A normative analysis of subsidization of all-electric vehicles in Germany

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May 2019

Abstract:

The German government undertook several supportive measures to increase market penetration of all-electric vehicles (AEVs), e.g. a purchase rebate of 4000 Euro. In this paper, the fiscal measures are analyzed from a normative perspective. First, none of the arguments of market failure could be found to validate government intervention. In a first-order approximation of damage cost savings, the reduced external effect through driving, due to the displacement of internal combustion engine vehicles through AEVs, was found to be 5 times lower than the expenditures through the subsidy. Adding climate cost savings, total lifetime savings from driving equal the subsidy. However, considering life-cycle impact and additional subsidies, the purchase rebate cannot be justified. Secondly, German industrial policy could also not serve to justify government intervention. The purchase subsidy does not directly qualify for the industrial policy argument and private investment in battery technology and the charging infrastructure is established and preferred. Finally, allocating the true costs to each transport mode and thus internalizing the external effects is suggested as the approach of first-choice. For vehicles it is suggested that certificates have to be held by fuel suppliers, who then pass the price for pollution on to the end user. This provides an efficient and effective market solution to mitigate climate change and pollution effects and can increase AEV market penetration, if this is socially beneficial.

I. Introduction

Road transport is a significant source of air pollution and greenhouse gases that are associated with global warming. It is, in fact, considered the main cause of air pollution in cities (European Commission, 2016). The WHO (WHO, 2016) estimates, that ambient air pollution causes 3 million premature deaths worldwide every year in 2012, a number that rose to 4.1 million in 2016 (WHO, 2018). Road transport contributes about 25 per cent to urban ambient air pollution from $PM_{2.5}$ (particulate matter of size smaller or equal to 2.5 microns in diameter) (Karagulian et al., 2015). $PM_{2.5}$ is in return believed to be one of the most ambient available contributors to ambient air pollution and often functions as a general indicator for an air pollution mixture (WHO, 2015).

To alleviate impacts from road transport, an expanding list of governments are planning to ban sales of Internal Combustion Engine Vehicles (ICEV) within the next 15 to 20 years (e.g. Norway in 2025, Germany, the Netherlands and India in 2030; China, Great Britain and France in 2040), even though -up to date- no binding policies are in place yet (GTM, 2017 and 2018; CCP, 2018). The alternative to ICEVs is seen in Plug-in electric vehicles (PEV), which combine Plug-in Hybrid Vehicles as well as all-electric vehicles (AEVs). All-electric vehicles (AEVs) have a large potential benefit in terms of reducing the air quality - and climate impact of road transport, particularly in cities. AEVs operate fully through use of an electric motor, powered by a battery. Therefore AEVs have no internal combustion engine and thus zero local tailpipe emissions.

Needless to say, the overall environmental and air-quality benefit of AEVs depends on the lifetime emissions of AEVs, which include emissions during vehicle and battery production, vehicle operation, and disposal. The lifetime benefit of AEVs in comparison with Internal Combustion Engine Vehicles (ICEV) is still heavily discussed (Buchal, et. al, 2019; Hajek, 2019; Wietschel, et al., 2019; Hall and Lutsey, 2018).

The lifetime emissions during operation depend on the cleanliness of the electricity provided for charging the batteries. But even if emissions are high during electricity generation or battery production, the local clean air effect within the city remains. Through the process of urbanization, most of the population is exposed to ambient air pollution within cities, which are also highly motorized. The net health benefit through locally cleaner within-city air is expected to be positive, as air quality improvements are associated with a reduction in illnesses and premature deaths (Tessum et al., 2014; Nopmongcol et al., 2017; Reiter and Kockelman, 2017). Air quality as well as climate benefits of AEVs can be improved by increasing the amount of non-fossil feedstocks used for electricity generation (REN21, 2016).

Despite these potential benefits, current market penetration is still small. Worldwide there were about 1.2 million AEVs in the market in 2016 (IEA, 2017a), raising to almost 2 million in 2017 (IEA, 2018). In 2018, another 1.4 million new AEVs were sold, a 70 per cent growth (Kane, 2019). This has to, however, be compared to total of about 1.3 billion cars in use worldwide (OICA, 2017), giving AEVs a market share of 0.26 per cent. Market penetration stays behind political targets in many countries due to costs of ownership, limited range of AEVs, sparse charging infrastructure and long charge times.

See table 1 for an overview of charge times, range, energy consumption and prices. As of 2016, there is a wide variation in AEVs (see for the following Battery University, 2016). On the lower end of the spectrum (e.g. Mitsubishi iMiEV) driving range on battery life is about 85 km with charging times of 7 to 13 hours. On the high end (e.g. Tesla S) is a range of 360 km and charge times of about 30 minutes.

Table 1: Comparison of exemplary low end, mid range and top end AEVS as of 2016.

AEV	Charge times	Range[1] (fully charged)	Energy consumption (kWh/km)	Price (standard fitting)
Mitsubishi iMiEV	13h (115 VAC) 7h (230 VAC) 30 minutes fast charge[4]	85 km (16 kWh battery)	19,0	≈ € 23,000[3]
BMWi3	4h (230 VAC) 30 minutes (SC)[2]	135 km (22 kWh battery)	16,5	≈ € 35,000[5]
Nissan Leaf	8 h (230 VAC, 15A) 4h (230 VAC, 30A)	160 km (30 kWh battery)	19,0	≈ € 34.385
The Tesla S 60	30 minutes (SC)[3]	275 km (60 kWh battery)	22,0	≈ € 69,000[6]
The Tesla S 90	30 minutes (SC)[3]	360 km (90 kWh battery)	24,0	≈ € 89,000[7]

Source: own depiction based on information from Battery University (2016).

1: Range and kWh/km are estimated under normal, non-optimized driving conditions.

2: charged to 80 per cent with 50 kW Supercharger

3 charged to 80 per cent with 120 kW Supercharger

4: see Mitsubishi Motors (2017).

5: see BMW (2017).

6: see Tesla (2017).

7: see U.S. News (2017).

8: see Nissan (2017), battery can be rented with monthly payments, which results in a price discount of € 6000.

In order to reach higher market penetration, many countries, including Germany, have fiscal incentives to drive down the costs of ownership and to support the

use of AEVs. Germany is the largest car market in the European Union and, as such, is a representative example for the market conditions of AEVs in Europe.

The political target of Germany is manifested in the *National Electromobility Development Plan* published by the German Federal Government in August 2009 (Bundesregierung, 2009). It stipulates a goal of bringing a fleet of one million electric vehicles on Germany's roads by 2020. As of January 2017, 34,022 AEVs were registered in Germany, accounting for less than 0.1 per cent of all passenger cars in the fleet (KBA, 2019). Even though the number of AEVs has risen to 83,175 as of 1.1.2019, overall market penetration is lagging far behind political expectations. Against this backdrop, the German federal government announced a policy package in May 2016. Fiscal incentives have 2 main targets: the consumers, through direct consumer subsidies via a *purchase rebate* and infrastructure providers, for an expansion of the *charging infrastructure*. In total the German Government allocated roughly 2 billion euros for research and development (R&D) of electro mobility between 2009 and 2018 to be spent until 2020 (BMWi, 2017a).

The consumer *purchase rebate*, the so-called environmental bonus ("Umweltbonus"), came into force mid 2016 (BMWi, 2017a). Buyers of AEVs can qualify for a purchase rebate of 4,000 euros (plug-in hybrid cars for a rebate of 3,000 euros) if the vehicle list price is below 60,000 euros. The total available funds for the scheme are capped at 1.2 billion euros financed in equal parts by the German Government and the car manufacturers. Given this funding limit, up to 300,000 all-electric vehicles (or 400,000 plug-in hybrid vehicles) could receive a rebate. Moreover, circulation tax exemptions for all-electric (and plug-in hybrid) vehicles were increased from 5 to 10 years (BMWi, 2017a).

To expand the *charging infrastructure*, 300 million euros were allocated to subsidize the construction of (semi-) public charging stations until 2020 (BMWi, 2017a). The German Federal Ministry of Transport and Digital Infrastructure (BMVI) subsidizes a DC[1] charging station with a capacity of 50 kW per hour with up to 12,000 euros, which charges a car to run for about 200 km. A charging station of 150 kW capacity, which needs only 20 minutes to charge the car identically, is subsidized with 30,000 euros per charging point and with up to 50,000 euros additionally for connecting it to the medium-voltage grid (BMVI, 2017; Schwarzer, 2017). As of summer 2017, 11,230 charging stations existed in Germany, of which 530 are fast charging stations (Sévin, 2018). It is estimated that Germany has a need for around 70,000 charging stations in 2020, of which 7,100 are fast chargers (NPE, 2017).

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[1] DC (direct current) facilitates fast charging, in contrast to AC (alternating current), which facilitates requires slow charging and thus long charge times.

With its fiscal incentives, the German government is putting an effort into increasing the market penetration of AEVs. This paper provides insight into whether these fiscal measures are justified from a normative perspective and whether there might be an alternative way to promote AEVs in Germany. The paper meanwhile provides a broad overview of the status quo of AEVs in Germany, as well as embedded in international context, and provides policy advice concerning the current promotion of AEVs and its infrastructure.

The remainder of this paper is organized as follows: Section II and III provide a detailed normative analysis of subsidies for AEV. Arguments of market failure (II) and industrial policy (III) will be considered. Section IV attempts to highlight an alternative way to promote market penetration of AEVs. Section V will conclude the main points and provide policy advice.

II. Market failure

Economic theory suggests two arguments (see e.g. Fritsch et al., 2007) that can justify government intervention in form of a subsidy. The first argument is found in occurring market failure. Under the very strong yet common assumptions of the model of perfect competition, market coordination (in a closed economy) is believed to bring about the optimal quantity of goods at the lowest possible costs (Arrow and Debreu, 1954). However, market failure can occur if assumptions of the model of perfect competition are violated (Bator, 1958) and might hence require government intervention.

The second argument, which will be analyzed in Part III, arises from industrial policy, where subsidizing a certain sector or firm can be justified in order to assist that sector of the economy to gain market power quickly and compete in international markets (e.g. List, 1841; Spencer and Brander, 1983).

Market failure occurs under three conditions, which will be discussed hereunder:

II.1. - the existence of technological external effects, either *negative* (*II.1.1.*) or *positive* (*II.1.2.*)

II.2. - the existence of imperfect information

II.3. - the existence of indivisibilities and irreversibility.

II.1. Market failure through technological external effects

Technological external effects exist when economic activities are not realized through transactions of the market mechanism and are thus not included in the market pricing calculations (Arrow, 1969; Baumol and Oates, 1988; Buchanan, 1962; Laffont, 2008; Pigou, 1932).

A lack of or poorly defined property rights can lead to two types of effects. When *negative technological external effects (NTEE)* arise, an economic player is not fully accountable for all the outcomes of his economic activity, for example for the emissions of his car. When *positive technological external effects* (*PTEE*) exist, an economic player is not fully entitled to all the outcomes of his economic activity, for example the societal benefits of an invention of an advanced battery cell technology. Private and social costs or benefits of an economic activity differ from each other and the economic player does not take into account the full cost or benefit of his economic activity. Market failure exists when the external effect is not internalized. When negative external effects occur, the originator produces a quantity of an economic activity that is higher than socially ideal, for positive external effects the quantity is smaller than the social optimum.

II.1.1. Negative technological external effects

In the case of NTEE of private vehicles a polluter might drive more than is socially optimal, because he is not accountable for all the costs that his driving induces. Up to day, ICEVs as well as AEVs cause *NTEE* in the form of emissions when being driven. The main categories of emissions from ICEVs as regulated in the European Emissions Standards are carbon monoxide (CO), carbon dioxide (CO_2), particulate matter (PM_{10}), nitrogen oxide (NOx) and hydrocarbons (HC).

For emissions from AEVs a distinction between exhaust- and non-exhaust emissions has to be made. Primarily, AEVs have zero local *exhaust emissions*, therefore, driving AEVs does not increase the number of incidences of premature mortality or morbidity from air pollution, but rather provides an opportunity for a reduction in these if conventionally fueled vehicles are being replaced by AEVs. Ownership of electric vehicles is most likely and most efficient in and around cities due to the actual limitation of range and at the same time the local health benefit is the biggest in traffic-dense urban areas. No studies as of 2018 could be found on the total amount of the public health effect of AEVs in any area.

Driving AEVs also causes *non-exhaust emissions*, some of which have a local effect and some of which have a non-local effect. Local *non-exhaust emissions* result, because driving of AEVs adds to ambient PM_{10}, as part of the brake and tire wear through driving (Platform for Electro-Mobility, 2016). It is argued that AEVs are heavier than ICEVs due to the weight of their batteries and might thus experience more wear (Timmers and Achten, 2016). Nevertheless, break and tire wear largely depends on conditions of the roads, driving behavior, as well as the tire quality and it is argued that the weight effect will be reduced by regenerative breaking (recharging the battery while breaking) in AEVs as well as steadily reduced weight of the batteries (Platform for Electro-Mobility, 2016). In addition, the combustion process of ICE vehicles contributes to ambient $PM_{2.5}$,

which is found to cause more severe health effects than PM_{10}, while break and tire wear mainly contributes to ambient PM_{10} (Krzyzanowski, et al., 2005).

Non-local exhaust emissions from driving AEVs result, because the electricity generation for charging the batteries of AEVs, depending on the source of electricity used for charging, is still likely to cause emissions non-locally at the production site. The electricity for charging AEVs comes (still mostly) from the public grid, which means that emissions resulting from the electricity generation needed for charging AEVs should be attributed to the AEV.

However, through the zero local exhaust emissions, there is potential for a reduction in health costs with AEVs in cities. The magnitude of this benefit needs to be determined in order to compare AEVs with passenger cars of different engines better. For example, the health costs of air pollution induced by road transport exhaust emissions in Germany are estimated to amount to about 8 billion Euro in 2010, according to a study of the German Economic Institute (Puls, 2013) which is at the lower end of estimated health costs from other studies (Schreyer et al., 2007; Baum, 2008; Friedemann et al., 2010). On top of that, actual emissions of ICE vehicles might be higher than stated, as seen in the current Volkswagen admittance of using defeat devices during test cycles to hide excessive on-road emissions of their vehicles (Chossière et al., 2017).

Additionally, non-exhaust emissions from the battery production need to be considered when looking at the life-cycle emissions of AEVs, as well as emissions stemming from the disposal of AEV parts. A variety of studies assess the life-cycle emissions of AEVs in comparison to vehicles of other engines and their impact on air quality and climate. Table 2 provides an overview of selected studies for various countries. Some studies use the global warming potential (GWP) in order to compare results. For this, all greenhouse gas (GHG) emissions of the life-cycle vehicle emissions are converted into CO_2 equivalents (eq), to approximate the sum of g CO_2-eq/km with the same global warming potential within 100 years as one g of CO_2 for reasons of comparison.

Table 2: Overview of selected studies concerning air quality or climate impact of AEVs.

Authors; countries/region under assessment	Objective and means of study	Findings
Hawkins et al. (2012); **International**	Meta-study of 51 life cycle analysis studies on the environmental impact of AEVs compared to ICEVs. GWP is most comparable result stated by all studies.	Lower emissions of VOC, CH_4, N_2O associated with life cycle of AEVs. Slightly higher SO_x values are associated with coal-fired electricity production. No significant differences for PM_{10}, CO, and NO_x are found. Conclusion: low-carbon electricity systems offer potential GHG emission reductions. GWP of ICEVs is 125-315 g CO_2-eq/km, GWP of AEVs is 48-260 g CO_2-eq/km, with an average of **120 g CO_2-eq/km**.
Hawkins et al. (2013a and 2013b); **Europe**	Life-cycle analysis of conventional cars and AEVs.	Environmental benefit of AEVS powered by European electricity mix. AEVs have 15-30 per cent lower GHG emissions than ICEVs. The benefit can be increased by cleaner energy sources and by reducing production supply chain impacts. GWP of AEVs around **185 g CO_2-eq/km**, GWP of ICEVs 230-260 g CO_2-eq/km
Holland et al. (2016); **USA**	Evaluation of air pollution damage costs of driving AEVs and gasoline vehicles in the U.S. via discrete choice model, econometric model of emissions from electricity sector, and AP2 air pollution model.	Environmental benefit of AEV use heavily relies on "cleanliness" of electricity grid and damages from local pollution. Mixed results (positive and negative) for the US. Overall benefit for metropolitan areas of **0.01 USD /mile**, with a range between 3.2 **USD cents/mile** for western and -**3.1 USD cents/mile** for the Midwestern metropolitan areas. Ideal subsidies are estimated at either 5000 USD or -5000 USD respectively.
Ji et al. (2015); **China**	Evaluation of AEV use in cities and the impact on $PM_{2.5}$-inhalation.	Use of AEVs in cities (higher income) relocates emission inhalation to more rural and low-income areas, increasing environmental injustice. Low-emission electricity production can help mitigate the problem.[2]

Ke et al. (2017); **China**	Simulation of changes in $PM_{2.5}$ concentration and other pollutions, caused by electrification of vehicle fleet of the Yangtze River Delta	AEV market penetration can **reduce** average **$PM_{2.5}$ concentration by 0.4 to 1.1 μg m^{-3}** and NO_2 concentration in the region, especially in traffic-dense urban areas of mega-cities.
Messagie et al. (2014); **Europe**	Range based life-cycle analysis of different vehicle types, including AEV100 (range of 100 km)	AEVs have lowest impact on climate change, low respiratory effects (energy source is important), recycling battery components significantly reduces impact on mineral resource depletion.
Michalek et al. (2011)[1]; **USA**	Life-cycle analysis of different vehicle types, including AEV240 (range of 240 km) to estimate potential of AEVS to reduce damage costs of vehicles.	Lifetime environmental costs of AEVs (**USD$_{2010}$ 4667**) are slightly lower than for ICEVs (**USD$_{2010}$ 4802**) in the US. Difference is assumed to be bigger in Europe due to higher fuel costs, lower electricity emissions, higher population density, greater use of diesel, shorter driving distances. High ownership costs of AEVs make social benefit of AEVs questionable in the US.
Timmers and Achten (2016)[3]; **International**	Literature Review on non-exhaust-emissions of different vehicle categories, focus on PM_{10} and $PM_{2.5}$.	AEVs contribute equally to PM_{10} concentration as ICEVs. Contribution to **$PM_{2.5}$ concentration is 22.4 mg/vkm** (vehicle kilometer) and 1 to 3 per cent less than contribution of ICEVs (22.6 - 23.2 mg/vkm).

Source: own depiction.

[1]: The time of research lies before improved battery life and highly reduced vehicle ownership costs

[2]: China's electricity production is highly dependent on coal (currently between 60 and 70 per cent).

[3]: Please note the corrigendum to the article and the possible conflict of interest of one of the authors.

Overall, the studies find positive environmental impacts of AEVs, regarding the climate as well as air pollution, especially in traffic-dense cities. A reduced impact of AEVs on local health in traffic-dense cities is given through zero non-exhaust emissions alone. The studies show that the intensity of the impact of AEVs highly depends on the electricity mix during charging. Electricity generation in Europe (EU-28) contributes less to air pollution and GHG emissions than electricity generation in the U.S. and China, due to a larger portion of renewables in the mix, a smaller portion of combustibles, and a higher portion of nuclear energy. The share of renewables in the EU-28 in 2015 is around 29 per cent, compared to 13.7 per cent in the U.S. and 24.7 per cent in China (REN21, 2016; Eurostat, 2017a). Thus, charging AEVs from the public grid on a general basis is more environmental friendly in Europe than it is in the U.S. or China, which is pointed out by most of the studies of Table 2.

Messagie et al. (2014) and van Mierlo (2016) find in their full life cycle analysis of AEVs and other cars, that AEVs underlying the European electricity mix, emit two times less CO_2 compared to Diesel engines, and cars with diesel engines emit about 20 per cent less CO_2 than cars with gasoline engines. Since the proportion of Germany's electricity generation from renewables with a share of 32.6 per cent (REN21, 2016) lies slightly above European average, the effect for Germany is expected to be bigger. In a "well-to-wheel" assessment for Belgium, van Mierlo estimates 4 times less PM_{10} emissions and twenty times less NOx emissions of AEVs in comparison to vehicles with ICEVs. Furthermore, Norway for example generated 100 per cent of its electricity from renewable energy sources in 2015 (Statistisk sentralbyrå, 2017). Van Mierlo estimates that CO_2 emissions could, in such case, be further reduced by a factor of 15.

Hawkins et al. (2013a and 2013b) find that, assuming the European electricity mix, AEVs have 17 to 21 per cent lower grams CO_2 equivalent per km (g CO_2-eq/km) than diesel vehicles and 26 to 30 per cent lower g CO_2-eq/km than gasoline vehicles. While Hawkins et al. find that for ICEVs most of the life-cycle CO_2 emission equivalents result from the vehicle use and only roughly 15 per cent from production, nearly half of the AEVs life-cycle CO_2 emission equivalents arise from its production. Battery production of the AEVs is associated with about 40 per cent of the total production impact. See Table 3 for a comparison of CO_2 emission equivalents from AEVs and ICEVs.

Table 3: Comparison of life-cycle CO_2 impact of AEVs versus ICEVs assuming European electricity mix; Hawkins et al. (2013a and 2013b).

Hawkins et al. (2013a and 2013b)	AEV (g CO_2-eq/km)[1]	Diesel (g CO_2-eq/km)	Gasoline (g CO_2-eq/km)
Battery	31-39	0.6	0.6
Production	72-81	44	44
Life-cycle impact	180-190	230	260
Advantage AEV (%)		17-21 %	26-30 %

[1]: g Co2-eq/km = g of carbon dioxide equivalents / km, illustrates the sum of all greenhouse gas emissions converted into CO_2 -equivalents per km driven.

For the characteristics of the AEV, the study uses those similar to the Nissan Leaf, which can be accounted for as a typical mid-range AEV. It assumes energy requirements of 0.623 MJ/km, which converts to 173 Wh/km. For all vehicles it assumes vehicle lifetimes of 150,000 km

Another study, Wilson (2013), assumes characteristics similar to Nissan Leaf for the AEV. The author assumes a well-to-wheels electricity use of 211 Wh/km and

vehicle lifetimes of 150,000 km for AEVs and 200,000 km for ICEVs. Since for any life-cycle analysis of AEVs the results are sensitive to assumptions about manufacturing costs, the energy intensity of the AEV and the electricity mix, some differences in the studies can be explained by differences in the assumptions. For every country that Wilson analyses, she uses the respective national average electricity mix. While for spatially smaller countries this might be close to the actual electricity mix used for charging, for countries like the U.S. there are big variations within. The electricity data stems from 2009 and there have been steady improvements towards cleaner electricity in many countries since then. Table 4 shows the results of the performance of AEVS in selected countries.

Table 4: Performance of AEVs in different countries according to life-cycle CO_2 emissions; Wilson (2013).

Wilson (2013) [1]	Total g CO_2-eq/km	Equivalent to gasoline car MPGUS; l/100km		Equivalent to diesel car MPGUS; l/100km	
Manufacturing of vehicle g CO_2-eq/km	70	40		40	
		MPGUS	**l/100km**	**MPGUS**	**l/100km**
Germany	177	47	5.0	53	4.5
UK	189	44	5.4	49	4.8
Iceland[2]	70	217	1.1	217	1.1
China[3]	258	30	7.9	34	6.9
USA[4]	202	40	5.8	46	5.1

[1]: Wilson (2013) used electricity emission factors for 2009.

[2]: Electricity generated from 100 per cent renewable sources.

[3]: Electricity generation in China is heavily coal-based.

[4]: Electricity generation in the USA is fossil heavy.

Abbreviations: g CO_2-eq/km = grams CO2 equivalent per km; MPGUS = Miles per U.S. gallon; l/100km = consumption of liters per 100km.

The results for Germany are in line with the findings of Hawkins et al. (2013a and 2013b). The lifetime g CO_2-eq/km of 177 for Germany are slightly lower than estimated for Hawkins (180-190). Similarly, the production cost of the AEV is slightly below Hawkins (70 g CO_2-eq/km versus 72-81 g CO_2-eq/km) while the electricity intensity or energy consumption is slightly higher (211 Wh/km versus 173 Wh/km). According to Wilson, driving an AEV is as CO_2-intense as driving a gasoline car that achieves 47 Miles per U.S. gallon or has a consumption of 5 liters per 100 km, which she compares to a top gasoline hybrid car. Equally, driving an AEV is as CO_2-intense as a diesel vehicle that achieves 53 Miles per

U.S. gallon or has a consumption of 4.5 liters per 100 km. However, local emissions are not considered and local air pollution is most likely going to be improved by AEVs, which is especially true in comparison with Diesel vehicles, due to their high NOx and PM_{10} exhaust emissions.

Generally, AEVs as well as ICEVs cause NTEE, however, they are typically lower for AEVs than for ICEVs. Therefore, one could argue that a subsidy is justified that follows the difference between the NTEE caused by the two types of vehicles.

In order to provide quantitative insight into the magnitude of the reduction of the NTEE from air pollution due to the use of AEVS in Germany, two plain analyses are done next. In a first step, the *lifetime air pollution costs* for an average car in Germany are calculated. In a second step, a simplified *first-order approximation of the net damage cost savings* due to the displacement of ICE vehicles is conducted. For a more detailed discussion of values and assumptions, please see the Annex.

Equation 1 shows the annual *average air pollution cost*, *AAPC*, per vehicle type *vt* and type of area *area*:

1. $\frac{VKM_{vt}^{total}}{VS_{vt}} \times MRAPC_{vt}^{area} = AAPC_{vt}^{area}$.

For the calculation for 2016, the total *vehicle kilometers travelled*, VKM_{vt}^{total}, per vehicle type are divided by the *vehicle stock*, VS_{vt}, per vehicle type and multiplied by the *marginal air pollution cost*, $MRAPC_{vt}^{area}$, per vehicle type and area.

VKM_{vt}^{total} and VS_{vt} are taken from surveys undertaken by KBA (2018a and 2018b). The marginal air pollution costs $MRAPC_{vt}^{area}$ stem from CE Delft, Infras, Fraunhofer ISI (2011). vt distinguishes between diesel and gasoline cars and *area* between *MRAPC* of a metropolitan area and an all-regions average. For an average diesel car, the annual average air pollution costs in metropolitan areas are found to be 805 euros and 155 euros for driving an average gasoline vehicle, which amounts to 373 euros for an average ICEV. In an average over all regions these costs amount to 251 euros for diesel and 65 euros for gasoline vehicles, and 127 for an average ICEV.

Assuming average *lifetime vehicle kilometers*, $LTVKM_{vt}$, of 160,000 km for each vt, which is a common guaranteed lifetime mileage of the battery of the AEV, equation 2 presents the *average lifetime air pollution costs*, $ALTAPC$, for an average ICEV in Germany:

2. $\sum_{vt=diesel}^{gasoline} LTVKM_{vt} \times MRAPC_{vt}^{area} \times \frac{VS_{vt}}{\sum_{vt=diesel}^{gasoline} VS_{vt}} = ALTAPC$.

$MRAPC_{vt}^{area}$ stands for the *marginal air pollution cost* per vehicle type and area, and is multiplied by the share of vehicle type in the total vehicle stock. Summed up for gasoline as well as diesel cars this yields the $ALTAPC$.

Based on the assumptions outlined above, average lifetime air pollution costs ($ALTAPC$) for an ICEV amount to 3,739 Euro for the metropolitan area and to 1,335 for an all-region average. For comparison purposes, AEV purchase in Germany is subsidized with 4,000 euros per vehicle, which is relatively close to the average monetized air quality benefit from a reduction in the use of one average ICE vehicle in the metropolitan area. It is 3 times higher, though as the all-region average. The $ALTAPC$ of driving an AEV due to the electricity production amount to 630 euros, underlying these assumptions.

Broken down for diesel and gasoline vehicles separately, $ALTAPC$ for a diesel vehicle driving in a metropolitan area amount to 6,464 euros and to 2,016 euros for that same vehicle in an all-region average. $ALTAPC$ for gasoline vehicles amount to 2,368 euros for metropolitan versus 992 Euro for an all-region average. Diesel vehicles reach the 160000 vehicle kilometers travelled almost twice as fast as gasoline vehicles, due to diesel vehicles driving twice as much annually on average.

Secondly, in order to calculate the total annual reduction in air-pollution related costs through a displacement of ICEs by AEVs in Germany, 7 scenarios are created (S1-S7). They create a range of potential damage cost savings, depending on replacement and market penetration assumptions. For scenario S1, it is assumed that the 34,022 AEVs that are registered in Germany as of 1.1.2017 replace an equal amount of diesel vehicles, while for S2 only gasoline vehicles are assumed to be replaced. For S3, AEVs are assumed to replace diesel and gasoline vehicles in equal share, but only 50 percent of the ICEVs are replaced. The other 50 per cent of the AEVs are considered to be additional vehicles on the road. For S4 to S7 it is assumed that the goal of 1 million AEVs in Germany is achieved. S4 then mirrors S1, S5 mirrors S2 and S6 mirrors S3, but with 1 million AEVs respectively. S7 assumes a replacement rate for ICEVs of 0.8, so that 200,000 additional vehicles are on the road as AEVs and 80 per cent of the ICEVs are replaced by AEVs.

The reduced damage costs through the adoption of AEVs are calculated for the scenarios S1 to S7 and for the year 2016. Equation 3 shows the calculation of the *damage cost savings*, DCS_{1-7}^{area}, according to area and scenario S1 to S7, S_{1-7}.

3. $rr * AEVS_{S1-7} * \frac{1}{vt} \sum_{vt_i=1}^{2} AAPC_{vt_i}^{area} = DCS_{S1-7}^{area}$

with:

S1: $rr = 1, AEVS_{S1} = 34022, vt_1 = 1 \ (diesel), vt_2 = 0 \ (gasoline)$

S2: $rr = 1, AEVS_{S2} = 34022, vt_1 = 0 \ (diesel), vt_2 = 1 \ (gasoline)$

S3: $rr = 0.5, AEVS_{S3} = 34022, vt_1 = 1 \ (diesel), vt_2 = 1 \ (gasoline)$

S4: $rr = 1, AEVS_{S4} = 1{,}000{,}000, vt_1 = 1 \ (diesel), vt_2 = 0 \ (gasoline)$

S5: $rr = 1, AEVS_{S5} = 1{,}000{,}000, vt_1 = 0 \ (diesel), vt_2 = 1 \ (gasoline)$

S6: $rr = 0.5, AEVS_{S6} = 1{,}000{,}000, vt_1 = 1 \ (diesel), vt_2 = 1 \ (gasoline)$

S7: $rr = 0.8, AEVS_{S7} = 17011, vt_1 = 1 \ (diesel), vt_2 = 1 \ (gasoline)$

rr stands for the *replacement rate* of ICEVs by AEVs, which is 1 for S1, S2, S4 and S5, 0.5 for S3 and S6 and 0.8 for S7. $AEVS_{S1-7}$ describes the *vehicle stock* of AEVs, which is 34,022 as of January 2017 for S1-S3, or describes the scenario of having 1 million AEVs on the roads for S4-S7. $AAPC_{vt}^{area}$ describes the *average air pollution costs* per *vehicle type vt* ($vt_1 = diesel, vt_2 = gasoline$).

AEVs have zero local tailpipe emissions. Therefore, there damage costs of zero euros could be applied. On the other hand, emissions that stem from electricity generation for charging AEVs can be deducted, in order to monetize an effect of driving AEVs. Therefore, it is here assumed that the *DCS* indicate reduced damage costs assuming that the electricity generation for charging AEVs is fully renewable or that zero air pollution costs for driving AEVs are implicit. Underlying the German electricity mix, this can be offset by the social cost of emissions that are caused by the electricity generation for charging AEVS. Therefore, in a next step, the damage costs caused by CO_2 emissions that arise during the generation of the electricity for the charging of AEVs are deducted in order to calculate the *net damage cost savings,* $NDCS_{S1-7}^{area}$.

4. $DCS_{S1-7}^{area} - VKM_{AEV}^{total} \times CO_2 EM \times CO_2 C = NDCS_{S1-7}^{area}$

VKM_{AEV}^{total} are the total *vehicle kilometers travelled* of AEVs in 2016, $CO_2 EM$ are the CO_2 *emissions* per km for an average AEV and $CO_2 C$ are the CO_2 *costs* per ton CO_2 in Euro.

VKM_{AEV}^{total} stem from a study by the German Aerospace Center (DLR) (Frenzel et al. 2015) and amount to 10,300 km/year. $CO_2 EM$ are from the ADAC Eco Test (ADAC, 2018a) and are assumed to amount to 120 g/100 km for an average AEV. $CO_2 C$ with a mean estimate of € 32.8 / t CO_2 are applied here as in Malina (2016) and discussed therein.

Figure 1 shows the results of the calculation of the *damage cost savings (DCS)* and *net damage cost savings (NDCS)* for S1, S2 and S3 for metropolitan regions versus all-regions average.

Fig. 1: **Sample calculation of damage cost savings (DCS) and net damage cost savings (NDCS) through AEVs in 2016 (in million euros) for S1, S2 and S3**
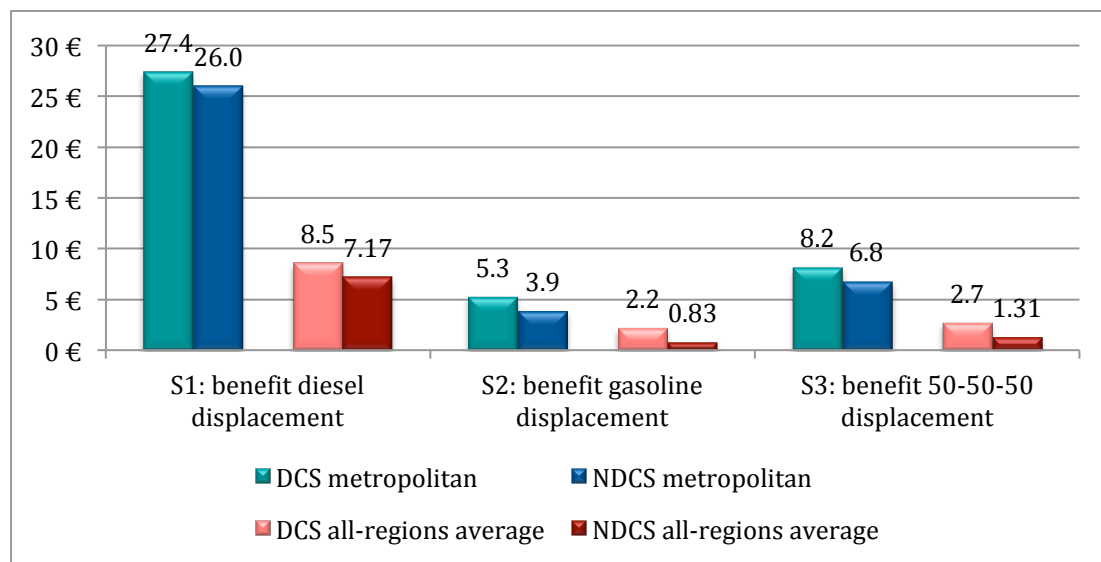
 Source: own depiction based on own calculations with Data from KBA (2018a, 2018b), Frenzel et al. (2015), ADAC (2018a), CE Delft, Infras, Fraunhofer ISI (2011), Malina (2016).

Notes: DCS= damage costs savongs, NDCS = Net damage cost savings. The difference between DCS and NDCS values are the damage costs caused by charging AEVs that arise through CO_2 emissions that are incurred during electricity generation in the German electricity mix.

S1: benefit diesel displacement: all 34022 AEVs replace diesel cars only.

S2: benefit gasoline displacement: all 34022 AEVS replace gasoline cars only

S3: benefit 50-50-50 displacement: Only 17011 AEVs displace diesel and gasoline cars in equal share, the other 17011 AEVs are considered to be additional cars on the road.

Bearing in mind that this is just a first-order approximation, a few conclusions can be drawn. In scenario S3, a total of 6.79 million euros are saved in 2016 by having 34,022 AEVs registered in Germany, when marginal costs of the metropolitan region are applied and half of the AEVs replace ICEVs. One might argue that this number is not high, as it amounts to 0.04 per cent of the total pollution damage costs of driving gasoline and diesel cars (16804 Mio. Euro in 2016, own calculations based on the same underlying assumptions). But AEVs also only make up 0.74 per cent of the total passenger car stock in Germany in 2016. Therefore, there is potential for damage cost reductions, even if actual numbers differ from the simplified approach presented here.

The difference between S1 and S2 shows the range of the environmental benefit, depending on whether diesel or gasoline vehicles are replaced. The effect of having AEVs on the road is the higher the more diesel engines are displaced, as diesel cars incur higher damage costs. However, this also assumes that the vehicles are driven less, as AEVs drive almost half of the km of diesel vehicles. One AEV occurs CO_2 pollution costs of 41 euros annually for driving 10300 km. If

driving 19930 km instead, the average annual kilometers of a diesel vehicle, then the costs almost double (79 euros). For S1 this means, for example, that the NDCS would be reduced by another 1.3 million euros, if diesel vehicle kilometers were applied.

Additionally, the effect is significantly higher in metropolitan areas than in an average over all regions. For S3 for example, 6.79 million euros could be saved in metropolitan areas, versus 1.31 million euros in average over all regions. This is due to the fact that the marginal air pollution costs for passenger cars in non-urban areas are ⅔ lower for gasoline cars and ¾ lower for diesel cars. The damage costs of AEVs through driving or respectively charging the AEVs are relatively low in comparison; they amount to 1.38 million euros.

Figure 2 shows the results of the calculation of the *net damage cost savings (NDCS)* for S4 to S7 for metropolitan regions versus the all-regions average.

Fig. 2: Sample calculation of total damage cost savings through AEVs in 2016 (in million euros) for S4 – S7
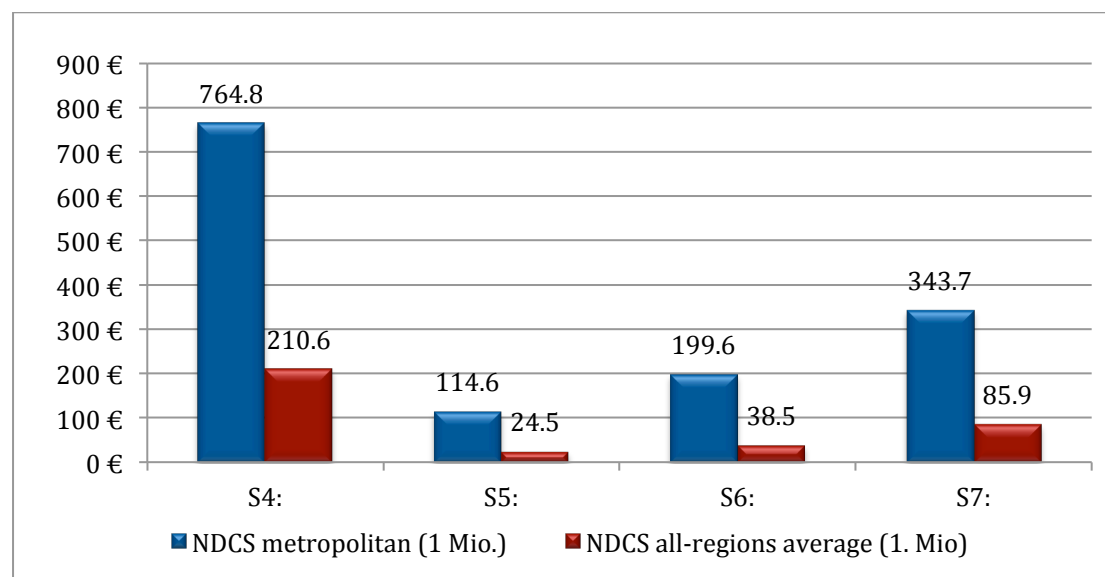
Source: own depiction based on own calculations with Data from KBA (2018a, 2018b), Frenzel et al. (2015), ADAC (2018a), CE Delft, Infras, Fraunhofer ISI (2011), Malina (2016).
Notes: NDCS = Net damage cost savings. Contrary to figure 1, only NDCS values are depicted, where the damage cost caused through CO_2 emissions for charging AEVs that are incurred during electricity generation with the German electricity mix, are already subtracted.
S4: benefit diesel displacement: all 1 million AEVs replace diesel cars only.
S5: benefit gasoline displacement: all 1 million AEVS replace gasoline cars only
S6: benefit 50-50-50 displacement: Only 0.5 million AEVs displace diesel and gasoline cars in equal share, the other 0.5 million AEVs are considered to be additional cars on the road.
S7: benefit 50-50-80 displacement: Only 0.8 million AEVs displace diesel and gasoline cars in equal share, the other 0.2 million AEVs are considered to be additional cars on the road.

The difference between S6 and S7 shows that damage cost savings are the bigger the more ICEVs are replaced by AEVs contrary to AEVs being additional vehicles on the roads. In S6, where of the 1 million AEVs only half replace ICEVs, the benefit amounts to approximately 200 million Euro for metropolitan areas, while

in S7, in which the 1 million AEVs replace 800 000 ICEVs, the benefit amounts to 344 million Euro in metropolitan areas. As of 2015, about half of the buyers of AEVs in Germany decided to replace an ICEVs with an AEV (Frenzel et al., 2015). An increase in the replacement rate of ICEVs raises the potential to generate higher environmental effects.

The diesel replacement in metropolitan areas (S4) generates benefits of 765 million euros (or 726 million euros, underlying the assumption that the AEVs drive the average km of diesel vehicles), while a complete gasoline replacement (S5) for an all-region average yields a benefit of 25 million Euro. The difference is indicative of the fact that, the less air pollution the ICEVs generate, the lower is the environmental effect of AEVs.

In order to relate these findings to the German consumer purchase rebate the above calculations are transferred and extended. The total amount of the consumer purchase rebate amounts to 1,200 million euros, of which 600 million euros stem from the German government. This is enough to subsidize the purchase of up to 300,000 AEVs. The *net damage costs savings* (NDCS) of 300,000 AEVs would, with above assumptions of 50-50-50 (replacement rate of 50 per cent and diesel and gasoline vehicles replaced in equal shares) amount to 60 million euros annually in metropolitan areas and to 12 million euros annually in an all-regions average. Assuming a simplified AEV lifetime of 10 years and equal parameters within these 10 years, the *NDCS* in the metropolitan area almost equal the purchase subsidy from the German government. However, in an all-regions average and under above assumptions, the direct consumer subsidy exceeds the net damage cost savings by a factor of 5 (600 million euros versus roughly 120 million euros savings). Since the government subsidy does not distinguish between metropolitan or rural areas, the all-regions average is the more plausible value, so that the subsidy can be considered multiple times more expensive than the potential net damage cost savings in the air quality.

Adding the climate costs to the air pollution costs that arise from driving ICEVs, the value of the subsidy can be matched for an all-region average. Climate costs for ICEVs stem from CE Delft, Infras, Fraunhofer ISI (2011) and a medium climate cost scenario is assumed. The ceteris paribus driving lifetime savings for 10 years amount to roughly 600 million. This estimation, however, only takes into account the driving costs, but leaves out the life-cycle costs of both vehicle types. As seen before, it is especially the production of the batteries for AEVs that is responsible for about 40 per cent of the lifetime emissions, while the production impact of ICEVs lies 30 to 40 times below that of AEVs, as seen in Table 3 (Hawkins et al., 2013a and 2013b). In conclusion, the subsidy is estimated to be close to the actual driving impact, however a closer look needs to be taken into the life-cycle impact. This analysis is also highly sensitive to the

underlying assumptions. But even with this first-order approximation the German purchase rebate can not be seen as a viable option for bringing additional AEVs vehicles on the road in general in Germany. See table 5 for an overview of the results. See the Annex for a detailed table of per car values.

Table 5: Overview of results from first-order-approximation of damage - and climate cost savings with regards to German purchase rebate (in million EUR).

	ICEV (savings)	AEV (costs)	Net-values[2]
Lifetime[1] climate costs		121	
Lifetime DCS[3]: metropolitan	720		599
Lifetime[1] DCS[3]: all-region average	237		116
Lifetime[1] climate cost savings	413		291
Lifetime[1] total costs savings: all-region	650		528

Source: based on own calculations with Data from KBA (2018a, 2018b), Frenzel et al. (2015), ADAC (2018a), CE Delft, Infras, Fraunhofer ISI (2011), Malina (2016)..
1: lifetime: a lifetime of 10 years is assumed.
2: For the air pollution, the NDCS (net damage cost savings) are depicted. For this value the damage cost caused through CO_2 emissions for charging AEVs incurred during electricity generation with the German electricity mix are subtracted to depict driven kilometers of AEVs. For the net-climate costs it is also distracted, but for the total values only ones.
3: DCS = damage cost savings through reduction in air pollution

In this first-order approximation other subsidies of AEVs are also not considered here, for example the exemption of the circulation tax for 10 years. For 300,000 AEVs this can easily amount to another subsidy between 100 million and 170 million euros (for vehicles between 1200 and 2000 kg) for the course of 10 years, which would only augment the surplus of the subsidy over benefit further.

II.1.2. Positive Technological External Effects

In case of PTEE, the social benefits are higher than private benefits, meaning that economic players might not recognize the full benefit of AEVs. This can lead to fewer AEVs on the market than socially optimal, in which case the government might need to intervene to increase market penetration of AEVs. PTEE in this context can firstly be found in the reduction of crude oil dependency and secondly in Research and Development spillover effects.

The first PTEE from electric vehicle use might stem from a long run reduced dependency from petroleum imports. The oil dependency, thus the need to import large quantities of crude oil and its products, brings with it a risk of supply interruptions (See for this and the following Delucci and Murphy, 2008; Eurostat, 2017c; Holland et al., 2016; Michalek et al., 2011; Parry et al., 2007). As a consequence this can lead to costs for additional supply storage, possible

military spending to reduce the risk of supply interruptions, as well as an increased dependency on volatile world market oil prices. It also leads to a dependency on the further depletion of natural oil reserves with all its negative impacts on the environment and people, e.g. through fracking. Finding alternatives that can lower petroleum dependency can reduce the negative effects associated with it. Michalek et al. (2011), for example, determine the life time oil dependency costs of an ICEV in the USA to amount to 1,284 USD in 2010, due to spending caused by supply disruption, world market oil price fluctuations and military spending.

AEVs do not consume gasoline or diesel, which is produced from petroleum. Oil sources in electricity generation are now well below l per cent in Germany and the U.S. and below 2 per cent in the European Union (World Bank, 2017), compared to the 1970s, when electricity generation from oil was more common and amounted to up to 25 per cent of the total generation. The 28 countries of the European Union import 89 per cent of their oil product energy needs, for Germany those imports amount to over 96 per cent (Eurostat, 2017b). Most of the oil imports come from Russia (30 per cent for the EU-28).

Natural gas, and gas-fueled vehicles could theoretically help to alleviate the dependency on oil, as gas reserves are spread out wider throughout the world. The US, for example, can almost produce as much natural gas as they consume. The EU-28 however imports roughly 70 per cent of its gas energy needs, of which almost 40 percent comes from Russia (Eurostat, 2017b). Germany imports 90 percent of its natural gas needed, so that gas-fueled vehicles do not seem like a viable long-term option for Germany to overcome natural resource dependency.

Fuels in the transport sector account for over 50 percent of the German crude oil products (36 per cent diesel fuels and 18 per cent gasoline fuels in 2015) and 94 per cent of the final energy consumption of the transport sector was attributable to crude oil in 2015 (BMWi, 2017b). Therefore, electric mobility can play a role in reducing dependency on petroleum. Because the advantage of independency is not recognized by producers of AEVs or reflected in the price of AEVs (PTEE), the rate of adoption of electric vehicles will be slower than is socially optimal, which is a potential argument for government purchase subsidies for electric vehicles.

While it is true that AEVs can reduce Germany's dependency on ICEVs and thus on oil imports, AEVs relocate the oil dependency to a different source, similar to gas as an alternative to oil. AEVs are highly dependent on their batteries, and thus on the battery manufacturers, of which over 80 percent stem from Asia, as well as the countries, from where the resources for the batteries are depleted

(see e.g. Holzer, 2019). Therefore subsidizing AEVs does not seem like a viable option to overcome resource dependency.

Above that, subsidizing the sales price is not expected to lead to a strongly rising demand and thus to developing the market for AEVs. In a study, the Fraunhofer Institute explains the overall low demand for AEVs with a gap between potential customers' expectations about AEVs and reality: they find the price too high, charging too difficult and the driving range too low (Fraunhofer Institut, 2010). These factors were confirmed as the main drawbacks of AEVs for consumers by an extensive literature review study (Li et al., 2017). Another paper found the limitation in range the major barrier for German drivers to buy an AEV, which could be resolved by increased battery capacity or an extensive fast charging network (Hackbarth and Madlener, 2016).

Figure 3 shows the monthly new registrations of AEVs, the market share of the new registrations of AEVs in all new registered passenger cars, and the total market shares in the passenger car market from 2009 till 2019.

Figure 3: Monthly number of new registrations of all-electric vehicles and market share in German passenger car fleet (monthly registrations and total), by year.
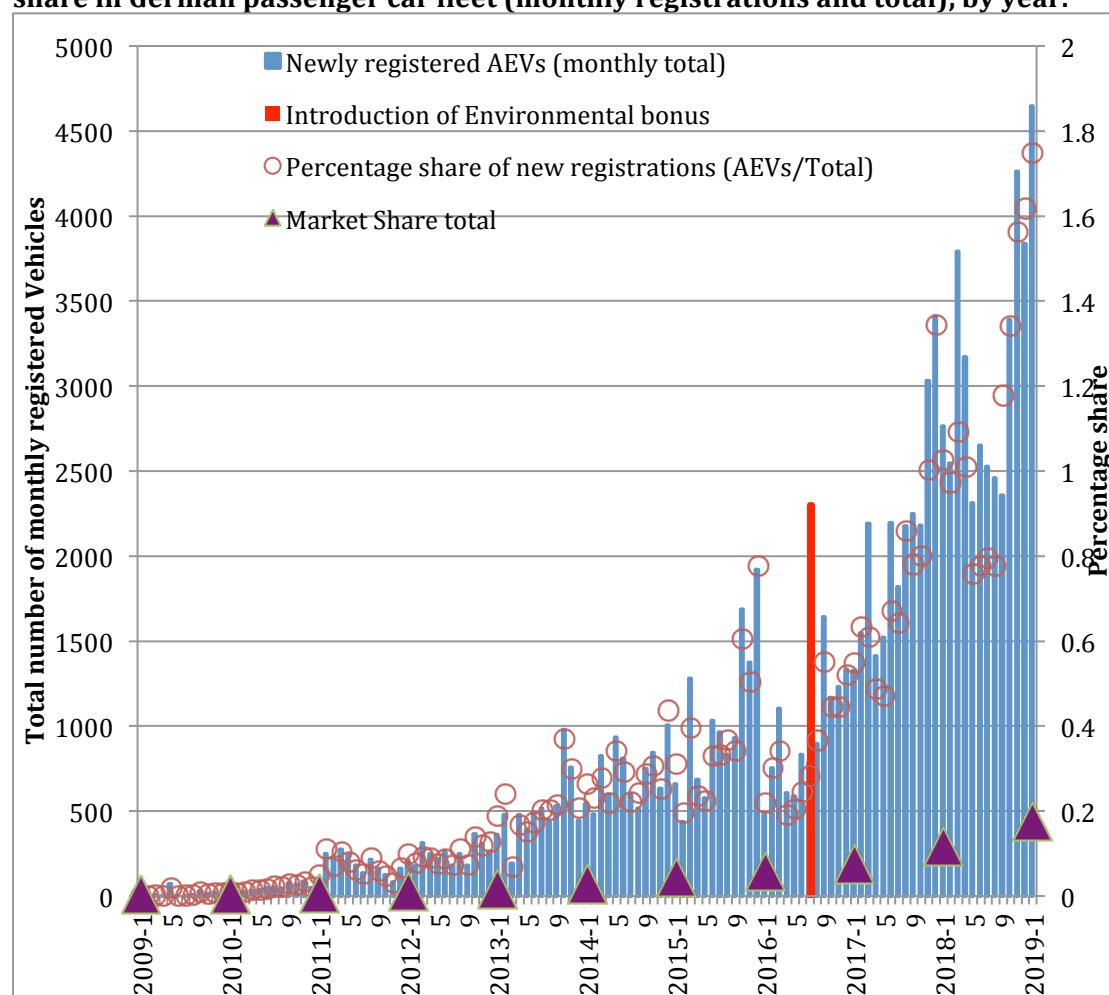
Based on data from KBA (various years).

The environmental bonus can be applied for since July 2016, which is reflected by the red vertical line. The decline in total sales just before the environmental bonus entered into force can be explained by the preannouncement that started in February 2016. The bonus was officially decided in April 2016 and might have led to buyers holding off on their purchase to later benefit from the purchase subsidy.

Looking at the data for newly registered AEVs in Germany in figure 3, without further intensive econometrical analysis no prediction can be made whether the subsidy promotes the development of the market by promoting higher sales. However, it can be seen, that even without the subsidy there is a trend towards higher sales between 2009 and 2019. Similarly, the share of monthly sales as well as the total share of AEVs in the market of passenger cars has risen. But the total market share of AEVs is still considerably small and lies at 0.18 per cent of all vehicles, as of 1.1.2019. The share of newly registered vehicles is higher but still only varies between 1 and 2 per cent of the total new registered vehicles in 2018. It seems that the decision to buy an electric car does not rely heavily on the price alone. Also, part of the premium (2000 euros) has to be given as a discount by car dealerships. This might lead to car dealers holding off on other discounts usually given, so that the price reduction might just have changed the origin instead of the total price (Busse et al., 2006; Kaul et al., 2016).

Overall, instead of subsidizing the purchase price of AEVs to enhance market penetration, the government could put a surcharge for the dependency of oil on fuel prices and thus internalize the external cost of oil dependency. This would make alternative energy more compatible, and along with it the use of electric cars, as the operating costs of ICE vehicles rise.

Another PTEE can be found in research and development (R&D). There are cases where the producer of the PTEE in R&D cannot exclude non-paying beneficiaries, as they, at the same time, do not have to bear the costs and risks of the research or if they can make use of the knowledge through the R&D at low cost. This might lead to underinvestment from a societal perspective and can be true for basic research (Arrow, 1962; Griliches, 1992; Hall, 1996; Nelson, 1959, Jones and Williams, 1998). It needs to be determined, whether electro mobility can still be counted as basic research, if non-paying beneficiaries can be excluded or if others can make use of the knowledge and if thus, the allocation of 2.2 billion euros through the German Government can be justified by this argument.

The three main subsidized fields that can be counted for under Research and Development are: (a) direct consumer demand subsidies through means of the environmental bonus (b) additional promotion of the expansion of the charging infrastructure and (c) funding of research for battery cell technology.

(a) The environmental bonus is a *direct sales subsidizes* for AEVs and is thus meant to develop the market for AEVs. But neither the term basic research nor non-excludability is applicable in this context. First, AEVs have been around for more than 100 years, so that their technology since then has indisputably been advanced, making AEVs more efficient than 100 years ago, but research on AEVs cannot be considered new or basic. This raises the question why the market should be subsidized just now in order to develop it. Contrary, advanced technology in AEVs can be compared to more efficient ICEVs, which are not subsidized. There is even a chance that, by subsidizing AEVs, the government picks the wrong technology while the development of a more efficient one might be hindered by AEV subsidies. The superiority of a technology will lead to higher demand and therefore higher market penetration, so that if AEVs are the superior technology, they will most likely succeed in the market without subsidies. One reason why ICEVs prevailed over AEVs in the past was the low price of fuel and its wide availability, without a consideration of the social costs of gasoline. If AEVs had been feasible in the past, or if the real costs of driving ICEVs had been taken into account and the external effect internalized, there might have been a strong market for AEVs by now.

Secondly, a superior technology would lead to higher demand and therefore higher market penetration and thus benefits for the producer, which can be realized by the producer himself. Therefore, excludability is given. R & D does not serve as an argument for direct consumer subsidies.

 (b) Neither the argument of basic research nor excludability can be applied to the *charging infrastructure* in order to validate government subsidies. The expansion of the charging infrastructure is crucial for using AEVs because limited access to charging stations can significantly decrease the market potential of AEVs (Hall and Lutsey, 2017). The other way around, an extensive charging infrastructure creates positive externalities, as it creates potential benefits such as potential range and optional utility to owners and future buyers of AEVs. Thus, it indirectly promotes the sales of AEVs, making it more attractive to buy an AEV. In this context, the chicken-and-egg situation is quoted as justification for government intervention, meaning that the infrastructure has to be developed through support from government subsides in order to develop the market for AEVs (see e.g. Beckers et al., 2015; EURELECTRIC, 2013; Gnann et al., 2015). Without an extensive charging infrastructure – so the argument – there will not be enough incentive for consumers to buy AEVs and the demand will remain low for both, infrastructure and AEVs.

On the other hand, there are several arguments against government intervention. Early adopters are most likely to have an overnight charging point at or close to their home, with which they can cover most of their electricity

needs (Bjerkan, 2016; Gnann et al., 2015; Gnannn et al., 2012; Linn and Greene, 2011). In 2018, around 80 per cent of the charging processes happened at private homes (BDEW, 2018). With a rising number of AEVs on the road, the demand for additional public charging stations will increase, which should provide an incentive to the market to provide charging stations. There have been steady improvements in the technology of the charging infrastructure, however, building up the infrastructure can hardly be considered as basic research.

Parallels can be drawn between the development of the ICEV market and the rising number of gas stations. At the beginning of the 20th century when the demand for gasoline cars rose, no subsidizing of filling stations was needed. In the United States in 1900, there were only about 4000 passenger cars and the luxury of possessing one remained for the rich (see for this and the following history of gasoline stations Beckmann, 2011; Rosofsky, 2007). Gas was bought at local retail stores or kerosene refineries in small cans. Drive-in filling stations started to appear after 1910, going hand in hand with the mass production of the first affordable passenger car, the Ford Model T and thus a fast rising demand for filling stations. Even though today's mobility needs might be different and overall mobility has changed immensely since then, both markets started with a few high priced cars with limited range exclusively used by customers with a high willingness-to-pay and only few and inconvenient filling stations at their disposal. With a rise in demand for affordable and compatible cars and the development of those, the market for the charging infrastructure took off on its own. On top of that, building, buying or renting a gas station is up to 10 times more expensive than the charging infrastructure for AEVs, yet investors were found without subsidies. These investments, in fact, represent normal entrepreneurial risk and investors make these investments for an risk-appropriate rate of return.

Additionally, non-paying actors can be excluded from consumption of electricity at the charging point at low costs and there is rivalry in consumption. According to economic theory, the charging infrastructure is thus a private good and the market can provide the good, so that government intervention is not needed. Selling the electricity can be a profitable business, comparable to selling electricity to private homes and companies and comparable to selling gasoline and diesel at gas stations.

 (c) The funding of research for *battery cell technology* is yet another approach in Germany to improve the performance and lower the price of AEVs. AEVs can become an economical viable product on the market without any further subsidizing if sold at similar prices to ICE vehicles. Battery costs are constantly declining (IEA, 2017a; Nykvist and Nilson, 2015; McKinsey & Company, 2017). Nykvist and Nilson (2015) found an average annual decline in battery prices of

14 per cent between 2007 and 2014, to a price of between 300 and 410 USD/kWh in 2014, while evaluating over 80 reported estimates. Others find a battery cost decline of 80 percent from about 1000 USD/kWh in 2010 to 224 USD/kWh in 2016, however, the battery cost still makes up roughly 30 per cent of the price of a car (McKinsey & Company, 2017, IEA 2017b).[2] The price is estimated to fall by another 70 per cent between 2017 and 2029 and price parity to ICE is expected to begin from 2024 onwards, when the costs falls below 100 USD/kWh (BNEF, 2018). As this annual price decline reveals ongoing research in battery improvement and its implementation it also shows that research cannot be considered basic anymore.

Above that, there is strong competition between manufacturers, driven by the motivation for gaining market share and making use of economies of scale. This makes government involvement in the market for battery cell technologies appear unnecessary. Worldwide battery cell capacity is on a rise from just over 25 GWh in 2016 to between 100 GWh and 125 GWh in 2017 and it is expected to double by 2020 (Perkowski, 2017; Ryan, 2017; Desjardins, 2017). This is enough to provide battery cells for roughly 1.5 to 13.7 million cars, depending on the model and its battery capacity (Ryan, 2017). This supply meets a demand for batteries that is expected to raise to 1300 GWH in 2030 (BNEF, 2017), which is about a tenfold more than currently exists. Therefore, car manufacturers and other private investors should be rather interested in improving the battery performance and invest in research privately, as it will provide them with possibly high profits (Sanderson, 2018).

In addition, non-paying consumers can be excluded from the use of the batteries and the battery technology cannot be easily copied without accumulating a lot of knowledge and without building complex factories (Hajek et al., 2017). Therefore, government funding for battery technology cannot be justified by the argument of the PTEE from R&D. Government funding of research for battery technology can only be justified if the expected innovation is incremental and otherwise unprofitable (Martin and Scott, 2000; Rodrick, 2004; Warwick, 2013, Harrison and Rodriguez-Clare, 2010).

In conclusion, neither NTEE nor PTEE serve as valid arguments for subsidies in the market for AEVs. Indeed, AEVs create lower NTEE, so the monetized difference could be utilized for the promotion of AEVs. However, internalization of external effects by allocating true costs to each transport mode is the preferred method. PTEE in the form of oil dependency can only partially justify promoting AEVs as an alternative technology to reduce this dependency, as one dependency is replaced by another, whereas R&D cannot justify the subsidy, as

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[2]   Prices are in 2016 US dollars.

there are market solutions to promote R&D in the AEV market and neither basic research nor non-excludability serve as valid arguments.

II.2. Market failure through imperfect information

The model of perfect competition assumes perfect information between the agents of an economic transaction. In reality, information is an economic good and consumers weigh marginal benefits and marginal costs to determine how much information to acquire (Stigler, 1961; Grossman and Stiglitz, 1976 and 1980). Transactions are mostly performed under a certain degree of *imperfect information*, either due to *information asymmetries* (II.2.1) between the parties*,* e.g. about the characteristics of goods or transactions, or due to *uncertainty* (II.2.2) about future events. Market failure can occur when the agents are uninformed in such a way that the transaction does not take place at all, or at a lower than optimal quantity (Greenwald and Stiglitz, 1986; Arnott et al., 1994; Rothschild and Stiglitz, 1976).

II.2.1 Information asymmetries

Information asymmetries occur, when a transaction is about to take place between agents who have different levels of information about the transaction. One party might, (a), not know all the qualities of a product when negotiating a transaction (hidden characteristics) which might lead to a process of *adverse selection* (Akerlof, 1970). A party might, (b), not be informed about the true performance of the opponent party in a transaction (hidden information or hidden actions) which might lead to *moral hazard* (Arrow, 1963). Or he might, (c) be dependent on specifics of a transaction and might not know the true intentions of his opponent party (hidden intentions), which can lead to *hold up* (Goldberg, 1976; Grossman and Hart, 1986; Hart and Moore, 1990; Williamson, 1975).

a) Hidden characteristics and adverse selection

Information asymmetries in the form of hidden characteristics applied to the market for AEVs means that, when purchasing an AEV, the buyer does not know the exact characteristics of the car, such as for example the exact range in different scenarios and the exact charging times. The same condition of hidden characteristics exists for new ICEVs, which are likewise not subsidized. For ICEVs, the fuel consumption for example can lie about 43 per cent above the stated values (Tietge et al. 2017), but this fact does not trigger a process of adverse selection. Likewise hidden characteristics in new AEVs do not trigger a

process of adverse selection and cannot serve as a valid argument for government intervention as a cause of market failure.

Information asymmetry, however, does exist for AEVs. The buyer can read the sellers advertised characteristics tested under ideal conditions, which, till the end of 2017 were accumulated in the New European Driving Cycle (NEDC) in the EU or with the Environmental Protection Agency (EPA) in the US. But characteristics vary heavily under more plausible driving conditions (hidden characteristics) (ACEA, 2017; ADAC, 2017a; Shahan, 2015; Peeters, 2017; Voelcker, 2015, Zhang and Yao, 2015;). The range, for example, is estimated to be between 30 to 37 per cent lower than advertised (Battery University, 2016).

If the buyer believes that the quality of the AEV is lower than advertised, he is only willing to pay a reduced price, lower to that requested for a high range, quick charge and general high quality AEV. This could lead to a process of adverse selection, where, at the end, there are only low quality AEVs and the market collapses. However, buyers have many possibilities to inform themselves. Consumer test reports and various test organizations can nowadays help buyers to screen the market and take a better-informed decision and to know about more realistic vehicle characteristics in advance (e.g. consumerreports.org; Battery University, 2016; Moody, 2017; Bloch, 2014; ADAC, 2017a). Screening is a market solution to overcome adverse selection and government subsidies can, thus, not be justified.

b) Hidden information, hidden actions and moral hazard

In a situation of hidden information or hidden action one party might change its activities ex post to the completion of the transaction to the disadvantage of the other party (Moral Hazard). The information asymmetry exists, because the altered ex-post behavior cannot be completely observed by the other party, either due to a lack of expertise (hidden information) or for practical reasons (hidden actions). In this situation the opponent can exploit the missing control options to his own advantage.

If the ill-informed party anticipates the moral hazard he will adjust the price to a level where the risk of hidden information or hidden action is included, which can lead to elevated prices and therefore a suboptimal low level of provision of the good. In the worst case the anticipation of moral hazard can lead to ex ante adverse selection.

There is a risk of moral hazard in the context of batteries in AEVs. Some manufacturers offer a warranty for their batteries of a certain amount of years, often but not always in combination with a limited amount of mileage (e.g. 8 years or 160,000 kilometers for BMW and Nissan Leaf, or 8 years and

unlimited mileage for Tesla). This warranty can be taken advantage of by the owner of an AEV. Batteries are known to last longer with battery-friendly usage, for example keeping batteries in moderate climate (neither hot nor cold), keeping a temperate state of charge (low depth of discharge and no full charge for prolonged time), moderate charge voltage and moderate charging temperatures (Arcus, 2016; Battery University 2016). In case of a warranty claim, the battery manufacturer has difficulties to observe the negligent conduct of the battery user (hidden action). Due to the warranty and the observation problem, the owner has no need to stick to careful handling of the battery (moral hazard). The producer can incorporate the risk for an early replacement and raise the battery price, which makes the battery purchase unattractive to some buyers. In the worst case this might lead to another case of adverse selection, where fever buyers are willing to pay a raised price. The market, yet, provides solutions to this problem, so that subsidies cannot be justified. For example, some AEVs can keep a record of stressful battery events (monitoring), which alleviates the observation problem and might, thus, dissolve warranty claims (Battery University, 2016). Regularly offered checkups, as another form of monitoring, as well as continued information about desirable battery usage can also prevent moral hazard.

c) Hidden intentions and hold up

Hold up refers to a scenario, where, ex ante to a transaction, a second party has strategies in mind (hidden intentions) that, ex post to the transaction, can lead to the disadvantage of the first party (hold up), because he cannot fully receive the returns of his investment. If the first party has taken a specific and irreversible investment prior to the transactions, it is dependent on the action and goodwill of the second party and it is then in risk of exploitation to the extend of his investment, (Goldberg, 1976; Grossman and Hart, 1986; Hart and Moore, 1990; Williamson, 1975). This might lead to market failure in form of ex ante underinvestment, if the hold-up is anticipated (Elliot and Talamàs, 2018).

In the literature the public charging infrastructure for AEVs is sometimes considered a specific and irreversible investment (Beckers et al., 2011). This can possibly be taken advantage of by the operator and / or electricity provider. Once the provider has made the investment for the public charging station, he would have to accept any raise in asked operating or electricity price, as he might otherwise lose the money for his investment.

However, the German charging infrastructure market for AEVs is a competitive one. Up to day (end of 2018) there are already more than 16,100 publicly available charging stations (BDEW, 2018), with up to 40,000 charging points and

more than 140 commercial providers and operators of charging infrastructure, which can be conveniently found via smart phone apps (e.g. www.lemnet.org/de, www.plugsurfing.com, www.goingelectric.de/stromtank-stellen/routenplaner, www.plugfinder.de). The existence of competition shows that specific investment does not hinder competition.

Competition decreases the dependency of the investor so that hold up becomes unlikely (Felli and Roberts, 2002 and 2016; Elliot and Talamàs, 2018). In a competitive market the infrastructure provider can find alternative transactions partners for delivery of electricity, such that the asked operating and electricity price will reflect the marginal revenue and the opponent cannot ask for a markup. Therefore, the investor can overcome a hypothetical market failure caused by hold up and should be able to obtain his marginal benefit, which will enhance the existence of equilibria with efficient investments (Bhaskar and Hopkins, 2016, Elliot and Talamàs, Makowski and Ostroy, 1955).

Additionally, the hold up potential of an specific investment is only as high as the quasi-rent of the good, meaning the excess rent that the investment has over its value in its next best use and thus the degree of specificity of the investment (Joskow, 2003, Klein et al. 1978, Williamson, 1979 and 1996). But in a competitive infrastructure market the quasi rent is near zero and like-wise the hold up potential, due to the negotiation potentials with competitors and the ability of the agent to retrieve the majority of benefit of his investment (Cole et al., 2001; Elliot and Talamàs, 2018, Felli and Roberts, 2002, Makowski and Ostroy, 1995).

Even if hold up proofs to be possible, then the market provides instruments to overcome hold up, such as long-term contracts and vertical integration (Williamson, 1971; Carlton, 1979). In Germany different types of providers and operators exists which reflect different market model approaches. This ranges from disintegrated market models to partial or complete vertical integration of charging station ownership, electricity distribution and retail of electricity (EURELECTRIC, 2010; 2013). For example, the charging infrastructure can be owned and operated by either a private person, by an electricity supplier or by vehicle manufacturers. In 2018, 75 per cent of the public charging stations is operated by the energy sector (BDEW, 2018). However, different market models exist and a potential hold up can be overcome.

Therefore, hidden intentions and a possible hold up due to potentially specific investment costs of the infrastructure cannot serve as an argument for government subsidies.

II.2.2 Uncertainty

Next to information asymmetries, market failure due to imperfect information can also be caused by *uncertainty* about future events. Imperfect information through uncertainty cannot be solved by gathering additional information, as many future events cannot be predicted and have unknown probabilities (Knight, 1921). Such events are for example major political occurrences or economic crisis. However, it is to be differentiated between quantifiable and non-quantifiable risk (Knight, 1921). In some cases there are no markets to bear unquantifiable risks, so that risk-adverse agents do not make socially preferable transactions in which case the market fails and welfare is reduced (Arrow, 1963). In case of market failure the government can introduce measures to overcome the market failure.

Entrepreneurial uncertainty is quantifiable, however, and describes the normal risk of any investment. Therefore entrepreneurial uncertainty itself does not validate government subsidies, as it is up to the entrepreneur to take the risk but also receive the benefits in case of success.

Car manufacturers face entrepreneurial uncertainty in the form of unpredictable events such as rapidly falling or consistently low oil prices for example. This could lower the demand for AEVs, as it causes low gasoline prices and makes driving an ICEV comparably cheaper. At the beginning of the 20th century, cheap and widely available oil was one of the causes for ICEVs to become the dominant mode of transportation, leaving electric cars nearly extinct. The low oil prices of 2009 or the continuous low oil prices since 2014 also pose a risk for manufacturers of AEVs. If driving ICEVs becomes relatively cheap, potential buyers might not opt for buying AEVs anymore. Oil prices might on the other hand rise up again, making AEVs comparably cheaper and thus raise the demand, providing benefits for investors.

Car manufacturers, at this moment (2018) are facing a growing market demand for AEVs. In 2018 almost 1 million new AEVs were sold worldwide and annual sales of 30 million new AEVs are predicted for 2030 (BNEF, 2018). While AEVs are still more expensive than comparable ICEVs, price parity is expected to begin in 2024, raising the demand for AEVs. This is due to a drop in battery prices for AEVS of 80 per cent since 2010 to a price of roughly 200 USD per kWh in 2018. In 2024 the battery price is expected to lie around 100 USD/kWh. Therefore, car manufacturers can expect profits from the AEVs market and apparently are willing to take up the risks of the markets, given the supply on the market. Their expectation of profits is higher than their risks validation.

The same reasoning applies to *providers of infrastructure*. Small numbers of AEVs on the roads lead to low demand for the usage of the charging infrastructure.

However, especially electric vehicle manufacturers and electricity suppliers might find financially attractive business models in the provision of public charging stations (NRC, 2015). Seeing the growth of the infrastructure the entrepreneurial risk is taken up in the infrastructure market as well.

Individual car buyers are also subject to uncertainty risks. There is significant uncertainty to the extension of the charging network and therefore the distance that can be reached with their AEV. Furthermore there was uncertainty about which charging standard would prevail. There is always the risk that the AEV bought today might soon be surpassed by a superior technology or a significantly cheaper model, so that an investment at the present moment would be an uneconomical decision. However, individuals buy cars according to their individual choice based on their utility function, so that the car choice is their personal risk instead of entrepreneurial risk in this case.

For quantifiable forms of non-entrepreneurial risk, such as the risk of fire in a factory for AEVs for example, a burn down of the charging infrastructure or the vehicle itself, the market provides a solution in form of insurance. For non-quantifiable and non-entrepreneurial risks certain market solutions exists, however, it is irrelevant in the context of the government subsidies considered in this paper.

Hence, neither information asymmetries nor uncertainties call for government intervention in the case of AEVs. The market provides sufficient solutions to overcome information asymmetry and uncertainty.

II.3. Market failure through indivisibilities and irreversibility

An argument that often arises in combination with high fixed costs of infrastructure is the existence of indivisibilities, meaning that the infrastructure cannot be divided arbitrarily (see for this and the following Baumol, 1987). In order to produce the first unit of a product, a certain amount of fixed costs must be incurred, while the production of the following units triggers large economies of scale, so that high capacity utilization lowers the average unit costs. Indivisibilities in combination with irreversibility (sunk costs) lead to the formation of an uncontestable natural monopoly, which can lead to inefficiencies and can make government intervention necessary.

Natural monopolies are commonly found for the provision of infrastructure, e.g. for pipelines or grids. High fixed costs of the infrastructure can then be spread over more output, so that the average costs decline with more output and economies of scale can be achieved (Baumol, 1987). But given the over 100 commercial providers for charging infrastructure, no relevant economies of scale exist in order for it to be more efficient to have one single provider. The

provision of the charging infrastructure for AEVs does incur fixed costs along with economies of scale per charge. The higher the number of AEVs being charged on a daily basis, the more the fixed costs can be spread over each charging process, decreasing the average costs per charge. However, the fixed costs are not arbitrarily high so that this applies per charging station and competitors are confronted with similar cost structures as incumbents. Each additional charging station faces the same investment decision once again. The costs for the hardware of a regular charging station are estimated to be around 5,000 euros in 2017 and are expected to decrease to 2500 euros in 2020 according to the German National Platform for Electric Mobility (See for this and the following cost estimations NPE, 2015). Additional costs associated with the installation of the charging structure can amount to 5,000 Euro, however, it is estimated that 4 charging sessions per day will be enough for an economically viable capacity utilization. Fast charging infrastructure stations cost about 15,000 Euro per station expected for the year 2020 and an additional 10,000 Euro for installation. It needs 10 charging processes per day to operate profitably. The average costs per fast charge of 80 per cent of the battery, which will provide an additional range of 150 to 200 km on average, is estimated at 8 euros. This includes a surcharge of up to 2 Euro for the user to pay for the extra service of fast charging. However, building, buying or renting a gas station for example is multiple times more expensive and is not subsidized, nor is it a natural monopoly that is not contestable. The investment in the AEV charging infrastructure represents, in fact, normal entrepreneurial risk and this risk will be taken when profit is expected. There is no relevant combination of indivisibilities and irreversibility that provokes market failure in the market for AEV charging infrastructure.

Table 6 concludes the market failure arguments of chapter II. As has been discussed, neither technological external effects, nor imperfect information, nor indivisibilities can justify government intervention in form of subsidies.

Table 6: Overview over market failure arguments to promote AEVs.

Market failure arguments	Is Intervention justified? - explanation → alternative
1) Technological external effect	**No**
- *(Lower) Negative technological external effect*	- Subsidy multiple times more expensive than net damage cost savings → internalization of external effect by allocating total costs to each transport mode
- *Positive technological external effect*:	
Independency of oil	- Purchase subsidy does not alleviate problem → internalizing external effect of oil dependency by allocation it to fuel price
Research and Development	
a) Direct sales subsidy	- Unwanted market distortions possible → internalizing external effect by allocating totals costs to each transport mode
b) Charging infrastructure	- Parallels to development of gas stations, regular entrepreneurial risk → market solution: private investment
c) Battery improvement	- Regular entrepreneurial risk, market solution exists → market solution: private investment
2) Imperfect information	**No**
-*Information asymmetries* a) adverse selection (hidden characteristics) b) moral hazard (hidden actions) c) hold up (hidden intentions)	- Non-existent and market solutions exist: → Screening of the AEVs on market → Monitoring of battery usage → Vertical integration and competition
-*Uncertainty*	- Entrepreneurial risk or insurance
3) Indivisibilities and irreversibility	**No**
Not relevant	- Entrepreneurial risk

Source: own depiction.

III. Industrial policy

As shown in the previous chapter, the causes of potential market failure cannot justify government intervention in the form of subsidies. In this chapter it will be analyzed whether the arguments of industrial policy can justify subsidizing the market for AEVs. Industrial policy of Germany was recently manifested in new guidelines (BMWi, 2019a) and is embedded in the legal framework of European industrial policy. The European Union has a set of policies summarized in its industrial policy, which target its industry and its manufacturing with the goal to enhance industrial competitiveness and sustainability, to promote investment

and innovation in clean technologies and to guide through industrial change (European Commission, 2017a).

For AEVs this means that, under German and European industrial policy, the competitiveness of AEVs from European producers is meant to be promoted. AEVs are regarded an innovational and clean technology and the automobile industry of Germany in general is considered of great importance for Germany as an industrial location (BMWi, 2019a). Therefore German or European producers of AEVs are intended to gain market power in the international market for AEVs and their by-products in early stages of market development. This market power enables them to compete in international markets and to increase the profitability of national firms in comparison to international ones.

Different theories back up this strategy and have one common underlying argument: scale economies of incumbents prevent newcomers from entering the market. The oldest one is the argument of facilitating the development of an infant industry dating back to the 1790s (Hamilton 1791; List, 1841), augmented by New Trade Theory in the 1970s (summary of relevant literature in Helpman and Krugman; 1985) and later Strategic Trade Theory in the 1980s (Spencer and Brander, 1983 and 1985).

The infant industry argument evolved from the idea that incumbent producers from foreign countries benefit from a temporal advantage and therefore lead in skill and experience, but do not necessarily have any other inherent advantage (Mill, 1848). Young industries often do not yet reach sufficient economies of scale and therefore cannot compete against incumbent competitors from foreign countries, which can realize these economies of scale and can thus benefit from cost advantages (Baldwin, 1969 and 2004). Therefore, the products' import prices might be below domestic costs. Import barriers, subsidies or quotas can promote national production until successful competition on international markets is possible. Production subsidies are often the preferred method, as unlike the others, they do not distort consumption (Melitz, 2005). Another argument for protecting an infant industry is the externality problem of a public good (see for this and the following Baldwin, 1969). The initial investment might not be made because the property rights of the later good are not well defined and information about the innovation might become freely available to competitors. The innovation can then be copied cheaply, so that the costs of the investment cannot be recovered by a revenue surplus over costs. In this case a direct subsidy of the knowledge to be acquired can overcome this technological spillover problem.

New Trade Theory (NTT) builds on the argument that incumbent industries have an advantage through realizing economies of scale. NTT expands the infant industry concept mathematically, underlining the importance of economies of

scale in combination with network effects in the formation of important industries (Krugman, 1980 and 1991). It is assumed that global competition is likely to become limited to a form of monopolistic competition, where first-movers face a significant competitive advantage (Krugman 1979).

Strategic Trade Theory (STT) expands the other theories by analyzing strategic government intervention in oligopolistic markets in order to shift profits from international to domestic firms with the goal to increase domestic welfare (see for this and the following Brander and Spencer, 1983, 1985; Spencer and Brander, 2008). Strategic government measures are export subsidies, import tariffs and subsidies to research and development. Any of these interventions lowers production costs of the home firms and gives them a comparative advantage to oligopolistic competitors on international markets. These measures can enable a newcomer to compete or even dominate international markets, which he could otherwise not.

For the market of AEVs these theories apply to three dimensions: a) the vehicles itself, b) the battery technology and c) the charging infrastructure. I will look at, whether the argument of industrial policy can be applied to any of the dimensions and then in d) provide some general criticism of the argument itself.

a) Subsidizing the sales of AEVs

The 2016 inner-German subsidy directly funding the sales of AEVs does not distinguish between the nationalities of the manufacturer but subsidizes the purchase of any AEV. Therefore, it can hardly be referred to under the argument of German industrial policy. A subsidy exclusively favoring German car manufacturers would most likely be illegal due to international laws. European Law prohibits the German government to subsidize only the sales of national car manufacturers for reasons of distortion of competition between member states (European Commission, 2017b). On a global scale, the World Trade Organization (WTO), which oversees global rules of trade between nations, prohibits its members' to impose targeted subsidies and directs countries to seek removal of such subsidy for the reason of distortion of international trade (WTO, 2017).

It could be argued, that the inner-German subsidy might, however, not directly but indirectly serve as a promotion for German car manufacturers because it is paid in Germany and German car buyers have a relatively strong preference for German cars (Aral AG, 2017; VDA, 2018). Table 7 summarizes the sales market shares of AEVs from German manufacturers, embedded in national and international context. The preference for national brands considering the sales of AEVs is evident: U.S. brands prevail in the U.S., Chinese brands predominate in the Chinese market, and German brands dominate the German sales market. In Germany, manufacturers hold a share of 66 per cent of the AEV sales in 2018.

Table 7: German AEV manufacturers in the international context

Geographic Area	Best selling models in 2017	Total share of German AEV models sold 2018[3]
Germany	Renault Zoe (17 %), VW e-Golf (12 %)[1]	66 %
European Union	Renault Zoe (10 %), BMWi3 (7 %)[2]	49 %
US	Tesla S (31 %), Tesla X (23 %)[2]	11 %
China	BAIC EC-Series (13 %), Zhidou D2 EV (7 %)[2]	5 %

Source: own depiction.

[1]: Own calculations based on KBA (2018c).

[2]: Shahan (2018).

[3]: VDA (2018).

Also, qua choice of AEV models, the subsidy has a statistically higher chance to support German manufacturers. For the German market there were 28 AEV models for sale in November 2017. Of these, 10 were German, 6 were French, 6 were Japanese, 3 were from the U.S. and 3 were South Korean. In total 36 per cent of all models available were made by German manufacturers (ADAC, 2017b). One year later, in December 2018, there were 64 AEV models for sale on the German market, 34 of which were from German manufacturers and therefore 53 per cent (ADAC, 2018b). Officially, thus, the current purchase subsidy cannot be subsumed under industrial policy but might indirectly promote German AEV manufacturers more than non-German ones, due to domestic demand and model availability.

Above that, industrial policy is not needed in order to promote sales of AEVs. Selling AEVs promises profits for the manufacturers in the same way as selling regular automobiles does. AEVs from German manufacturers dominate the European market, where half of the AEVs sold in 2018 stem from German manufacturers (see Table 7), albeit overall low sales of AEVs in Europe (2 per cent of new sales in 2018, (ACEA, 2019)). German AEV sale shares follow national and international German sale shares of ICEVs (VDA, 2018). This demonstrates a European preference for German cars. However, ICEVs face a similar demand, but without direct sales subsidies. This is true for Germany, where a direct sales subsidy for AEVs might indirectly support German manufacturers, as well as for Europe, where no German direct sales subsidy is applied.

The infant industry argument can also not hold, given that the German car market cannot be considered young. According to Schumpeter (1975), large firms have an advantage to finance investment in innovations and to find possible applications for new products. Current car manufacturers (e.g. VW, BMW, Audi, Mercedes) are large in size so they can benefit from their size and

network, making it less risky to invest in new technologies. But even newcomers, like the German start up e.GO Mobile AG for example, which has a new AEV model on the market since 2018, can compete (Baumann, 2017). Tesla started as a newcomer in the U.S. in 2003 and has now become a market leader worldwide.

Investment by manufacturers, therefore, cannot and does not have the need not to be supported through subsidies under the umbrella of industrial policy. The potential ban of ICE vehicles (Cohen, 2018; Deign, J., 2018; Buss, 2018) will encourage the demand for AEVs even further in the coming years.

b) Battery technology:

The worldwide demand for batteries is predicted to grow from 21 GWh in 2016 to 1,300 GWh in 2030 and 270 GWh of production are expected to exits by 2021 (BNEF, 2017). On average the batteries of AEVs make up about 40 per cent of the vehicle price in 2018, lower percentage shares of around 20 per cent are predicted for market leaders (Küpper et al., 2018; Curry, 2017; Holland, 2017). In order to benefit from AEVs, maufacturers need to partake in the value-added process from batteries, so the argument of industrial policy.

Currently, in 2019, most big battery cell manufacturers for electric cars come from Asia. Panasonic was the biggest manufacturer in 2018, but is closely followed by the rapidly growing companies CATL and BYD, with all 3 together holding a world market share of about 2/3 (Manthey, 2018; Gasgoo, 2019; Hajek et al., 2017). As of 2019, CATL from China is predicted to be the biggest producer, raising Chinas current world market share from slightly over 50 per cent in 2019 to 70 per cent in 2021 (BNEF, 2018).

The last German company producing lithium-ion batteries in Germany (EAS) went bankrupt in June 2017 (Eisert, 2017). Daimler stopped its production in 2015. As of the end of 2018 there is no German or European production for lithium-ion battery cell production neither in Germany nor in Europe.

There are plans for building Lithium-ion battery cell factories in Europe, and thereunder Germany, with the goal to promote the competiveness of European AEV manufacturing companies and in order to reduce dependency on Asian production, thus following European industrial policy arguments (Nikolian and Lancrenon, 2018) as well as German industrial policy strategy (BMWi, 2019a). High investment costs for giga factories, lack of regional raw materials and the market dominance of Asian companies impede European involvement (Eckl-Dorna and Sorge, 2018; Zacharakis, 2017). At this moment (January 2019), it is the incumbent Asian firms who invest in production facilities in Europe. However, this investment is by private companies. The German Federal Ministry for Economic Affairs and Energy (BMWi) provides 16 Million Euro annually for

research for battery cell technology and its components since 2017 and commits in its 2019 household to provide up to 1 billion Euro to promote German battery cell production until 2022 (BMWi, 2019b), subsumed under German Trade Policy.

Nevertheless, the market itself, via the feasibility of a factory, can regulate this investment problem and the argument of industrial policy alone is insufficient reason to justify government intervention. Growing demand makes production in Europe feasible in which case private investment will be found. A European example is the company Northvolt, which was founded at the end of 2016 and receives investment from international industries (Dierig, 2019).

Through international trade policy, research in new and improved battery technology can be subsidized. An infant industry can be supported in case of a public good with ill-defined property rights (Baldwin, 1969), such as basic research. However, this calls for a long-term institutional frame and not just short-timed substitution to overcome innovation market failure and underinvestment in novel technologies, so that basic research and its commercialization can take place (Martin and Scott, 2000). In addition, it remains questionable if research in battery technology falls into the category of basic research as a public good. The process to full market maturity production of a battery takes several years, so that a new technology cannot be copied quickly and profits are likely to be made by then (Hajek et al., 2017). Therefore, measures of industrial policy might not really be applicable here.

c) charging infrastructure

Table 8 shows the public charging infrastructure for the countries with the most developed charging infrastructure network in Europe and the numbers for the European Union (EU-28) in total. In terms of charging stations, Germany is positioned at the forefront in Europe, right behind the Netherlands with the most developed charging network in total numbers of public charging points and followed by France. Those three countries together provide 65 per cent of the European charging infrastructure. Qua density, Germany is positioned in the midrange of Europe, with 7.2 Plug-in Electric vehicles (PEV). AEVs and Plug-in hybrid vehicles are both taken into account in the PEV, as they both compete for charging points. Overall, the table shows that Germany, in comparison with other European countries, has an established charging network. There does not seem to be any urgent need for government intervention under the argument of industrial policy to develop a new industry.

Table 8: Public charging infrastructure and AEVs in 2018 (2017)

Country	Charging stations 2018 (2017)	AEVs 2018 (2017)	PEV[1] per public charging point
Netherlands	36,962 (33,633)	38,944 (21,115)	3.8 (3.6)
Germany	27,459 (25,373)	85,605 (59,672)	7.2 (5.3)
France	24,850 (22,011)	106,498 (89,631)	6.2 (5.8)
United Kingdom	19,076 (16,553)	50,258 (42,829)	10.1 (10)
Norway	12,096 (10,333)	160,615 (130532)	25.5 (22.9)
European Union[2]	138,612 (126,601)	381,730 (290,031)	7 (5.9)

Source: own depiction based on data from European Alternative Fuels Observatory (2019).

[1]: Plug-in electric vehicles (PEV) combine AEV and plug-in hybrid vehicles, which cause competition to AEVs for the charging stations

[2]: The European Union as of January 2019 with its 28 member states.

The charging network can still be improved, however, private investment should be the preferred method. Tesla, e.g. installs its own supercharger network and above that promotes charging stations at public places with its destination charging approach, giving out free wall boxes to restaurant, accommodations and similar places (Field, 2019). In Germany, 3 of 4 of the public charging stations are owned and operated by the energy sector (BDEW, 2018). Some of the extension plans of the network are taken up by a joint venture from big car manufacturers, ionity, which are building a fast charging network of 400 stations with a capacity of 359 kW of DC power in Europe until 2020 (Holland, 2018).

Another way of extending the network of the charging infrastructure and to save resources is ensuring compatibility between charging options of different providers or manufacturers (Martin and Scott, 2000). Even though this should be in the interest of the provider due to positive network externalities of the infrastructure (Katz and Shapiro, 1985; Farrell and Saloner, 1985; Farrell and Saloner, 1986), historically various different charging standards emerged. Via the Directive 2014/94/EU of the European Parliament and of the Council (European Parliament and the Council of the European Union; 2014) a new common standard for the members of the European Union was enacted in 2014. The CCS (Combined Charging System) is mandatory for any charging station in Europe after November 2017 and extends the network and therefore its profitability, without subsidies and without industrial policy.

In practice the public charging process still brings about challenges. Further problems arise, for example, through the large number of providers and their different charging and billing approaches (charging cards, apps, contracts, instant access, roaming, user accounts and so on, see e.g. ADAC, 2019).

Unification is needed and can help improve the practicality of the charging network and its feasibility; however without subsidies.

d) Criticism on industrial policy

There is general criticism of the protectionist approach of industrial policy. It is argued that the existence of higher production costs than those of foreign competitors during the early period of production does not, on its own, justify economic intervention (Meade, 1955). If after a learning period unit costs are low enough to generate profits and a comparative advantage over competitors, it should be possible to find the relevant funding in order to cover initial investment costs and possible short-term operation without profits (Baldwin, 2004; Dosi, 1988). This argument emphasizes the fact that entrepreneurs take up the investment risk against a risk-appropriate rate of return, as it is done in the market for AEVs.

Additionally, there are three main risk factors for government intervention as a result of industrial policy: government failure, rent seeking behavior of economic agents and misuse of industrial policy for protectionism (Warwick, 2013). Governments often operate under a lack of required information, capability and incentive to come up with effective industrial policies based on economic merits (Rodrik, 2008; Naudé 2010). This can lead to an ineffective allocation of resources, where supporting a selective branch of industry might not generate positive net welfare gains.

All in all, the arguments of industrial policy could not be applied to justify subsidizing the market of AEVs in Germany and, according to the general criticism, care should be exercised with industrial policy in general.

IV. Alternative suggestion – pricing of CO_2 in ICE vehicles

Neither market failure nor industrial policy could serve as sufficient justification for government intervention in the form of subsidies in the market for AEVs. Contrary to every argument in favor of subsidies, it is superior to put a direct price on the externality relative to other indirect corrective measures (Holland et al., 2016). Therefore in this chapter, true-cost pricing in transport is discussed as an alternative way to promote the sales of AEVs.

As discussed earlier, driving a car will always create negative technological external effects in the form of - inter alia - emissions. Thus, the private and social marginal costs diverge by the amount of the external costs and it is economically desired to internalize the external costs. Subsidizing AEVs can lower total emissions from driving by bringing more AEVs on the road that replace ICEVs.

This reduces social marginal costs of ICEVs and makes the overall vehicle fleet in Germany less emission intensive, under the assumption of low emissions from the electricity mix generation and disregarding the global social effect, for which the costs and benefits of this subsidy must be evaluated. Contrary to subsidizing a product with a lower negative external effect, one could also directly internalize the external effect of ICEVs by allocating the social cost of each vehicle type to the vehicle driver itself and thus to the originator of the external effect.

In concrete terms, internalizing external costs can be done by putting a price onto the emissions that arise from driving cars through trading "emission allowances" (certificates) through an emission trading system. The focus of the emission trading usually lies on CO_2 emissions, which is why CO_2 will be discussed here. The same mechanism, however, could also be applied to other pollutants, to reflect the climate as well as the air quality impact. CO_2 emissions are stoichiometrically related to the consumption of fuel, from which follows that by knowing the chemical reaction that happens in diesel and gasoline engines, the CO_2 emissions per liter of diesel or gasoline consumed by a car can be accurately calculated. The precise figures of the emissions per liter depend on the actual quality of the fuel (DHZ, 2017). However, the amount of emissions per liter of fuel filled into the tank of a car can be calculated and represented in the form of negotiable emission permits.

Some research on integrating road traffic into an emission-trading scheme has been done already, either Germany-specific or for the European Union, for example by Hartwig et al. (2008), Deuber (2002), Kniestedt (1999), Bergmann et al. (2005), Hohenstein et al. (2002), Michaelis (2006a and 2006b) and Michaelis and Zerle (2006). An article by Junkernheinrich (1998) presents an overview over older approaches.

Hartwig et al. (2008) propose three possible ways to integrate private passenger cars into a certificate-trading scheme in Germany, which will be briefly presented here: an *upstream approach*, a *mid-stream approach* and a *downstream approach*.

The *downstream approach* follows the 'polluter pays' principle. In this case the user of the vehicle has to hold certificates, which he uses every time he fills up the car at the gas station. The innovative capabilities of this approach are high due to the abatement options, as vehicle users can adapt by traffic avoidance, modal shift, and demand for energy efficient vehicles. Transaction costs of this approach are disproportionally high, however, due to the high number of the economic players involved. In the *mid-stream approach* the car manufacturer is required to hold certificates. When selling the vehicles, car manufacturers have to obtain certificates for the amount of emissions that are likely to be caused by

their vehicles throughout their life-cycle. In this scenario, the environmental effectiveness is not given, as the actual mileage throughout the life cycle of a car cannot be controlled for and a rise in mileage will lead to higher emissions. In the *upstream approach*, the fuel suppliers are responsible for holding certificates for the amount of the fuel that they sell into the market. This approach cannot be applied to private passenger cars alone but would be relevant for all vehicles using fuel. Transaction costs in this scenario seem relatively low as the number of economic players in Germany is low and it could be applied similarly to and instead of the mineral oil tax. Therefore, this is the preferred approach.

Properly designed environmental certificate trading is considered an effective as well as efficient measure in achieving climate goals and internalizing NTEEs at least economic costs while inducing technological advancement (Hartwig, 2007; Dales, 1968). Emission trading is environmentally effective, because a quantity of new CO_2 emissions can be determined a priori via a limited number of emission allowances. Polluters need to obtain these allowances for the quantity of their emissions and have to otherwise pay a fine. The a priori set emission target of CO_2 is thus likely to be met within a time frame and region. Furthermore emission trading is efficient, because it allows for emissions to be reduced where it is most cost effective, so that the overall marginal abatement costs can be minimalized. It also sets incentives for environmental technological progress in order to reduce the marginal abatement costs. Avoiding transport in total, switching to another way of transport (e.g. bicycles, public transport or carpooling) or switching to more efficient or less emitting vehicles such as AEVs can be ways to abate emissions. Additionally, technological progress is incentivized through stimulating car manufacturers to produce more fuel efficient vehicles and fuel suppliers to produce fuels with lower emissions. This can go beyond fleet consumption, which is set at European level for manufacturers and the European car fleet.

If certificate trading is carried out well, it can attribute the true costs of ICEVs, which will then be borne by the drivers of the vehicle that incur them, as they pay a price for their exhaust emissions. This can be an effective and efficient way for mitigating climate change and might, if and only if socially beneficial, lead to an increase in AEV market penetration. The external costs of the ambient CO_2 emissions that arise through electricity production, which then powers AEVs, is already internalized through trading emission certificates for electricity generation under the European Union Emissions Trading System.

V. Conclusion

In this paper, subsidization of all-electric vehicles (AEVs) in Germany is investigated from a normative perspective regarding three aspects: the direct purchase subsidy, the infrastructure and the battery technology. In this context, market failure arguments as well as arguments from the theory of industrial policy are considered. Neither of these arguments can justify government intervention in the form of subsidies.

First, the market failure argument of technological external effects is assessed. AEVs are found to have lower negative technological external effects (NTEE) than internal combustion engine vehicles (ICEVs) considering their life-cycle emissions. A simplified first-order approximation of the net damage cost savings (NDCS) and the saved climate costs was conducted, to evaluate the benefit of driving AEVs promoted by the subsidy. Benefits were found to equal the purchase subsidy from the German government for an all-regions average. However, not just the driving, but particularly the lifetime impact needs to be considered. Battery production has the biggest impact on lifetime emissions of AEVs and therefore the current subsidy cannot be justified through lower NTEE. A profound econometrical analysis and sensitivity analysis on the assumptions could provide a more thorough inside, however this goes beyond the scope of this paper and is left for further research.

Positive technological external effects (PTEE) can be found in a reduction of dependency on petroleum imports, which is however, traded for a dependency on battery imports and the battery's raw materials. PTEEs from research and development (R&D) could not be found to justify government subsidies. Contrary, market solutions such as true-cost pricing for ICEVs and AEVs, as well as private investment for a risk-appropriate rate of return can contribute to enhance R&D. Secondly, next to technological external effects, imperfect information is not found to validate subsidies, either. Neither adverse selection, nor moral hazard nor hold up is found to be of relevance, or respectively the market provides options to overcome potential problems. Thirdly, indivisibilities in combination with irreversibility are not found to applicable for the charging infrastructure of AEVs.

Next, an assessment of arguments of industrial policy was performed for the three aspects and could not confirm subsidies as necessary. First, the purchase rebate cannot be referred to under German Industrial Policy, as it doesn't exclusively favor German manufacturers, though, it might have an indirect effect on German models. Secondly, Batteries for AEVs are facing a rapidly growing demand in the next years but most of the current supply comes from Asia. European factories can be built without German subsidies through private investment, as shown by examples. Thirdly, private investment is the preferred

method for investment in the infrastructure. Investment is currently taken up mainly by the energy sector, but investment from a consortium of car manufacturers is building up.

The results of this paper lead to the following policy advice: The German goal of bringing 1 million electric vehicles on the road by 2020 is far from being fulfilled. However, this goal cannot be reached through subsidies and no normative reasons could justify subsidization. Charging and range problems are regarded the main barrier for potential consumers. Private companies are building fast charging capacities of 350 kW. They can shorten charge processes for AEVs to 10 minutes and are predicted to start operation by the end of 2019. The government can assist advances in the charging facilities by creating a stimulating long-term institutional frame for investment in charging infrastructure and by encouraging common charging and billing standards, preferably Europe-wide.

Therefore subsidies for the AEV market should be removed, or at least not be extended. The auto industry, under the pressure of existing competition, is obligated to invest into AEVs and its technology if it wants to participate in this growing market. Government intervention possibilities lie in facilitating true cost pricing for passenger cars, which can support the market to bring about the most efficient way of transport. AEVs can then possibly function as competition for ICEVs in order to compete for environmental friendlier mobility with a lower air quality and climate impact.

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ANNEX

For the first-order approximation of the saved damage costs and reduced climate costs of AEVs in comparison with ICEVs, the data sources and steps that were taken are to be explained in more detail here:

The mileage of diesel and gasoline vehicles were calculated based on surveys of the KBA (2018a and 2018b). In 2016 an average diesel car drove 19,935 km and an average gasoline car drove 10,485 km.

The marginal air pollution costs stem from CE Delft, Infras, Fraunhofer ISI (2011). In this study they were determined for 2008. The marginal air pollution costs are assumed to be lower by now as cars have become cleaner with the European Emission Standards. But on the other hand more people might be affected in cities. Also, this is an average value for all European Countries (EU-27), but Germany is towards the high end of the pollution costs for passenger cars in Europe. Therefore using the 2008 value seems justifiable, lacking a more up-to-date value. For diesel cars, the marginal air pollution costs amount to euros 40.40 for 1000 vkm (vehicle kilometers) in metropolitan areas and euro 12.6 per 1000 vkm in an all-regions average. For gasoline cars these costs amount to 14.80 euros per 1,000 vkm in metropolitan areas and 6.20 euros per 1,000 vkm in an all-regions average.

The average air pollution cost per diesel car for 2016 is thus 805,36 euros for a metropolitan area and 251,18 euros, for an all-regions average. The average air pollution cost per gasoline car is 155,17 euros, respectively 65,00 euros.

Several scenarios where created to look at the crowding out effect of AEVs towards ICEV. Table 9 provides an overview of the scenarios S1 to S7 for the calculation of the damage cost savings.

Table 9: Overview of Scenarios S1-S7 for calculation of damage costs savings

Scenario S1 –S7	Quantity of diesel ICEs replaced through AEV	Quantity of gasoline ICEs replaced through AEV	Replacement of ICEVs
S1	34022	-	full
S2	-	34022	full
S3	8505.5	8505.5	50 %
S4	1,000,000	-	full
S5	-	1,000,000	Full
S6	250,000	250,000	50 %
S7	400,000	400,00	80 %

Source: own depiction.

Additionally, the social costs of emissions caused by the electricity generation for charging AEVs are calculated, underlying the German electricity mix. An AEV on average drives about 10300 km per year, only slightly less than a gasoline car, according to a study by the German Aerospace Center (DLR) (Frenzel et al. 2015; comparison based on AEV data from 2015 and ICEV data from 2016). With 34022 AEVs on the road the estimated km driven in total for 2016 amount to 350,426,600 km.

The most common AEV sold in Germany is the Renault Zoe intense, with an average consumption of 13.3 kWh/100 km, according to the manufacturer. Considering the ADAC EcoTest well-to-wheel approach, which includes load losses during charging, the overall consumption is 19.9 kWh/100 km (ADAC, 2018a). This corresponds to CO_2 emissions of 112 g/100km when underlying the German electricity mix. The Renault Zoe intense is the newer model of the Renault Zoe life, which has a consumption of 21.4 kWh/100km consumption in the ADAC test mode which corresponds to CO_2 emissions of 120 g/100 km.

The monetary changes induced by climate change brought about by CO_2 emissions and the uncertainties that are associated with it are discussed in a wide body of literature (see for an overview Tol, 2012). Here a mean estimate of 32.8 euros/ t CO_2 is applied as in Malina (2016) and discussed therein.

For the total km travelled this means a total of 39,247.78 t CO_2 or 42,051.19 t CO_2 respectively. This leads to total damage costs of between 1,287,327 euros (for 112 g CO_2/100 km) and 1.379.279 euros (for 120 g CO_2/100 km) for all the AEVs. The higher value calculated for emissions of 120 g CO_2/100 km is used for further estimation as the 34022 AEVs most likely include more of the higher consuming vehicles. Distracting those damage costs from the damage cost savings listed above this yields the results for the different scenarios, that are depicted in table 11.

Table 10 provides an overview of the scenarios S1 to S3. This table corresponds to Fig. 1.

Table 10: Overview of Scenarios S1-S7 for calculation of damage costs savings

	DCS metropolitan area	NDCS metropolitan area	DCS all-regions average	NDCS all-regions average
diesel replacement	27.399.976 €	26.020.697 €	8.545.537 €	7.166.258 €
gasoline replacement	5.279.248 €	3.899.969 €	2.211.577 €	832.298 €
50-50-50 replacement	8.169.806 €	6.790.527 €	2.689.278 €	1.309.999 €

Source: own depiction. DCS= damage cost savings; NDCS = net damage cost savings.

The net damage cost savings in a metropolitan area amount to 26 Mio. € in a scenario where 34022 AEVs displace the same number of diesel vehicles in 2016. For the displacement of 34022 gasoline vehicles by the same number of AEVs, the savings amount to roughly 4 Mio. €. For the last scenario, 17011 vehicles, half gasoline cars, half diesel cars, are replaced by 17011 AEVs and 17011 additional AEVs drive on the roads. In this scenario, roughly 7 Mio. euros are saved in 2016.

Damage costs through PM_{10} caused by tire and break wear are neglected here, since, as to my knowledge, there is no such estimation of it for AEVs.

Table 11 provides an overview of the costs per vehicle, annually as well as during their lifetime. Covered are the annual average air pollution costs (AAPC) as well as the annual climate costs, both accumulated from driving. For the lifetime driving costs, the average lifetime air pollution costs (ALTAP) and the lifetime driving costs were added up.

Table 11: Overview of per car values of air pollution and climate values, annually and lifetime (in euros)

	Area covered	diesel	gasoline	ICEV average	AEV
AAPC (p.a.)	metropolitan	805	155	373	
	all-region	251	65	127	
Climate cost (p.a.)	all-region	373	177	243	41
Sum (p.a.)	all-region	624	242	370	41
ALTAPC	metropolitan	6,464	2,368 €	3,739 €	
	all-region	2,016	992	1,335	
climate costs (lifetime driving)	all-region	2,992	2,704	2,832	630
Sum (lifetime driving)	all-region	5,008	3,696	4,167	630

Source: own depiction based on own calculations with Data from KBA (2018a, 2018b), Frenzel et al. (2015), ADAC (2018a), CE Delft, Infras, Fraunhofer ISI (2011), Malina (2016).
Notes: AAPC= average air pollution costs, ALTAPC= average lifetime air pollution costs, (160 000 km driven are assumed for lifetime values)

Again, the difference between all-region areas and metropolitan areas can be noted. Air pollution has an almost 3 times higher impact in metropolitan areas, due to population density, while the climate impact, naturally, is global.

Especially diesel vehicles stand out negatively with their impact in metropolitan areas (805 euros p.a.). The annual driving impact of an average ICEV is 370 euros for the all-region area. Summed up to the lifetime of 160000 km, this amounts to 4167 euros.

In order to put these values in perspective and provide some reference: A study by Beckers et al. (2012) found air pollution costs in 2008 to be around 155 Euro per registered car annually. This has to be compared to 127 euros, depicted here in table 11. Average environmental cost per car in Germany were found to lie between roughly estimated 200 and 800 Euro per year, depending on whether a high or low scenario is chosen for environmental costs (for the year 2008). In my calculations, a medium scenario was applied and costs amount to 243 euros annually. Therefore, values calculated here seem to be rather conservative in comparison. Becker et al. (2012) estimate overall air pollution and climate cost of 900 euro per registered car annually, while this study estimates them to be around 370. The big difference can be explained by the difference in assumptions about climate costs, as the air pollution costs are relatively close to each other. Please note that the estimated costs in this study only evaluate the driving costs. For a more profound analyses, lifetime air pollution and climate costs have to be assessed.