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Enlarging the scale of BEVs through environmental zoning to reduce GHG emissions: a case study for the city of Hamburg

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Abstract

This study investigates the power of environmental zoning for promoting battery electric vehicles in order to reduce greenhouse gas (GHG) emissions in Hamburg. Concepts of environmental zoning will be analysed to identify their GHG relevance and the specific role of electric mobility. The scenario calculations show that with the same number of vehicles as today the share of battery electric vehicles (BEVs) should rise to 75% to reach the GHG emission goal set by the government. However, it would not be enough to tax only commercial vehicles for entry into environmental zones; this must also apply to private vehicles. At the same time, energy consumption for charging would have to be improved, in ecological terms, by more than half in order to meet the desired climate targets. Environmental zones can be a measure to increase the proportion of BEVs, but further accompanying measures are required to achieve the GHG reduction targets.

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Keywords: electric mobility; environmental zones; GHG accounting; environmental impact; battery electric vehicle

1. Introduction

In conjunction with worldwide and European goals to achieve a remarkable greenhouse gas (GHG) reduction, the German government aims to reduce GHG emissions as much as possible in order to minimize the gap to the 40% reduction goal for 2020, progressively decreasing to finally 80-95% in 2050, compared to the reference year 1990

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(UBA 2016). The basis of the German Climate Action Plan 2050 stems from the climate summit in Paris in 2015, where a resolution was passed to achieve GHG emission neutrality during the second half of this century (BMUB 2016). According to the climate plan, this will only be feasible if energy systems worldwide are completely decarbonised at the same time (BMUB 2016).

The German government's climate plan for 2050 also forms the basis for setting out strategies and measures in various spheres of activity in order to protect the climate. This includes a reduction of 61-62% in the energy sector and 40-42% for transport by 2030, compared to the reference year 1990. In this respect taking the correlation of these sectors into account is deemed increasingly important (BMUB 2016).

By 2013, an overall reduction of 22% was achieved mainly in the energy sector, by fostering renewable energy and increasing the efficiency in the building and housing sector (BMUB 2014). So far, no relevant reduction of transport induced GHG emissions could be accounted for. Whereas GHG emissions caused by passenger traffic have decreased slightly since 1990, even though transport volumes have increased, freight traffic-induced GHG emissions increased (Flämig and Wolff 2016). An analysis conducted by the German government for the Federal Transport Infrastructure Plan (BMVI 2014) found that annual kilometres driven will increase by 10% for cars and 28% for trucks between 2010 and 2030. This poses a further challenge to the government's climate plan for 2050. Over the 20-year period this is equivalent to a jump from 599 billion vehicle kilometres driven (vkm) to 657 billion vkm annually, and an increase for trucks from 78 billion vkm to 100 billion vkm annually (BMVI 2014).

In Germany, around 20% of GHG emissions result from transportation (UBA 2016). This is not least due to transport's energy consumption that has more than trebled in Germany since 1960. Nowadays, 30% of total domestic energy consumption is generated by transport, of which over 90% stems from petroleum. Whereas rail traffic is predominantly electrified, passenger and goods traffic on roads, in the air and on water is still almost entirely dependent on fossil fuels.

The greenhouse gas emissions produced by transport need to be reduced in order to achieve the goals set out in the climate plan. The objective is to rid the transport sector almost entirely of using fossil fuels by 2050 and, thereby, largely freeing this sector of GHG emissions. This is to be achieved primarily by developing renewable energy sources and implementing energy-efficient measures. At the core of this consideration is the introduction and propagation of direct electrical motor technologies, as well as the use of electric-based fuels, with the aim of attaining a CO_2-neutral power supply. This means a reduction of 95 to 98 million tons of CO_2-equivalent by 2030 (BMUB 2016).

Because up to 80% of GHG is emitted within urban areas, action is needed by the cities to achieve international climate goals (United Nations 2017). In recent years, a sharp increase in the number of restrictions reducing the accessibility of cities has been observed throughout many countries. For instance, Wen and Eglese (2016) discuss road tolls as a measure for achieving climate goals in cities such as Stockholm, Singapore and London. In other countries like China, in Beijing, congestion charging on traffic is implemented. Wu et al. (2017) show that this measure has the potential to increase public transit and reduce CO and HC emissions but also has a negative impact on emissions in peripheral areas of cities, and entire main urban areas. Valázquez-Martínez et al. (2016) propose a method of assigning vehicles to delivery areas for CO_2 emissions reduction for Mexico City. Nakamura and Hayashi (2013) give an overview of measures in different countries for designing low-carbon cities. The policy tool mostly used in Germany is the environmental zone. These are usually low emission zones (LEZ) as they are directly connected to specified limits of air-pollutant emissions of road vehicles. Originally, environmental zones did not refer to climate change actions, but was applied as a tool to meet the European limits of local airborne pollutants and noise caused by traffic (Michiels et al. 2012).

The research question is whether political climate targets can be achieved by only enlarging the share of battery electric vehicles (BEV) on the streets without implementing an environmental zone. In other words, what is the ecological benefit in terms of GHG reduction of introducing an environmental zone which only a BEV can access? Therefore, the objective of this study is to examine the effectiveness of environmental zones on promoting electric mobility to reduce greenhouse gas emissions. The study begins by reviewing the history of environmental zoning and the relationship between electric mobility and greenhouse gas emissions. Then, data on registered vehicles in the city of Hamburg is used to determine the existing fleet structure and corresponding energy consumption and travel characteristics of component groups of the fleet. The results of this analysis are used to assess several BEV adoption scenarios and resulting emissions reductions. The study concludes with a critical reflection on environmental zoning, and whether alone it is a strong enough measure to meet the current emissions reduction goals.

2. State-of-the-Art: The impact of environmental zones

2.1. Environmental zones

Environmental zones have been studied intensively in literature. There is some research classifying environmental zones as one measure among others in a specific target system, e.g. air quality, externalities (e.g. De Borger and Proost 2013). Some publications also focus on the implementation of environmental zones in specific cities, e.g. Berlin, London, Lisbon, Leipzig, and (partially) compare the situation before and after starting it in terms of different environmental and social impact categories (e.g. Ferreira et al. 2015; Flämig and Wolff 2016; Lutz and Rauterberg-Wulff 2009; Rasch et al. 2013). Others prefer to focus on one specific impact category such as fleet renewability or air pollutant emissions and consider several cities in one country or even work European wide (e.g. Boogaard et al. 2012; Holman et al. 2015).

Driven by European and national policies and a raised awareness for human health, environmental zoning is nowadays applied widely throughout Europe. These restricted areas are usually built up in inner cities, but they sometimes cover agglomerations with a high density as in the Ruhr Area. In Germany, there are so far 58 environmental zones based on three different Euro-standards implemented (UBA 2018). These are the three pollutant classes Euro 1 to Euro 3, which provide information about the respective fine dust emissions of the vehicle. In 2008, there were 267 cities with accessibility restrictions, whereas in 2016 around 500 (+87%) cities had implemented restrictions (Leifheit 2016). Thereby, the proportion of emission-based restrictions increased by 238% to a total of 243 environmental zones in Europe (Leifheit 2016).

Usually, accessibility restrictions of environmental zones focus on air pollutant emissions and thus refer to the emissions standard, like Euro 5 or Euro 6, instead of GHG. In consequence, recent research rarely deals with the relation of environmental zones and electric mobility.

In Germany, one pursued effect of environmental zoning is fleet renewability (UBA 2018), in other words vehicles with emission classes below the required Euro-standard are exchanged for ones with higher classes, e.g. BEVs. Indeed, emission standards can also be met by installing an appropriate filter system. However, there are several cases where the implementation of emission zones led to a recognisable fleet renewability.

Lutz and Rauterberg-Wulff (2009) as well as Rauterberg-Wulff (2011) provided evidence for fleet renewability implied by a LEZ. Firstly, Lutz and Rauterberg-Wulff (2009) stated that the fleet renewability not only has an effect inside the LEZ but in the city as a whole. However, in the neighbouring counties (here Potsdam or Cottbus) the share of appropriate vehicles was considerably smaller. Rauterberg-Wulff (2011) showed figures of the fleet composition in comparison to a trend scenario and stated that the increase factor of the fleet share of LEZ-compatible vehicles is between 1.5 and 3. More precisely, this means that the proportion of LEZ-compatible passenger diesel cars is 1.9 times higher than without the introduction of the environmental zone. For light commercial vehicles (LCV) the share has tripled and for trucks larger than 3.5 tons gross vehicle weight (GVWR) the share of LEZ-compatible vehicles in the fleet is 2.5 times higher than without the introduction of LEZ.

Likewise, Ellison et al. (2013) analysed the effects achieved by the different stages of the LEZ in London for rigid and articulated trucks as well as for LCVs. The first stage of the LEZ implemented in 2008 affected vehicles with a GVWR greater than 12 tons and required Euro 3 emission standard. For rigid vehicles within London, the replacement rate was 20% above average, i.e. the share of Euro 3 vehicles was 20% lower for the LEZ. Due to higher replacement costs, the effect for articulated vehicles was smaller, notably around 10%. In 2012, the LEZ phase 3 required Euro 4 standard to enter the zone, and also affected LCV greater than 1,305 kg GVWR. Just under 60% of freight-carrying vehicles were covered by this. Comparing the share of LCVs not meeting the LEZ requirements from before and after implementing the environmental zone, a substantial effect of an extra 10% by affected LCV fleets in comparison to the national average of environmental fleet renewability was once again observed.

Bozem at al. (2013) conducted a nationwide survey on public attitudes to alternative drive technologies. One of the questions dealt with the potential behaviour of private car owners in case an environmental zone is implemented that completely excludes conventional propulsion technologies. Most respondents would switch to public transport and only a few people would buy or rent a car with alternative propulsion technology.

However, it can be stated that the research community does not show a clear picture when it comes to impact evaluation of environmental zones. To date, it is not known if environmental zoning also contributes to GHG reduction, in particular not a LEZ.

2.2. GHG reduction and electric mobility

Electric mobility is seen to be the key tool in improving energy efficiency as well as reducing CO_2 emissions in the transport sector, in order to, wherever possible, reach the climate goals that have been set (Braun et al. 2014). Life cycle assessment (well-to-wheel) of BEVs using the current energy mix shows a higher efficiency in contrast to combustion engines, and can, therefore, contribute to the reduction of CO_2 emissions (Die Bundesregierung 2009). Nevertheless, it is not only the exhaust emissions of BEV in use that have to be observed during the ecological audit. A study undertaken by BMVI (2016) illustrates that environmental impacts caused during the manufacturing process of BEVs are significantly higher (+60%) in comparison with conventional vehicles featuring internal combustion engines. This stems from the manufacturing of the battery and the high degree of environmental impacts in respect of mining the raw materials and the actual manufacturing process. The higher burdens in the production phase will be offset over the entire life cycle by lower burdens in the utilization phase, if the energy mix contains a high degree of renewable energies (BMVI 2016; Die Bundesregierung 2009).

The modelled scenarios show that the greatest ecological value can be achieved by procuring charging from its current form to renewable energy sources (BMVI, 2016). Even Schott et al. (2012) state that electric mobility only reduces greenhouse gas emissions if the electricity required comes from using additional renewable energies. In their study, Ma et al. (2012) compare the GHG emissions of BEVs to conventional vehicles throughout their entire life cycle and also come to the conclusion that even though BEVs are highly efficient, significant savings are only possible if the GHG intensity of the power supply is as low as possible. Zhao and Heywood (2017), similar to Ou et al. (2010), evaluate the impact of different electricity scenarios on the energy demand and GHG emissions with the result, that there is a potential to reduce energy demand, oil dependence and GHG emissions. Even Zhou et al. (2017), which compared a battery electric truck with a diesel truck considering several variables, conclude that the battery electric truck has lower GHG emissions and higher lifetime total cost of ownership (TCO). However, this does not apply to all cases. On the contrary, Zhao et al. (2017) refer to Canals Casals et al. (2016), which point out, "[…] UK and Germany are such high GHG emitters that an increase of the EVs on the road would not reduce the global warming potential". Woo et al. (2017) underline the statement that the sustainability of the BEVs depends on the energy mix of the individual countries.

3. Research approach

This research investigates the power of environmental zoning for fostering electric mobility to reduce GHG emissions in Hamburg. In a first step, the aforementioned results of a literature study have been worked out. The environmental zone was introduced as a policy measure in the form of an access restriction. Thus, different concepts of environmental zoning were analysed to identify their environmental impact, e.g. their GHG relevance and the specific role of electric mobility.

As there has hardly been any investigation to date into the availability of data on the role of the BEV and environmental impacts on climate change, this scenario is conducted with a case study. The city of Hamburg has been chosen as it is one of the few cities in Germany with more than 1 million inhabitants where an environmental zone has not yet been set in place. At the same time the degree of political support of the government of the city of Hamburg to foster electric mobility is very high.

Following a brief description of the current ecological situation in Hamburg, the political goals of the local government and the measures set out, an estimate was undertaken to determine the proportion of BEVs needed as a total of vehicles registered in Hamburg in order to be able to achieve the environmental goals.

4. The city of Hamburg: Climate measures, electric mobility, and environmental zoning

Pursuant to Hamburg's climate action plan, CO_2 emissions will gradually be reduced at least by 80% by 2050 compared to the reference year 1990. By 2030, CO_2 emissions are to be halved (Bürgerschaft der Freien und Hansestadt Hamburg 2015; FHH 2013), which is somewhat less ambitious than the goal of the German government (see above). Overall, Hamburg emitted around 17 million tons of CO_2 in 2013, thereof the transport sector share was 24% (FHH 2016). Hamburg has formulated a reduction target of greenhouse gas emissions by 40% by 2020 compared to the reference year 1990 (Bürgerschaft der Freien und Hansestadt Hamburg 2015). On the whole, mobility measures are estimated to contribute with 9,300 tons, including 6,100 tons reduced by electric mobility (Bürgerschaft der Freien und Hansestadt Hamburg 2015). This only corresponds to 0.5% of the aspired 2 million tons of CO_2 reduction. Considering that almost a quarter of GHG emissions are generated by traffic, it appears that more measures should be taken. The Hamburg Senate has defined the following areas of action (Bürgerschaft der Freien und Hansestadt Hamburg 2015):

- Increasing environmentally friendly modes of transport
- Systematic correlation of renewable energies and intelligent transport engineering
- Increase in percentage of low-emission cars on roads as total of all newly registered vehicles to 10% by 2020 and 30% by 2030
- Optimised planning guidelines

A significant point in the Senate’s action plan is taking into account the ecological aspect when replacing fleet vehicles, as such vehicles have a higher total kilometres driven and, therefore, promise best possible success in reducing the amount of emissions. The Senate is focusing on successively integrating low-emission engines within Hamburg’s taxi fleets and a gradual electrification of other commercial vehicle services, such as electrified car sharing fleets or ‘on-demand’ shuttles, in order to increase the number of BEVs on the city roads. Furthermore, further electrification of commercial transport is to be pursued with the Chamber of Commerce, as well as expanding the number of charging stations available to the public.

The Senate intends to assume a pioneering role. The Hamburg Climate Plan states that the share in electrically run fleet vehicles is to be increased to 50% in the Free and Hanseatic City of Hamburg by 2020. At the same time, the Senate wishes to work towards raising the number of BEVs and LCVs from currently 17% to 20% by 2020, as well as the share in public-sector companies using BEVs from currently 36% to at least 50%. Following a decree signed by the city’s mayor in 2014, all Free and Hanseatic City of Hamburg offices are to buy only electrically powered vehicles in the EU category M1 and N1 when buying or replacing vehicles. Reasons have to be given where vehicles are procured, which run on combustion engines.

On 1 January 2016, in Hamburg 858 BEVs were registered, which is equivalent to a share of 0.13% registered vehicles in Hamburg and 3.4% of all registered BEVs in Germany (KBA 2016a). Hamburg planned to have 3,000 BEVs registered in the city by 2017 in order to achieve its long-term emission reduction target (Bürgerschaft der Freien und Hansestadt Hamburg 2015). From today’s perspective, the measures adopted to date in Hamburg do not appear sufficient, in order to achieve the required percentage of low emission vehicles. As mentioned in the current status of research, many researchers as well as planners and politicians therefore see the implementation of an environmental zoning as an important measure to achieve the reduction goal. Whether this makes sense for Hamburg is discussed below.

4.1. Data sources

Various data sources are used to evaluate the potential in reducing GHG emissions within different scenarios.

The Kraftfahrtbundesamt (KBA), the Federal Bureau of Motor Vehicles and Drivers (KBA 2016a) provides information on registered vehicles by vehicle class and propulsion type for Hamburg. KBA does not provide registration data for different passenger car types, such as mini, compact or utility cars, on a federal state level. However, figures for different passenger car types registered in Hamburg were derived from a former study by Schüle (2013). The author analysed data from the “Mobilität in Deutschland 2008” (MiD, mobility in Germany) survey. The

MiD is a cross-sectional study on the mobility behaviour of the German population and is provided by the ministry of Transport and Digital Infrastructure. It offers differentiated evaluation opportunities of demographic, socio-economic and regional mobility patterns of households.

The same source (i.e. MiD 2008 seen in Schüle 2013), was used for mileage per year in respect of different passenger car types. For other (than passenger) vehicles, such as motorcycles, buses, trucks and trailers again the KBA provides mileage data (KBA 2016b).

Energy consumption data for different types of propulsion are taken from different sources. Assumptions for fuel consumption regarding internal combustion engines as well as energy consumption for BEVs, are based on the one hand on a final report published by the BMVI (2016): "Assessment of the practicability and environmental impacts of electric vehicles", concomitant and impact research conducted as part of the showcase programme "Schaufenster Elektromobilität" (2015). On the other hand, findings of a non-profit advisory organisation are used (co2online gBmbH 2017). Fuel consumption of utilities also stem from the interim report of the Wuppertal Institute (2012) "Analysis of measured data on running and charging electric vehicles". These consumptions are only stated for diesel vehicles and were also used as the calculation basis for petrol-fuelled vehicles. The fuel consumption of commercial vehicles has been taken from the Shell Study which researches the future of road freight transport and public road passenger transport (Shell 2016). The reports by BMVI (2016) and Schaufenster Elektromobilität (2015) assess the practicality of BEVs and compare them with manufacturers' data on reference vehicles. The results of the test vehicles from both reports are used below, as these portray the true consumption of the vehicles. Figures from both sources are used for the final calculation with overlapping data in the individual vehicle segments. Consequently, small cars have, for example, an average consumption of 0.168 kWh/km as shown in Table 1. For motorcycles a study from the Institute for Energy and Environmental Research (ifeu) was used (Dünnebeil et al. 2004).

Fuel consumptions of internal combustion engines are subdivided into diesel and petrol for all segments with the exception of utility vehicles. Where no consumption values were available for the individual commercial vehicle weight classes, the mean values of the values presented in the study are used.

Table 1. Vehicles and energy consumption (own compilation based on BMVI 2016, Schaufenster Elektromobilität 2015, co2online 2017, Wuppertal Institute 2017, Shell 2016, Dünnebeil et al. 2004).

Vehicle Type	1 diesel/km	1 petrol/km	kWh/km
Motorcycles	0.04	0.04	0.142
Buses	0.29		
Rigid Trucks			
<= 3.5t GVWR	0.083	0.078	0.23
>3.5t GVWR	0.2655		
Passenger Vehicles			
Mini cars	0.0372	0.0473	0.142
Small Cars	0.045	0.073	0.168
Compact Cars	0.043	0.0573	0.1815
Mid-range	0.068	0.087	0.185
Upper mid-range	0.089	0.126	0.216
Mini-Vans	0.048		0.23
Big-Vans and Utility Cars	0.074		0.322
Trailer	0.345		
Other	0.345		

Emission factors for fuel are used as proposed by the Federal Environment Agency as seen in Schüle (2013) (petrol 2.33 kg/l and diesel 2.63 kg/l). Regarding the electricity emission factor, results of a study by Nitsch (2016) are used here and for the various scenarios as shown in Table 2. Nitsch (2016) explores the electricity mix (and resulting GHG emissions) for one base line scenario ("Trend 2015") and two future scenarios depending on implemented policy for different time horizons. The scenario "Trend 2050" considers the impact resulting from current federal policy. The basis for the scenario is the objective of the energy and climate protection concept from the year 2011 and the targets for what is known as the 'Expansion of Renewable Energies Act'. Nitsch (2016) assumes that the National Action Plan for Energy Efficiency and the Action Program on Climate Protection 2050 will have an impact on the energy mix. The scenario "Klima 2050" takes into account a stronger focus on renewable energy and accompanying measures. Nitsch (2016) is aiming at the upper reduction target of the Energy Concept 2011, which sets a goal of 95% reduction of greenhouse gas emissions in 2050. This requires a 100% energy supply from renewable energy.

Table 2. Electricity emission factors (Nitsch 2016).

Scenario	Electricity emission factor
Trend 2015	0.483 kg/kWh
Trend 2050	0.208 kg/kWh
Klima 2050	0.005 kg/kWh

5. As-is situation (BEV share <1%) with 3 scenarios of energy mix

On 1 January 2016, 879,843 vehicles were registered in Hamburg: thereof 761,655 passenger cars. According to KBA's statistics, different types of passenger cars are classified. Most of the passenger cars are small or compact cars, both segments accounting for just under a third, followed by mini and mid-range cars as well as mini vans: all representing roughly 8%. Other passenger car types have rather a low share in Hamburg.

Moreover, there are 52,285 rigid trucks (44,717 LCV ≤ 3.5 tons GVWR, and 7,568 > 3.5 tons GVWR), 3,355 articulated trucks, 52,535 motorcycles, 1,714 buses, and 8,299 other vehicles as shown in Table 3.

Depending on the vehicle class, different annual mileages per vehicle are typically travelled. Calculated using the number of registered vehicles, it becomes evident that especially small and compact cars account for a large share of mileage travelled due to their amount of registered vehicles. Mid-range, upper mid-range and the group of luxury, off-road and sports cars also contribute to mileage travelled by vehicles registered in Hamburg. In addition, trucks (esp. LCVs) and buses have a high mileage per vehicle and, consequently, a relatively high proportion of total mileages.

Table 3. Vehicles and energy consumption (own compilation based on BMVI 2016, Schaufenster Elektromobilität 2015, co2online 2017, Wuppertal Institute 2017, Shell 2016, Dünnebeil et al. 2004).

Vehicle Class	Registered Vehicles in Hamburg on 1.1.2016	Share of Vehicles	Annual Mileages per Vehicles (in km)	Mileages Travelled per Vehicle Class (in 1,000 km)	Share of Mileages
Passenger Cars					
Mini Cars	62,144	7.1%	8,272	514,057	4.77%
Small Cars	246,196	28.0%	9,348	2,301,440	21.37%
Compact Cars	237,842	27.0%	12,605	2,997,999	27.83%
Mid-Range and Upper Mid-Range cars	72,362	8.2%	14,482	1,047,917	9.73%
Luxury, off-road and sports cars	54,132	6.2%	15,966	864,279	8.02%
Mini-Vans	56,777	6.5%	16,125	915,526	8.50%
Big-Vans and utility cars	32,201	3.7%	12,693	408,711	3.79%
Motorcycles	52,535	6.0%	2,302	120,936	1.12%
Buses	1,714	0.2%	57,311	98,231	0.91%

Rigid Trucks					
<= 3.5t GVWR	44,717	5.1%	19,388	241,189	2.24%
>3.5t GVWR	7,568	0.9%	31,870	338,516	3.14%
Articulated Trucks	3,355	0.4%	100,899	338,516	3.14%
Others	8,299	0.9%	6,749	56,010	0.52%
∑	879,843			10,771,784	

In terms of drive technologies, most registered vehicles have an internal combustion engine (ICE). In total, 868,667 vehicles (98.7%), of which 322,046 are diesel and 546,621 petrol vehicles. 10,961 vehicles have alternative drive technology: 6,884 vehicles run on natural gas or LPG (CNG, LNG), 2,936 hybrid electric vehicles (HEV) and 1,141 BEV. Depending on the propulsion technology, different energy consumption factors were used as introduced as part of the database. Consumption values for ICE vehicles were referred to 'as litres of fuel per km'; for BEV consumption factors, it was 'kWh per km'.

With regard to emission factors, the following approach was taken. First, for BEV an emission factor is taken as applied to the current energy mix in Germany (hereafter: 'base line scenario'). Second, two future values for the year 2050 were used for calculations: one considers federal business as usual (hereafter: 'Planned line scenario'), the other factor represents the most advanced efforts seeking to stop climate change (hereafter 'Climate line scenario').

By multiplying the energy consumption for the different vehicle types and the respective emission factor of drive the GHG emissions per km and vehicle are calculated. Together with the number of registered vehicles and the average mileage for each vehicle type the GHG emissions in total for each scenario are determined.

Within the different scenarios of the as-is situation, i.e. BEV share less than 1%, values for diesel and petrol vehicles stay the same; only electricity emission factors are variegated as shown in Table 2. Table 4 shows that the results of all three scenarios are almost the same, as the relatively low share of BEV regarding overall vehicles does not provide a range for dynamics.

Table 4. GHG emissions in three energy scenarios of the as-is situation (own calculation).

Scenario	GHG in 1,000 tons
Base line scenario	2,202,914
Planned line scenario	2,202,183
Climate line scenario	2,201,643

6. Mental-game situation: Target 40% GHG reduction

Registered vehicles and mileage travelled stay the same within the mental-game situation. The main change in comparison to the as-is situation is a strong increase of BEVs in passenger cars and LCVs. Based on the abovementioned starting conditions, the following calculation is referred to as a mental-game, since the focus is just on an isolated change in the BEV stock. Within the calculation model, the share of BEVs was increased as long as the targeted GHG decrease of 40% (see above) was reached. In the base line scenario with the energy mix 2015, it is not possible to reach the climate goals. Even with a 100% replacement of all ICE by BEV, the targeted 40% are impossible. A BEV share of 75% for passenger cars and LCVs only lead to reduction of 23% in GHG emissions (see Figure 1). Within the planned line scenario, a share of 75% of BEV for passenger cars and LCVs is accounted for and is just above the threshold value of 40%. Regarding the most climate friendly scenario: here already a share of 56% BEVs would be enough if the climate line scenario 2050 constructed by Nitsch (2016) were to be realised to meet the goal of 40% of GHG reduction. A 75% share of BEVs would even realise a GHG reduction of more than 50%. Figure 1 shows the different scenarios of the mental-game situation in comparison to the as-is situation. For the latter only the base line scenario is portrayed, since the scenarios do not vary that much.

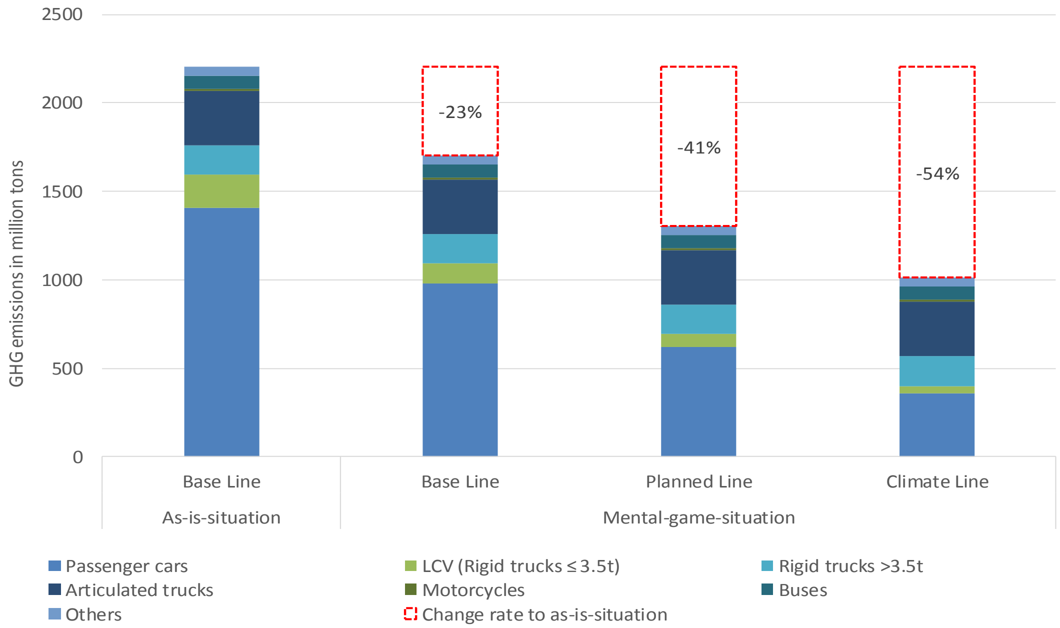

Fig. 1. Comparison of GHG emissions in different scenarios of the energy mix (own calculation, BEV share passenger cars and LCVs: 75%).

In addition, commercially used vehicles were identified as the target group for electric mobility by the Hamburg Senate. Commercial procurement decisions, which mainly take into account economic factors, speak in favour of this. Total cost of ownership calculations reveal that BEVs – especially those with high mileage on the clock – pay off, which is generally the case in a commercial context.

Commercially used vehicles drive significantly more kilometres than private vehicles (Wermuth et al. 2012). For example, a modification to the drive technology of LCVs has a greater impact than in vehicle segments, which have lower mileage per year. Hamburg is an important interregional trade-hub and a port-city with a disproportionately high share of commercial fleets and local politics (in line with scientific results) have identified this market as important early adopters for a larger introduction of the technology (Aichinger et al. 2015; Aichinger 2014; Grausam et al. 2015).

For this reason, a further calculation was carried out to determine what reduction would result from a (partial) renewal of the fleet. However, calculations showed that ecological specifications mainly imposed on commercial vehicles for entering environmental zones would not be sufficient. Presuming a share of 100% of BEV-LCV and of 30% of BEV-passenger cars on the whole fleet and an energy mix of scenario “KLIMA 2050” it can only attain a reduction of 27% in GHG emissions. The 30% includes a full substitution of all commercially registered passenger cars, which in Hamburg corresponds to about 20% (KBA 2018b), and a certain proportion of privately used passenger cars to meet the target as proposed by the Hamburg Senate (Bürgerschaft der Freien und Hansestadt Hamburg 2015).

7. Limitations of the calculation

Hereafter, assumptions and limitations are described that have been made due to the lack of adequate and detailed data.

From KBA, the share of different passenger car types is not known for different propulsion types. Due to this, an equal distribution was assumed.

With regard to energy consumption, the following assumptions are applied. For hybrid and gas propulsion vehicles, no information on energy consumption (from a comparable source to the other ones used) was available. Consequently, they were treated as petrol vehicles. For some vehicle classes (e.g. buses or heavy trucks) no values for electrified vehicles could be found. These vehicles (approximately 20 in Hamburg) were excluded from the calculation. No data could be found for electric motorcycles, here the value of a mini car was taken.

The different data bases used partially referred to different aggregation levels for vehicles. To equalise the structure average values were calculated for aggregation.

The focus of this research, especially the dynamic of the scenarios, is on passenger cars and LCVs. Here the most detailed data was available. Hence, assumptions were evaluated not to falsify results. Moreover, it was not possible to take into account efficiency gains in ICE vehicles, meaning that the number of BEVs required as a share in the total fleet may indeed be less in order to be able to achieve the political target on climate values.

Furthermore, the results are influenced by the emission factors, which have been assumed. However, the direct influence of these is deemed as minor, as factors contributing to the emissions are in proportion to consumption.

In addition, however, since no data was available for the proportions of locally registered vehicles and foreign vehicles, the vehicle inventory data from Hamburg was used for the calculation. It is assumed that the amount of registered vehicles corresponds approximately to the number of vehicles driving in Hamburg, since they are mixed with vehicles from other registration districts.

Furthermore, these are the findings of a local examination and only the emissions emitted by the vehicles during use are considered. A holistic approach concerning the life cycle of BEVs is not integrated.

8. Conclusion

To reach the climate goal of the German government different measures are discussed. Electric vehicles might be a possibility to have a positive ecological effect. Nevertheless, the amount of registered BEVs is far below the formulated goal of 10% by the year 2020. Therefore, the question arises how it would be possible to foster electric mobility in terms of GHG reduction. To answer the question a literature study was worked out in a first step to identify already analysed measures. In Germany, the mostly used policy tool is the environmental zone, which is defined as an access restriction.

The results of the literature analysis reveal that after introducing an environmental zone a brief acceleration of fleet renewal at the beginning, but no significant changes to the structure of the fleet can be observed. As the assessment of environmental zones shows, replacements in the shape of new vehicles occur, although the manner was relatively small. Several analyses of the impact of the German motorway toll have shown that fleet vehicles are deployed on monitored roads or sections of roads in accordance with ecological standards (Flämig and Wolff 2016; Lindberg and Fridstrøm 2015). This will also be the case with the implementation of environmental zoning, i.e. more recent vehicles will drive inside the environmental zones and the older models will remain outside of the zones.

The part played by an environmental zone in slowing down climate change has barely been investigated and is not clearly pictured in literature.

The city of Hamburg was taken as an example to assess the climate-relevant impact because of a widespread introduction of BEVs. Registered fleet vehicles in Hamburg in 2016 comprised approximately 36.6% diesel, 62.1% petrol-fuelled cars, 0.13% BEVs and 1.1% others.

Scenario calculations show that, if the energy mix remains at the level of 2015, substituting 75% of the entire vehicle fleet in Hamburg with BEVs would mean that 23% of the current GHG emissions from Hamburg vehicles is avoidable based on vehicle kilometres driven under survey. This would not meet the formulated target of 40% GHG reduction by 2020.

If the energy used for recharging these vehicles would improve, in ecological terms, by more than half in comparison to the level of the year 2015 a reduction of 40% in GHG emissions, which complies with the mid-term goal for Hamburg, is possible by a substitution of 75% of total fleet count with BEVs. In other words, the number of BEVs would have to increase to 75% based on the same total fleet count to reach the mentioned goals both in private and commercial use.

The findings also presuppose that all measures in terms of energy policy come into force, which have been proposed by the German government until 2015 (Nitsch 2016). Measures must also be considered to counteract the potential rebound effect of a widespread penetration of BEVs, i.e. life cycle approach. Based on the findings of the calculation, the question arises as to how the goal of BEVs accounting for 75% of all registered vehicles could be achieved. This paper pursues the hypothesis that a widespread penetration of BEVs in the entire vehicle fleet will not occur without accompanying measures. However, as mentioned before, the measure of environmental zoning lead to a renewability of the fleet. As Rauterberg-Wulff stated, the fleet renewability through environmental zones not only has an effect inside the zone but in the city as a whole. Therefore, certain spatial boundaries play a minor role as long as an environmental zone exists of a certain size. By implementing an EZ in the city area of Hamburg, where only battery electric vehicles are allowed to access, a fleet renewability can be expected. Despite the start of fleet renewal, substitution cannot be expected to the extent that it would be necessary to achieve the climate objectives. Therefore, the implementation of low emission zones as an environmental zone might help to foster electric mobility in the city of Hamburg but accompanying measures are required.

These results can be used by authorities in the context of planning measures to strengthen electric mobility in other German cities, i.e. when the introduction of an entry restriction is discussed.

The turn to renewable energies ("Energiewende") is imperative in order to reach climate goals. If this is not the case, other, even stricter, accompanying political or planning measures will have to be introduced where legislation imposes a regulation prescribing that vehicles with diesel and petrol-fuelled engines are no longer allowed. A similar policy has recently been implemented in the city of Hamburg which did not exist before. Two streets with the highest pollution in the city have imposed transit restrictions to ban diesel vehicles which do not comply with the Euro 6 emission standard (BUE 2018). As of January 1st 2018, there are approximately 169,453 diesel vehicles registered in Hamburg which are affected by this ban (KBA 2018a). This suggests the government has begun to recognize the urgency of this issue, and has taken one step closer towards implementing environmental zones.

Reaching climate goals remains challenging and so does attaining the energy mix used for the calculation. Here a paradigm shift is necessary: not only is the substitution through BEVs an option to reduce GHG emissions, savings could possibly be reached by implementing a modal shift in urban areas. Therefore, the calculation model could be extended and other modes of transport could be integrated. A shift to walking and cycling or traffic avoidance should also be discussed for transportation by planning authorities and in further research.

References

Aichinger, W., Appelhans, N., Gerlach, J., Gies, J., Hanke, S., Klein-Hitpaß, A., Warnecke, T., 2015. Elektromobilität in der kommunalen Umsetzung. Bericht, Deutsches Institut für Urbanistik, Berlin.

Aichinger, W., 2014. Elektromobilität im städtischen Wirtschaftsverkehr. Bericht, Deutsches Institut für Urbanistik, Berlin.

BMUB, Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, 2016. Klimaschutzplan 2050.

BMUB, Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, 2014. Die deutsche Klimaschutzpolitik.

Boogaard, H., Janssen, NA., Fischer, PH., Kos, GP., Weijers, EP., Cassee, FR., van der Zee, SC., de Hartog, JJ., Meliefste, K., Wang, M., Brunekreef, B., Hoek, G., 2012. Impact of low emission zones and local traffic policies on ambient air pollution concentrations. Science of the total environment 435 (2012): 132-140.

Bozem, K., Nagl, A., Rath, V., Haubrock, A., 2013. Elektromobilität: Kundensicht, Strategien, Geschäftsmodelle. Springer Wiesbaden.

Bürgerschaft der Freien und Hansestadt Hamburg, 2015. Drucksache 21/2521 vom 08.12.2015. Mitteilung des Senats an die Bürgerschaft. Hamburger Klimaplan.

BMVI, Bundesministerium für Verkehr und digitale Infrastruktur, 2016. Abschlussbericht: Bewertung der Praxistauglichkeit und Umweltwirkungen von Elektrofahrzeugen. Berlin.

BMVI, Bundesministerium für Verkehr und digitale Infrastruktur, 2014. Verkehrsverflechtungsprognose 2030. Schlussbericht.

Braun, A., Hager, K., Rid, W., 2014. Energieeffiziente Elektroautos? Zum realen Stromverbrauch von Elektrofahrzeugen.

BUE, Behörde für Umwelt und Energie Hamburg, 2018. Bundesverwaltungsgericht gestattet Fahrverbote. Available: http://www.hamburg.de/pressearchiv-fhh/10542402/2018-02-27-bue-diesel-fahrverbote/.

Canals Casals, L., Martinez-Laserna, E., Amante García, B., Nieto, N., 2016. Sustainability analysis of the electric vehicle use in Europe for CO2 emissions reduction. Journal of Cleaner Production 127: 425-437.

Co2online gBmbH, 2017. CO2-Ausstoß und Klimabilanz von PKWs. Available: http://www.co2online.de/klima-schuetzen/mobilitaet/auto-co2-ausstoss.

De Borger, B., Proost, S., 2013. Traffic externalities in cities: the economics of speed bumps, low emission zones and city bypasses. Journal of Urban Economics 76 (2013): 53-70.

Die Bundesregierung, 2009. Nationaler Entwicklungsplan Elektromobilität der Bundesregierung.

Dünnebeil, F., Höpfner, U., Lambrecht, U., Reuter, C., 2004. Motorrad-Umwelt-Liste, Analyse der umweltrelevanten Eigenschaften von Motorrädern. Institut für Energie- und Umweltforschung Heidelberg.

Ellison, R., Greaves, S., Hensher, D., 2013. Five years of London's emission zone: Effects on vehicle fleet composition and air quality. Transportation Research Part D: Transport and Environment, 23 (2013): 25–33.

Ferreira, F., Gomes, P., Tente, H., Carvalho, A.C., Pereira, P., Monjardino, J., 2015. Air quality improvements following implementation of Lisbon's Low Emission Zone. Atmospheric Environment 122 (2015): 373-381.

FHH, Freie und Hansestadt Hamburg, 2016. Energie-und CO2-Bilanz. Available: http://www.hamburg.de/co2-bilanz-hh/.

FHH, Freie und Hansestadt Hamburg, 2013. Mobilitätsprogramm 2013. Grundlage für eine kontinuierliche Verkehrsentwicklungsplanung in Hamburg.

Flämig, H., Wolff, J., 2016. Impacts of planning and policy strategies on freight flows in urban areas. In: Taniguchi, Eiichi; Thompson, Russell. G. (Eds.): Conference Proceedings of the 9th International Conference on City Logistics. S. 693-707

Grausam, M., Parzinger, G., Müller, U., 2015. Elektromobilität in Flotten. Bericht, Städtebau-Institut Universität Stuttgart, Stuttgart.

Holman, C., Harrison, R., Querol, X., 2015. Review of the efficacy of low emission zones to improve urban air quality in European cities. Atmospheric Environment 111 (2015): 161-169.

KBA, Kraftfahrtbundesamt, 2018a. Bestand an Kraftfahrzeugen und Kraftfahrzeuganhängern nach Zulassungsbezirken, 1. Januar 2018, (FZ 1).

KBA, Kraftfahrtbundesamt, 2018b. Bestand an Pkw am 1. Januar 2018 nach privaten und gewerblichen Haltern. Available: https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/Halter/2018_b_halter_dusl.html?nn=658008.

KBA, Kraftfahrtbundesamt, 2016a. Fahrzeugzulassungen (FZ): Bestand an Kraftfahrzeugen nach Umwelt-Merkmalen 1. Januar 2016, (FZ 13).

KBA, Kraftfahrtbundesamt, 2016b. Verkehr in Kilometern der deutschen Kraftfahrzeuge im Jahr 2015.

Leifheit, S., 2016, at IAA-Kongress "Urbane Logistik der Zukunft", "Präsentation des Projektes Urbane Logistik Hannover" 28.09.2016. Hannover.

Lindberg, G., Fridstrøm, L., 2015. Policy strategies for vehicle electrification. International Transport Forum Discussion Paper, No. 2015-16, Organisation for Economic Co-operation and Development (OECD), International Transport Forum, Paris.

Lutz, M., Rauterberg-Wulff, A., 2009, Ein Jahr Umweltzone Berlin: Wirkungsuntersuchungen.

Ma, H., Balthasar, F., Tait, N., Riera-Palou, X., Harrison, A., 2012. A new comparison between the life cycle greenhouse gas emissions of battery electric vehicles and internal combustion vehicles. Energy Policy, Volume 44 (2012): 160-173

Michiels, H., Beckx, C., Schrooten, L., Stijn, V., Tobias, D., 2012. Exploring the transition to a clean vehicle fleet: From stakeholder views to transport policy implications. Transport Policy, Volume 22 (2012): S. 70 – 79.

MiD, Mobilität in Deutschland (mobility in Germany), 2008.

Nakamura, K., Hayashi, Y., 2013. Strategies and instruments for low-carbon urban transport: An international review on trends and effects. Transport Policy, Volume 29 (2013): 264 – 274.

Nitsch, J., 2016. Die Energiewende nach COP 21 – Aktuelle Szenarien der deutschen Energieversorgung. Stuttgart.

Ou, X., Zhang, X., Chang, S., 2010. Scenario analysis on alternative fuel/vehicle for China`s future road transport: life-cycle energy demand and GHG emissions. Energy Policy 38 (8): 3943-3956.

Rasch, F., Birmili, W., Weinhold, K., Nordmann, S., Sonntag, A., Spindler, G., Herrmann, H., Wiedensohler, A., Löschau, G., 2013. Signifikante Minderung von Ruß und der Anzahl ultrafeiner Partikel in der Außenluft als Folge der Umweltzone in Leipzig. Gefahrstoffe-Reinhaltung der Luft (2013): 11-12.

Rauterberg-Wulff, A., 2011. Umweltzone Berlin: Erfahrungen mit der Einführung der Stufe 2 und erste Wirkungsanalysen.

Schaufenster Elektromobilität (Begleit- und Wirkungsforschung Schaufenster Elektromobilität), 2015. Fragen rund um das Elektrofahrzeug: Wie kommen die Angaben über den Stromverbrauch und die Reichweite von Elektrofahrzeugen zustande?

Schüle, R., 2013. CO2-Monitoring und -Evaluierung zum Hamburger Klimaschutzkonzept 2007-2012 – Gesamtbilanz. Abschlussbericht.

Schott, B., Püttner, A., Nieder, T., Bermpohl, F., Rohn, M., Mey, J., 2012. Entwicklung der Elektromobilität in Deutschland im internationalen Vergleich und Analysen zum Stromverbrauch.

Shell, 2016. Shell Nutzfahrzeug-Studie. Diesel oder alternative Antriebe – womit fahren Lkw und Bus morgen? Fakten Trends und Perspektiven bis 2040. Berlin.

UBA, Umweltbundesamt, 2018. Website Umweltzonen in Deutschland. Available: https://www.umweltbundesamt.de/themen/luft/luftschadstoffe/feinstaub/umweltzonen-in-deutschland#textpart-1.

UBA, Umweltbundesamt, 2016. Submission under the United Nations Framework Convention on Climate Change and the Kyoto Protocol 2016. National Inventory Report for the German Greenhouse Gas Inventory 1990-2014. Dessau-Roßlau.

United Nations, 2017. Website Sustainable Development: Goal 11: Make cities inclusive, safe, resilient and sustainable. Available: http://www.un.org/sustainabledevelopment/cities/.

Velázquez-Martínez, J., Fransoo, J., Blanco, E., Valenzuela-Ocaña, K., 2016. A new statistical method of assigning vehicles to delivery areas for CO2 emissions reduction. Transportation Research Part D: Transport and Environment, 43 (2016): 133-144.

Wen, L., Eglese, R., 2016. Minimizing CO2e emissions by setting a road toll. Transportation Research Part D: Transport and Environment, 44 (2016): 1-13.

Wermuth, M., Neef, C., Wirth, R., Hanitz, I., Löhner, H., Hautzinger, H., Stock, W., Pfeiffer, M., Fuchs, M., Lenz, B., Ehrler, V., Schneider, S., Heinzmann, H.-J., 2012. Kraftfahrzeugverkehr in Deutschland 2010. (KiD 2010). Schlussbericht. Ed. Prof. Dr. Wermuth Verkehrsforschung und Infrastrukturplanung GmbH, Institut für angewandte Verkehrs- und Tourismusforschung e.V., Deutsches Zentrum für Luft- und Raumfahrt e.V. und Kraftfahrt-Bundesamt. Braunschweig.

Woo, J., Choi, H., Ahn, J., 2017. Well-to-wheel analysis of greenhouse gas emissions for electric vehicles based on electricity generation mix: A global perspective. Transportation Research Part D: Transport and Environment, Volume 51, February 2017, Pages 340-350.

Wu, K., Chen, Y., Ma, J., Bai, S., Tang, X., 2017. Traffic and emissions impact of congestion charging in the central Beijing urban area: A simulation analysis. Transportation Research Part D: Transport and Environment, 51 (2017): 203-215.

Wuppertal Institute, 2012. Analyse der Messdaten zum Betrieb und zur Ladung von Elektrofahrzeugen. Teilbericht im Rahmen der Umweltbegleitforschung Elektromobilität im Förderschwerpunkt „Modellregionen Elektromobilität". Wuppertal.

Zhou, T., Roorda, M., MacLean, H., Luk, J., 2017. Life cycle GHG emissions and lifetime costs of medium-duty diesel and battery electric trucks in Toronto, Canada. Transportation Research Part D: Transport and Environment, 55 (2017): 91-98.

Zhao, S., Heywood, J., 2017. Projected pathways and environmental impact of China's electrified passenger vehicles. Transportation Research Part D: Transport and Environment, 53 (2017): 334-353.