs as explained in previous paragraphs.

Table 5.1 - Overview mechanisms in creating FMAs

Mechanism	Ability to create FMAs	Rationale
Economies of scale	+/-	Expected to be moderate due to low tech components and high share of labor on total costs
Marketing cost asymmetries	-	Not expected to create FMA as consumers first have to become aware of BEV
Preemption of input factors	-	No scarce resources are needed
Preemption of space	+	A pioneer is able to preempt important and attractive locations although, when slow charging is considered, less important
Technological factors	-	Due to low tech components it is unlikely pioneer is able to differentiate its product or obtain cost advantages through technological innovations
Switching costs	+/-	Via contracts pioneer can commit consumers to its service. However, contracts can only bind consumers to a provider for a short period.
Buyer choice under uncertainty	-	Service providers can be easily compared and in the take-off phase consumer power increases due to new entrants.
Network effects	+	Pioneer can build a large network and create a strong competitive advantage. However, utilization will be low at start due to low amount of BEVs. Pioneer also needs to be able to scale up in time when take-off occurs to not lose its competitive advantage and be overtaken by others.

5.2   First-Mover-Advantages based on firm resources

Besides the moderating effects of the product-market characteristics on FMAs, also the firm's resources have a moderating effect on the FMA creating mechanisms. Based on Paragraph 5.1 and Table 5.1 it became clear that especially network effects and the ability to preempt space can generate FMAs and create entry barriers for followers. Whether these FMAs are durable on the long run is questionable, however; the pace of technology evolution is slow but this doesn't necessarily account for the pace of the market evolution. According to Suarez and Lanzolla (2005), when both pace in market and technology evolution are smooth, firm resources are less important[31] but as discussed, the pace of market evolution is, although initially slow, increasing rapidly and has a very steep growing curve at the moment of take-off. In this scenario, a pioneer should be able to keep up with demand. In case of an infrastructure provider this means large resources in distribution, production as well as large-scale marketing to target all possible markets. Furthermore, in the beginning the revenues generated by the limited amount of BEVs on the road are probably not enough to cover the costs of the installed networks; a pioneer should thus have a large financial buffer to cope with these early losses.

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████████████████████████████████ see Table E.1), it can be seen that BN scores relatively ██████████████████████████████████████ as well as the ██████████ ████████████████████████████████████. On the technical level they score relatively low as Ballast Nedam has not developed or placed any recharge stations yet. The reason that ██████ scores well in this respect is █████████████████████████████████████ ██ ██ ██████████████████████████████████ However, all ████████████████ ████████████████ score relatively low ████████████████ as they don't have much knowledge in this field although Ballast Nedam, through CNGnet, is gaining experience in this field. The flexibility and risk behavior is more or less the same for all ████████████████ ████████████████████████ scores slightly higher as they have already put resources into developing their ████████████████████████████ which is also the reason why e-mobility has a higher priority in this company compared to the others.

Moving on to the ████████████████████████, it can be seen that on technological level, ████████ scores well; ████████████, being a subsidiary from ██████, developed its own recharge stations and thus not has to cooperate with hardware suppliers. ████████ also scores well on marketing as they already gained some publicity in the Dutch e-mobility market and because they have a lot of knowledge concerning marketing in the B2C context as they are very active in the consumer market. ████████ however scores very well on marketing in the B2B context as

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[31] See also Table E.1 in appendix E2

they have a large market share in the B2B market which could be an interesting market for e-mobility as well. In finance and the ability to form partnerships ██████ scores relatively well. Also the flexibility and risk behavior of ██████ is rated higher by the employees of ██████ ████ as the corporate priority on e-mobility.

Of the ████████████████████████████████████ one stands out, namely ██████ ████████████████████████ is a ██████████████████████████ and is currently building an electric vehicle network in ████████████████████████████████████ ████████████████████████. As they carried out many pilot projects they have already knowledge on consumer behavior, utilization of recharge networks, etc which is valuable information as it has impact on the recharge infrastructure. They also formed several ██ an energy company in Denmark. On technological level ████████████ score relatively well except ████████████. On corporate priority all expect ████████ score high on corporate priority as the only market for these companies is the e-mobility market.

The last group of companies are the ████████████. In this group '████████ ████████ scores well; they are relatively small and therefore have less financial resources but as they are specialized in offering electric vehicles to customers they have a lot of knowhow about customer needs and marketing compared to the other fleet owners in the market. This is also why they are fully focused toward e-mobility in contrast to the other fleet owners which are focused on conventional vehicles.

5.3   Advise BN

Now that the results of the SD model on product-market characteristics are generated, the effectiveness of the mechanism in creating FMAs is determined and the analysis of firm resources and capabilities of players in the market are specified, it is time to give advice to BN concerning the moment of entry decision into the e-mobility market. First of all, from the base run it became clear that the transition towards BEV is initially slow. In 2020, only 140.000 BEVs will be on the road which is 1.8% of the total passenger vehicle population. The sales rate in 2020 will be about 5% of the annual passenger vehicle sales which means that about 26.000 BEVs will be sold in that year. These numbers might be conservative but the numbers found in other reports (G4V, 2011; ING-Economisch-Bureau, 2011; Tankpro and Aarts, 2011) corresponds with the outcome of the model in the first timeframe (2010-2020). Also, looking at the number of hybrid vehicles on the road in the Netherlands, 140.000 BEVs in 2020 seems high. On January 2011, there were about 56.000 hybrids on the road (Bovag-Rai, 2010) which is 0.7% of the total passenger vehicle population. The share of purchase of these hybrids in the year 2009 was 4.1% (~16.100 vehicles). Considering hybrids are commercially available in the Netherlands since 2000 and the fact that hybrids are less 'radical' compared to BEVs underlines that the diffusion of alternative vehicles is slow.

Based on the figures of the product-market, it is not considered wise to enter the market in the timeframe before 2020 on full scale; the chance to build up high entry barriers for followers is low. The mechanisms that are most effective in this market are network effects and preemption of space but the effectiveness of these mechanisms in creating FMAs and possible entry barriers for followers in this timeframe will be minimal due to the low amount of BEVs on the road. Also, in the beginning the utilization rate of the stations will be low which imposes high risks.

Although predictions after 2020 are less clear it is unlikely that take-off will occur before 2025 as the attractiveness of the BEV is not expected to be equal to the ICE before this time; only innovators and early adopters might take the lower attractiveness of the four attributes for granted. After 2025, when the BEV is expected to outperform the ICE, take-off becomes more likely but how fast it will occur depends on how fast people will perceive the increased attractiveness of the BEV. Diesel vehicles for instance became popular in several European countries but failed to become widely accepted in Sweden, although its attractiveness has improved considerable (Zhang, 2007)[32]. Familiarity about

Figure 5.1 - Cartoon

a product, as was discussed in the Paragraph 4.2, is very important for the success of the BEV in the early phase.

In the base case, the take-off in sales will occur from 2030 onwards. Between 2030-2035 the installed base will increase from 500.000 vehicles to over 1.1 million vehicles and share in purchase from 16% to about 42% of the total annual sales. Looking at the timeframe 2020-2030 it is wise for an infrastructure company to enter as take-off is likely to occur. Also, risks will be less as recharge behavior of consumers will be better understood due to the discovery costs pioneers have made. Furthermore, technology and equipment will be further standardized and the technology will be more mature reducing the risks of failure. The entry barrier created by the pioneer, predominately due to a larger number of stations and pre-emption of space, should still be possible to overcome as initially the number of stations will be relatively low. Also, when take-off occurs, the number of stations that need to be build is high which means that followers can gain a large installed base as well. Just before take-off occurs, an increase in the number of firms in the market occurs (Golder and Tellis, 1997; Shen and Villas-Boas, 2010). An increase in infrastructure providers could be an important indicator that take-off is likely in the near future.

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[32] See also appendix D5

A late entrant strategy, enter the market after 2030, is not considered optimal as many players are likely to have entered the market which will make it difficult to build up a large installed base and create a competitive advantage In summary, based on the product-market characteristics, it is most suitable to enter around 2025 on full-scale and thus to have a follower strategy instead of a pioneering strategy. It could, however, be wise to enter on small scale to gain experience in the field for instance by providing infrastructure for large corporations who have multiple locations. This way, Ballast Nedam is ensured that the recharge stations will be used and they can already gain information about consumer behavior. Also, according to Katz and Shapiro (1994), large firms are often the natural candidates to be the network sponsors.

Looking at the firm resources of Ballast Nedam, it would also be advisable to enter as a follower. The company doesn't has the necessary ████████████████████████ ███████████████████████████████ ████████████████████████████████ ███████████████████████████████ ██████████████████████████████ ██████████████████████████ (Schoenecker and Cooper, 1998; Sinha and Noble, 2005).

When BN would cooperate, it could decide to enter earlier as risks are more spread. As BN does not have ███████████████ they could decide to cooperate with one of the ██████████████████████████████ would be a good party in this respect as they already have a brand name and score very well on most of the indicators. Another good ██████████ would be ████████. As ████████████████████████████ would be the best choice as they score on most indicators higher than ████████. In the █████████████ ████████, the ████████████████ would be a good partner although they lack financial resources. It should also be said that the other fleet owners have a much larger customer base which could be an important asset for capturing potential BEV drivers.

6 Conclusions and recommendations

In this final chapter the conclusions and limitations of this study are discussed. Also recommendations for future research are given.

6.1 Conclusion

The goal of this report was to investigate what for Ballast Nedam, as a provider of recharge infrastructure, would be the most suitable moment of entry into the e-mobility market. Hence, the main research question of this report, *"What is for Ballast Nedam, as a provider of recharge infrastructure, the most suitable moment of entry into the electric mobility market?",* was investigated. From the literature review it became clear that the moment of entry decision depends on whether there are first-mover-advantages in the e-mobility market and if a company is able to secure them and by doing so create barriers to entry for following firms. There are several drivers, so called 'isolating mechanisms', from which first-mover-advantages can arise. These mechanisms, which can be divided in four categories, are listed in Table 6.1 below.

Table 6.1 - Isolating mechanisms

Economic factors:	Preemptive factors:
• Scale & experience economies • Marketing cost asymmetries	• Preemption of input factors • Preemption of space
Technological factors:	Behavioral factors
• Product & Process innovations • Organizational innovations	• Switching costs • Buyer choice under uncertainty • Network effect

Whether these mechanisms are effective in creating first-mover-advantages for a certain company depends on the product-market characteristics, also called the macro side, and on the firm characteristics, called the micro side. Hence, to answer the main research question, two sub questions were defined. The first sub question, *"How will the technological transition from fossil-fuel driven vehicles towards battery electric vehicles develop?"* applies to the product-market characteristics. To answer this question, a system dynamics model was developed to simulate the transition towards BEVs. The model incorporates findings from literature on transition dynamics, survey data of consumers' willingness to adopt a BEV and (technical) developments of the BEV and ICE platform.

From the base run it became clear that the attractiveness of the BEV will be inferior to the ICE till about 2025 and therefore, take-off in BEV sales before 2025 is not expected. The BEV will not displace the old technology (= ICE) if it scores lower on the four attributes (lower quality). Especially price is important; if the price difference is significant even if the score on the other three attributes is higher than the ICE, the BEV will not replace the ICE. This

corresponds with Windrum and Birchenhall (2004). Also, as the increase in familiarity about the BEV under the driver population is slow, take-off in sales will be delayed further and is not likely to occur before 2030; from this moment on the early majority starts to realize and perceive the (higher) attractiveness of the BEV as more information about the BEV becomes available. Furthermore, as passenger cars in the Netherlands are on average disassembled after 16 years, the number of BEVs on the road will not exceed the total number of ICE on the road before 2050. This is a large delay which should be taken into consideration as it affects the familiarity of the BEV. Furthermore, the slow speed with which the ICE is replaced by the BEV indicates that it takes considerable amount of time before the recharge stations will be used to their full potential.

Based on the characteristics of the e-mobility market and the simulation results, first-mover-advantages for providers of recharge infrastructure can be found primarily in the ability to preempt important locations and the ability to build up a large installed base of stations. As the take-off moment, in number of BEVs and in the number of charge stations, is not expected before 2025-2030, a pioneer has a long time to build up the installed base and create entry barriers for followers. However, when take-off occurs in BEVs and the construction rate of recharge stations growths significantly, it will be difficult to keep up with demand and other players are likely to enter the market (Golder and Tellis, 1997) and could reduce the FMA build up by the pioneer relatively quick due to rapid growth in construction rate. Furthermore, the pioneer will face high risks, as utilization rates of the recharge stations will initially be low due to low amount of BEVs on the road and the possibility that the market won't take off. Also, recharge behavior of BEV drivers is still unknown which creates extra risks. Furthermore, followers can learn from the pioneer and consumer behavior can easily be observed reducing the learning costs of followers.

Besides the influence of product-market characteristics on FMAs, also the firm resources and capabilities influence the ability to create and obtain FMAs. Therefore, the second sub-question, *"What are the strengths and weaknesses of the resources and capabilities of Ballast Nedam compared to other players in the market?"* was researched. From the analysis it became clear that Ballast Nedam scores well on ██████████████████████████████ ██ ██████████████████████████████ Also, ████████████████ ██████████████████████████. As take-off is not expected before 2025, it requires patience and careful planning on part of the managers. Also, expectations of higher management and investors should be managed to avoid early withdrawn of the product. For a pioneer to enter the e-mobility market, large financial resources and a large direct sales force (marketing resource), who can play a role in market education, are important. Based on the firm resources of Ballast Nedam, it is suggested to be a follower instead of a pioneer and enter the e-mobility market not before 2020 as the risk of failure is very high. Especially in the early

stages of the transition, the exposure to the BEV plays a very important role in whether or not the BEV will be a success or a failure.

Coming back to the main research question "*What is for Ballast Nedam the most suitable moment of entry into the electric mobility market as a provider of recharge infrastructure?*", the recommendation for Ballast Nedam is to follow a follower strategy and not to enter the market on large scale before 2020. It is suggested that Ballast Nedam enters in the timeframe 2020-2025, just before take-off is expected to occur. Also, consumer behavior will be better understood concerning recharge needs reducing the risks of failure.

6.2   Limitations and future research

The purpose of this study was to give answer about when Ballast Nedam should enter the e-mobility market. The literature used in this thesis concerns literature on first-mover-advantages, technological transitions and the resource-based view. To research if there are FMAs and if Ballast Nedam is able to exploit them, a system dynamics approach was used to model how the e-mobility market is likely to develop. By means of a survey the resources and capabilities of Ballast Nedam and other players in the market where identified.

While the model generates meaningful results concerning the product-market characteristics and includes the three central actors in the market as well as the ability to include different policies such as government subsidies, not all actors were included. Actors not included are for instance consumer lobby groups, grid operators and large fleet owners who could have an effect on the transition. Since all models include an abstraction of the real world and which variables to include or exclude is subjected to debate, there will always be room for error. In the model for instance, consumer and company behavior is idealized which gives room for error. Furthermore, only the four most important attributes are included, neglecting other possible important attributes such as safety concerns potential BEV drivers might have about the BEV.

From the analysis it also became clear that familiarity has a large impact on the simulation results. Familiarity depends on the marketing strength, forget rate and the strength of word of mouth from BEV drivers and nonBEV drivers. Data on these variables is hard to grasp and collect and although literature provides some directions, it remains subjected to debate. Another possible source of error stems from the technological predictions on for instance battery cost and the number of stations needed per vehicle. These predictions differ among researcher. However, as noted by Sterman (2000)[33] "by the time sufficient observations have developed for reliable estimation, it is too late to use the estimates for forecasting purposes". The analysis of the resources and capabilities of Ballast Nedam and other players in the market

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[33] Sterman (2000), page 330

is based on the know-how about these companies and the market from just a few employees of Ballast Nedam, giving room for bias.

Future research could extend the model by including more actors who are believed to influence the system as well. Another possible model extension is to model individual infrastructure providers to see how different entry moments influence the expected market share. In Appendix G an initial extension has been made which could be used for further research. The extension includes two individual infrastructure providers who can compete with each other on four different attributes; (i) number of stations per subscriber available (network utilization/blocking probability), (ii) the absolute number of stations an infrastructure provider has, (iii) the subscription fee and (iv) the attractiveness of the recharge locations of the provider.

Also, more research concerning the recharge behavior of BEV drivers is needed as it influences the profitability of a recharge station. Furthermore, extra alternative platforms could be included such as the hydrogen vehicle or CNG vehicles. These could have a significant impact on the adoption of the BEV as those platforms will not only compete with the ICE platform but also with the BEV platform. It might be that, due to all these different types of platforms, none of the alternative platforms can get enough momentum to replace the ICE. Another consideration that might be valuable to add is the increase in familiarity due to public recharge infrastructure. When recharge stations pop up in the public domain, people will be often reminded about the BEV which increases the familiarity about the BEV platform faster.

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-Appendices-

Why Wait?
Timing the moment of entry into the
e-mobility market

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Appendices

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List of Abbreviations

ATR	Attribute
BEV	Battery Electric Vehicle *(also called FEV)*
BN	Ballast Nedam
BPM	Tax for passenger cars and motorcycles *(Belasting Personenauto's en Motorrijwielen)*
CBS	Statistics Netherlands *(Centraal Bureau voor de Statistiek)*
CLD	Causal Loop Diagram
CNG	Compressed Natural Gas
CO_2	Carbon-di-Oxide
EEA	European Environment Agency
EPA	Environmental Protection Agency
FEV	Full Electric Vehicle *(also called BEV)*
FMA	First-Mover-Advantage
GHG	GreenHouse Gas
GM	General Motors
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
IEA	International Energy Agency
MLP	Multi-Level-Perspective
NGOs	Non-Governmental Organizations
NO_x	Nitrogen Oxides
PHEV	Plug-In Hybrid Electric Vehicle
PM	Particulate Matter
PPP	Public-Private-Partnerships
RDW	Government department for roadtraffic *((Rijks)Dienst voor het Wegverkeer)*
SD	System Dynamics
SFD	Stock-and-Flow Diagram
SHEV	Series Hybrid Electric Vehicle
SoC	State-of-Charge
ST-system	Socio-Technical system
TCO	Total Cost of Ownership
TT	Technological Transition
TtW	Tank-to-Wheel
VAT	Value Added Tax
VW	Volkswagen
WF	Weight Factor
WoM	Word of Mouth
WoT	Word of Town
WtW	Well-to-Wheel

Appendix A - Company description

The research was conducted at Ballast Nedam which is one of the five largest construction and infrastructure companies in the Netherlands. The company, founded in 1877, realized a turnover of about 1.4 billion euro's in 2010 (Ballast-Nedam, 2010). At the moment there are about 4000 employees working at Ballast Nedam who are located across six different clusters. The mission of Ballast Nedam is "to improve the quality of the living environment, which we achieve through commitment, quality, reliability, flexibility and expertise" (Ballast-Nedam, 2010).

Company structure

Ballast Nedam's strategy focuses on integrated projects, i.e. they are involved in the development, construction and management phases. The sequence of these phases forms the "horizontal value chain". By focusing on integrated projects the products and services "are becoming ever more specific, with a growing number of product-market combinations in the horizontal value chain" (Ballast-Nedam, 2010). The horizontal value chain is supported by the vertical value chain which is formed by specialized and supply companies which serve as the procurement specialists for the entire organization. The product range of these specialized companies is constantly being expanded, and their position enhanced while the supply companies are looking for opportunities to expand the concessions that exist (Ballast-Nedam, 2010). In Figure A.1 the horizontal and vertical value chains are shown.
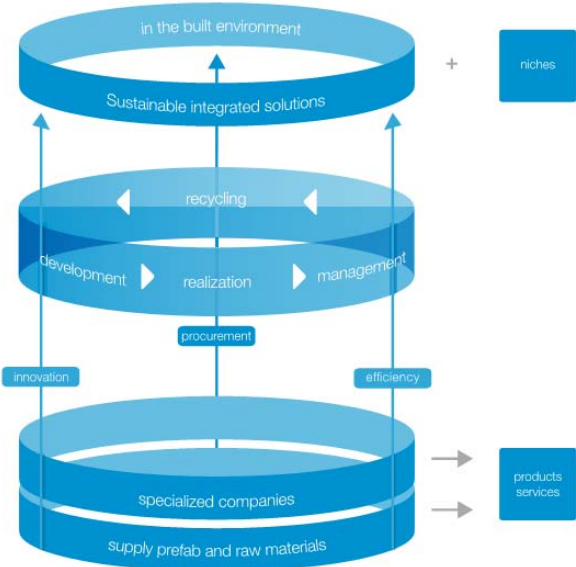
Figure A.1 - Horizontal and Vertical value chains
source: (Ballast-Nedam, 2010)

Ballast Nedam Concessions

The research was conducted at Ballast Nedam Concessions, which is part of the cluster "Ballast Nedam Infra". Ballast Nedam Concessions develops, realizes, finances and manages long-term PPP-concession projects (Public-Private-Partnerships). The core activities of concessions are: contract management, project management and financial engineering. Concessions bundles the knowledge and expertise of the Ballast Nedam organization and for every PPP-project they form a consortium together with partners that provide supplementary knowledge. Ballast Nedam Concessions offers an integral provision of services for the customer where they will handle the whole project, from architect till exploitation. The core sectors Ballast Nedam Concessions is operating in are accommodations, mobility, energy, care, education and leisure (Ballast-Nedam, 2011)

Appendix B - Model documentation

B1 - SFD modeling approach

Although causal loop diagrams, discussed in chapter 3, are useful to explain interdependencies and feedback processes, they have limitations too. One of the most important limitations of CLDs is their inability to capture the stock and flow structure of a system. Stocks and flows, along with feedback, are the two central concepts of system dynamics (Sterman, 2000). They present the conceptual and mathematical definition of stocks and flows and give generally a more detailed specification of what is believed to be happening. The stocks in a system are the accumulations; they characterize the state of the system and generate information upon which decisions and actions are based. Stocks create delays by accumulating the difference between the inflow to a stock minus its outflow.

In the CLD discussed in Paragraph 3.1, the following stocks and flows can be identified (see also Figure B.1 on the next page, bottom): two stocks ('*Installed Base BEV*' and '*Nr of Recharge Stations*'), two inflows ('*sales rate*' and '*construction rate*') and two outflows ('*vehicle discard rate*' and '*station discard rate*'). The values of these two stocks are influenced by the inflow and outflow of the stocks. The stock *'Installed Base BEV'* increases when the sales rate increases while the stock decreases when a vehicle gets discarded. The mathematical representation of this stock is

$$\texttt{Installed Base BEV(t)} = \int_{t_o}^{t} [\texttt{sales rate - vehicle discard rate}] ds + \texttt{Installed Base BEV(t}_0)$$

$$(1)^{[34]}$$

Or when written as a differential equation

$$\frac{d(\texttt{Installed Base BEV})}{dt} = \texttt{Net change in stock = Sales rate(t)-Vechile discard rate(t)}$$

$$(2)$$

The Stock and Flow Diagram can, unlike CLDs, be used in simulation programs[35] to calculate the model and simulate different scenarios. The SFD however has some limitations as well; it can be seen as too complex, technical and can encourage inappropriate detail.

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[34] For clarity, the whole variable name will be given in the formulas (formulation principle: Sterman, 2000; page 527)

[35] The simulation program used in this thesis is Vensim PLE (2011) from Ventana Systems
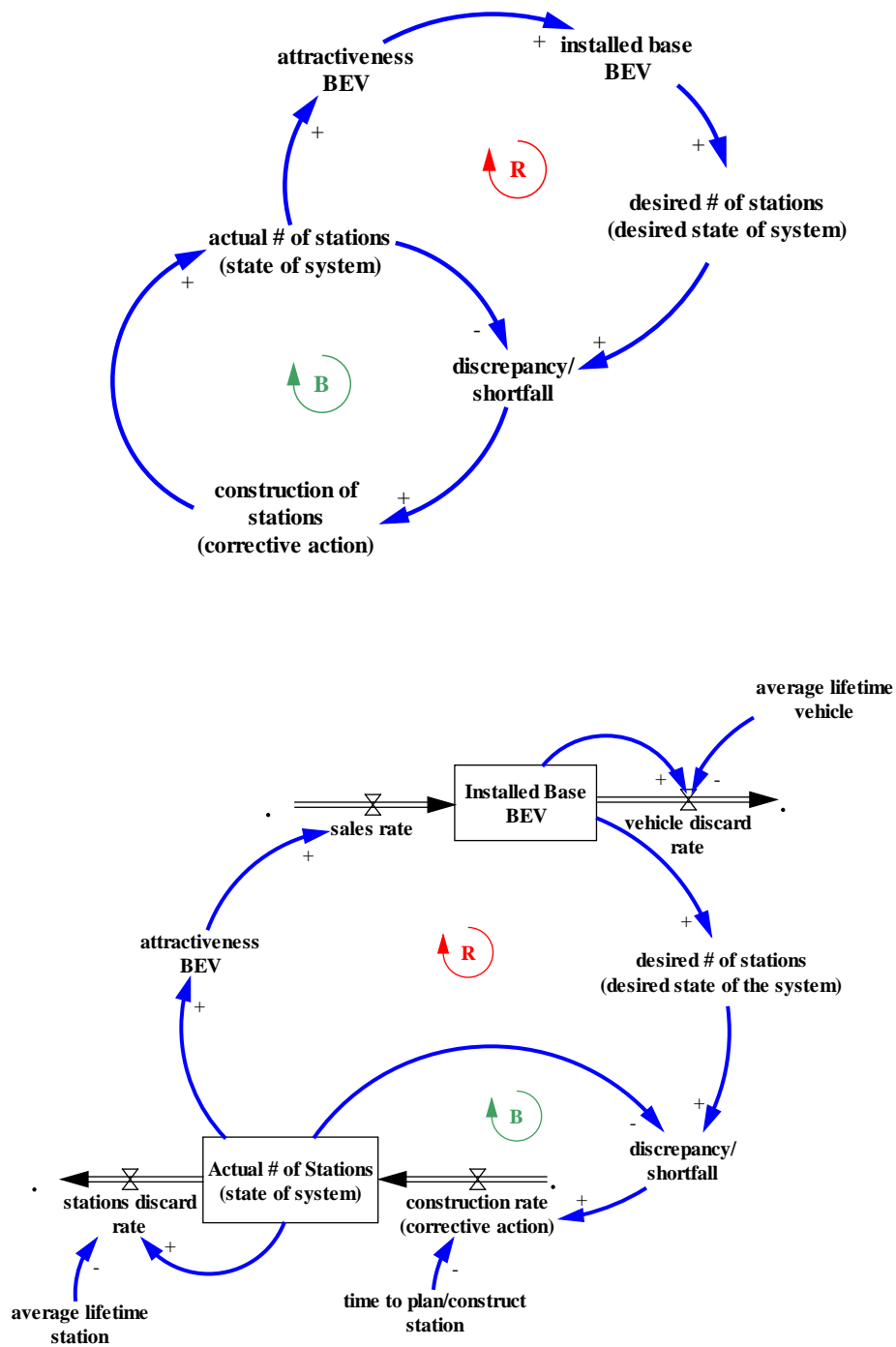
Figure B.1 - CLD (top) & SFD with a Reinforcing (R) and a Balancing (B) feedback loop

B2 - Model Setup

In this section the formulation of the Stock-and-Flow Diagram is discussed. The CLDs discussed in chapter 3 are converted into the SFDs including equations and initial conditions.

B2.1   ICE and BEV platform

In the model only two platforms are considered; the ICE and BEV platforms. There are several reasons why only these two platforms are included. First, the ICE is at the moment the dominant platform[36] with which the BEV platform has to compete. For comparison purposes the BEV will be compared with the gasoline ICE platform as more than 80% of the vehicles in the Netherlands use gasoline as a fuel (CBS-Statline, 2011). Second, no other alternative vehicle platforms such as the hydrogen fuel cell vehicle are included as the BEV is considered the most market ready alternative platform. The cost of hydrogen fuel cells is currently very high compared with a battery cell, hydrogen itself is much more expensive than electricity and would require the construction of an entirely new infrastructure to distribute the fuel to customers (Eaves and Eaves, 2004; Electrification-Coalition, 2009). Commercially available fuel cell vehicles are expected the earliest on the market in 2025 (Eaves and Eaves, 2004; Berg *et al.*, 2009). However, it should be noted that in the long run the fuel cell platform could become a competing platform for the BEV and ICE. Later SD models therefore could include this platform.

B2.2   Installed base

In Figure B.2 the aging chain of the ICE is shown[37]. The installed base of each platform accumulates vehicle sales for that particular platform minus the discarded vehicles of that platform (ptf)

$$\frac{d\texttt{Installed base}_{ptf}}{d\texttt{t}} = \texttt{sales}_{ptf} - \texttt{discards}_{ptf} \tag{3}$$

The installed base of a platform is divided into three stocks with each stock representing a share of the installed base for that particular platform. The share of each stock is based on the vehicle's age (0-7; 7-15; 15<older). When a vehicle is purchased, in this case an ICE, it will enter the first stock (0-7 years) and moves on subsequently to the second stock and third stock when the age of the vehicle is increasing and eventually it will be discarded (i.e. scraped). However, not all vehicles will move on to the next stock; some vehicles will be discarded before they enter the next stock. This is for instance the case when the vehicle becomes a total loss

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[36] ICE vehicles have ~99% market share (Vliet *et al,* 2011)

[37] The aging chain of the BEV is not shown for simplicity reasons as it has the same structure as the aging chain of the ICE.

due to an accident or is exported. When a vehicle is discarded it will leave the stock and thus the total installed base of the ICE (or BEV) will be reduced. However, when a vehicle gets discarded, it will result in the purchase of a new vehicle which will be either an ICE or a BEV. For instance, when 10 ICE vehicles are discarded, it will result in 10 new vehicles being purchased which will enter the first stock of either the BEV or the ICE platform. Thus, 10 ICE discards don't necessarily result in 10 new ICE vehicles being purchased and the same accounts for the BEV, 10 BEV discards don't necessarily result in 10 new BEVs. As discussed in Paragraph 3.3 the share of purchase for a platform depends on the *'perceived attractiveness'* of both platforms, which depends on the familiarity of the platform and its actual attractiveness.

The total installed base of the two platforms combined is considered to be constant meaning that there is no growth in the total installed base (i.e. total number of vehicles is not growing and sales are only generated when a vehicle is discarded). As the automotive market in the Netherlands can be considered a mature market with only a small increase in the total number of vehicles on the road, this is appropriate. Furthermore, in the last ten years, vehicle sales in the Netherlands have remained constant with about 510.000 vehicles per year which is about the same number of vehicles being discarded every year (CBS-Statline, 2011). Data on discard percentages for each age stock and initial fleet size for every stock for the ICE is derived from data of the CBS[38]. Initial fleet number for electric vehicles is 534 which was the amount of registered BEVs on the road in the Netherlands on May 2011[39]. All vehicles of the BEV are placed in the first stock (age 0-7) and thus are considered to be younger than 7 years. An overview of all exogenous variables used in the model can be found in appendix B3.

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[38] CBS – Centraal Bureau voor de Statistiek (Statistics Netherlands)
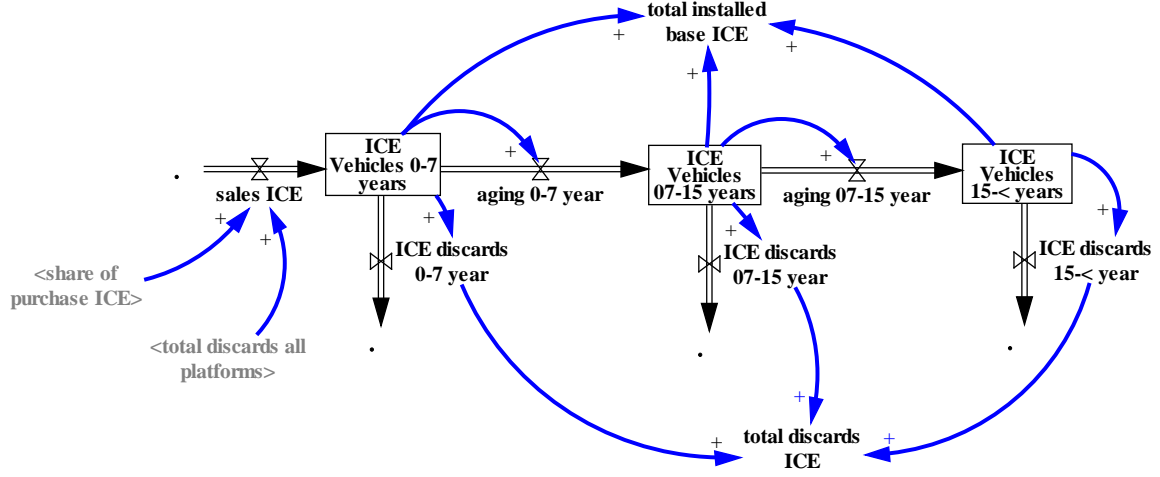
[39] See also rdw.nl

Figure B.2 - SFD - Aging chain IC
* Aging chain BEV has same structure

B2.3 Share of purchase of ICE and BEV platform

Whether a vehicle that is discarded will result in a new BEV purchase or an ICE purchase depends on perceived attractiveness of the vehicle platform divided by the sum of the perceived attractiveness of both platforms

$$\text{share of purchase}_{ptf} = \frac{\text{perc. attractivess}_{ptf}}{\sum_{ptf} \text{perc. attractivness}_{ptf}} \tag{4}$$

Perceived attractiveness is calculated by two variables; (i) attractiveness of the platform and (ii) whether drivers are familiar with the platform (i.e. if they consider it in their consideration set). The '*attractiveness*$_{ptf}$' captures the actual performance of each platform while the '*familiarity*$_{ptf}$' captures the familiarity someone has with the platform and whether they will consider it when they are going to purchase a new vehicle

$$\text{Perc. attractiveness}_{ptf} = \text{Familiarity}_{ptf} * \text{attractiveness}_{ptf} \tag{5}$$

B2.4 Familiarity platform

Whether someone considers a platform in their consideration set when they purchase a vehicle depends on how familiar the person is with the particular platform. The feedback loops discussed in Paragraph 3.3 can be seen in the SFD of Figure B.5. The SFD simulates the familiarity of the BEV under nonBEV drivers (i.e. potential adopters). As only two platforms are considered, these nonBEV drivers are all ICE drivers (ICE drivers are thus considered potential adopters of the BEV). Drivers who drive an ICE are considered to be fully familiar with the ICE platform (i.e. $\text{FAM}_{\text{ICE,ICE}} = 1$) and likewise for BEV drivers; they are fully familiar with the BEV platform (i.e. $\text{FAM}_{\text{BEV,BEV}} = 1$). Also, because the ICE is fully embedded in society, it is assumed that people who are driving a BEV are also fully familiar with the ICE

platform (i.e. $FAM_{BEV,ICE} = 1$). This means that only ICE drivers are initially not familiar with the BEV platform (i.e. $FAM_{ICE,BEV} = 0$) and thus don't consider the BEV platform at the start of the simulation ($t_0 = 2010$); the *'share of purchase BEV'* is zero regardless of the BEV's attractiveness. BEV drivers on the other hand always consider the ICE platform as they are fully familiar with the ICE platform. As only the value of variable $FAM_{ICE,BEV}$ can change (as it is considered that familiarity of the ICE will not change in the time horizon modeled), only one stock has to be considered namely the stock *'Familiarity consumers about BEVs'* which resembles the familiarity of ICE drivers (i.e. potential consumers) about the BEV platform.

Both the increase and decay in familiarity about BEVs under ICE drivers is determined by the total exposure the ICE drivers receive about the BEV.

$$\frac{d\mathtt{Fam}_{ICE,BEV}}{d\mathtt{t}} = \overbrace{\mathtt{tot.\ exp.\ BEV}_{ptf} * (1 - \mathtt{FAM}_{ICE,BEV})}^{\text{familiarity increase}} - \overbrace{\mathtt{frac.\ fam.\ decay\ rate\ *\ FAM}_{ICE,BEV}}^{\text{familiarity decay}} \quad (6)$$

Familiarity increase depends on the current familiarity multiplied with the total exposure to the BEV platform and levels off when familiarity reaches 1. *'Total exposure to the BEV platform'* itself is determined by three components; WoM from BEV drivers, WoM from non-BEV drivers (as only two platforms are under consideration, nonBEV drivers are ICE drivers) and marketing efforts[40].

$$\mathtt{tot.\ exp.\ BEV}_{ptf} = \mathtt{WoM\ BEV\ drivers} + \mathtt{WoM\ nonBEV\ drivers} + \mathtt{marketing\ effort} \quad (7)$$

The distinction between WoM of BEV drivers and WoM of non-BEV drivers is made as it is assumed that WoM from a BEV driver has more strength as they share more information about the BEV and the information is considered to be more creditable compared to WoM of nonBEV drivers (Dattée and Weil, 2007; Struben and Sterman, 2008). Whether someone comes in contact with a nonBEV driver or a BEV driver depends on the market share of both platforms; the higher the market share of the ICE the higher the share of WoM from nonBEV drivers as the probability to meet someone of this platform increases. The strength of WoM from a BEV and nonBEV driver is roughly estimated, based on the survey conducted by Ballast Nedam, parameters used by Sterman (2000) and other diffusion cases[41]. The sensitivity of these parameters is discussed in Appendix B4. Marketing effectiveness is considered to be constant. Especially in the beginning advertising will be important for familiarity generation as word of mouth will be low (see also graph C in Figure 4.1). The marketing effort is considered to be constant and active during the whole simulation.

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[40] Sterman (2000), page 365

[41] Diffusion of VHS and Betamax, Sterman (2000)

Besides increase in familiarity, a potential adopter (i.e. ICE driver) can also forget information about the BEV platform[42]. This "forgetting" is captured by the second term in formula 6 and is calculated by multiplying the average familiarity a potential adopter has at that moment with a fractional decay rate. The *'fractional familiarity decay rate'* is calculated by a linear function

frac. fam. decay rate = ε * reference rate tot. exp + (0.5-ε*tot.exp BEV$_{ptf}$) (8)

In Figure B.3 this function is shown in a graph. When total exposure to the BEV platform (x-axis) is under a certain value (0.025), the fractional familiarity decay rate will be 1 (i.e. familiarity increase BEV = familiarity decay). Once the total exposure to the BEV platform increases, the fractional decay rate reduces, reducing the decay or loss in familiarity. At the *'reference rate total exposure',* the fractional familiarity decay rate is half the value of the maximum fractional familiarity decay rate. In Figure B.3 the reference rate of total exposure = 0.05 and hence, once total exposure is at this value the fractional familiarity decay rate is 0.5, reducing the current familiarity about BEVs with half per unit of time. When exposure to the BEV platform increases further, the fractional familiarity decay rate will become zero and familiarity about the BEV platform will no longer decay (given that the total exposure remains above 0.075); the BEV will be set in the minds of potential adopters and they will consider the BEV platform as a possible alternative to purchase besides the ICE platform which is always in their consideration set (as familiarity of the ICE is considered 1 during the whole simulation period). The ICE has, until familiarity of the BEV becomes 1, an advantage as it is already fully familiar (i.e. $FAM_{ICE} = 1$).

fractional familiarity decay rate as function of total exposure
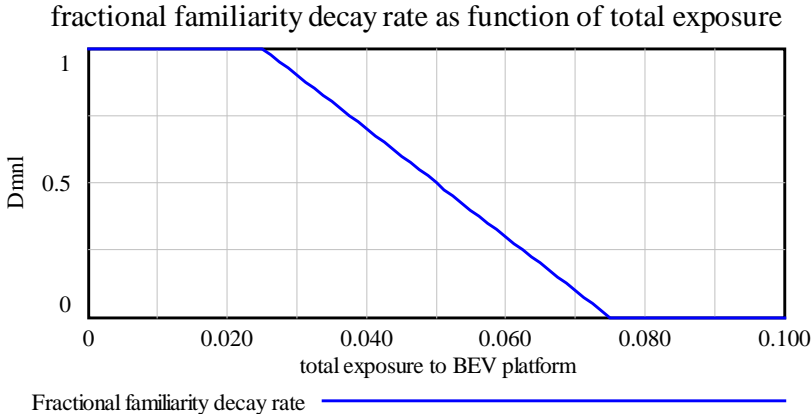
Figure B.3 - Fractional familiarity decay rate as function of total exposure

In Figure B.4 the increase and decay in familiarity as well as net familiarity non-BEV drivers have with the BEV platform is shown. In the beginning total exposure is still low and hence the gain in familiarity (green line) only slightly exceeds the loss of familiarity (red line) which results in only a small gain in the familiarity of the BEV platform (blue line); loop B1

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[42] See also Sterman (2000), page 505-507

dominates loop R3. Once total exposure exceeds a certain threshold, the BEV platform gets internalized under consumers and the effect of the balancing loop B1 ('forgetting loop') diminishes quickly until no longer loss of familiarity occurs.

Figure B.4 - Increase, decay and overall familiarity BEV

Figure B.5 - SFD – Familiarity of platform (consumer section)

B2.5 Attractiveness platform

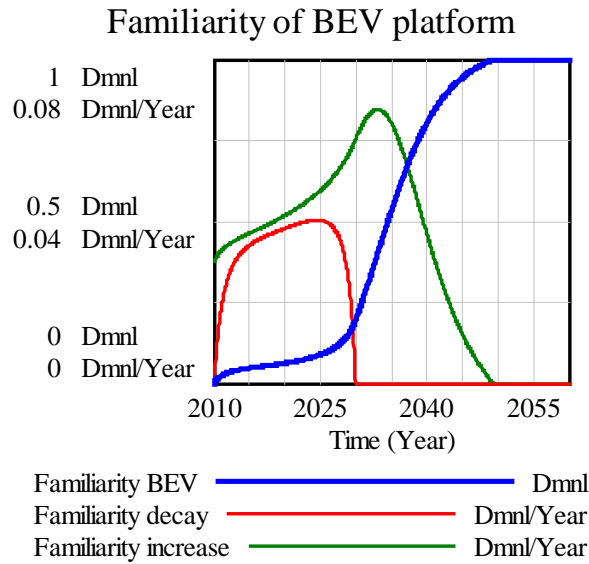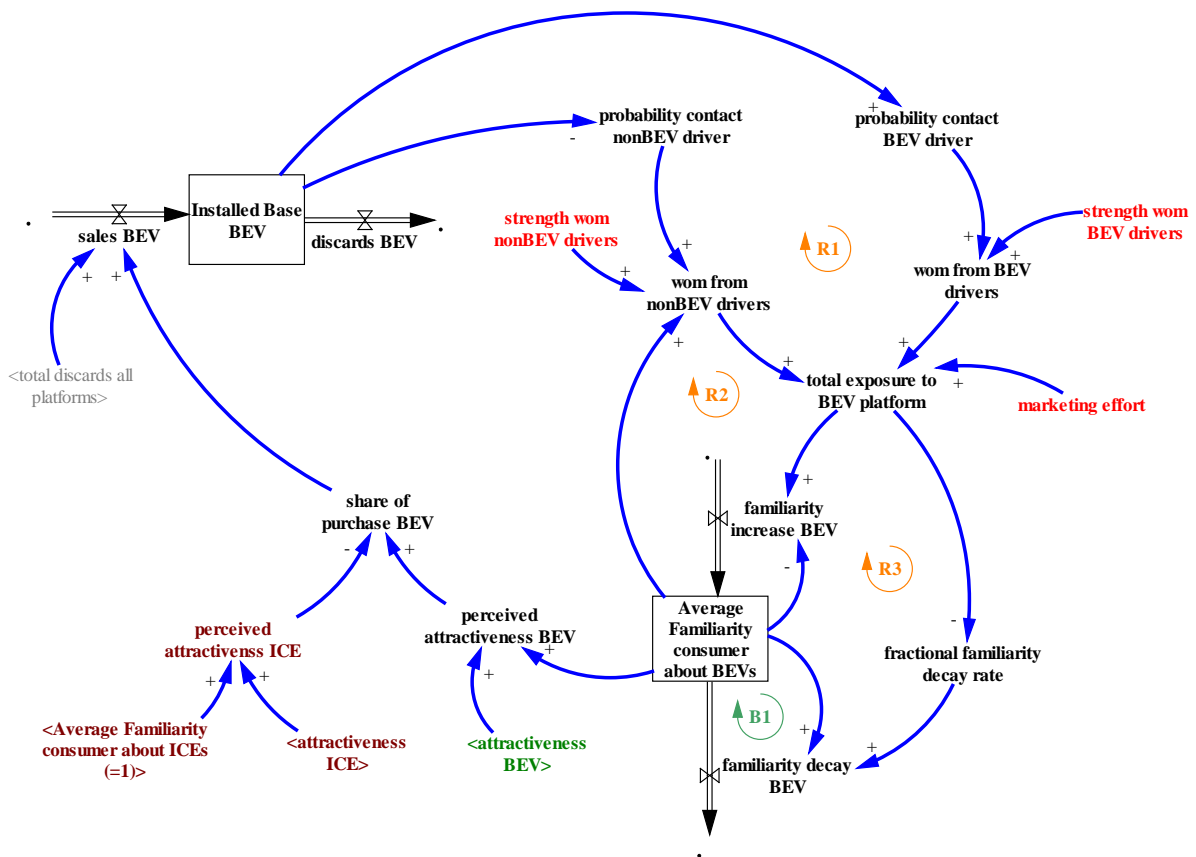The second variable that determines the perceived attractiveness of a platform, besides the variable '*familiarity$_{ptf}$*', is the actual attractiveness of a platform (*attractiveness$_{ptf}$*). From the literature (Gärling and Thøgersen, 2001) and surveys held by Ballast Nedam and Ecomobiel under the Dutch population, it became clear that there are four attributes that are found most important when people are considering a vehicle; (i) price, (ii) driving range, (iii) infrastructure density and (iv) recharge/refuel time[43]. In the SD model these four attributes determine the attractiveness of the platform with each attribute having a weight factor (wf) which is based on the importance people gave to each attribute in the surveys

$$\text{attractiveness}_{ptf} = \frac{\text{atr}_{price,ptf}*\text{wf}_{\text{price}}+\text{atr}_{dr,ptf}*\text{wf}_{\text{dr}}+\text{atr}_{id,ptf}*\text{wf}_{\text{id}}+\text{atr}_{rt,ptf}*\text{wf}_{rt}}{\text{wf}_{\text{price}}+\text{wf}_{\text{dr}}+\text{wf}_{\text{id}}+\text{wf}_{rt}} \quad (9)$$

with wf$_{\text{price}}$=▮▮▮(price), wf$_{\text{dr}}$=▮▮▮(driving range), wf$_{\text{id}}$=▮▮▮ (infrastructure density) and wf$_{\text{rt}}$=▮▮▮ (recharge time)

The use of this formula has some implications however when extreme conditions are considered[44]. For instance, consider a driving range of 0km (atr$_{dr,bev}$= 0) for a BEV; the attractiveness of a BEV with a driving range of 0km should be 0 no matter how attractive the other attributes are. This is not the case when the wf$_{dr}$ is a constant (▮▮▮); the other attributes still determine for a large part the attractiveness of the vehicle platform. Therefore, it is assumed that the weight factor (wf) of each attribute has a u-shape; when extreme conditions such as a zero driving range occur, the weigh factor will become ≈ ∞ which will result in an attractiveness of ≈ 0 for the particular platform. On the other hand, when driving range is for instance 10.000km, the other attributes also become less important (that is, if they don't have an extreme value as well) and therefore a u-shape is used for the weighing factors. Under normal conditions, the weigh factors stated above are used.

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[43] See appendix D1 & D2 for an overview of the survey results

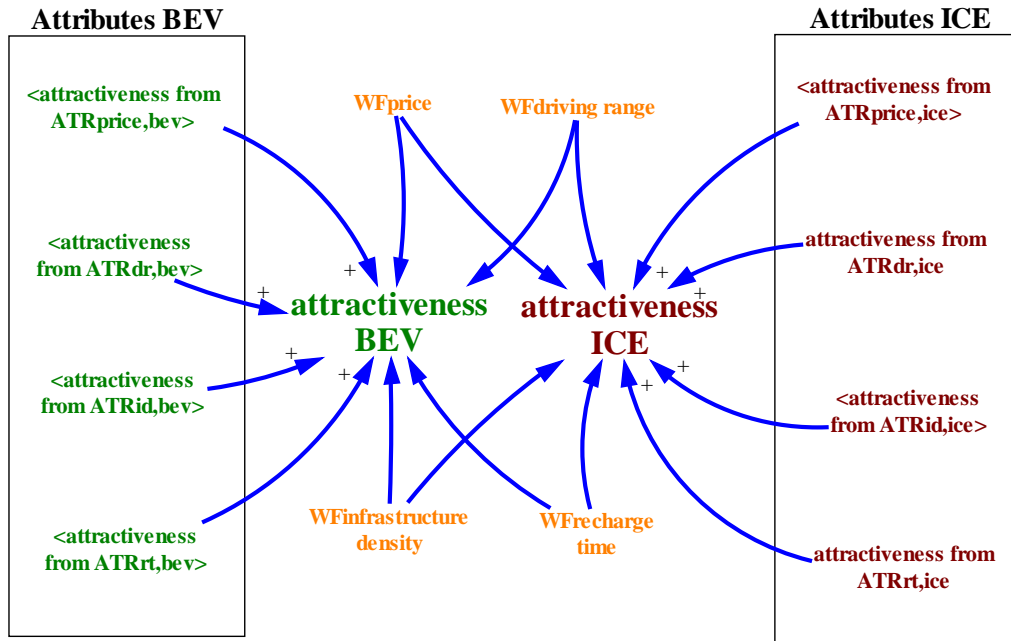[44] See also Sterman (2000), page 528

Figure B.6 - the four attributes that determine attractiveness of a platform

B2.5.1   Price of platform

The price of a platform is determined in the automotive section as discussed in Paragraph 3.4. Only one stock is present in the automotive section namely the *'cumulative sales'* stock which is used to calculate the scale effect on the manufacturing cost of each platform. The formula to calculate the scale effect is as follow[45]:

$$\text{scale effect} = \left(\frac{\text{Cumulative Sales}_{ptf}}{\text{Initial fleet size}_{ptf}} \right)^{\text{scale factor}} \tag{10}$$

With:

$$\text{scale factor} = \frac{\ln\left(1 + \text{cost reduction factor}\right)}{\ln\left(2\right)} \tag{11}$$

This formula (10) indicates that when cumulative sales double relative to past sales, the production cost will reduce with a certain factor (i.e. the cost reduction factor). This cost reduction factor is set to 0.15 and is based on guidelines of NASA (2011) and Offer *et al.* (2010). The initial fleet size has to be set as well to calculate the economy of scale effect. The cumulative vehicle sales of the last 20 years will be used for the ICE in the Netherlands. For the BEV platform, an initial fleet size of 90.000 is set. Although this number of BEVs have not been produced and sold in the last 20 years in the Netherlands, the BEV platform has

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[45] Formula extracted from Sterman (2000), page 338, 507

benefited from spillover and learning effects from the ICE. Furthermore, the largest cost reduction of the BEV platform will occur through battery cost price reductions (Offer *et al.*, 2010; rai-vereniging, 2011; van Vliet *et al.*, 2011). Also, from the sensitivity analysis[46] it became clear that the scale effect on cost of the BEV platform is minimal and will have minimal effect on its attractiveness.

For the ICE platform, manufacturing costs are solely reduced through scale effects. As a reference for the initial cost and purchase price of an ICE vehicle, a 5 doors hatchback model (VW golf trendline 1.4 16v) is used as this is one of the most sold ICE vehicles and segment in the Netherlands (segment C) (Bovag-Rai, 2010). The Nissan Leaf is used as reference model for the BEV platform as it is currently one of the BEV models that is sold commercially, has the largest market share among BEVs (ZER-auto, 2010) and falls in the same segment as the VW golf, the reference ICE. For a comparison of both platforms see appendix C5.

The total manufacturing costs for the BEV is separated into manufacturing costs and battery costs. The battery costs are based on prediction of several papers (Electrification-Coalition, 2009; Offer *et al.*, 2010; ING-Economisch-Bureau, 2011; van Vliet *et al.*, 2011). The battery costs predicted by these researchers differ considerably; van Vliet *et al.* (2011) state that the cost per kWh in 2010 was 960 Euro and will be 800 Euro/kWh in 2015 and 400 Euro/kWh in 2030 while the Electrification-Coalition (2009) state a price of 450 Euro/kWh in 2010, 400 Euro/kWh in 2015 and 140 Euro/kWh in 2030. In an interview with a leading figure of Nissan it was revealed that the battery pack of the Nissan Leaf (24 kWh) costs 22.224 Euro which is 926 Euro/kWh[47] [48]. In Figure B.7 the battery costs of several researchers are plotted. In the base case the battery price stated by Nissan for 2010 is used and for the future predictions the battery costs laying between those stated by Offer *et al.* (2010) and Van Vliet *et al.* (2011) are taken as these, considering the battery costs stated by Nissan, are considered more realistic[49][50]. In the scenario and sensitivity analysis the impact of battery price is analyzed further.

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[46] See appendix B4

[47] ZERauto

[48] Note however that battery prices are kept secret by carmakers and therefore figures stated by automotive officials should be taken with caution link

[49] The black/orange line is also considered most realistic by Prof. Dr. Notten from the TU/e (personal communication).

[50] See also appendix C6
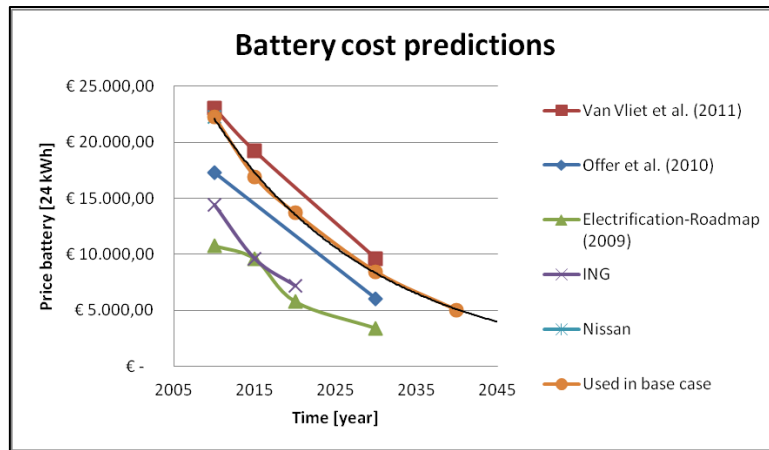
Figure B.7 - Battery cost predictions
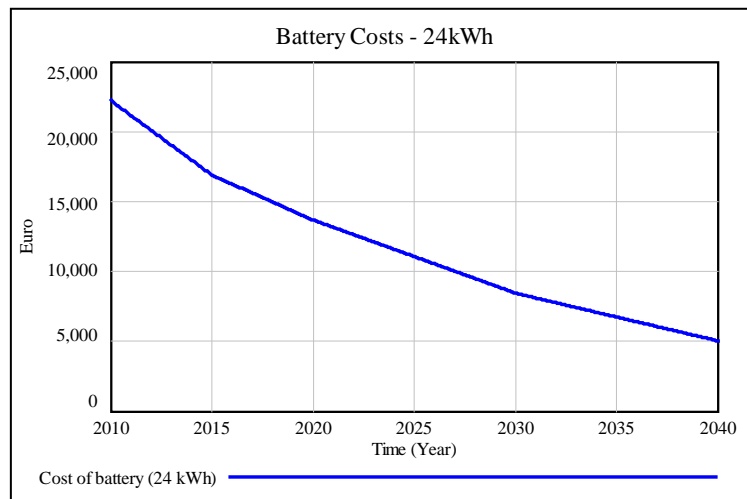
Figure B.8 - Battery costs - Base case

To get the purchase price of each platform, the manufacturing costs are multiplied with a margin of 1.5 and on top of that the BPM[51] and VAT. For the BEV, no BMP is charged which is beneficial[52].

$$\text{purchase price}_{ptf} = \text{manufacturing costs}_{ptf} * \text{margin} * \text{BPM} * \text{VAT} \qquad (12)$$

For the purchase price of the BEV platform at the start of the simulation (t_0 =2010) the purchase price of the Nissan Leaf in the Netherlands (€ 34.990) is taken and for the ICE platform the purchase price of the Volkswagen Golf 1.4 16v trendline (€ 20.285).

The total price of each platform is calculated by adding the purchase price to total operating costs of the first 4 years. The total operation costs are comprised of fuel costs, maintenance costs and tax costs.

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[51] BPM = Belasting Personenauto's en Motorrijwielen *(Tax for passenger cars and motorcycles)*

[52] Autobelastingen

$$\text{total price}_{ptf} = \text{purchase price}_{ptf} + \text{operating costs first 4 years}_{ptf} \qquad (13)$$

The total price of the ICE and the BEV are compared with a reference value which is the total price of an ICE at t_0 to compare the relative increase/decrease in total costs of both platforms. For a deduction of the initial cost of each platform, see appendix C5.
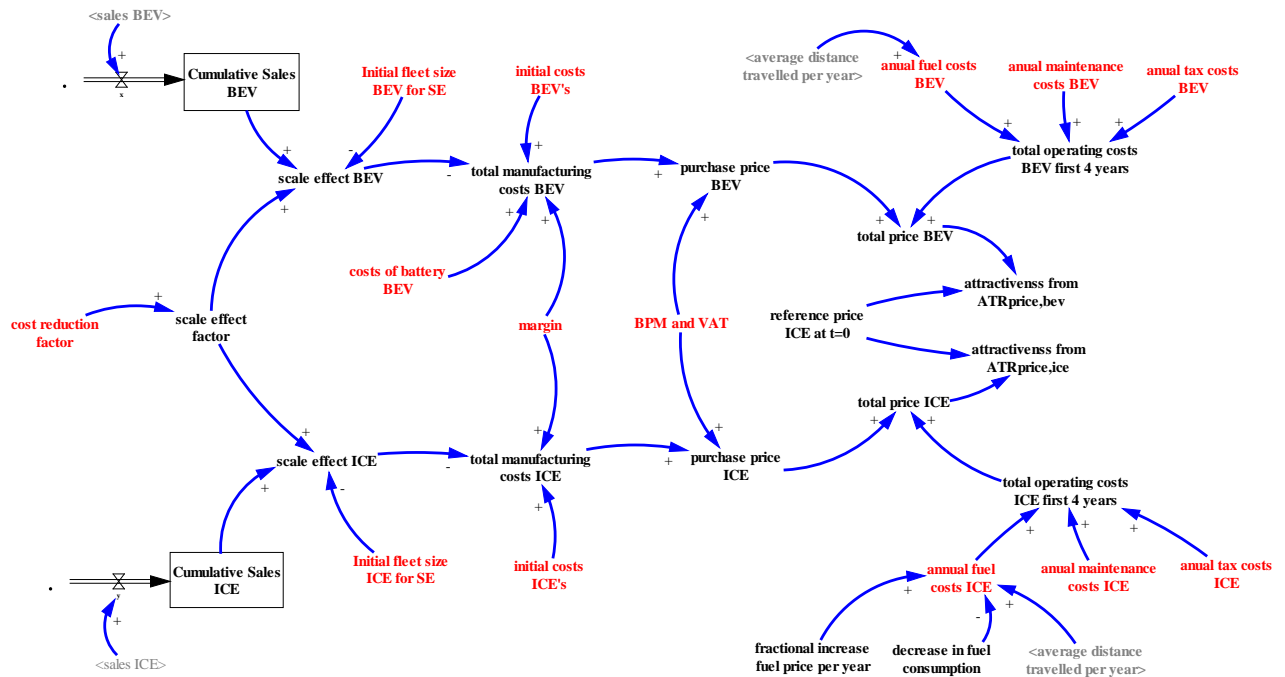
Figure B.9 - SFD – Attribute price of platform (atrprice,ptf)

B2.5.2 Driving range of platform

The attribute *'driving range'* ($\text{atr}_{dr,ptf}$) is considered an exogenous variable and is based on the predictions made (Electrification-Coalition, 2009; G4V, 2011). In Figure B.10 the driving range of a BEV is shown over time (left figure). The Dutch population considers driving range the second most important attribute with ▮▮▮▮▮ (price of the vehicle is the most important attribute). The driving range of the current BEV used for comparison, the Nissan Leaf, is about 160 km[53]. The VW golf used for initial comparison for the ICE platform has a driving range of about 600 km[54] which is more than 4 times as much compared to the Nissan leaf.

Looking just at the driving range, the BEV initially performs poor, affecting its overall attractiveness. According to the survey of Ballast Nedam, 10% of the Dutch driver population would accept a driving range of 200km[55]. A survey held by Ecomobiel (2011) found that 23% of

[53] egmCarTech

[54] autoweek

[55] See appendix D1 for results Ballast Nedam survey

the population would accept a driving range of 200km[56]. The Nissan Leaf, with a driving range of 160km, is thus a potential vehicle for 10% ~ 23% of the population (if only driving range is considered). When the driving range of the electric vehicle increases further, the attractiveness to drive will increase and the BEV will become a potential vehicle for a larger percentage of the population; the attractiveness of the BEV platform increases (given all other attributes remain constant). To model the increase in attractiveness due to driving range ($atr_{dr,bev}$), a lookup function is used. When the driving range is 0km, $atr_{dr,bev}=0$. When the driving range is 600km, $atr_{dr,bev}=1$ as the reference driving range is 600km (i.e. the driving range of an ICE at t_0). The driving range of the ICE is considered fixed with 600km and thus $atr_{dr,ice}=1$ over the whole period (see also Figure B.10, right). A increase in BEV driving range above that of the reference driving range of 600km will increase $atr_{dr,bev}$ above 1. The values of $atr_{dr,bev}$ are based on the survey results of Ecomobiel. The results show that 10% of the driver population accept a driving range of 150km, 23% a driving range of 200km, etc. These results are included in the lookup function (Figure B.10, right).
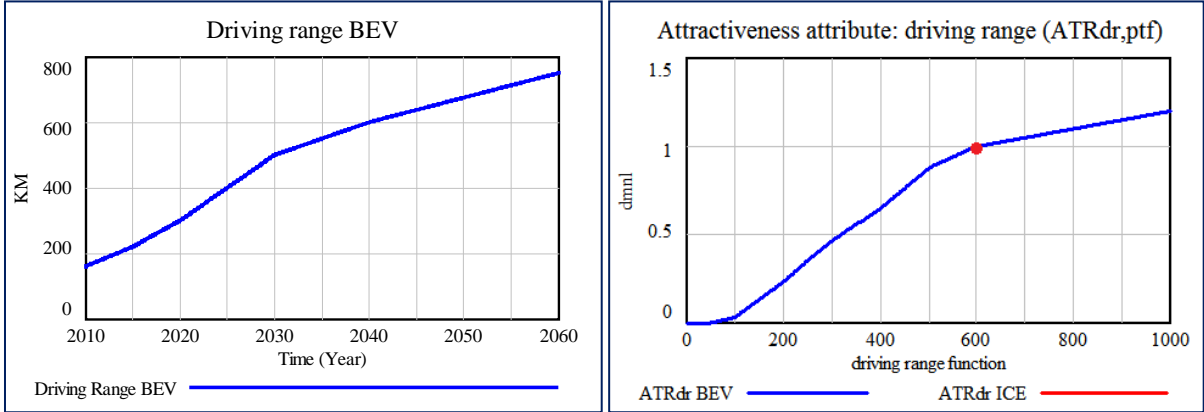
Figure B.10 - Driving range BEV and attractiveness attribute driving range (atrdr,ptf)

It should be noted that about 91% of the driver population in the Netherlands drives less than 150km a day and 65% even less than 50km per day[57] which means that the BEV is more than capable to satisfy the average daily driving needs for the majority of the population. One of the reasons why people consider driving range so important is due to the fact that people are used to the driving range of an ICE and due to 'range anxiety'; the fear that a BEV has insufficient range to reach the desired destination. Lessons learned from pilot projects show that this "range anxiety" exists primarily in the beginning, once the market becomes aware and adopters get used to the BEV, range anxiety reduces as people become aware that the driving range of

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[56] See appendix D2 for results Ecomobiel survey

[57] See appendix D3 for daily drive movement

the BEV is sufficient to suffice in their daily driving needs[58] (Narich *et al.*, 2011). Also, once more public recharge stations are in place, 'range anxiety' will diminish as well.

Figure B.11 - Attribute driving range (atrdr,ptf)
(note: attractiveness driving range of ICE is a constant)

B2.5.3   Infrastructure density of platform

Besides influencing the attractiveness of a platform in a direct way, driving range also influences the number of fuel/recharge stations needed pe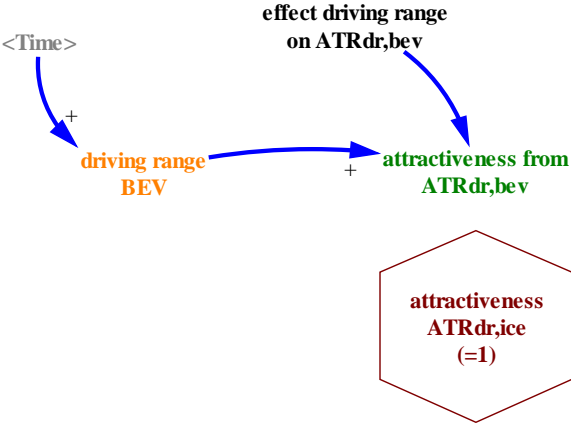r vehicle. The shorter the driving range, the higher the recharge frequency, resulting in more stations per vehicle needed. In Figure B.12 the number of recharge stations needed per vehicle as a function of the driving range is shown which is based on predictions made by the Electrification Coalition (2009). In the graph, at a driving range of 150km, two charge stations per vehicle are needed while at a driving range of 500km or further, one charge station per vehicle is needed.

It should be noted that the higher the number of recharge stations deployed, the less each recharge station will be used. This is an important implication for infrastructure providers and although it may sound counterintuitive, experience in Japan & Israel underline this. In Japan for instance, TEPCO[59] had a fleet of BEVs with recharge stations located at the company's office. The BEVs, upon return to the office, often had high States of Charge (SoC) left in their batteries. After TEPCO installed one fast recharge station in the city, the BEVs upon return had suddenly low states of charge left upon return to the office[60]. This was surprising as it was expected that the drivers would charge their batteries in the city whenever they had the chance. However, this wasn't the case; by knowing that there was a recharge station in the city the drivers were more comfortable and confident which reduced their 'range anxiety' and the

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[58] http://reviews.cnet.com/8301-13746_7-20103608-48/for-many-ev-drivers-range-anxiety-drops-after-three-months-study/

[59] TEPCO = The Tokyo Electric Power Company

[60] See Figure D.6 in appendix D4

driving patterns of the drivers became more widespread and longer than before the recharge station was installed.

This example shows that recharge infrastructure is important to reduce 'range anxiety' among BEV drivers and make consumers more comfortable about purchasing a BEV. However, it is likely that, once people become confident about the BEV, the utilization rate of public recharge stations will be lower than was anticipated before. This has implications for providers of recharge infrastructure as the time to recover the investments made could be longer, reducing profitability and therefore providers of recharge infrastructure should carefully consider the number of stations they want to deploy.
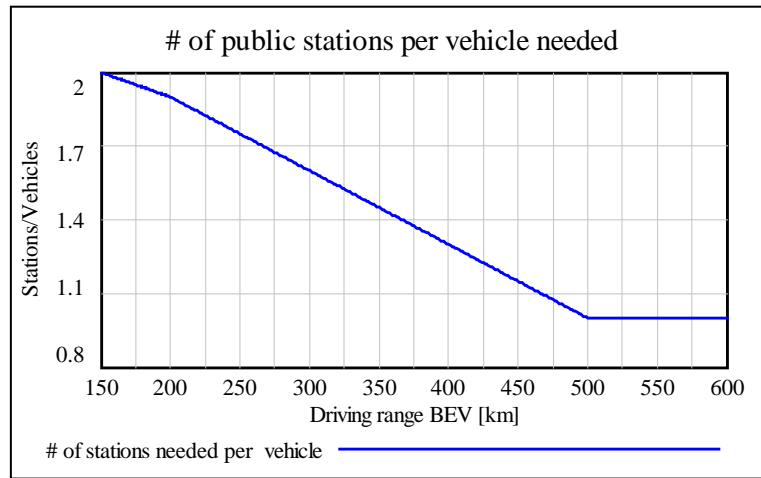
Figure B.12 - # of public recharge stations needed per vehicle - base case
source: (Electrification-Coalition, 2009)

As discussed in Paragraph 3.5, the recharge demand, which depends on the installed base of the BEV, determines together with the number of stations needed per vehicle and actual number of stations build, the total number of stations needed (goal)

$$\text{\# of stations needed}_{ptf} = \text{recharge demand} * \text{\# of stations needed per vehicle} - \text{\# of stations build} \tag{14}$$

If this value increases, the station shortfall increases (if actual number of stations is held constant). Infrastructure providers need to fill in this gap but need time to perceive the gap and start constructing new stations; a delay thus exists before the station is actually build. In the model this delay is set to 1 year. When the recharge stations are completed, the shortfall or gap will be closed and infrastructure density increases; increasing the attractiveness to drive a BEV. A reduction in installed base and thus recharge demand will result in a negative shortfall of stations and the total number of stations will be reduced.

At the moment there are 4243 fuel stations in the Netherlands which have in total 18683 fuel positions to refuel (Bovag, 2009)[61]. The density of fuel positions in the Netherlands is 3.11 fuel positions per square kilometer and a carrying capacity of 2.61 fuel positions per 1000 vehicles[62]. The carrying capacity for slow recharge stations is, as stated, 2000 fuel positions per 1000 vehicles in 2010 but reduces when driving range increases. The carrying capacity of both platforms thus differs substantially. It is difficult to compare these figures with each other to determine the attractiveness of attribute $atr_{id,ptf}$. First of all, ICE drivers have to refuel at a fuel station while people who drive a BEV can recharge their vehicle from almost any power outlet. In the Netherlands, 35% of the households have a garage or carport, i.e. they are able to recharge their car on private property[63]. Also recharge time influences the infrastructure density and attractiveness (see next paragraph) as well as driving range. The recharge times for the BEV are changing while for the ICE these are fixed. For instance refuel time of an ICE is 5~10 minutes and is not considered to change in the future. To determine the attractiveness of the ICE ($atr_{id,ice}$), the reference density of 3.11 fuel position/km2 at t_0 will be used. When the installed base of the ICE decreases, the number of fuel stations reduces and thus infrastructure density; $atr_{id,ice}$ will become less then 1. To determine the $atr_{id,bev}$ the survey results of Ecomobiel are used.

In Figure B.13 the attractiveness ($atr_{id,bev}$) as function of infrastructure density is shown.
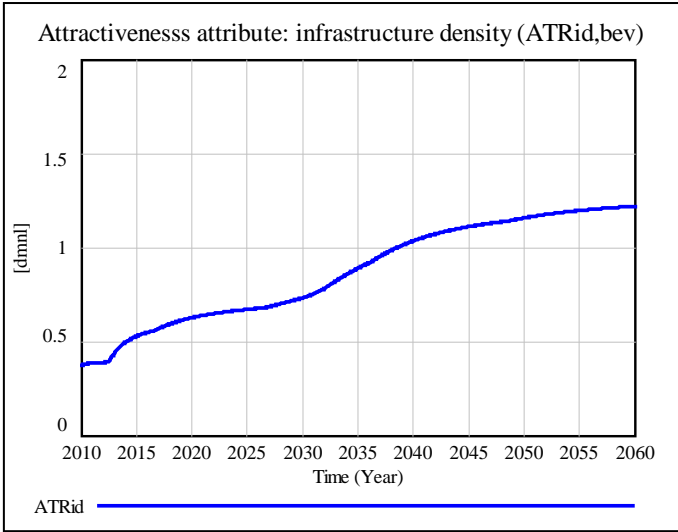

Figure B.13 - Attractiveness Infrastructure density (ATRid,ptf)

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[61] See also appendix C8

[62] Considering an ICE installed base of 7.147.270 vehicle @ t_0=2010

[63] CBS-statline (2010), see also appendix C9.
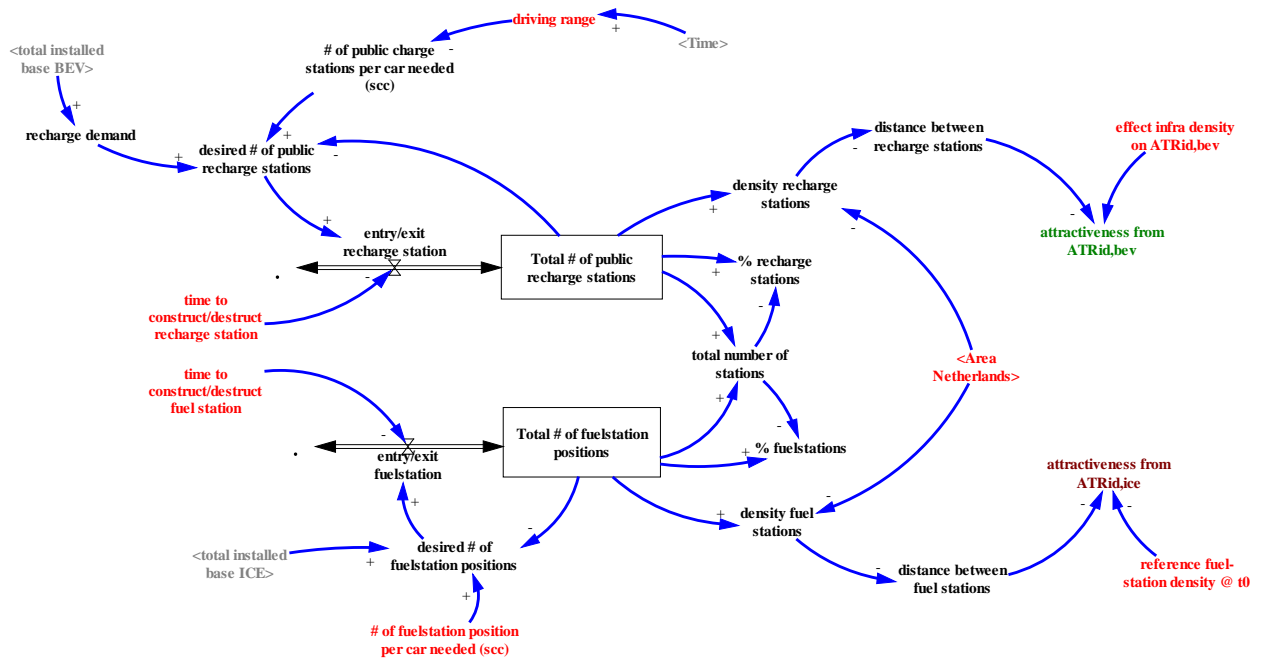
Figure B.14 - SFD – Infrastructure section

B2.5.4   Recharge/refuel time of platform

The last attribute is the recharge/refuel time of a platform. Compared to the BEV, an ICE can be refueled very fast; within 5~10 minutes and thus the recharge technology attribute ($atr_{rt,ice}$) is very attractive ($atr_{rt,ice} = 1$). For the BEV however, different recharge technologies exist; slow and fast charging, battery swap and induction charging[64]. The difficulty is that for instance a fast recharge station is expensive compared to the slow recharge station. Furthermore it is unclear what the utilization rate is going to be. The TEPCO example discussed in Paragraph B2.5.3 indicates that when the stations are deployed, it does not necessarily mean that they will be used extensively. Only in case of an emergency or when someone needs to travel for a far distance they will be used. As the 91% of the daily commuters travel less than 150 km a day the recharge station will only be used on rare occasions by this group of people although the other 9% might be a potential target group.

Also fewer stations are needed when recharging times are shortened as the carrying capacity of stations increases and thus also affecting the station density. Furthermore, how will people pay the provider for services? If the provider charges per kWh it needs to be close to the actual cost price as otherwise people will charge at a normal power outlet. However if the companies charge per kWh, ROI will be very long as it would take many years before the investment would be earned back which is risky.

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[64] See appendix C3

In the model, the base case only considers slow charging from a 230 power outlet found in the Netherlands. To fully charge the battery of a Nissan Leaf or similar vehicle (with a battery of 24 kWh) from a normal power outlet takes about 420 minutes (8 hours or 20km/h) for 160km; or about 20km per hour charge. A fast charger can recharge the battery in about 30 minutes (320 km/h).

These recharge times are compared to the ICE, very long. The surveys of Ecomobiel and Ballast Nedam indicate that the majority of people don't want a charging time of longer than 4 hours (at home). As stated, recharging a full battery takes about 8 hours so it is not very attractive. However, it should also be noted that, as stated previously, about 65% of the driver population drives less then 50km a day. In their case it would take about 2.5 hour to recharge their battery[65]. Looking at the survey results indicate that about 65% would accept this recharge time. For the base case therefore it is assumed that the attribute of recharge time has an attractiveness of 0.65*0.65 = 0.4225 ($\text{atr}_{rt,bev}$=0.4225) at t_0. When recharge time decreases further due to new technologies, the attractiveness of this attribute will increase.

Figure B.15 - Cartoon

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[65] If they charge every day at home

B3 - List of exogenous variables

Table B.1 - List of exogenous variables

Parameter	Value	Unit	Description	Source
aging time 0-7	7	year	time to age from 0-7 year	-
aging time 07-15	8	year	time to age from 7-15 year	-
annual maintenance costs BEV	1260	Euro/Year	estimated maintenance costs BEV	Autozine.nl
annual maintenance costs ICE	1575	Euro/Year	estimated maintenance costs ICE	Autozine.nl
annual tax costs BEV	0	Euro/Year	no tax for BEV	Autobelastingen, (link)
annual tax costs ICE	480	Euro/Year	estimated tax costs ICE: 120 euro per quarter autoweek: Motorrijtuigenbelasting: 40 Euro/mnd	Rekenwijzer, (link);
area Netherlands	6001	km2	ground surface of the Netherlands	CBS
average battery capacity BEV	24	kWh	battery capacity Nissan Leaf	Nissan Leaf fact sheet
average distance travelled per year	15000	km	distance travel per year	Bovag/Rai (table 8.10)
average familiarity ICE	1	dmnl	the familiarity driver population has with ICE platform	-
BPM & VAT ICE	1+0.19+0.277	dmnl	BPM and VAT for c-segment car 2010	Bovag/Rai (table 2.3)
cost of 1 kWh	0,25	euro	used to calculate fuel costs BEV	link
cost of 1 liter of fuel @ t=2010	1,55	euro	used to calculate fuel cost ICE	Bovag/Rai
cost reduction factor	0.15	dmnl	used to calculate scale effect	Nasa, (link); Offer *et al* (2010)
discard fraction 0-7 years	0.0085	dmnl	percentage of vehicles discarded in age class 0-7	CBS statline
discard fraction 15-< years	0.2451	dmnl	percentage of vehicles discarded in age class 15-<	CBS statline
discard fraction 7-15 years	0.0708	dmnl	percentage of vehicles discarded in age class 7-15	CBS statline
epsilon	20	dmnl	ε is the slope of fractional familiarity decay at reference rate	Struben
fraction decrease in fuel consumption	0.1025	l/km	data on www.werkelijkverbruik.nl. in 2010 fuel consumption for VW golf 5d 7.55 l/100 km and in 2003 8.37 l/100 km	werkelijkverbruik.nl, (link)
fractional increase fuel price	0,03687	euro/year	increase in price of 1 liter of fuel. Fuelprice in 2000 was 1,1903 euro/liter, in 2010 around 1.55 euro/liter	Bovag/Rai
initial cost BEV	4786	Euro	cost of producing platform (lower due to less parts, excluding battery	
initial costs ICE	9218	Euro	cost of producing platform	Bovag/Rai (table 2.3)

initial fam ICE drivers about BEVs	0	dmnl	The initial familiarity about BEV's under ICE drivers	-
initial fleet size BEV for SE	90000	Vehicles	Initial number of vehicles (set high to reduce high scale effect)	-
initial fleet size ICE for SE	7069860	Vehicles	Initial number of vehicles (total sales of Netherlands in last 14 years)	CBS statline
initial stock BEV 0-7 years	534	Vehicles	vehicles on the road in age class 0-7 years	RDW, (link)
initial stock BEV 15-< years	0	Vehicles	vehicles on the road in age class 7-15 years	CBS statline
initial stock BEV 7-15 years	0	Vehicles	vehicles on the road in age class 15 years and older	CBS statline
initial stock ICE 0-7 years	3422596	Vehicles	vehicles on the road in age class 0-7 years	CBS statline
initial stock ICE 15-< years	761474	Vehicles	vehicles on the road in age class 7-15 years	CBS statline
initial stock ICE 7-15 years	2963206	Vehicles	vehicles on the road in age class 15 years and older	CBS statline
initial attractiveness ICE	1	dmnl	initial attractiveness of ICE at t=0	-
margin	1,5	dmnl	margin over manufacturing costs used to calculate purchase price	-
marketing effectiveness	0.03	dmnl	marketing effort to increase awareness of BEV's	Sterman, Bass, Struben
max familiarity decay rate	1	dmnl	maximum decay of familiarity in a year	-
reference rate exposure	0.05	dmnl	reference rate of social exposure where familiarity loss will be half of the normal rate	Struben
strength WoM BEV driver	0.25	dmnl	effectiveness of word of mouth about BEVs from a BEV driver	Struben, Sterman, survey
strength WoM nonBEV driver	0.15	dmnl	effectiveness of word of mouth about BEVs from an ICE driver	Struben, Sterman
time to construct/destruct fuel station	3	year	time needed to plan/perceive/(de)struct fuel station	-
time to construct/destruct recharge station	1	year	time needed to plan/perceive/(de)struct recharge station	-
WFdriving range	■■■	dmnl	weightfactor for attractiveness of driving range attribute	survey BN and Ecomobiel
WFinfrastructure density	■■■	dmnl	weightfactor for attractiveness of infra density attribute	survey BN and Ecomobiel
WFprice	■■■	dmnl	weightfactor for attractiveness of price attribute	survey BN and Ecomobiel
WFrecharge time	■■■	dmnl	weightfactor for attractiveness of recharge time attribute	survey BN and Ecomobiel

B4 Sensitivity Analysis

As all models are simplistic representations of reality, a sensitivity test is carried out to see what the implications are on the result of the model when exogenous variables are changed (Sterman, 2000). It results in a more thorough understanding of different results in simulations that occur by applying different values/user inputs to different variables. A sensitivity analysis involves the following steps (Deaton and Winebrake, 2000):

1   Identify the exogenous variables in the system. These are the variables whose values do not depend on other quantities in the system, but are instead set by the user.

2   For each exogenous variable, make a series of model runs, changing the value slightly from run to run. Variables should be varied over a fixed range or a fixed percentage for instance plus or minus 25% of the value.

3   Observe and compare the system behavior for each run. Determine the extent to which the system behavior changes when each exogenous variable is changed. Changes in the system behavior can manifest themselves as changes in the overall shape of the system response over time or in the level of response. In the model the exogenous variables will vary between the highest setting (+25% of original value) and the lowest setting (-25% of original value).

4   Identify those variables that have the most impact and those that appear to have little impact. If possible, give a rationale for the way each variable is classified.

In Table B.2 the results of the sensitivity analysis are given. In the table the exogenous variables are given including their description, values (normal, lowest and highest setting), the impact on installed base at three different moments in time, and if the exogenous has no, low or a high effect on the installed base.

Exogenous variables that have a low effect have a minimal impact on the outcome of the model. This can be important for policy makers to know; when an exogenous variable can be changed without affecting the model significantly, it can result in economic or other benefits. Exogenous variables that have a high effect however, have a significant impact on the model outcome. If the value of such a variable is changed slightly, the behavior of the system can change significantly. It is important to closely monitor these variables and try to explain them as good as possible.

Table B.2 - Results Sensitivity analysis

Exogenous Variables [unit]	Description	High value (+25%) Base value Low value (-25%)	Outcome Installed Base BEV @ t =2020	change in %	Outcome Installed Base BEV @ t = 2030	change in %	Outcome Installed Base BEV @ t = 2040	change in %	Effect (low, moderate ,high)
Annual maintenance costs BEV [Euro]	estimated maintenance costs	1575	127488	-3%	425313	-6%	1848000	-6%	low
		1260	131919		454204		1972000		
		945	136722	4%	488336	8%	2103000	7%	
annual maintenance costs ICE [euro]	estimated maintenance costs ICE	1968,75	137568	4%	487790	7%	2086000	6%	low
		1575	131919		454204		1972000		
		1181,25	126321	-4%	423380	-7%	1853000	-6%	
annual tax costs BEV [Euro]	no tax for BEV till at least 2018	240	128511	-3%	431785	-5%	1877000	-5%	low
		0	131919		454204		1972000		
		-	-	-	-	-	-	-	
annual tax costs ICE [ICE]	estimated tax costs ICE: 120 euro per quarter	600	133635	1%	464125	2%	2007000	2%	none
		480	131919		454204		1972000		
		360	130207	-1%	444539	-2%	1936000	-2%	
average distance travelled per year [km]	distance travelled per year per person	18750	136556	4%	481450	6%	2064000	5%	low
		15000	131919		454204		1972000		
		11250	127167	-4%	427793	-6%	1871000	-5%	
average familiarity ICE [dmnl]	the familiarity driver population has with ICE platform	-	-	-	-	-	-	-	high
		1	131919		454204		1972000		
		0,75	184252	40%	885637	95%	2915000	48%	
Cost reduction factor	used to calculate cost	0,1875	132059	0%	459710	1%	2000000	1%	none

[dmnl]	reduction of a vehicle platform through scale effects	0,15	131919		454204		1972000		
		0,1125	131773	0%	448391	-1%	1940000	-2%	
fraction decrease in fuel consumption [dmnl]	in 2010 fuel consumption for VW golf 5d 7.55 l/100 km and in 2003 8.37 l/100 km	0,128125	131715	0%	451777	-1%	1959000	-1%	
		0,1025	131919		454204		1972000		none
		0,076875	132128	0%	456752	1%	1984000	1%	
fractional increase fuel price [dmnl]	increase in price of 1 liter of fuel. Fuelprice in 2000 was 1,1903 euro/liter, in 2010 around 1.55 euro/liter	0,04609	132490	0%	460583	1%	2002000	2%	
		0,03687	131919		454204		1972000		none
		0,02765	131344	0%	447830	-1%	1941000	-2%	
initial cost BEV [Euro]	cost of producing platform (lower due to less parts & excluding battery)	5982,5	124717	-5%	413672	-9%	1813000	-8%	
		4786	131919		454204		1972000		low
		3589,5	140082	6%	505050	11%	2139000	8%	
initial costs ICE [Euro]	cost of producing platform	11523	150292	14%	573537	26%	2316000	17%	
		9218	131919		454204		1972000		moderate
		6914	114082	-14%	363709	-20%	1587000	-20%	
initial fam ICE drivers about BEVs [dmnl]	the initial familiarity about BEV's under ICE drivers	0,05	159277	21%	530590	17%	2163000	10%	
		0	131919		454204		1972000		moderate
		-	-	-	-	-	-	-	
Initial fleet size BEV for SE [Vehicles]	initial nr of vehicles to calculate cost reduction of a platform through scale effects	112500	131497	0%	448345	-1%	1948000	-1%	
		90000	131919		454204		1972000		none
		67500	132722	1%	462314	2%	2002000	2%	
Initial fleet size ICE for SE	initial nr of vehicles to calculate cost reduction	8837325	131919	0%	457444	1%	1992000	1%	
		7069860	131919		454204		1972000		none

[Vehicles]		5302395	131919	0%	446463	-2%	1936000	-2%	
Marketing Effectiveness [dmnl]	marketing effort for the Electric Vehicle	0,0375	269797	105%	1736000	282%	3364000	71%	**high**
		0,03	131919		454204		1972000		
		0,0225	75883	-42%	186759	-59%	360151	-82%	
Strength WoM nonBEV drivers [dmnl]	strength word of mouth of nonBEV drivers (Word of Town loop)	0,1875	152866	16%	913137	101%	2781000	41%	**high**
		0,15	131919		454204		1972000		
		0,1125	117916	-11%	334970	-26%	1079000	-45%	
Strength WoM BEV drivers [dmnl]	strength word of mouth of BEV drivers (Word of Mouth loop)	0,3125	136599	4%	629995	39%	2423000	23%	**moderate**
		0,25	131919		454204		1972000		
		0,1875	127591	-3%	366653	-19%	1262000	-36%	
WFdriving range [dmnl]	weightfactor for attractiveness of driving range attribute								**low**
WFinfrastructure density [dmnl]	weightfactor for attractiveness of infra density attribute							-2%	**low**
Wfprice [dmnl]	weightfactor for attractiveness of price attribute								**low**
WFrecharge time [dmnl]	weightfactor for attractiveness of recharge time attribute								**low**

As can be seen from the table, the variables that influence familiarity (*'Word of Mouth BEV drivers', 'Word of Mouth nonBEV drivers", 'Marketing Effectiveness'* and *'Average familiarity about ICE'*) have a high impact on the simulation results. Looking at Figure B.16 an explanation for this large impact on the simulation results can be found. When looking just at the attractiveness of both platforms (top graph), it can be seen that the attractiveness of the BEV platform (at t_0) is about half the attractiveness of the ICE platform (red and black line). This is due to the fact that the BEV on all attributes (price, driving range, infrastructure density and recharge time) scores initially low. As the attractiveness of these attributes increases (especially the price attribute of the BEV platform due to battery cost reduction and lower TCO), the overall attractiveness of the BEV increases and around 2024 the BEV becomes more attractive than the ICE platform. The attractiveness of the ICE platform slightly decreases due to the decrease in fuel infrastructure density of the ICE.

Although the BEV becomes more attractive in 2024 (red line), due to the low familiarity of the BEV (blue line), consumers don't yet perceive this attractiveness of the BEV platform (green line). In other words, the majority of consumers is not yet fully confident about the BEV and don't fully include the BEV platform in their consideration set when they are going to purchase a vehicle. In this case, only around 2037 and later the BEV platform is perceived as a more attractive platform than the ICE platform. This is also visible in the lower graph of Figure B.16 as at that point in time, the share of purchase being a BEV exceeds the ICE purchases.

Around 2030 the growth phase starts and therefore the uncertainty and sensitivity of the results is increasing because the positive word of mouth loops are dominating; small changes in the parameters that control the word of mouth loops intensify the large differences in installed base and sales (Sterman, 2000)[66]. When the market saturates, these word of mouth loops become less dominant and hence the uncertainty and sensitivity in the results decrease as can be seen in the table.

In the base case discussed in Paragraph 4.1, the installed base of the BEV in 2020 amounts to ~140.000 vehicles. Compared with predictions made by the Dutch Government, which initially predicted 1.000.000 vehicles around 2020 (Berg *et al.*, 2009)[67], the 140.000 vehicle predicted by the model may seem very low. However, other rapports and researchers indicate about the same number of vehicles in 2020, between 140.000 and 200.000 vehicles(G4V, 2011; ING-Economisch-Bureau, 2011) which gives confidence in the first simulation period of the model. However, as discussed, the growth phase and take-off period are less certain; that it is going to happen is almost certain but how fast depends for a large part on word of mouth and advertising.

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[66] Sterman (2000), Page 886

[67] The government recently lowered their expectations to 700.000 BEVs in 2025 (Inia, 2011)
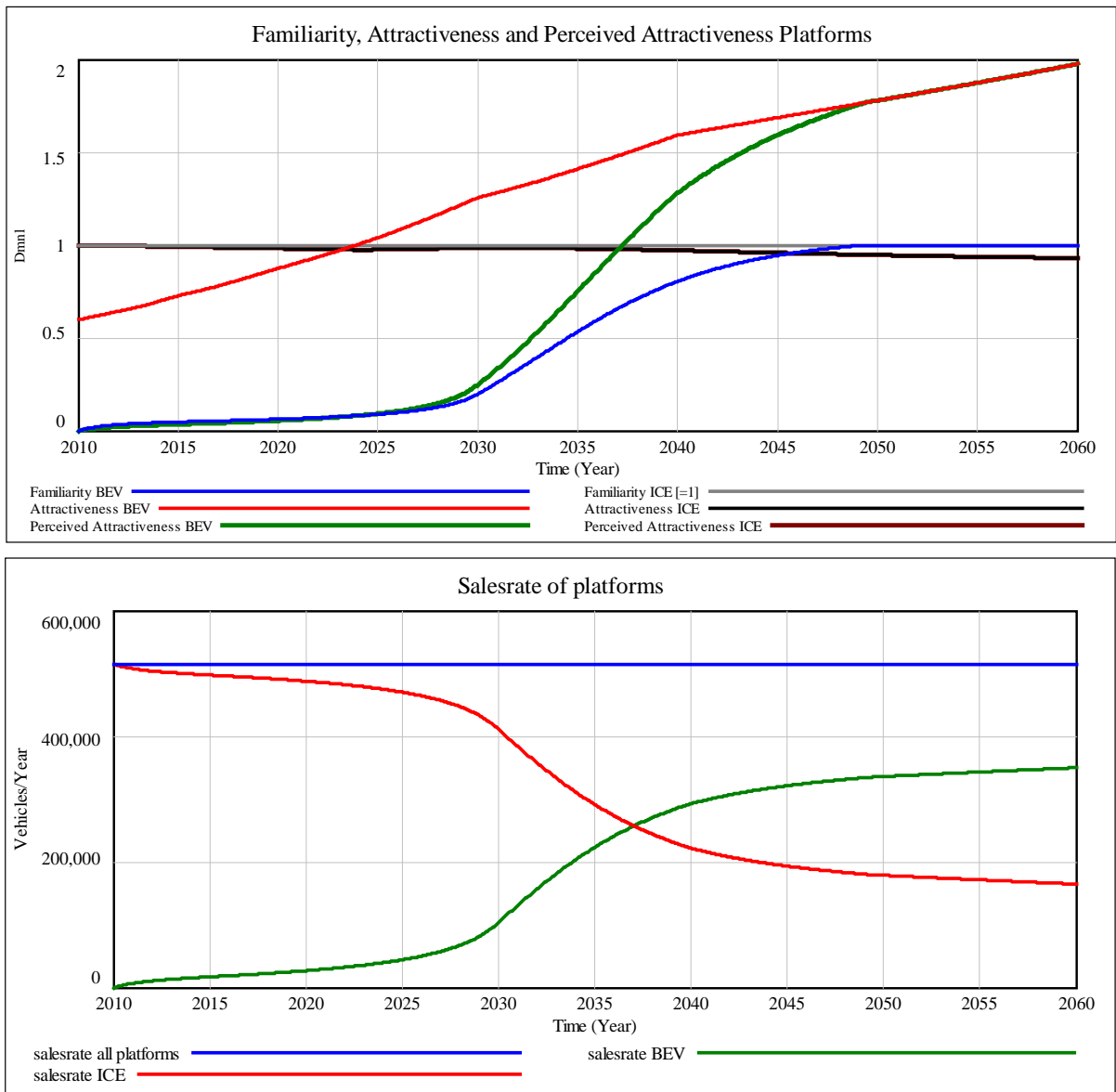
Figure B.16 - Familiarity, (Perceived) Attractiveness platform (top) and sales rate platforms

Appendix C - Technical documentation

## C1 - History of the electric vehicle

The first electric vehicle prototypes dates back as far as to the 1840s and used a rechargeable lead battery as energy source. Around 1900 there were three competing platforms; (i) steam powered vehicles, (ii) electric powered vehicles and (iii) vehicles powered by an Internal Combustion Engine (ICE) (Gärling and Thøgersen, 2001). Electric vehicles were considered to be clean, quiet, reliable and easy to handle and even broke the land speed record in 1899. However, electric vehicles were, due to their limited driving range, only useful within the city, which in the beginning wasn't a problem. The car was considered an urban car, as only cities had large amounts of asphalt and brick roads on which the fragile cars could drive (Geels, 2005). However, when the road system was improved the need arose for longer-range vehicles and, as improvements in battery technology had stalled, the electric vehicle couldn't foresee in this need. Also batteries were vulnerable and suffered from frequent breakdowns reducing the attractiveness and enthusiasm further. In the mean time, improvements of the ICE, such as the invention of the electric starter, increased its attractiveness and due to mass production of the ICE and the abundance of cheap oil, the price of the ICE dropped and became more affordable, increasing its market share even further. The electric vehicle could no longer compete with the ICE and by 1935 the electric vehicle had disappeared all together.

In the 1950s the invention of the semiconductor and improvements in motors and controllers resulted again in some interest in the electric vehicle in the 1960s. Around that time also the first emission regulations for vehicles were enforced; first by the state of California and later followed by the rest of the world which increased the interest further as it could reduce the problems of exhaust emissions that ICEs produced. The oil crisis in the 70s and 80s and increasing emission regulations further spurred the interest in electric vehicles (Gärling and Thøgersen, 2001) which resulted in several cars to be introduced on the market with the EV1 from General Motors (GM) as most successful. However, the EV1 didn't become a commercial success and in 1999 the production was stopped by GM.

Due to the economic recession in the late 2000s, increasing concerns about climate change and pollution, increasing fuel prices and the high dependency on other countries for the supply of fossil fuels, there is again an interest in electric vehicles and as discussed in the previous section, electric cars are again introduced onto the market.

C2 - Types of Electric Vehicles

There are three different types of electric vehicles: (i) the Hybrid Electric Vehicle (HEV), (ii) the Plug-In Hybrid Electric Vehicle (PHEV) and (iii) the Battery Electric Vehicle (BEV) also called a Full Electric Vehicle (FEV). In Figure C.1 below the three types and their key features are explained. In this report only the BEV is considered.
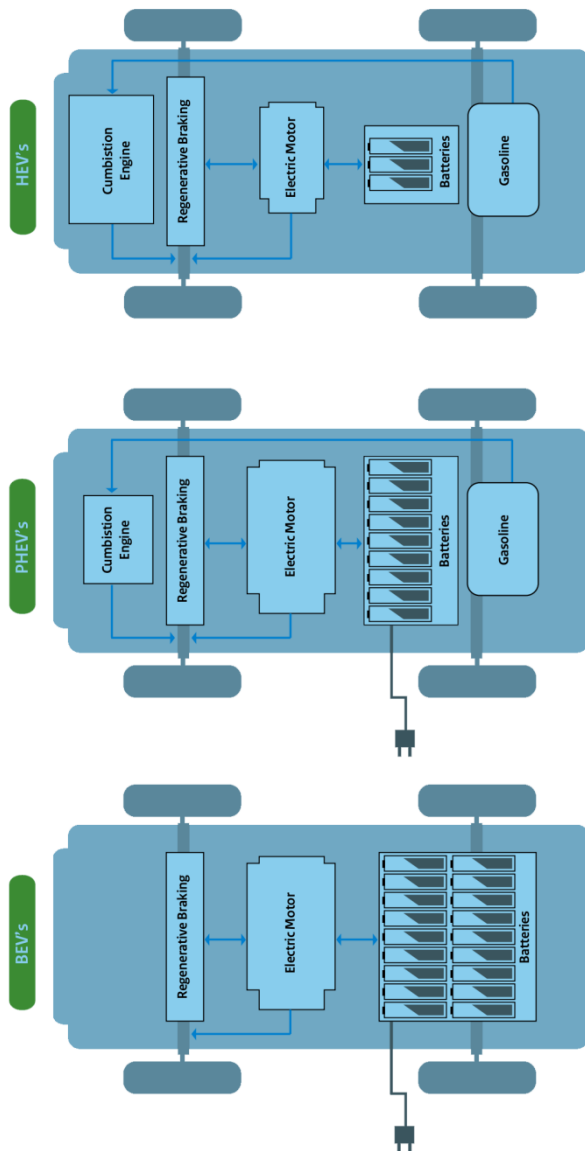
HEVs retain the use of an ICE, and require a liquid fuel tank. Additional energy is stored in a battery, from which electricity flows to an electric motor. The motor transforms electrical energy into mechanical energy, which provides some measure of torque to the wheels. In a typical parallel hybrid system, both the engine and the motor provide torque to the wheels. In a series hybrid system (SHEV), only the electric motor provides torque to the wheels, and the battery is charged via an onboard generator.

Like traditional hybrids, PHEVs retain the use of an internal combustion engine and fuel tank while adding a battery and electric motor. However, PHEVs utilize much larger batteries, which can be charged and recharged by plugging into the electric grid. PHEV batteries are capable of powering the vehicle purely on electricity at normal speeds over significant distances without any assistance of the ICE. When the battery is depleted, PHEVs use the ICE as a generator to power the electric motor and extend their range.

BEVs do not incorporate an ICE or conventional fuel system. Electric vehicles rely on one or more electric motors that receive power from an onboard battery to provide the vehicle's propulsion and operation of its accessories. BEV batteries, which are typically larger than batteries in HEVs or PHEVs to support vehicle range, are charged by plugging the car into the electric grid

Figure C.1 - Types of electric vehicles
Source: (Electrification-Coalition, 2009; Rijkswaterstaat, 2009)

C3 - Recharge Infrastructure

An electric vehicle can get its energy from an internal or external source. An internal source is for instance the electricity generated through regenerative breaking. In this report only the external source (via a source of electricity) is considered. To charge electric vehicles, three basic types of energy transmission can be distinguished; (i) conductive charging (plug and cable), (ii) inductive charging and (iii) replacing empty batteries (battery swap). Conductive charging has the advantage that stations are easy to install and is fairly cheap compared to the other technologies. Inductive charging is the most convenient solution as the vehicle can be charged while driving but also at the parking lot without having to connect the vehicle. Inductive charging is, according to the SAP forecast, however, not available within the next 10-20 years and has not been standardized yet. Battery swap has the advantage that it can be very fast compared to the other technologies but on the other hand it needs lot of investments and agreement between car manufacturers about standardization of the battery pack. In this report only the first type of energy transmission, conductive charging, is considered.

In Table C.1 below an overview of the different charging times is shown depending on the power supply used.

Table C.1 - Recharge times with different power outputs

Power supply	Voltage / Max current	Charging time
3,3 kW (single phase)	230 VAC / 16 A	6-8 hours
10 kW (three phase)	400 VAC / 16 A	2-3 hours
7 kW (single phase)	230 VAC / 32 A	3-4 hours
24 kW (three phase)	400 VAC / 32 A	1-2 hours
43 kW (three phase)	400 VAC / 63 A	20-30 minutes
50 kW (direct current)	400-500 VDC / 100-125A	20-30 minutes
* charging times for a 20-25 kW battery		

To ensure that BEV drivers are able to charge their vehicles at different locations and recharge stations without the need to bring different types of plugs to connect to the station, public recharge stations in the Netherlands have to comply with a standard plug and recharge mode which is based on the IEC 62196, an international standard for electrical connectors and charging modes. The norm used in the Netherlands (type 2 – mode 3)[68], is now also the standard in Germany, Belgium, Ireland, the United Kingdom and the Scandinavian countries.

C3.1 Locations
There are different types of locations where people can charge their vehicles. The location where people charge their BEV has implications for providers of recharge infrastructure as it

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[68] E-laad.nl (link)

affects the charging behavior, the economics and planning of the recharge infrastructure. An overview of different types of locations is given in Table C.2 below.

Type of location	Description
Private – Home charging	Charging will take place on private properties (houses, apartments with garages, etc). Will mainly consists out of overnight, slow charging
Private – Office charging	Charging that takes place at company garages and private parking lots. Charging will take place during the day and will mainly consist of slow charging
Semi-public – Convenience charging	Charging that takes place at public garages that are privately owned, retail locations such as shopping centers, fuel stations and motorway restaurants. Charging will consist out of a mix of slow and fast charging
Public – Convenience charging	Charging takes place at park and ride areas and (reserved) parking places in the public domain. Charging will consist out of a mix of slow and fast charging

C3.2 Pricing

There are two basic pricing strategies to generate revenue from recharge stations; (i) drivers pay per kWh they have used or (ii) drivers pay a monthly or annual subscription fee for using the recharge stations of a provider (Philip and Wiederer, 2010). In the pay per kWh strategy the revenue depends on the degree of utilization of the charge station (the hours per day vehicles are actually charging at the recharge station) multiplied with the capacity of the station (the amount of kW that can be delivered to a vehicle per hour) multiplied with a margin charged per kWh by the recharge provider (see also Figure C.2, left). In the subscription strategy the revenues per station are generated by the subscription fee a driver pays multiplied with the number of vehicles per charge station.

Although the calculation is straightforward it is unclear what utilization rates can be expected[69] or how many stations are needed per vehicle now and in the future. Also unclear is whether consumers are willing to pay an extra margin per kWh or are willing to subscribe to a service. For instance, if a consumer has the option to charge at home or at the office, would he or she be willing to pay more per kWh to charge in the (semi-)public space or is he or she willing to subscribe?
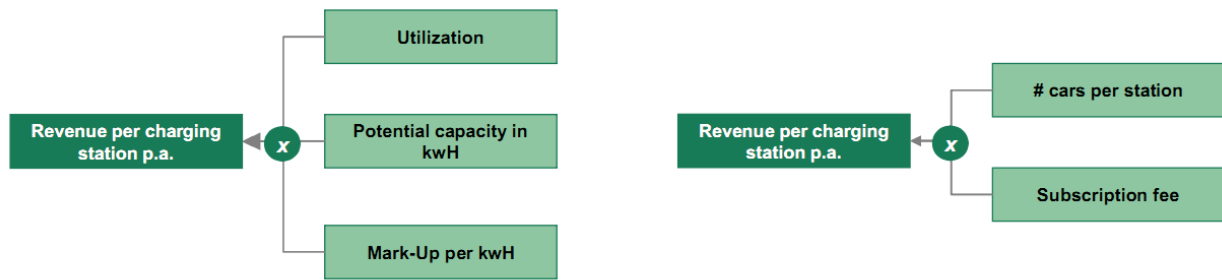
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[69] Pike Research, keynote 4 (link)

Figure C.2 - Two basic pricing strategies to generate revenue
Source: (Philip and Wiederer, 2010)

C3.3 Modes of charging and plug types

There are four possible operation modes of charging stations. These are listed in table C.3 below. Besides the four possible operation modes, there are also three different plug types for conductive charging which are also listed in Table C.3. In the Netherlands, all public recharge stations comply with the type 2, mode 3 standard.

Table C.3 - Operation modes and plug types for recharge stations *source: (G4V, 2011)*

Mode	Description	Specification
Mode 1	Connection by one-or three-phase to a AC grid, standardized socket as well as protective earth and line conductor	Max 16A, not exceeding 250 VAC (single phase) or 480 VAC (3 phase)
Mode 2	Connection by one-or three-phase to a AC grid, standardized socket, earth and line conductor in combination with a control function between EV and plug or control device	Max 32A, not exceeding 250 VAC (single phase) or 480 VAC (3 phase)
Mode 3	Direct connection of the EV to the AC grid using an application specific EV power supply which has a pilot function (conductor) leading all the way to the device continuously connected to the AC grid	
Mode 4	fast charging; indirect connection of the EV using an external charging device. A pilot function has to lead all the way to the device continuously connected to the AC grid	
Type	**Plug description**	**Specification**
Type 1	Single phase vehicle coupler	SAE J1772/2009
Type 2	Single and three phase vehicle coupler	VDE-AR-E 2623-2-2
Type 3	Single and three phase vehicle coupler with shutters	EV plug Alliance
* In the Netherlands the Mode 3 – Type 2 is the standard		

C4 - Advantages e-mobility

The transition towards electric mobility has several advantages. First of all, the generation of electricity can come from a diverse set of different fuels such as gas, coal and renewable energy sources. Unlike oil, many of these sources can be found in the Netherlands, making the Netherlands less dependable and vulnerable in case oil supply is interrupted. Also, if the supply of one of the fuels used for the generation of electricity is interrupted, it can be made up by the other fuels. Furthermore, there is already a nationwide electricity network, making it easier to implement electric mobility than other proposed alternatives such as hydrogen. Still, recharge infrastructure needs to be constructed but unlike hydrogen, the generation, transmission and distribution is already in place (Electrification-Coalition, 2009).

The use of electricity is also beneficial for the climate. Figure C.3 shows the Well-to-Wheel (WtW) GreenHouse Gas (GHG) emissions of a BEV (= BPEV in Figure C.3) compared to other configurations such as the conventional ICE vehicle (diesel and petrol engine). As can be seen in the graph, the GHG emissions are much lower for the BEV although it must be said that the GHG emissions of electric vehicles depend heavily on the source used to generate the electricity. The GHG emissions from using fossil fuels to generate electricity can range from 127g $CO_{2\,eq}$ km^{-1} using a coal fired power plant, to 55g $CO_{2\,eq}$ km^{-1} using a natural gas combined power plant (van Vliet *et al.*, 2011). If the electricity is produced from renewable energy sources such as wind- and solar energy, the GHG emission can even be reduced further resulting in a CO_2 reduction of almost 100% (Rijkswaterstaat, 2010). The GHG emissions of the BEV in Figure C.3 are based on emissions produced by the production park in the Netherlands to generate electricity.
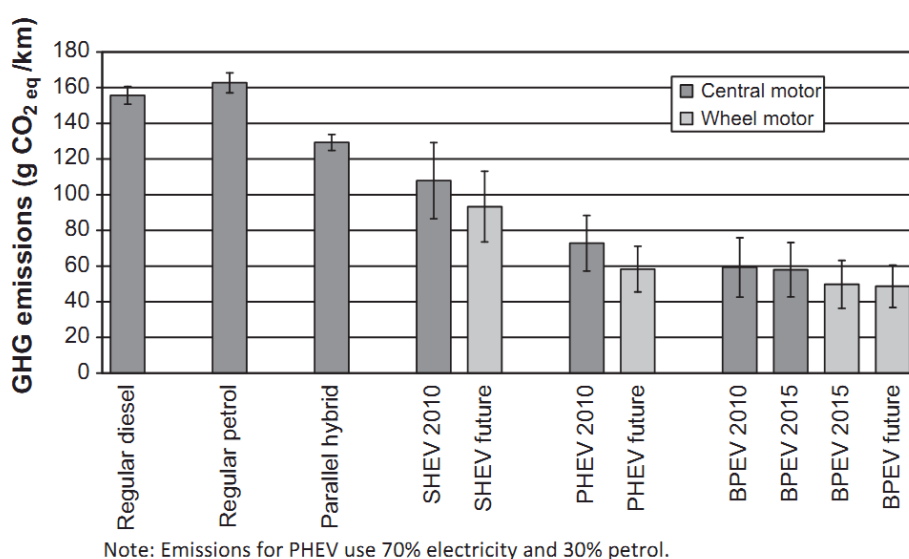

Figure C.3 - GreenHouseGas (GHG) emissions (WtW) for different vehicle configurations
Source: (van Vliet *et al.*, 2011)

Besides GHG emissions, also local emissions can be reduced significantly. The Tank-to-Wheel (TtW) emissions of a BEV are almost zero. With respect to PM- and NO_x emissions, the BEV scores very well especially when compared with a diesel engine (see Figure C.4). Furthermore, the BEV hardly produces any sound, especially at low speeds which gives the BEV the potential to reduce noise pollution in cities. However, only when a substantial part of the vehicles on the road is electric, will the BEV contribute to the reduction of noise. The BEV could also be a solution for the distribution of goods in cities, as vehicles are often bounded to a timeframe in which goods can be delivered due to noise nuisance. With a BEV, companies can deliver goods in a wider timeframe which can be beneficial for companies. (Rijkswaterstaat, 2010).
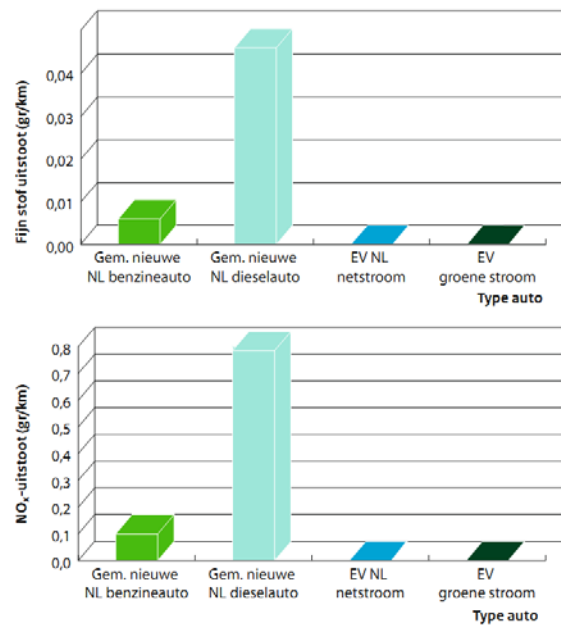
Figure C.4 - Comparison PM and NOx emissions (green=petrol; l. blue=diesel; d. blue=BEV, line-electricity; black=BEV, green electricity
Source: (Rijkswaterstaat, 2010)

C5 - Reference vehicles – Nissan Leaf (BEV) and VW Golf (ICE)

Table C.4 - Parameters used to calculate initial costs of platforms

parameters used to calculate <u>initial</u> platform costs @ t=2010*		ICE platform	BEV platform	
		(VW 1.4 16v trendline	(Nissan Leaf)	
Purchase price [€]		€ 20.285	€ 34.990	Autoweek
VAT [-]		19%	19%	Autoweek
BPM [-]		27,7%	0%	BPM calculator
Catalogus price [€]		€ 13.828	€ 29.403	
Initial Battery cost [€]		€ -	€ 22.224	ZERauto
Markup [-]		1,5	1,5	-
Cost platform [€]		€ 9.218	€ 4.786	(BEV = ex. battery)
yearly driven [km]		15000	15000	BOVAG, mobility monitor, Table 8.10
Fuel efficiency [km/l] v [km/kWh]		13,25	7	werkelijkverbruik.nl
Fuel price [€/l] v [€/kWh]		€ 1,55	€ 0,25	
Annual fuel costs		€ 1.755	€ 536	
Annual maintenance costs		€ 1.575	€ 1.260	Autozine.nl
Annual tax costs		€ 480	€ -	autobelastingen.nl/
*platform costs are variable over time due to increase in fuel efficiency, fuel costs, battery costs, etc				

C6 - Battery cost predictions

Table C.5 - Battery cost predictions

Price of battery (24 kWh)	Offer et al. (2010)	Van Vliet et al. (2011)	Electrification -Roadmap (2009)	ING	Nissan	Used in base case
2010	€ 17280 (720 €/kWh)	€ 23040 (960 €/kWh)	€ 10800 (450€/kWh)	€ 14400 (600 €/kWh)	€ 22224 (926 €/kWh)	€ 22224 (926 €/kWh)
2015	-	€ 19200 (800 €/kWh)	€ 9600 (400 €/kWh)	€ 9600 (400 €/kWh)	-	€ 16896 (704 €/kWh)
2020	-		€ 5760 (240 €/kWh)	€ 7200 (300 €/kWh)		€ 13680 (570 €/kWh)
2030	€ 6000 (250 €/kWh)	€ 9600 (400 €/kWh)	€ 3360 (140 €/kWh)	-	-	€ 8448 (352 €/kWh)
2040	-	-	-	-	-	€ 5040 (210 €/kWh)

Values based on scientific papers and personal communication with Prof. Dr. Notten from the TU/e.

C7 - Disassembly age passenger cars in the Netherlands

AVERAGE DISASSEMBLY AGE PASSENGER CARS (IN YEARS)
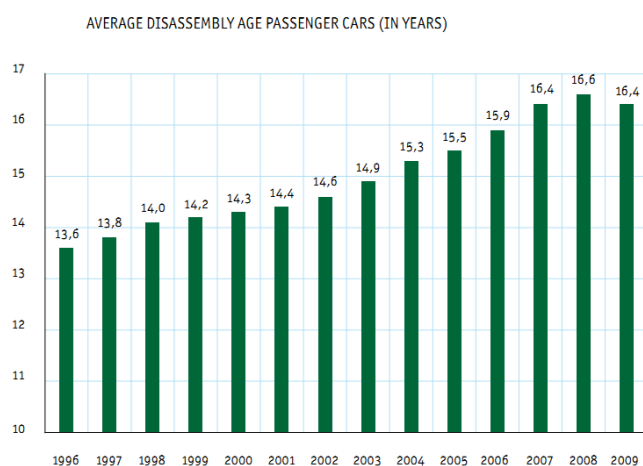
Bron/Source: Auto Recycling Nederland (ARN)

Figure C.5 - Average disassembly age passenger cars

C8 - Number of fuel positions in the Netherlands

Opstelplaatsen	Benzine/diesel	LPG	Truck
GEEN*	93	2.310	3.159
1	111	222	322
2	657	1.458	528
3	261	29	84
4	1.619	201	84
5	194	3	18
6	830	12	29
7	64	2	4
8	263	5	8
9	13	0	0
10+	138	1	7
TOTAAL	**4.243**	**4.243**	**4.243**

Figure C.6 - Number of fuel stations and fuel positions in the Netherlands
Source: (Bovag, 2009)

Number of fuel stations:	4243
Number of fuel positions:	18683
Total ground surface Netherlands:	33883 km^2
Available surface:[70]	6000 km^2
Fuel station density:	0.707 station/km^2
Fuel position density:	3.114 position/km^2
Number of vehicles:	7 147 800
Station carrying capacity:	1684.6 vehicles/station
Position carrying capacity:	382.6 vehicles/position

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[70] Available surface includes: road surface, (semi) build-up area and recreational areas (excludes ground surface of nature and agricultural land)

C9 - Percentage of Dutch population with(out) garage

Houses with and without garage and/or carport					
Region		Period	Houses with Garage/carport x 1 000	Houses with no Garage/carport x 1 000	Percentage houses Garage/carport %
Netherlands	Total number of houses	1998	1929	4224	34%
		1999	1910	4322	33%
		2000	1939	4355	33%
		2002	1974,4	4422,6	33%
		2006	2038,8	4513	34%
		2009	2185,6	4552,4	35%

C10 - Driving range of different BEVs
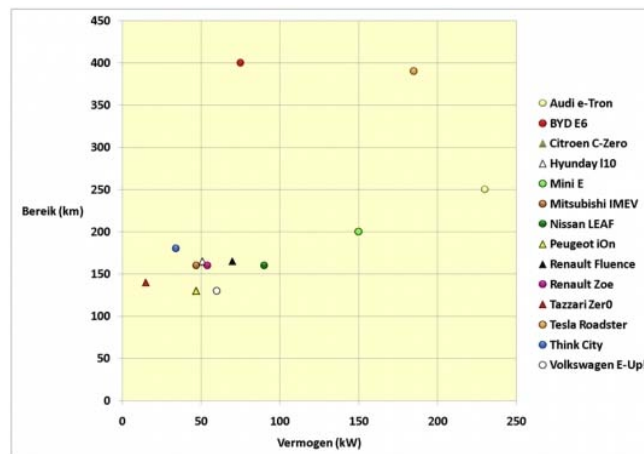
Figure C.7 - Driving range of different BEVs

C11 - Relative costs BEV according to TCO calculations
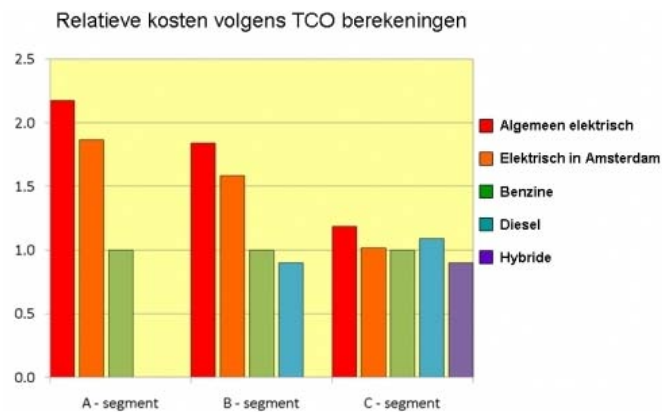
Figure C.8 - Relative costs according to TCO calculation
Source: ZERautos

Appendix D - Consumer behavior

D1 - Survey results Ballast Nedam (2011)

For more information on survey and the results see Bongard (2011). Full report in possession of Ballast-Nedam *('Elektrisch rijden in de toekomst')*

D2 - Survey results Ecomobiel (2011)

Sample population: Dutch population

Sample size: 10.804 persons

Figure D.1 - Minimal driving range a BEV should have according to consumer
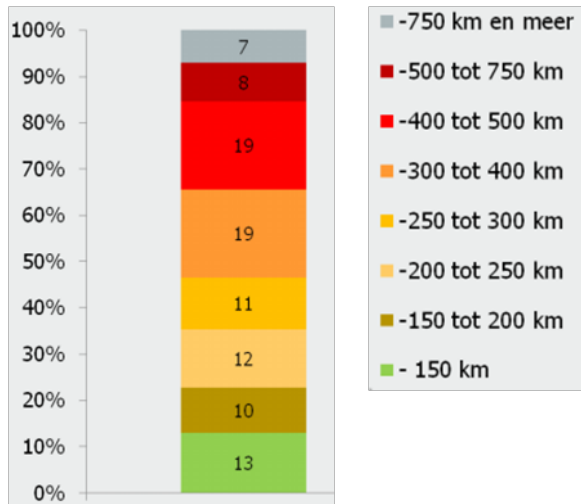
Which driving range should a BEV at least have?

N= 10.804 persons

Figure D.2 - Maximum time to charge a BEV
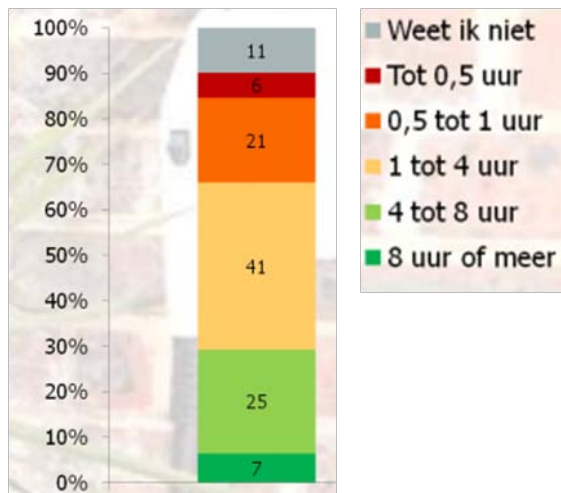
Can you indicate the maximum recharge time for a battery?
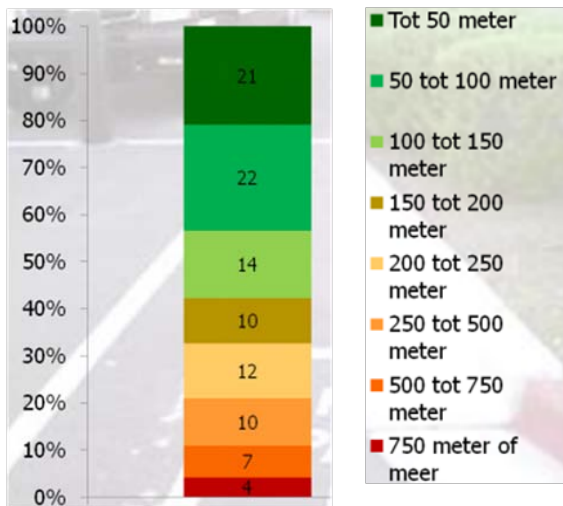
N = 10.804

What is the acceptable distance to a recharge station?

N = 6.286 (persons without garage or carport)

Figure D.3 - Acceptable distance to recharge station according to consumer
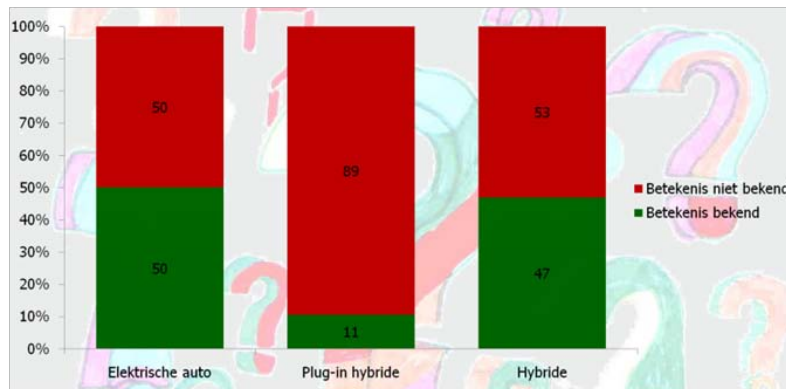
Have you heard about the following types of vehicles?

N = 10.804 persons

Figure D.4 - Familiarity consumers with different types of vehicle platforms

Research conducted by *Milieu Centraal* found that 2/3 of the Dutch population only knows the electric vehicle by name ([link](#)).

D3 - Mobility Dutch driver population
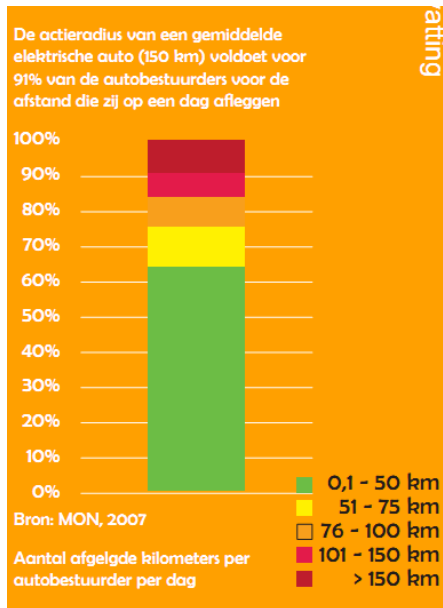
Source: (Berg *et al.*, 2009)

Figure D.5 - Number of kilometers traveled per driver per day

This percentage corresponds with other research; Malcolm, Narich *et al.* (2009) for instance found that 90% of the European population drove less than 100km a day.

D4 - State of Charge battery before and after installing recharge station
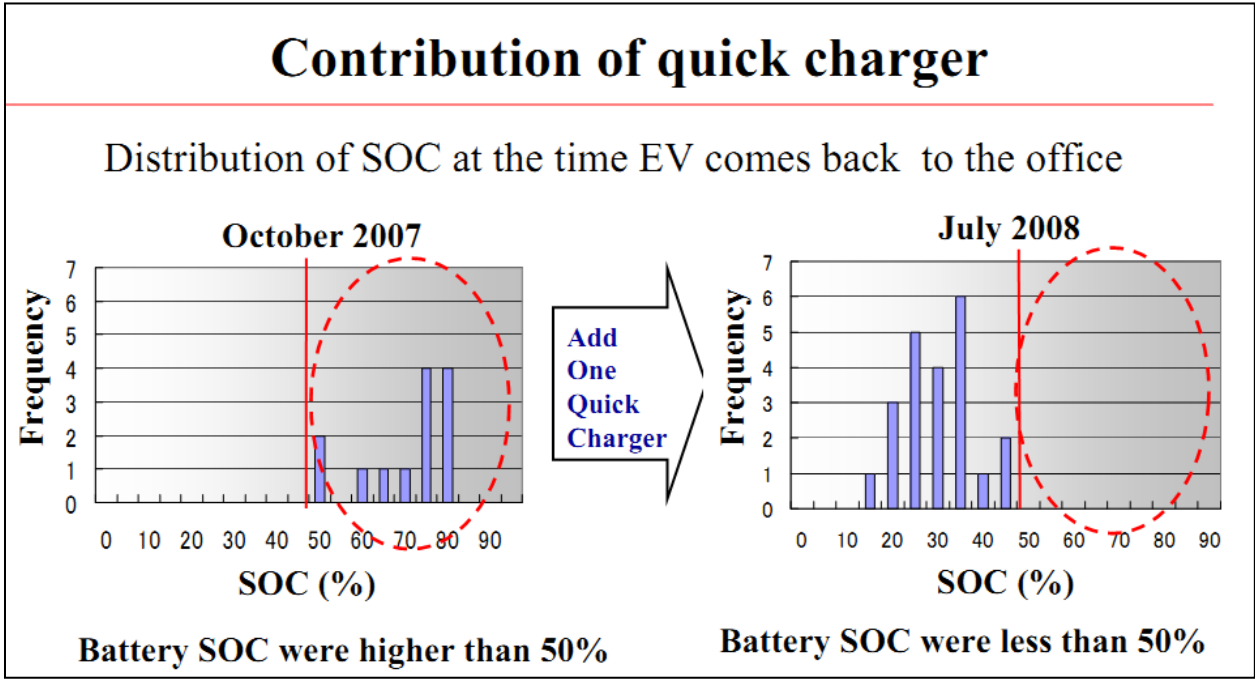
Figure D.6 - State of Charge BEVs before and after installing a fast recharge station
Source: (TEPCO, 2008)

D5 - Diesel share in new passenger vehicle registrations
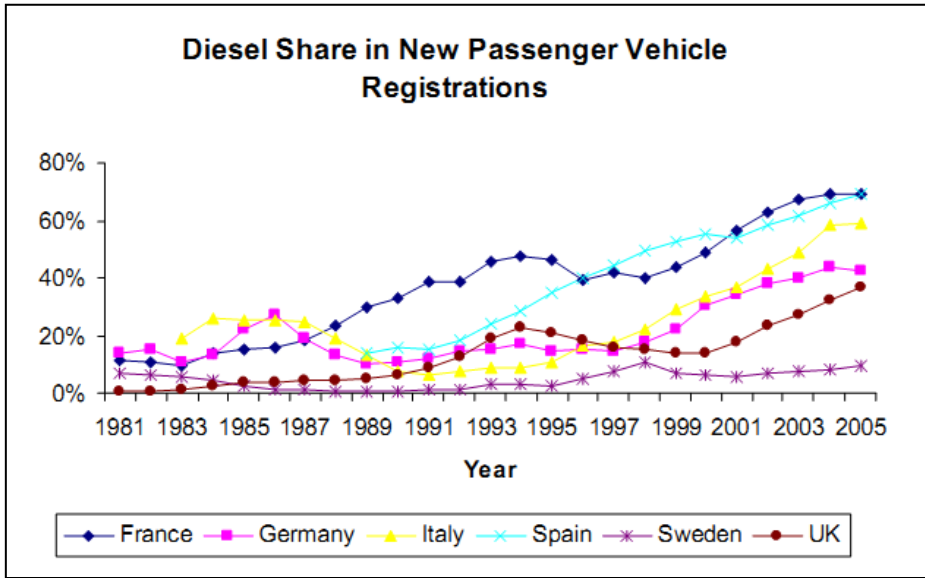
Figure D.7 - Diesel share in new passenger vehicle registrations
Source: (Zhang, 2007)

Appendix E – First-Mover Advantages

E1 - Pace of market evolution and the effect on FMAs
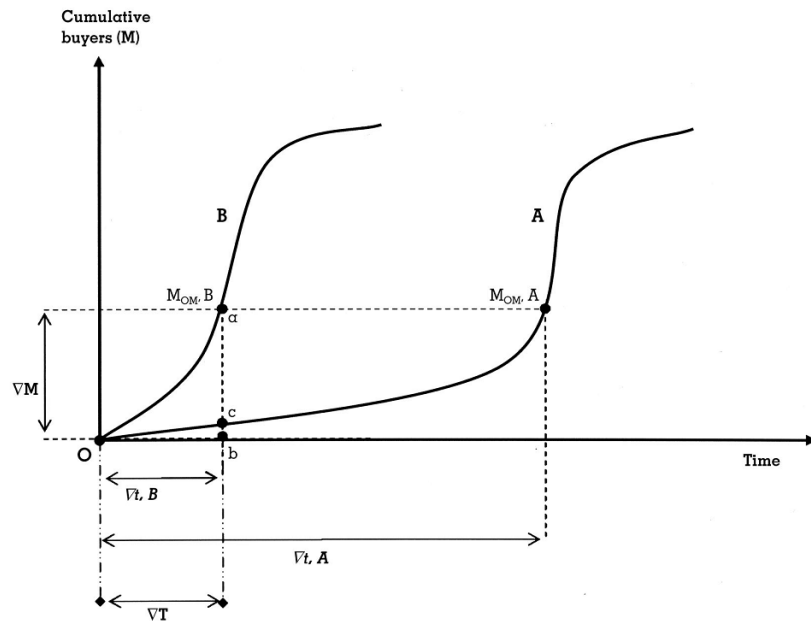
Source: Suarez and Lanzolla, 2007

Figure E.1 - Two scenarios for pace of market evolution

Let us call M the cumulative level of market-related resources in a given product category (e.g., cumulative buyers or cumulative sales) and M_{OM} the level of market-related resources at the industry's Onset to Maturity (OM). *Let us further consider two reference scenario*s for the pace of market evolution: an abrupt pace (curve B) and a smooth pace (curve A). For any fixed ∇T, firms operating in an environment with a higher pace of market evolution will benefit from a greater level of available market resources (e.g. buyers or sales). In fact, the segment "ab," representing market resources deployed in ∇T in scenario B, is longer than the corresponding segment, "bc," for scenario A. Unlike the slow pace scenario, when market growth occurs at a fast pace, other things being equal, a larger amount of consumer resources becomes available to the existing companies in the market for any given ∇T; this process undermines early entry inertial advantages. Alternatively, for any given fixed ∇M, there is a longer Vt in reference scenario A (Vt, A), slow-paced market growth, than in reference scenario B (Vt, B), fast-paced market growth. That is, a fixed amount of resources will have to "feed" all active firms for a longer period of time in scenario A than in scenario B, assuming a given distribution of entry and exit into the market over time (the longer the time, the greater the number of entrants).

E2 - Combined effects of Market and Technology evolution

Source: Suarez and Lanzolla, 2005; 2007

Suarez and Lanzolla (2005, 2007) constructed a matrix which has four possible scenarios. In the scenario of *"Calm Waters"*, the pace of both market and technology is slow. The gradual pace of change allows pioneers to create a dominant position that is long lasting. Due to gradual pace of change in the technology makes it hard for followers to differentiate their products from the pioneer and even if find a way to do so, the differences are not rapid enough to prevent the pioneer to incorporate them in its own product-line. The slow pace of change in the market enables pioneers to create, defend and develop new market segments. An example of a product is the vacuum cleaner and scotch tape. In the scenario of "Calm Waters" resources are less critical than they would be in the other scenarios. The more important ones are brand image/recognition and physical assets such as strategic locations and financial resources.

In *"The Market Leads"* scenario, the pace of technology evolves slowly but the market grows fast. In this case it is very likely that the first-mover-advantages will be short lived in case the pioneer has limited resources and skills. An example of a product in this scenario is the walkman introduced by Sony, which used mature technologies readily available. The market however grew abruptly. The reason why Sony still had a market share of 48% after 10 years was due their superior resources. Another product however, the sewing machine, was invented by a small company and soon a follower with greater resources took over the market.

The third scenario, *"The Technology Leads"*, the situation is reversed; fast pace in technology evolution and slow pace in market evolution. For a pioneer to have success it should have substantial resources and effort in R&D and finance to survive in this hostile environment and withstand a considerable delay before durable FMAs can be obtained. An example of a product is the digital camera where sales did not gather momentum for at least 10 years and even after that sales remained low for another 10 years. After many upgrades in technology sales finally took off.
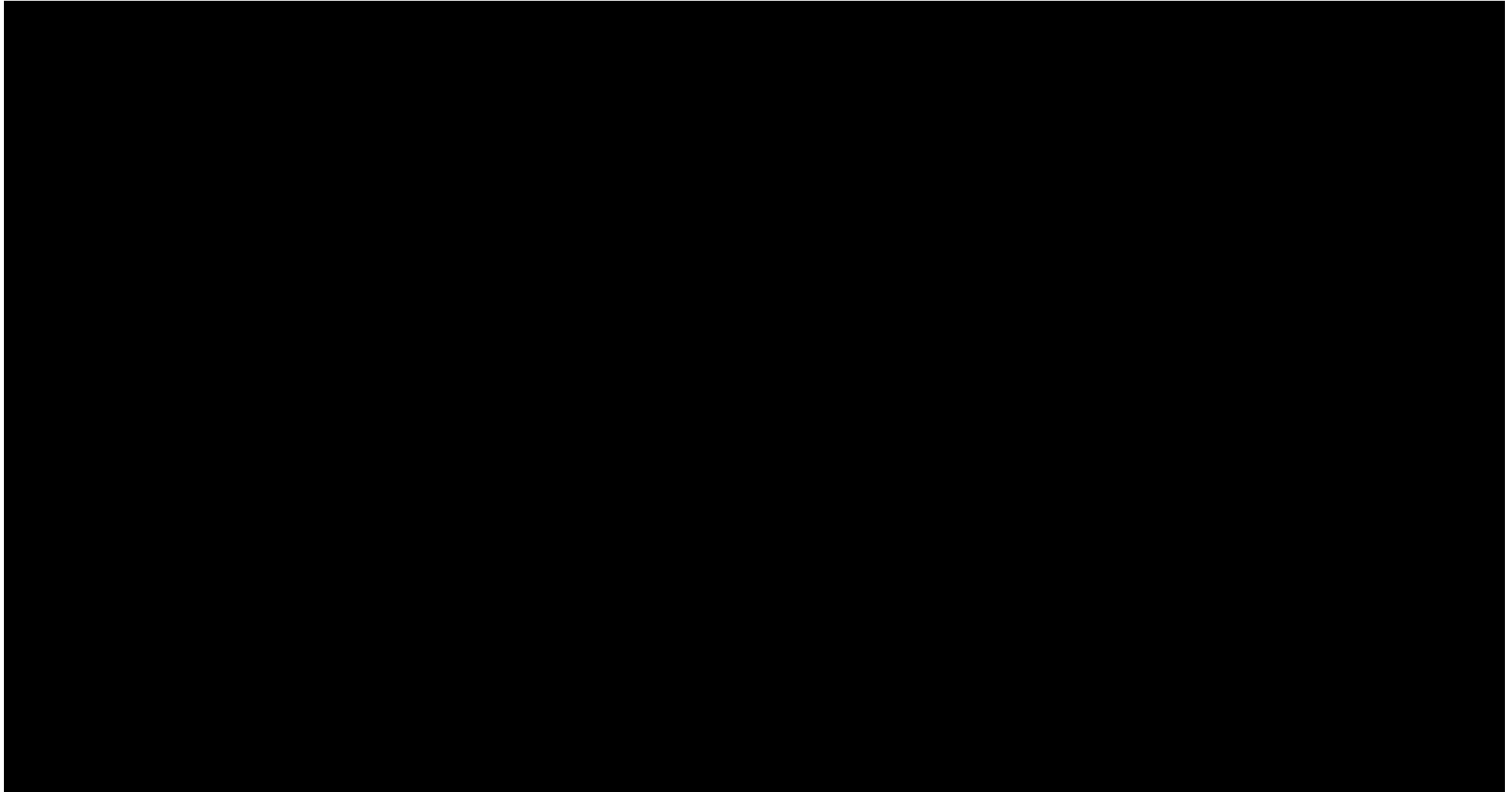
"Rough Waters" is the last scenario; fast pace in both technology and market evolution. In this scenario pioneers are highly vulnerable as it requires superior resources in many fields; R&D, marketing, production and distribution. As the product underlying technology changes vary rapidly, the product quickly becomes obsolete and often new versions of such products are overtaken by versions of followers. The fast growing market is an extra challenge for the pioneer as it opens opportunities for followers to exploit unused spaces. A pioneer often lacks the production capacity or marketing reach to serve a rapidly expanding customer base. Short-lived FMAs are very likely in this scenario. Netscape who created the first internet browser for instance was quickly overtaken by Microsoft's internet explorer. Durable FMAs are not impossible however as Intel shows.

Table E.1 - FMA and resources required (Source: Suarez and Lanzolla, 2005)

| | First-Mover-Advantage | | |
Situation	Short-lived	Durable	Key resources required
Calm Waters	Unlikely Even if attainable, advantage is not large	Very likely Moving first will almost certainly pay off	Brand awareness helpful but resources less crucial in this scenario
The Market Leads	Very Likely Even if you can't dominate the category, you should be able to hold onto your customer base	Likely Make sure you have the resources to address all market segments as they emerge	Large-scale marketing, distribution, and production capacity
The Technology Leads	Very Unlikely A fast changing technology in a slow-growing market is the enemy of short-term gains	Unlikely Fast technological change will give later entrants lots of weapons for attacking you	Strong R&D and new product development, deep pockets
Rough Waters	Likely A quick-in, quick-out strategy may make good sense here, unless your resources are awesome	Very unlikely There's little change of long-term success, even if you are a good swimmer. These conditions are the worst	Large-scale marketing, distribution, production and strong R&D (all at once)

Appendix F - Firm resources and capabilities

Appendix G – Model extension (future research)

In this section, a possible extension to the model will be discussed. This model extension makes it possible to include specific infrastructure providers and to model the impact on for instance market share when infrastructure providers enter the e-mobility market at different moments in time.

G1.1 Market share infrastructure provider

A BEV driver chooses an infrastructure provider depending how well the providers scores on the following four attributes; (i) number of stations per subscriber available (network utilization/blocking probability), (ii) the absolute number of stations an infrastructure provider has, (iii) the subscription fee and (iv) the attractiveness of the recharge locations of the provider. If two companies are considered, the following SFD can be constructed (Figure G.1). Every subscriber pays a fixed amount per month to the infrastructure provider. This subscription fee generates income and revenue for the infrastructure provider. Furthermore, the number of subscribers determines the recharge demand for the particular infrastructure provider.
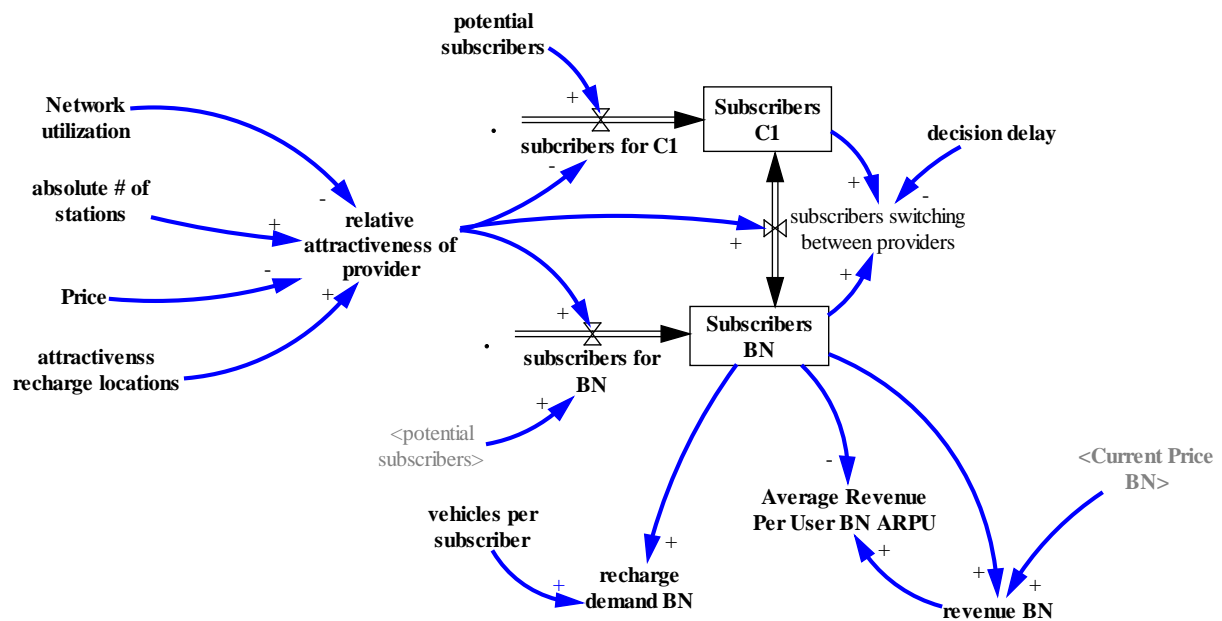

Figure G.1 – Market share infrastructure provider

G1.2 Capital available

How much capital is available to the infrastructure provider depends on the income, generated by the number of subscribers, minus the expenses the infrastructure provider has. Expenses for an infrastructure provider are for instance the maintenance costs and possible loan the provider has to amortize. If expenses are less than the income the company makes a profit which and capital becomes available to the company which can be used to invest in more stations.
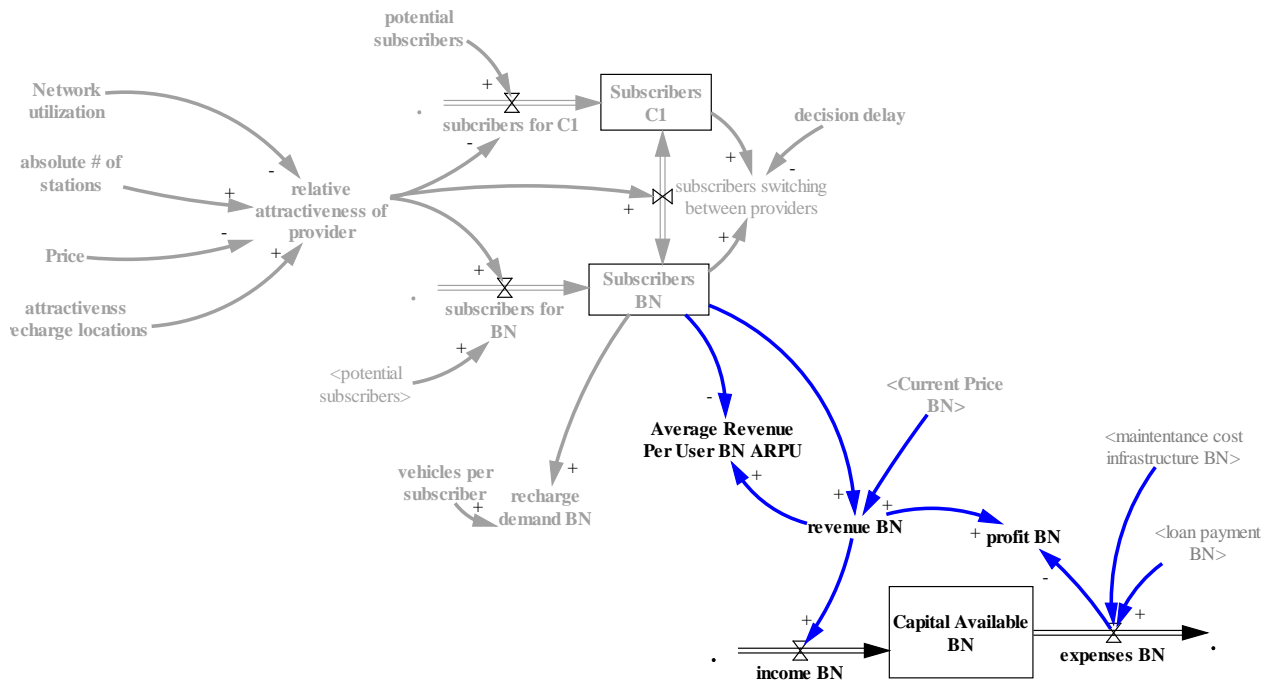
Figure G.2 - Capital available

G1.3 Network extension

When the number of subscribers increases, the recharge demand will increase. If no stations are being built, the network utilization will increase which decreases the quality of the network as the blocking probability increases (the chance that a subscriber finds an already occupied station increases). Subscribers will start to switch to another network if the network utilization becomes too high. The *'network utilization'* (stations/vehicle) depends on the recharge demand and the number of stations the provider has. When the *'network utilization'* is too high compared to the *'reference station utilization',* the provider wants to build extra stations (*'desired additional stations').* The desired investment the provider wants to make depends on the extra number of stations needed multiplied with the construction costs of a station. If enough capital is available, new stations will be purchased and constructed. As it takes some time to build a station there is a delay before the *'desired network utilization'* is reached. Furthermore, besides the decrease in network utilization (decrease blocking probability), maintenance costs will increase. Together with the possible loan the provider has to amortize, the maintenance costs determine the yearly average cost per subscriber. If this number becomes above that of the *'average revenue per user'*, the provider has to increase its price or increase utilization of its network (and decrease quality of its network).
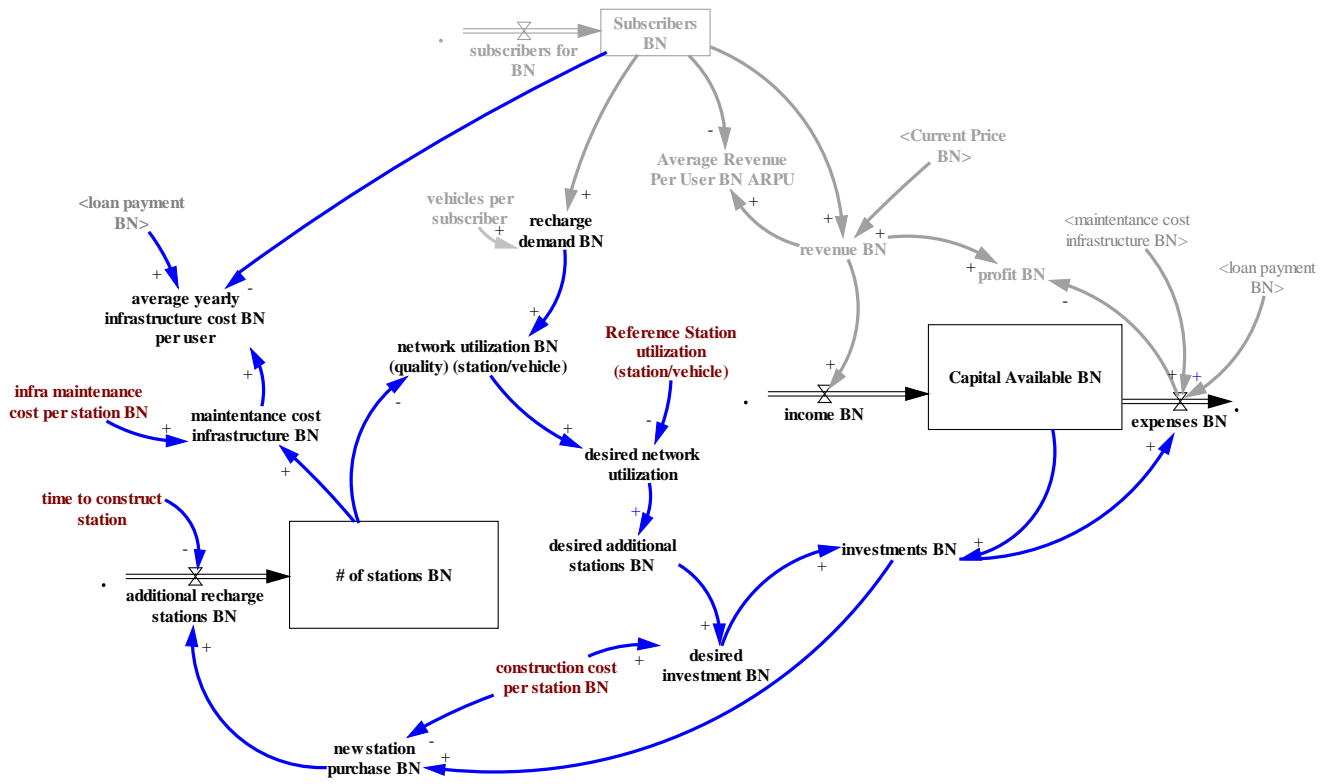
Figure G.3 - Extension of network

G1.4 Initial number of stations

By using seed capital, the provider can place an initial number of stations to start its business. This initial seed capital has to be amortized over a certain amount of time.
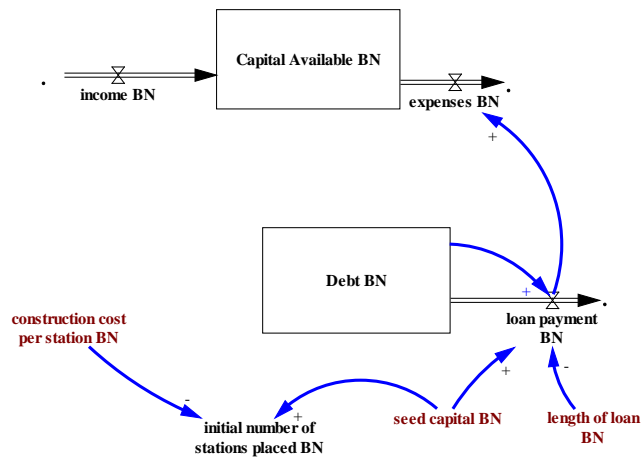

Figure G.4 - Initial number of stations

G1.5   Conclusion

Although the discussed model is not completed yet, it could be a good starting point for future research. However, more information is for instance needed on what potential subscribers find most important from an infrastructure provider; (i) number of stations per subscriber available, (ii) the absolute number of stations an infrastructure provider has, (iii) the subscription fee or (iv) the attractiveness of the recharge locations of the provider? At the moment this data is not available.