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„Stakeholder Impact on Sustainable Technologies:

The Case of Alternative Fuel Vehicles in Europe“

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List of Abbreviations

AFV *alternative fuel vehicle*

BEV *battery electric vehicle*

CCS combined charging system

CEP *Clean Energy Partnership*

CNG *compressed natural gas*

EAM *European automotive market*

EU *European Union*

EV *electric vehicle*

FCEV *fuel cell electric vehicle*

GHG *greenhouse gas*

HEV *hybrid electric vehicle*

ICE *internal combustion engine*

ICT *information and communications technology*

LNG *liquified natural gas*

LPG *liquefied petroleum gas*

NGV *natural gas vehicle*

OEM *original equipment manufacturer*

PHEV *plug-in hybrid electric vehicle*

PTG *power to gas*

RE *renewable energy*

REEV *range-extended electric vehicle*

RPH *renewable power hydrogen*

RPM *renewable power methane*

TCO *total cost of ownership*

TTW *tank-to-wheel*

ULEZ *ultra low emission zone*

VDA *German association of the automotive industry (Verband der Automobilindustrie)*

WTT *well-to-tank*

WTW *well-to-wheel*

ZEV *zero emission vehicle*

1. Introduction

Technological change and global economic-, political, and socio-economic forces increasingly pressure the automotive industry to shift towards CO2 neutral mobility solutions (Winkel et al. 2016; Hill et al. 2013; Bouza et al. 2009). Therefore, in the long-term, a transition of our mobility seems unavoidable. Today, several promising alternatives to replace the internal combustion engine (ICE) and fossil fuels exist. These include battery electricity, hydrogen, biofuels, natural gas, and renewable synthetic fuels (European Commission 2016d; Ramachandran, Stimming 2015).

However, alternative fuel vehicles (AFVs) currently represent only 4% of new vehicle registrations in Europe (ACEA 2017). Several technological and socio economic barriers such as a lacking infrastructure and immature technologies slow down the transition towards AFVs (Rosenstiel et al. 2015; Köhler et al. 2010). Furthermore, not all stakeholders in the European automotive industry are equally interested in speeding up the development, production and diffusion of AFVs. While stakeholders can function as driving forces, they might also slow down the pace of innovation. Consumers for example call for more sustainable products but they are not willing to pay a surcharge for sustainability (McKinsey 2017). While Tesla and Toyota encourage the race towards technological leadership in battery electric and hydrogen technology, European original equipment manufacturers (OEM) do currently not show significant efforts to scale up AFV production. This is because in the short-term, the optimization of ICE technology and investment into other mega trends including shared mobility and automation promise higher returns (McKinsey 2017). Intensified CO2 regulation pressures vehicles producers to increase their investment into AFVs. Too much pressure however, could harm the European automotive industry in terms of both, profitability and competitiveness (McKinsey & Company 2011).

In this context, several questions arise. First, it remains open which technologies will dominate the future mobility market (Ramachandran, Stimming 2015). Second, it is also unknown how the shift towards sustainable mobility solutions will influence the European automotive industry in the long term. To find an answer to these questions and to project the future development, existing research in this field frequently applies techno-economic and diffusion analyses (Schenuit et al. 2016; Hill et al. 2013; Meyer, Winebrake 2009). However, these findings do not address the bigger picture and fail to take into account the complex interrelationships of several stakeholders (Spickermann et al. 2014). It fails to capture how stakeholders influence each other and how these interactions shape the further development of powertrain technologies. Existing findings therefore reflect the current situation in a one-sided and fuzzy way. In order to gain a holistic understanding of the situation, a new approach is required. By looking at the situation from a multi stakeholder perspective, this thesis paper sheds light on the complex system driven by various stakeholders and their interests. The results serve to better understand and project the transition towards sustainable technologies in the European automotive industry.

1.1. Aim

The aim of this thesis is to analyze the development of different AFV technologies in the European automotive market. In contrast to existing research findings, this thesis analyses the AFV market development from a stakeholder perspective.

Several studies that focus on the development of AFVs and infrastructure exist (e.g. Adolf 2017; Scott 2016; McKinsey & Company 2011; Bouza et al. 2009; Oltra, Saint Jean 2009, etc.). However, these studies frequently fail to consider key aspects such as socio-economical barriers, political regulation and other market forces. Existing studies that address the topic of power train technologies focus primarily on a technological or economical perspective but "only few articles have addressed the topics of future mobility and relationship research" (Spickermann et al. 2014, p. 204). Furthermore, they often focus on a limited number of alternative technologies. Hardly any study takes into account the entire spectrum of technological possibilities while simultaneously considering the influence of several stakeholders in the market. Therefore, existing literature findings that aim to predict the future of our mobility system vary greatly. The number of AFVs projected on Europe´s streets has been frequently overestimated in the past (Christidis et al. 2005). Today, the market uptake of AFVs in Europe lies still below 4% (ACEA 2017). It seems that the picture that theory draws fails to display the complex relationships as they influence the development of AFVs in practice. So far, no research exists that analyses the development of AFVs from a holistic perspective. Most studies on AFV development fail to take into account the influence of several stakeholders that influence the market development. Hence, a gap in literature exists.

This thesis contributes to fill this gap in literature by discussing the development of AFVs from a multi-stakeholder perspective. The approach is closely linked to Freeman et al.´s (2013) stakeholder theory. According to this theory, markets can be understood as set of relationships between primary and secondary stakeholders. Freeman et al. (2013) argue that everything can be understood when one can understand the market that the company is operating in. Based on this concept, the following research takes a new approach to analyze the transition towards AFVs in Europe.

The overall aim of this thesis is to find out how different stakeholder interests in the European automotive industry influence the development of AFVs. To follow this aim, the current development of AFV technologies in Europe is analyzed in a holistic way from a stakeholder perspective. In this context, it is crucial to understand the relationship between different stakeholders. The underlying aim is therefore to identify the key stakeholders, their interests, barriers and opportunities. Then, the question arises to what extent several stakeholder interests match and where interests are traded off against another. All these questions are addressed in the scope of this thesis paper. This will serve as solid basis to understand the impact of key stakeholders and their influence to the development of AFVs.

The result of this thesis contributes to existing literature findings in three ways. First, it fills an existing gap in literature. As explained above, previous research on the development of AFVs failed to represent the complex relationships that influence the development of AFVs in a comprehensive way. Therefore, this research is the first to address the topic from a stakeholder perspective. Second, the result does not only serve as basis to display several stakeholder interests from a theoretical perspective. It also allows decision makers to better understand, predict, and manage the future development of AFVs in Europe. The findings help to shed light on the complex interrelationships in the automotive industry. Therefore, they represent a valuable tool for decision makers in both, politics and industry. Last, the findings provide a foundation for further research to be carried out in various disciplines. They form the basis for further economic and technological analyses such as cost-benefit, diffusion, or relationship analyses. Further research in the field of relationship research in the automotive industry might also include a more detailed analysis of the power distribution among individual stakeholders.

1.2. Research Question

To follow the aim as outlined above, this thesis will answer the following research question:

0. How do different stakeholder interests in the European automotive industry influence the development of AFVs?

In order to find a comprehensive answer to the main research question, the following sub-questions were defined. These will guide the reader through the individual chapters of the thesis paper.

R1: Who are the critical stakeholders in the automotive industry?

R2: What are the technological and socio economical barriers to the implementation of each technology in the automotive industry and how can they be overcome?

R3: What are the entrenched interests, barriers, and opportunities of critical stakeholders with respect to the development of AFV technologies?

R4: How do stakeholders currently address their interests?

R5: Is there a gap between stakeholder´s opportunities and their actions taken?

1.3. Method and Structure

The method applied in this thesis includes primary and secondary research data. The literature review is based on journal articles, legal documents, information on company webpages (e.g. press releases), and findings from international organizations and consulting companies (e.g. McKinsey, Roland Berger). In addition, primary research is carried out in order to complement the findings from secondary literature. Primary sources include data and statistics from international organizations including European and global industry experts (e.g. ACEA, OICA). By looking at both, primary and secondary findings, this thesis will provide a comprehensive overview about key stakeholders in the European automotive industry. Finally, these results will be discussed and interpreted in order to find how these stakeholders influence the overall development of AFVs.

The following, second chapter, serves as theoretical background and clarifies the scope of this thesis and its limitations. Chapter 2.1 introduces the reader to basic concepts of stakeholder theory and research in the field of AFVs. This chapter also provides an answer to the first sub-question "Who are the critical stakeholders in the automotive industry?". Chapter 2.2 differentiates and defines different AFs and AFVs. Then, chapter 2.3 gives an overview about the European automotive industry. Within the scope of this paper the European market is defined by the EU-28 member states as well as the four EFTA countries Norway, Iceland, Switzerland, and Liechtenstein. Certainly, developments that occur outside Europe also significantly influence the development in the European market. Especially big players such as China and the U.S. are of key relevance at this point. To answer the research question as comprehensively as possible, we cannot simply neglect such developments. However, a detailed analysis of the global automotive market would go beyond the scope of this thesis. Hence, although the overall focus of this analysis is the European market, global forces that are considered as most relevant to the development in Europe, will also form part of the analysis in some chapters. Last, previous literature findings addressing the projection of AFVs are discussed in chapter 2.4.

The third chapter gives an overview about the broad environment of the European automotive industry. This chapter highlights the most relevant aspects associated with sociocultural, global technological, global economic, and global political forces. This chapter will partially answer the second sub question "What are the technological and socio economical barriers to the implementation of each technology in the automotive industry and how can they be overcome?" Further barriers will be discussed in the upcoming stakeholder analysis. Therefore, the second research question will be further answered within the fourth chapter.

The fourth chapter describes the role of several key stakeholders in the European automotive industry. These include European OEMs, competitors, the EU, national public authorities, local public authorities, customers, interest groups, suppliers, and energy companies. The aim of this chapter is to describe the interests of individual stakeholders, their barriers, opportunities, and their current position towards the development of AFVs. In this chapter the focus lies on answering the following sub-questions: "What are the entrenched interests, barriers, and opportunities of critical stakeholders" and "How do individual stakeholders currently address their interests?".

Chapter five structures and summarizes the key results of this thesis. The research findings are summarized in a matrix. This stakeholder matrix serves as tool to visualize stakeholder interests and their influence on the development of different technologies. Furthermore, all sub-questions will be answered in chapter 5.1. These findings function as basis to the following discussion in chapter 5.2. This discussion serves to answer the overall research question, i.e.: How do different stakeholder interests in the European automotive influence the development of AFVs? Finally, the overall findings are summarized and concluded in the last and sixth chapter.

2. Background

This chapter clarifies the scope of this thesis paper and serves as basis for the further understanding of this analysis. First, an overview about stakeholder theory is given. Then, technological alternatives that could replace conventional powertrain technologies will be discussed. Current data and statistics are shortly presented to provide an overview about the automotive market in Europe. Last, current research findings aiming to project the development of AFVs will be reviewed.

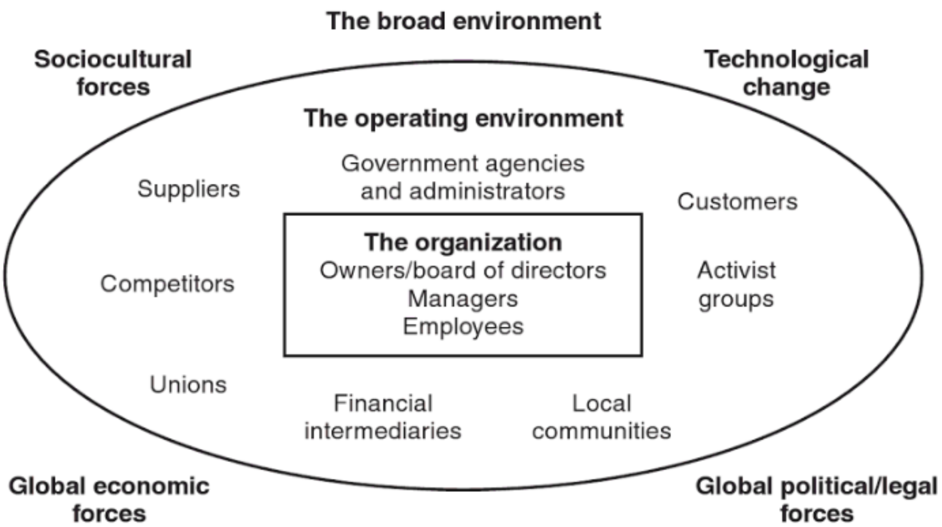
2.1. Stakeholder Theory

In the following, the term *stakeholder* is defined and an insight into the field of stakeholder theory is given. Then, the existing lack of stakeholder research with respect to the case of AFV development will be discussed. Based on this discussion, nine key stakeholders can be identified. These stakeholders form the basis for the analysis in the further course of the study.

Freeman et al. (2013) define the term *stakeholder* in a narrow way claiming that businesses create value for "those groups without whose support, the business would cease to be viable" (p.26). The broader definition of stakeholders, i.e. the *secondary* or *instrumental* stakeholders, include "any group or individual that can affect or be affected by the realization of an organization´s purpose" (Freeman et al. 2013, p.26). According to Freeman et al. (2013) "no stakeholder stands alone in the process of value creation. The stakes of each stakeholder group are multifaceted, and inherently connected to each other" (p.27). This is especially true in the automotive industry, which involves a large number of stakeholders that are interrelated in complex relationships. As Freeman et al. (2013) furthermore articulates, "it is not always easy to find a way to accommodate all stakeholder interests. It is easier to trade off one against another" (p.27).

Harrison & John´s (1998) model "The organization and its primary stakeholders" demonstrates the environment in which a business is typically operating in (Figure 1). This model goes along with Freeman et al.´s definition of primary and secondary stakeholders, as represented by the organization and its operating environment. The model also considers external global forces. Harrison & John (1998) refer to these external forces as the broad environment. Forces in the broad environment influence both, the organization and its stakeholders.

Figure 1: The organization and its primary stakeholders



Source: Harrison & John (1998)

For the scope of this thesis, this model serves as basic framework to analyze how different stakeholder interests influence the development of AFVs in Europe. In fact, a wide range of research findings exists in the field of stakeholder theory. Similarly, several authors address the case of AFV development. However, so far, only a small number of research findings exist that combine both fields, i.e. to address the topic of AFV development from a stakeholder perspective. The following literature review provides an overview about these existing findings.

Ogunlowo et al. (2017) analyzed the use of compressed natural gas (CNG) in Nigeria´s automotive industry. They identified four stakeholder groups: supply (petrol downstream, oil exploration and production companies, shipping and transmission), demand (fleet managers, public transport operators, private vehicle owner, vehicle retailers), regulatory (ministries, departments and agencies, enforcement agencies, development agencies), and advocacy (academia, professional institutions, trade unions, NGOs).

In their “qualitative study about perceptions of European automotive sector's contribution to lower greenhouse gas emissions“ Morgadinho et al. (2015) evaluate the perceptions towards GHG emissions of automotive manufacturers and related industries such as the battery, oil, tyre, and information technology and communication industry. They conclude that there is a strong interest among all industries to reduce greenhouse gas (GHG) emissions.

Spickermann et al. (2014) apply a comprehensive stakeholder approach to assess the future of urban mobility. They consider three major stakeholders and their interests. These stakeholders include industry experts (OEMs, suppliers, service providers, consulting associations), public authorities (federal-, district- and local authorities, public transport organizations), and customers (young adults, employees, retired persons, associations).

Byrne and Polonsky (2001) discuss the effect of AFV adoption considering six main stakeholders. Key stakeholders include the government, producers, suppliers, competition, activist groups, and consumers. However, the study does not differentiate between individual power train solutions, as they exist today. Therefore, the question of how several technological and economical barriers affect the development of individual technologies remains unanswered.

Considering these literature findings, it becomes evident that all of these findings address a rather specific research topic. Hence, none of the studies takes a stakeholder perspective while simultaneously addressing the specific case of AFV development. Therefore, there is still a lack of a holistic stakeholder perspective on the case of AFV development in current research. The result of this thesis will therefore contribute to fill this gap in literature. The aim is to ensure a comprehensive stakeholder analysis by identifying the most critical stakeholders. The model by Harrison & John (1998) and Freeman et al.´s (2013) stakeholder theory serve as basis to identify the most relevant stakeholders for this analysis. In addition, several stakeholders as identified by Ogunlowo et al. (2017), Spickermann et al. (2014), and Byrne and Polonsky (2001) were be taken into account. Based on the model and previous literature findings as discussed above, nine key stakeholders were selected (Table 1). These stakeholder groups form the basis for this research. The aim is to identify their interests, barriers, opportunities and their overall influence to the development of several AFV technologies. Each of these stakeholders will be analyzed in more detail in chapter four.

Table 1: Key stakeholders in the European automotive industry

• European OEMs • Competition • The European Union (EU) • National public authorities • Local public authorities	• Customers • Interest Groups • Suppliers • Energy companies

Source: Own representation

2.2. Alternative Fuel Vehicles (AFV)

Before looking at the broad environment of the European automotive industry and its stakeholders in the third and fourth chapter, the following chapter clarifies the terms *alternative fuel* (AF) and *alternative fuel vehicle* as it will be used during the course of this study.

According to the European Commission (2013b, p. 12) AFs "substitute fossil oil sources in the energy supply to transport" while contributing to the decarbonization of transport. AFs include "electricity, hydrogen, biofuels as defined in Directive 2009/28/EC of the European Parliament and the Council, synthetic fuels, natural gas, including biomethane, in gaseous form (Compressed Natural Gas – CNG) and liquefied form (Liquefied Natural Gas - LNG), and – Liquefied Petroleum Gas (LPG)" (European Commission 2013b, p. 12).

At this point one must consider that the use of these AFs, as defined above, still emit emissions to the environment. In order to declare a fuel as *zero emission* or *carbon neutral* alternative, one must consider the production process of the specific AF. Therefore, and throughout the entire content of this thesis paper, one must not confuse AFs with zero emission or carbon neutral fuels. The following paragraph serves for the further understanding of this topic. It refers to the case of natural gas as AF, as explained by Schenuit et al. (2016) and Sterner (2009). In the further scope of this thesis, chapter 3.4 provides a more detailed overview about the production process and the environmental impact of various AFs

Whether natural gas is produced conventionally or whether it has a renewable energy source (e.g. sun, wind, water), its chemical structure remains the same (Schenuit et al., 2016). Hence, a vehicle powered by gas produces emissions from burning methane, independently of how methane was produced. The main difference between conventionally produced and renewable methane however lies in these gases production processes. In contrast to conventional methane, the production process of renewable methane includes capturing CO2 from external sources. Capturing CO2 in the production of renewable methane while causing CO2 in burning it at a later step, results in a carbon neutral lifecycle. In contrast, methane from fossil sources only emits CO2 through burning, while no CO2 is captured beforehand. This way renewable methane is a carbon neutral substitute for conventionally produced natural gas. It could hence be key to achieve climate and decarbonization goals (Schenuit et al., 2016; Sterner, 2009).

This principle of capturing and producing emissions also holds true for other AFs, including electricity, hydrogen, and synthetic fuels. Therefore, in order to assess the actual environmental impact of AFs, it is essential to consider the fuel´s entire life span. This analysis is also referred to as *well-to-wheel* (WTW) analysis (Ramachandran, Stimming 2015). The WTW analysis is split into two separate evaluations: well-to-tank (WTT) and tank-to-wheel (TTW). WTT refers to the impact caused during all steps starting from raw material production to delivering the fuel into the tank. TTW is the impact caused when converting the fuel into energy while driving. An effective reduction of GHG emissions from transport is therefore only possible when carbon neutrality is ensured from WTW. Therefore, electricity, hydrogen, and methaneous fuels must be generated from renewable sources in order to minimize their environmental impact (Ramachandran, Stimming 2015).

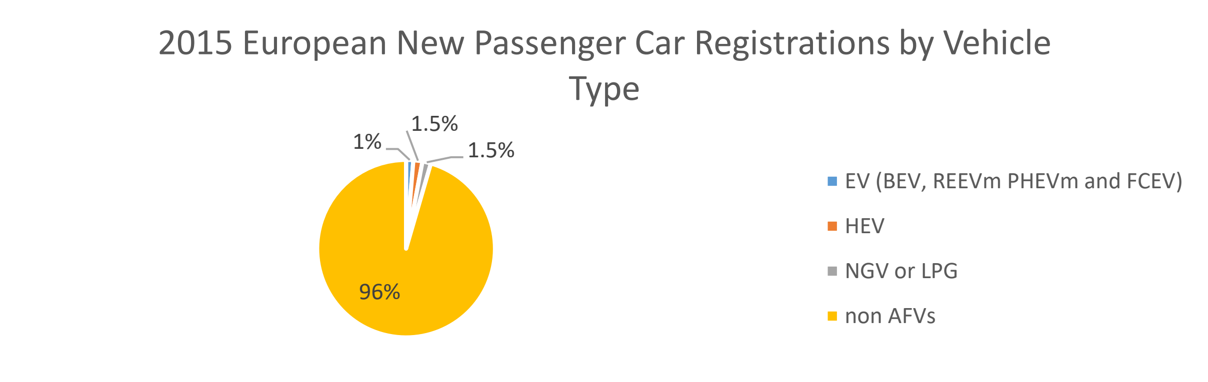
In this thesis, AFVs will be categorized based on their engine technology and the respective AF. There is no one single definition of what an electric vehicle (EV) is. Instead, an EV is defined differently by several sources (McKinsey & Company 2014). Within this thesis paper, a vehicle is defined as EV when the primary propulsion source is an electric motor. This includes PHEV, REEV, BEV, and FCEVs. ICEs and HEVs are therefore not considered an EV.

In the following we shortly describe several types of vehicles: ICE, hybrid electric vehicle (HEV), plug-in hybrid electric vehicles (PHEVs), range-extended electric vehicles (REEVs), battery electric vehicles (BEVs), fuel cell electric vehicles (FCEVs) and natural gas vehicles (NGVs). At a later point, in chapter 3.4., a more detailed description of individual AFs and AFVs, including their advantages and disadvantages, will be discussed.

The following classification is based on information derived from the European Automobile Manufacturer´s Association (ACEA 2017a) and an industry report by McKinsey & Company (2014). An ICE is driving with a conventional combustion engine only. A HEV has an ICE and an e-motor. The ICE is the main source of energy in HEVs. Due to the small e-motor and a small battery charged by the ICE, fully electric driving is only possible for short distances and at low speed. A PHEV also contains both, an ICE and an e-motor that is powered by a battery. It can also use the combustion engine in a hybrid mode and uses a plug-in to recharge the battery. Due to the use of both electric and ICE power, PHEVs emit significantly fewer emissions. At longer trips however, the ICE becomes the main source of energy, leading to substantial emissions. A REEV drives with an e-motor as primary source of energy. To recharge the battery either a combination of ICE and plug in or fuel cells are used. A range-extender driven by a combustion engine is used when the battery is depleted. A main benefit is a substantial emission reduction compared to ICEs because emissions are only caused when the range extender is used. Furthermore, the range extender allows a higher range than a BEV. However, the additional range is limited. In addition the complexity and cost for a REEV is higher compared to an BEV. A BEV drives with an e-motor only and energy is stored in a battery. There is no other source of energy. Major drawbacks of BEVs include charging time, limited range and lacking charging infrastructure. A FCEV drives with an e-motor only and stores its energy in hydrogen. FCEVs offer two main benefits as compared to BEVs: a higher range and fast refueling time. However, hydrogen refueling infrastructure is very limited (ACEA 2017a; McKinsey & Company 2014). Last, a NGV can be fueled with CNG or Liquefied Natural Gas (LNG). Natural Gas is high of octane and therefore combusts more efficiently while producing fewer emissions than other fuels (NGV 2017).

As shown in Figure 2Figure 2, in 2015 only four percent of newly registered cars in Europe were AFVs, including EVs (1%), HEVs (1.5%), and NGVs or LPGs (1.5%). The remaining 96% of newly registered cars were powered by a conventional combustion engine (ACEA 2017).

Figure 2: 2015 European (EU-28 + EFTA) new passenger car registrations by vehicle type



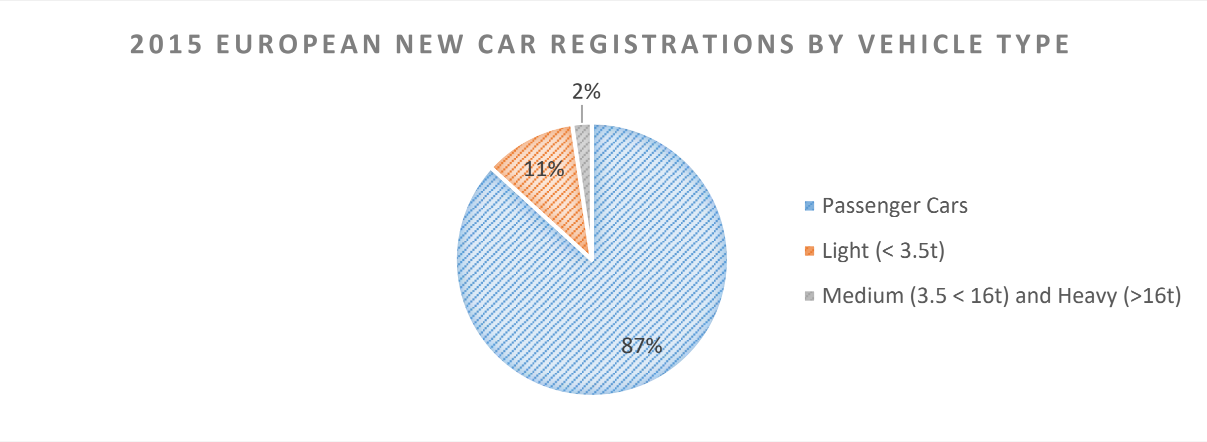
Source: Own representation based on ACEA (2017)

2.3. The European Automotive Market (EAM) for Passenger Cars (PC)

Tis chapter provides an overview about the EAM and serves to clarify the scope of this thesis with respect to different vehicle types. The EAM, as defined for the scope of this paper, includes the EU-28 member states and four EFTA countries: Norway, Iceland, Switzerland, and Liechtenstein. Data about total vehicles in use, and information about new vehicle registrations serve to demonstrate the importance of the EAM and the dominance of PCs.

In 2014 there were 1.2 billion vehicles in use worldwide (OICA 2016). Of these vehicles in use, the EAM represented about one quarter, i.e. 300 million vehicles. Vehicle types can be broadly categorized into PCs, light- medium and heavy-duty vehicles. PCs represented 85% of all vehicles in use in 2015 (OICA 2016). Taking into account the number of new vehicle registrations in Europe, we can confirm the dominance of PCs. There were a total of 16.4 million new vehicles registered in Europe in 2015 (ACEA 2015b). As shown in **Figure 3**, nine out of ten newly registered vehicles in Europe were PCs. Light-, medium- and heavy-duty vehicles including commercial vehicles, busses, or coaches represented only 13% of all new vehicles registered (ACEA 2015b). To limit the scope and the complexity of the analysis, this research paper will focus on PCs in the EAM for the further. Nonetheless, information on light duty vehicles, heavy-duty vehicles, trucks and busses is included in some chapters. This is done mainly, if the information is considered relevant to the overall understanding of the topic.

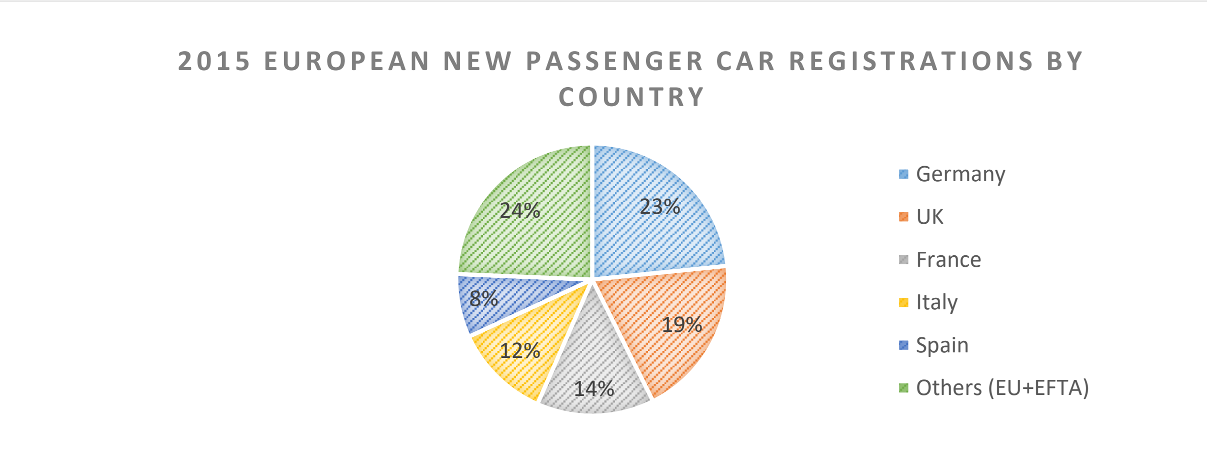
Figure 3: 2015 European (EU-28 +EFTA) new car registrations by vehicle type



Source: Own representation based on ACEA (2015b)

Figure 4 shows the distribution of newly registered PCs among several European countries in 2015. Most PCs were registered in Germany, the UK, France, Italy, and Spain. These countries represent three out of four newly registered PCs in Europe (ACEA 2015b).

Figure 4: 2015 European (EU-28+EFTA) new passenger car registrations by country

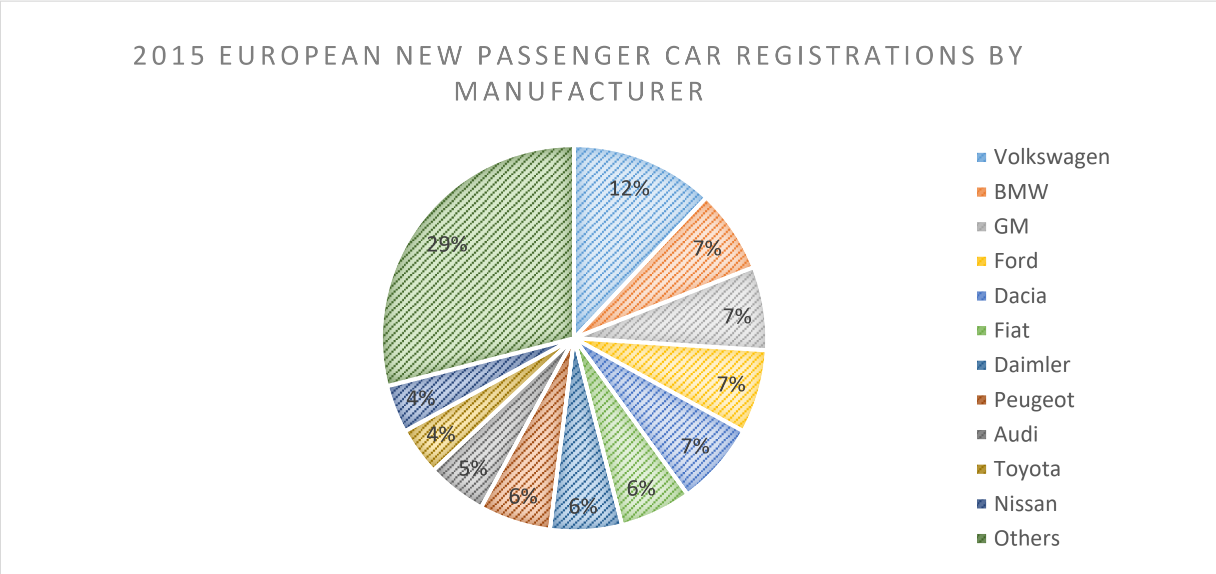


Source: Own representation based on ACEA (2015b)

Figure 5 shows the market share of new PC registrations in Europe in 2015 (ACEA 2015a). There is a large number of global brands operating on the market for PCs in Europe. Key players include OEMs from Europe, U.S., Japan, and Korea. The largest seven manufacturers capture only 40% of the market. One out of three cars is sold by brands outside the top ten.

In terms of market share, Volkswagen is the largest player, followed by BMW, GM, Ford, and Dacia. All other brands capture less than six percent of the market.

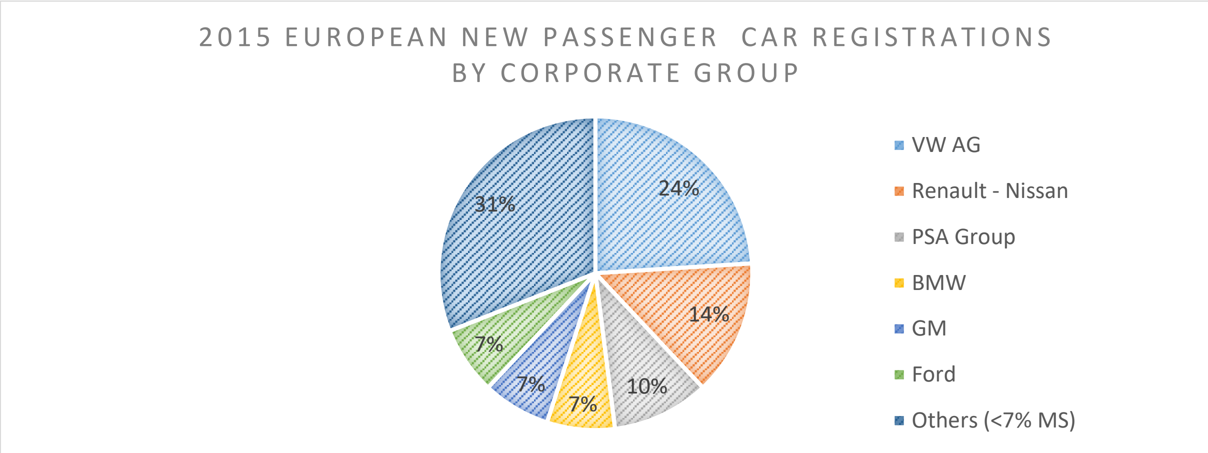
Figure 5: 2015 European (EU-28 + EFTA) new passenger car registrations by manufacturer.



Source: Own representation based on ACEA (2015a)

The market as shown in Figure 5 represents a competitive and highly fragmented industry. However, in the European automotive industry, several brands belong to a group or parent company. Figure 6 represents the market share of newly registered PCs by corporate group. From this perspective, only three large corporate groups dominate 50% of the market (ACEA 2015a). Among these are the Volkswagen Group (Audi, Seat, Skoda, Volkswagen, etc.), the Renault-Nissan Alliance (Dacia, Renault, Nissan), and the PSA Group (Peugeot, Citroen, DS). The BMW Group is the fourth largest player and includes the brands BMW, Mini, and Rolls-Royce. Ford and GM hold a seven percent market share each and represent the strongest U.S. brands on the EAM. The rest of the market is distributed between further European (e.g. Fiat, Daimler), Japanese (e.g. Toyota, Honda, Mazda, Mitsubishi), and Korean (e.g. Hyundai, Kia) OEMs. The market share of each of these producers is smaller than seven percent.

Figure 6: 2015 European (EU-28 + EFTA) new passenger car registrations by corporation



Source: Own representation based on ACEA (2015a)

2.4. Projecting the Development of AFVs

When it comes to projecting future power engine technology, study results vary greatly. In the following academic research findings and studies by major consulting companies on the projection of AFV development are discussed. It becomes evident that the predicted outcome about a preferred AF technology has constantly changed within the past decade.

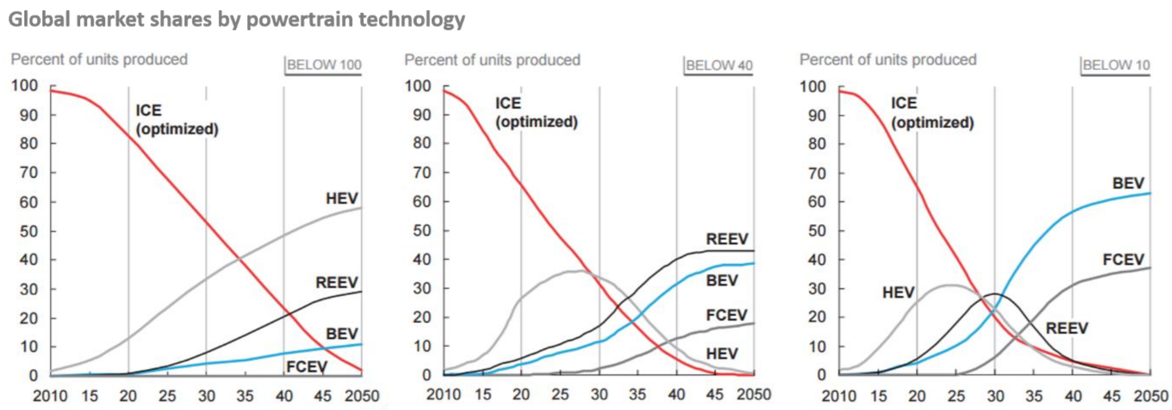
In the past, HEV technology was often regarded as most promising. For example, Christidis et al. (2005) predicted a 6% and 12% market share for HEVs in 2010 and 2012 respectively. In 2009, Oltra and Saint Jean, conducted a patent analysis and projected that until 2040, ICE technology will dominate and less than 30% market share is distributed among FCEV, HEV, and NGVs. They found that the share in HEV patents increased strongly since 1995. Mainly due to the advantage of synergies and spillover effects among HEVs and other technologies, the authors conclude that HEVs function as transition technology towards FCEVs. They see Toyota in a technological leadership position due to their first-mover advantage on HEVs. They furthermore project FCEVs as optimal long-term solution. BEVs are not considered as promising alternative because patents for BEV decreased since the end of 1990 (Oltra, Saint Jean 2009).

Bouza et al. (2009) claim that the hydrogen fuel cell will have the greatest potential of having a 20%+ market share by 2050, followed by battery electric, electric-gasoline hybrid, electric-natural gas hybrid, alternative liquid fuels (e.g. bio-ethanol, bio-diesel) with ICE, and natural gas ICE. Scott (2016) projects the worldwide production of FCEVs at 70,000 vehicles produced annually by 2027. This would only represent 0.1 percent of all vehicles produced by 2027 (Scott 2016).

Shell conducted a study about the hydrogen vehicle market. The results show that after 2020 the cost of energy per mileage of FCEVs and BEVs will be lower than the energy used for petrol cars. However, the high purchase price of FCEVs is still a major barrier. According to the study, the purchase price for FCEVs will decrease significantly due to economies of scale, learning curves, and technological development, while costs for other drivetrains technologies such as direct injection and hybrids, will increase (Adolf 2017).

Depending on how strict CO2 emissions are regulated in future, McKinsey & Company (2011) developed three different scenarios to project the future powertrain portfolio (Figure 7). The scenarios assume an emission regulation either below 100g, 40g or 10g CO2/km in 2050. The below 100g scenario implies that 2020 standards remain unchanged. The below 40g scenario assumes a tighter regulation and the 10g scenario prescribes an emission reduction that is in line with the overall aim to reduce global warming to 2°C max. The results show that in the first, moderate below 100 scenario, the market will be dominated by HEVs, REEVs and BEVs in 2050. In this scenario, ICEs will be dominant until 2030+ and FCEVs are not existing due to a lack of infrastructure. In the below 40g scenario, ICEs and HEVs dominate the market until 2030, but they are fully replaced by a mix of REEVs, BEVs and FCEVs in 2050. In the strictest below 10 gCo2/km scenario, ICEs lose market dominance in 2025 and in the long-term only BEVs (for smaller cars) and FCEVs (for large cars) will exist. HEVs and REEVs function as bridging technology and peak in the 2025-2030 period (McKinsey & Company 2011).

Figure 7: Future powertrain scenarios



Source: (McKinsey & Company 2011, p. 7)

3. The Broad Environment of AFVs

This chapter provides an overview of the broad environment of the EAM. The discussion is based on the model by Harrison & John (1998) "The organization and its primary stakeholders " (Figure 1) as introduced in chapter 2.1. In their model Harrison & John (1998) categorize the broad environment into four key forces that influence the organization and its primary stakeholders: sociocultural forces, global economic forces, global political and legal forces, and technological change. Each of these forces is applied to the case of AFVs in Europe and is discussed in a separate subchapter. The last chapter "Technological Change" introduces technological possibilities related to AFs and AFVs. It will therefore be discussed in a more comprehensive way than the previous chapters.

3.1. Sociocultural Forces

In his report about the EV market development, Anderman (2016b, p. 6) argues that "lower CO2 emissions in the longer term are the most important driver for society and government". This lets us conclude that governments and society perceive an increasing necessity to limit global warming and to reduce its associated negative impacts on the environment. This thought can be supported by the example of the 2015 Paris Agreement. Today, 145 out of 197 parties of the united nations framework convention on climate change (UNFCCC) ratified the agreement and thereby committed towards the goals to combat global warming (unfccc 2017). The agreement does not include binding targets. However, it confirms that the majority of nations is aware of the need to combat global warming. From a sociocultural perspective, this step can hence be considered as major milestone in the shift towards a carbon neutral economy.

Already in 2011, a study by (McKinsey & Company 2011) showed that consumer perceptions change from cars being seen as status symbols, towards the need for eco-friendly and flexible mobility concepts. As current results shows, this change in consumer perceptions caused an increasing demand for EVs nowadays (McKinsey 2017). Today 30 to 40 percent of potential buyers in Germany consider purchasing an EV. Especially in China, consumer interest in EV is growing rapidly. This is a considerable amount, even though only a small share (3-4%) of consumers ultimately purchase an EV (McKinsey 2017). Based on the assumption that by 2030 there will be over 1.1 billion people living in urban areas, McKinsey (2017) project an increasing demand for sustainable solutions in the mobility sector. Furthermore, they also find that a shift from vehicle ownership towards shared mobility solutions including car pooling, shared e-hailing, and car sharing can already be observed.

To sum it up, we identified several socio-cultural forces that could affect the market development for AFVs in Europe. Among these forces are the trend towards urbanization, a shift from vehicle ownership towards shared mobility concepts, changing consumer perceptions, as well as an increased societal consensus to lower CO2 emissions in the long-term. As discussed above, we found that these forces cause an increasing demand for sustainable solutions.

3.2. Global Economic Forces

The following is a discussion of global economic forces that might influence the EAM. First, a focus is set on the market for PCs and related growth trends. Furthermore, the shift of global energy consumption and the long-term trend in global CO2 production is of major interest of this analysis.

Considering the 15 strongest markets on a global perspective, vehicle sales are increasing at a 2% growth rate (ICCT 2016). Positive sales occurred in Europe, South Korea, India, US, Mexico and China. On the other hand, sales were rather flat or even dropped for example in Australia, Japan, Canada, Russia and Brazil. In the past five years, 50% of all cars were sold either in the US or in China (ICCT 2016). In Europe, the growth in car sales can be explained by developments in economic activities in both, passenger and freight transportation (European Commission 2016c). Until 2030, freight transportation is growing even stronger than the passenger sector. Saturation effects and a nearly stagnating population after 2040 will limit the growth of passenger cars on Europe´s streets. Similarly, the growth rate of freight transport is expected to slow down due to the increasing importance of the service sector (European Commission 2016c).

Global energy consumption and CO2 emission trends represent further global economic forces that should not be neglected. Olivier et al. (2016) provide insights about the distribution of energy sources for global primary energy consumption in 2015. These were fossil fuels (86%), hydropower (7%), nuclear energy (4%), and wind and solar (3%). This is however not to confuse with sources for global power generation which was distributed as follows: fossil fuels

(66%), hydropower (16%), nuclear energy (11%), and wind and solar energy (7%) in 2015 (Olivier et al. 2016).

Furthermore, the price for fossil fuels fell on a global basis in 2015. At the same time total energy consumption in 2014 and 2015 increased by only 1%, as compared to a 10-year average of 2%. Low regional fuel prices caused a shift from coal to gas and oil in the global fuel mix. As a result, global consumption in oil and gas increased by 2% in 2015 as compared to 2014. This increase is mainly due to consumption trends in the U.S. and Europe. The share of fossil fuels, especially coal, decreased in 2015 as compared to the previous year. At the same time the share of nuclear energy, hydropower, wind, and solar energy increased (Olivier et al. 2016).

According to Olivier et al. (2016), global CO2 emission growth peaked in 2015 and a decoupling between CO2 and GDP is taking place. Hence, the global slowdown in CO2 emission growth is very likely not a short term trend. Instead, it may reflect structural changes in the economy including increased energy efficiency and a shifting energy mix of key players. In this context, the top emitting nations China, the U.S. and Europe play an important role. In the following a short insight about these nation´s CO2 developments is given. From 2000 to 2014, CO2 emissions in China grew constantly. In 2015, China decreased its emissions by 0.7%. The main reason for this development were structural changes in China´s economy and their energy mix. As a result, China´s significantly contributed to the global decrease in fossil fuel consumption and global CO2 emissions in 2015. The United States decreased its CO2 emissions by 2.6% in 2015. This can be explained by a 13% annual decrease in coal consumption. This results in the largest decrease of any fossil fuel in the U.S. in the past fifty years. Furthermore energy-related CO2 emissions in the U.S decreased by 12% during the past ten years. This development is explained by a constant electricity demand while the source for electricity shifted from coal to natural gas. In Europe, CO2 emissions decreased by 3% annually during 2011-2014. In 2015, Spain increased their coal consumption by 24% and Italy experienced an eight percent increase in natural gas and oil. This caused overall CO2 emissions in Europe to increase by 1.3% in 2015 (Olivier et al. 2016).

Last, the global labor market can be considered as important force that shapes the future EAM. The long-term trend calls for highly skilled workers and work becomes more knowledge-intensive. In order to adapt to technological change there is a need for technical specialists with team-working and problem-solving skills (EASC 2017).

As discussed above, we identified several global economic forces that might influence the development of the EAM. First, we can expect a global market growth for PCs of 2% until the projected growth rate is going to decrease after 2040 (ICCT 2016). Second, structural changes in the economy influence the global energy mix (Olivier et al. 2016). As a result, global energy consumption shifts away from fossil fuels towards renewable energies. Third, we can expect the global slow-down of CO_2 growth to continue in the long-term. This is due to the changing energy mix as well as increasing energy efficiency. Last, the global labor market is shifting and increases the demand for technological specialists (EASC 2017).

3.3. Global Political and Legal Forces

Nowadays, the necessity to limit global warming and to reduce its associated negative impacts on the environment has become an increasingly relevant issue for governments and society. From a political perspective, the 2015 Paris Agreement can be considered a major milestone (unfccc 2017). At the 2015 Parisian Climate Conference participating nations agreed to limit global climate change below 2°C until 2100. Based on this goal, the EU needs to reduce GHG emissions by 40% until 2030 and 95% by 2050 as compared to 1990 levels. The renewable energy (RE) industry as well as the transport industry play a major role in this context. Important targets as set by the EU include the reduction of GHG emissions in the transport sector by 20% and 60% until 2030 and 2050 respectively (COM 2011). Furthermore, the Union defined the goals of a minimum share of 27% of renewable energy and a 27% increase in energy efficiency until 2030 (COM 2013). Renewable electricity should make up 50% of total electricity consumption in 2030 (European Commission; European Commission 2016d).

CO_2 legislation and increased standardization can be considered as common tools as implemented on a global scale to drive emission reduction from traffic. The Combined Charging System (CCS) standard is an example for a standardized charging infrastructure for EVs (Lambert 2016). Miller et al. (2017) report the long-term health and climate benefits of current CO_2 regulation for vehicles by use of scenario analysis. A key finding is that the adoption of world-class standards, if implemented by all G-20 countries, would result in significant environmental benefits (Miller et al. 2017). Intensified regulations are expected to increase on a global level. Norway strives for car sales in 2025 to be 100% electric, Germany implemented tax credits, monetary subsidies, and green zones (e.g. Berlin). Several states in the US adopted a standard set by the CARB (California Air Resources Board). The ZEV standard is stipulating that 14% of the vehicle fleet of OEMs that sell more than 60.000 vehicles annually must be ZEV (McKinsey 2017). California set a target of 1.5 million AFVs on the road by 2025. Furthermore they implemented initiatives to promote the uptake of AFVs including subsidies and infrastructure investment (Brown 2016). Winkel et al. (2016) find that policy trends of alternative fuel development often result from geographical and economic characteristics that are unique in each market. AFV policies from foreign markets can be a valuable to understand drivers and barriers of AFV development. However, one must also consider that these dynamics are not completely applicable to the European market, due to different market dynamics (Winkel et al. 2016).

To sum it up, some important global political and legal forces that influence the EAM could be identified. With the Paris Agreement, several nations agreed that global CO2 reduction is a major goal. In this context, Europe has defined a strategy including the boost of renewable energies and long-term goals to reduce CO2 emissions in all industries. Furthermore, the degree of international standardization (e.g. charging infrastructure) and CO2 regulation are constantly increasing on a global scale.

3.4. Technological Change

In the past decades, technological change did not only lead to the development of new powertrain solutions. Other megatrends that shape the future of the automotive industry include autonomy, connectivity, and shared mobility services (e.g. VW Ag 2017a; Renault Group 2017). Due to the focus of this thesis paper, the following chapter will especially highlight technological developments in the field of AFs and AFVs. Therefore, the topics discussed in the following include ICE technology, synthetic fuels, battery technology, CNG, LNG, LPG, fuel cell technology, and power to gas concepts. This chapter discussed several technological barriers related to a broad range of technologies in the field of AFVs. It thereby partially serves to answer the following research question: “What are the technological and socio economical barriers to the implementation of each technology in the automotive industry and how can they be overcome?”

3.4.1. ICE Technology

ICEs were the dominant powertrain solution for more than 125 years (McKinsey & Company 2011). Today, the ICE is still the dominant power train technology. Figure 2 shows the distribution of the EAM 2015 new passenger car registrations by fuel type. Considering today’s base of 130g CO2/km in Europe, the potential abatement of ICE vehicles is estimated around 25% if more radical and aggressive measures are taken. Such actions include engine downsizing, incorporation of lightweight construction, hybrid-system rollout, and improved aerodynamics. These initiatives cannot be considered as driver for AFV development. Instead, investment into AFV R&D and marketing is delayed (McKinsey 2017).

Among the alternatives to conventional fuels such as petrol and diesel are biodiesel, ethanol and synthetic fuels. Biodiesel is added via blending to conventional diesel. While biodiesel emits less CO2 emissions than diesel, it still produces NOx emissions (Winkel et al. 2016). Europe is the largest biodiesel market, followed by the U.S. and Brazil. The main cost driver of biofuels is feedstock. Production costs depend on the feedstock market, which is expected to increase in 2020. Costs for infrastructure are low but transportation costs are high due to the distance between refineries and dispensing stations. Ethanol, now represents 7% of global fuel consumption. Ethanol consumption is concentrated in the U.S. and Brazil. Synthetic fuels experience a strong growth trend. The production of synthetic fuels is concentrated in South Africa, Qatar, China and the US (Winkel et al. 2016). In 2014, Audi formed several partnerships, for example with the company Sunfire, to research on synthetic non food-based fuels. These synthetic fuels include synthetic gas, synthetic gasoline, synthetic diesel, and synthetic ethanol. Since different types of synthetic fuels exist, we must clearly differentiate between synthetic fuels that are based on fossil sources on the one hand, and synthetic fuels produced from renewable resources, on the other hand. The latter are of main interest in the context of this thesis and will be referred to as *renewable synthetic fuels*. Audi´s synthetic gas is based on the renewable energies and is further discussed at a later point. Renewable synthetic diesel is produced through CO2, water, and renewable electricity. Renewable synthetic ethanol is produced from CO2 and sunlight. The O2 can be captured from factory exhaust or from the air. It has the same chemical structure as bio-ethanol. A major advantage of e-fuels is that no biomass is required, making production possible in regions with poor agriculture. E-fuel´s yield per acre is estimated 20 times higher than conventional food-based biofuels. Audi claims that "A car that uses Audi e-fuels ultimately has a CO2 footprint on par with that of an electric car powered by electricity generated with wind or solar energy." (Audi 2017, para. 11).

3.4.2. Battery Electricity

Compared to car registrations in 2014, there was a growth rate of 110% for EVs and 25% for HEVs in Europe (ACEA 2017). However, several barriers to the uptake of EVs still exist today. Consumer concerns about the driving range, high battery costs, and a lacking charging infrastructure make it difficult for EVs to compete with ICEs at the present moment (McKinsey 2017).

The high costs of batteries remain the biggest barrier to profitability of BEVs. This barrier is not to be overcome until the next two or three product cycles (2025-2030). In the period from 2010 to 2016, battery prices fell about 80% from $1,000 to $227 per kWh. The projected price fall is $190 per kWh by 2020 and $100 per kWh by 2030. This development could drop the costs of base car versions significantly. However, without subsidies, the price of a BEV is not likely to compete with an average new vehicle within the next decade. Price parity is expected only in certain segments when a price below $100 per kWh is achieved. Technological progress has also improved the battery capacity. To give an example, in the period from 2013 to 2016 battery capacity of the Nissan model Leaf increased from 24 kWh to 30 kWh. Similarly, the Tesla model S improved its capacity from 60 kWh to 75 kWh. As a result, the driving range increased from 75 to 107 miles (Nissan Leaf) and from 208 to 249 miles (Tesla Model S). Finally, there is great potential for an accelerating charging infrastructure. Car producers in the US and Europe and the Chinese Government announced ambitious goals and new investments into EV technology and infrastructure (McKinsey 2017).

Leading markets for electric vehicles in terms of vehicles sold, are the U.S., followed by Japan, China, and Europe (Winkel et al. 2016). A study by Roland Berger (2017) found that R&D funding for EVs is highest in China, followed by Germany and France. The share of R&D in terms of GDP is highest in France (0.046%), followed by China (0.045%) and Germany (0.036%). The market leader however, as calculated as EV share of total vehicles sold between 2015 and 2016, is France (1.7%), China (1.2%), and the U.S. (0.9%), Germany (0.7%). Industry leadership is calculated as cumulative national production of both, EVs and battery cells, from 2014 until 2018. Thereby, taking into account BEV and PHEV production, China is the clear leader, followed by the US, Germany, Japan, France, and Korea (Roland Berger 2017).

As it is the case with any other AF technology, vehicles that are powered by electricity can only be considered carbon neutral, if the source of energy is derived from renewable sources

(Ramachandran, Stimming 2015). Therefore, a nation´s overall RE strategy is a key factor that impacts the further development of the automotive industry, i.e. emissions that are caused from transportation.

3.4.3. Natural Gas

NGVs are fueled with CNG or LNG. Compared to conventional fuels, they emit 20% less CO2 (Rosenstiel et al. 2015). Methane is the main substance of natural gas. It can be produced from fossil or renewable sources. Renewables include biomethane and synthetic natural gas (NGVA 2016). As previously mentioned, and as it will be explained in more detail in chapter 3.4.5, one must clearly differentiate between methane and renewable methane. As methane can be produced either from renewable, or from fossil sources, it can be or cannot be considered as carbon neutral fuel Schenuit et al. (2016) and Sterner (2009).

According to Winkel et al. (2016), natural gas is a mature technology in Europe, Brazil, China, and India. It is scaling up in the USA and it is in the R&D stage in most other countries. However, natural gas represents less than one per cent of global fuel consumption for road transport. In India and China NGVs experienced rapid growth in. India and China are therefore expected to become leading gas vehicle markets in future (Winkel et al. 2016). According to Rosenstiel et al. (2015), the average purchase price of a NGV in Germany is €3500 more expensive than a conventional vehicle, but it amortizes after 30.000 km on average due to reduced fueling costs. Difficulties to setup a refueling infrastructure is a major barrier for the uptake of NGVs. This is often due to the distance between the gas grid and filling stations (Rosenstiel et al. 2015). The EU-28 PC market share for NGVs is 1.5% on average. It includes vehicles powered by CNP, LNG and LPG. This is mainly due to an 11% market share in Italy, followed by a 1.5% NGV market share in Sweden. In all other EU-28 countries, the share for NGVs is less than one per cent (ICCT 2016). Overall European NGV registrations declined by 10% in 2015 as compared to 2014 (ACEA 2017). Next to CNG and LNG, LPG is a further alternative. LPG is a mixture of propane and butane and is mainly used in trucks and busses. Turkey, Russia, Poland, Korea, and Italy are most important markets. Together, these countries account for almost 50% of all LPG vehicles in use (Winkel et al. 2016).

3.4.4. Fuel Cells

FCEVs as powered by hydrogen seem to be a promising long-term alternative to conventional vehicles. However, also hydrogen, as it is produced conventionally, causes emissions, that can only be avoided if hydrogen is produced from renewable sources (Ramachandran, Stimming 2015). In the next chapter, the approach of renewable hydrogen production will be further explained.

A major advantage of FCEVs is the short recharging time which is comparable to those of conventional vehicles. The built up of hydrogen infrastructure however is a major barrier due to its high cost of approximately three million USD per filling station (Scott 2016). Currently the costs of establishing a hydrogen station exceeds those of conventional gas stations five times. Hydrogen is transported under high pressure or at low temperature. Transportation cost is the major cost component of hydrogen. Further costs are attributed to platinum in fuel cells, and cathodes for water splitting. Due to high costs of hydrogen storage and the refueling infrastructure, hydrogen is expected to be competitive only when the price for fuel increases (Winkel et al. 2016). To compete with conventional vehicles, the cost of a fuel cell needs to achieve USD 30/kW. FCEVs can be cost competitive to conventional vehicles once high production volume is achieved and the amount of platinum needed decreases. Most studies do not expect such a development before 2030-2040 (Winkel et al. 2016).

The Toyota Mirai is the first FCEV worldwide to become mass-produced. It has a 500 km range, 3 minutes recharging time and went on sale in Japan, Europe, and USA for about USD 57.500 or €52.000. (Winkel et al. 2016). Today, there are about 100 stations available globally. (Scott 2016). There are currently 88 hydrogen filling stations set up in Europe. About half of them can be used to charge passenger cars. Of those being used for passenger cars, there are eleven stations set up in the UK, ten in Germany, eight in Denmark, six in France and four in Spain, Norway, the Netherlands and Austria. (EAFO 2017). The total number of FCEVs on European streets today is 350 (EAFO 2017).

Hydrogen is on the agenda in most countries but Europe and Russia pay minimal attention to hydrogen, although the hydrogen market in Europe is growing (Winkel et al. 2016). Fuel cell technology is the focus of research (Winkel et al. 2016). Hydrogen fueling stations experience a rather slow growth and are mostly established in the context of pilot projects. Toyota is the key driver and plans to make fuel cell coaches, buses and cars commercially available in near future (Winkel et al. 2016).

3.4.5. Power to Gas (PTG)

In his doctoral thesis Prof. Sterner (2009), presented a new approach, the so called "renewable power methane" (RPM). Alternatively, this approach is often referred to as PTG (Schenuit et al., 2016). The idea is to use surplus renewable power, such as wind, ocean, hydropower, or solar energy and convert it into hydrogen through electrolysis in a first step and into RPM through methanation in a second step. Theoretically, RPM can be reconverted into electricity. However, from an economical perspective, this is currently the least attractive form of RPM usage (Schenuit et al. 2016). In the course of this paper, a clear distinction will be made between the production of methane, i.e. RPM, and hydrogen from renewable power. The production of hydrogen is referred to as *renewable power hydrogen* (RPH).

There are several advantages associated with RPM and RPH. According to Schiebahn et al. (2015) both approaches are technically feasible and can lead to the creation of an energy market by linking the electricity, mobility and heating sector (Schiebahn et al. 2015). RPM has the same chemical structure as conventionally produced gases (Schenuit et al. 2016; Sterner 2009). This way RPM substitutes natural gas in a carbon neutral way and can be used in all sectors including industry, heating, mobility, and electricity. It hence represents a major opportunity to achieve global decarbonization goals (Schenuit et al. 2016). According to Sterner (2009), a major opportunity is to feed RPM into the gas grid, where it serves as short- and long-term storage. In the electricity sector, RPM can serve to balance power and foster grid stability. Furthermore, in contrast to hydropower, RPM can be generated in any country (Sterner 2009). According to Schenuit et al. (2016), a country implementing RPM can furthermore gain an economic advantage, for example through pursuing technological leadership or by creating export opportunities. In the heating sector, RPM is more expensive than conventional gas. Gas products that contain a certain amount of RPM, could be sold to environmentally conscious consumers who are willing to pay a price premium. In the transport sector, emissions can be reduced by using RPM in ICEs or through the use of RPH in FCEVs (Schiebahn et al. 2015; Sterner 2009). This approach seems promising due to strict CO2 regulations and a relatively high price for energy in form of fuels (Schenuit et al. 2016). Renewable electricity can hence be converted into hydrogen which is stored in tanks and can be reconverted with fuel cells or a hydrogen combustion engine into electricity (Gahleitner 2013). Compressed or liquefied RPM is already compatible with new power train solutions such as PHEVs, REEVs, EVs, and FEVs, and CNG vehicles (Sterner 2009). Schiebahn et al. (2015) argue that hydrogen can compete with gasoline due to the FCEVs high efficiency.

RPM technology is currently still in the research stage to market introduction and it cannot yet compete with conventional gas and hydrogen production. There are technical and regulatory issues to this dilemma. One major drawback is the efficiency level of RPM generation (Schenuit et al., 2016). The efficiency for the conversion of electricity to hydrogen varies from 54 to 77 % (Jentsch et al. 2014). Due to the electrolysis and methanation process, the efficiency level of converting energy into gas is between 46-75%, or 63% on average (Sterner 2009). To date 96% of all hydrogen is produced from fossil fuels such as natural gas, coal, and liquid hydrocarbons. Today, there is no market willing to justify the additional cost of RPH, resulting in a trade-off between the carbon footprint of hydrogen and its cost (Scott 2016). According to Schenuit et al. (2016), the biggest barrier for the market introduction of RPM are not technical, but regulatory issues.

Overall, the power-to-gas concept is of considerable interest in Europe. Gahleitner (2013) reviewed several planned or realized power-to-gas plants on an international basis. In their case study about CO2 sources in Austria, Reiter and Lindorfer (2015) demonstrate that there are enough CO2 sources available in order to convert renewable electricity into gas. Although the highest amount of CO2 is produced in the iron and steel production industry and in power plants due to fossil fuel combustion, these are not the most favorable sources of CO2 capture. Instead, biogas upgrading facilities and bioethanol plants are better sources of CO2 due to the relatively low capture costs and short distances to renewable energy carriers such as wind plants. Only in the long-term CO2 capture from the atmosphere is a possible solution, because capture costs need to be reduced significantly (Reiter, Lindorfer 2015).

To sum it up, the RPM and RPH concepts are technologically feasible, but the costs for feeding these gases into the gas grid are substantially higher and economically not feasible (Sterner 2009). However, emission trading policies and pressure on organizations to reduce their overall emissions, can further promote price parity between conventional and renewable gases (Schenuit et al. 2016). In the mobility sector, RPH seems to be a promising alternative to fossil fuels (Schiebahn et al. 2015). According to Schenuit et al. (2016) science and industry are already looking for new ways to substitute products based on oil and gas with RPM solutions. Therefore, one can expect the development of further fields of application for RPM and RPH in future. In the further context of this thesis, we will clearly differentiate between methane and hydrogen as produced conventionally or as they are based on renewable energies (RPM and RPH).

4. Stakeholder Analysis

This chapter analyses the development of different AFV technologies from the perspective of key stakeholders. Based on previous stakeholder literature, nine key stakeholders were identified. These include European OEMs, competition, the EU, national public authorities, local public authorities, customers, interest groups, suppliers, and energy companies. Each of these key stakeholders will be analyzed in this chapter. The aim is to find an answer to the following research questions:

> R2: What are the technological and socio economical barriers to the implementation of each technology in the automotive industry and how can they be overcome?
>
> R3: What are the entrenched interests, barriers, and opportunities of critical stakeholders with respect to the development of AFV technologies?
>
> R4: How do stakeholders currently address their interests?
>
> R5: Is there a gap between stakeholder´s opportunities and their actions taken?

4.1. European OEMs

The largest OEMs in terms of market share operating on the EAM include: Volkswagen, BMW, GM, Ford, Dacia, Fiat, Daimler, Peugeot, Audi, Toyota, and Nissan. Each of these brands has a market share between four and twelve percent. Volkswagen is holding the largest (12%) market share, followed by other brands in the above mentioned order. From a corporate perspective, the three major groups Volkswagen, Renault-Nissan, and the PSA commonly represent 50% of the market (ACEA 2015a). A more detailed distribution is shown in chapter 2.3. The following chapter will highlight the interests of European OEMs. Brands from Japan, Korea and the U.S. will be separately discussed in the next chapter (4.2. Competitors).

4.1.1. Interests

According to Anderman (2016b), the ultimate driver for OEMs to engage in the market development for EVs is to comply with legal regulations at the lowest cost (Anderman 2016b).

A study by McKinsey (2017) supports this view. If OEMs do not meet regulatory targets, they can accept a penalty or, alternatively, they lower their fleet emission level. The study showed that OEMs are likely to comply with regulation and invest in CO2 abatement technology as soon as penalties are about 70% more expensive relative to their investments in emission reduction technology and infrastructure (McKinsey 2017). Next to meeting CO2 targets, OEMs aim is to meet consumer expectations and to operate profitably. A further interest of OEMs is therefore to invest into technologies that yield high ROIs. Considering the rapid development of several technologies that affect the automotive market, including autonomy, connectivity, and shared mobility, one must consider that OEMs need to distribute their R&D resources economically among different technologies. How, when, and where to invest remains a challenging question, given the wide span of possible fields for investment (McKinsey 2017). As discussed in chapter 3.4., technological and economical barriers of individual technologies hinder the development of AFVs. According to Bouza et al. (2009) the fear of lagging behind is a further reason why companies engage in R&D in the field of AFVs. This is supported by Winkel et al. (2016) who find that technological specialization and know-how from U.S. and Japanese brands could put European manufacturers at risk of technology dependence. It is therefore crucial to keep up with technological advancements through R&D commitment and partnerships with foreign manufactures (Winkel et al. 2016). In order to participate in the technological knowledge trading process, European OEMs must contribute to the technological development themselves. A further driver and interest of OEMs is to gain a competitive advantage. Therefore they pursue an image of technological leadership and increased speed to market (Bouza et al. 2009).

4.1.2. Challenges

Considering these various interests as discussed above, one might suggest that OEMs heavily invest into the development of AFV technologies. However, one must also consider that forces exist that slow-down their development. Anderman (2016b) find that OEMs face several concerns and uncertainties that prevent OEMs from investing into certain technologies. One major concern is the uncertainty regarding future CO2 policies and regulations as European regulators proposed to move towards stricter restrictions (70-75 gm CO2/km) in future. Tougher restrictions on conventional fuels would increase the competitiveness of AFs. Overall, "carmakers must be prepared for worst case regulations" (Anderman 2016b, p. 8). Furthermore, there is no guarantee that customer incentives for AFVs stay in place after 2019.

It remains open how customer demand will develop after subsidies shrink. Low customer interest will force OEMs to subsidize their AFVs in order to meet Co2 emission regulations. An important question that remains unanswered is how an EV can be offered at the same performance level as an ICE, but at a lower price and after subsidies cease (Anderman 2016b).

According to McKinsey (2017), the greatest challenge remains the development of an e-mobility strategy including new car models that simultaneously allow meeting Co2 targets, meeting consumer expectations, and operating profitably. While the premium segment is more promising in terms of ROI, customers demand small cars and SUVs. This represents a major barrier and causes a mismatch in supply and demand of EVs today (McKinsey 2017).

PSA Group´s CEO Carlos Tavares also confirms some of the difficulties as mentioned above. As he is cited by Horell (2017, para. 6):

> "We don't know about the scarcity of raw materials. Or about battery recycling. Or the development of clean power generation. Or how taxes on petrol and diesel will move to electricity – governments need the revenue. We don't know what the charging network density will be."

Furthermore, he criticizes the political involvement in the technological development of AFVs:

> "We have moved from governments wanting an emissions target to the point where specific propulsion technology is determined by governments. They have chosen EV – by taxation, or by limitations on the use of other products." (Horell 2017, para. 11)

4.1.3. Opportunities

Opportunities to push the development of AFV technologies do exist in several forms. With respect to battery technology, OEMs can achieve significant cost reductions through economies of scale for the production of EVs, materials, packs, modules, and cells (Anderman 2016a). Also McKinsey (2017) find that opportunities to push electrification forward in a profitable way do exist for both, near-term and long-term EV buyers. Among those opportunities are underserved consumer segments looking for basic e-mobility solutions (lower range). OEMs must develop vehicles that match the emerging demand (near-term buyers). To address these opportunities, OEMs need to better understand customer preferences and clear up customer misconceptions associated with EVs (McKinsey 2017). To match the need for long-term buyers in a profitable way, OEMs could deploy new business models. OEMs shall focus on total cost of ownership (TCO) instead of purchase price. In doing so, they can sell EVs as package and as service. This represents an opportunity to increase sales without sacrificing on profitability. In practice this calls for new business models such as carpooling, e-hailing, shared e-hailing, car-sharing, p2p car rental, and fleet operators (McKinsey 2017). Indeed, OEMs already recognized the potential. According to Renault, the vision of a zero-emission, connected and autonomous vehicle in the next five years is shared by all. The challenge is to choose the fastest, most reliable and cost-effective way to follow this vision. In 2014, Renault and Bolloré formed the joint venture Bluealliance to establish a car-sharing network in Europe (Renault Group 2017). Volkswagen also announced investment in autonomous driving, information and communications technology (ICT) , and new business models such as Ride Hailing, Robotaxis, Carsharing and on demand mobility solutions (VW Ag 2017b)

A study by YouGov (2017) analyzed factors that influence customer acceptance of EVs. The findings point towards the importance of an adequate communication strategy of OEMs towards their customers. In contrast to most OEMs on the market, Tesla is the only brand that successfully managed to communicate the benefits of an AFV towards their customers. Considering the low amount of electric vehicles on German streets, one must therefore question the sub-brand strategies of German OEMs (YouGov 2017). This view is shared by Winkel et al. (2016) who argue that European OEMs could rethink their own practices. Building on Tesla´s strategy, European OEMs could consider introducing franchise organizations, new services, and free charging.

4.1.4. Impact

After having analyzed the interests, concerns and opportunities, the following chapter will serve to identify how European OEMs influence the development of the AFV market. Therefore, strategic priorities of European OEMs in terms of their AFV R&D and production efforts AFVs will be discussed. The information is based on recent data and statistics, and announcements on individual OEM´s websites.

A study by McKinsey (2017) compares annual electric vehicle sales by vehicle manufacturer. The result shows that there was a strong increase in EVs sold from 2014 to 2015. However, EVs still represent less than 2% of European OEMs´ sales (except Tesla). This indicates that European OEMs are facing difficulties to scale up EV production (McKinsey 2017). Winkel et al. (2016) find that European OEMs also lack behind in fuel cell technology as compared to their Japanese competitors. In Europe, Hydrogen is considered as long-term option, while Japanese Toyota already established a pioneering role in hydrogen mobility (Winkel et al. 2016). Next to Toyota, also Hyundai and Honda already introduced FCEVs (Hyundai 2017).

As mentioned before, McKinsey (2017) finds that due to higher ROI from ICEs, OEMs tend to invest into ICE platforms, incremental engine and transmission improvements and other mobility trends. CO2 efficiency in ICE´s can still be improved by 25% through engine downsizing, lightweight construction, hybridization, and improved aerodynamics. As a result, investments into EV plants, R&D, tooling, and marketing strategies are delayed (McKinsey 2017). Anderman (2016a) further supports this idea and argues that for most OEMs the main motivation to produce AFVs is solely based on the interest to comply with CO2 regulations or to satisfy developing markets. This lets us conclude that investment into ICE technology is still a major priority. This view is supported by the results of a patent analysis by Oltra and Saint Jean (2009). Their findings show that OEMs dedicate half of all patents related to powertrain technologies to ICE technology. This confirms that OEMs are interested in exploiting the increasing returns of the ICE technology and therefore further invest into the dominant design (Oltra, Saint Jean 2009). At this point it must be mentioned, that the analysis by Oltra and Saint Jean (2009) does only include data from 1990 until 2005. Their findings must therefore be interpreted carefully. However, it has become evident that almost all OEMs use some form of defeat device to meet regulatory targets at lowest possible cost (BMVI, 2016). The discrepancy between laboratory and real-time testing was around 8% in 2001 and increased to 36% on average in 2015 (Tietge et al. 2015). This is because OEMs increasingly exploited the flexibilities and tolerances in laboratory testing (ICCT 2016).

In their 1990-2005 patent data analysis about AFVs Oltra, Saint Jean (2009) furthermore find that manufacturers diversify their patent portfolios. This means that individual brands seem to focus on different alternative technologies (Oltra, Saint Jean 2009). In order to confirm this finding, we must identify individual OEM´s technological priorities. In the following, we will look at different technologies as expressed by the share of OEM´s vehicle fleet.

The data is derived from the International Council on Clean Transportation (ICCT 2016). We will compare the following AFV technologies: NGVs, HEVs, PHEVS, and BEVs. The largest share of AFVs among European OEMs, as calculated by 2015 car sales, were NGVs. NGVs produced by Fiat, Dacia and Opel achieved a 9%, 6% and 4% share of total cars sold respectively. Volvo has the largest share of PHEVs (3% of all Volvos sold in 2015). In 2015 BEVs account for 2.5% of Nissan cars and for 2% of all Renaults sold in Europe. The share of any EV sold by other OEMs was below 1% for all other OEMs (ICCT 2016).

In order to compare individual brands´ position on the EAM for AFVs, one might also consider the bestselling models of technologies. The following information is based on 2016 data and is derived from the European Alternative Fuel Observatory (EAFO 2017). The 2016 bestselling PHEVs were the Mitsubishi Outlander (18%), Volkswagen Passat GTE (11%), Volkswagen Golf GTE (10%), Mercedes C350e (9%),Volvo XC90 PHEV (8%). These five models make up about half (56%) of the PHEV market (EAFO 2017). The 2016 best selling BEVs were the Renault Zoe (23%), Nissan Leaf (20%), Tesla Model S (14%), BMW i3 (10%), Volkswagen e-Golf (7,3%). These five models made up 75% of the market for BEVs (EAFO 2017). Today Renault offers four all electric models: ZOE, Kangoo Z.E., Twizy and RSM SM3 Z.E.

According to McKinsey (2017) there is a mismatch of supply and demand in EVs. The number of potential EV buyers is growing and the majority of consumers is interested in small cars and SUVs. However, most of the EV models that are currently available focus on the premium market due to lower price sensitivity (McKinsey 2017). Interestingly, a study by Roland Berger (2017) shows different results regarding the availability of AFVs in different price segments. Roland Berger (2017) analyzed and compared the value for money of leading car manufacturing countries in terms of sales price and the average technology level. The results show that German OEMs expand their model portfolio offering both BEVs and HEVs and increase the driving range. In Germany, the trend leads towards increasing EV sales in the upper and middle price segment. French OEMs offer fewer models and focus on small low-priced BEVs. In the low price segment, Renault ZOE is the dominant model. Italian OEMs have no mass produced EVs at all. In terms of technology leadership as calculated by both, value for money and national R&D programs, leading brands are from Germany and France. Korean brands are focusing on PHEVs and Chinese OEMs position their EVs in technologically less valuable markets. U.S. OEMs move from an upper into a medium prized segment. In Germany the top three models projected for 2017 are the VW Golf GTE PHEV, BMW i3, and the Audi A3 e-tron. In France Renault ZOE Z.E., Renault Kangoo Z.E. and smart fortwo ED will be most popular (Roland Berger 2017). European OEMs also engage in infrastructure development. BMW, Porsche, Mercedes, Ford, and Audi formed a joint venture to set up a fast charging BEV infrastructure in Europe. Starting in 2017, the join-venture announced to set up 400 initial stations in Europe using the CCS standard (Lambert 2016).

Looking at individual OEM´s strategic positioning towards AFVs, we find interesting results. Most European OEMs have positioned themselves towards a certain AFV technology. After the scandal, Volkswagen defined a new strategy including a radical transformation of their core business. VW aims to develop battery technology as key competence. The group announced to introduce 30 new BEV models and three million electric vehicles sold yearly until 2025. This would equal around one quarter of total sales (VW Ag 2017b). Already in 2009, the Renault Group announced to commit towards affordable electric vehicles. Renault position themselves as drivers of the energy transition and defined three priorities of innovation: the electric vehicle, autonomous driving, and connected cars and services. The group invests into the development of infrastructure and fast charging stations in European cites. Renault´s business models includes the option to rent the battery to make BEVs more affordable. Furthermore, by using batteries to store electricity after their car life, Renault develops another approach for energy storage and supply. According to Renault´s vision, batteries could be used to supply distribution networks, office buildings, or BEV charging stations (Renault Group 2017). The PSA Group formulated a strategic growth plan for the 2016-2012 period. While connectivity and autonomy and an open innovation approach are explicitly mentioned as part of their strategy, PSA does not explicitly commit towards any specific alternative propulsion system (PSA 2017). BMW conducts research in both, BEV and FCEV technology. To exchange know-how in fuel cell and diesel technology, BMW formed a technology sharing partnership with Toyota including fuel cells, hydrogen tank, electric motor and battery systems (BMW 2017).

According to Winkel et al (2016), European OEMs are not paying particular attention to synthetic fuels because they are largely produced as drop-in fuels. However, Audi seems to be an exception. Audi formed partnerships and started several projects to research synthetic fuels including synthetic gas, gasoline, diesel, and ethanol (Audi 2017). Audi invested to conduct further research on these alternatives and established two facilities in Werlte and Viessmann in Germay. The A3 and A4 g-tron are CNG vehicles to be powered by RPM. They should run on RPH in future (A3 and A4 h-tron). Furthermore, in 2014, Audi formed a partnership with the French company Global Bioenergies to research on synthetic non-food-based fuels. In 2014, Audi and their project partners Climeworks and Sunfire started an synthetic diesel project in Dresden (Audi 2017).

Having analyzed relevant statistics, data and individual OEM´s official communication channels, we find that the majority of European OEMs committed towards one or more AFV technologies. It seems that currently, expertise in the field of battery electricity determines the overall technological leadership position in the industry. Major European OEMs defined a long-term strategy towards BEV development and formed a joint-venture for the set-up of a BEV infrastructure. However, OEMs also consider hydrogen as long-term option and invest into fuel cell technology. Partnerships that promote the knowledge exchange in fuel cell technology include for example the partnership between BMW and Toyota. Alternatively, as shown by the case of the Volkswagen Group, R&D is carried out internally: Within the VW Group, Audi takes the leading role in the development of hydrogen and synthetic fuels. Interestingly, none of the above mentioned OEMs mentioned NGVs as strategic priority. Audi is the only brand that explicitly formulated a strategy targeted towards R&D in the field of synthetic fuels. Looking at European OEM´s R&D initiatives, one can observe cooperation and partnerships form the basis in several technological field for AFs. Furthermore, OEMs already invest into new business models such as shared mobility services. Regarding model availability, a shift from upper to midsize and lower price segments in the AFV market can be observed. Overall AFVs still represent a minority of total car sales and in the short-term, the development of the ICE remains a key priority, which slows down the overall development of AFVs.

4.2. Competitors

In the following, the interests and the influence of European OEMs main competitors with respect to AFVs are being discussed. For this analysis, a special focus is put on OEMs that already engage in the development of battery and hydrogen technology. These include the following brands: Tesla (U.S.), Toyota (Japan), Honda (Japan), Hyundai and Kia (Korea).

4.2.1. Tesla

Tesla follows a strategy that is fully committed towards battery technology. In 2016 Tesla sold their vehicles at an average 25% margin, resulting in seven billion dollar revenues (Sorge 2017). In contrast to the U.S. or European governments, Tesla managed to bring EVs closer to an average driver and they managed to create a domestic battery industry (Anderman 2016a).

Therefore, Tesla is often considered as leader the electric vehicle market. The company operates a super-charger network including about 5300 charging points. First Tesla offered their super chargers free of charge. Today customers are charged a fee, which makes Tesla also an infrastructure provider (Sorge 2017). Tesla moves from the luxury car segment to meeting the demand of the mass market. Starting with their sports car (Roadster), Tesla built a sedan (S Class) and a SUV (X Class). All of them are positioned in the luxury segment. Tesla´s vision is to produce the Model 3, a small to midsize luxury car. The model 3 was released in 2017. Customers already placed more than 400.000 pre-orders. This is the largest number of cars ever pre-ordered in history (Sorge 2017). It should be available to the mass market in a 2020 time frame (Anderman 2016a).

In 2014, Tesla announced to build a giga factory in Nevada, US. The following technological and economic benefits make such a large scale BEV production possible: low metal pricing, a larger cell format and higher energy capacities of batteries, material procurement in China, cost savings through economies of scale, government incentives, as well as low cost of labor, land, and utility in Nevada. Due to these benefits, a 30% reduction of EV costs is achievable (Anderman 2016a). Due to lack of know-how in cell-fabrication, Tesla needs to cooperate with major cell makers. Tesla announced a cooperation with Panasonic to build the giga factory (Anderman 2016a). Thereby, Tesla became a powerful purchase power with respect to the BEV supply chain (Sorge 2017). Tesla´s impact on battery suppliers such as Panasonic is further discussed in chapter 4.4.

While Tesla´s strategy seems promising, it is uncertain whether Tesla can operate profitable in the long-term. This concern is based on findings by Anderman (2016a), who points out several risks and uncertainties that Tesla is exposed to. For example, it remains open whether material suppliers will join Tesla´s project, and whether the investment really leads to a lucrative EV market. Californian ZEV credits seem to be an important factor for Tesla to operate profitable. In the upcoming five years, it is still less risky for OEMs to buy certificates than investing in their own EVs. It seems unrealistic that Tesla is able to speed up its production to 500k units yearly in 2018, as the company announced. Due to the US federal tax credit of $7500, US customers have a strong incentive to purchase EVs. However, this incentive will shrink after 2018. It remains open whether Tesla will be able to operate profitable after subsidies shrink (Anderman 2016a; Anderman 2016b). At this point one must also consider that although Tesla lost 675 million dollar in 2016, the share experienced a record high at 300 USD in April 2017. Losses were mainly due to large investments (Sorge 2017). This shows that investors believe in Tesla´s long-term success.

In 2014, Tesla´s CEO Elon Musk announced to free their patents. It seems as if Tesla´s decision is driven by their interest to promote battery technology and to encourage other players to invest in electro mobility. By allowing other OEMs to use their technology, Tesla fights against their real competition, ICEs:

> "Our true competition is not the small trickle of non-Tesla electric cars being produced, but rather the enormous flood of gasoline cars pouring out of the world's factories every day. We believe that Tesla, other companies making electric cars, and the world would all benefit from a common, rapidly-evolving technology platform. Technology leadership is not defined by patents, which history has repeatedly shown to be small protection indeed against a determined competitor, but rather by the ability of a company to attract and motivate the world's most talented engineers. We believe that applying the open source philosophy to our patents will strengthen rather than diminish Tesla's position in this regard." (Musk 2014)

Considering the findings as discussed above, we can conclude that a major interest of Tesla is to define BEVs as the dominant technology of the future. Furthermore, the case of Tesla provides valuable insights for European OEMs. With Tesla being the first to invest into BEV technology on large scale, European OEMs could for example benefit from second mover advantages. A further driving force for European OEMs to invest into BEV results from Tesla´s open platform philosophy. As long as no dominant AFV technology is yet defined, Tesla is interested in knowledge transfer with other OEMs in order to develop an industry platform. This offers the opportunity to European OEMs to gain access to know-how and participate in the knowledge trading process.

4.2.2. Toyota

Toyota is following a long-term strategy towards hydrogen technology. As part of their differentiation strategy, Toyota already invested into the development of AFV back in the 90s. The Mirai is the first FCEV worldwide to become mass-produced. It has a 500 km range, 3 minutes recharging time and went on sale in Japan, Europe, and USA for about USD 57.500 or €52.000 (Winkel et al. 2016). One year after Tesla´s announcement in 2014, Toyota also announced to make about 5600 patents on their fuel-cell technology available until 2020.

Thereby Toyota invites industry players to join the hydrogen platform (Toyota 2015). Currently Toyota is leading the HEV market. Every fourth Toyota sold (27%) in Europe in 2015 was a HEV (without PHEV) (ICCT 2016). The share of HEVs in all other OEM portfolios is below one percent. Next to PCs, Toyota aims to make AFV coaches and buses commercially available (EAFO 2017, Winkel et al. 2016). In order to bring FCEVs to the market, Toyota implemented various initiatives. In the U.S., Toyota formed a partnership with Shell to promote hydrogen infrastructure. Further agreements include partnerships among Japanese energy companies and manufacturers to build a refueling network of 100 stations. Initial buyers of the Toyota Mirai get three years´ value of free hydrogen and Toyota leased its first FCEV to the Japanese government (Winkel et al. 2016).

To sum it up, as Tesla pioneers the BEV market, Toyota pioneers the HEV and fuel cell technology. The further development of fuel cell technology requires several industry players and stakeholders to participate. As it is the case with battery technology, also the success of fuel cell technology depends on whether or not other OEMs contribute to the further development. This represents an opportunity for European OEMs to participate in the technology platform, participate in knowledge exchange and to enter the market without significant barriers.

4.2.3. Hyundai

In the short-term Hyundai´s focus lies on improving diesel and petrol engines (Hyundai 2017). However, while EVs form part of Hyundai´s mid-term strategy, their long-term strategy builds on the development of the FCEV (Hyundai 2017, Undercoffler 2016). The company already introduced AFVs including BEVs (Hyundai Ionic, Kia Soul) and PHEVs (Hyundai Ionic, Hyundai Sonata, Kia Optima). After Hyundai released their first FCEV "Santa Fe" and the "Tucson" in 2000 and 2004, the ix35 Fuel Cell is the third generation FCEV. The middle-class vehicle reaches 160 km/h. The driving range is 594 km. Hyundai cooperates with LG on battery technology and claims to operate the worldwide biggest research center for fuel-cells in Korea. To promote the roll out of fuel-cell infrastructure, Hyundai cooperates with non-profit organizations, European governments, the European Commission, gas stations (e.g. OMV in Austria) and further industry participants. In 2012, the UK government funded the "UK H2 Mobility" project to investigate the potential of FCEVs in the UK (Hyundai 2017).

4.2.4. Honda

Until now, Honda produced only few AFVs. These include their first and only NGV "Civic GX" (1998), a FCEV "FCX Clarity" (2008), which is only available in California, the BEV model "Fit" (2013) and a PHEV (2013) (Honda 2017a). However, the company committed towards a global electric future. They defined the goal of two out of three cars sold in Europe by 2025 to be either BEV, HEVs or FCEVs. Further commitments include the expansion of a public charging infrastructure in Europe. In June 2017, Honda opened Europe´s "most advanced" charging station at their German R&D center. The station is powered by REs. Further milestones of their research project include the integration of a hydrogen filling station (Honda 2017b). As Toyota and BMW, also GM and Honda collaborate on fuel cell technology. This allows Japanese OEMs to enter the market, while all OEMs benefit from increasing market development (Winkel et al. 2016).

Currently, the Toyota Mirai, the Hyundai ix35 and the Honda Clarity are the only FCEVs available in selected markets . According to a study by Scott (2016), there should be about 17 FCEV models available in the upcoming eleven years since more OEMs invest in FCEV technology. Production of FCEV is expected to shift from Korea and Japan to Europe by 2021, putting Europe into a leadership position on fuel cell technology. However, they will still represent just about 0.1 percent of total vehicles produced by 2027 (Scott 2016).

To sum it up, OEMs from the U.S., Japan, and Korea are committed towards either the development of BEV and FCEV technologies, or both technologies. Tesla is the only brand fully committed to battery technology. Toyota and Hyundai focus on hydrogen technology in the long-term and consider EVs as mid-term solution. Honda´s long-term strategy includes both EVs and FCEVs, including infrastructure investment into both technologies. We conclude that all of these OEMs are interested in actively promoting the development of AFVs and their infrastructure. This conclusion is based on the following main findings as discussed above. First, all OEMs defined a long-term AFV strategy as officially communicated on their websites. Second, OEMs already formed partnerships with major European stakeholders (e.g. energy companies, governments). Last, they actively engage in the setup of AFV infrastructure, they invest into R&D projects in AFV technology, and offer attractive customer incentives. All these initiatives can also be considered as best practice examples and major opportunities for European OEMs.

4.3. The European Union

In the context of this thesis, the EU is a key stakeholder and driving force in the market for AFVs. The aim of this chapter is therefore to discover the interest that drive decision makers in the EU. An analysis about several actions, initiatives, regulations and directives as implemented by European regulators is part of this chapter. Thereby we identified various initiatives targeted towards the EAM for AFVs. The result is explained and discussed at the end of this chapter. The overall aim is in to find out how the EU influences the technological development of AFVs.

4.3.1. Interests

With only 7% of the world population, the EU accounts for 15% of global international exports and 15% of international imports. In terms of GDP, the EU was ahead of the US in 2014 with €14.600 billion. Thus, next to the U.S. and China, the EU represents one of the three largest players in terms of global trading power (europa.eu 2017). Considering these findings, one can conclude that it is a key interest to defend the EU´s competitive position against China and the U.S. Accordingly, the EU´s economic policy aims "to sustain growth by investing in transport, energy and research – while minimising the impact of further economic development on the environment" (europa.eu 2017).

A further interest as derived from the EU´s official website includes breaking energy dependency. This is due to more than 50% of EU´s energy needs being imported (europa.eu 2017). Furthermore, Europe´s transport system is heavily dependent on oil. In 2010, oil was responsible for 94% of energy for transportation with 84% of it being imported. The mobility system depends on regions where political stability and security of supply is at risk. Speculation on oil supply causes price hikes, driving the Europe´s expenses on imported oil (European Commission 2013a). Another interest of the EU is to increase R&D spending to bring it in line with those of China and the U.S. With respect to the automotive market, it is the EU´s interest to develop an efficient, secure, safe, and environmentally friendly transport system (europa.eu 2017).

These interests also form the basis of Europe´s strategy towards future mobility systems. In 2011, the EU defined the goal to reduce GHG emissions in the transport sector by 20% until 2030 and by 60% until 2050 (COM 2011). As outlined in the 2013 "European alternative fuels strategy", the transition towards AFVs should help the EU to break oil dependence, to secure energy supply, to support economic growth and industry competitiveness, and to reduce GHG emissions caused by transport (European Commission 2013a). In the following, some literature findings that suggest how the EU can achieve these goals will be discussed.

Winkel et al. (2016) suggest that the EU needs to position itself clearly and prioritize certain technologies to achieve innovation and market leadership. Opportunities lie especially in electricity and electricity based fuels. To realize these opportunities, strategic priorities and a long-term commitment in R&D is crucial (Winkel et al. 2016).

According to the Dutch ministry of infrastructure (MIE 2016), the main challenge the EU faces with respect to CO2 reduction regulation in the automotive industry is to balance the aim of achieving a front-running position, shifting towards zero emissions, while simultaneously ensuring investment security and technical feasibility. Therefore, in order to achieve emission reduction effects, standardization is considered as most effective tool. The main benefits of CO2 standardization include stimulation of innovation, promotion of a competitive industry, and opportunities to achieve economies of scale for European brands. Further important instruments include economic driving behavior, the use of ICT, and tax incentives. They do not consider biofuels as long-term solution. Instead, they recommend a mix of both, BEVs and FCEVs. The study also analyzes policy options to maximize the sales of AFVs. The findings suggest that CO2 targets of 70 g CO2 in 2025 and 35g CO2/km in 2030 are best suited to support Europe´s climate goals (MIE 2016). At this point we must consider the following dilemma as articulated by (McKinsey & Company 2011): While strict regulations can harm profitability, too loose regulations will not have the desired effect. A further study by McKinsey (2017) showed that OEMs likelihood to comply with regulations increases when they are penalized.

4.3.2. Legislation

Considering these findings, only little can be told about the actual role that the EU currently plays in the AFV industry. Therefore, this next chapter serves to demonstrate several actions targeted towards the development of sustainable technologies as they were implemented by European regulators.

To identify the role of the EU as key stakeholder in the EAM, several initiatives related to the AFV market development in Europe were identified. The following research is based on official papers as published by the European Commission and as they are publicly available. These initiatives include strategy papers, targets, regulations, directives, decisions, working groups, and funding programs. The result is summarized in Table 2. To limit the scope of this research, the results displays those actions that are perceived as most relevant to the topic of AFV development. Those initiatives that have a considerable impact on other stakeholder in the EAM will now be shortly explained. Then, the impact of several actions to the development of AFVs will be discussed in the next chapter.

Table 2: European legislation to promote AFs and AFVs

Type	Year	Initiative	Topics relevant to AFV take up
Strategy Paper	2009	A sustainable future of Transport - COM(2009) 279	White Paper on fostering European automotive industry competitiveness
		2020 Strategy COM(2010) 2020	Strategy in response to decreasing vehicle demand in Europe
	2011	Roadmap to a Single European Transport Area	Whitepaper including a 2050 target to reduce GHG emissions in transport sector by 60%
	2012	CARS 2020 - COM(2012) 636	Action plan to invest into sustainable technologies, regulation, competitiveness, adaptation
	2013	A 2030 climate & energy framework: COM(2013) 169	Green Paper including 2030 targets: -40% GHG, 27% RE, +27% Energy Efficiency
		Clean Power for Transport Package: A European alternative fuels strategy - COM(2013) 17	AFV Strategy including the formulation of technology neutrality in AFV development
	2015	Climate Conference Paris	Climate Goal Agreement: keep Global Warming below 2°C (base 1990)
	2016	A European Strategy for Low-Emission Mobility - COM(2016) 501	AFV Strategy so ensure funding, infrastructure development, standardization for AFVs
Regulation	2009	EU Regulation No 443/2009 on Passenger Cars	Regulation for passenger cars limiting fleet average CO emissions to 130g/km in 2015, 95g/km in 2020; Super-Credits for emissions below 50g/km
	2011	legislation on CO2 emissions from light commercial vehicles (vans)	CO2 Regulation for vans
	2016	RDE Package 1-4	Implementation of PEMS; conformity factor 2.1 in 2017 and 1.5 in 2020; considering vehicle cold start emissions & independent RDE testing
Directive	1993-2009	Euro 1 -5 Emission Standards	Standards limiting emissions (PM, Nox, HC, CO) in vehicles
	2009	2020 Climate and Energy Package (including several directives)	2020 climate and energy targets: -20% CO2 (1990), 20% renewable energy, +20% energy efficiency
	2013	Directive on the deployment of alternative fuels infrastructure 2014/94	Member states must ensure a minimum number of electricity, CNG, LNG and hydrogen refueling points
	2014	Euro 6 Emission Standard - - 459/2012/EC	Standard limiting emissions (PM, Nox, HC, CO) in vehicles
	2016	Revised Directive on Renewable Energies	Directive on RE integration, AF development, reduction of food-based biofuels
	2010	Cars 21	High Level Group for a competitive and sustainable automotive industry

Decision, Working Group, Work Program	2015	European Automotive Skills Council	Networking Platform: EU Project to match skills and needs of labor market
	2016	Work Program: Smart, green and integrated transport	Work program 2016-2017 under the Horizon Societal Challenges Pillar to boost automotive industry competitiveness, growth, green vehicles, and automation
		Gear 2030	High Level Group to reinforce the competitiveness, autonomous vehicle rollout. Focus on ZEV in Project Team 2 in Working Group 1
		Real Driving Emissions (RDE)	Working Group to reduce the gap between on-road and laboratory emission testing
Funding Program	2014	Horizon 2020	4-year EU funding program (2014-2020)
Public Private Partnerships (PPP)	2008	Fuel Cells and Hydrogen (FCH)	PPP to promote fuel cell and Hydrogen market development
		Factories of the Future	PPP - project funding, R&D in innovative production technologies
	2009	Green Cars Initiative	PPP - project funding to respond to global crisis in 2008, focusing on energy efficiency and alternative powertrains (2009-2013)
	2014	Green Vehicle Initiative (EGVI) under Horizon	PPP - project funding to promote green vehicle R&D projects under Horizon 2020 (2014-2020)
		FCH under Horizon	PPP to promote fuel cell and Hydrogen market development under Horizon 2020 (2014-2020)

Source: Own representation

A key regulation that affects the development of AFVs is the 2009 regulation on passenger cars. It requires the reduction of fleet average CO2 emissions. As shown in Table 3, the official average CO2 emission level from new passenger cars in Europe was set to 130 g/km in 2015. Until 2021, this target should be further reduced to 95 g/km. Long-term targets for the period after 2020 are not yet defined (European Commission 2017b).

Table 3: Official CO2 emission targets

Year / Target	Reduction in % (base 2007: 158 g/km)	Co2 g/km	Petrol / diesel l/100km
2015	18 %	130 g/km	5.6l / 4.9l
2021	40 %	95g/km	4.1 / 3.6
Post 2020	-	-	-

Source: Own representation based on European Commission (2017b)

In 2013, the European Commission defined a long-term strategy towards renewable energies. The strategy includes the aim to combat climate change and to improve security of supply while encouraging economic growth and job creation (European Commission 2013a). In the “2030 climate and energy framework”, the EU set targets to reduce GHG emissions by 40%, to achieve a share of 27% in renewable energies, and to improve energy efficiency by 27% until 2030 (European Commission 2014a). In 2013, the European Commission furthermore defined the “European alternative fuel strategy”. It aims to support the development of alternative mobility systems and their infrastructure. The transition towards AFVs should lead to yearly oil savings of 4.2. billion until 2020, €9.3 billion in 2030, and €1 billion yearly due to the absence of price hikes. Furthermore the European Climate Foundation projects 700.000 additional jobs created from AFVs by 2025 (European Commission 2013a) The alternative fuel strategy builds on a mix of alternative solutions without preferring any technology in particular (European Commission 2013a). In addition, in order to respond to the chicken and egg dilemma, the Commission published the "Directive on the deployment of alternative fuels infrastructure" including financial support from funds and the European Investment Bank (European Commission 2013a). Horizon 2020 is a R&D funding program that might also serve to finance AFV projects (European Commission 2013a). The Euro 6 emission standard as introduced in 2014, regulates emissions of particulate matter, nitrogen oxides (also referred to as NOx), un-burnt hydrocarbons, and carbon monoxide (European Commission 2016a). Euro 6 requires new vehicles to limit their emissions between 68 and 96 per cent as compared to the Euro 1 standard released in 2001 (ICCT 2016). Finally, in the scope of the 2015 Paris Climate Agreement, the EU has committed to make the reduction of global warming a major goal (unfccc 2017).

A revised Directive as launched on 30 November 2016 aims to further boost renewable energies in order to achieve the European Union´s energy objectives. Next to promoting renewables in the electricity, heating and cooling sector, a further aim is to empower consumers. Consumers and communities should benefit through greater ease of producing their own electricity and by making sure they are compensated for electricity fed into the grid (European Commission 2016d). Furthermore, renewable energies should be better integrated into the European energy and electricity markets in order to match supply and demand continuously and economically (European Commission; European Commission 2016d). Finally, the directive also aims to further decarbonize the transport sector by promoting the use of "advanced biofuels, electricity, hydrogen and renewable synthetic fuels". These alternatives aim towards a 70% GHG reduction in the transport sector as compared to fossil fuels until

2030. Furthermore, food-based biofuels should be reduced and by use of national fuel data, traceability should be ensured (European Commission 2016d).

4.3.3. Impact

The formulation of initiatives and regulations as outlined in Table 2 is an important milestone to shift towards AFV mobility. In the following, the impact of the EU´s initiatives regarding RE and AFV development are being discussed.

The EU currently has a strong interest in many alternative fuel technologies (Winkel et al. 2016). Our research confirms this view: In their “European Alternative Fuels Strategy”, the European Commission (2013a) defined a technology neutral strategy, building on a comprehensive alternative fuel mix. Therefore a clear positioning and prioritization of certain technologies as suggested by Winkel et al. (2016) does not seem compatible with Europe´s technology neutral strategy. This lets us conclude that a strategy focusing on one preferred solution can therefore only be defined on a national level.

As Winkel et al. (2016) found, Europe lags behind, with the lowest R&D/GDP ratio compared to China, Japan, and the U.S. Our analysis showed that this is also true in the case of AFVs and renewable energies:

> “While in the field of road transport, Europe still leads on patents for the improvement of internal combustion engines, the rest of the world benefits from a higher number of patents on alternative energy and markets for low-emission vehicles are growing faster outside the EU” (COM 2016).

A lack of R&D investment is also shown by the following example. To strengthen Europe´s industry, the EU initiated its biggest research and investment program: Horizon 2020. Six billion euros out of the program´s total €80 billion is invested to transport (European Commission 2014b). However, within the budget for transport, a predefined budget is attributed to sustainable projects. There is no defined budget targeted towards the development of AFV development. AFV projects must therefore compete with other projects resulting in only limited EU funding that effectively benefits the development of AFVs. With these policies in place, the EU invests a limited amount into the development of AFVs. At this point, it one must also point out that it seems unlikely that the EU is going to follow the example of the U.S. In order to give rise to the development of a BEV market, the U.S. government functioned as venture capitalist, lending Tesla USD 465 million (Lutsey 2015).

At this point, Europe´s efforts to push the development of REs should also be considered. To ensure emission-free electricity in the long-term, energy must be derived from renewable sources (Ramachandran, Stimming 2015). The European Commission has set ambitious goals towards 2030 in which RE sources RES play a major role (European Commission 2014a). The 2016 RE Directive should encourage the use of alternative fuels while reducing food-based fuels. Furthermore it should ensure greater ease of feeding electricity as it is produced by communities and consumers into the grid (European Commission 2016d). However, looking at overall EU spending, in 2016, the EU invested €44 billion in renewable energies and thereby accounted for only 18% of global investments in renewables. In 2011 the EU invested more than twice as much, accounting for 50% of global investments in renewables (European Commission 2016d).

The result of the analysis above lets us furthermore conclude, that EU´s policies were rather vaguely formulated until 2016. Interestingly, after the emission scandal in 2015, the EU implemented measures that are more effective. To support this argument, one must consider the following initiatives and their effects, as they will be discussed in the following. The EU expressed the need for alternative mobility solutions already in their 2009 paper on "A sustainable future of Transport". However, a comprehensive strategy towards low-emission mobility was not formulated until 2016. In 2009, the EU Regulation No 443/2009 on Passenger Cars was enforced to limit fleet average CO2 emission levels. However, according to the ICCT (2016), the emission targets are met under laboratory testing conditions, but do not confirm with on-road driving results. The reason therefore are various loopholes in the laboratory testing procedure that allow manufacturers to achieve the required emission targets under artificial testing conditions. After the revealing of Volkswagen´s use of illegal devices to manipulate test results, further investigations showed that all manufacturers use some kind of defeat device (BMVI, 2016). In contrast to the U.S., the use of defeat devices is not an exception in Europe. U.S. regulation requires manufacturers to apply for the use of a defeat device at the Environmental Protection Agency before a new model is certified. Only when no technical alternative to control exhaust emissions under several driving conditions exist, the Agency makes an exception to the ban of defeat devices (ICCT 2016). Finally, in 2016 the new Real Driving Emissions (RDE) working group was initiated by the European Commission. The group aims to include on-road testing systems into the approval process of passenger cars in the EU. The so called portable emissions measurement systems (PEMS) shall be implemented in addition to laboratory testing (RDE package #1). In 2016, on-road tests were conducted for monitoring reasons. In 2017, the allowed difference between laboratory and on-road emissions will be regulated by a so called conformity factor of 2.1 (RDE package #2). Hence, the laboratory limit for a new diesel car in 2017 is 80mg/km of Nox, but 168mg/km under on-road testing conditions. This factor will be further reduced to 1.5 in 2020 (ICCT 2016).

However, there are still areas of improvement in the RDE regulation. Since 50% of the tests are carried out by vehicle manufacturers, one can assume that these are performed under most favorable conditions and do not consider boundary conditions. The ICCT (2017) criticizes the current situation in several ways: First, there is a lack of independent testing authorities. Second, only pre-production, and no in-Euro 6 use vehicles are currently tested. Third, the RDE test does still not consider realistic driving conditions when it comes to temperature, altitude and dynamic driving conditions. Last, the RDE regulation focuses on pollutant emissions and it also records Co2 emissions. While pollutants are systematically analyzed, the system fails to analyze CO2 emissions. Some of these issues will be addressed in the fourth RDE package (ICCT 2017). In this context, we should also consider standards for light commercial and heavy duty vehicles in Europe. Standards for light commercial vehicles have their own standard of 175g/km target in 2017 and a 147g/km target in 2020. When it comes to heavy-duty vehicles, the EU is the only truck market worldwide that has not implemented any CO2 regulation. As a result, the trucks´ fuel-consumption was not reduced since the beginning of the 21st century. In 2016, the European Commission expressed their objective of introducing compulsive standards for trucks only before 2030 (ICCT 2016).

We can furthermore conclude that the EU does not exploit their full potential when it comes to promoting initiatives to promote the shift towards AFVs on a European level. A best practice example for multi-stakeholder cooperation on a national basis is the Clean Cities project in the U.S. The project was initiated in 1993 and aims at the reduction of petroleum use in transport at a state, national, and local level. Participating stakeholders include businesses, vehicle fleets, fuel providers, government agencies, and communities. The program promotes partnerships, tools and publications, and technical assistance to implement AFV concepts (DOE 2017). Comparing the U.S. and European initiatives, we can conclude, that EU has failed to establish initiatives based on multi-state collaboration in order to promote the uptake of AFVs.

Finally, one more weakness in the European policy framework could be identified in the context of this analysis. There is a lack of long-term targets in terms of CO2 emission from passenger cars. This results in unpredictability for OEMs and a lack of pressure to invest in AFVs. To solve this issue, the GEAR 2030 high-level group has been established in 2016. The aim of the group is to develop recommendations that help decision makers to foster Europe´s automotive industry competitiveness. The group is composed of twelve member state representatives, seven industry players, and six other representatives including consumers and trade unions. One out of nine project teams (Project Team 2 in Working Group 1) is dedicated to the topic of AFVs (European Commission 2017a). Interestingly BEVs are the main topic as they are discussed in the high level group. It remains open to what extent the EU will intensify AFV development in the mid- and long-term. According to the MIE (2016), intensifying CO2 regulations to 70 g CO2/km as early as in 2025, as it was suggested by the Dutch Ministry of Infrastructure and Development, would have required the submission of a corresponding proposal as soon as in 2016 (MIE 2016).

Considering the findings as discussed above, the European Commission seems committed to strive towards technological leadership in both, the automotive and the RE industry. Next to CO2 reduction potentials which exist in both industries, employment benefits and technological leadership are further key drivers for the EU to invest into the development of sustainable technologies in these sectors. The EU has established policies targeted towards the development of AFVs, AFV infrastructure, and REEs. This approach seems promising since both, vehicles and infrastructure are needed for AFV take up. However, the pressure that the EU exerts on both, its member states and the automotive industry, can still be considered as rather moderate and short-lived. This is due to the lack of long-term regulations and a limited effect of CO2 regulation in vehicles due to OEM´s use of defeat devices so far. Furthermore, the lack of prioritizing a certain technology fails to encourage OEMs to commit to long-term investments of one certain technology. Although AFVs seem to fully replace ICEs in the long-term, there is still a relatively low share of R&D spending attributed to projects related to AFV development. Summing up, the EU has the potential to increase the pressure and thereby speed up AFV market development. It remains open however, to which extent the EU will formulate long-term policies, intensify regulations that promote the development of a European alternative fuel market, and begin to prioritize certain technologies. Since the high-level group is composed of different stakeholders including industry players and nations, it seems unrealistic that the EU is going to intensify their regulations to the highest degree possible.

4.4. National Public Authorities

The following chapter serves to understand the role of national public authorities in the EAM. The aim is to highlight the interest of public decision makers as well as barriers to the development of certain technologies. Finally, individual nations will be compared according to their engagement in AFV market and infrastructure development.

4.4.1. Interests

Government decisions are driven by the interests of the society. Only when there is strong societal consensus that there is a need for more sustainable mobility solutions, there is enough pressure for the government to commit to significant and long-term subsidies in new technologies (Köhler et al. 2010). As discussed in previous chapters, we found that society increasingly calls for sustainable solutions. Assuming that this trend will further increase in future, we can expect that also the pressure for the government will further increase. This development can be considered as positive driver for the development of AFVs.

Nations are furthermore interested in revenue from tax. In Germany, for example, the income of registration and fuel tax amounts to almost 8% of national tax income (Rosenstiel et al. 2015). The EU -28 Weighted Average taxation share in the end consumer price is 62% for Euro-Super 95 and 57% for diesel (European Commission 2017c).The question arises how a shift towards AFVs would affect the tax income of individual member states. Assuming that fuel consumption would be reduced significantly due to the shift towards AFVs, this development would not meet the nations´ interest due to the lack of tax income.

The interests of powerful unions and interest parties might also influence national decision makers. To give an example, the German Association of the Automotive Industry is a powerful stakeholder in the EAM. We will therefore consider the union as separate stakeholder. It will be discussed at a later point in a separate chapter.

As discussed in the previous chapter, the EU is a major stakeholder that influences the decisions and interest of individual member states. In the course of the Paris Climate Agreement, the EU committed to reduce GHG emissions by 30% until 2030 as compared to 2005 levels. Therefore, individual member states must achieve binding CO_2 reduction targets ranging from zero to 40% depending on their GDP per capita. The member states are free to decide how to achieve these targets (European Commission 2016b). Due to the cost structure of AFVs and the lack of existing infrastructure, the adoption of AFVs cannot be implemented naturally through market mechanisms. Therefore, to promote the transition in the mobility system towards AFVs, the European Commission (2013a) launched the directive on AFV infrastructure. The directive requires member states to build up a minimum infrastructure including electricity, CNG, LNG and hydrogen refueling points within a given timeframe (European Commission 2013a). For individual member states, this means that they must achieve CO2 and AFV infrastructure targets as decided on a European level. European member states therefore face the challenge to balance these binding EU-level targets and the interest of society. The latter implies several national challenges including industry competitiveness, employment, and economic growth for example. Thereby each state is subject to its own political, legal and social system, which varies greatly among individual states. In addition, as discussed previously, further challenges include the lack of a long-term European strategy towards AFVs, the lack of a preferred technology due to Europe´s technology-neutral strategy, and a lack of standardization among European member states with regard to RE and AFV policies.

4.4.2. Opportunities

In this chapter, we aim to discover the opportunities for national public authorities in the field of AFV development. We will look at both, research findings analyzing the reasons for success and failure of AFV uptake. The aim is to apply these learnings to the current case in order to identify opportunities and best practice examples for national decision makers.

Rosenstiel et al. (2015) find that a major reason for the failure of NGV uptake was due to a failure to coordinate NGV manufacturers and infrastructure providers. As a result, low coverage of refueling stations caused high convenience costs for drivers and low demand for NGVs. Looking at these findings, it can be concluded that in order to promote the development of AFVs, public authorities should focus on the promotion of both, vehicles and infrastructure. Finally, they recommend several actions to encourage the development of a NGV market. These include for example the implementation of negative externalities such as fuel taxes, better coordination of vehicles and infrastructure, encouraging competition among gas companies, vehicle manufacturers, and filling stations, increasing social acceptance of NGVs and gaining support for NGV adoption from public institutions and corporations (Rosenstiel et al. 2015). Schenuit et al. (2016) address the barriers of RPM and RPH development. Due to its cost structure, renewable hydrogen and methane, will not replace conventionally produced gases. Since RPM and RPH cannot be implemented naturally through market mechanisms, regulatory incentives are required. To promote PTG, federal- and national legislation must better coordinate their strategies and long-term goals (Schenuit et al. 2016). Lutsey (2015) find that best practice incentives to AFV uptake are R&D support, consumer incentives that reduce total cost of ownership, and infrastructure availability. This view is shared by Winkel et al. (2016) and McKinsey&Company (2011) who find that government regulation, funding, and financial incentives are indispensable until alternative technologies become cost-competitive. Effective incentives for consumers include for example lane and parking allowances (Winkel et al. 2016). There is also broad consensus in literature that the rapid development of alternative power train systems in Norway and the Netherlands is due to regulatory benefits and fiscal policies (McKinsey 2017).

Further opportunities also lie in taxation of fossil fuels to subsidize renewables These taxes increase with each liter of fuel consumed and cylinder size, i.e. GHG emissions (Rosenstiel et al. 2015). Such taxation policies are also known as the-polluter-pays principle (EAFO 2017). However, increasing the price for fuels is not sufficient to promote alternative technologies due to the fossil fuel´s low price elasticity (Rosenstiel et al. 2015).

For a country to achieve market leadership, a clear technology positioning and the priorisation of few alternatives is key (Winkel et al. 2016). This view is also shared by McKinsey & Company (2011), arguing that the powertrain industry shall consider a "preferred" powertrain technology. Further key aspects include employment qualifications, material supply, infrastructure, incentives, and regulations. In order to establish a strong local industry, the power train industry and the public sector need to strongly cooperate (McKinsey & Company 2011). To attract private technology investment and the build-up of infrastructure, internal markets need a strong policy framework and binding targets. (European Commission 2013a). Lutsey (2015) recommend international collaboration to promote AFVs. Furthermore, they call for long-term AFV deployment targets. At this point, the state of California ca be mentioned as best practice example. California has set the target of 1.5 million AFVs on its roadways including BEVs, FCEVs, and PHEVs by 2025. Actions to achieve this aim include the following initiatives: raising consumer awareness, AFV subsidies (purchase subsidies and lane access), investment into infrastructure, R&D and AFV projects targeted at lower-income consumers, integration of the government as early adopter, multi-state collaboration and international coordination (Brown 2016). Last, they argue that a common vision can help to send signals and prioritize government action (Lutsey 2015).

Based on the findings by Winkel et al. (2016) and Rosenstiel et al. (2015), we can identify further opportunities. Rosenstiel et al. (2015) find that the public sector could function as early adopter and thereby contribute to the uptake of AFVs. This is already the case in Japan, where the government agreed to lease Toyota´s FCEVs (Winkel et al. 2016). Based on these findings, it can be concluded that the public sector could play an increasingly important role in countries where the government is responsible for a larger share of vehicle registrations. Last, referring to the case of Tesla, governments can also function as venture capitalist. The company lent money from the U.S. government for the development of the Tesla S. (Lutsey 2015).

Schenuit et al. (2016) identify further opportunities related to the concept of PTG. A major potential lies in linking the electricity, mobility and heating sectors through the development of RPM and RPH. This applies especially in Germany since they follow a strategy of phasing out nuclear energy and the use of lignite-fired power stations as reserve mechanisms. As a result, the share of RE supply is expected to increase. It is very likely that there will be more situations in which electricity is traded at a very low or even negative price due to surplus energy in the electricity system. Hence, there will be an increased need for flexibility. PTG could be used to allow for a more flexible electric system through feeding electricity from PTG in and out, depending on fluctuations in demand (Schenuit et al. 2016). Jentsch et al. (2014) further investigate on the PTG scenario in Germany. They simulate a 85% RE scenario and verify positive economic effects due to the integration of a PTG approach. The results show that economic costs and Co2 emissions are reduced. The highest benefit is achieved when PTG plants are located in the north of Germany. An economic optimum is found at a PTG capacity between six and twelve GW. Results of an economic assessment of the PTG approach suggests that PTG could be a key technology used to realize the German "Energiewende" and move towards more sustainable energy system (Varone, Ferrari 2015).

4.4.3. AFV Incentives

According to Lutsey (2015), several member states in Europe deploy different policy and infrastructure incentives to promote AFV adoption. In the following, we will analyze to what extent individual countries prioritize certain technologies, and whether they implement subsidies and fiscal policies to promote AFV development.

As today, there is a lack of common standards and infrastructure among European nations. (European Commission 2013a). Most nations implemented targets such as a specific AFV market share. Norway for example strives for car sales in 2025 to be 100% electric (McKinsey 2017). However, individual countries frequently overestimated the targets set towards AFV deployment. According to Lutsey (2015), the global amount of EV sales would amount to a total of 15 million EVs in 2020 and 25 million by 2025-2030 if national goals are met. However, it is unlikely that these goals are met, as governments acknowledged and several findings suggest (Lutsey 2015). This view is shared by Anderman (2016a), arguing that in contrast to Tesla, European governments failed to bring EVs closer to consumers.

There are also significant differences in each country´s subsidy policy. The EAFO (2017), an initiative started by the European Commission, provides information and statistics on alternative fuels including electricity, hydrogen, and natural gas. A national comparison of alternative fuel incentives shows that the type and extent of subsidies for alternative fuels varies greatly. Bulgaria, Estonia, Poland, and Slovakia are the only countries that have no incentives or subsidies for alternative fuels at all. All other countries implemented at least two of the following incentives or benefits: purchase subsidies (P), registration tax benefits (RT), ownership tax benefits (OT), company tax benefits (CT), VAT Benefits (VAT), other financial Benefits (OF), local incentives (LI), or infrastructure incentives. Table 4 shows the top twelve countries (EU-28 + EFTA) as defined by EV market share (BEVs and PHEVs) and their different incentives in place (EAFO, 2017).

Table 4: AFV incentives of EU member states

Countries		EV Market Share in %	P	RT	OT	CT	VAT	OF	LI	Infrastructure
Norway		37		Y	Y	Y	Y		Y	
Iceland		14		Y			Y		Y	Y
Sweden		5,3	Y		Y	Y				
Switzerland		2,6			Y			Y		
Belgium		2	Y	Y	Y	Y				
Luxembourg		1,8	Y		Y	Y				
Austria		1,6	Y	Y	Y	Y	Y		Y	
UK		1,4	Y	Y	Y	Y			Y	Y
Netherlands		1,4		Y	Y	Y				
Portugal		1,1	Y	Y	Y	Y			Y	
Germany		1,1	Y		Y	Y			Y	
France		0,7	Y	Y	Y	Y			Y	

Source: Own representation based on EAFO (2017)

Looking at these numbers, one can conclude that Norway and Iceland, the countries with the highest EV market shares, implemented no purchase subsidies. Half of all other countries do offer some form of purchase subsidy. All EU-28 and NAFTA countries implemented ownership or registration tax benefits, or both. The only exemptions are Poland, Slovakia and Liechtenstein. Company Tax Benefits are very common among the top twelve countries. Interestingly, only few of all countries outside the top-12 offer company tax benefits. Norway, Iceland and Austria are the only countries among all EU-28 + EFTA countries that offer VAT benefits. About a third of all EU-28 + EFTA countries offer Infrastructure Benefits.

To demonstrate the impact of government incentives on EV market shares, the cases of EV uptake in Denmark, Norway, and Germany is outlined in more detail in the following. In Norway, two out of five vehicles are either a BEV (18%) or a PHEV (19%). This might be explained by Norway´s long-term zero-emission incentive program, which is in place since 1990 following a polluter-pays policy (EAFO 2017). The effectiveness of subsidies is shown by a EV market growth of 90% in Norway and 1900% in the Netherlands (Winkel et al. 2016). In Denmark, registration tax benefits can be considered a major driver for the EV uptake. In 2015 the market share of BEVs peaked at 2,2% in 2015. Until 2016, EVs were exempt from the registration tax, which is 180% of the sales value of the car. Since 2016, EVs are charged 20% of the registration tax. This tax is increased stepwise up to 100% in 2020. In 2016, the market share of EVs dropped to 0,6% and it decreased further to 0,03% in February 2017 (EAFO 2017). However, long-term subsidies as they are implemented in Norway are missing.

4.4.4. Case Study

If we compare the initiatives to promote AFVs in Europe´s largest automotive markets to those implemented by the state of California, it becomes evident that European countries lack behind. Germany, UK, France, Italy and Spain account for three out of four new passenger car registrations in the EAM (ACEA 2015b). However, it seems that none of these countries has implemented a long-term strategy towards AFV development. In the following, we look at the case of Germany in further detail. The aim is to analyze the nations´ efforts with respect to individual AFV technologies. We first analyze Germany´s strategy with respect to battery and hydrogen technology, before discussing their initiatives related to the uptake of NGVs and the concept of PTG.

Several member states started a debate about the total prohibition of ICEs. The German Parliament for example published a resolution recommending that only emission free passenger cars shall be registered from 2030 onwards in order to achieve a zero emission mobility system until 2050 (Bundesrat 2016). Furthermore, the German government set a target of 1 million EVs until 2020 (BMVI 2017). However, in Germany the market share for BEVs and PHEVs in 2016 was 0,6% and 0,7% respectively (EAFO 2017). According to (Yang et al. 2016) Germany´s low market share for EVs might be due to a lack of incentives and a higher VAT for electric cars due to a higher sales price. The German national platform for electro mobility "Nationale Plattform Elektromobilität" (NPE) was started in 2010. The aim is to meet the government´s target, which is to achieve BEV market leadership until 2020. Therefore the government commits to R&D investment of 360 million € in a 2017-2020 period and private-public funding of 550 million € for the establishment of charging infrastructure until 2020. However, the NPE´s website does not contain information about targets for the period after 2020. However, the NPE plays a key role in setting standards and norms for BEVs and charging infrastructure. Thereby it contributed greatly to the implementation of a new national regulation on electric charging stations. The regulation entered into force in May 2017 and ensures non-discriminatory access to charging stations for BEV drivers (NPE 2017). The federal government website documents various initiatives in German e-mobility cluster regions and the government´s funding programs (BMVI 2017). However, all initiatives concerning electric mobility ended in 2015 and no information can be found on future investment targets. The Federal Ministry of Transport and Digital Infrastructure is also investing to establish a total of 15,000 electric charging stations between 2017 and 2020. For the time period after 2020, there are currently no targets set (BMVI 2017). To sum it up, there is a clear lack of mid- or long-term targets on the further development on battery technology from German public authorities. It is therefore not surprising that other projects and platforms such as the NPE do not show further commitment for the period after 2020.

For the development of hydrogen and fuel cell technology however, the German government extended their National Innovation Program (NIP) for ten more years until 2016. The program includes government funding of 250 million euros for the period 2016-2019 (BMVI 2017).To respond to the EU directive on AFV infrastructure and to promote and finance the development of FCEVs and infrastructure several initiatives exist in Germany. These include for example the Clean Energy Partnership (CEP), and the National Organization Hydrogen and Fuel Cell Technology (NOW). The CEP, a government initiative including 20 industry partners, was started in 2002 and ended in 2016. The aim of the project was the development of FCEV technology and infrastructure. In 2009, in the context of this project, six industry players (OMV, Shell, Total, Air Liquide, Daimler and Linde) agreed on the common aim to build a hydrogen infrastructure in Germany, starting with the establishment of 50 hydrogen filling stations. (CEP 2017). In 2014, they formed the joint venture *H2 Mobility* and set concrete targets including 100 hydrogen filling stations in 2018. Depending on future FCEV registration numbers, the next target includes up to 400 stations until 2023. Further project partners include BMW, Honda, Toyota, Volkswagen, Intelligent Energy, and NOW. (h2mobility 2017b). NOW is coordinating the National Innovation Program for Hydrogen and Fuel Cell Technology (NIP) and various model regions for electric mobility. In their first ten-year program (2007-2016), the NIP invested 1.4 billion into R&D in hydrogen mobility. The program was extended for the period 2017-2016 (NOW 2017).

With fuel tax for NGVs being 80% lower, gas vehicles are overcompensated since they only emit 20% less CO2. In Germany, tax compensations combined with a low CNG price result in fuel costs for NGVs of only 50% as compared to gasoline vehicles. Nonetheless, NGV uptake in Germany did not succeed. This shows that tax incentives alone are not enough for AFV uptake. Rosenstiel et al. (2015) analyzed the failure of NGV uptake in Germany. They found that a major barrier for the built up of a gas infrastructure is the distance between filling stations and the gas grid. Transporting CNG to highway filling stations via road transport is an expensive alternative (Rosenstiel et al. 2015). NGVs currently gain a low market share. However, looking at a scenario where the PTG concept is successfully implemented on the future energy market, one might suggest that society could devote more attention towards NGVs. This thought is only based on pure assumptions. It is a fact however, that several federal states in Germany recognized the potential of RPM and RPH already and started to invest into PTG R&D and several pilot projects. In Germany, the following PTG clusters exist already: Cluster Rhein - Main - Ruhr, Berlin - Brandenburg, Unterelbe – Weser - Ems, and the cluster around Neckar. In these regions a rapid development of PTG applications is expected (Schenuit et al. 2016).

To sum up the case of Germany, the government defined an electric mobility strategy but the strategy might find an end in 2020. Currently it seems that currently hydrogen is the preferred alternative due to a long-term investments guaranteed for FCEV technology and infrastructure. The uptake of NGVs failed in the past. However, investment into R&D in RPM and RPH is visible and several German clusters exist already.

Based on the overall discussion of national public authorities as major stakeholder, we can confirm that national governments play a significant role in the development of AFVs. We identified several interests and opportunities for national decision makers to promote the development of AFVs. Among these are for example to define AFV targets, to intensify AFV incentives, to develop AFV infrastructure, or to implement stricter Co2 and tax regulation that promote AFVs. It remains open, whether individual nations will seize these opportunities. As long as national decision makers do not define long-term targets, OEMs remain exposed to regulative uncertainties. As discussed in previous chapters, these uncertainties slow down the development of AFVs. Therefore, if national decision makers do not act, the situation remains unchanged, and the development of AFVs will not be enhanced.

4.5. Local Public Authorities

By looking at the situation from the viewpoint of European cities, we derive a further perspective on the development of the EAM with regard to the development of AFV technologies. In order to do so, this chapter provides insights into the case of some major European cities. To limit the scope, a focus is set on the initiatives by two major cities: Berlin and London.

As mentioned earlier, public decision makers are driven by the interests of the society (Köhler et al. 2010). We assume that this applies to both, national and local decision makers. A study by Rode and Hoffmann (2015) finds that the importance of car ownership for citizens has been constantly decreasing in the past. They investigate especially on the case in Berlin and London. In 2013, London´s public transport represented the most popular mode of transportation (45%), followed by driving (33%), walking (21%) and cycling (2%). In Berlin, car travel was the most popular transportation mode for daily travel (37%), followed by public transport (30%), cycling (17%) and walking (8%). The share of zero-car households has been increasing in both cities. 50% of car users in Berlin feel that their daily travel is also possible without cars and less than one out of six residents identifies themselves strongly with car ownership (Rode, Hoffmann 2015).

Starting with the city of London, its mayor expressed the need for mobility concepts that encourage physical activity, reduce traffic, improve air quality, handle increasing numbers of passengers, ensure accessibility and safety, and thereby create new homes and jobs (Tfl 2017a). Similarly, in Berlin, major interests include the reduction of negative effects due to car travel including noise, pollution, accidents, traffic jams and lacking parking space (Berlin 2017). Next to these interests as outlined on these cities´ public websites, one must keep in mind, that the EU has set CO2 targets to be achieved until xx. These regulations can also be considered as major driver for cities to take action and reduce their overall emissions, even though the message towards citizens might primarily highlight benefits related to health and safety.

Both cities implemented strategies to reduce negative externalities in the mobility sector and thereby improve their cities quality of life. In 2008, Berlin introduced a low emission zone (Umweltzone) in the inner districts in 2008. Within this zone, only low-emission vehicles as indicated by a green sticker are permitted. The city of Berlin furthermore invested heavily cycling infrastructure, with in 1000km of cycling paths currently available (Rode, Hoffmann 2015). London´s so called *Healthy Streets Approach* encourages investments into cycling routes, public transport, new pedestrian and cycle crossings and the introduction of ultra-low emission zones (ULEZ) (Tfl 2017a). Emission surcharges and ULEZ will be implemented by 2020. In the ULEZ, all vehicles that do not meet certain emission standards must pay a daily travel charge. The communicated benefit behind the ULEZ is to reduce illness and deaths caused by low air quality (Tfl 2017b). Furthermore, the London Council is cooperating with car club operators to promote the shift away from private vehicle ownership (Roland Berger 2017). Alternative fuel vehicles are not explicitly mentioned within London´s strategy (Tfl

2017b). It seems that the city is aiming towards a reduction of overall vehicle use, rather than investing into sustainable solutions with respect to alternative drive technologies. However, some efforts to promote the diffusion of battery technology do exist. These include awareness raising, investment into EV infrastructure and collaborations between key stakeholders (Roland Berger 2017).

In contrast to London, Berlin represents an important knowledge cluster for transport, mobility and logistics. Stakeholders include OEMs, suppliers, universities (e.g. technical University Berlin), and institutions (e.g. Fraunhofer institute) (mobilität-bb.de 2017). Next to investments into electro mobility, Berlin also considers itself as pioneer city with respect to hydrogen technology. In 2004 Berlin started the worldwide biggest hydrogen pilot project including two hydrogen filling stations and 17 hydrogen vehicles. Further investments into hydrogen stations and vehicles are on the agenda since 2008. The overall aim for the clusters Berlin and Hamburg is to achieve a leading position in Europe with regards to automotive and alternative fuel technology (infabb 2017).

In Austrian cities, noise seems to be a major driver to implement alternative concepts and to promote e-mobility. 42% of citizens in Klagenfurt are suffering from traffic noise (Hafner 2017). To respond to these negative externalities, Klagenfurt implemented a pilot project for BEVs. Furthermore, the city has set goals to reduce private mobility from 60% to 40% and increase the share pf public transport until 2025. Based on the five-year pilot project, which ended in 2015, Hafner (2017) found major success factors to boost the future development of AFVs. First, it is crucial to integrate decision makers and stakeholders on a local, regional and an EU level. Further actions that lead to successful AFV development include: an innovative public sector, political support, national and international public funding and the involvement of several stakeholders. Last, to bring AFVs closer to the customer it is crucial to communicate with target groups, introduce possibilities to test e-vehicles, offer free public charging stations, and to foster the exchange and learning with other cities (Hafner 2017).

Overall, we found that in Berlin and London there is an increasing trend towards public transport, walking, cycling, and shared mobility concepts, including the use of ICT technology. Also smaller cities such as Klagenfurt are interested in the benefits of AFVs and already some actions to promote the development of certain technologies. This indicates and confirms again, that society is increasingly ready to move towards alternative means of transportation.

We can therefore assume that this shifting interest in society function as driver for local decision makers to further push the development of sustainable solution in the mobility sector. Simultaneously local decision makers drive the diffusion through customer incentives and thereby further promote the shift from car ownership towards sustainable solutions. The initiatives as identified in this discussion positively influence the diffusion of existing AFVs. Currently these mainly include BEVs and NGVs since to date there are only few FCEV available. This can be considered as positive driver for the overall development of AFVs in general.

4.6. Customers

As discussed in previous chapters, there is an increasing demand in society for sustainable solutions. That also applies to customer demand in the mobility sector. For our analysis customer interest in AFVs plays an important role. Especially when government subsidies diminish or when they are removed completely customer interest will determine the demand for AFV and thereby influence their development (Anderman 2016b). The aim of this chapter is therefore to identify the interests, concerns, and opportunities of consumers in the EAM.

Customer interests can be subjective and include for example valuing the pioneering role of OEMs, energy source based on domestic origins, and environmental friendliness. An objective consumer interest is the ambition to achieve cost savings. Both, subjective and objective interests both affect consumers´ decision making-process (Saukkonen et al. 2017). As Rosenstiel et al. (2015) point out, consumers are interested in AFVs that compete with conventional vehicles concerning purchase price, range and infrastructure. They are interested in parking availability and traffic flow, i.e. avoiding traffic jams. Furthermore, consumers tend to be price inelastic towards fossil fuels. Younger consumers that are more environmentally aware are more likely to prefer alternative technologies (Rosenstiel et al. 2015). Today, 64% of German car drivers view the BEV as means of transport of the future and 53% can imagine to buy an electric vehicle within the next four years (YouGov 2017). When it comes to the benefits that owners value in EVs, a shift can be observed from environmental and economic benefits in 2010 to additional benefits such as acceleration and performance in 2016 (McKinsey 2017). According to YouGov (2017) however, acceleration is not one of the major advantages that near-term buyers associate with AFVs. Instead, they appreciate their environmental friendliness, less noise, tax advantages, and lower consumption cost.

Interestingly, 80% of consumers in Germany and the US trust new EVs from traditional brands, even though their portfolio consists mainly of ICEs rather than trusting other rising automakers (McKinsey 2017 p.17). These findings are confirmed by YouGov (2017). The study provides a detailed profile about high potential EV consumers. The result includes EV related consumer characteristics, demand, critical vehicle characteristics, current vehicle models that meet consumer requirements, and relevant communication channels to reach the customer. According to YouGov (2017) twelve percent of consumers, Tesla would represent their first choice if they would purchase an EV. Fifteen percent of respondents however indicate they would choose Volkswagen if they decided to buy an EV. This proves that there is a positive resonance to German Brands. Volkswagen and BMW are mentioned more frequently among e-mobility enthusiasts. There is no difference in perception between Opel and Mercedes-Benz (YouGov 2017).

Although there is a general trend towards more sustainable solutions, only a minority of consumers is willing to pay a surcharge for sustainability. It seems that sustainability alone does not outweigh technological and infrastructure barriers. The acceptance rate of AFVs is still low unless vehicles are subsidized. The most cited barriers for customers related to EVs are the purchase price, driving range, charging availability, charging time and non availability of vehicles (McKinsey 2017; YouGov 2017). Due to power degradation and range reduction of BEVs, customers will experience a drop in battery power after 6-10 years. (Anderman 2016a). A significant amount of consumers will not accept EVs as long as they do not offer the same benefits as traditional vehicles. Similar results are found in the case of NGVs. According to Rosenstiel et al. (2015) a barrier to NGV adoption is imperfect information such as neglecting fuel savings. As a result, lower total cost of ownership are often not enough to switch to alternative fuels. Further reasons include innovation resistance, perceived risk due to safety concerns related to gas, and a low coverage of gas filling stations (Rosenstiel et al. 2015). Safety is the main concern associated with FCEVs. To reduce these concerns among customers, it is crucial to educate customers (Winkel et al. 2016). This applies to AFVs in general. Many barriers are due to technological limitations. Some barriers however, such as charging, maintenance, reliability, and performance are often misconceived and can therefore be overcome through education. To give an example, compared to ICEs, maintenance costs for EVs are 20-40% lower on a five-year basis (McKinsey 2017). Rosenstiel et al. (2015) find that a NGV amortizes on average after 30.000km due to lower fuel costs and is hence competitive with an ICE. It seems as if many consumers do not yet realize that EV models that fulfill their expectations do already exist (YouGov 2017). Educating customers about the benefits of AFVs can hence be considered as opportunity to increase AFV acceptance. Looking at EVs however, Tesla is the only brand that managed to bring BEVs closer to an average driver, while European governments have failed to do so (Anderman 2016a). Several forms of incentives for consumer adoption exist. According to Winkel et al. (2016), incentive policies such as lane or parking allowances are most effective incentives to promote consumer adoption of AFVs. In addition to the public sector, further groups that are considered promising as early adopters for AFVs include “green" companies and multicar households (Saukkonen et al. 2017). According to Rosenstiel et al. (2015), who analyzed the failure of NGV uptake, found that the German government did not function as early adopter due to neglecting of AFV´s advantages. They furthermore find that company cars amount 10% of new car purchases in Germany. As early adopters, they could contribute to the adoption of NGVs. However, due to a lack in income tax incentives NGVs are not chosen as company cars by employers. Overall, there is no sufficient incentive for retailers and governments to promote NGVs and provide sufficient information to consumers (Rosenstiel et al. 2015).

It seems that EVs and NGVs models that are available today already meet the interests of certain consumers and are therefore a viable alternative. We can hence conclude that opportunities to increase consumers demand do exist. These are to provide consumers with better information and to focus on total cost of ownership instead of purchase price when comparing the value of conventional vehicles and AFVs. Incentives for company cars represent a further opportunity that could boost the diffusion of AFVs. An AFV infrastructure is a further main prerequisite to stimulate demand for AFVs.

4.7. Interest Groups

The German association of the automotive industry (VDA) defends the interests of German automotive manufacturers and suppliers. In the past, major German OEMs again and again managed to negotiate special arrangements and to gain additional time when it came to achieving their fleet´s emission targets (Spiegel 2016). Hence, the VDA thereby represents an important stakeholder that influences the development of AFV technologies in Europe. The following chapter highlights the interests, challenges and current position of the VDA.

According to the VDA (2009), the automotive industry is aware of the need to substitute fossil fuels. They agree that there is a need to innovate and to produce vehicles that are powered by sustainable technologies in the mid- to long-term. In 2016, however, the VDA positioned themselves clearly against a politically enforced abolishment of ICEs by 2030, as it has been discussed in Germany (VDA 2016b). This leads to the conclusion that in the short-term, the VDA´s interest is to reduce political pressure. Their aim is to limit the degree of CO2 reduction regulation in order to help OEMs to operate profitable. Since it is the interest of the union to defend the interest of German OEMs, we must consider OEM´s interests and concerns. As discussed in the previous chapters, the automotive industry is under pressure due to three major reasons. First, EU legislation implemented ambitious CO2 targets. Second, shareholders pressure OEMs towards short-term returns. Third, strong competitors pressure OEMs to keep up with technological developments. Politically enforced regulations such as the currently discussed abolishment of ICEs in Germany in 2030, would force OEMs to offer EVs within 13 years, which equals two product life-cycles. It remains open whether OEMs can follow such regulations without sacrificing on profitability. According to McKinsey (2017), the high costs of batteries remain the biggest barrier to profitability. And this barrier is not to be overcome until the next two or three product cycles, i.e. between 2025 and 2030 (McKinsey 2017). If this projection by McKinsey is correct, then it should indeed be possible for OEMs to produce EVs in a profitable way until 2030. Furthermore, one must consider the consequences if the German automotive industry fails to compete in e-mobility technology. This might imply a lack of a local industry, which would mean that a major part of the supply chain is shifted to foreign countries. This would negatively affect the national labor market. The German automotive industry must therefore find a way to shift away from fossil fuels without sacrificing on profitability and competitiveness.

To better understand the VDA´s position in this debate, we will highlight their arguments as outlined in a 2009 report. There, the VDA emphasized the potential of CO2 reduction in other industries or initiatives that are not directly related to powertrain technology. For example, by reminding that “in all other sectors of the industry CO2-prevention costs lie below those of motor vehicles“ (VDA 2009). Furthermore the VDA pleaded for CO2 reduction based on improvements in diesel-efficiency, an increased share of Clean Diesel, ICT technology, driver-training, the use of bio-fuels or measures for fuel-saving such as gear-change timing indicators, LEDs, or solar roofs (VDA 2009). Based on this information from 2009, one might conclude that the VDA tried to shift responsibility to reduce CO2 to other areas and industries. However, in current press releases the VDA emphasizes a strong commitment towards electric mobility. According to current statements, the VDA´s aim is to push the German automotive industry towards technology leadership in e-mobility in order to ensure the competitiveness of the German industry (VDA 2016a). This leaves us with the question what caused this drastic change in the union´s position. It might appear that the shift in interests is related to the establishment of the National Electric Mobility Platform (NPE), which initiated strategic discussions involving key industry players, unions, science, and politics.

Overall, it remains open for debate to what extent the automotive industry is actually committed towards e-mobility. Public announcements pushing the idea of e-mobility might also be a tool used to follow their interest of promoting the image of technological leadership. In a press release, the president of the VDA, Matthias Wissmann, proposed synthetic fuels as mid- to long-term solution for the shift towards AFVs (VDA 2016b). He emphasizes that emission free electric mobility is only possible when electricity is retrieved from renewable sources. Therefore the ICE could offer a better solution towards zero-emission mobility in the medium- and long-term through the employment of synthetic fuels (VDA 2016b). Referring to the statement by Wissmann, one might conclude that the automotive industry is not interested in actively pushing the development of electric vehicles. Instead, the development of synthetic fuels and the deployment alternative fuels in ICEs as future zero-emission solution seem to be the union´s preferred alternative to fossil fuels

Based on the findings as discussed above, we conclude that the VDA´s main interest is to engage in political negotiations in order to gain enough time for the transition towards alternative mobility concepts. Considering the technological development of the future powertrain, the true interest of the VDA remains uncertain. Based on the discussion in this chapter, one can assume, that the union accepts electricity and fuel cell technology as long-term solutions. However, while the VDA communicates a strong commitment towards electric-mobility, it seems that conventional fuels in the short-term and synthetic fuel in the long-term, i.e. the use of an ICE, remain the preferred alternative from the VDA´s perspective.

In the following a brief overview about further interest groups and associations that aim to promote a certain technology is given. These include hydrogen, electricity, PTG, PTH, NGV, and others. Hydrogen Europe is an industry association and represents over 100 partners.

Their aim is to bring together European, national, and regional fuel cell and hydrogen networks and promote the development of hydrogen mobility in Europe (Hydrogen Europe 2017). H2ME includes over 40 international partners to connect energy, transport and hydrogen industries (h2me 2017). The EU initiated their first Fuel Cells and Hydrogen (FCH) Joint Undertaking in 2008. The second initiative followed in 2014 with the aim of establishing hydrogen as major pillar of the European transport system (FCH 2017).

The Scandinavian Hydrogen Highway Partnership (SHHP) is a partnership of public and private industry players in Scandinavian regions interested in the development of a strong and competitive industry for electric and hydrogen mobility in Scandinavia (SHHP 2017)

The CEP is a German initiative founded in 2002. It includes 20 industry partners including industry experts, energy companies and OEMs (CEP 2017). H2 Mobility is a joint venture including OEMs and gas station operators. They pursue the common aim to setup up to 400 stations until 2023 (h2mobility 2017b). Hydrogen infrastructure initiatives as carried out by the German joint venture H2Mobility and the OMV are also part of the Connecting Hydrogen Refueling Stations (COHRS) initiative. The COHRS is a project funded by the EU aiming at the build up of 20 hydrogen filling stations in Germany and Austria. Further initiatives include research on customer acceptance and the development of business models for a future FCEV mobility system (Iwan 2017).

The natural and bio gas vehicle association (NGVA) is a European industry platform promoting the use natural and renewable gas as vehicle fuel. Board members include OEMs, gas suppliers and distributors. Board members representing OEMs include Audi, Daimler and Volvo. Shell, Air Liquide and Westport are some of the major energy suppliers that joined the NGVA (NGVA 2016). Eni, Total and Volkswagen are further candidates to join the NGVA in future (NGVA 2017). Further stakeholders and partnerships promoting the future of gas powered vehicles include the European Automobile Manufacturers Association (ACEA), the European Biogas Association (EBA), Gas Natural a joint initiative including six associations that represent the European Natural Gas industry, the International Gas Union (IGU), the International Road Union (IRU), and the NGV Global.

Associations such as the OICA are engaged in harmonizing vehicle regulations on a global basis. The OICA also participates in forums initiated by the UN (e.g. WP29) aiming at the harmonization and development of global technical standards (OICA 2017). Breathelife 2030 is a campaign to raise awareness, to educate and to encourage individuals, organizations and cities in order to achieve better air quality levels by 2030. The campaign is a joint undertaking by the world health organization, the United Nations Environment, and the Climate & Clean Air Coalition. The health risks caused from pollution is the key argument used to convince and initiate action. By joining the network, cities benefit from enhanced asset for communicating their air pollution efforts. Thereby the overall aim is also to contribute to stop climate warming (Breathelife 2017).

4.8. Suppliers

This chapter serves to identify the role of suppliers in the EAM and with respect to the development of AFVs. Therefore, we provide an insight into the global market for battery cells. Furthermore, we discuss the partnership between Tesla and Panasonic. Last, the role of financial intermediaries and their impact on to other stakeholders in the AFV industry will be highlighted. Overall, to limit the scope of this paper, the focus lies on few but relevant topics that demonstrate the complex interrelationships in the EAM with special interest given to the supply side.

According to Anderman (2016b), the market for Li-Ion batteries in 2020 will be distributed among EV OEMs (43%) and EV replacement (3%), Bus-OEMs (16%) and replacement (10%), PHEVs (18%), PHEV busses (3%), and HEVs (6%). Tesla is currently the largest Li-Ion user worldwide. Due to their cooperation with Tesla, Panasonic holds the leading position in battery cell production (Anderman 2016a). Roland Berger (2017) identify the leading nations in terms of global battery cell production. These are Japan, China, Korea, and the U.S. The leading battery cell producers in terms of expected global market share in 2018 are Panasonic Sanyo (33%), BYD (18%), LG Chem (17%), Samsung (9%), China Wanxiang (5%), GS Yuasa (3%) and Lishen (3%). Li-Tec, the only German producer stopped their production in 2016 and there is no production expected in other European countries (Roland Berger 2017). Anderman (2016b) confirms the raise of battery cell production in China. Due to a change in Chinese regulations in 2014, Chinese battery producers increased their production rapidly, leading to a sharp increase from $ 500 million in 2014 to more than $ 3000 million in 2016. This includes cells for BEVs and PHEVs. This is a 600% increase in production, while the second biggest market player Panasonic doubled its production from 500 million to almost 1000 million (Anderman 2016b).

To explain the role of battery cell suppliers in further detail, we discuss the case of Tesla and Panasonic in the following. The information is based on a case study by Anderman (2016a). The Tesla-Panasonic partnership forms the basis for a planned giga factory in Nevada (see also chapter 4.2.1). At the beginning of 2016, Tesla committed towards a \$1.7 billion order of Panasonic cells, which is about 195k EV packs. To meet Tesla´s production plan, Panasonic needs to commit to \$1.5 billion capital investment. However, Panasonic is interested in incremental investments depending on the future market development. This is because neither Panasonic nor its suppliers may have the capacity to such rapid production of machinery. So far, Panasonic only committed \$225 million capital. That equals a 7GWh installation. Even though large investments imply additional risk for Panasonic, there is a strong incentive to commit to such investments. If Panasonic cannot keep up to Tesla´s demand, Samsung or LG Chem cells could be an alternative (Anderman 2016a). Looking at this case, we can conclude that Tesla holds a dominant position over their suppliers. This can be explained by Tesla´s purchase power and a considerable number of battery cell producers on the market. As a result, suppliers such as Panasonic are under pressure to commit to large capital investments. At the same time, Panasonic depends on their supplier´s ability to satisfy demand. Keeping in mind that the future of battery technology is still uncertain, we find that battery cell suppliers currently face a high degree of uncertainty. To cope with these uncertainties of a moving market, (McKinsey & Company 2011) suggests scenario thinking. EV Market players need to define market entry strategies and create new business models (McKinsey & Company 2011).

Next to market uncertainties and pressure from OEMs and competitors, suppliers in the AFV market are also influenced by further stakeholders and their actions. These stakeholders include for example financial intermediaries. To demonstrate this thought, one should consider the findings by Sanderson (2017) and Scott (2016). Sanderson (2017) find that investment funds such as Pala Investments (SUI) or Shanghai Chaos (CHN) are speculating on the rise of electric vehicles and purchased 17% (6.000 tons) of 2016s global cobalt production. Cobalt is used in lithium-ion batteries and global demand is expected to exceed supply by 900 tons in 2017. Demand is furthermore expected to increase by 20% yearly in the next years, generating a "vacuum in supply" (Sanderson 2017). Similarly, Scott (2016) argues that the demand for platinum will increase once FCEVs become commercially available. The amount of platinum that is used in fuel cells is five times that of conventional engine technologies. The amount needed in fuel cells is likely to be reduced once the technology is mature and research is done in the field of non-noble metals. Overall. platinum producers can still expect positive long-term prospects in terms of demand (Scott 2016). To identify the extent to which such speculative actions influence the price and hence the further development of alternative technologies, further research is required. This would go beyond the scope of this paper. For the current thesis however, it is crucial to consider that financial intermediaries such as investment funds function as relevant stakeholder in the market for AFVs. As demonstrated in the examples above, these stakeholders might influence the development of certain technologies especially in terms of raw material supply and demand.

To sum up this chapter, we conclude that Europe failed to establish an industry for battery cell production. The value chain for EVs as considered from the supply side is located in Asian countries and the U.S. With no producers on the European market, a shift of battery cell production and know-how towards Europe cannot be expected in near future. The case of Tesla and Panasonic shows that Tesla boosts the development of battery technology and thereby fosters the development of the battery industry. Furthermore, we found that the success of battery technology not only determines the future of OEMs such as Tesla. It will also affect their first- and second tier suppliers. Overall, we confirmed that the future success of AFV technologies is not guaranteed. It can be assumed that these uncertainties pose risks not only to players in the battery industry, but also in other AF industries. Finally, we also found that financial intermediaries play a key role due to their speculation on raw materials such as cobalt and platinum.

4.9. Energy companies

The rather slow development of low emission power train solutions and the inability to predict future technological developments also impact the oil and gas industry (Morgadinho et al. 2015, Rosenstiel et al. 2015). In the following, we first look at existing literature findings to understand the role of energy companies concerning the development of AFs and AFVs. We will then analyze several energy companies that operate in Europe. The aim is to identify their strategic positioning and priorities with respect to R&D in alternative technologies. Based on these findings, we find that energy companies indeed function as driver for the development of certain AFs.

From the perspective of energy companies, investment into AFV infrastructure is irreversible and its profitability depends on the demand of future AFV demand (Saukkonen et al. 2017). This poses risks to energy companies and slows-down the development of AFV infrastructure. According to Morgadinho et al. (2015) the oil industry establishes different investment strategies regarding their energy resource plans in order to respond to the above mentioned uncertainties. A great extent of those investments are targeted towards the natural gas and biofuel industries. Which strategy is pursued, depends on external conditions such as the geographical scope and local government regulations and legislation. In this context, especially those regulations concerning emission reductions are of great importance and can vary greatly within different countries (Morgadinho et al. 2015).

Rosenstiel et al. (2015) argues that, among other barriers, the market structure of oil and gas companies could have contributed to the failure of NGV uptake in Germany. Most fueling stations are owned by oil companies. Gas stations are then established and leased to the filling stations. This market structure shifts power to the oil companies. Oil companies however might not want to support competing technologies. The construction costs of €200.000 for a CNG-pump are only profitable for long-term commission contracts, while filling stations are interested in short-term contracts (Rosenstiel et al. 2015). Hence, we can conclude that oil companies and filling station operators have different interest (short term vs long-term contracts). Furthermore, there is no incentive for oil companies to establish CNG filling stations.

The findings as mentioned above do not provide sufficient insights to determine whether energy companies actually prefer one AF technology to another. To identify the actual interests of European energy companies with respect to the development of alternative fuels, selected organizations were analyzed. Table 5 summarizes the information as derived from the organizations´ official websites. The aim was to identify their interests on the basis of their strategic R&D focus. The selected companies include eleven of the largest international oil and gas companies that operate on the European market.

Table 5: Energy companies´ R&D priorities in AFs

Organization	Field of R&D	Alternative Fuel Projects and Partnerships	Source
OMV	Hydrogen, RPH	Filling stations in Austria and Germany (h2 mobility), RPH (wind 2 hydrogen)	OMV (2017a, 2017b)
Total (GER)	Hydrogen	Multi Energy Filling Station Berlin	(Total 2017)
Shell	Hydrogen, RPH, advanced biofuels	First hydrogen (RPH) station in Cobham, UK , H2 mobility	(Shell 2017)
Air Liquide	hydrogen	H2 mobility, hydrogen filling station in Germany	(h2mobility 2017a)
Linde	Biofuels, hydrogen, LNG	H2 mobility	(Linde Group 2017)
BP (Aral)	Gas, advanced biofuels, renewable electricity (BEV)s	No specific projects in Europe	(BP 2017b, 2017a)
Exxon Mobil (Esso)	Renewable electricity (BEVs)	No specific projects in Europe	(Exxonmobil 2017)
Gazprom	Methane-hydrogen	No specific projects in Europe	(Gazprom 2017)
Petro China	No specific mobility strategy, R&D focus: Biodiesel, shale gas, nonfood ethanol	No specific projects in Europe	(Petrochina 2015)
Petrobraz	No specific mobility strategy, R&D focus: Biofuel,- oil,- gas	No specific projects in Europe	(Petrobras 2017)
ENI/ Agip	No specific mobility strategy	No specific projects in Europe	(ENI 2013)

Source: Own representation

Overall, in the short term, all energy companies as listed above, target their R&D towards increasing the efficiency of conventional fuels. Advanced biofuels are on the agenda of several companies including for example Shell, Linde, and BP. In the long-term however, several energy companies follow different strategies with respect to AFV development. In general, they tend to support the vision of either a hydrogen, or a biofuel, or an electric future.

The OMV, and other energy companies such as Shell, Intelligent Energy, Total, Air Liquide, and Linde are part of the *H2 Mobility* partnership which aims to build up to 400 hydrogen filling stations until 2023 (h2mobility 2017b). These companies also devoted their focus towards hydrogen mobility and initiated several projects such as the setup of filling stations and pilot plants in Europe. The OMV for example, builds on hydrogen mobility and built a hydrogen filling station in Germany already in 2009 (Iwan 2017). Today, five OMV hydrogen filling stations exist in Germany. Within the scope of the EU funded COHRS initiative, the OMV also established four hydrogen filling stations in the Austrian cities Vienna, Linz, Innsbruck, and

Graz (Iwan 2017, OMV 2017a). Furthermore, the OMV operates a RPH pilot plant in Austria (OMV 2017b).

BP and Exxon Mobil bet on an electric future (BP 2017a, 2017b). BP set different strategic priorities. Instead of focusing on hydrogen, BP´s focus lies on a shift towards gas and advantaged oil. Research addressing the future mobility system is targeted towards plant-based and recycled oils (BP 2017b). The BP Energy Outlook projects that in 2025 REs will make up to 40% of electricity generation in Europe (BP 2017a). BP also beliefs that in 2035 six percent of all vehicles on the road will be electric. As a result, the company supports the development of electric vehicles by offering retail services and by collaborating with OEMs on improving fuel efficiency (BP 2017b). Gazprom conducts research in the field of methane and hydrogen without specific infrastructure investments in Europe being planned (Gazprom 2017). For other brands such as Petro China, Petrobraz, and Eni, no specific research focus on the field of alternative fuels could be identified (Petrochina 2015).

5. Results

The overall aim of this thesis was to analyze the development of AFVs in Europe from a stakeholder perspective. Therefore, this research identified the interests, barriers, opportunities, and the role of nine different stakeholder groups. The result is summarized and displayed in a matrix (Table 6). This matrix represents the key findings and will be presented in chapter 5.1. In this context, all underlying research questions will be answered. The following discussion in chapter 5.2. serves to answer the overall research question which is as follows:

0. How do different stakeholder interests in the European automotive industry influence the development of AFVs?

5.1. Findings

Based on existing literature that combines stakeholder literature and research about AFVs, the following first research question was answered:

R1: Who are the critical stakeholders in the automotive industry?

As discussed in chapter two, nine critical stakeholder groups were identified and chosen for the scope of this research. These include European OEMs, competition, the EU, national public authorities, local public authorities, consumers, interest groups, suppliers and energy companies.

We furthermore identified a range of AFVs that might replace the conventional ICE. These include EVs (BEV, REEV, PHEV), HEVs, FCEVs, and NGVs. CO2 neutral driving presupposes that the source of energy is derived from renewable sources. AFs that meet these requirements and might therefore replace conventional fuels include RPM, RPH, and synthetic fuels. RPM and RPH seem promising alternatives to replace natural gas and industrial hydrogen. Simultaneously, synthetic gasoline, diesel, or ethanol give hope to keeping up the traditional ICE. However, a dominant technology is not yet defined. Instead, all these AFVs and AFs as mentioned above are still in the research stage to market and therefore not competitive with the ICE. This leads us to the next sub-question:

> R2: What are the technological and socio economical barriers to the implementation of each technology in the automotive industry and how can they be overcome?

To better understand drivers and barriers as they arise within the broad environment of the European automotive industry, several technological, economic, sociocultural, and political forces were identified. Among others, these include for example technological trends such as ICT, new competitors entering the automotive market, increased societal consensus for the need to combat global warming, and a European strategy promoting REs to reduce energy dependence. Technological barriers as identified in the scope of this thesis include for example high costs for batteries and a limited driving range of BEVs. FCEVs cannot compete with conventional vehicles due to the high costs of both, fuel cell technology and hydrogen. Similarly, RPM and RPH are not cost competitive due to efficiency losses in the conversion of electricity to methane and hydrogen. NGVs can be considered as mature from a technological perspective. However, the lack of a filling infrastructure contributed to the failure of NGV uptake in the past. A lacking infrastructure is also considered a major barrier to the uptake of EVs and FCEVs. This chicken-and-egg dilemma can only be solved through simultaneous investment into both, AFVs and the respective infrastructure. Next to a lacking infrastructure and technological barriers, also socioeconomic and regulatory barriers slow-down the development of alternative technologies. To identify how these barriers can be overcome, the complex network of interacting stakeholders was analyzed in more detail by looking at the operating environment of the automotive industry. It could be concluded that individual stakeholders follow their own individual interests while simultaneously being influence the interests and decisions of other powerful stakeholders. Thereby they influence the development of alternative drive technologies and their respective infrastructure. The results are summarized in Table 6 and will be shortly summarized in the following paragraph. The stakeholder matrix serves as basis to answer the following research questions:

R3: What are the entrenched interests, barriers, and opportunities of critical stakeholders with respect to the development of AFV technologies?

R4: How do stakeholders currently address their interests?

R5: Is there a gap between stakeholder´s opportunities and their actions taken?

Table 6: Stakeholder matrix

Stakeholder	Interests	Barriers	Opportunites	Current Position and Influence
European OEMs	• technological leadership • shareholder ROI • meeting customer needs	• immature AFV technologies • no dominant technology • lacking infrastructure • regulatory uncertainty from EU, national, and local authorities • ICE yields high short-term ROI	• cooperation: technology platforms, partnerships • new business models focusing on underserved customer needs • educating customers	• R&D priorities: ICE improvement, electricity, autonomy, connectivity • fields of investment: hydrogen, RPM, RPH, synthetic fuels • Disinvestment: NGVs, biofuels • AFVs: low production volume, increased model availability, shift to lower price segments • joint-venture for BEV infrastructure development
Competition	• define a dominant technology • create a technology platform for BEVs (e.g. Tesla), FCEVs (e.g. Toyota) • technological leadership	• uncertain development of EV/FCEV market • uncertain future subsidy policy and CO2 regulation • dependency on material suppliers	• investment into specific AFV technology and infrastructure • develop dominant design • cost reduction through economies of scale • enter European market	• long-term commitment to electricity (Tesla, Honda) or fuel cell technology (Toyota, Hyundai, Honda) • HEV market leadership (Toyota) • intense cooperation with industry players • considerable investment into infrastructure development and customer incentives
EU Regulators	• defend position vs. U.S. and China • global leadership of AFV and REE industry • achieve climate goals (Paris Agreement)	• impact of intense CO2 restrictions on industry profitability • clear technology positioning vs. technology decided by market forces	• long-term strategy, goals and funding • prioritizing certain technologies • intensified regulation e.g. infrastructure and CO2 targets for nations and OEMs • function as venture capitalist	• failure to implement long-term CO2 regulation and targets • technology neutral strategy • Past regulation fails: OEMs implement defeat devices • limited investment in R&D and infrastructure • failure to promote nationwide and multi-stakeholder collaboration
National Public Authorities	• balance interests of society and industry • economic growth, employment, industry competitiveness • national (tax) income	• EU regulatory uncertainty • lacking standardization among member states • RPM not yet considered as REE	• long-term regulatory benefits and fiscal policies for OEMs • customer incentives (e.g. lane and parking allowances) • infrastructure investment • taxation (polluter-pays) • function as early adopter or venture capitalist • linking national electricity, mobility and heating sectors to gain synergy effects • multi-state collaboration	• current regulation fails to boost AFV uptake • lack of standardized subsidy policy and infrastructure among member states • poor cooperation with industry players • best practice examples: Norway, Netherlands (BEVs), Germany (RPM, RPH clusters)
Local Public Authorities	• reduce noise, traffic, pollution, private vehicle ownership • increase physical activity, accessibility, safety • create jobs and homes	• AFVs compete with cycling infrastructure and public transport for investment and funding	• infrastructure development (cycling, AFV) • low emission zones • total prohibition of ICEs • public sector as early adopter • AFV incentives (tax, lane access, parking)	• customer incentives, polluter-pays taxation, infrastructure investment, pilot projects, low emission zones • knowledge cluster for electricity and hydrogen (e.g. Berlin) • drive shift from car ownership towards shared mobility concepts and ICT • government fleets mostly fail to act as early adopter

Stakeholder	Interests	Barriers	Opportunites	Current Position and Influence
Customer	• subjective: e.g. pioneering spirit, domestic energy source, environmental friendliness • objective: e.g. cost savings: price parity of AFVs and ICEs, subsidies • fluent traffic, parking availability	• model availability, purchase price, range, infrastructure availability • safety concerns • imperfect information • lacking incentives • mismatch of supply and demand	• gain information to reduce concerns • focus on TCO instead of purchase price • benefit from subsidies and tax incentives • governments, companies, and multi-vehicle households as early adopters	• EV models that fulfill customer expectations already exist • share of potential EV buyers increases • market share for AFVs still low • subsidies and infrastructure remain prerequisite for AFV uptake • increasing demand for AFVs and sustainable solutions
Interest Groups (VDA)	• defend interests of automotive industry • gain time for the transition towards alternative mobility concepts	• regulatory uncertainty from EU, national, and local authorities • high ROI from traditional technologies slow-down AFV production	• increased awareness for the need to shift towards sustainable solutions • strong influence on political decision makers to promote industry competitiveness	• focus on short term interests: ICE production • reduce political pressure (Co2 regulation) • increased commitment to AFVs since 2015 • no clear long-term technology positioning, AF options: electricity, hydrogen, synthetic fuels
Supplier	• long-term success of AFV technologies • technological excellence • incremental investments into uncertain technology	• uncertain, fast moving market environment • capacity limitations • price volatility of raw materials	• growing market • cost reduction through economies of scale • new business model development • long-term partnerships with OEMs	• Japan, China, Korea lead global battery cell production • Europe fails to establish national battery cell industry • complex network among suppliers and OEMs • powerful OEMs force suppliers to commit to large capital investments
Energy companies	• definition of long-term resource strategy • profitable infrastructure investment	• uncertain future • irreversible investment into infrastructure • differences in geographic and local legislation	• infrastructure development • partnerships with OEMs • adapt investment strategy to local conditions (geography, legislation)	• exploit improvement potential of conventional fuels in the short to medium term • different long-term investment strategies include hydrogen (e.g. OMV, Shell, Total, Airliquide, Linde), biofuel (Shell, Linde, BP), or electricity (BP, Exxon Mobile) • FCEV and BEV infrastructure development but low incentive to invest into gas filling stations • cooperation with other stakeholders

Source: Own representation

Major European OEMs as analyzed in this thesis include the Volkswagen Group, Renault-Nissan, the PSA Group and BMW. Their key interests include gaining a technological leadership position, achieving high shareholder return, and meeting customer expectations. However, there is a lack of long-term strategies, goals and incentives for AFVs from European and national regulators. This regulatory uncertainty for OEMs slows down the development of AFVs. Major opportunities were identified. First, by joining technology platforms, OEMs can drive the development of a dominant technology. The formation of partnerships with key stakeholders represents further opportunities including participation in the knowledge trading process (e.g. with other OEMs), boosting the AFV uptake (e.g. public sector) and infrastructure development (e.g. energy providers). Second, OEMs develop new business models such as shared mobility services to market AFVs profitably. OEMs can help to bring AFVs closer to the customer with incentives (e.g. free charging) and by eliminating their concerns (e.g. safety, costs) through education or by focusing on TCO instead of purchase price. Future models should focus on underserved needs of near term buyers, i.e. basic and lower-range mobility solutions. Looking at their current position towards AFVs, we found that in the short term, the improvement of ICE technology remains a key priority for European OEMs. Accordingly, AFVs represent only 2% of European OEM´s car fleet. A limited availability of AFV models causes a mismatch of supply and demand. Furthermore, low production volumes of AFVs hinder OEMs to realize economies of scale and thereby further increase overall production cost. However, OEMs announced to increase their BEV production and model availability in the upcoming years. Furthermore, they increased their efforts in the setup of a standardized fast-charging infrastructure. Simultaneously, FCEVs remain on the long-term agenda and OEMs participate in the knowledge trading process on hydrogen technology through partnerships and multi-stakeholder networks (e.g. Hydrogen Europe). Individual brands also investigate in PTG technology and synthetic fuels (e.g. Audi). It can therefore be concluded that European OEMs currently boost the uptake of EVs, while simultaneously driving the development of FCEVs, PTG technology and synthetic fuels. Only little attention is given to NGVs and biofuels. European OEMs distribute their R&D and marketing efforts among a mix of AFV technologies including battery, hydrogen, PTG and synthetic fuels. However, one might suggest, that European OEMs did not give up on finding a CO2 neutral mobility solution based on ICE technology. This assumption is based on their interest to maintain their long-standing excellence in ICE technology as well as their current investment strategy targeting towards the development of both, ICE technology and synthetic fuels.

Major competitors include Tesla, Toyota, Hyundai and Honda. Tesla is fully committed towards battery technology. Toyota and Hyundai show strong commitment towards fuel cell technology, while ICEs, HEVs and BEVs serve as short and mid-term solutions. Honda considers both, BEVs and FCEVs as potential long-term solutions. These brands invest considerably into the development of BEVs and FCEVs and the corresponding infrastructure. The development of a dominant power train technology requires the joint commitment of several stakeholders. OEMs therefore drive the creation of a technology platform and increasingly invest into partnerships and initiatives that involve several key stakeholders. These include OEMs, suppliers, public authorities, energy companies, and customers. Such initiatives include for example the large-scale production of BEVs, infrastructure development, customer incentives (e.g. free charging), and participation in the knowledge trading process (e.g. free patents). Overall, competitors are considered as key drivers for both, battery and fuel cell technology, with research also being targeted towards renewable sources of energy. The development of HEVs is also on the agenda since these are considered as bridging technology in the short- and medium-term.

A key interest of European regulators is to defend the EU´s global competitive position against China and the U.S. Furthermore, the EU committed to combat global warming and reduce CO2 emissions as defined in the 2015 Paris Agreement. Based on these interests, the EU aims towards a global industry leadership position in the AFV and RE sectors. To follow this aim, the European Commission published several strategy papers, regulations, directives, and established working groups, partnerships and funding programs. We identified a major challenge, which is to find the ideal degree of CO2 regulation. While too loose regulations might not have the desired effect, too strict regulations negatively affect industry profitability. To boost the development of sustainable technologies without sacrificing on short-term profits, several opportunities for European regulators were identified. These include the definition of a long-term AFV strategy, prioritizing certain AFV technologies, long-term funding and AFV infrastructure development, intensifying current CO2 and infrastructure targets for OEMs and member states, improvement of CO2 testing procedure, as well as tax policies that promote AFVs and REs. Looking at the EU´s current position, it could be concluded that a considerable gap exists between Europe´s opportunities and their actions taken. The findings showed that, instead of encouraging the production of AFVs, current EU regulation rather promotes the improvement of ICE technology and led to the use of defeat devices among OEMs. Furthermore, the EU defined a technology neutral strategy and failed to define long-term goals. Last, there is only limited funding attributed specifically to the development of AFVs. The findings showed that current EU legislation causes regulatory uncertainty and thereby affects key stakeholders in a way that slows-down the development of any specific AFV technology. Unless the EU fails to define a clear technology position including concrete long-term targets towards AFV development, it cannot be considered a key driving force to the development of a competitive European AFV industry.

National public authorities are driven by the interest of the society and they are subject to EU legislation. They are also interested in a positive national income, i.e. income from taxes. Several opportunities for national decision makers to boost the development of AFVs and infrastructure were identified. These include: prioritizing certain technologies, establishing long-term targets, multi-state collaboration, cooperation between power train industry and the public sector, implementation of regulatory benefits, fiscal policies and consumer incentives, taxation of fossil fuels, the public sector functioning as early adopter and venture capitalist, and linking the national electricity, mobility and heating sectors to gain synergy effects. Although many opportunities exist, most European governments failed to establish a regulatory framework that drives the development of AFVs. Member states frequently failed to meet their own national AFV targets. A major barrier to the uptake of AFVs as identified in this analysis include for example the lack of a joint AFV strategy among member states. The lack of cooperation also applies to standards, subsidies, and infrastructure development and hence prevents nations to benefit from synergy effects and standardization. Last, the findings suggest that governments often failed to function as early adopters for AFVs due to a lack of incentives for decision makers. However, exceptions exist. For example, the market share of AFVs is 37% in Norway, and clusters for the development of RPM and RPH can be found in Germany. Such initiatives can be considered as best practice examples that positively contribute to shifting towards sustainable mobility solutions. Overall, it can be concluded that European national public authorities do currently not function as powerful driving force to the development of AFVs in the EAM.

In contrast, local public authorities, i.e. decision makers from major cities were identified as relevant drivers for an AFV uptake. By looking at the example of two major cities, Berlin and

London, we found that these cities implemented or plan several initiatives that drive the development of AFVs. Such initiatives include for example the implementation of low-emission zones, subsidies, tax incentives, lane and parking allowances, and infrastructure development. Furthermore, they increasingly invest into public transport and cycling infrastructure and thereby drive the shift from car ownership to shared mobility solutions. The latter can be considered as positive driver to the development of sustainable mobility concepts. However, it could also be interpreted as investment fields that compete with AFVs for budget and funding. Overall, it can be concluded that local public authorities face several opportunities to promote the development of AFVs. The findings suggest that especially decision makers in large cities such as Berlin and London function as best practice examples and implement a great extent of initiatives. Therefore, they considerably contribute to the development and uptake of AFVs.

Customers are increasingly interested in adopting sustainable mobility solutions, however, although the share of potential customers increases, the acceptance rate remains low unless AFVs are subsidized. Customers expect AFVs to compete with conventional vehicles on price, range, and infrastructure availability. They are interested in safe and reliable vehicles, fluent traffic and parking availability and trust into local brands when purchasing an AFV. Barriers to the uptake of AFVs include high purchase cost, limited driving range, neglecting of fuel savings, safety concerns, and lacking infrastructure availability. Next to private consumers, governments, companies and multicar households were identified as potential early adopters. Tax schemes and incentives as implemented by other stakeholders should be increasingly targeted towards these groups. Further, we found that AFVs that meet customer requirements for private vehicle owners already exist. To realize their opportunities, customers must gain more information and focus on TCO instead of purchase price. Overall, there is an increasing demand for sustainable mobility concepts and customers are increasingly ready to purchase AFVs. Considering that the price of AFV technologies will further decrease due to technological progress, the demand for AFVs is expected to decrease. Customers can therefore be considered as positive drivers for AFVs.

The interest group VDA is interested in securing the automotive industry´s profitability and competitiveness. Their role in the development of AFVs is to reduce political pressure to gain additional time for the transition and profit in the short to medium-term from high returns gained from ICE technology. In the past year, the VDA increasingly committed towards AFVs as long-term solution. A preferred solution, as from the VDA´s perspective was not identified. Instead, potential technologies include BEVs, FCEVs, and synthetic fuels. We can therefore conclude that in the past the VDA functioned as barrier to the development of AFVs. To date, although they increasingly accept AFVs in the long-term, they slow-down the development of AFV in the short- and medium-term. Associations are considered as positive driver to the development of AFV technologies because they promote multi-stakeholder cooperation. Associations exist in the field of electricity, hydrogen, and gas based fuels and AFVs. These include for example Hydrogen Europe, the CEP and the NGVA. Overall, these can be considered as positive drivers for the market development of AFV technologies including FCEVs, BEVs, and NGVs. Hence, among several interest groups and associations as analyzed in this thesis, the VDA is acting as rather negative driver to the development of AFVs and several further associations that drive the development of a certain technology.

Suppliers that are part of the AFV supply chain are interested in the long-term success of AFVs. They pursue technological excellence and play an important role in the technological development of AFV technologies such as battery cells and fuel cells. However, they operate in an uncertain and fast moving environment and are restricted to capacity limitations based on the ability of second-tier suppliers. Furthermore, price hikes caused through speculation on raw materials (e.g. cobalt) result in volatile prices. Last, powerful OEMs influence and shape their supplier´s future market and investment strategies. A growing market represents a major opportunity to AFV suppliers to scale up production and form long-term partnerships with powerful OEMs. In order to adapt to changing market conditions suppliers might establish new business models. Having analyzed the case of the battery cell supply chain in further detail, we concluded that a large and complex network of partnerships between OEMs and foreign battery cell suppliers exists. In contrast to Tesla, European OEMs failed to establish a national battery industry and producers from Japan, China, and Korea currently lead the global market for battery cells. This can be considered as negative force to the establishment of a European BEV industry. Currently Panasonic committed to invest into Tesla´s giga factory, which is considered as major driver for the development of battery technology and might result in significant cost reductions for BEVs due to economies of scale.

Energy companies are interested in defining a profitable long-term energy and infrastructure strategy. Barriers include the risk associated with irreversible investments into infrastructure, market uncertainty and differences in local geography and legislation. To respond to these challenges, energy companies established different AFV investment strategies. In the short-term, all companies analyzed in this thesis invest into the further development of conventional fuels. In the long-term, companies follow different investment strategies. While a considerable number of companies invests into hydrogen technology (e.g. OMV, Shell, Total) and biofuels (Shell, Linde, BP), others belief into battery technology (BP, Exxon Mobile). Furthermore, we found that energy companies and OEMs formed partnerships with respect to biofuels, hydrogen and battery technology. Thereby they show strong commitment and cooperate with major industry players to invest in R&D and infrastructure for battery and hydrogen technologies. Due to the market structure and technological barriers associated with the set-up of gas filling stations, there is a lack of incentives for energy companies to invest into NGV infrastructure. Energy companies can hence be considered as positive drivers for the development of conventional fuels and biofuels in the short-term, as well as hydrogen and battery technology in the medium and long-term.

5.2. Discussion

The following discussion serves to provide an answer to the main research question

0. How do different stakeholder interests in the European automotive industry influence the development of AFVs?

The aim of this thesis was to better understand the impact of stakeholder relationships to the development of AFVs. Therefore, the interests, barriers, and opportunities of nine key stakeholders were identified. The findings suggest that several opportunities to boost the uptake of AFVs exist for each stakeholder. While some stakeholders already take advantage of these opportunities, others failed to do so and thereby slow-down the shift towards sustainable mobility concepts. Thereby, the following forces that drive the shift towards sustainable mobility solutions were found: an increasing demand among customers for sustainable solutions, consensus among all stakeholders that a shift towards CO2 neutral mobility solutions is indispensable in the long-term, increasing competition, and European regulation aiming to reduce emissions caused by traffic. On the other hand, several forces that slow-down the development of AFVs exist. These include a European technology neutral strategy, the failure of European and national decision makers to implement long-term targets, the lack of cooperation among stakeholders, short-term interests of European OEMs to exploit high ROI from conventional technologies, and a powerful interest group of the German automotive industry.

Considering several driving forces from various stakeholders, the development of AFVs, i.e. the shift away from ICE technology remains a priority as compared to the development of AFs (including synthetic fuels, RPM and RPH). In this respect, European regulation plays a major role due to current CO2 regulation. However, there is consensus that the ICE will dominate the market in the short to medium term until alternative solutions are more mature. The findings also suggest that there is a shift away from food-based biofuels and several stakeholders agree that the source of energy must be CO2 neutral in the long-term.

With respect to the European market for AFVs, it can be concluded that EVs currently outperform other technologies (FCEVs and NGVs) regarding their market uptake, consumer acceptance, and infrastructure availability. Hence, it seems reasonable that major OEMs targeted their mid- and long-term R&D efforts towards the development of battery technology. There is consensus among the majority of stakeholders that HEVs function as bridging technology until BEVs are more mature. It furthermore becomes clear that a considerable amount of stakeholders strongly beliefs in the long-term success of FCEVs. In contrast, NGVs do not seem to be a key priority of key stakeholders. Thus, all stakeholders drive the development of either battery electricity or fuel cells, with some stakeholders also investing into both technologies. While some stakeholders are fully committed and hence represent a powerful driving force (e.g. Tesla), others are primarily driven by external forces (e.g. European OEMs). Looking at the overall stakeholder-network as analyzed in this thesis, it can be concluded that the current network functions as major driving force for the development of both, battery and fuel cell technology. This includes the production of BEVs, HEVs, and FCEVs, and the buildup of a Europe wide charging and hydrogen infrastructure. It remains open, however, whether BEVs or FCEVs, or both technologies will dominate the EAM in the long-term. At this point one must consider that several stakeholders as mentioned above positioned themselves towards only one of these alternatives. One could furthermore assume that these stakeholders with competing interests in AFV technology (e.g. Tesla vs. Toyota, OMV vs. BP, battery cell vs. fuel cell suppliers) are unlikely to switch due to sunk costs of irreversible investments already made and the lack in know-how of the alternative technology. Taking this one step further, it can be assumed that the development of BEVs and FCEVs will be further developed, independently from another. As a result, BEVs and FCEVs might co-exist in the long-term. The degree of each technology´s development will be determined by several forces in the broad and internal environment of the EAM. This represents a potential field of further research to be conducted.

One must however not forget the potential of synthetic fuels and the development of RPM. Although it seems that these technologies are not a key priority among most stakeholders, there are few but powerful stakeholders that continue to invest into these technologies. Among these stakeholders are for example European OEMs and gas suppliers. Based on this analysis, it can be assumed that European OEMs are strongly interested in maintaining their leadership position based on ICE technology. Therefore, it seems reasonable, that they are also interested in developing synthetic fuels, or investing into RPM technologies, which implies the interest in promoting the diffusion of NGVs. In Germany several knowledge clusters in the field of RPM exist already, which further supports this idea. As previously discussed, the interest group representing the German automotive industry (VDA) has a major influence on national decision makers. Furthermore, the interests of German public authorities influence the further development of European legislators. Due to the lack of a European long-term strategy in the field of AFVs, it remains open for debate whether Europe will follow a technology neutral strategy in future. Considering that European legislation is influenced by German public authorities and their interests, that are again influenced by local OEMs and the VDA, it does not seem unlikely that interests of European OEMs will shape the overall European future position. This opens up a new scenario in which Europe could start to invest into a technology that would put European OEMs and other key industry players at the leading position of technological expertise, i.e. ICE and NGVs. This idea is based on underlying assumptions and must therefore treated with caution. However, it clearly shows that the ICE and NGVs, even though they currently gain only limited attention, should be considered as potential long-term solutions. Next, to BEVs and FCEVs, political decision makers and research focusing on AFV research should not neglect these alternatives. Based on the findings as discussed above, this thesis suggests that both alternatives, the ICE powered by synthetic fuels, as well as NGVs powered by RPM, represent valid long-term alternatives to replace conventional technologies. As it is the case with other AFVs, there are technological and regulatory barriers that must first be overcome. However, European regulators and other powerful stakeholders in the European automotive industry face several opportunities that allow them to shape the future engine technology in a way that puts them into a technological leadership position, be it BEVs, FCEVs, NGVs, or ICEs based on synthetic fuels.

6. Conclusion

The aim of this thesis was to analyze the European automotive industry from a stakeholder perspective in order to identify how key stakeholders influence the development of AFV technologies. To better understand the role of relevant industry players, the interest, concerns and opportunities of nine key stakeholders were discussed. These include European OEMs, competitors, the EU, national and local public authorities, customers, interest groups, suppliers, and energy companies. Based on these findings, their influence on the development of several technologies could be identified.

The findings of this thesis suggest that BEVs and FCEVs are currently the main focus of both, political decision makers and research conducted in the field of alternative powertrain technologies. The findings confirmed that both, BEVs and FCEVs represent promising long-term solutions and they are likely to co-exist in future. Furthermore, science and regulative forces attribute only little interest is to AFs including synthetic fuels, RPM and RPH. However, the findings of this stakeholder analysis suggest that few yet powerful stakeholders in the EAM drive the development of these alternatives. RPH serves as alternative to hydrogen and is already on the agenda in the context of research on FCEVs. As alternative to natural gas, RPM could offer new opportunities to the uptake of NGVs. Similarly, the rise of synthetic fuels implies that the era of the ICE must not necessarily come to an end. Therefore, next to BEVs and FCEVs, also ICEs and NGVs represent potential long-term solutions to shift towards a CO2 neutral mobility system. Future powertrain scenarios should therefore consider a technology mix including the following AFVs (AFs): ICEs (synthetic fuels), NGVs (RPM), EVs (RE), and FCEVs (RPH). It still remains open for debate which technologies will dominate the future market. However, this thesis served to demonstrate that the development of sustainable powertrain technologies cannot simply be projected by means of quantifiable data such as technological or economic indicators. To understand how the market works, it is simply not enough to analyze only a small dimension of the whole system. Previous AFV research is often restricted to single data such as for example the number of patents, the capacity or price of battery technology, the intensity of CO2 regulation, or the market share of certain AFVs. Therefore, it represents the market development in a one-sided way. In contrast, this research demonstrated that technological progress is influenced by a large number of stakeholders that are constantly interacting and influencing technological developments. Furthermore, previous research often focused on few technological alternatives and neglected the whole span of alternatives, including AFVs and AFs. As the findings of this thesis suggest, in order to understand the further development of several AFV technologies, one must first understand the interests and decisions of individual stakeholders, and how these influence each other. Thereby several technological alternatives as they exist today must be considered.

Overall, this thesis shed light to the complex multi-stakeholder network that is shaping the development of different powertrain technologies. It thereby represents the first academic research paper that applied the concept of stakeholder theory to the development of AFVs in the European automotive industry. The findings contribute to existing findings in a novel way: This thesis is the first to demonstrate how the interests of key stakeholders influence the technological development of AFVs without restricting the research scope towards only a few technological alternatives. The findings offer decision makers from politics and industry a valuable tool to better understand the automotive market. Furthermore, it provides a new approach to discover positive and negative market forces and to find out how these influence the development of alternative technologies. Last, a further key finding is that relationship research should be considered as a viable technique to complement existing quantitative research in the field of AFV development.

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Abstract

The automotive industry is under pressure to shift towards more sustainable and CO2 neutral mobility solutions and the question arises which powertrain technologies will dominate the automotive market in the long-term. In contrast to existing research findings, this thesis examines the influence and interdependence of different stakeholder groups with respect to the development of AFV technologies. It is furthermore the first academic paper that applies stakeholder theory to AFV research without limiting the scope to only few and selected powertrain technologies. The outcome is a stakeholder matrix that highlights the interests, barriers, opportunities, and the current position of nine key stakeholders. The findings suggest, that conventional fuels and food-based biofuels come to an end in the mid- to long-term. Vehicles based on battery and fuel cell technology are seen as promising long-term solutions that might co-exist in future. However, further alternatives exist, that currently gain only limited attention within the industry but they could have a revolutionizing effect, once existing barriers are overcome. Among these alternatives are synthetic fuels and gases as produced from renewable sources of energy. Therefore, the findings suggest that ICEs and NGVs still represent a serious competition to BEVs or FCEVs. Overall, by analyzing the case of AFV technologies in the European automotive industry from a multi stakeholder perspective, this research contributed to existing AFV research in a novel yet valuable way: This analysis highlighted the interests of several key stakeholders and considered a wide span of technological alternatives. Thereby this thesis presents a new approach to projecting technological progress. It can be considered as a valuable tool for decision makers from politics and industry because it helps them to better understand the complex system that drives technological developments in a holistic and comprehensive way.

Abstrakt

Die Automobilindustrie gerät zunehmend unter Druck emissionsreduzierende Mobilitätskonzepte zu entwickeln. Es bleibt jedoch offen, welche Antriebstechnologien langfristig dominieren. Anders als bisherige Forschungsarbeiten, blickt diese Arbeit aus einer Stakeholderperspektive auf die Entwicklung von alternativen Antriebstechnologien. Ziel der Arbeit ist es, die Beziehungen und Interdependenzen einzelner Interessensparteien zu beleuchten und somit Aufschluss über die Entwicklung der Antriebstechnologie zu erhalten. Damit ist diese Arbeit die erste wissenschaftliche Arbeit, welche dieses Thema aus der Stakeholderperspektive beleuchtet, ohne sich dabei auf wenige ausgewählte Technologien zu begrenzen. Das Ergebnis ist in einer Matrix dargestellt, welche die Interessen, Barrieren, Möglichkeiten, sowie die aktuelle Position von neun zentralen Interessensparteien aufzeigt. Das Ergebnis zeigt, dass sich konventionelle Kraftstoffe, sowie auf Lebensmittel basierende Bio-Kraftstoffe, langfristig nicht durchsetzen werden. Stattdessen sind Batterie- und Wasserstoffbetriebene Fahrzeuge vielversprechende Technologien, deren Co-Existenz nicht ausgeschlossen werden kann. Allerdings bestehen noch weitere, aktuell unterschätze, Alternativen. Zu diesen zählen synthetische Kraftstoffe und Gase, welche aus erneuerbaren Energieträgern gewonnen werden. Daraus folgt, dass der konventionelle Verbrennungsmotor sowie gasbetriebene Fahrzeuge nach wie vor eine ernstzunehmende Konkurrenz für Batterie oder Wasserstoffbetriebenen Fahrzeugen darstellen. Diese Arbeit spricht für die Verwendung der stakeholderbasierten Methode zur Untersuchung von technologischem Fortschritt und Marktdiffusion. Die Methode erweist sich als besonders wertvoll, denn sie hilft Entscheidungsträgern aus Industrie und Politik komplexe Systeme, welche den technologischen Fortschritt beeinflussen, ganzheitlichen und umfassenden darzustellen und besser zu verstehen.