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Evaluation of Alternative Powertrains for German Automotive Suppliers

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Abstract

The present thesis deals with alternative powertrains, focusing on electric vehicles and hybrid vehicles and which of those alternative powertrains is considered as sustainable for the future. It explores the question, which alternative powertrain is worthwhile investing in for German automotive suppliers. The aim is to clarify which of the two powertrains is already established on the market and what the future prospects of those powertrains are. The question here is evaluated based on the analysis of current literature as well as through the use of a SWOT analysis and the use of the scoring model.

As a result it is clear that there is a need for alternative powertrains and the entire automotive industry invests a lot in the development and research of alternative powertrains. According to the German Federal Government, one million electric vehicles should be on German roads by 2020. With pure electric vehicles, however, the goal will be difficult to reach. Therefore, there is a lot of vested interest in the development of hybrid vehicles on the market. It shows that the hybrid vehicle has considerable advantages over the electric vehicle and the hybrid vehicle is already seen as a transitional solution for pure electric vehicles. The hybrid vehicle is also already established in the market and has better chances on the market in the future. Therefore, it makes sense for German automotive suppliers to invest in hybrid vehicles and to focus on this market, since there the chances of success are greater and the future potential of this market is higher.

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CO_2	Carbon dioxide
EJ	Exajoule
EV	Electric vehicle
BEV	Battery electric vehicle
ICE	Internal combustion engine
FCEV	Fuel cell electric vehicle
HEV	Hybrid electric vehicle
PHV	Plug-in hybrid vehicle
SWOT	Strengths, weaknesses, opportunities, threats
ppm	Parts per million
EVSE	Electric vehicle supply equipment

1 Introduction

The demand for raw materials and the resulting increase in raw material prices, as well as increased environmental awareness, have shaped the development of the world economy significantly in recent years, with oil prices, the limited availability of resources and climate change having a particularly large impact. Therefore, automotive manufacturers and automotive suppliers are carrying out research and development in sustainable mobility which is renewable, as CO2-neutral as possible and not in conflict with the limited resources availability. This will also offer new opportunities for companies that have not previously worked in the automotive industry. Above all, suppliers now have the opportunity to invest in new developments and alternative powertrains. In this project, the two alternative powertrains, electric vehicle and hybrid vehicle, will be compared and their advantages and disadvantages will be pointed out. The aim is to clarify which of these two alternative powertrains has the best opportunities in the market and is also sustainable in the future and which alternative powertrain is worth investing in for German automotive suppliers.

As a starting point the various drivers for change with regard to alternative powertrains are discussed in Chapter 2. Thereby, climate change and global warming, limited resource availability and rising oil prices, customer requirements, urbanization and legislation are part of Chapter 2. Chapter 3 describes the technical basics of electric vehicles and hybrid vehicles. There, a distinction is made between battery electric vehicles and fuel cell electric vehicles and between hybrid electric vehicles and plug-in hybrid electric vehicles. Also, the advantages and disadvantages of the two powertrains are shown briefly. As the thesis should answer the question of which alternative powertrain German automotive suppliers should invest in, the major German automotive suppliers and the competition from abroad will be presented in Chapter 4. There, a distinction is made between those suppliers which deliver directly to the automobile manufacturers and those which deliver to subcontractors. The market of direct suppliers will change in the future due to the development of alternative powertrains. In order to make an initial distinction between electric vehicles and hybrid vehicles, a SWOT analysis is applied in Chapter 5 to identify the strengths weaknesses, opportunities and threats of the two powertrains. In this chapter a theoretical background to the SWOT analysis is given at first, then the factors considered in the SWOT analysis are explained and subsequently applied to electric vehicles and hybrid vehicles. The chapter concludes with an evaluation of the SWOT analysis. If a choice must be made between several very similar alternatives, the scoring model is a tool for determining the preferred alternative. For this reason, in Chapter 6 the scoring model is applied to determine which alternative powertrain is worth investing in. Thereby the two alternative powertrains are evaluated. In Chapter 7 the future potential of the alternative powertrains are investigated and the different changes in the automotive industry, in particular changes in the value chain, are analyzed. In addition, fields of action for policy, research, the economy and the customers are identified and recommendations are made. In Chapter 8 a brief summary of the results of the work is given and there is an explanation of which alternative powertrain automotive suppliers should invest in and why.

2 The Automotive Industry in Change

After more than 100 years of developments in the internal combustion engine, there are signs of a technological revolution in transport due to the development of electric and hybrid mobility. The electrification of powertrains is a key factor for sustainable mobility. It offers a way to reduce dependency on oil, to minimize emissions and to integrate vehicles better into a multimodal transport system. In the foreseeable future the internal combustion engine (ICE) will still maintain its importance for traffic, and this requires continued efficiency improvement as well as the use of biogenic fuels. However, there are already considerations for making the progressive transition to new energy-efficient technologies.[1]

2.1 The Driving Forces of Change

The development of alternative powertrains is influenced by several factors. One influencing factor constitutes the legislature which directly affects efforts in the research and development of automotive manufacturers and automotive suppliers by the specification of regulations. Another key factor is the customer, who constantly creates new demands on the automotive industry due to his multifaceted needs. Both the limited availability of resources and global pollution are also important factors that determine the development of alternative powertrains.[2] Furthermore, urbanization represents a significant factor for change. Thus, the issue “mobility in large cities” will be of growing importance in the future.

2.1.1 Climate Change and Global Warming

Climate change and the resulting global warming are becoming more topical. The decade 2000 – 2009 was the warmest decade ever recorded and efforts to counteract global warming since then have been bigger than ever. A further increase in the average temperature would have far-reaching consequences, such as accelerat-

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1 Bundesministerium für Bildung und Forschung, *Nationaler Entwicklungsplan Elektromobilität der Bundesregierung*, (2009), retrieved April 22, 2013 from: http://www.bmbf.de/pubRD/nationaler_entwicklungsplan_elektromobilitaet.pdf. (translation J.Winter)

2 Wallentowitz, H. / Freialdenhoven, A., *Strategien zur Elektrifizierung des Antriebsstranges*, (2011), p.3. (translation J.Winter)

ed glacier melting, rising sea levels, changes in precipitation and increasing occurrence of extreme weather. One reason why the average temperature is continuously rising is the intensification of the natural greenhouse effect by humans. In particular the burning of fossil fuels produces the environmentally harmful gas CO2, which further exacerbates the greenhouse effect and thus global warming. In order to slow climate change down and perhaps even stop it, it is especially important to reduce CO2 emissions significantly. However this would require solutions like switching from fossil fuels to renewable energy sources and the increasing efficiency of all energy consumers.[3] The target of the German Federal Government is therefore to have one million electric vehicles on the road by 2020 and six million electric vehicles by 2030 in order to reduce CO2 emissions.[4]

2.1.2 Limited Resource Availability and Rising Fuel Prices

In addition to climate changes, the limited availability of resources has a major effect on the world. This is one of the main causes of the increasing search for alternative powertrain technologies. Fossil fuels, such as those used for conventional combustion engines, are not available in unlimited quantities, yet the daily requirement increases. One reason for the decreasing resources is the growing industrialization of emerging countries, but population growth, rising living standards and careless handling of raw materials also contribute to this development. In the near future – the exact date is controversial – the global peak oil will be reached. From this point on, supply and demand diverge and it will no longer be possible to satisfy all requirements. As a result, prices are already rising in almost all raw material sectors. Thus, in the long term there is no way we can avoid having first to drastically reduce and then to fully eliminate the dependence of social mobility on the limited resource "crude oil".[5]

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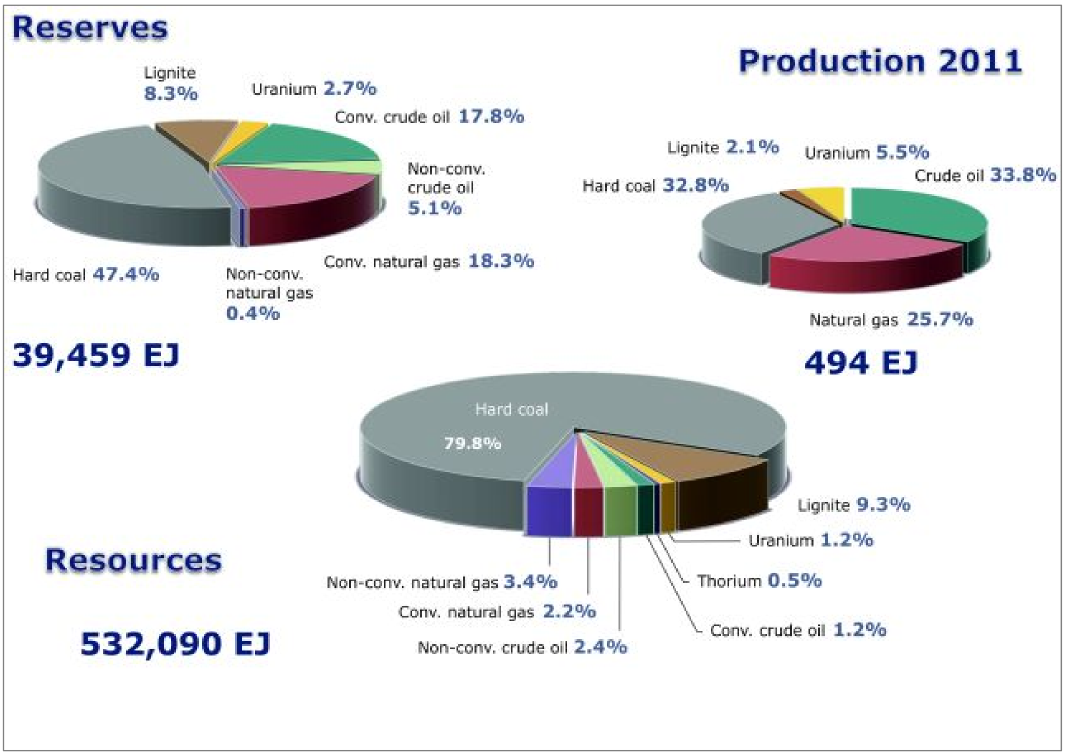
3 BMW Group PressClub Deutschland, *Pressemappe Innovationstage Mobilität der Zukunft*, (2010), retrieved April 22, 2013 from: https://www.press.bmwgroup.com. (translation J.Winter)

4 Bundesministerium für Bildung und Forschung, *Nationaler Entwicklungsplan Elektromobilität der Bundesregierung*, (2009), retrieved April 22, 2013 from: http://www.bmbf.de/pubRD/nationaler_entwicklungsplan_elektromobilitaet.pdf.

5 Wallentowitz, H. / Freialdenhoven, A., *Strategien zur Elektrifizierung des Antriebsstranges*, (2011), p.26 ff. (translation J.Winter)

Figure 1: Reserves, Resources and Availability of Energy Resources 2012



Source: http://www.bgr.bund.de/EN/Themen/Energie/Produkte

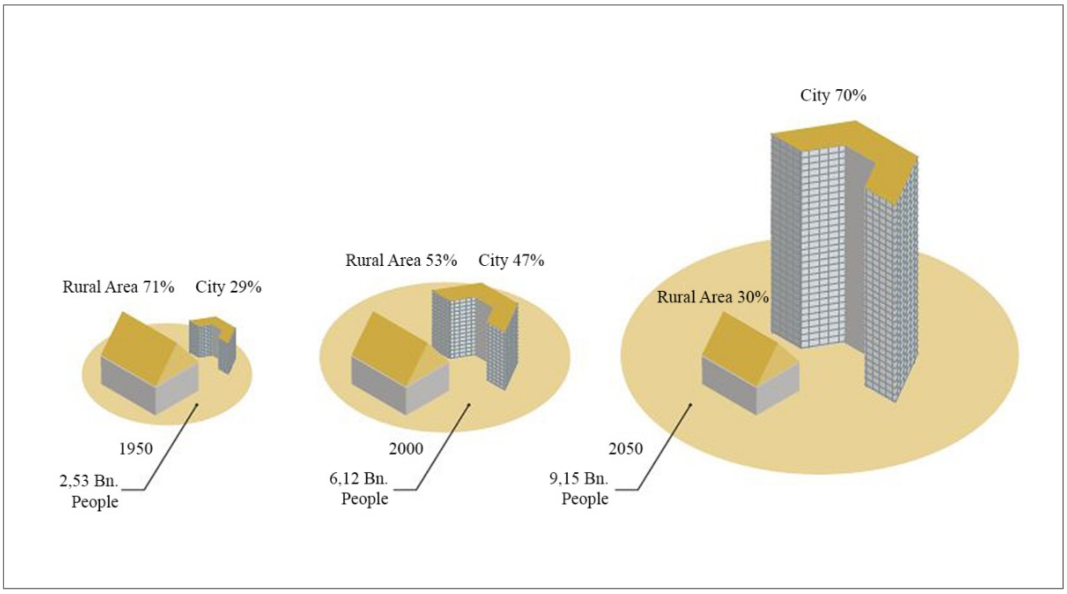
2.1.3 Customer Requirements

In the last few years, customer requirements have changed significantly due to the increasing public discussion of climate development, the shortage of resources, and the rising fuel prices, as well as the influence of government. Many people are already aware and want to act, especially with regard to future generations, consciously and responsibly and they also want to live a sustainable lifestyle. Therefore, more fuel-efficient vehicles are in demand, which in the coming years will lead to alternative powertrains, such as the electric motor, playing an increasingly important role. Based on this trend, both automotive manufacturers and automotive suppliers will have to provide products that meet the new requirements of the market. Only in this way they can adapt to the long term changes in the automobile industry and the resulting changes in the market requirements.

2.1.4 Urbanization

Another trend is the changing society and increasing urbanization. Currently, over 7.1 billion people live on Earth, but the population in rural areas is constantly decreasing while the population density in metropolitan areas is increasing. In 2007, more than half of the world's population lived in cities. According to UN forecasts, the global proportion of urban population will rise to 60 percent by 2030 and will reach 70 percent in 2050. Worldwide, there are already over 130 cities with more than three million people.[6]

Figure 2: Urban Growth 1950 - 2050



Source: http://www.elektromobilität-vda.de

2.1.5 Legislation

The increased regulatory requirements are a relevant driver of the development of alternative powertrains. In essence, the aim of legislative requirements is to improve the environmental compatibility of automobiles. Here in Germany, the government uses a lot of different instruments to try to counter rising CO2 emissions, such as the introduction of certifications for zero emission vehicles, access restrictions and ambitious fleet legislation.

[6] VDA - Verband der Automobilindustrie , *Elektromobilität - Eine Alternative zum Öl*, (2011), retrieved April 22, 2013 from: http://www.elektromobilitaet-vda.de. (translation J.Winter)

3 Alternative Powertrains – New Forms of Mobility

Due to the current climate debate, a steady tightening of emission regulations and the ever-rising cost of crude oil and thus gasoline and diesel, interest in alternative powertrain concepts, which manage with reduced fuel consumption or even without fossil fuels, is growing. The most popular and developed powertrains are battery electric vehicles (BEVs), fuel cell electric vehicles (FCEVs), hybrid electric vehicles (HEVs) and plug-in hybrid vehicles (PHVs); the various technologies are described in the following.

3.1 Electric Vehicles

Nowadays the term electric vehicle (EV) represents several concepts that have the common feature that the driving force is generated by electric motors in the vehicle. As early as 1900, the car manufacturer Ferdinand Porsche developed an electric vehicle and presented it at the World Exhibition in Paris.[7] Subsequently, research was carried out several times but the EVs were gradually displaced by the internal combustion engine (ICE). Only the BEV and the FCEV can be considered as promising for the future. Therefore those two types of EVs are explained in detail below.

3.1.1 Battery Electric Vehicles

BEVs are propelled by an electric motor powered by rechargeable battery packs. The energy is stored in a battery for vehicle propulsion. BEVs are more energy efficient than ICEs. They convert about 59 – 62 % of the electrical energy from the grid to power the wheels in comparison to vehicles with ICEs, which only convert 17-21 % of the energy. Due to progress in battery technology, the ongoing debate on climate change and rising fuel prices, the BEV is currently seen as the solution to all the problems of the future. Therefore, according to the Development Plan of Electromobility of the Federal Government of Germany, one million

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[7] Elektro-Autos, *Elektrofahrzeuge – schon 1900 gebaut aber heute erst konkurrenzfähig*, , retrieved April 28, 2013 from: http://www.elektro-autos.info/elektrofahrzeug.html. (translation J.Winter)

EVs should be in use on German roads by 2020.[8] However, sales for EVs are slow and the number of registrations for EVs is very low. At the beginning of 2012 there were only 4,500 registered BEVs of a total of 43 million registered vehicles in Germany[9], despite the fact, according to the Federal Government, that Germany is the leading market for BEVs. Due to the reported advances in battery technology resulting from a shift to lithium-ion, and the ongoing debate on climate change and rising fuel prices, the BEV is being viewed as a solution to future problems.

3.1.2 Fuel Cell Electric Vehicles

Many car manufacturers and suppliers see FCEVs as an alternative to BEVs. Fuel cell electric vehicles are another type of zero-emission vehicle producing no CO2 or other emissions. They have an electric powertrain and the required electrical energy is generated from hydrogen or methanol, which is directly converted as motion in electric motors or is temporarily buffered in a traction battery.[10] Simply, fuel cells generate electricity from the chemical reaction of hydrogen and oxygen. Since the early 1990s, the major automotive corporations such as Daimler, Opel, Ford and Toyota have been working on the development of FCEVs, but the fuel cell powertrain and the fuel cell itself are still in an experimental phase. FCEVs have the advantage that they have a large driving range of around 500 km and the raw material water is available without restriction. Furthermore FCEVs have a good driving performance by using an electric motor as the powertrain and a locally emission-free operation is possible. However, FCEVs also have disadvantages. The fuel cell is very expensive and has only a short service life. There is no infrastructure for the hydrogen supply and fueling and storage of hydrogen is very expensive.[11]

8 Bundesministerium für Bildung und Forschung, *Nationaler Entwicklungsplan Elektromobilität der Bundesregierung*, (2009), retrieved April 22, 2013 from: http://www.bmbf.de/pubRD/nationaler_entwicklungsplan_elektromobilitaet.pdf. (translation J.Winter)

9 Spiegel, *Gipfel im Kanzleramt: Merkel streitet mit Konzernen über Ziele bei Elektroautos*, (2012), retrieved April 28, 2013 from: http://www.spiegel.de/wirtschaft/soziales/elektroautos-regierung-haelt-an-millionen-ziel-bis-2020-fest-a-858936.html. (translation J.Winter)

10 Planet Wissen, *Brennstoffzelle*, (2009), retrieved April 28, 2013 from: http://www.planet-wissen.de/natur_technik/energie/brennstoffzelle/. (translation J.Winter)

11 Wallentowitz, H. / Freialdenhoven, A., *Strategien zur Elektrifizierung des Antriebsstranges*, (2011), p. 79. (translation J.Winter)

3.2 Hybrid Vehicles

The alternative to EVs is hybrid vehicles (HVs). A HV is a vehicle that uses two or more distinct power sources to move the vehicle. The history of hybrid cars stretches back over 100 years. Hybrid cars are defined as any car that runs on two sources of power. The most common hybrid powertrain combines a gasoline engine with an electric motor. These cars are known as HEVs. The other common hybrid powertrain is the PHV. While it may seem that hybrids are a recent phenomenon, the technology has been around since the creation of the automobile. In fact, car manufacturers have been developing and building hybrids since the beginning of the automobile industry.[12]

3.2.1 Hybrid Electric Vehicles

Hybrid electric vehicles (HEVs) combine the internal combustion engine of a conventional vehicle with the battery and the electric motor of an EV. Therefore, HEVs have several advantages over conventional vehicles. As HEVs use regenerative braking, which minimizes energy loss, they have greater operating efficiency. Furthermore, hybrids consume significantly less fuel than vehicles powered by gasoline alone. HEVs also reduce energy dependence, because they can run on alternative fuels. However, HEVs also have some disadvantages. They have much slower acceleration times and the price compared to vehicles with ICEs is higher. They also require more maintenance.[13] HEVs can be either mild or full hybrids. Mild hybrids, also often called micro hybrids, use a battery and an electric motor to help power the vehicle and can allow the engine to shut off when the vehicle stops, thereby improving fuel economy. However, mild hybrid systems cannot power the vehicle with electricity alone. Full hybrids have a more powerful electric motor and larger batteries which can drive the vehicle on just electric power for short distances and at low speeds. These systems cost more than mild hybrids, but provide better fuel economy benefits.[14]

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[12] Wallentowitz, H. / Freialdenhoven, A., *Strategien zur Elektrifizierung des Antriebsstranges*, (2011), p.58 ff. (translation J.Winter)

[13] U.S. Department of Energy, *Hybrid Electric Vehicles*, (2013), retrieved April 22, 2013 from: http://www1.eere.energy.gov/vehiclesandfuels/technologies/systems/hybrid_electric_vehicles.html.

[14] Wallentowitz, H. / Freialdenhoven, A., *Strategien zur Elektrifizierung des Antriebsstranges*, (2011), p. 58 ff. (translation J.Winter)

3.2.2 Plug-In Hybrid Vehicles

A PHV is a hybrid vehicle which utilizes rechargeable batteries, or another energy storage device, that can be restored to full charge by connecting a plug to an external electric power source. A PHEV shares the characteristics of a conventional hybrid electric vehicle, having an electric motor and an ICE and having a plug to connect to the electrical grid. Therefore the hybrid battery is divided into two sections: one section that can be recharged from a plug socket at home and then many kilometers of pure electric driving is possible; the other section offers the usual range of a HEV. With a PHV it is possible to drive greater distances without the use of the ICE.[15] The concept of the PHV allows a gradual transition from the conventional internal combustion engine to the electric powertrain. The PHV combines the advantages of hybrid vehicles in terms of energy consumption and driving range with the advantages of electric vehicles by the opportunity to operate the vehicle in pure electric mode or to fuel it directly at the power grid. On the negative side of the PHV are the expenses for the double infrastructure in the vehicle and for fueling, the increased weight of the vehicle and the higher price for the vehicle.

15 Die Hybrid-Piloten, *Mild-, Voll-und Plug-in Hybrid*, (2013), retrieved June 25, 2013 from: http://hybrid-piloten.de/mild-voll-und-plug-in-hybrid/. (translation J.Winter)

4 Automotive Suppliers

As this thesis should answer the question, which alternative powertrain German automotive suppliers should invest in, the major German automotive suppliers and the competition from abroad will be presented in the following. Here, a distinction is made between those suppliers which deliver directly to the automobile manufacturers and those which supply the subcontractors. The market of direct suppliers will change in the future due to the development of alternative powertrains. Companies which were so far no suppliers in the automotive industry could be a potential supplier in the future, while automotive suppliers that are established on the market could maybe completely disappear or have to change their product range completely. A supplier which supplies for example oil pumps at the moment can possibly sell them in the future in only small numbers due to the development of alternative powertrains. This, therefore, leads to lower prices for the remaining quantity and thus to ruinous competition. On the other hand, suppliers such as battery manufacturers can become more important through the development of alternative powertrains.

Figure 3: Ranking of Automotive Suppliers 2012

Ranking	Company	Turnover 2011/12 in Mio. US-Dollar	Ranking 2011
1	→Bosch	42 356	1
2	→Continental	40 478	3
3	Denso	38 886	2
4	Bridgestone	31 866	4
5	Aisin Seiki	28 905	5
6	Magna	28 748	6
7	Michelin	28 287	7
8	→Johnson Controls	25 940	8
9	Goodyear	22 767	9
10	Faurecia	22 554	10
11	→ZF Group	19 229	11
12	→Thyssen Krupp	16 414	14
13	TRW Automotive	16 244	12
14	Delphi	16 041	13
15	Valeo	15 140	15

Source: http://www.staufenbiel.de/ingenieure/schwerpunkt-automotive/dossier-zulieferer/top-automobil-zulieferer.html

Figure 3 shows a ranking of the largest automotive suppliers in 2012. As the market contains a large number of automotive suppliers, only those suppliers expected to have a great importance in the future in connection with the development of alternative powertrains are presented in the following; some may not be in the ranking yet.

4.1 Direct Automotive Suppliers

4.1.1 Robert Bosch GmbH

Robert Bosch GmbH was founded in 1886 by Robert Bosch. Robert Bosch GmbH is a supplier to the automotive industry, manufacturer of consumer goods such as electric tools and appliances, and manufacturer of industrial and building technology, as well as packaging technology. Robert Bosch GmbH is a multinational company and the leading global automotive supplier.[16] In 2004, the Bosch Group was for the first time the automotive supplier with the highest turnover. In 2005, Bosch generated 26 billion euros in sales with its largest business sector "Automotive Engineering", which amounted to 61.9 % of total sales.[17] Since Bosch also has a very high level of competence, the company actually has good opportunities to enter into the market for alternative powertrains. However, the corporate culture of Robert Bosch GmbH is more authoritarian, conservative and security conscious, which in the light of the current rapid development of alternative powertrains can be an obstacle. In addition, Bosch is still specialized on vehicles with ICEs. Thus, for example, Bosch supplies most of the engine electronics and the injection systems for vehicles with ICEs and this part of the company is significantly bigger than the part for EVs or HVs.

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16 Bosch, *Unternehmensgeschichte*, , retrieved July 11, 2013 from: http://www.bosch.de/de/de/our_company_1/history_1/history.html. (translation J.Winter)

17 Bosch, *Bosch in Zahlen*, , retrieved July 11, 2013 from: http://www.bosch.de/de/de/our_company_1/facts_and_figures_1/facts-and-figures.php. (translation J.Winter)

4.1.2 Continental AG

Continental AG is a publicly listed company in the automotive industry, which was founded in 1871 as a stock company. In Germany, Continental is the market leader in tire production; however, the Group has developed in recent years from a pure tire manufacturer to one of the largest automotive suppliers in the world and the second largest in Europe. In 1995, the company Continental Automotive Systems (CAS) was established as a producer of electronically controlled running gear systems and vehicle safety systems. In this sector, the company is a global supplier in the fields of driving safety, powertrains and comfort.[18] Thus, Continental also has a good chance to dominate the market for alternative powertrains. Thanks to its expertise in the fields of electric motors and electronics and its flexible, open and rapid corporate culture, Continental could catch Robert Bosch GmbH. Continental is also very active in the design of mobility services and that is exactly what is needed in the future.[19]

4.1.3 Siemens AG

Siemens AG is an integrated technology company which was founded in 1847. The group focuses on the four main areas of energy, medical technology, industry, and infrastructure and cities. In addition, Siemens is one of the world's largest companies in electrical engineering and electronics. In 2007, Siemens sold the subsidiary VDO and therefore dropped out of the automotive industry. Consequently, Siemens lost not only the technical expertise, but also the automotive expertise and the contacts to OEMs.[20] Despite this complete absence from the classic car business with ICEs, the rise of alternative powertrains means Siemens would now like to establish itself again on the market, relying on many years of experience in the areas energy, mobility and IT. Thus, Siemens already offers products and solutions for the future of alternative powertrains, including electric motors, voltage converters and further components, as well as power stations and a comprehensive software portfolio. With efficient automation solutions, Siemens

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[18] Continental AG, *Geschichte*, , retrieved July 11, 2013 from: http://www.continental-corporation.com/www/portal_com_de/themen/continental/geschichte/. (translation J.Winter)

[19] Continental AG, *Continental-Konzern*, , retrieved July 11, 2013 from: http://www.continental-corporation.com/www/portal_com_de/themen/continental/zahlen/fakten_de.html. (translation J.Winter)

[20] Siemens, *Geschichte*, , retrieved July 11, 2013 from: http://www.siemens.de/ueberuns/geschichte/Seiten/home.aspx. (translation J.Winter)

continues to support the large-scale production of high-performance batteries. The solution portfolio covers the entire value chain and includes the simulation of a complete battery cell production system. The aim of this integrated automation is to reduce the manufacturing costs of the key component lithium-ion battery and thus to reduce the price for EVs and HVs significantly. For this reason, Siemens has a very good chance of establishing itself in the market in the area of mobility.[21]

4.1.4 Denso and other Japanese Suppliers

Denso Corporation is a global automotive supplier listed on the Tokyo stock exchange. Denso was founded in 1949 and specializes in automotive electronics and automotive mechatronics.[22] Denso, and also other Japanese suppliers are much more dependent on the local OEMs and German companies. Due to the strong financial and organizational linkages, Japanese suppliers mostly act as in-house suppliers. Therefore, it can be assumed that only a few new companies can establish themselves on the market as a supplier.[23]

4.1.5 Samsung and Sanyo

The Samsung Group is the largest South Korean conglomerate and was founded in 1938. It is the dominant company in the manufacturing of lithium-ion batteries, which is fundamental for the development of EVs and HVs.[24] Similarly, Sanyo is also a dominant company in the production of lithium-ion batteries. Sanyo is a Japanese company that was established in 1947 and today is a wholly owned subsidiary of Panasonic.[25] Since these two companies are the dominant companies in the field of lithium-ion batteries, Samsung and Sanyo will certainly establish themselves in the market for automobile fuel cell manufacturing.

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21 Siemens, *Unser Portfolio*, , retrieved July 11, 2013 from: http://www.siemens.de/ueberuns/portfolio/Seiten/home.aspx. (translation J.Winter)

22 Denso, *Our History*, , retrieved July 11, 2013 from: http://denso-europe.com/about-denso/our-history/.

23 Hundertmark, H., *Beziehungsmanagement in der Automobilindustrie*, (2013), p. 17 ff. (translation J.Winter)

24 Samsung, *Geschichte*, , retrieved July 11, 2013 from: http://de.samsung.com/de/about/history.aspx.

25 Panasonic, *History*, , retrieved July 11, 2013 from: http://panasonic.net/sanyo/corporate/profile/history/history01.html.

4.1.6 Semiconductor Companies

In the future, a larger part of the value chain will be the manufacturing of power electronics. This is required, for example, to control the electric motor. This is where companies such as Infineon and Delphi can position themselves. However, the aforementioned electronics companies such as Bosch, Continental and Siemens can also manufacture these power electronics and will certainly expand their portfolios in the future to do so. Since the investment in semiconductor factories is very high, only financially strong and established companies can afford to invest. In this context, the unique step taken by Toyota should be mentioned: It has established its own manufacturing division for power electronics, requiring an investment of approximately one billion euros.

4.1.7 Material Manufacturers

EVs and HVs must be kept very light, so that they become cheaper to run as lighter vehicles require less energy. As a result, light materials, particularly aluminum, are gaining in importance. Currently, the material carbon is much in discussion. However, this material is still very expensive and is therefore used only in premium products. Other applications are also found in trucks or rail cars. Raw material recyclers are gaining more and more importance due to rising raw material costs.[26]

4.2 Subcontractors

German subcontractors are mostly medium-sized companies. These are very highly dependent on where the technology of the customers develops. In most cases, these companies are still run by the owner and therefore very flexible. They tend to have their core competencies in production, can quickly develop new products that are compatible with this manufacturing technology, and can offer good prices. However, this is also a problem. If the existing manufacturing facilities are no longer compatible with the new products, many of these suppliers will not be able

[26] Neues Energiezeitalter, *Elektromobilität: Neues Werkstoffkonzept für das Batteriegehäuse spart Gewicht und gibt Sicherheit*, , retrieved July 11, 2013 from: http://neues-energiezeitalter.de/2013/elektromobilitaet-neues-werkstoffkonzept-fuer-das-batteriegehaeuse-spart-gewicht-und-gibt-sicherheit/. (translation J.Winter)

to continue to offer this technology. Often, the subcontractors are finding themselves in a sort of limbo as they cannot even invest in the necessary new technologies and therefore may miss the transition into the market of alternative powertrains. However, EVs have many mechanical and electrical components, on which German suppliers are specialized in production. Thus, they can utilize the advantage of Germany as a location of industry and their knowledge of the automotive process. Many OEMs and direct suppliers prefer to award contracts to known Germany companies.

5 SWOT Analysis of Alternative Powertrains

Germany's strengths in alternative powertrains lie in the powerful and highly successful automotive industry and an ambitious environmental policy. However, the question arises, especially for the automotive suppliers, whether the market is already prepared for alternative powertrains. Another important aspect is the current market situation of alternative powertrains and how the market situation will develop in the future. For this reason it is important to examine which of the above explained powertrains will have the most success in the future. This chapter uses a SWOT analysis to examine the market situation and the potential success of alternative powertrains.

5.1 SWOT Analysis – Theoretical Background

SWOT is an acronym for strengths, weaknesses, opportunities and threats. In general, a SWOT analysis is a commonly used form of marketing analysis. It is a tool for auditing and analyzing the strategy of a business and its environment. It is the foundation for evaluating the internal potential and limitations and the external opportunities and threats, and in doing so it considers all the positive and negative factors that affect success.[27] A SWOT analysis is a suitable tool for the:

- Creation of a conceptual framework for identifying and analyzing strengths, weaknesses, opportunities and threats.
- Development of appropriate strategies.
- Determination of core skills and competencies.

However, these advantages are counterbalanced by some disadvantages that must be considered. A SWOT analysis describes rather than analyzes, and it also ignores priorities. Moreover, although this is not inherent to the SWOT analysis itself, it is often not considered in the subsequent planning process.[28]

Nevertheless, the SWOT analysis is the appropriate tool to analyze the market for alternative powertrains. Therefore, in this case, the SWOT analysis is used to ana-

27 Management Study Guide, *SWOT Analysis*, , retrieved June 05, 2013 from: http://www.managementstudyguide.com/swot-analysis.htm.

28 Handelsblatt, M. B., *Die besten Checklisten für Manager*, (2005), p.128 ff. (translation J.Winter)

lyze the strengths, weaknesses, threats and opportunities of EVs and HVs. It is divided into a product analysis that includes the strengths and weaknesses and an environmental analysis that includes the opportunities and risks. The SWOT analysis shall help to identify the advantages and disadvantages of alternative powertrains and to see which is most likely to carve a sustainable niche in this market.

5.2 The Four Elements of a SWOT Analysis

A SWOT analysis focuses on the four elements strengths, weaknesses, opportunities and threats, which make up the acronym. Strengths and weaknesses are internal factors and components of the product analysis of the SWOT analysis, in this case of EVs and HVs. Opportunities and threats are external factors and components of the environmental analysis of EVs and HVs. It is important to know and understand the four elements of a SWOT analysis, because this allows companies to identify forces influencing a strategy, action or initiative. It also important for deciding which aspects are considered for the SWOT analysis of EVs and HVs.

5.2.1 Internal Factors / Product Analysis

In a SWOT analysis, strengths and weaknesses are the internal factors. The internal analysis is a comprehensive evaluation of the internal potential of a company, product or action. Factors such as company culture, company image, operational efficiency, market share and so forth should be evaluated. In the SWOT analysis of EVs and HVs strengths and weaknesses are part of the product analysis. Per definition, a product analysis is the “review of existing products according to specific criteria on quality, design and competitiveness at a specific time.”[29] The aim of the product analysis is to examine the marketability of the product compared to the competition.

5.2.1.1 Strengths

In a SWOT analysis the first letter in the acronym stands for strengths. Strengths describe the core competencies of a company or a market. Strengths refer to inter-

[29] Gabler Wirtschaftslexikon, *Produktanalyse*, , retrieved June 06, 2013 from: http://wirtschaftslexikon.gabler.de/Definition/produktanalyse.html. (translation J.Winter)

nal factors, which mean that the resources and experience are readily available. In general, strengths in a SWOT analysis are the capabilities and resources that allow a company to engage in activities to generate economic value and perhaps competitive advantage. This may be a company's ability to create unique products or to provide high-level customer service. It may also be a company's culture, its employees or the quality of its managers.[30] Any abilities of a company can be regarded as strength. In the SWOT analysis of EVs and HVs, strengths are positive characteristics of the product which help it to be successful on the market.

5.2.1.2 Weaknesses

In a SWOT analysis the second letter in the acronym stands for weaknesses. Weaknesses are a source of competitive disadvantage and usually a lack of resources or capabilities that can make a certain project less likely to succeed. Weaknesses prevent a company from achieving certain goals or from gaining competitive advantage.[31] Weaknesses may be a low market share, poor quality, high costs, low productivity and so forth. In the SWOT analysis of EVs and HVs, weaknesses are negative characteristics of the product which prevent a successful market launch or survival on the market.

5.2.2 External Factors / Environmental Analysis

In a SWOT analysis, opportunities and threats are the external factors. The external analysis is a comprehensive evaluation of the external environment of a company. Every company or organization is influenced by external factors such as market trends, economic trends or demographics. In the SWOT analysis of EVs and HVs, opportunities and threats are part of the environmental analysis. Per definition, an environmental analysis is the "evaluation of the possible or probable effects of external forces and conditions on an organization's survival and growth

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30 Reference for Business, *SWOT Analysis*, , retrieved June 06, 2013 from: http://www.referenceforbusiness.com/management/Pr-Sa/SWOT-Analysis.html.

31 Business News Daily, *SWOT Analysis: Examples, Templates & Definition*, (2013), retrieved June 06, 2013 from: http://www.businessnewsdaily.com/4245-swot-analysis.html.

strategies."[32] The aim of the environmental analysis is to analyze the product in terms of external factors.

5.2.2.1 Opportunities

Opportunities are areas that may generate higher profits and provide a company with a chance to improve its performance and competitive advantage. Opportunities mostly arise when a company can take advantage of conditions in its environment. Opportunities also may arise when there are niches for new products or services.[33] In the SWOT analysis of EVs and HVs, opportunities are the chances for a product to enter into the market or to be successful on the market due to the positive external environmental circumstances.

5.2.2.2 Threats

Threats are the final element of a SWOT analysis; they have the potential to harm a business. Threats increase the difficulty of a business to perform at high level. Threats arise when conditions in external environment endanger the reliability and profitability of the business or the market. The emergence of threats is uncontrollable, but they can be predicted or preempted, allowing countermeasures to be taken. Possible threats are unfavorable changes to laws, higher taxes and changes in consumer preferences.[34] In the SWOT analysis of EVs and HVs, threats are the barriers for a product to enter into a market or to be successful on the market due to negative external environmental circumstances.

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[32] Business Dictionary, *Environmental Analysis,* , retrieved June 11, 2013 from: http://www.businessdictionary.com/definition/environmental-analysis.html.

[33] Griffin, R., *Management*, (2011), p.241 ff.

[34] Griffin, R., *Fundamentals of Management*, (2008), p.67 ff.

Figure 4: SWOT Analysis

Source: http://www.easy-marketing-strategies.com/swot-analysis.html

5.3 SWOT Analysis – The Aspects Considered

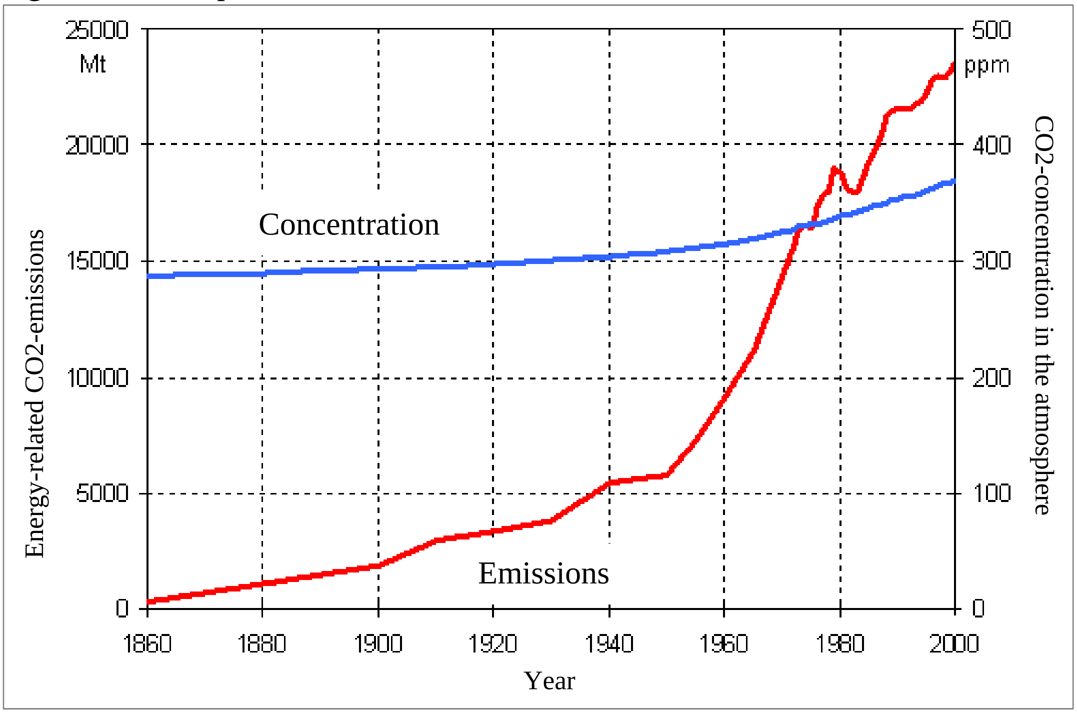
Before starting with the SWOT analysis for EVs and HVs, it is important to determine the aspects considered. Furthermore, it is necessary to know about the aspects and the situation in Germany. The aspects considered in the subsequent SWOT analysis for EVs and HVs are:

- Environment, global warming and pollution
- Limited resource availability
- Infrastructure and charging time
- Maintenance, comfort and driving range
- Acquisition cost and operating expenses
- Market situation and the role of the state

5.3.1 Environment, Global Warming and Pollution

As explained in the beginning, the aspect “Environment” is one of the main drivers of change. The exact causes of the global warming observed these days have been the subject of much discussion in politics, economy and society for several years and will continue to be so in the future. Some scientists hold the current weather changes for natural variations, as they existed on ice ages. Climate scientist, however, point to the rise in CO2 levels in the atmosphere, which then leads to the so-called greenhouse effect.[35] Per definition, the greenhouse effect is a "phenomenon whereby the earth's atmosphere traps solar radiation, caused by the presence in the atmosphere of gases such as carbon dioxide, water vapor, and methane that allow incoming sunlight to pass through but absorb heat radiated back from the earth's surface."[36] Figure 5 shows that the CO2 concentration has risen since industrialization around the year 1900. It can be concluded that the human being is involved in the development of the CO2 concentration. At the beginning of the industrial age the proportion of CO2 in the air was not even 100 ppm. This proportion increased exponentially over the years, so that in 2008 it was already 385 ppm. These values are a cause for concern. Thus, reducing CO2 also represents a measure to reduce the consumption of carbon-based fuels in the form of gas, oil or coal, which is explained in the following section.[37]

Figure 5: Development of CO2 Concentration in the Air



Source: http://www.volker-quaschning.de/artikel/klimaexperiment/index.php

[35] Wallentowitz, H. / Freialdenhoven, A., *Strategien zur Elektrifizierung des Antriebsstranges*, (2011), p. 3 ff. (translation J.Winter)

[36] The Free Dictionary, *Greenhouse Effect*, (2005), retrieved July 3, 2013 from: http://www.thefreedictionary.com/greenhouse+effect.

[37] Wallentowitz, H. / Freialdenhoven, A., *Strategien zur Elektrifizierung des Antriebsstranges*, (2011), p. 4 ff. (translation J.Winter)

5.3.2 Limited Resource Availability

Experts have been aware for some time now that due to the scarcity of fossil fuels new solutions must be found that allow the decoupling of mobility from oil. While the demand for fossil fuels is still growing significantly, more and more reserves are becoming exhausted. This applies particularly to oil. The maximum global oil production (peak oil) is likely to be reached soon. Some decades later, gas should also be globally scarce; the gas in many areas, such as the North Sea, are already on the decline. However, the question of how long oil will remain available can only be answered accurately if there are clear statements about the availability of oil reserves and its suitability for future oil demand, and if that actual future demand can be predicted with sufficient precision. [38]

5.3.3 Infrastructure and Charging Time

The infrastructure for alternative powertrains and the charging time for vehicles with alternative powertrains is one of the most important aspects whether HVs or EVs can be used in Germany or not. An extensive network of charging stations is the basic requirement for the use of alternative powertrains. It has to be the aim to develop a comprehensive and modular infrastructure that makes simple and safe recharging with electricity possible anywhere. Therefore, it is important to examine the infrastructure of charging stations for EVs and HVs in Germany. In this context, a further important factor is the charging time of EVs and HVs, which is accordingly also discussed in detail. First of all, the term "charging station", also known as charging point or electric vehicle supply equipment (EVSE), is defined briefly.

A charging station is a charging option for EVs and HVs which can be public or private. The simplest case is a socket at which the battery of an electrically driven vehicle can be charged via a cable connection.[39] Charging stations can be public, semi-public or non-public. Public charging stations and semi-public charging stations can be found in parking lots, in parking garages of malls or in companies. In

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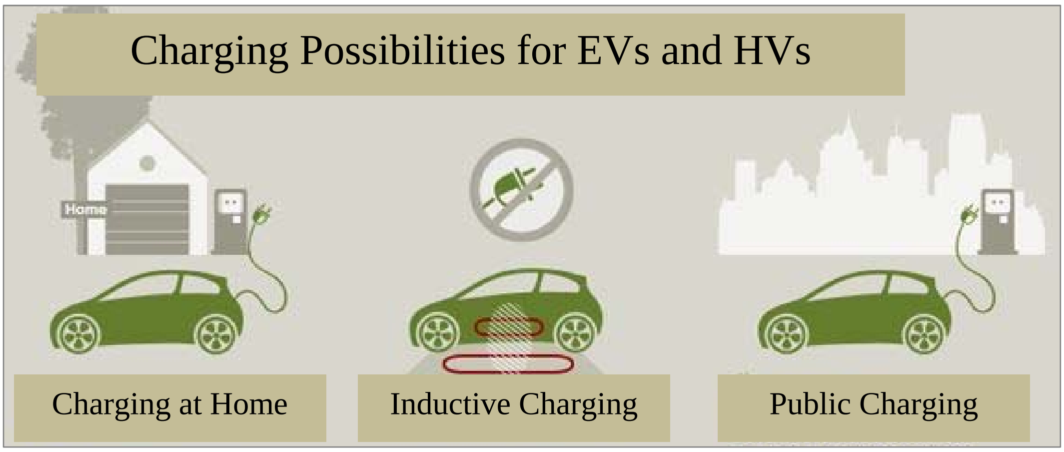
[38] Wallentowitz, H. / Freialdenhoven, A., *Strategien zur Elektrifizierung des Antriebsstranges*, (2011), p.26 ff. (translation J.Winter)

[39] Fremdwort.de, *Stromtankstelle*, (2013), retrieved July 08, 2013 from: http://www.fremdwort.de/suchen/bedeutung/Stromtankstelle. (translation J.Winter)

Germany, also a few fast-charging stations are available. The owner of an EV or HV can go shopping or visit a restaurant while charging his car battery at the same time. It is also possible to charge the EV or HV at home, which is non-public charging. Here, the owner of an EV or HV has the option of a convenient recharge of his car overnight. This represents over 90 % of all charging processes. Only a small proportion of EVs and HVs are charged at public charging stations, as the infrastructure is not yet developed enough. At the moment, the so-called inductive charging method is being developed; this enables the EV or HV to be charged without wires. Thereby a fully recessed coil in the bottom, the so-called primary coil, is the connection to the public power grid. If the operator starts the charging process, electricity flows through the primary coil. As a result, a magnetic field is generated, which excites electric power in the secondary coil mounted on the vehicle. This induced power charges the battery of the electric vehicle. The charging stations can be integrated almost invisibly into any environment. The contactless charging method is wear-free and vandal resistant. However, this technique is not yet fully-developed in Germany.[40]

Figure 6: Charging Possibilities for EVs and HVs



Source: http://www.siemens.de/elektromobilitaet/stromtankstellen.html

When someone considers the option of buying an EV or a HV, the question of where to charge the car with electricity arises. For this purpose, there are charging stations, which are usually associated with normal gas stations. However, in Germany it is not always easy to find a suitable point to charge the EV or the HV. There are already a few hundred charging stations in Germany, but most are to be

[40] Siemens, *Stromtankstellen für jeden Bedarf*, (2013), retrieved July 08, 2013 from: http://www.siemens.de/elektromobilitaet/stromtankstellen.html. (translation J.Winter)

found in large cities, with very few in rural areas. After a census in October 2012, there are 2,821 charging stations in Germany; in comparison, in Switzerland and Austria together there are 270,669 accessible charging stations. Overall, the number of charging stations is increasing.[41]

When talking about the infrastructure, it is important to mention energy suppliers, such as E.ON, RWE und Vattenfall, who see great potential in new mobilities and alternative powertrains such EVs and HVs. However, it should be noted that the electricity demand of EVs and HVs are only a few percent of the total demand and thus it is hardly profitable. Public charging stations are very expensive to build and to maintain and therefore this field is also barely profitable. In addition, the OEMs are now entering the market for power supply. VW have invested in combined heat and power generation and Audi in wind farms. In contrast to the energy suppliers such as E.ON, RWE and Vattenfall, the OEMs are currently financially very strong, innovative and accustomed to the competition for decades. Nevertheless, there are still new opportunities and requirements for the energy supplier. Many households, employers and public authorities are installing a charging station. This creates new jobs.[42]

As mentioned above, the charging time of EVs and HVs plays a major role. For HVs it is not of such great importance, since they are equipped with an ICE and therefore can always rely on the ICE. Especially for EVs, however, it is important to know the charging times and the various possibilities. The charging of batteries can be divided into four different categories: regular charging, semi-fast charging, fast charging, and changing the entire battery pack. Today, regular charging can basically be done at home from the existing grid. This is a time-consuming form of charging and it requires that the car is out of use for a number of hours in order to reach a full charge. Semi-fast charging is a good alternative if the owner of an EV spends a certain amount of time in one place, estimated between 1-3 hours, which is shorter than the time needed for regular charging. For fast charging, more developed charging equipment and battery technology is required to enable batteries to be charged in 30 minutes. Another alternative is to exchange the entire

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41 Stromtankstellen, *Stromtankstellen Deutschland*, , retrieved July 080, 2013 from: http://www.stromtankstellen.eu/stromtankstelle_deutschland.html. (translation J.Winter)

42 Lienkamp, M., *Elektromobilität - Hype oder Revolution*, (2012), p. 63 ff. (translation J.Winter)

battery pack for a new one when it is needed and this procedure will only take a few minutes. Currently, only the regular charging is possible in Germany.[43]

At the time of writing, it is still difficult to find a charging station for EVs and HVs, especially outside of urban areas. Thus, expansion of the network is profitable; indeed, expanding the network would serve to encourage consumers to buy an EV or a HV, as numbers are very low. Currently, users of about 5,960 EVs in Germany can access 2,821 charging stations.[44] In Germany, therefore great efforts still need to be made to ensure that by 2020 the German Federal Government's goal of one million EVs can be realized.

5.3.4 Maintenance, Comfort and Driving Range

Driving range is a subject which has been at the forefront of much discussion about EVs and HVs. Most cars with ICEs can be considered to have indefinite range, as they can be refueled very quickly. EVs have a much shorter driving, currently making them only suitable for city trips and other short hauls. Nevertheless, there are cars now which are able to offer journey capacity of up to 250 kilometers on a full charge, which is more than enough for the average daily travel which is estimated at around 100 kilometers. However, there are some issues when considering longer journeys which are causing some concern amongst the users of EVs. The HV has a longer driving range, as it is equipped with an ICE.[45]

Maintenance is also an important point to consider. The main problem is to find a mechanic or a repair shop capable of carrying out the necessary work. Most automobile mechanics are trained with ICEs. This means that the car has to be taken to the dealership for most servicing. Depending on how good the warranty is, this may or may not cost more than at local service stations. The most expensive and complicated part in EVs and HVs is the battery. The array of power cells that makes an electric car run is large, heavy and complex. The longer you own an electric car, the shorter its driving range will become. This will start happening

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43 CLP Online, *Charging System*, (2013), retrieved June 13, 2013 from: https://www.clponline.com.hk/EV/Pages/ChargingSystem_ChargingMethods.aspx.

44 Hagen-Bauer, *Der Traum geht weiter: 1 Million Elektroautos*, (2012), retrieved July 12, 2013 from: http://www.hagen-bauer.de/tag/elektroautos. (translation J.Winter)

45 Fueleconomy, *Electric Vehicles*, (2013), retrieved July 13, 2013 from: http://www.fueleconomy.gov/feg/evtech.shtml.

from day one. Most estimates predict that the typical lithium-ion electric car battery will be good for more than 160,934 kilometers of driving while still maintaining a decent driving range. If the battery has to be exchanged, this is expensive. A battery back for EVs or HVs costs about 11,000 euros.[46]

The comfort of HVs, and especially of EVs, is limited as the battery pack needs a lot of space and so there is not enough room for other additional features, as there is in vehicles with an ICE.

5.3.5 Acquisition Cost and Operating Expenses

This section looks at the acquisition cost of EVs and HVs and compares it with the acquisition cost of vehicles with ICEs.

Due to the currently high cost of batteries and different vehicle components, together with higher research and development cost and higher margins, the prices for EVs and HVs, especially in the market launch phase, are significantly higher than the prices for vehicles with ICEs. The average list price for EVs and HVs is around 26,400 euros; the average list price for a vehicle with ICE is around 10,800 euros. The difference of 15,600 euros is mainly caused by the most expensive vehicle components. Another cost driver is the sales tax, which will be added to the percentage of the higher production costs of HVs and EVs. Thus the acquisition cost for HVs and EVs is higher than the acquisition cost for vehicles with an ICE.[47]

In addition to the acquisition cost, operating expenses are also an important point. For this purpose a distinction is made between the cost of electricity compared to gasoline and the cost of insurance and taxes. For the power consumption of an electric vehicle, however, there are different estimates. The company Opel GmbH has specified current costs of 0.02 euros per kilometer for the Opel Ampera, compared with gasoline costs of 0.09 euros per kilometer. Basic data for the fuel costs are a fuel consumption of approximately 7.72 l for a 100-kilometer journey and gasoline prices of 1.16 euros per liter (European average). According to the cur-

46 U.S. Department of Energy, *Alternative Fuels Data Center,* (2013), retrieved July 13, 2013 from: http://www.afdc.energy.gov/vehicles/electric_maintenance.html.

47 Elektro-Autos.info, *Elektroauto Preise – Vom Stadtauto bis hin zum Sportwagen*, , retrieved July 10, 2013 from: http://www.elektro-autos.info/elektroauto_preise.html. (translation J.Winter)

rent battery capacity, the daily distance for EVs is 60 kilometers and the annual driving performance is 22,000 kilometers. Thus, there is a fuel save of 1,700 liters per year. According to this data, an electric car with the assumed annual mileage of 22,000 miles has a fuel cost saving of 1,980 euros per year.[48]

Insurance costs also constitute an operating expense, as do car tax rates. In Germany there are no tax rates for the first five years for EVs. The annual cost savings compared to vehicles with ICEs is about 120 euros a year. Insurance rates for EVs are comparable to the rates for vehicles with ICEs. For this reason, in the future it can be assumed that an EV has no significant economic advantage or disadvantage in the amount of the insurance premium compared to vehicles with ICEs.[49]

5.3.6 Market Situation and the Role of the State

Mobility faces major changes in the coming years. It is planned that HVs and EVs will replace vehicles with ICEs in the future. Each automotive manufacturer already has a strategy for EVs and HVs and the goal is the mass production of EVs and HVs as soon as possible, with HVs being seen as the first step for the mass production of EVs. However, the short driving range of EVs and the expensive battery technologies currently prevent cost-efficient mass production of EVs.

Under the National Development Plan for Electric Mobility, the German Federal Government provides 500 million euros exclusively for the development of EVs. The way to "leading the market in electric mobility" consists of three phases:

1. 2009 - 2011: Market Preparation
2. 2012 - 2016: Market Acceleration
3. 2017 - 2020: Volume Market

48 Backhaus et al., *Elektroauto – Milliardengrab oder Erfolgsstory*, (2010), p. 93 ff. (translation J.Winter)

49 Elektroauto-Hybridauto: Antriebskonzepte mit Zukunft, *Elektroauto Kosten*, (2013), retrieved June 24, 2013 from: http://www.elektroauto-hybridauto.de/elektroauto/elektroauto-kosten-leistung-und-ersparnis-beim-elektromotor-gegenuber-normalen-motoren/. (translation J.Winter)

The following objectives were formulated:

- 2020: Approximately one million EVs in Germany
- 2030: Over 5 million EVs in Germany
- 2050: Traffic in cities with virtually no fossil fuels

The Federal Government of Germany has set a goal of having one million EVs on German roads by 2020. Currently under discussion is how Germany can become a leading supplier and a leading market for EVs and HVs, with a number of stakeholders involved in these discussions.[50] Policy also has to ensure effective and affordable mobility for the citizens in the future but at the same time policy must protect the German automotive industry and the many jobs associated with it. This often leads to conflicts between politics and the automotive industry. Hence, politicians should focus on the following measures:

- Regarding mobility the state could set a good example by using portals for carpooling, promoting the use of the train and avoiding flights for only a few people.
- In legislation and government subsidies of EVs and HVs, the state has held back so far. At this stage, it would have probably led to the encouragement of foreign OEMs that are sometimes faster on the market and can thus distort the market.

However, the state can act legislatively in different areas:

- The state should eliminate the tax deductibility of the commuter's travel allowance.
- For vehicles with ICEs, refueling at company expense should be abolished. There may be a mobility allowance depending on the job.
- Fuel taxation should be based on the energy content, and should already take in consideration the future development of the oil price.
- Regarding urban vehicles, the state can become a customer and increase the demand for EVs and HVs.

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50 Bundesministerium für Bildung und Forschung, *Nationaler Entwicklungsplan Elektromobilität der Bundesregierung*, (2009), retrieved April 22, 2013 from: http://www.bmbf.de/pubRD/nationaler_entwicklungsplan_elektromobilitaet.pdf. (translation J.Winter)

- To stimulate the production of battery cells in Germany, a compulsory quota for the local production of battery cells could be required.

In changing the mobility, the state can also intervene effectively:

- On busy routes, the government could introduce special lanes for buses, EVs and HVs and vehicles that are occupied by at least 2 people. California already has the so called high-occupancy vehicle lane.
- Kerosene for aircrafts should be taxed in the same way as fuels for vehicles to remove the distortion in the competition.
- Generally, the state should also think about setting a budget per capita for CO2 and crude oil in long term. Up to this limit, no citizen would have additional costs.[51]

5.4 SWOT Analysis for Electric Vehicles

EVs are already being considered as the mobility of the future. In Germany, car manufacturers and automotive suppliers are investing a lot of money in the development of EVs. Applying the SWOT analysis to EVs will show whether EVs will be successful on the German market and where potentials, opportunities and possible weak points lie. This SWOT analysis focuses only on BEVs, as they are the most promising powertrain of EVs in the future, and analyses the following aspects:

- Environment and limited resource availability
- Infrastructure and charging time
- Maintenance, comfort and driving range
- Acquisition cost and operating expenses
- Market situation and the role of the state

51 Lienkamp, M., *Elektromobilität - Hype oder Revolution*, (2012), p. 65 ff. (translation J.Winter)

5.4.1 Environment and Limited Resource Availability

Every time a normal car is set in motion, a little is contributed to the depletion of the oil resources. However, BEVs allow driving with a clear conscience. While being driven, BEVs emit neither CO2 nor other pollutants. In this way fossil fuels can be substituted by BEVs, which leads to an independence from fossil fuels. However, BEVs will have significant consequences for the demand for important and rare metals. For metals, which are particularly important for the production of BEVs, it can lead to shortages. This affects copper for the entire manufacturing process, lithium and cobalt for the battery production, and rare metals such as neodymium for the electric motors, as well as gold, silver and platinum for other components, such as power electronics.[52] Furthermore, BEVs can reduce the CO2 emissions of the car traffic up to 80 % until 2050. According to the Federal Environment Agency of Germany, in 2050 approximately 75 % of the total amount of cars in Germany will be BEVs. Thus, with BEVs 80 % of CO2 emissions can be saved by 2050. With conventional powertrains, like ICEs, only 20 % of CO2 emissions can be saved.[53] Therefore the power must come from renewable sources. If the electricity comes from renewable energy sources, BEVs are almost completely environmentally friendly and carbon neutral. BEVs are also very quiet, which leads to a higher quality of life, especially in big cities.

5.4.2 Infrastructure and Charging Time

E-mobility will depend upon an infrastructure that will enable charging BEVs. Nowadays a prospective buyer of a BEV still needs to consider exactly where to use his car. It is easy if the power supply is in the garage at home or if the journey to work can be managed with a single battery charge. It is still difficult to drive longer distances with a BEV and it will be years before the network of charging stations is as dense as for classical stations.[54] What is needed are charging locations which match driving patterns and usage. The different types of charging can

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52 Öko-Institut e.V. - Institut für angewandte Ökologie, *Zukunft Elektromobilität - Potenziale und Umweltauswirkungen*, (2012), retrieved June 13, 2013 from: http://www.oeko.de/oekodoc/1348/2012-001-de.pdf. (translation J.Winter)

53 Umweltbundesamt, *Energieziel 2050*, (2010), retrieved June 13, 2013 from: http://www.umweltdaten.de/publikationen/fpdf-l/3997.pdf. (translation J.Winter)

54 Stromtankstellen, *Infrastruktur Elektromobilität*, , retrieved June 13, 2013 from: http://www.stromtankstellen.eu/infrastruktur_elektromobilitaet.html. (translation J.Winter)

be classified according to the characteristics of the chargers. The charging of batteries can be divided into four different categories: regular charging, semi-fast charging, fast charging, and changing the whole battery pack. Today, regular charging can basically be done at home from the existing grid. This is a time-consuming form of charging and it requires that the car is out of use for a number of hours in order to reach a full charge. Semi-fast charging is a good alternative if the owner of a BEV spends a certain amount of time in one place, estimated between 1-3 hours, which is shorter than the time needed for regular charging. For fast charging, more developed charging equipment and battery technology is required to enable batteries to be charged in 30 minutes. Another alternative is to exchange the entire battery pack for a new one when it is needed and this procedure will only take a few minutes.[55] Nowadays, only regular charging is possible in Germany.

In connection with the charging, the problem of the battery of EVs will be explained now. The batteries of EVs face a lot of challenges. As already explained the infrastructure in Germany is not sufficient yet to drive an EV without thinking where to go. Also the limited driving range, which will be explained in detail in the following, constitutes a problem. Furthermore, the battery is currently the most expensive element in electric car with a short and limited lifetime. One main challenge is the recycling of the lithium-ion battery of the EV. In every EV is a 100 kilogram lithium-ion battery. As a car needs in his life two to three electric batteries, there is a mass of recycled goods. The transition to electric mobility, however, is only economically and ecologically meaningful when the recycling of the arising depleted batteries is regulated.

5.4.3 Maintenance, Comfort and Driving Range

BEVs are more expensive to purchase than vehicles with ICEs, but require less maintenance as they have a considerably simpler construction than vehicles with ICEs and fewer mechanical components. Therefore they also have a longer life period. According to the Institute for the Automotive Industry (IFA), maintenance costs for EVs are up to 35% less than for vehicles with ICEs, since BEVs do not

[55] CLP Online, *Charging System*, (2013), retrieved June 13, 2013 from: https://www.clponline.com.hk/EV/Pages/ChargingSystem_ChargingMethods.aspx.

need oil changes, have less wear on the braking systems and there are no exhaust systems or clutch systems to be replaced. However, the costs for the battery are very high in BEVs. It is by far the most expensive component with an average life period of three to five years and if the battery fails, it is tantamount to a complete write-off of the vehicle.[56]

With regard to comfort and driving range for BEVs, there is still room for improvement. Due to the voluminous battery, which is also very heavy, space is limited especially in small BEVs. In addition, standardizations such as standardized connector systems, which are necessary to build up a meaningful charging infrastructure, are still under development. Moreover, a thermal management system for BEVs is not yet available, which has negative impact on the driving range. Thermal management is defined as the energy optimization of the heat balance in the motor vehicle. The goal is to optimally manage heat flows to reduce fuel consumption and improve interior comfort. The thermal management in EVs, which during cooling or heating consume additional electrical energy, reduces the already limited driving range of EVs.[57] Despite the long charging time for the batteries of up to ten hours, BEVs only have a driving range of about 300 kilometers. Due to the limited range, BEVs are mainly suitable for city driving or for drivers who rarely drive long distances. For frequent travelers, BEVs on their current level are still not ideal.

5.4.4 Acquisition Cost and Operating Expenses

The major disadvantage of the current generation of BEVs is the high acquisition costs. The high acquisition costs of BEVs are mainly due to the expensive batteries. The batteries currently cost between 15,000 and 20,000 euros in a double pack. However, automotive suppliers are currently working on the development and production of cheaper and more powerful lithium-ion batteries with a price from 1,500 to 2,000 euros, which are much cheaper than the conventional batteries. Currently, a BEV costs about 50 percent more than an equivalent vehicle with

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56 Auto, Motor und Sport, *Elektroautos punkten in der Werktstatt*, (2012), retrieved June 24, 2013 from: http://www.auto-motor-und-sport.de/news/studie-zu-wartungskosten-elektroautos-punkten-in-der-werkstatt-6146082.html. (translation J.Winter)

57 Behr, *Thermomanagement - Was ist das eigentlich?*, (2013), retrieved June 24, 2013 from: http://www.behr.de/Internet/behrcms.nsf/%28$All%29/C97226D8D619BB16C125783900457EE2?OpenDocument#. (translation J.Winter)

an ICE. At the same time, new vehicles have become increasingly more expensive due to better equipment and currently cost around 26,000 euros, which is one reason for the stagnation in the German automobile market. However, the operating expense for a BEV is low, as an electric car is refueled with electricity instead of petrol or diesel. Thus a fuelling, depending on the current electricity tariff and consumption, costs a maximum 1.45 euros for a 100 kilometer ride. In addition, only low tax charges and low insurance contributions are incurred for BEVs. In the year the average vehicle tax for BEVs is about 10 to 30 euros; insurance costs are around 100 euros annually.[58]

5.4.5 Market Situation and the Role of the State

A much discussed issue is the question of whether the German state should support electric cars with subsidies. Additionally, there are also considerable doubts about whether the target of the German Federal Government of one million EVs by 2020 is even remotely feasible. In actual fact, there is state funding for research and development but not for the purchase of EVs, and without financial support there is no incentive to buy. Should state support for purchasing an EV be introduced, this – together with the rising demand for new mobility concepts – would raise the volume of sales. This leads to new mobility concepts for the automotive industry and to market entry opportunities for new automotive suppliers, which stimulate the competition and the market. Currently, however, there is no monetary support. The discrepancy between the expected price and the actual price is also too high, which discourages many buyers. More realistic prices and targeted information supply is needed to make EVs more attractive to potential consumers, as are large investments from both the state and the economy.

58 Elektroauto-Hybridauto: Antriebskonzepte mit Zukunft, *Elektroauto Kosten*, (2013), retrieved June 24, 2013 from: http://www.elektroauto-hybridauto.de/elektroauto/elektroauto-kosten-leistung-und-ersparnis-beim-elektromotor-gegenuber-normalen-motoren/. (translation J.Winter)

5.4.6 Overview: SWOT Analysis for Electric Vehicles

Table 1: Overview SWOT-Analysis for Electric Vehicles

	Strengths	**Weaknesses**
Product Analysis	o Substitution of fossil fuels, therefore independence o Low maintenance costs, since elimination of mechanical components o Reduction of pollutant emissions o Infrastructure for standard charge partially available, private charging possible o Less maintenance	o Low driving range o Little space available by voluminous battery, high battery weight, recycling of the battery o Standardization is still under development o Thermal management is not yet available o High acquisition cost, mainly due to high battery costs o Infrastructure for charging is not available. o Dependence on important rare metals o Without financial support in Germany no incentive to buy
	Opportunities	**Threats**
Environmental Analysis	o Contribution to climate and environmental goals o Market entry opportunity for new automotive suppliers o Revenue growth o New mobility concepts for the automotive industry o Customer acquisition through targeted supply of information o Zero-emission vehicles	o Large investments of state and economy required o Monetary support remains without effective o Discrepancy between expected and actual price o Displacement of existing automotive suppliers due to new technologies

Source: Own illustration

5.5 SWOT Analysis for Hybrid Vehicles

HVs offer drivers an innovative, efficient and affordable option. After years of development, HVs have become a practical choice for consumers. The Toyota Prius, the most successful mass-market hybrid and the best-selling hybrid car, is now in its thirteenth year on the market. The task now is to find out how the hybrid market will develop in the future. Applying the SWOT analysis to HVs should reveal whether HVs will have further success on the German market and where more potential and opportunities and possible weak points lie. This SWOT analysis focuses only on PHVs, as they are the most promising powertrain of HVs in the future and they are already established on the market. The SWOT Analysis of PHVs discusses the same aspects as the SWOT Analysis of BEVs:

- Environment and limited resource availability
- Infrastructure and charging time
- Maintenance, comfort and driving range
- Acquisition cost and operating expenses
- Market situation and the role of the state

5.5.1 Environment and Limited Resource Availability

By supporting the electric motor, fuels and resources can be saved during the operation of the vehicle. This technique is used by PHVs. PHVs have a better fuel efficiency than other similarly sized cars and therefore environmental pollution is lower than for vehicles with an ICE. A statement on the exact percentage of savings cannot be made, because it depends heavily on the operating conditions and the area the vehicle is being used in: In the city the electric drive in a PHV can significantly lower the fuel consumption. On long car trips, however, the electric engine of PHV remains almost completely ineffective. The energy mix used to charge the battery also plays a significant role. Competency and potential for generating electricity from renewable energy sources are available. Thus, resources can be especially protected when the power and electricity is produced completely from renewable energy such as off-shore wind power stations.

A major disadvantage of all hybrid vehicles is the continued, albeit reduced dependence on fossil fuels. Accordingly, PHVs represent only a development stage to vehicles completely without ICEs. However, it is likely that the increasing awareness of environmental issues will keep the demand for PHVs high.[59]

5.5.2 Infrastructure and Charging Time

To take meaningful advantage of the electric motor in a PHV, an infrastructure is needed. For a consumer it is important to know where he can charge his car. It is not as complicated to charge a PHV as it is for a BEV. A PHV has two powertrains, an electric motor and an ICE. Thus, one is not dependent on the electric motor, because the ICE can also be used. What is needed, just as with BEVs, are charging locations which suit driving patterns and usage. A system for the infrastructure of charging station has still to be installed. The charging time for a PHV is between four and seven hours. Therefore, the best alternative is to change the complete battery pack for a new one when it is needed as this procedure will only take a few minutes. Nowadays you can only charge your PHV at your power socket at home.

5.5.3 Maintenance, Comfort and Driving Range

PHVs are very complex and HVs have more parts that can be damaged. As a result, maintenance and repairs are more expensive than with vehicles with normal ICEs. Moreover, the batteries have a really short life. A further disadvantage is that not all repair shops offer services for PHVs. Especially in small, independent repair shops there is a lack of professionals, so your vehicle is damaged, you have to use the more expensive, authorized repair shops.[60]

There is still room for improvement in the comfort of a PHV. Due to the voluminous battery, which is also very heavy, space is limited. Due to the additional installation of electric motors and electrical energy storage units, PHVs are generally much heavier, which in turn has an adverse effect on overall efficiency. The corresponding space for the additional built-in technology usually also restricts

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59 Auto-Hybridantrieb, *Hybridantrieb Vor-und Nachteile*, , retrieved July 10, 2013 from: http://www.auto-hybridantrieb.de/allgemein/hybridantrieb-vor-und-nachteile/. (translation J.Winter)

60 U.S. Department of Energy, *Alternative Fuels Data Center*, (2013), retrieved July 13, 2013 from: http://www.afdc.energy.gov/vehicles/electric_maintenance.html. (translation J.Winter)

the available storage space, especially in the area of the trunk. Many hybrid vehicles are built higher off the ground to prevent the supplementary electrical engineering interaction in the subsoil. In addition, standardizations such as standardized connector systems, which are necessary to build up a meaningful charging infrastructure, are still under development. The driving range of a PHV is the same as for vehicles with ICEs, i.e. it depends on the driving conditions. Nevertheless, a PHV is comfortable and quiet with smooth acceleration and with braking without gear changes. A PHV can be equipped with all sorts of high-tech features, like vehicles with ICEs. The performance of a PHV is good for normal use, there is no problem reaching and exceeding normal cruising speeds. A big advantage is the evolution of PHVs with batteries with higher capacities and a powertrain designed to operate for extended periods in an only-electric mode.[61]

5.5.4 Acquisition Cost and Operating Expenses

Hybrid vehicles are significantly more expensive to purchase than the vehicles with ICEs. On average, a vehicle equipped with a hybrid drive costs 6,000 euros to 8,000 euros more than a vehicle with an ICE. This is around 30% more compared to a conventional model. The higher price is primarily due to the price of the batteries, which are added to power the electric motor. However, on the whole, the costs are also high due to the sophisticated technology and the extensive basic equipment. The high price is also an incentive barrier for consumers. However, the average consumption is less in a hybrid vehicle. Especially in stop-and-go traffic, you can save considerable fuel with a hybrid. Under favorable conditions, the consumption can even be reduced by 20 to 40 percent. Concerning tax savings, there are no advantages to owning a PHV. However, the tax share, which is dependent on CO2 is lower than for vehicles with ICEs, even if it is only a few euros a year.[62]

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61 Wallentowitz, H. / Freialdenhoven, A., *Strategien zur Elektrifizierung des Antriebsstranges*, (2011), p. 70. (translation J.Winter)

62 Handelsblatt, *Hybrid spart nur begrenzt*, (2013), retrieved June 25, 2013 from: http://www.handelsblatt.com/auto/test-technik/auto-unterhaltskosten-hybrid-spart-nur-begrenzt/7600182.html. (translation J.Winter)

5.5.5 Market situation and the Role of the State

The same discussions are ongoing for PHVs as for BEVs. The question is, whether the German state should support hybrid cars with subsidies. To comply with environmental agreements, the government should subsidize vehicles with lower emissions. In actual fact, it is the same problem as with BEVs. The state encourages research and development but not the purchase of PHVs, and without financial support, there is no incentive to buy. The market performance of international car manufacturers in relation to the hybrid drive is rather marginal. However, some hybrid vehicles have already become established on the market. The Toyota Prius model 5 is currently regarded as the market leader for hybrid vehicles. As PHVs have already become established on the market, they are no longer reliant on as much financial support as BEVs. Nevertheless, the volume of scales can be further increased by governmental support. Due to the new mobility concepts for the automotive industry and the market entry opportunity for new automotive suppliers, the market and the competition is stimulated. A further problem is also the discrepancy between the expected price and the actual price. The discrepancy is too high, which discourages many consumers from buying a PHV. The consumers are not informed about the benefits of PHV and are therefore not willing to pay the higher price. For this reason, it is important to ensure consumers receive solid and sufficient information about PHVs. However, to make PHVs attractive to consumers, investments from the state and the economy are still required.

5.5.6 Overview: SWOT Analysis for Hybrid Vehicles

Table 2: Overview: SWOT Analysis for Hybrid Vehicles

	Strengths	Weaknesses
Product Analysis	o Lower pollution o Better fuel efficiency o Infrastructure for standard charge partially available, private charging possible o Smooth acceleration o Braking without gear changes o Can be equipped with high-tech features o Evolution PHVs	o Remains reliant on fossil fuels o Little space available by voluminous battery, high battery weight o Standardization is still under development o High acquisition cost, mainly due to high battery costs o Infrastructure for charging is not available. o Without financial support in Germany no incentive to buy o More Maintenance
	Opportunities	**Threats**
Environmental Analysis	o Contribution to climate and environmental goals o Market entry opportunity for new automotive suppliers o Revenue growth o New mobility concepts for the automotive industry o Customer acquisition through targeted supply of information	o Large investments of state and economy required o Monetary support remains without effective o Discrepancy between expected and actual price o Displacement of existing automotive suppliers due to new technologies

Source: Own illustration

5.6 Evaluation of the SWOT Analysis

Using the SWOT analysis has demonstrated the actual situation of BEVs and PHVs on the market. On the one hand, the SWOT analysis has investigated and presented strengths and weaknesses of each alternative powertrain by the product analysis and on the other hand it has examined the opportunities and threats by the environmental analysis.

It has been determined that PHVs in direct comparison to the BEVs have more advantages. In relation to environment and limited resource availability, both are at the same level. Both have little or no emissions, but a PHV is not independent of fossil fuels, whereas a BEV is completely independent of fossil fuels. In the area of infrastructure and charging time, PHVs perform better because they do not rely on charging stations, as they are also equipped with a conventional ICE. For the BEVs, it is unfortunately the case that the infrastructure is not yet developed, and therefore the charging is a bit difficult. In addition, the charging time for BEVs is very long. In terms of maintenance, comfort and driving range, PHVs also have advantages compared to BEVs. Due to the additional ICE, PHVs have a much longer driving range than the BEVs and also the comfort is greater because a PHV can be equipped with more features than a BEV. However, BEVs are cheaper in maintenance than the PHVs. In terms of acquisition cost and operating expenses, both types of alternative powertrains are the same. The acquisition cost for both PHVs and BEVs is about 30% higher than for conventional models. Also, the maintenance costs are relatively equal for both. With regard to the market situation, PHVs also have advantages because they already are established on the market and they are not so dependent on the financial support of the government than BEVs.

The SWOT analysis has now given a helpful and meaningful overview of the strengths and weaknesses of the two alternative powertrains, the PHV and BEV. This has created a first impression of the two alternative powertrains. However, the SWOT analysis describes only a state, and the results do not set evaluation criteria for the four areas. Furthermore, the results are insufficient to quantify and evaluate. Therefore, with the help of the scoring model, the main evaluation criteria of two powertrains are now compared and weighted in order to find out which of the two powertrains it is worthwhile for the automotive suppliers to invest in.

6 Scoring Model for Alternative Powertrains

Since it is very important for German automotive suppliers to know if it is worth investing more in HVs or EVs, it is now important to determine the value of the two alternative powertrains. This is carried out using the scoring model. If a choice must be made between several very similar alternatives, the scoring model is a tool for determining the preferred alternative. For this reason, the scoring model is applied to determine which alternative powertrain it is worth investing in.

6.1 Scoring Model – Theoretical Background

The scoring model, which is also often called utility analysis, is a "method for the evaluation of alternatives, and alternatives in which alternatives are also measured against criteria which cannot be expressed in monetary units. In the utility analysis, for example, technical, psychological and social assessment criteria are considered that are based on quantitative and qualitative characteristics. This is also called multi-attribute utility analysis."[63]

The scoring model is one of the non-monetary quantitative analyses of decision theory. It was introduced in the mid-1970s by Zangemeister and Bechmann. The scoring model or the utility analysis is an evaluation process with which alternatives can be evaluated and compared according to several different target criteria. In general terms, the scoring model represents a scoring method to evaluate objects or situations based on specific characteristics with the help of numerical values. While only quantitative evaluation criteria are considered in static or dynamic investment calculation methods, qualitative evaluation criteria are included in the scoring model. The principle of the method of scoring models essentially consists to reduce the parameters not comparable to a common denominator, thus making it possible to take decisions on alternatives.[64]

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63 Gabler Wirtschaftslexikon, *Nutzwertanalyse*, , retrieved June 29, 2013 from: http://wirtschaftslexikon.gabler.de/Definition/nutzwertanalyse.html?referenceKeywordName=Scoring-Modell. (translation J.Winter)

64 Kollmann, T., *E-Entrepreneurship*, (2011), p.133ff. (translation J.Winter)

6.2 The Procedure for Using the Scoring Model

The operation of scoring models is based on a systematic sequence of steps which is explained in the following.

- The first step of the evaluation of alternatives is the definition and specification of the relevant assessment criteria. The criteria should not overlap to avoid that any one aspect which is recorded in multiple targets is weighted too heavily.
- The second step involves the evaluation of the criteria set. To obtain a direct comparison of the individual target achievement levels, all reviews must be subjected to an identical assessment procedure. For this purpose, scoring models usually use a rating scale. The rating scale must be determined and used for all criteria. Subsequently, the individual decision alternatives areit is evaluated to see the extent to which they meet the criteria set.[65]
- In the third step, the criteria are initially weighted. The weighting factors are determined for the characteristics of the target according to their influence on the overall benefit. In this case, a scale is determined which defines the different weightings.
- In the fourth step, the expected value is determined by multiplication or addition of the evaluation points and weighting points. The additive approach is chosen if the criteria have highly different weightings. The multiplicative operation is preferred, however, if products are desired with a balanced profile.[66]

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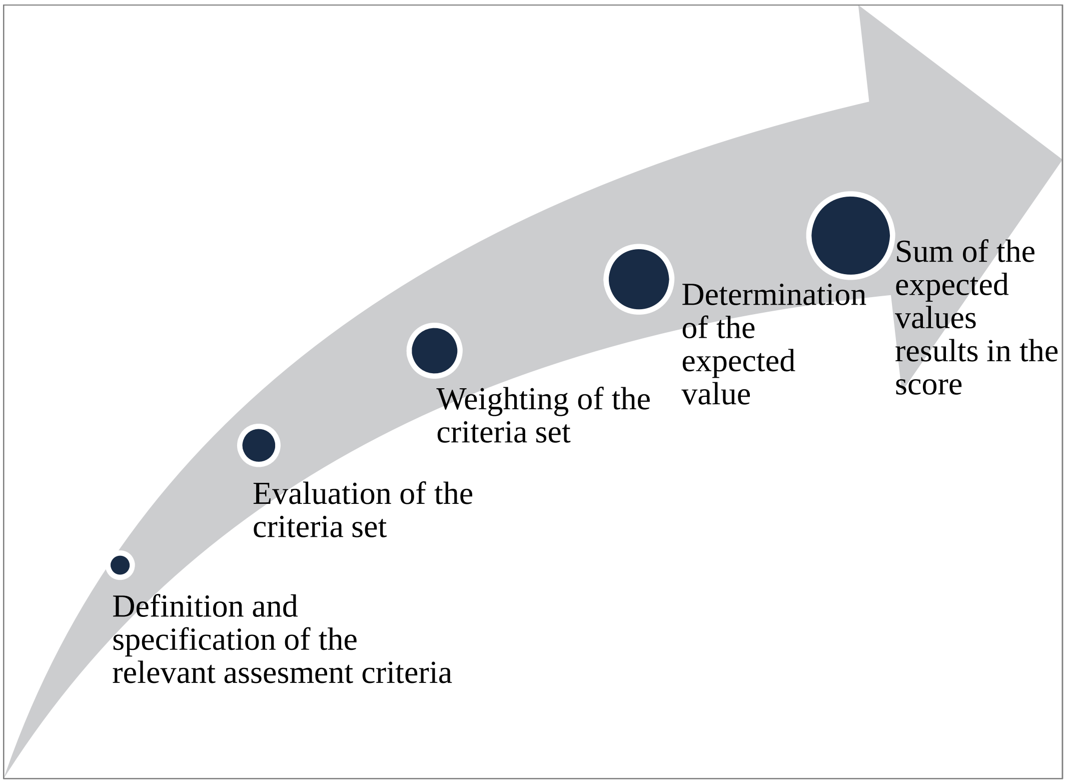
65 Wirtschaftslexikon, *Scoring-Modell*, , retrieved June 29, 2013 from: http://www.wirtschaftslexikon24.com/d/scoring-modell/scoring-modell.htm. (translation J.Winter)

66 von Ahsen, Anette, *Bewertung von Innovationen im Mittelstand*, (2010), p.50 ff. (translation J.Winter)

Figure 7: Steps of the Scoring Model



Source: Own illustration

6.3 Application of the Scoring Model to EVs and HVs

Now the individual steps of the scoring model are applied to the evaluation of the two alternative powertrains, the HV and the EV. The powertrain with the higher final score will have more opportunities in the market in the near future and it is worthwhile for automotive suppliers to invest in the powertrain with the higher score. All four steps are carried out in sequence.

6.3.1 Step 1: Definition and Specification of the Relevant Criteria

The first step to be carried out is to define and specify the evaluation criteria. The same evaluation criteria are used for both powertrains so the score at the end is comparable. The same aspects are used as evaluation criteria as the ones which were used in the SWOT analysis. These are:

- Environment
- Limited resource availability
- Infrastructure
- Charging Time

- Maintenance
- Comfort
- Driving Range
- Acquisition Cost
- Operating Expenses
- Market situation
- Role of the state

The above mentioned criteria have been considered and explained in the context of the SWOT analysis. The same evaluation criteria as for the SWOT analysis enables an easier comparison between the two powertrains and also enables a better understanding, because the chosen criteria have already been explained and are thus known.

6.3.2 Step 2: Evaluation of the Criteria Set

A rating scale is defined for the evaluation of the criteria. The scale has a range of 1-5, where 1 represents the criterion which is least relevant, or has least impact on the success of each powertrain. In contrast, a score of 5 is given to criteria which are regarded as most important and represent the greatest impact and the most important aspect when considering the respective powertrains. The relevant criteria are re-evaluated for both powertrains equally, so that a comparison is possible.

The results of the rating are shown in Table 3. The environmental aspect is rated with a 5 because we live in times of heightened environmental consciousness and the environmental aspect is a much discussed issue. Related to this is the limited availability of resources, which is always an issue of politicians and conservationists, but also a topic in the economy. Since this has a major impact on the potential success of each powertrain, the limited availability of resources is rated with a 4. Infrastructure and charging time were given a 5 because this is one of the main problems that still stands in the way of the success of HVs and EVs. Without a functioning, well-developed infrastructure it is not possible to pursue normal driving activities, especially with EVs. Long charging times are a particularly significant barrier in today's fast-moving society. In this context, driving range was rated with a 4 because it is not yet possible to drive long distances without the fear of running out of battery power. The cost of acquisition and maintenance were evaluated here with a 3 because they only have a moderate impact on the potential success of the two powertrains, but should not be underestimated. Many consumers are put off by the higher acquisition cost, while the small number of workshops that perform maintenance on EVs and HVs also represent a problem. It is different in terms of comfort and operating expense. The comfort, especially in the HVs is the same as for vehicles with ICEs and there are no significant savings in terms of maintenance costs. Therefore, both criteria were evaluated with a 1. The market situation is rated with a 2 because it is still difficult to evaluate how the market is evolving and the impact is relatively small. The role of the state, however, is given a 3, mainly because EVs still need financial subsidies to gain a foothold on the market.

Table 3: Evaluation of the Individual Criterion

Criterion	Evaluation
Environment	5
Limited Resource Availability	4
Infrastructure	5
Charging Time	5
Driving Range	4
Acquisition Cost	3
Maintenance	3
Comfort	1
Operating Expense	1
Market Situation	2
Role of the State	3

Source: Own illustration

6.3.3 Step 3: Weighting of the Criteria Set

Now, the weighting of each criterion takes place. Here both powertrains are now considered separately, since the weighting refers not to the criterion itself but to the powertrain. The aim here is to assess how well or badly each powertrain meets the criteria. The weighting is done on a scale of 1-10, with 1 being the worst a criterion is fulfilled and 10 the best. The weighting is based on the SWOT analysis, as each criterion was given a pre-weighting in the SWOT analysis and the reasoning behind one was already explained. Therefore, only the scale values are indicated with a short explanation.

6.3.3.1 Weighting of the Criteria Set for EVs

Table 4: Weighting of Each Criterion for EVs

Criterion	Weighting
Environment	10
Limited Resource Availability	7
Infrastructure	1
Charging Time	1
Driving Range	2
Acquisition Cost	5
Maintenance	5
Comfort	4
Operating Expense	6
Market Situation	5
Role of the State	8

Source: Own illustration

The criteria for EVs are weighted in Table 4. The environmental aspect of the EVs was weighted with a 10 because EVs emit absolutely no pollutants. Limited resource availability was weighted with a 7 because although EVs are complete independent of fossil fuels, they do depend on some rare metals. Since there is almost no infrastructure in Germany for EVs and also the charging time is very long, these aspects are weighted with a 1. The range of EVs is sufficient only for short distances and therefore only gets a 2. The cost of acquisition and maintenance get a 5 because both perform mediocrely. The acquisition costs are higher for EVs, but the maintenance costs are in turn lower. In terms of comfort, EVs are weighted only with a 4 due to the large battery pack which takes up a lot of space and also thermal management for EVs is not yet possible. Furthermore the recycling of the battery is a main problem. The operating expenses are lower than for a vehicle with a conventional ICE, so here it is weighted with a 6. The market situation gets a 5 because EVs are not yet established in the market. The role of the state, however, plays a major role, as support in the form of subsidies is still needed and will be needed in the future. Therefore, the role of the state is weighted with an 8.

6.3.3.2 Weighting for the Criteria Set for HVs

Table 5: Weighting of Each Criterion for HVs

Criterion	Weighting
Environment	6
Limited Resource Availability	5
Infrastructure	5
Charging Time	2
Driving Range	10
Acquisition Cost	5
Maintenance	4
Comfort	6
Operating Expense	2
Market Situation	7
Role of the State	7

Source: Own illustration

For the HVs, the environmental aspects are weighted with a 6 because HVs are equipped with a standard ICE, and yet can drive only a short distance under battery power, and thus HVs emit pollutants. HVs are also still dependent on fossil fuels, which is why this criterion is only weighted with a 5. HVs are not dependent on the infrastructure for charging the battery pack, as they can always use and move with their usual ICE. Therefore it is weighted with a 5. Since the battery pack of HVs is smaller than the battery pack of EVs, the charging time is slightly lower and therefore the charging time of EVs is rated with a 1 and the charging time of HVs is rated with a 2. Since HVs are equipped with a normal ICE, there are 10 points for the driving range. The cost of acquisition and maintenance are weighted with a 5 and a 4, respectively, because both the acquisition cost and the maintenance costs are higher than for vehicles with ICEs. When it comes to comfort, HVs get a 6 because they can be equipped with all the additional features. The operating expenses of a HV are the same as for vehicles with conventional ICEs and are therefore weighted with a 2. Concerning tax savings, HVs have no benefits. There is no explicit tax advantage for HVs, though, the tax share, which is dependent on CO2, is lower than for vehicles with ICEs, even if it is only a few euros a year. The market situation of HVs is good since they are already established in the market. Moreover, the dependence on subsidies from the state is low, which is why both criteria, market situation and the role of the state were rated with a 7.

6.3.4 Step 4: Calculation of the Expected Value

When comparing the two power trains, EV and HV, the expected value is calculated by multiplying the assessment and weighting points, since the weightings of two power trains are close and thus the profiles are very similar. The sum of all expected values results in the score, which is then compared.

Table 6: Expected Values and Score for EVs

Criterion	Evaluation	Weighting	Expected Value
Environment	5	10	50
Limited Resource Availability	4	7	28
Infrastructure	5	1	5
Charging Time	5	1	5
Driving Range	4	2	8
Acquisition Cost	3	5	15
Maintenance	3	5	15
Comfort	1	4	4
Operating Expense	1	6	6
Market Situation	2	5	10
Role of the State	3	8	24
		Score	**170**

Source: Own illustration

Table 6 shows the expected values of EVs and the score, which is 170. Table 7 shows the expected values of HVs and the score, which is 195. Both scores are close together; nevertheless the score of HVs is higher than the score of EVs. This means that HVs are further developed and match better today's consumer demands. HVs are also better established in the market and it can be assumed that the hybrid in the future will also enjoy long-term success on the market. Thus, it is advisable for automotive suppliers to concentrate on the hybrid market and invest in the development of HVs.

Table 7: Expected Values and Score for HVs

Criterion	Evaluation	Weighting	Expected Value
Environment	5	6	30
Limited Resource Availability	4	5	20
Infrastructure	5	5	25
Charging Time	5	2	10
Driving Range	4	10	40
Acquisition Cost	3	5	15
Maintenance	3	4	12
Comfort	1	6	6
Operating Expense	1	2	2
Market Situation	2	7	14
Role of the State	3	7	21
		Score	**195**

Source: Own illustration

6.4 Evaluation of the Scoring Analysis

The two powertrains were evaluated and compared using the scoring mode, which established that the HV has a score of 195 and the EV has a score of 170. The difference in the scores is because both powertrains have advantages and disadvantages and these are weighted differently.

In summary it can be said that EVs have both advantages and disadvantages. Their biggest advantage is their great environmental friendliness as the EV causes no harmful emissions during driving. In addition, EVs are almost silent. Another advantage is that EVs require less maintenance and the operating expenses are a bit lower compared to vehicles with ICEs. However, the main disadvantage is the high purchase price of EVs, which results primarily from the expensive batteries. In addition, the batteries require a very long charging time and the driving range is only about 300 kilometers.

HVs have more advantages than EVs, which also accounts for the higher score. In brief, the advantages of a conventional internal combustion engine are coupled with those of an additional electric motor. With the help of a control system it is possible to switch between the two powertrains. In addition, the vehicle is also extremely quiet. At a certain speed, the system automatically switches to the ICE. While the vehicle is operated with the conventional internal combustion engine, the electric motor is recharged – another big advantage of HVs. This recovered energy ensures, for example, that the hybrid car has full air-conditioning included as standard in the basic package, which increases the comfort of HVs. However, HVs also have disadvantages. Alongside the high cost – about 8,000 euros more than for an equivalent powered by a conventional internal combustion engine vehicle – the low life of the batteries is a disadvantage. Because it has two engines, a hybrid car is also significantly heavier than regular cars.

Because HVs have far more benefits than EVs, the higher score of HVs of 195 is justified. This proves that more future potential lies in HVs and that the greatest opportunities in the market can be found for HVs. Thus, it makes more sense for German automotive supplier, according to the results of the scoring models, to invest in HVs.

7 Future Outlook for Alternative Powertrains

In this section, the future potential of the alternative powertrains EVs HVs are investigated and the different changes in the automotive industry, in particular changes in the value chain are analyzed. In addition, fields of action for policy, research, the economy and customers are identified and recommendations will be made which will serve as a stimulus.

7.1 Potentials of EVs and HVs

With the global climate problems, the pressure for action to reduce greenhouse gas emissions and become independent of fossil fuels is increasing. As already mentioned, EVs and HVs represent significant options in this context. The goal of the Federal Government of Germany of one million electric vehicles on the market by the year of 2020 was formulated in August 2009 and to this end the government launched several development programs. At the same time, automotive manufacturers and energy suppliers are making efforts to further develop EVs and HVs and the necessary charging stations.

A decisive factor for the breakthrough of EVs and HVs is their acceptance among users. Therefore, one focus was on the question of whether EVs and HVs can be integrated into company fleets. Another question is if EVs and HVs are accepted by the drivers and if drivers are changing their individual behavior regarding mobility. For this purpose, the Öko-Institut carried out a scientific fleet test together with the Institute for Social-Ecological Research (ISOE) with SAP AG. SAP AG is a German multinational software corporation that produces enterprise software to manage business operations and customer relations. The ISOE examined user behavior and acceptance of the employees of SAP for EVs and the Öko-Institut analyzed the environmental benefits of electric company cars.

The two institutions evaluated in detail data from 27 pure EVs from the fleet of the SAP company. The result was that one fifth of the company cars of SAP AG could be operated all-electric by the year 2030. In connection with HVs, which can be operated both electrically and with an ICE, up to 80 percent of the company's fleet could even be EVs and HVs. This would make it possible to save about half of the CO_2 emissions compared to a conventionally operated fleet by 2030. Experts predict that the population and businesses will accept electric cars more if the additional expenditure compared to vehicles with an ICE falls.[67]

Although there are many arguments on the German market for the expansion of EVs and HVs, the problems must still be considered. Possible solutions must be designed today for the rising demand for raw materials, especially for rare metals in the batteries and the electric motors, and a sophisticated recycling system for EVs and HVs must be developed. 12 metals are especially important for the production of EVs and HVs. These are copper for all components, rare earths such as neodymium, praseodymium, dysprosium and terbium for the electric motors, as well as indium, gallium, germanium, gold, silver, platinum and palladium for the other components, such as power electronics. In order to contain medium and long-term supply shortages, there are two main strategies: Firstly, resources must be used efficiently and maybe also replaced by other technologies. Secondly, it is important to develop recycling strategies for rare earths and other critical metals and to bring those new strategies to market in order to avoid shortages in the long run. Currently, recycling processes for the lithium-ion batteries that are necessary for electric mobility and contain important metals such as lithium, cobalt, nickel and others, are in development.

7.2 Changes in the Value Chain

The complexity of the topic of electric mobility and the strategic importance of the automotive industry in Germany require an overall view of the automotive value chain, as it will be subject in the future due to massive changes through new technologies. Regarding raw material procurement, proof the process of innovation is in full swing can be seen in the use of modified materials such as lithium for batteries. There will be a shift in the share of the value chain of a vehicle between pure automotive manufacturers and automotive suppliers. Especially in the area of the automotive suppliers new companies will be added as a system supplier or supplier of modules and mostly those companies have not yet been in contact

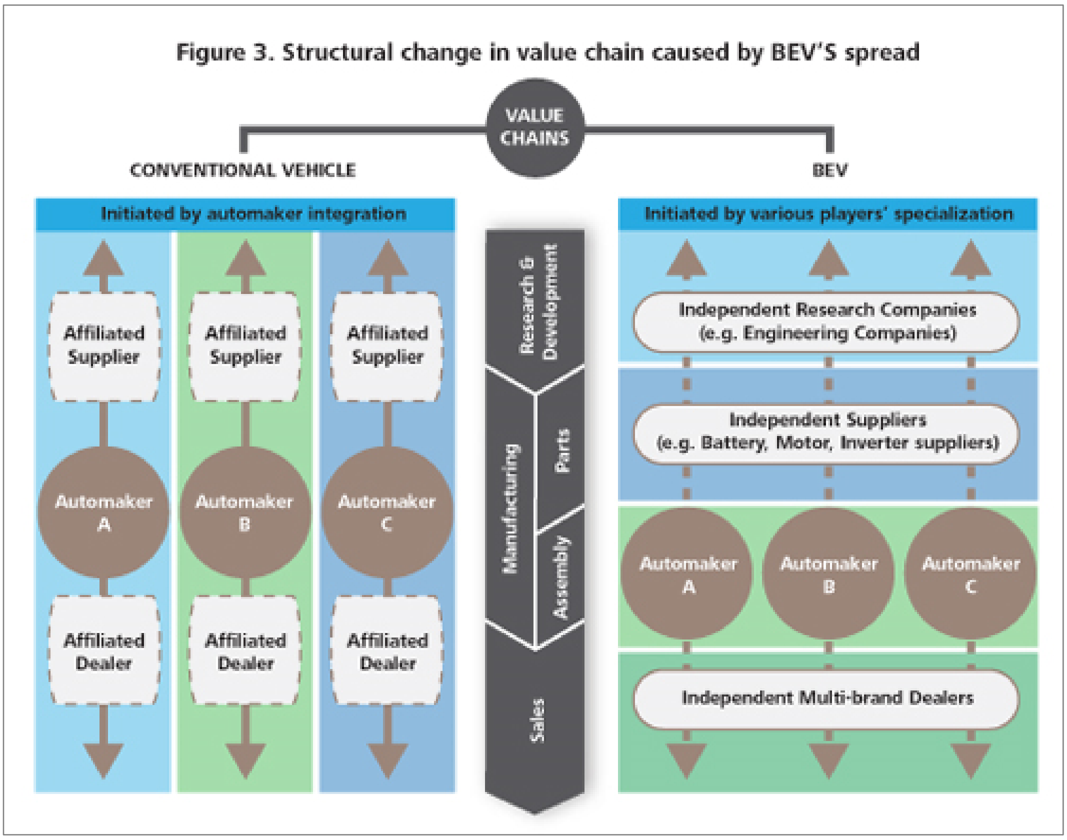
[67] Öko-Institut e.V. - Institut für angewandte Ökologie, *Elektromobilität: Fahren unter Strom*, , retrieved July 15, 2013 from: http://www.oeko.de/forschung_beratung/themen/nachhaltige_mobilitaet/dok/993.php. (translation J.Winter)

with the automotive industry. The battery as a component will represent the largest share of the added value for EVs and HVs in the future. Thus, for example, large German chemicals companies are carrying out R&D in this field. According to estimates, the market for lithium-ion batteries will represent a global potential of 47.5 billion euros in 2020. Overall, experts predict a shift from traditional automotive components, such as the internal combustion engine, the exhaust system and the fuel tank, to new components such as the battery, the electric motor and the power electronic.[68] Apart from the addition demand for expertise for current and future suppliers and for automotive manufacturers themselves, other actors will belong to the future automotive value chain. In addition to the current energy suppliers, these are manufacturers and operators of the charging infrastructure and also new mobility providers. This restructuring of the value chain is related to the expected change in the labor market. Thus, the German Federal Ministry for Environment, Nature Conservation and Nuclear Safety forecast a loss of 46,000 full-time jobs in the worldwide supply industry, with German suppliers being affected disproportionately. At the same time about 250,000 new full-time jobs will be created in the areas of new automotive parts worldwide. Employment potentials are even being predicted for ICEs. Here there is a special situation that there will be loss of jobs in the production of engines, but new full-time workers will be needed simultaneously for other technologies to increase the efficiency of internal combustion engines. In summary, automobile manufacturers, established suppliers and new entrants such as various German chemicals corporations will have to reposition themselves in the automotive value chain of the future.[69]

68 Fraunhofer Institut, *Zukünftige Wertschöpfungspotenziale und -strukturen,* , retrieved July 15, 2013 from: http://isi.fraunhofer.de/elektromobilitaet/Zukuenftige_Wertschoepfungspotenziale_und_-strukturen. (translation J.Winter)

69 Backhaus et al., *Elektroauto – Milliardengrab oder Erfolgsstory,* (2010), p. 93 ff. (translation J.Winter)

Figure 8: Structural Change in Value Chain



Source: http://www.deloitte.com

7.3 Recommended Actions

From the results of this work there are key areas for action, which are summarized as recommendations to political actors, to members in the value chain and to customers.

7.3.1 Political Actors

First, the government of the Federal Republic of Germany must improve the framework conditions for a significant increase in the share of renewable energy in primary energy consumption. In this context, there must be a better supply of information to consumers in order to make them more aware of the composition of the energy mix. Consequently, it is necessary to establish legislatively a meaningful and effective battery recycling system to preserve or recover raw materials such as lithium. It is also important to minimize the environmental impact caused by the extraction of raw materials. Both aspects need to be communicated to consumers, so that their environmental thinking is satisfied. In the financial incentive systems, the increased willingness of customers to purchase is to be noted. A government subsidy on the purchase price would attract more new customers for EVs and HVs. Here the Federal Government of Germany has to reexamine whether such a subsidy, as it already is used increasingly in other countries, is possible and useful in Germany. Furthermore, the sale of EVs and HVs can be promoted through the provision of low-interest loans to offset the difference in price to vehicles with ICEs.

7.3.2 Members of the Value Chain

There is a positive correlation between the level of information of the customers and their willingness to buy an EV or a HV. Therefore, a recommended action for manufacturers and suppliers in the automotive industry is to improve this level of information. The acceptance, especially for EVs, could be significantly increased, if the vehicles had a secure driving range of over 200 km, and with the increasing driving range the acceptance for EVs will also increase linearly. This is accompanied by the thermal management of EVs, which in heating or cooling the EV consumes additional electrical energy and thus reduces the driving range. Here it is advisable to develop innovative solutions to prevent the need for larger and heavier batteries for the additional consumption of electrical energy. Since the majority of customers seem to not accept less space in their vehicles, another challenge for automotive manufacturers and automotive suppliers is to find solutions to create more space in EVs and HVs. Here it is important to design the vehicle in accordance with the increased space requirements of the batteries. With innovative interior designs of new vehicles, the battery can be better integrated in future into the overall concept and the previously familiar space of the vehicles could be available again. Consumer acceptance of the current charging times of the batteries is low. The bundling of the core competencies of various industries and companies while promoting efforts to make batteries cheaper and more powerful, could counteract the low driving range and the high price of the batteries. Also, for the energy suppliers there is a potential for development. For example an additional incentive to buy an EV or an HV can be created through the provision of a free electricity contingent. Possible measures could be new mobility concepts to convince customers of the product and the pricing structure. Another aspect is the scarcity of resources. Since raw materials are limited, it is important for the battery manufacturer and suppliers to ensure sustainable access to raw materials such as lithium in order to fully tap into the potential of this growing market. The last point in this list of recommendations applies to automotive manufacturers, automotive suppliers and the automotive trade. Those members of the value chain must further develop the skills of their employees through staff training. The necessary expertise must be built up and strengthened to develop, operate and repair innovative products like EVs and HVs. In summary, it can be said that the fundamentals in the different areas are available. It is important to optimize and expand these fundamentals through research and through networking. In particular, the key technology of the battery needs to be further developed to withstand the global competition or even to take a leadership position.

7.3.3 Customers

The recommendation for action for the consumer mainly affects the level of information regarding the technology and a closing of the gap between actual user behavior and expectations. The discrepancy between the expected and required driving range reflects this gap clearly. Despite potentially sufficient battery capacity to complete most everyday journeys, customers want a greater driving range. Here, customers should increase their awareness of whether this expectation is necessary, even with the expected charging times of EVs and HVs. On the one hand, the vehicle is in a parking lot for most of the day, either at home or at the employer; on the other hand, customers require the shortest possible charging time. Due to the usual parking duration of vehicles such a short charging time is not necessary. A standard charge of 6 to 8 hours is feasible without sacrificing comfort. In the area of the space in EVs and HVs, most customers do not accept a reduction of the available space like in vehicles with ICEs. At the same time, there are only a few vehicles which are fully occupied in daily traffic. Again, the question is then whether the expectations for the available space are justified and if this space is actually needed. In summary, customers should familiarize themselves with the current technology and match their capabilities with their actual needs.

8 Conclusion

The topic of alternative powertrains is currently much discussed in Germany and is still a current issue for politics, for the economy, for car manufacturers and for automotive suppliers. The development of improved and alternative powertrains is to a large degree determined by the factors of climate change and global warming, limited resource availability and rising fuel prices, changes in customer requirements, urbanization and stricter legislative requirements. Those main drivers mean that in the automotive industry massive efforts are being made to meet future challenges, for example in terms of fuel efficiency. However, in this context, the automotive industry is very nervous. EVs are too expensive and have a too limited driving range – this is the main image that customers have of electric mobility. Indeed, they are not entirely wrong. There is considerable unrest in the R&D departments of research institutions and of German automobile manufacturers. It is no longer just about who can develop the best solution as fast as possible for electric mobility, but about winning the customer’s acceptance as fast as possible. The manufacturers are under pressure. Therefore, they are investing a lot of money into advertising for electric mobility. Outwardly, it is indeed promoted hard, but inside the manufacturers are preparing a quiet withdrawal from pure electric mobility.

One million EVs should be on German roads by 2020 according to the German Federal Government. However, this raises the question of what electric mobility actually is. With pure EVs it will be difficult to reach the goal, therefore the hybrid vehicles play an important role. There will be a silent shift from pure electric vehicles to the electrification of the powertrain with hybrids, plug-in hybrids and range extenders, all of which are a combination of combustion engine and electric motor on the basis of different technologies. Of course, the initial electric hype is now over, but now it settles at a reasonable level. The registration numbers of the Federal Motor Transport Authority in past years make this level clearly. At 1 January 2011, 2,307 EVs were registered, in 2012, 4,451 EVs were registered and so far in 2013, 7,114 EVs. Expressed in percent, 0.01 percent of all cars on German roads were EVs. There is currently a lack of 992,886 EVs to achieve the goal of the Federal Government by 2020.[70] Therefore, HVs are no longer seen only as a

70 Senfter, S., *Der E-Anstrich*, Markt und Mittelstand, (2013), p. 14 (translation J.Winter)

bridge technology. A few years ago, manufacturers stated that hybrid technology is only an intermediate solution. Also, the PHVs should only be a bridge on the way to pure EVs. Now the creeping expansion of electric mobility is in full swing.

In summary it can be said that the combination of combustion engine and electric motor today is no longer just a bridge technology for the coming electric age. The mass motorization with pure EVs is currently still a dream, but also German manufacturers have decided in the meantime for HVs, albeit after much hesitation. The first hybrid models from BMW, Mercedes, Porsche and VW are already in the showrooms. Hybrid vehicles are already implemented in practice and accepted, EVs at the moment not yet, mainly due to the battery problem. However, the trend goes to the third vehicle for urban transport, and therefore the EV should not be ignored as a long-term solution in the future. However, it needs to increase advances in battery technology to increase the acceptance of the consumers.

Here is also worth mentioning that the bottleneck of EVs is the battery. The range of the battery is too low for the normal, average daily use of a consumer. Also the battery lifetime is short, so that an EV needs 2-3 batteries during his life, which is expensive. The batteries are also very heavy and take up much space in an EV. There the major challenge lies with the supplier.

The biggest problem, however, is seen in the recycling of the lithium-ion batteries. Thus the recycling of the battery is a challenge. Without a comprehensive recycling concept, the widespread use of lithium-ion battery does ecologically not make sense. The recycling of the battery has to be considered in connection with EVs. There are still no economically and ecologically sustainable solutions in the industry for the recovery of lithium and other active materials that allow a return as secondary raw material in the production of batteries. Necessary is the development of a network for returning and recycling lithium-ion batteries. Thereby the large amounts of aged batteries can be collected efficiently. Moreover, the problem of the rising demand of lithium ion can be solved by recovered materials at least partially.

Therefore, it makes sense for the German automotive supplier to invest more in HVs and to focus on this market, since there the prospects for success are greater and the potential of this market is higher than for EVs. This result can also be seen in the SWOT analysis, which established that HVs have more advantages compared to EVs. Also, the value of the scoring model for HVs of 195 to 170 for EVs makes it clear that today HVs enjoy more success on the market and the development of the market for HVs has more future potential.

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Declaration of Originality

I hereby declare that this thesis and the work reported herein was composed by and originated entirely from me. Information derived from the published and unpublished work of others has been acknowledged in the text and references are given in the list of sources.

Lorch, 30.07.2013: ....

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