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The Electric Vehicle: A SWOT analysis of the German Automotive Industry

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1. Introduction

Continuous global population growth and an unbroken trend of increasing urbanization has exacerbated mobility challenges and intensified worries about climate change. Roughly 10 billion people will live on this planet by 2050 (United Nations, 2017) and two-thirds of this population will live in cities by 2050 (Global Challenge Insight Report, 2016) giving rise to dozens of new megacities globally that will push the demands of mobility and transportation to its very limits. Furthermore, the Paris Agreement, an agenda within the United Nations Framework Convention, requires all participating nations to pursue ambitions efforts to combat climate change (United Nations, 2016). Essentially, if emissions were to be reduced gradually, they would need to reach zero within about 50 years, in order to stay within the carbon emissions budget (van Vuuren, Boot, Hof, & den Elzen, 2017). The magnitude of this task is enormous, necessitating an energy transition towards new, climate-neutral infrastructure in order have a remote chance of fulfilling the emission targets. *Appendix 1* illustrates the extent of the difficulty of these goals. A transition policy that is fixated on the rapid implementation of all infrastructural, technological and institutional prerequisites is essential and requires a large-scale application of low-carbon technologies in order to be successful.

Despite the afore mentioned complexities shaping our world, one thing will remain a constant; that is the need for transportation. Transport as a derived demand will remain essential, no matter where the mobility of the future takes us, in catering to varying needs of society in respect to trade, logistic, commuting, trade, leisure, etc. Hence, it is essential that all major players in the automotive industry undergo constant planning and revision in order to adapt to the challenges and changes its environment undergoes.

1.1 The German Mobility Market

Few, if any nation has developed an enthusiasm and love for cars quite like the Germans have. Since Carl Benz's invention of the world's first practical automobile in 1885 the automotive industry has developed into a cornerstone of the German economy and boasts an illustrious history of car manufacturing. Consequently, the uncertainty and challenges surrounding the mobility of the future are already causing radical changes and new approaches to traditional and established best practices of the German automotive world. Previously highly successful strategies are being questioned and reconsidered in an attempt to once more be the front-runner of a new and highly uncertain era of mobility.

Car ownership in Germany continues to grow slightly. Between January 2009 and January 2017, the number of passenger cars in Germany rose from 41.3 million to 46.5 million passenger cars. The majority of the German passenger car fleet is still equipped with a gasoline engine. However, their share decreased to 65.5% in 2018. By contrast, the share of passenger cars with diesel engines rose in the same period (32.8% until 2018). The most significant increases over the last decade were seen in the market for electric vehicles and hybrid vehicles, rising by 58.3% and 43.1% respectively. Nevertheless, the total market share of these alternative engines remains comparatively low at 1.8% (Kraftfahrt Bundesamt, 2018). Cars had a 56% market share amongst all possible transport modes during 2018. In other words, slightly over half of all trips are made by automotive vehicles. In 2018, the traffic participation rate of mobile persons per day is 90.1% and the daily average distance travelled for Germans is 40.9 km per person per day (with an average of 3.27 trips undertaken daily). Traffic participation is at a similar level in all types of areas. From highly urban to very rural areas, the traffic participation rate always lies between 90%< and < 94% (Ecke, et al., 2018).

1.1.2 The rise of the Electric Vehicle

As has now been brought to light in the sections above, the main challenges of the German automotive industry faces are rooted in the theory of the "Consumer City" (Glaeser, Kolko, & Saiz, 2001), describing the ongoing densification of urban environments due to the availability of urban amenities and productivity gains. The continuous growth in population, the rise of new technology and opportunities, as well as the needed energy and urban-mobility transition to decrease pollution and improve sustainability are the main challenges policy makers and importantly for this paper automotive stakeholders face.

Long-term visions for transportation have always been shaped by bold claims and high expectations. While the 20th century visionaries predicted travel in nuclear-powered jetpacks, solar-powered helicopters or flying cars, reality has seen a much more lethargic and gradual disruption of current transport systems and technologies. Currently everything points towards the future of vehicles being electrically powered (BEV). In order to meet stringent emission regulations, and changing consumer perspectives, a move away from internal combustion engines is a necessary measure to stay competitive and carry on selling thousands of cars yearly.

As will be clarified in the next chapter, the overwhelming evidence for the German automotive industry market it no different; it is rooted to electrical motorisation. This emerging trend of the battery electric vehicle (BEV), is the critical element to this research. Given the infancy of the BEV industry plenty of noise and uncertainty surrounds the fact that all the major players (VW, Audi, Mercedes and BMW) are investing billions of euros into electrical technology, signifying to the world that this is the superlative and possibly only approach to alleviating global emissions. Yet it is also a strategy that entails huge risks, leaving very little room for error or deviations from this electrical trend. Hence, the remainder of this paper is going to adopt this inclination of electrical motorisation within the German market and focus on evaluating the supportive arguments against the hinderances to be negated in order to define another era of unprecedented success of German car making. The central research question, will consequently be formulated as follows:

To what extent is the German automotive industry's move towards the electrification of its vehicle fleet a logical decision?

Scientifically this research is relevant given how central these discussions on future mobility and sustainability are for many political agendas. This paper will bring together the perspectives and challenges of all parties involved (consumers, producers and governments). The social relevance is equally critical to the debate. For consumers particularly, the lingering presence of diesel bans in inner-city areas and the uncertainty surrounding the switch to electrical vehicles or other forms of transport necessitates clear and intuitive answers which this paper will aim to provide.

The remainder of this report will entail a theoretical framework, describing the mechanisms behind a SWOT analysis that will be conducted to answer the central research question. Following that, the results in the form of strengths, weaknesses, opportunities and threats for the German automotive industry will be discussed before a conclusion will be constructed, evaluating the key insights from the analysis and answering the central research question.

2. Theoretical Framework

2.1. Trends behind the electric vehicle

Significantly reducing Carbon dioxide (CO_2) and Nitric oxide (NO_x) is evidently the principal reason why ICE vehicles needed to be replaced by a cleaner source of motorisation. According to a (J.P.Morgan Chase & co, 2018) report, by 2046 the worlds electric vehicle fleet will topple 1 billion cars which will mean that by 2050 80% of all vehicles will be electrically powered. The graphic gives a clearer indication of the ambitious route that the automotive industry is embarking on by embracing electrical thrust and phasing out internal combustion engines (ICEs). Both battery electric vehicles (BEVs) and hybrid electric vehicles (HEVs) - cars that combine a fuel engine with electric elements showcase a steadily growing market (*Figure 1*). By 2025, BEVs and HEVs will account for an estimated 30% of all vehicle sales. By comparison, slightly less than 1 million vehicles or 1% of global car sales came from plug-in electric vehicles (PEVs) in 2016. A decade later, by 2025, these figures will rise close to 8.4 million vehicles or a 7.7% market share according to J.P. Morgan. Furthermore, estimates anticipate a jump from merely 3% of global market share to more than 23% (25 million vehicles) of global sales for all HEVs over the same time period. Consequently, ICE vehicles will have around 70% of the market share in 2025. By 2030 this is predicted to fall to around 40%, largely in emerging markets.

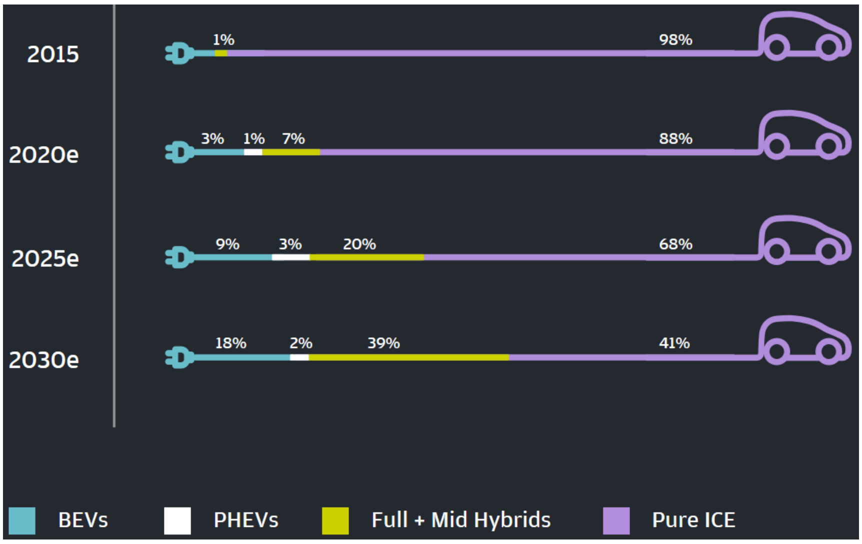


Figure 1 - Global Electric Vehicle Forecast. Source: J.P. Morgan estimates

Evidently, vehicles with either a partial or fully electric engine have been deemed the solution and are envisioned to reach the 4th stage of McKinseys' disruptive trend graph (*appendix 2*) sooner rather than later. This paradigm shift from combustion engines to electric propulsion has occurred in part due to technological advancements such as the high recharge capacities of Lithium-ion batteries and falling costs in battery production, but also through other singularities that have forced the hand of car manufacturers to radically change their long-standing approach to car production. The ensuing trends are all factors contributing to the huge electric vehicle momentum emerging in Germany, which now boasts Europe’s second-largest BEV market, outperformed only by Norway (Hertzke, Müller, Schenk, & Wu, 2018).

2.1.1. Substantial Investment

The total investment in electric vehicles from the German Industry amounts to almost €140 billion. Around €72 billion of them flow within the Federal Republic, the large remainder will be invested for the Chinese market (Lienert & Chan, 2019). Volkswagen for example, the largest automotive manufacturer in the world, is currently revamping an entire factory in Zwickau in order to produce up to 100 000 fully electric vehicles yearly from 2020 onwards (Capital, 2019). Further factories in Emden and Hannover will be revamped to produce solely VWs electric fleets. The group plans to spend $34 billion on e-mobility initiatives and $57 billion on battery procurement through 2025. Furthermore, 50 battery electric and 30 hybrid electric models are to be introduced by 2025, including 12 electrified models for Audi. Ultimately, 300 fully electrified versions will be offered from its 12-brand global portfolio (Manager Magazine, 2018). Daimler plans to electrify the entire Mercedes portfolio by 2022. In every Mercedes series there will be at least one electrified model, with a dozen of them being fully electric. The group announced that €10 billion will be invested in the expansion of the Mercedes electric fleet over the next few years. Another billion will go into a global battery production network to build six battery factories on three continents (Menzel, 2019). Daimler plans to unveil 130 electrified vehicles, including hybrids and fuel cells, by 2030. Electric vans and heavy trucks will be added to its fleet. Its Smart brand will be entirely electric by 2020 (Lienert & Chan, 2019). BMW desires to present 12 new battery electric vehicles and 13 plug-in hybrids over the next 6 years. €340 million will be invested in a Leipzig BEV plant and €225 million in a Munich battery plant. Additionally, the company is cooperatively investing €770 million with partner Great Wall to build Mini EVs in China (Lienert & Chan, 2019). According to the Federal Government by 2020 around 1 million BEVs, rising to 6 million 2030 will be on the roads in Germany (Netze BW, 2019).

2.1.2. Synergies

A key factor driving this paradigm shift of phasing out ICEs and focusing resources on BEVs and HEVs is the so-called Deutschland Allianz (Gulde & Mayer, Kommt die große Deutschland Allianz?, 2019). The development costs of electric vehicles are, as described previously exorbitant, yet it is essential for the likes of Mercedes, BMW and the VW Group to still make positive returns. This means, the previously unthinkable notion of forming synergies and developing cars together is a critical step to overcoming stagnating sales, boundless development costs and shrinking profits whilst also mitigating the risks of investing so much on one technology. Baik, Hensley, Hertzke, & Knupfer (2019), estimate that a BEV, costs OEMs[1] roughly €12,000 more to produce than comparable ICEs in the small- to midsize-car segment and the small-utility-vehicle segment. This stems predominantly from the fact that batteries make up one third of the cost of an electric vehicle (Goldie-Scott, 2018). Clearly through collaboration among the German car manufacturing giants from Stuttgart, Munich, Ingolstadt and Wolfsburg, economies of scale can be achieved, and costs significantly reduced. BMW and Daimler have already initialised a joint procurement strategy for E-components and battery cells. Furthermore, VW CEO Herbert Diess is advocating for his southern German rivals to share the same modular electronic construction kit for the BEV fleets, which would bring in billions of euros in savings.

Aside from keeping cost bearable, synergies are also vital to protect themselves against growing competitive pressure from the US and China. A bundling of forces is necessary to deal with competition from firms such as, Google, Amazon and Tesla, to name a few. All of whom are getting progressively involved in the mobility business and either benefit from first mover-advantages (Tesla) or substantially deeper pockets of funding (Google & Amazon). Hence, new potential partnerships with competitors are being formed to share R&D, tooling, and production costs for new BEV platforms, autonomous driving and other platforms such as ride sharing.

According to McKinsey, BMW and Daimler could save between 1500 and 2000 dollars per Vehicle from developing and utilising the same E-Platform which can substantially boost margins. Clearly the firms still want to maintain their renowned identities, thus

[1] Original Equipment Manufacturers, car manufacturers throughout this paper

maximum differentiation amongst visible components will be coupled with maximum commonality of standard parts (such as the E-Platforms) to preserve a brands personality (Kacher, 2019).

Over the last decade, both Daimler and BMW expanded into a new line of business by providing mobility service in the form of their ride-sharing platforms Car2go and DriveNow. A recent fusion of services between the two Southern-German car-making giants, followed by a combined €5 billion investment means around 60 million customers will have to get used to new services in a bid to counter platforms such as Uber and Google. ReachNow, ChargeNow, FreeNow, ParkNow and ShareNow are the names of the new services surrounding driving, renting, parking or charging (Gulde & Mayer, Kommt die große Deutschland Allianz?, 2019). BMW-Chef Harald Kruger proudly considers this cooperation with Daimler as a step towards becoming champions together and starting the future of mobility (Kacher, 2019).

In another bid to illustrate their seriousness encompassing future mobility issues, BMW and Daimler together with Audi acquired Nokia's navigation service Here (Gulde & Mayer, Kommt die große Deutschland Allianz?, 2019). Although the reaction to the attack of tech companies, such as Waymo[2] with their autonomous driving and *Robotaxi* programmes, arrived late, the German car makers are now showing that they are ready to make up for lost time. The common platform not only saves money on development, but also creates standards for the entire industry as it has become the central networking tool for automated vehicles and fast charging stations for electrics cars in Europe. The quality of the service increases with the number of cars involved, meaning that for newcomers it is increasingly difficult to catch up to the level of growing expertise acquired by Here (Kreimeier, 2018).

Yet mergers and ensuing synergy creation in the Automotive industry can also get very messy as a recent attempt between Fiat Chrysler Automobiles (FCA) and Renault shows. At the beginning of June 2019, the two firms looked on course for a 50-50 merger that would have created a $35-billion global auto giant and the 3rd biggest car manufacturer in the world (DeBord, 2019). It was a deal that would have enabled FCA and Renault to better develop electric vehicles and self-driving cars, whilst also improving the flat

[2] Subsidiary company of Alphabet, originally the self-driving car project within Google

European and struggling Chinese markets. Ultimately the nature of French government's involvement in the deal, who owns 15% of Renault, led to negotiations being torn apart. The French state had pleaded for more influence over the merged company, stringent job guarantees for French workers and better terms for Renault shareholders (Reuters & Bloomberg, 2019).

2.1.3. Regulation

Lingering and costly bans are the last factor that have driven this rapid change to electrification of fleets. If German car manufacturers fall short of the EUs strict regulatory targets, they have to make a trade-off decision: accept a penalty or absorb the cost of lowering their fleet emission levels. As can be seen in *Figure 2*, a McKinsey calculation shows that automakers are likely to be better positioned if they take an approach to "comply" with instructed levels, thus avoiding penalty payments. Fines could be up to 70% more expensive, relative to investing in cleaner technology indicating that OEMs are likely to pursue regulatory compliance by investing in carbon dioxide abatement technologies such as hybridization, electrification and expanding the BEV infrastructure (Knupfer, et al., 2017). Furthermore, with cities such as Berlin creating "green zones," where drivers of higher-emission vehicles are forced to pay steep fines if they enter these zones mean that the German OEMs will need to offer cleaner vehicles if they are to retain their customer base.

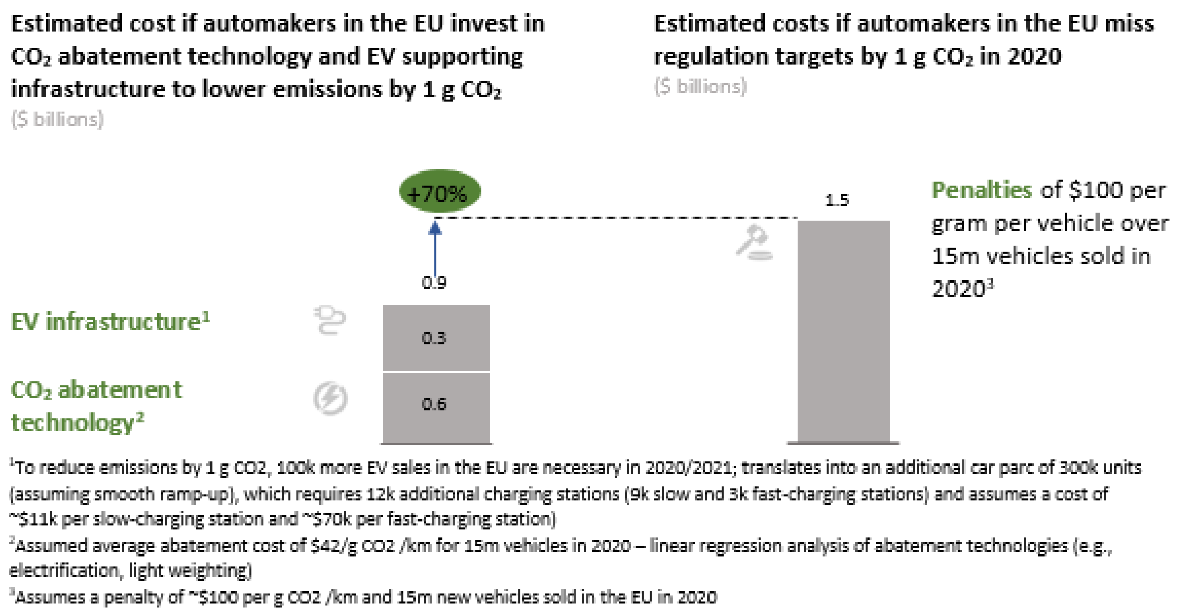


Figure 2 – CO_2 penalties relative to investing in necessary infrastructure and technologies. Source: McKinsey Sustainable Mobility Initiative, European Commission

2.1.4. Mobility as a Service

The advent of mobility as a service (MaaS) which include autonomous cars and ride-sharing services will have a central role to play in the success of the BEV, according to Randall (2016) from Bloomberg New Energy Finance. MaaS represents the ultimate form of integrated mobility and ideally offers a variety of services such that customers are convinced to no longer need to own a private vehicle (Mingardo & Witte, 2018). The growth of this market is highly dependant on factors such as e-hailing, car sharing and P2P car rental, yet these concepts are still in their infancy in Germany and need time to develop and establish themselves (see chapter 3.2). Although reduced private vehicle ownerships through increased availability and quality of mobility services might be considered catastrophic for the automotive industry, MaaS also represents an enormous market for the OEM's if they can convince themselves to become players in this lucrative environment. Existing platforms such as Uber and Lyft require their vehicles to drive more than 30,000km yearly, which is good news for BEV manufacturers, given that battery packs become increasingly economical with distance driven. Thus, if these services can further grow and expand their markets, then German car manufacturers could greatly boost their BEV sales and expand their own respective market shares.

2.2. SWOT analysis

A common framework used to evaluate a company's competitive position and to develop strategic planning is referred to as a SWOT (strengths, weaknesses, opportunities, and threats) analysis. It is intended to enable a realistic, data-driven technique to essentially assess the performance, risk, and potential competition of a business or even an entire industry as is the case in this paper. The SWOT analysis will aim to provide greater understanding to current and future developments of the German automotive industry in light of their seemingly irreversible decision to invest so heavily in the electrification of their vehicle fleet. Ultimately, the conclusions drawn from this SWOT analysis render on a given level of uncertainty given the number of factors, which are presently still developing, that need to be accounted for and the overall volatile nature of this electric vehicle industry in its relative infancy. This analysis is likely dealing with level 3 uncertainty in terms of the future outcomes according to Walker, Hassnoot & Kwakkels (2013) uncertainty matrix (*Appendix 3.1*). It allows for the ranking of possible future outcomes based on perceived likelihoods. *Table* 1, below, depicts the SWOT matrix with the key factors central to the near-future developments of German automotive industry placed in their relevant quadrants.

Table 1 - SWOT analysis matrix

Strengths: • Hybrid Engines • Mobility as a Service • Driving Bans • Leasing policy	Weaknesses: ▪ Environmental impact – at present ▪ Policy - charging infrastructure ▪ Costs & affordability ▪ Manufacturer business model ▪ Consumer misconceptions
Opportunities: • Charging infrastructure • German energy mix • Consumer preferences • Solid-state batteries	Threats: ▪ Alternatives to the BEV ▪ Resource scarcity ▪ Taxation

3. Strengths

3.1. Hybrid Vehicles

A major benefit for the automotive industry has been brought about through hybrid vehicles. They pave the way for electric vehicles in two major ways. Firstly, introducing hybrids to the market has familiarised consumers with the performance and overall feeling of driving with electrical power. Notably, the instant acceleration from a standstill is something only a few internal combustion engines can match. Secondly, competences are developed in decisive areas such as batteries, electric motors, and other electric drive components when developing and manufacturing hybrid vehicles. Furthermore, they loosen the stranglehold of petroleum on consumers and have set a high standard in terms of fuel economy and emissions. Hybrids started the paradigm shift away from fossil fuelled engines and encouraged improvements in electric drive trains and battery technologies (Turrentine, Delucchi , Kurani, Sun, & Heffner, 2006).

Notably, the plug-in-hybrid[3] (PHEV) with a modern diesel[4] combustion engine presents itself as the most suitable and flexible option of the near future. They can be charged like standard BEVs, allowing for a fully electric range of 50 – 70km which is easily enough to cover the daily commute (Germans drive 40,9km on average per day) especially if charging can occur at the workplace. For journeys over longer distances the diesel engine will jump into use. The latest estimations predict that PHEVs will be equipped with an electric range of up to 130km, quite a substantial distance, within the next 1-2 years (Mayer & Stegmaier, 2019). Two drawbacks of the Plug-in are the significantly higher prices that manufacturers charge for these engine variants and the issue that they require most driving to occur in full-electric mode and consistent recharging. Otherwise, the efficiency balance tilts and they end up consuming significantly more than a regular non hybrid vehicle due to the increased weight of their battery packs (Dralle & Leicht, 2019).

3.2. Mobility as a Service

The concepts and merits of MaaS for the automotive industry, especially with regards to electric mobility were already introduced earlier in the paper. Hence, three specific and enticing MaaS models that are presently developing on the German market will be analysed below. All of which have the potential to boost the automotive producers' ability to grow and market the reputation of their electric vehicle fleets.

<u>E-hailing & (shared e-hailing)</u>: is essentially the on-demand hiring of a private (shared occupancy) car using an app; allowing for one (multiple) group(s) of riders matching with one driver. Fleet managers of such hailing services are likely to prefer BEV models over ICE models given their lower total cost of ownership. Automakers are therefore encouraged to offer fleet operators more competitive sales/leasing options that point to lower operating costs of BEVs compared to ICE variants.

The German market for such e-hailing services is clearly still in its very infancy, as demonstrated by Gawron, Keoleian, De Kleine, Wallington, & Kim (2018) study which shows that 73% of Germans have never used such services. 20% use them rarely and only 7% of use them on a weekly basis. Around 27% of the consumers that have experienced ride-hailing services question their need to own a vehicle in the future which

[3] three other variants of the hybrid engine exist: mild hybrid, full hybrid and range extender hybrids
[4] gasoline engine versions also exist and are often slightly cheaper but showcase a less optimal fuel economy when driven non-electrically

demonstrates the capacity of this market for Germany (Canaan, 2017). While Uber and MyTaxi exist sporadically in Germany, the first and only proper provider of Ride Hailing services is CleverShuttle. A fundamental difference to the former two providers is that CleverShuttle employs only electric and hydrogen vehicles. The fleet, thus, does not contribute to the traffic noise, and drives with green electricity. CelverShuttle further differentiates itself from Uber by making pooling an integral part of its service. This means that users do not decide whether they want to be transported alone or not, rather algorithms constantly strive to achieve the best possible utilization of the vehicles to increase efficiency and reduce the overall traffic (Ginnuth, 2018).

Car sharing: on demand short-term car rentals (monthly- or mileage base subscriptions) with the vehicles owned and managed by a fleet operator. Subscribers of such programs could be incentivized to choose BEVs, perhaps by being offered free charging as part of the service. This business model negates the need for consumers to pay substantial upfront prices for a BEV whilst offering customers a flexible vehicle choice dependent on need (HEVs and ICEs would still exist for long trips). Although automakers do not sell BEVs directly to consumers they are still able to guarantee electric vehicle volumes are achieved (and included in zero-emission vehicle mandates and fleet-wide emission targets).
Car sharing is already available in 740 locations throughout Germany, provided by around 170 different car sharing providers where more than 2.46 million Germans are registered (14% increase from 2018) (Spiegel Online, 2019). Share Now (car2go and DriveNow), the recent merger of BMW and Daimler is by far the biggest car sharing provider in Germany. Flinkster (provided by the Deutsche Bahn) and Cambio are other notable providers. Small- and medium-sized cities often only have one provider that organizes car sharing, whilst larger cities have a variety of providers, Berlin alone has more than 10 such services (Car-Sharing News, 2019).

P2P (peer-to-peer) car rental: consumers can share individual vehicles on individual platforms. Given that private vehicle utilization is only around 4% in Germany, P2P car rental allows BEV owners to share their owned vehicle to offset the higher upfront cost of such a car with more specifications such as larger batteries. Furthermore, vehicles with higher utilization rates encounter lower maintenance, energy, and driver costs. Through partnering with, or providing, a platform for such BEV car rentals, car manufacturers could significantly lower the cost barrier for buyers who cannot justify expensing so much on an electric vehicle without additional income from a P2P platform. Tesla owners already have such platforms available to them. In Germany this form of the sharing economy is growing in recognition. A recent survey by Gossen, Flick, Henseling, & Bätzing (2016) finds that consumers find the resource saving potential, financial benefits and social impact particularly convincing. Ecological benefits of peer-to-peer sharing are also evident to most respondents and viewed positively. The biggest obstacles remain the uncertainty regarding the trustworthiness and reliability of peers as well as legal ambiguities that exist in P2P networks.

3.3. Driving Bans

A further positive development from the perspective of BEV sales are the driving bans that are being implemented throughout German cities. Hamburg, Frankfurt, Berlin and Stuttgart already have bans for diesel cars with diesel norms lower than Euro 5 set up in certain areas of the cities. Many other cities are likely to introduce these diesel bans in 2019, such as Mainz, Aachen, Köln and Bonn (Hägler, 2018). It is becoming apparent that even modern diesel cars up to and including class 6c could be affected by driving bans in the near future. Of course, estimating the dynamics of this development is difficult but the bans will certainly increase the appeal of electric engines for many future buyers.

3.4. Leasing Policy

For leasing contracts, typically used by firms, a better solution seems to have materialised to stimulate demand for BEVs. Normally, a company car user has to pay monthly taxes on one percent of the vehicles list price as a non-cash benefit. For electrified cars only half a percent will have to be taxed in the future. A 50,000-euro-expensive car, such as a Tesla Model 3, is linked to €250 in taxes, whereas a similarly valued combustion vehicle would be burden with twice that amount (Hägler, 2018). Given that roughly 800,000 cars are sold to corporate customers every year in Germany, this market could become a significantly influential factor for the BEV market.

4. Weaknesses

4.1. The Environment

The discussion is as old as the electric vehicle itself: Are BEVs genuinely cleaner than vehicles with internal combustion engines? It is commonly believed that the harmful gases produced are merely emitted from the power plant vent instead of the exhaust and that during battery production, more CO_2 is produced than a BEV will ever be able to make up for in driving distance over its lifetime. While there is merit to both these thoughts, the truth does paint a more positive picture of electric vehicle emissions. It is important to make two distinctions when evaluating the impact on the environment of the BEV. This distinction lies between the pollutants that are harmful to humans - such as Nitric Oxide (NO_x) and particulate matter with CO_2 which does not harm living beings but is considered to be the main cause of climate change.

0.44 grams of Nitric Oxide (NO_x) per generated kilowatt-hour occur with the current German electricity mix (Umweltbundesamt, 2016). A BEV that consumes 18kWh[5] per 100km indirectly emits 79 mg/km, which would easily meet the strict Euro 6d-Temp-Norm[6] (168 mg/km).

The case is a little more complex when examining the contribution of BEVs to particulate matter. Not merely the combustion engine causes the particulate matter but also abrasion of brakes, tires or asphalt and the constant stirring up of the particles by passing cars (Gulde, Ist das E-Auto wirklich umweltfreundlicher?, 2019). According to investigations by the (Bundesanstalt für Umwelt , 2018), in the province of Baden-Württemberg 85% of the PM-10[7] fine dust is turbulent abrasion. Clearly BEVs can swirl up just as much of this matter as ICEs. Nevertheless, some physicians consider the ultrafine particles of engines to be more dangerous than the coarser abrasions. However, a reliable assessment by the Federal Environmental Agency is still lacking. The assessment of particulate pollution in the air is currently only carried out in Europe by the mass of PM and not according to the frequency or chemical composition of the particles

Evidently the air in densely populated cities would benefit from more BEVs. Yet the carbon footprint of a BEV does not look as rosy as the EU often likes to make out. The predominant factor in this is Germany's energy mix, which will be described later in chapter 5.2. Essentially the more the country manages to move away from fossil fuels for its power generation the cleaner the electric vehicle is going to become. Yet the first problem is that

[5] average consumption for current electric vehicles ceteris paribus (ADAC, 2018)
[6] European emission standards define the acceptable limits for exhaust emissions of new vehicles sold in the European Union and EEA member states.
[7] particulate matter with a diameter up to 10mm

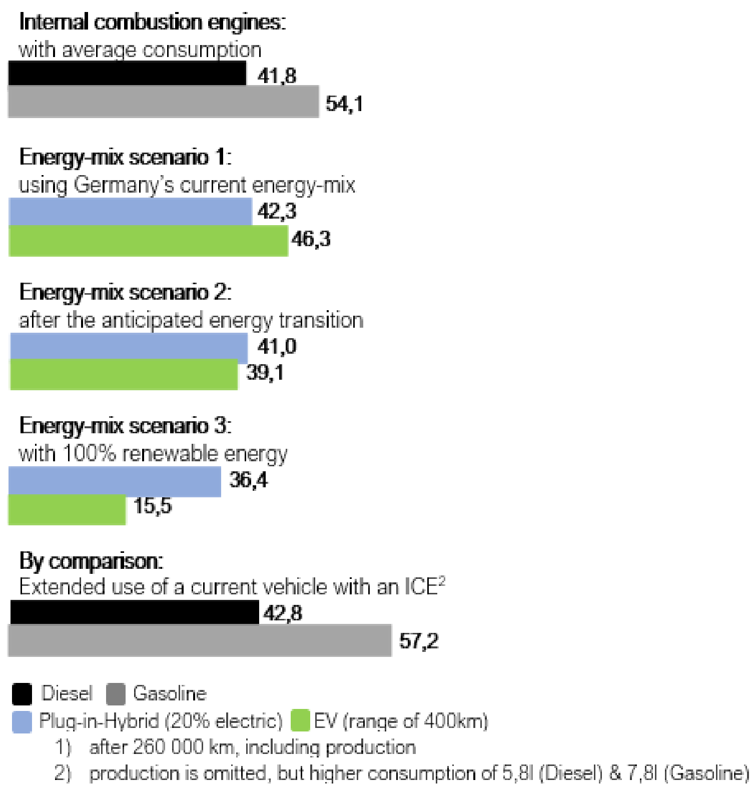


Figure 3 - Overview of CO_2 emissions (in tonnes) for new fossil- and electric fuelled cars in different scenarios. Source: (Heidelberger Institut für Energie- und Umweltforschung, 2018)

the larger the battery capacity to maximise driving range the more energy is required during production. Given that currently most batteries for the German OEMs are produced in countries such as China, who still generate power mostly through fossil fuels, the ecological advantage of the BEV over alternatives decreases rapidly. This means that BEVs with short driving ranges of around 100km (less battery capacity) would represent the best option. This represents a problem, given that most German consumers demand vehicles to drive at least 400km before needing a recharge. In fact, given Germany's current energy mix, *figure 3* illustrates that modern diesel engines will have emitted around 5 tonnes less CO_2 into the atmosphere than a BEV (with a range of 400km) after 260 000 driven kilometres including production (Heidelberger Institut für Energie- und Umweltforschung, 2018). Only if the planned energy transition is further fostered by the government (energy-mix scenario 2) will faint advantages in favour of plug-in-hybrids and the BEVs appear. Should Germany foresee a complete energy revolution and generate power 100% through renewable sources, then the BEV truly shines as the lowest polluter (energy-mix scenario 3). Otherwise, as the bottom of the figure indicates there is little that speaks against extending the use of current diesel engines. The bottom line is that about twice as much CO_2 is produced in the production of a BEV compared to standard ICE vehicles. Additionally, the bigger the battery, the greater the CO_2 burden becomes, emphasising the need to drive Germany's energy transition (Gulde, Ist das E-Auto wirklich umweltfreundlicher?, 2019).

4.2. Policy – charging infrastructure

According to Randall (2016), governments offering incentives to lower the costs of electric vehicles or developing charging infrastructure is essential if the industry is going attract a large and diverse customer base. Hertzke, Müller, Schenk, & Wu (2018), agree to this notion of government action being a central tool.

Currently there are around 16,000 charging points for electric vehicles, of which 75% are operated by energy providers (Bundesverband der Energie- und Wasserwirtschaft , 2019). Yet with the introduction of the German calibration law (Eichrecht), from April 1, 2019, charging stations can only be billed for correctly measured kilowatt hours. Suitable devices however, to complete this measuring and billing processes according to the new law do not exist.

This means that the pioneers of the industry are being punished, who, under their own initiative placed high levels of investment into this charging infrastructure. Of course, the costs of retrofitting the charging columns must be carried out by each operator of a charging device, approximated at several thousand euros per charging station (Bender-Napp, New laws are slowing down electromobility, 2019). It is hardly surprising then, that the adaptation to charging stations compliant with new laws have been hampering the market for a while now, given that barely anyone dares to invest. That's not all, since by 2021 charging stations must also be equipped with a BSI-compliant measuring system. These so-called smart meter gateways will enable safe charging and billing processes in compliance with data protection rights. But again, technical solutions for this technology are currently not in sight. In a sense these new laws are praiseworthy, they are attempting to create transparency and conformity in a presently chaotic charging environment. The overwhelming feeling remains though that the introduction of these new laws is slowing down the German electromobility market.

This is without having even mentioned the other hurdles that exist. For example, all co-owners of property have to agree for a private charging point to be installed in a collective parking garage. For installing such stations on private property, network operators first have to carry out prerequisite checks. The situation is no different for public charging stations, where numerous regulations and permits have to be met and obtained - from the location feasibility and grid connection contract to the building permit (Bender-Napp, New laws are slowing down electromobility, 2019).

Purchase premiums showcase a slightly more positive, even if not entirely successful, initiative of the German authorities to stimulate the BEV market. Despite the German Federal Office of Economics and Export Control offering a state-sponsored environmental bonus, since 2017, for purchasing an electric car, the market breakthrough has not materialized as expansively as envisioned. The positive side effect is of course that half the funding pot (€600 million) remains for further subsidies. Officially, the program runs until June 30th, 2019, which is a hinderance given that only now are suitable electric cars becoming available, yet the program is coming to an end. However, given the often-lengthy delivery times for pure electric cars, the Federal Government is considering extending this deadline. For pure electric vehicles a bonus of €4000 is paid out to the buyer, for hybrid vehicles €3000 is paid out. Luxury cars with a list price of more than €60,000 are excluded from the promotion (Balser & Gammelin, 2016).

4.3. Costs & affordability

Although this section presently still stands as a weakness for car manufacturers, it must be approached with caution. Given the rate of investment and technological breakthroughs that this industry has already experienced over a short period of time, it is conceivable that costs of BEVs could match those of ICEs. One manner in which BEV are already cheaper than their ICE counterparts is in terms of maintenance costs. Based on a comparison of five BEVs across five automakers, BEVs typically had 20-40% lower five-year maintenance costs than similar sized and branded ICEs (Knupfer, et al., 2017). Currently however, the notion still stands that for the BEV to become truly competitive, the cost of batteries must come down significantly (Randall, 2016). Technological breakthroughs and ingenious suppliers could accelerate the segment's profitability even further until the early to mid-2020s (Hertzke, Müller, Schenk, & Wu, 2018).

As can be seen in *figure* 4 (next page), from 2010 to 2016, battery pack prices reduced by approximately 80% from ~$1,000/kWh to ~$227/kWh. In 2018 alone they fell by 35% (Goldie-Scott, 2018). Current forecasts put BEV battery pack prices below $190/kWh by the end of the decade, and suggest the potential for pack prices to fall below $100/kWh by 2030 (Knupfer, et al., 2017). Essentially this places unsubsidised BEVs on a trajectory to make them as affordable as their gasoline counterparts in the next six years (by 2025), which could well induce the start of a real mass-market launch of the electric vehicle. The story of falling batter prices is twofold, as it will likely translate into lower costs in other production practices thanks to the economies of scale those extra sales will unlock.

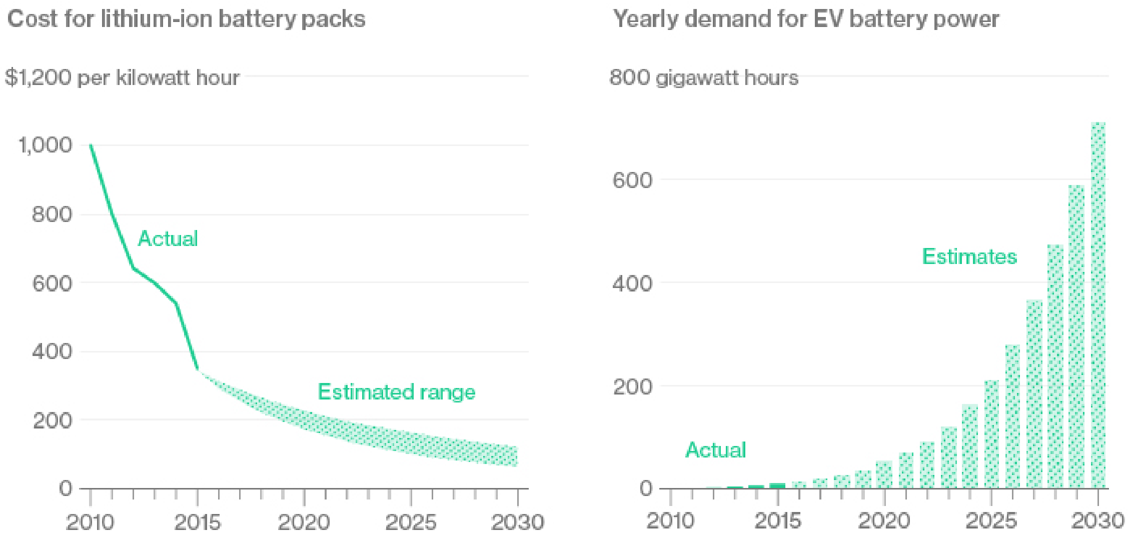


Figure 4 - Trajectory of battery costs. Source: (Goldie-Scott, 2018)

The average new car price for Germany in 2018 climbed above the € 30,000 mark for the very first time. On average, according to German Automobile Trust (DAT), the Germans spent €31,130 on a brand-new car. The investments in used models was €11,780 on average over the last year (Deutsche Automobil Treuhand, 2019). The most popular German electric vehicles currently available are the BMW i3 (€37,550 & 200km range), Mercedes B Class (€39,200 & 200km), the VW e-Golf (€35,900 & 300km), and the electric Smart (€22,000 & 160km) (Reuß, 2018). The prices listed are those with the most basic specifications and smallest battery packs. Any desires to increase the driving range or include other specifications will results in thousands of euros in additional costs. Clearly these prices, especially factoring in the low driving ranges and rather modest vehicles sizes are very expensive compared to their ICE counterparts.

4.4. Manufacturer business model

Tied closely to the previous section is a notion of acceptance from a producer perspective. In 2017 an Ernst & Young (EY) evaluation indicated that car manufacturers roughly have a 6 – 11% margin on their vehicles sold. BMW were found to be the most profitable car maker world-wide with an achieved margin of 10.8 % (Szymkowksi, 2018). This image is expected to change, at least temporarily, with the introduction of BEVs where the profit margins are razor thin at present. Some analysts believe that losses are even made by certain manufacturers with every BEV produced (Frost, 2018). German car manufacturers must be able to accept extremely low profit margins for the coming years (Randall, 2016). Frank Lindenberg, Chief Financial Officer of the Mercedes division, added to this notion by stating that their electric models are likely to be only half as profitable as the ICE version they are replacing (Frankfurter Allgemeine, 2017).

Another important adjustment which may have to be made in order to save profitability is for automakers to consider waiving car dealerships. The classic car dealer with large yards acting as an intermediary between manufacturer and customer may have as little future in the world of electric cars as the printed newspaper, the CD or the phone booth. Currently the likes of BMW, Mercedes and VW incur costs of around €4000 – €7000 on dealer margins and incentives (sales incentives) (Viehmann, 2018). By implementing a direct sales model, such as Tesla does, customers can configure and order their cars exclusively online and then pick them up at delivery centers. It is only a matter of time, before even the most traditional of manufacturers move towards an online marketplace to save thousands of euros per vehicle.

Autonomous driving:

Electric propulsion systems seem perfectly aligned to the needs of autonomous driving, which is widely predicted to feature heavily in future urban mobility (Mccauley, 2017). It is being heavily driven, amongst others, by the German vehicle manufacturers who are embedding increasingly more sensors and safety-focused technology in their vehicles to incrementally inspire consumer confidence and acceptance of this technology. Autonomous vehicles (AVs) are thought to be able to reduce labour costs by requiring less drivers, operate 24/7 which lowers parking requirements, allow for more efficient route planning through high connectivity and improve road safety and consequently congestion. (Gordon, 2018)

Similar to the reasoning behind the advantages of electric engines for car-sharing services, the high usage rate of AVs increases the economic appeal of electric cars. The two technologies are very complementary, not only because any up-front battery costs are likely to be shared (AVs less likely for sole private use) but also since it is easier for computers to drive electric vehicles. Furthermore, a study conducted by Gawron, Keoleian, De Kleine, Wallington, & Kim (2018) claims that the added weight of AVs (due to various sensors and cameras) has a more substantial negative effect on gasoline-rather than for electric vehicles. More importantly, the study argues that the reason AVs will align with EVs is that these will help reduce transport emissions significantly, which is critical in the eyes of policymakers. Moreover, while in the short-term autonomous technology will increase emissions, once integrated effectively with BEVs, the technology becomes a benefit rather than a burden. Rather unsurprisingly then, autonomous fleets of electric vehicles are already being proposed by companies such as GM and Uber (Mccauley, 2017).

From a German OEM perspective, automation needs to be approached with a certain degree of scepticism. In terms of this technology they have fallen so far behind tech firms such as Waymo, Amazon and even Uber. The front runners remain Waymo, who thrive on their first-mover advantages from their dedicated launch to focus on automation almost a decade ago (Setzer, 2017). Waymo is now driving almost 1 million miles per month and has accumulated 8 million miles since inception, according to their CEO John Krafcik (Silver, 2018).

The first traditional carmaker to follow these tech giants is General Motors, who is believed to have accumulated around 16,370 autonomously driven kilometres which is vastly less than Waymo. Bosch, Mercedes and BMW are the leading the German market, with merely 1,600 autonomously driven kilometres (Setzer, 2017). This is about one-hundredth of what Waymo has to offer, and the frequency of human interventions is significantly higher. If Alphabet were to buy a small car manufacturer for Waymo in the near future, the need for the cooperation which presently exists would vanish. Essentially, the value chain would be complete. Morgan Stanley estimates that Waymo's value, purely based on the immense number of kilometres driven and resulting future sales, at $ 70 billion – which is more than the stock market value of BMW.

The German automotive manufacturers delayed entry to this market, and their resulting fall behind the industry standard, presents a substantial and unique problem for an industry, that for so long was always the pioneer itself. Recent investments signify the belief to turn this situation around and that reaching level 5 autonomy is a marathon, not a sprint. In early 2017, Audi founded its own development company for reinventing driving, named "Autonomous Intelligent Driving" GmbH (AID) which works on behalf of the entire Volkswagen Group (Becker, 2018). BMW soon followed suit by building an "Autonomous Driving Campus" last year, where all automation levels (3,4 &5) are developed simultaneously. 1800 specialists will work there for the Munich based company and their own data center with currently 120 Petabyte of storage evaluates all test fleet information to make it available for simulations (Becker, 2018).

4.5. Consumer Misconceptions

The latest edition of the mobilty report conducted by the Deutsche Automobil Treuhand (2019) paints a slightly less appealing picture about the suitabilty of BEVs. As depicted in appendix 4.1, a limited range and high acquisition costs are the major drawbacks of purchasing a BEV. 60% of new-car buyers and 55% of used-car buyers are turned off by the limited range. The high initial purchase prices are slightly less concerning for new-car buyers (53%) than for used-car ones (68%). Other reasons[8] to abstain from BEVs include long charging times (41%), insufficient charging infrastructure (39%), less driving enjoyment (22%), a preference for combustion engines (12%) and uncertainty about the safety of battery packs (12%).

Knupfer, et al. (2017) find that a subgroup of potential buyers in Germany are concerned about higher maintenance costs for BEVs despite fewer moving parts coupled with slower and less fun driving experiences compared to ICEs. Consequently, the authors suggest tools such as educational campaigns should be implemented to proactively address such views and other misconceptions including vehicle/brand type availability, performance/handling and warranties.

From the previous section, the merits of autonomous driving are apparent, yet the German population in general are still very sceptical about the technology, especially with high levels of autonomy (Canaan, 2017). Appendix 4.2 exemplifies this statement, which shows that the Germans appreciate some forms of autonomy, such as adaptive cruise control or lane centering technology, as long as they are still in control of the vehicle. This agreement with autonomous driving falls drastically below (30%) for limited- and full self-driving technologies amongst respondents (Giffi, Vitale, Robinson, & Pingitore, 2016). Furthermore, only around 30% of Germans strongly agree with wanting full self-driving automation, with the change in consumer preference for these vehicles actually decreasing by 2.8% since 2014. Both these findings place the Germans far below other

[8] The percentages provided reflect those of new-car buyers

leading innovative nations such as the US, Japan, South Korea and China in terms of consumer acceptance of this technology. Aside from playing catch-up with Waymo, Uber and Tesla and developing a roadworthy technology, the German car manufacturers are clearly further challenged to convince their customer base to buy into these automated technologies, especially when they are extremely unwilling to pay extra for such systems (Giffi, Vitale, Robinson, & Pingitore, 2016).

5. Opportunities

5.1. Charging infrastructure

By the end of 2018, nearly 200,000 electric vehicles had been registered in Germany. Only slightly more than half of them were plug-in due to the significant increases in demand for purely battery-powered cars. Clearly these BEVs and HEVs registrations are expected to exponentially grow over the next decade as will the number of charging stations throughout the country. The Alternative Fuel Infrastructure Directive (AFID) of the EU Commission and the National Platform for Electromobility (NPE) indicate conflicting figures for the necessary ramp-up of the charging infrastructure. The AFID wants to see 207,888 public charging points in Germany by 2025, while the NPE believes 143,966 will be sufficient (Schwarzer, 2018). Either way both figures represent vast increases over the next 6 years compared to the current figure of around 16,000 charging points. In addition to this, Ionity plan to install hundreds of high power (350kW) charging stations in Germany, which will allow a full recharge to take between 20-30min - around 7x quicker than currently (ADAC , 2019). This progress raises the daunting question of whether the German power network can cope with such substantial electricity demands.

It is not the pure amount of electricity that is the problem, rather its distribution. For the most part, the power grid is designed especially in the low voltage level and thus focused on a completely different consumption behaviour than is required for E-mobility. It is conceivable, that if several vehicles are connected at the same time during evening hours, the peak loads could easily rise to the critical range. For grid operators, the challenge now is to modernize the power grid and adapt it to the new consumption behaviour that e-mobility demands. (Bender-Napp, Reicht der Strom für die Elektromobilität, 2019). Despite this, the project “E-Mobilty-Allee” has shown that even in areas with older technology, problems do not necessarily have to occur because of this additional stress on the network (Bönnighausen, 2019). In Germany, all network operators are however obliged by law to carry out network expansions, if necessary.

More importantly, it is critical to make use of intelligent charging management for BEVs in the future, which aim to distribute the electricity evenly. For example, if several cars are parked all night, they could be charged either one after the other or with much lower voltage. According to an Oliver-Wymann analysis the network expansion would actually be surplus to requirement if at least 92.5% of BEVs would be charged intelligently (Oliver Wyman, 2017). In principle then, there is enough power for everyone. Nevertheless, if the technology for its distribution is not modernized and intelligent energy management not used, then it becomes conceivable that the German power grid will become exposed.

5.2. The German Energy Mix

The overarching goal is that by 2050, Germany wants to source 80% of its electricity from renewables, mainly from wind turbines and photovoltaic systems. As depicted in *figure 5,* Germany's energy-mix is still heavily reliant on fossil fuels. 37% and 13% is still generated from coal and gas respectively with nuclear power also making up around12% (Statistisches Bundesamt , 2018). Whilst 33% renewable energy might be deemed promising in comparison to other global powerhouses such as the US and China, it simply isn't nearly enough for a promising future of the electric vehicle. Hence Germany's commitment to switching its energy supply fundamentally to renewable energies and dealing with energy more efficiently is praiseworthy. Currently, wind energy comprises around a third of the renewable energy sector, with biomass and photovoltaics

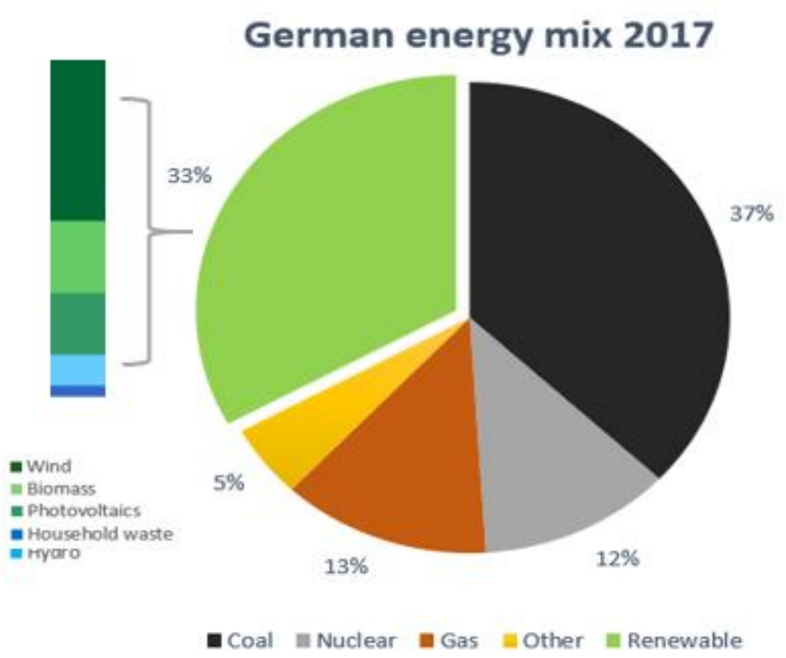


Figure 5 - Share of energy production in gross electricity production, in percent. Source (Statistisches Bundesamt, 2018)

making up round 12% each. In 2015, €15 Billion were invested in order to set up a new energy infrastructure and carry out energy-efficiency measures, that is three times more than in the early 2000s. Furthermore, by the end of 2022, the eight nuclear power plants currently still supplying electricity will be shut down (Federal Foreign Office, 2018). Although Frank-Walter Steinmeier, Federal Minister for Foreign Affairs, likened Germany's energy transition to getting the first man to the moon, there is reason to be optimist about this transition. Renewable energy already provides over 60% of Germany's electricity supply at certain times, and this share will continue to increase in the coming years. The various renewable sources complement each other. Pilot projects have shown that it is possible to combine power generation from the various types of plants, thus enabling them to provide a far more reliable supply of electricity. At times when there is no sunshine or wind, storage systems will bridge the gap during such periods in the future. Transnational grid expansions and the integration of what were previously separate regional electricity markets in Europe are also bringing about greater stability and flexibility in Germany (Federal Foreign Office, 2018).

5.3. Consumer preferences

In a nation like Germany, where the pride of driving the world's best automobiles has always played a substantial role, consumer preferences regarding the electric vehicle are likely to be a major determinant of future success. Randall (2016), believes that German customers will need to be acceptant and willing to pay more to drive electric in the future. According to a recent McKinsey study, a large gap exists between perceived and real-world "range anxiety" and charging availability. Despite a natural positive bias from BEV owners, the data from respondents in the US and Germany suggests that potential BEV buyers are 46% and 39% more anxious about driving range and charging availability respectively, compared to BEV owners (Knupfer, et al., 2017). This presents an opportunity to be exploited by the automotive industry. Hertzke, Müller, Schenk, & Wu (2018) indicate that a rising customer acceptance of the electric vehicle is forming in the German market.

Consumer likelihood to purchase a BEV increased from 20 to 40% when they were able to choose a model with a Tesla badge (first mover advantage) over other premium or volume car brands such as VW or Mercedes. Yet in terms of "trust," traditional brands remain the most compelling. 80% of customers would prefer buying a BEV from an established OEM, which serves as a promising sign for the German industry (Knupfer, et al., 2017). The quality and diversity of the BEV fleet is another important aspect for possible customers.

The McKinsey Sustainable Mobility Initiative (2016) gives a description of the German near-term (5-10year horizon) electric vehicle buyers. As can be seen in appendix 5.1, the three up-and-coming consumer segments are the “mainstream mobility seekers,” “mass premium seekers,” and “low-cost performance,” all of whom demonstrate high BEV consideration today. These near-term buyers have lower household incomes than early adopter and thus less costly, purpose-built BEVs with smaller battery packs and shorter ranges are appealing to them (appendix 5.2). They live mostly in urban settings and travel 40 to 55 km on average per day, thus easily within the achievable range of current BEV models and 20 to 30% less than consumers from the suburbs. This is positive news for manufacturers given the present state of the technology. While pricing remains an issue, catering for modest range requirements and altogether smaller, compact vehicles is well within the current capabilities of the industry. This is seen in models such as the VW E-Up, ID and BMW’s electric Mini being released within the next year. The horizon of long-term buyers of BEVs extends beyond the scope of this paper, yet it can be noted that these consumers have higher expectations for vehicle range, performance, and features and are unlikely to pay significant premiums.

The latest McKinsey consumer research on vehicle electrification indicates that today a large share (44%) of prospective new vehicle buyers in Germany consider purchasing a BEV model (*Figure* 6).

Figure 6 - Percentage of consumers that identify themselves at each purchase funnel stage. Source (Knupfer, et al., 2017)

Whilst the early adopters of BEVs were predominantly focused on high-tech features and sustainability, the perceived benefits are broadening to the potential buyers. Acceleration and driving performance, features that the German car industry has always excelled in, are among the primary benefits of buyers when considering BEVs. Other benefits include decreased engine noises, avoiding fuel stations and lower fuel costs (Knupfer, et al., 2017). Such positive consumer preference developments are all long standing characteristics of brands such as Audi, BMW and Mercedes enabling them to extend their expertise in driving and material quality for their electric models.

5.4. Solid-state batteries

Solid-state batteries, although not yet scalable and still confined to the lab, are the latest technological development which could significantly enhance the BEV landscape and certainly represent more of an opportunity for the industry than a threat. Lithium-ion batteries use a liquid electrolytic solution to regulate flow, whilst solid-state batteries use a solid electrolyte. This allows for smaller battery packs to be produced, with a higher energy density, longer lifespan, and increased safety as they are completely inflammable. Solid-state batteries theoretically could store twice as much energy as a lithium-ion battery, which would make an electric range of 800km very feasible (Gonzalez, 2018). Moreover, charging times can be significantly reduced with these battery types. Additionally, solid-state batteries, unlike lithium-ion ones, can be produced largely without toxic or questionable substances (Tempel, 2018). Volkswagen recently formed a joint venture with the Californian start-up Quantum Scape, to test the industrial production of solid-state cells over the next two to three years. Herbert Diess, CEO of the VW group, says it is essential that in the long run, the company doesn't become reliant on a few Asian manufacturers for such technologies. The technical developments are already promising, resulting in a pilot project to be conceivable from 2022/23, and series production is likely from around 2024/25 (Ecomento , 2018).

6. Threats

6.1. Alternatives

There are strong cases to be made for many alternatives to electric vehicles that do not receive enough attention or merit by the German automotive industry. Of course, there are significant drawbacks to all of the following concepts, but as has been made pretty clear already, the BEV isn't a flawless package itself. Fuel Cell Electric Vehicles, which run by burning hydrogen and oxygen offer arguably the cleanest form of motorisation. Unfortunately, extremely high production costs and little infrastructure deter significant investment in these vehicles.

According to researchers at Bosch, synthetic fuels or E-fuels, represent a bright alternative to the electric vehicle. One of their studies indicates that E-fuels can make a noteworthy contribution to attaining climate targets if they are steadily used in passenger vehicles. Given that the use of arable land is not required for production, these fuels do not compromise agricultural land. Instead, E-fuels are produced exclusively with renewable sources of energy as well as with the combination of hydrogen and carbon which can be combined to make synthetic gasoline, diesel, and kerosene. From vintage cars to family vehicles, every car with a combustion engine can run on synthetic fuels. Moreover, future synthetic fuels can allow for almost soot-free combustion (Ruth, 2017). Furthermore, they are compatible with the current infrastructure and engine generation, meaning that a high degree of market penetration would take far less time than electrifying the existing vehicle fleet.

Despite the afore mentioned promise, substantial efforts are still required before synthetic fuels become established. Pilot projects surrounding synthetic diesel, gasoline, and gas are currently underway in Norway and Germany. The main issues are that the processing facilities are very costly and only a few test plants exist. The German Ministry for Economic Affairs and Energy has consequently supported the research into synthetic fuels as part of its alternative energy initiative. It is believed that the widespread use of these E-fuels will be helped by the growing availability, and thus falling prices for electricity from renewables. It is envisioned that if favourable developments occur synthetic fuels could become available for €1-1.40 per litre, plus taxes.

If the breakthrough is made, the results could be revolutionary. Bosch experts believe that by 2050, the use of synthetic fuels, in Europe alone, as a planned supplement to electrification could save up to 2.8 gigatons of CO_2. This represents three times Germany's carbon-dioxide emissions from 2016 (Robert Bosch GmbH, 2017)

6.2. Resource scarcity

There exist persistent fears that with the rapid growth in electrical mobility that the worlds natural resources required for lithium-ion batteries will become exhausted. Yet the overwhelming evidence point towards that necessary extraction rates will be more constraining than total amounts. Given the rapid expansion of electric propulsion systems, not just in BEVs has analysts worried that production levels won't be able to keep pace with the scramble for lithium. Lithium ion battery consumption increased by 73% from 2010 to 2014, whilst production levels only augmented by 28%. The number of cell-producing factories, such as Tesla's in Nevada, with more than one gigawatt-hour of battery production capacity per year – has expanded to over 20 today. In 2014 there were only a handful such factories. At this rate lithium demand could be doubled or tripled by 2030 according to many analysts (Göß, 2018). It seems that there is little risk of lithium supplies running low in an absolute sense but rather that lithium won't be recovered and made available quickly enough to meet the rising demand. Bloomberg New Energy Finance (BNEF) reached the same conclusion. They believe that until 2030, battery packs will require less than 1% of the known reserves of lithium, nickel, manganese, and 4% of copper reserves (Goldie-Scott, 2018). Beyond 2030, BNEF does however envision lighter, smaller and cheaper battery packs through new chemical compositions.

The distribution of lithium is very divided, meaning a great trade imbalance is to be expected in the future (Grosjean, Miranda, Perrin, & Poggi, 2012). *Figure* 7 (next page) illustrates the global distribution of lithium resources. Clearly Europe, and notably the German industry, is at risk of becoming a victim of this geostrategic bottleneck. The industry is the largest-expected consumer of lithium but has virtually no own resources. South America on the other hand will benefit hugely and turn into a full exporter, due to lack of inner consumption, of low-cost salt-lake brine-based lithium carbonate. Australia, Asia, and North America are likely to have trade amid their production and own requirement. China will benefit from its proximity to Russian hard rock minerals deposits to extract its required Lithium. Grosjean et al. (2012) find that despite the technological breakthrough of BEVs the current state of resources shows that there is no danger for the planet to run out of lithium. Yet, as already mentioned, the authors believe that lithium shortages are likely to arise and threaten the BEV market supply, especially given how geographically concentrated the resources are. Furthermore, it seems that the scale adaptation of current production facilities is not in line with current lithium demand.

Hence for the electric vehicle industry to exist and last sustainably, their paper suggests stockpiling strategically, adopting long-term supply contracts and exploiting the uncharted lithium rich brines and ores in an environment friendly manner.

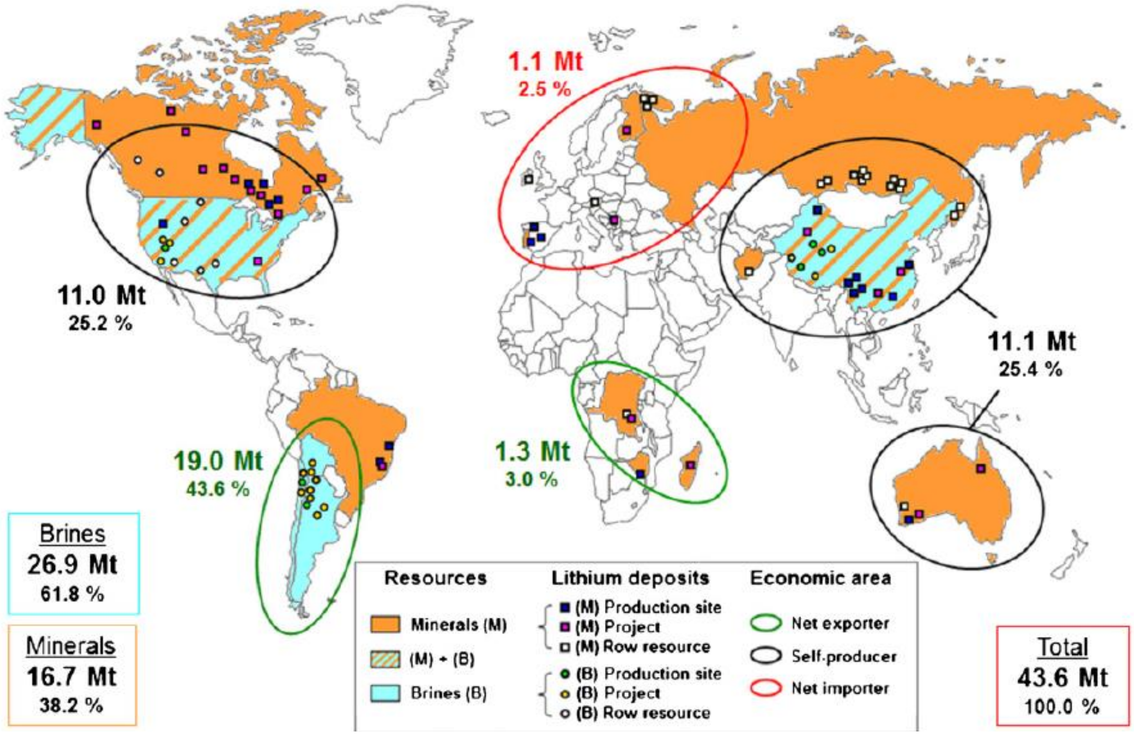


Figure 7 - Global lithium resource availability and geostrategic impacts. Source: (Grosjean, Miranda, Perrin, & Poggi, 2012)

Kushnir and Sanden (2012) take a slightly more critical stance towards the availability of lithium. They state that it would be a mistake to look at lithium resource stocks and conclude that there is enough of it as this also hinders recycling efforts. Thus, policy support may be essential to aid effective recycling, because only then would resource exhaustion become a non-credible threat. Some automotive manufacturers, such as BMW and Daimler, are already actively involved in second-life repurposing of batteries (Curry, 2017). This paper again reiterates the importance of time dimensions. Given lithium's dependency on a polarized selection of producing countries, problems encompassing the required rate of lithium flows, will occur well before any resource limits are reached (Kushnir & Sanden, 2012).

6.3. Taxation

Energy taxes have always been a major source of revenue for the German government. Given that it is the largest federal tax, the state finances a significant part of its expenditures with it. The share of energy taxes in the entire federal budget in 2017 was at around 12.5%. Last year (2018), €41 billion euros were collected, representing its highest level in 14 years. Gasoline and diesel represented 90% of the tax intake with the remaining 10% being split between natural gas and heating oil (Birger, 2018).

In the not so distant future however, this federal income will decline with the success of the electric vehicle. Hypothetically, if all BEVs were to replace ICEs then the revenue from the energy tax would fall by 90% according to Christian Küchen, the Chief Executive of the Petroleum Industry Association (Birger, 2018). While such a large share of electric cars is at least unlikely for the next decades, the difference in taxation is nevertheless huge. Currently, at a consumption of 15 kilowatt hours per 100 km, the state receives €31 cents of electricity taxes from a BEV. A conventional car with a fuel consumption of 6 litres per 100 km earns the state a revenue of €3.93. Evidently the higher the proportion of BEVs, the greater the losses in energy taxes become - according to the current state.

Summerton (2017), believes that there are two options for governments – either to increase existing fuel duty or introduce new taxes for motorists. He believes, the short-term option would be to increase the rate of fuel duty because of advantages such as incentivising consumers to buy cleaner cars; handicap the use of the most polluting cars and negate having to increase taxes on income, employment or consumption. In the long-term road pricing schemes present the best option as the author believes it not only replaces ever falling energy tax revenues but can also discourage road travel and thus congestion to grid-locked urban areas (Summerton, 2017).

Edmund King, the AA's president in the UK recently proposed a road pricing scheme, whereby drivers would be given an 'allowance' of 3,000 miles per year free of charge. Any distance driven beyond that amount would be charged. He noted that BEV owners, or drivers from rural areas would receive a greater allowance of tax-free mileage. (Wiltshire, 2018). Another benefit that arises from mileage taxing, is that in the long-term, it allows for a simpler implementation of dynamic pricing. With standard fuel taxes this is impossible, however with road pricing it would be relatively straightforward to introduce a mileage tax that varies by location and hour-of-day (Davis & Sallee, 2019).

Prior (2019), believes that the simplest form of road pricing comes through utilising the vehicle itself. All the latest BEVs will of course be registered and connected, probably with some app, meaning the car will know precisely how much electricity you 'filled up' with

each month. The source of power is irrelevant as long as the vehicle can keep track of recharging occurrences, which can then be easily taxed at flat and fair rate. The hardware necessary for this is inside virtually every electric car that comes to the market (Prior, 2019).
Another debatable topic is the substantial tax disparity between gasoline (65,45 cent a litre) and diesel (47,04 cent). Professor Claudia Kemfert from the German Institute for Economic Research (DIW) believes a diesel tax increase (to the level of gasoline) is long overdue and the higher revenues collected could be used to expand the charging infrastructure for BEVs (Das Elektroauto- & E-Mobilitäts-Portal, 2019).

7. Conclusion

Throughout this analysis many factors have been portrayed that will shape the electric future of the German automotive industry. Clearly some factors are more critical than others and have the potential to either disrupt the paradigm shift or foster an unforeseen acceleration of the market.

First and foremost, the nation's energy mix and charging infrastructure represent the backbone of future success. The great challenge is to restructure the electricity market. Germany has started a reform process in this field and put the first measures into practice, where ensuring flexibility is vital. All actors in the electricity market must react as well as possible to the fluctuations in the electricity generated by wind and solar energy. At the same time, there must be competition between the various balancing options in order to keep the overall costs low and truly move towards 100% renewable energy. It seems conceivable that Germany is on a very good track in this regard, especially compared to other world powers such as the US or China.

Electrified cars and charging infrastructure are a classic marketplace business, where a balance between supply and demand should be made. If the charging infrastructure is lacking, the manufacturer actually only has half a product to offer to the end customer (Setzer, 2017). Presently however, given the size of the country and disrupting policies the expansion of the charging grid has been slow. This is still a major stumbling block of the industry and one can only hope that the government will resist complicating matters further. Yet, increasing cooperation between the German OEMs and start-ups such as Ionity are accelerating the expansion process to diminish charging concerns by future consumers. These processes need to be further stimulated through the installation of thousands of additional charging points coupled with smart charging solutions in order to diminish range and practicality anxieties whilst complying with the capabilities of the German electricity network.

Evaluating the environmental aspect of the electric vehicle remains slightly ambiguous. Urban air quality benefits greatly from the electric vehicle but given that it takes years for the BEV to compensate for the CO_2 disadvantage of its production it cannot be deemed the climate neutral solution that many policy makers proclaim it to be. Currently then, the BEV is not yet a notably cleaner solution than modern ICEs and it is certainly hampered by practicality problems in terms of sparse charging opportunities. Thus, for frequent travellers of large distances, which is by no means uncommon in Germany, diesels (presently) remain the best manner with which to do so (Capital, 2019). However, in the (near) future the German energy grid will become increasingly powered by renewable energy sources, meaning BEVs will automatically become greener and greener.

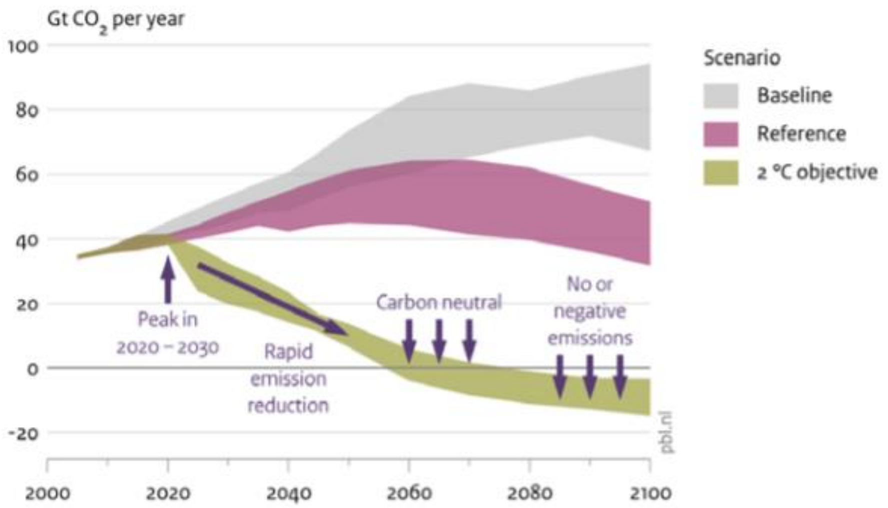
Notably, the tech giants from America and increasingly from China too, represent lingering concerns to the German industry. The fact that Amazon and Google have no plans to build their own fleet of vehicles for their respective parcel- delivery and ride-sharing services was once considered good news for the OEMs. Yet if the core of engineering no longer stems from carmakers, it will quickly become irrelevant if the chassis comes from Fiat-Chrysler, Kia, or China. It will signify that the carmaker has slipped a step lower in the food chain, to a supplier. A major advantage of Google, Amazon and co. is that their apps are already running on most phones. Thus, it takes little further imagination for the idea of Google Maps not only calculating a route, but also ordering a Robotaxi to take you to your destination. Against such heavyweights, mergers and strong cooperation's, which luckily are occurring, seem to be the only viable alternative for the German OEMs. Numerous and differing small apps will stand no chance against the established tech-firms of the Silicon Valley.

The same is true for electromobility. Battery cells are presently derived almost exclusively from Asian manufacturers. This means that currently the German carmakers can focus on establishing know-how and building factories in order to exploit the next generation of energy storage, expected for 2025 in the form of solid-state batteries. Such batteries would allow the range of VW E-Golf to increase from 300 km to about 750 km (ADAC , 2019). Yet, if breakthroughs stall, a heavy reliance on the Chinese market for battery-packs will persist which presents a disastrous scenario for the Germany industry. The same is true for the extraction of lithium which likely to create trade tensions as demand rises. Germany's position is a vulnerable one is this regard as it is completely dependent on other nations for this resource once the OEMs increase their own production of battery packs. Long term trade deals will need to be negotiated smartly, especially with South American mass producers in order to maintain a stable supply chain.

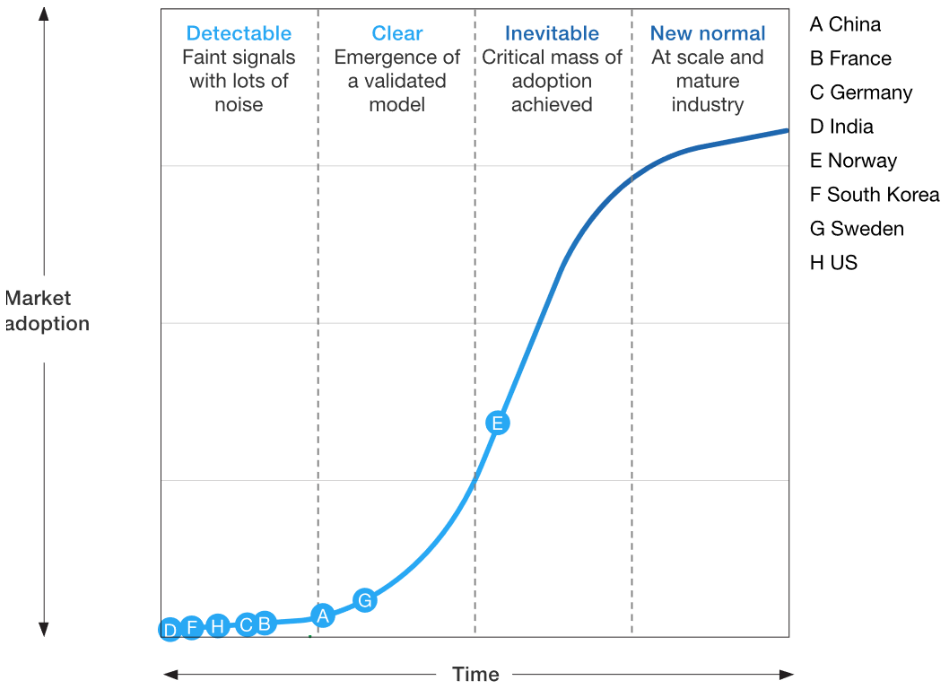
In conclusion then, it remains immensely difficult to draw up a concise answer to the question of whether the German automotive industry's decision to electrify its fleet represents a calculated decision. As was made clear throughout the paper, numerous factors, many of them surrounded by high uncertainty, will shape the future of this industry. Overall the drive to electrify, resulted from the lingering bans for needing to produce a cleaner fleet of vehicles and the acceptance to form synergies with longstanding rivals in order to reduce costs and spread the risks of this new technology. The main weaknesses come in the form of complicated policy, expensive prices of BEVs and a slow start into autonomous driving concepts. The latter two issues will diminish rapidly once economies of scale kick-in and new competencies materialise from the substantial investments made. One can only hope that the German government will stimulate rather than hinder developments moving forward. Both the opportunities and threats for this market are difficult to assess without knowing future developments. If the manufacturers can continue their high success with modern combustion and hybrid engines, this will present a strong platform to phase the electric vehicle into the market and consolidate its industry market share. Ideally, research and development in alternative propulsion systems such as synthetic fuels and hydrogen will be carried out simultaneously, but all alternatives carry many risks and uncertainties alike and the costs are no less substantial. Thus, given the need for immediate cleaner solutions to the traditional ICE, the decision to electrify seems, at least presently, to be a correct and comprehensible one. A very interesting and highly complicated matter to observe will be the manner in which the government will recuperate lost tax money through diminishing diesel and gasoline sales. The arousal of new costs placed on consumers through new taxation schemes for BEVs could have detrimental impact on the industry. As of yet however, no forecasts on the scale or manner of such taxing schemes can be made.

8. Appendix

Appendix 1: Global CO2 emissions. Source: (Tavoni, et al., 2015)



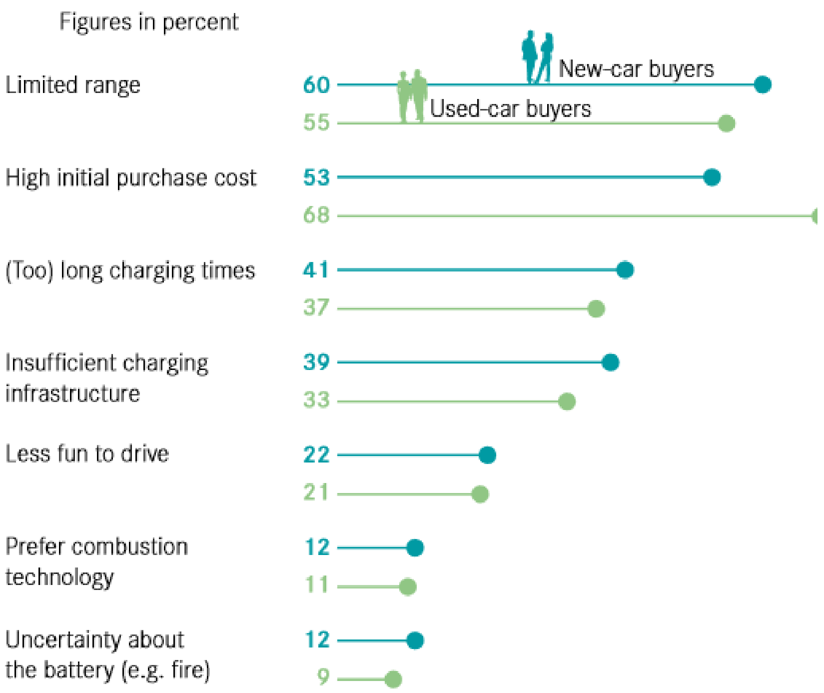
Appendix 2: The 4 stages of a disruptive trend – focus on electric-vehicle market adoption. Source: (Bradely, Hirt, & Smit, 2019)



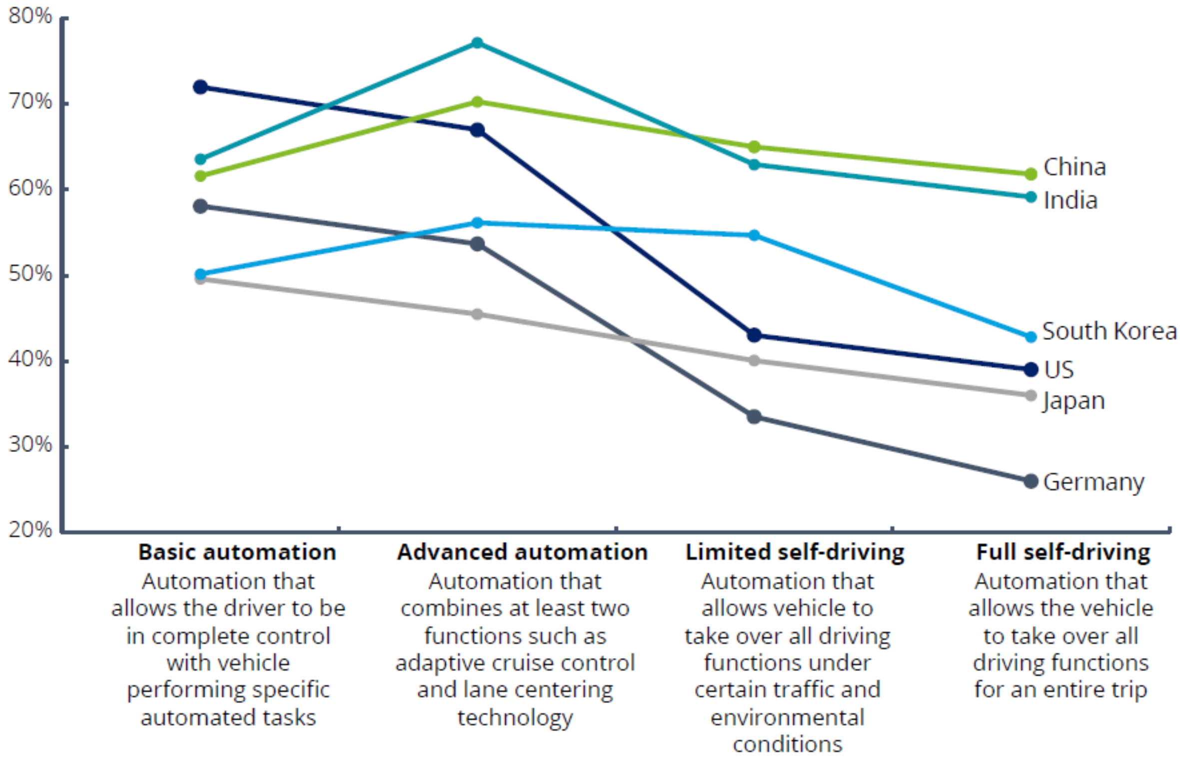
Appendix 3.1: Uncertainty Matrix. Source: (Walker, Haasnoot, & Kwakkel, 2013)

		LEVEL					
		Complete Certainty	Level 1	Level 2	Level 3	Level 4	Level 5	Total ignorance
LOCATION	Context		A clear enough future	Alternate futures (with probabilities)	Alternate futures with ranking	A multiplicity of plausible futures	An unknown future	
	System model		A single (deterministic) system model	A single (stochastic) system model	Several system models, one of which is most likely	Several system models, with different structures	Unknown system model; know we don't know	
	System outcomes		A point estimate for each outcome	A confidence interval for each outcome	Several sets of point estimates, ranked according to their perceived likelihood	A known range of outcomes	Unknown outcomes; know we don't know	
	Weights on outcomes		A single set of weights	Several sets of weights, with a probability attached to each set	Several sets of weights, ranked according to their perceived likelihood	A known range of weights	Unknown weights; know we don't know	

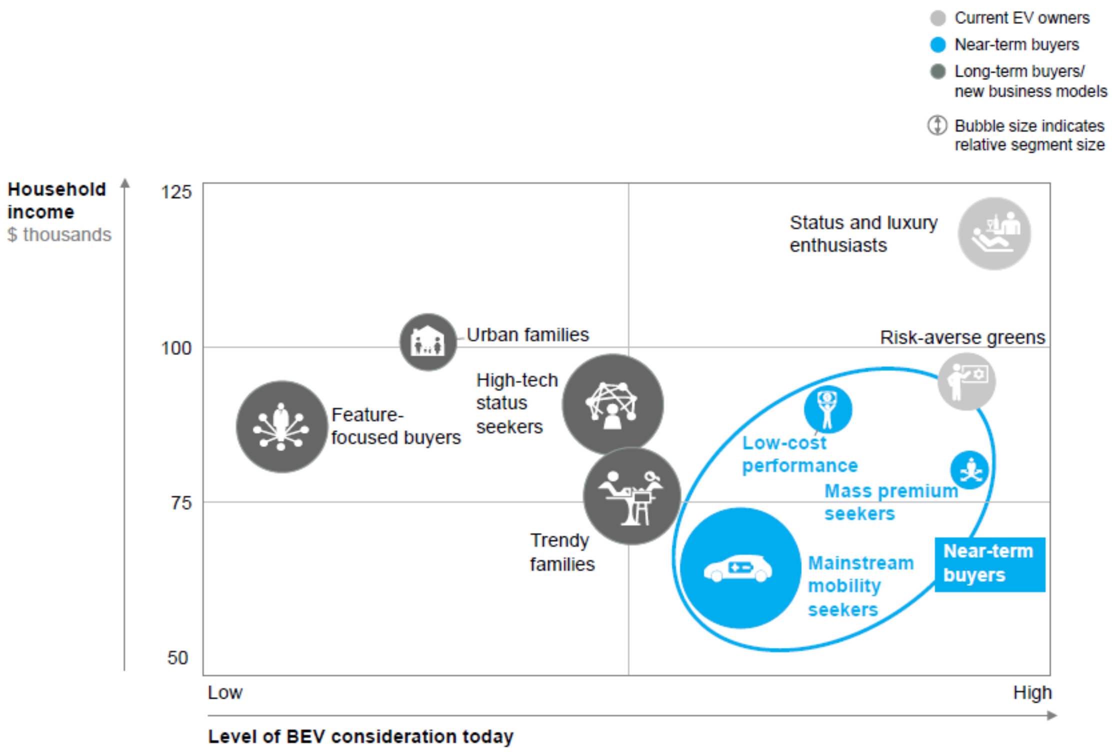
Appendix 4.1 BEVs – main reasons not to buy one in 2018. Source: (Deutsche Automobil Treuhand, 2019)



Appendix 4.2 Consumer level of agreement with different levels of vehicle automation. Source: (Giffi, Vitale, Robinson, & Pingitore, 2016)



Appendix 5.1: Consumer segments likely to increase electric vehicle ownership. Source: (Knupfer, et al., 2017)



Appendix 5.2: Three consumer segments of near-term buyers. Source: (Knupfer, et al., 2017)

Segment	Living area(s)	Average daily commute	Importance of ... Range	Tech-nology	Branding/ design	Perfor-mance	Potential EV offering
Mainstream mobility seekers	Urban areas	25 miles	Medium	Medium	Low	Medium	Low-cost small EV with reduced battery size, lower performance, and fewer advanced tech-nology features as standard
Mass premium seekers	Urban areas	30 miles	Low	High	High	High	An entry-level EV model from a premium brand with good performance and style, used primarily for short commutes
Low-cost performance	Suburban/urban	35 miles	Medium	Medium	Low	High	"No frills" mass-market brand EV with good driving performance at an affordable price

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