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Modal Shifting Effects and Climate Impacts through Electric Bicycle Use in Germany

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Abstract

Sales rates of electric bicycles (e-bikes) have grown rapidly over the last ten years, not only in Germany but all over Europe. Thus, the strongest movement towards electric mobility on German roads is yet dominantly pushed by e-bikes, whereas electric cars need to catch up. So far, there are hardly any reliable investigations about everyday use patterns, modal shift effects and potentials to reduce climate impact. An assessment of the significance of e-bikes for achieving climate and energy policy guidelines from the "German Federal Government's National Energy Concept" from 2010 has not been possible so far. The project "Pedelection" analysed these questions by conducting a field test focused on people who purchased their e-bike only recently. The main finding from the field test is that e-bikes have the potential to substitute a considerable amount of car mileage. Since the climate balance of distance travelled by e-bikes is by factor 10 better, additional induced traffic or shifting from bicycle/walking is negligible to a certain degree. Bicycles – with or without electric assistance – are serious means of transport and a genuine alternative to passenger cars on short and medium distances up to 15 km.

Keywords: electric mobility, bike, environmental impact, mobility patterns

1 Introduction

Mobility is an important basis for many economic and private activities and thus is a crucial part of our life. However, mobility is also energy consuming and leads to substantial environmental problems. In 2015, the transport sector was responsible for 28% of the final energy consumption in Germany. More than 80% of the transport energy consumption is thus consumed by road traffic, and more than

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90% of this energy consumption is based on the use of fossil fuels. This leads to a share of 18% of CO_2 emissions caused solely by the transportation sector (Umweltbundesamt, 2015). Although air quality improved over the last decades in Germany, NO_X concentration and noise in urban areas still remain a problem. The current challenges for the road transport are the reduction of energy consumption, greenhouse gas (GHG) emissions and other air pollutants. This demands for new and improved technologies in the transportation system. However the ambitious national goals to reduce CO_2-emissions and energy consumption cannot be met by only using more efficient vehicles. A broader transformation of the transport sector is needed which also focuses on mobility patterns of people in general.

Electric mobility is discussed as the main choice to reduce fossil fuel consumption and integrate renewable energies into the transportation sector. Until now, the discussion of electric mobility is mainly focused on electric cars. But other modes of transport offer electric mobility choices, too, such as the electric bicycle (e-bike). The concept is not completely new since they were introduced to our roads in the 90s. But advances in technology (e.g. lithium-ion battery) helped the e-bike to reinvent itself and gain popularity for different mobility purposes in Germany and other European countries (Budde et al., 2012). There are two general concepts of e-bikes available: (1) E-bike with pedal electric assistance and (2) E-bikes with exclusive electric propulsion. This article is focused on the first concept which requires pedalling by the cyclist because this vehicle is still treated like a conventional bicycle by German law.

As Figure 1 indicates, sales rates of e-bikes have grown rapidly over the last ten years, not only in Germany but all over Europe (ZIV, 2015). The image of e-bikes has improved due to a broader range of models from an everyday-bike to an ambitious sport vehicle or lifestyle product. E-bikes can be used as conventional bikes but the electric assistance may have an impact on use patterns since distances and difference in altitude become less relevant. So far, there are hardly any reliable investigations about everyday use patterns, modal shifting effects and potentials as well as use and non-use motives of German e-bikes users. An assessment of the significance of e-bikes for achieving climate and energy policy guidelines from the "German Federal Government’s National Energy Concept" from 2010 has not been possible so far. The project "Pedelection" closed this research gap (Lienhop et al, 2015).

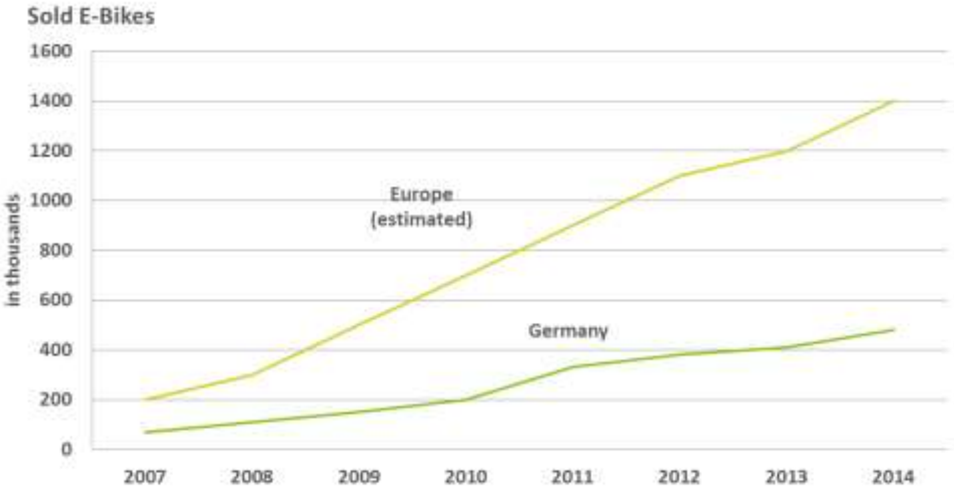

Figure 1: Number of electric bikes sold in Germany and Europe per year (ZIV, 2015).

2 Method

The project "Pedelection" had a comprehensive research design by using qualitative as well as quantitative methodology in order to answer the broad set of questions. Modal shifting effects and climate impacts by e-bike usage were primarily answered with quantitative methodology but also findings from the qualitative assessments had an impact on the research progress.

2.1 Outline of the field test

In order to analyse the modal shifting effects and climate impacts, a field test in Germany was conducted with two groups with a different volume of data collected. The core group was selected from four metropolitan regions: (1) Munich, (2) Frankfurt, (3) Brunswick-Hannover and (4) Bremen-Oldenburg. Participants were not required to live directly in the city itself, the intention was rather to have participants from different regions in Germany to gain a higher representativeness of the results. The core group (70 participants) was equipped with data loggers in order to record driving and charging data. Every participant was instructed to provide data for four separate weeks throughout one year to cover different seasons. Additionally, participants logged all their daily trips for the same four weeks. The core group was accompanied by a second group (312 participants) which only participated in the online survey to log their daily trips for four weeks throughout the year. The online survey did not have any regional constraint. The field test started with 382 participants in the first week and ended with 216 participants in the last week due to panel mortality. To get data covering the whole year, the weeks were scheduled in advance for the different participants.

2.2 The sample

The aim of the sample selection was to gain a high representativeness concerning German e-bike users. Nevertheless, it was challenging to spread the sample throughout different social groups, since e-bike users are currently predominantly male, older than 40 years and bike enthusiasts. Therefore, the sample comprised of only 30% female users against 70% male users. Young e-bike users were underrepresented since only 15% of the sample was under 45 years old, 23% was over 65 years. Up to 47% of the sample had a university degree which is higher than average share. Concerning the work situation, 64% were either in a full-time or part-time employment. 27% of the users were pensioners. In addition to covering different social groups, it was aimed to get participants into the sample which only recently used an e-bike. The average e-bike experience of the sample at the beginning of the field test was eight months.

E-bikes in Germany follow mainly two concepts due to legal regulation. An e-bike is treated by German law as a normal bicycle, if it has an engine performance of maximum 250 W and electric pedal assistance up to a speed limit of 25 km/h (e-bike-25). Higher engine performances or assistance up to higher speeds require registration of the vehicle and are accompanied with certain obligations such as mandatory helmets (e-bike-S). Today the concepts of "e-bike-25" and the "e-bike-S" are established on the German market. 84% of the sample possessed an "e-bike-25" and only 10% an "e-bike-S", the rest were retrofitted bicycles.

The sample was analysed for three different user groups who shared similar mobility profiles: (1) Commuter, (2) Everyday user and (3) Leisure user. The group "Commuter" consisted of participants who had a significant number of trips to work in their total journey protocol. The group "Everyday user" made 50% of their trips for daily purposes such as shopping, private errands or undefined purposes. "Leisure users" used their e-bikes mainly for leisure trips to relax or for physical activity. 41% of the sample belonged to the group of "Commuters", 40% to the group of "Everyday users" and 19% to the group of "Leisure users".

2.3 Compilation of Data

In order to answer the research questions three sources of primary data were available: (1) GPS-data of journeys, (2) charging data for the battery and (3) metadata for single trips. Further information to assess climate impacts of vehicles and mobility patterns was also derived from secondary data such as results from a lifecycle assessment of different vehicle concepts (Helms et al., 2011, 2016; Weidema et al., 2013). Compiling the primary data was a complex task because there were no standard compiling systems available and the two logging systems produced different data formats. The main challenge was to match the data and find inconsistencies due to handling errors of the participants. Unfortunately, 12% of the submitted data could not be used because of handling errors.

3 Main Results

The motorization of the e-bike enables the cyclist to cover larger distances and/or shorter travel durations in comparison to the conventional bike. The average travel distance on an e-bike is 11.4 km and the average duration is about 50 minutes. Compared to average results for a conventional bicycle and a car, the e-bike is closer to the bicycle in terms of travel distance (see figure 2). The relatively high average duration is due to constraints in data measurement (stops up to 30 minutes are included) and a considerable amount of leisure day trips. 90% of all e-bike trips are under 26 km and under 120 minutes. The frequency distribution of trip distances shows a peak at 4 km, after that it decreases constantly. Examining the distribution of duration, it peaks between 20 to 30 minutes.

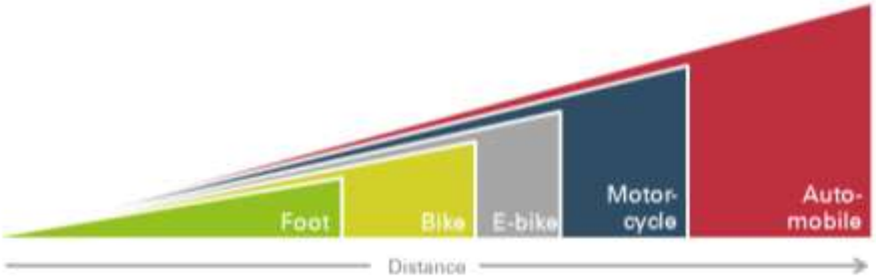

Figure 2. Potential range of individual means of transport.

Figure 3 shows the analysis of the speed distribution. The average speed is 15 km/h for all e-bike trips, with the majority ranging between 12 and 20 km/h. After 20 km/h follows an abrupt decline due to the high number of e-bike-25 owners in the sample. The average speed of 20 km/h for e-bike-S owners is considerably higher. The same accounts for the group of commuters which travels with an average speed of 17 km/h. Selected participants were equipped with a cadence sensor. The average cadence was 59 rpm which is a rather low value for cyclists. The study of DHBW (2014) observed the same pattern with a 30% lower cadence as for conventional cyclists. They also concluded that e-bike cyclists pedal less continuously due to the combination of fast acceleration and followed freewheeling. The aspect of lower exertion to cover higher elevations was less distinctive in the field test than expected since 45% of trips only covered a positive change in elevations of 20 meters. This especially accounts for daily trips and of course for trips in Northern Germany. The average for South German trips was a cumulative change in altitude of 68 meter per trip.

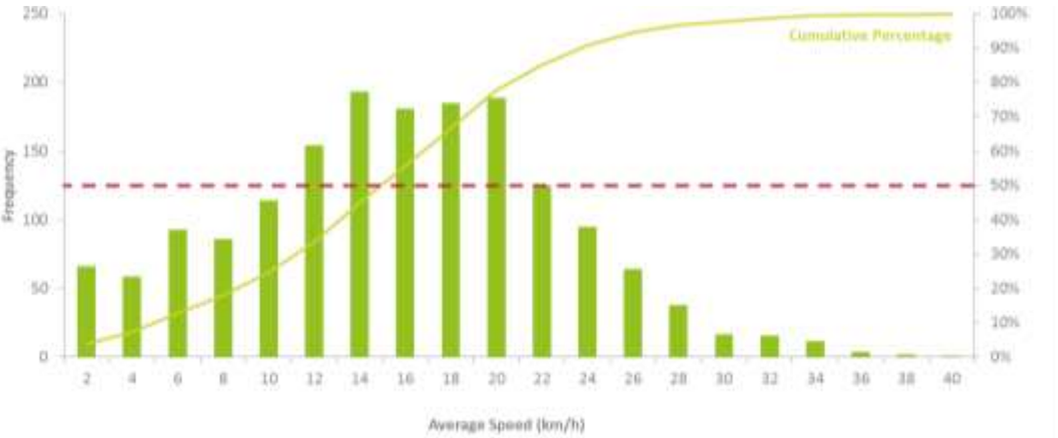

Figure 3. Distribution of frequency of average speed by trip.

The analysis of the mobility patterns of e-bike users shows that in general only 21% use their e-bike exclusively for leisure and holiday trips, while around 80% use it as a full means of transport for commuting and other everyday trips. Distances and duration show a high dependency on the purpose of the trip. Table 1 summarises the distribution of distance and duration by trip purpose. It has to be noted that the duration not only includes the actual moving time but also stops up to 30 minutes. It is thus the duration of the whole journey. Long stopping periods especially account for shopping and private duty trips, because the shopping itself is often included in the data. The overall duration of the journey to and from the workplace shows no relevant stopping times except for normal traffic stops. The field test showed sensitivity due to seasons: 70% of e-bike trips were completed from April to September; winter use was considerably lower.

Table 1. Purpose of e-bike trips.

	Work related		**Leisure / Everyday**			
	Commuting	**Business trip**	**Leisure/ Holiday**	**Private duty**	**Shopping**	**Other**
Total Share	38%	2%	21%	18%	12%	9%
Ø distance (km)	11.7	-	17.8	7.5	6.1	10.3
Ø duration (minutes)	46.3	-	98.2	54.6	64.6	53.5

3.1 Modal Shifting Effects through E-bike Use

An important focus of the study is the modal shift induced by e-bikes: 41% of the e-bike trips and 45% of the e-bike mileage replaced car trips (respectively car mileage), while 38% of the e-bike trips and 32% of the distance were completed with a conventional bicycle before buying an e-bike (see figure 4). The participants only marginally substituted other means of transport like public transport or walking. Nevertheless, an additional traffic of 10% is induced by e-bike ownership if the mileage is considered. Especially the replacement of car mileage is noteworthy, since it has the potential for a considerable decrease of environmental impacts as well as other related effects such as urban congestion. Car mileage replacement was also much higher in the group of e-bikes-S users (70%), aged under 45 (57%), employees (57%) and frequent cyclists (47%).

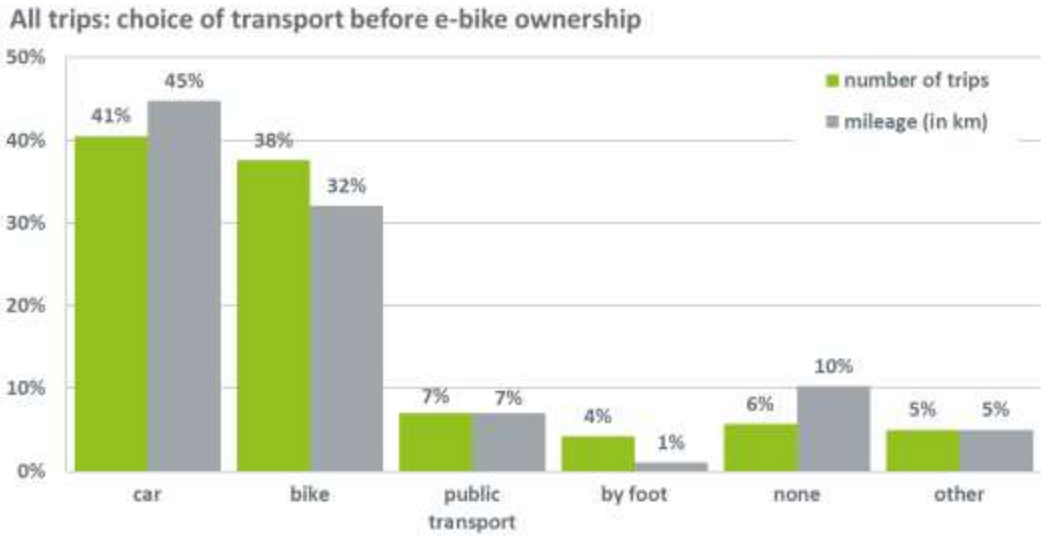

Figure 4. Modal shift induced by e-bikes.

The modal shift effects clearly differ between different mobility profiles and are highest for the group of “commuters”, with over 60% of the e-bike mileage substituting passenger car mileage (see figure 5). On the other hand, “leisure users” largely substitute conventional bicycle mileage by e-bikes (60%) and thus potentially lead to an increase in energy consumption and environmental impacts. For this group, there is also a considerable share of additionally induced mileage, which is also evident for the “everyday user”. The impact on public transport is in general low but the group of “commuters” at least substituted 10% of their mileage. This could have a negative impact on passenger numbers of public transport. However, e-bikes have the potential to reduce pressure on public transport during the rush hour.

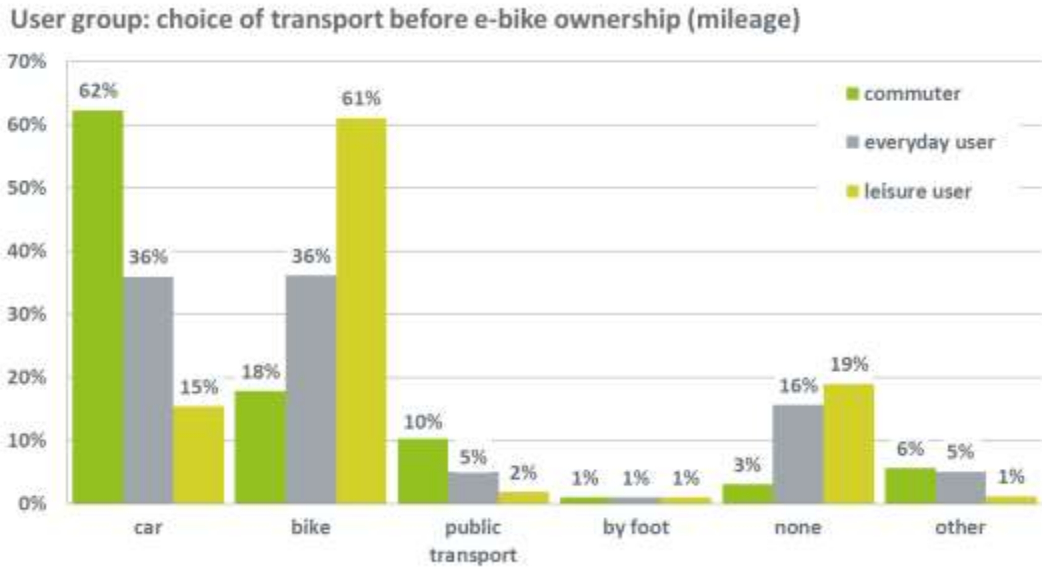

Figure 5. Modal shift induced by different e-bike user groups.

Figure 6 shows the result of combining the aspect of trip purpose and modal shifting effect. Again, it can be observed that car and public transport trips were mainly to travel to and from the workplace. A negative effect results from the shift between using the conventional bike and walking and by inducing new traffic (represented by “none” in the choice of transport). These categories show high shares of leisure trips and private duties. Shopping has the highest share for the transport categories “by foot” (18%) and “bike” (16%). The question arises how much additional traffic and negative modal shifting can be levelled out by positive modal shifting effects (from motorised vehicles). The following section therefore analyses and compares the environmental impacts of different vehicle types in more detail.

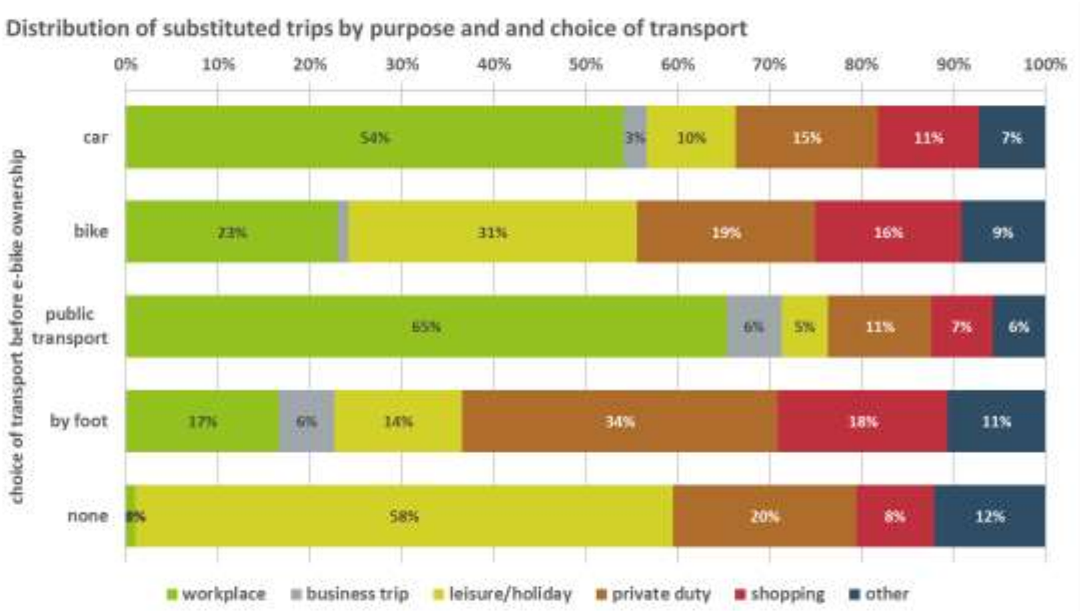

Figure 6. Combination of trip purpose and modal shifting effect.

3.2 Climate Impacts through Electric Bicycle Use

In order to assess climate impacts of these modal shifts, a life cycle assessment (LCA) approach was applied to different modes of transport. The scope of the analysis comprises the entire life-cycle from vehicle manufacturing to the use phase and to end-of-life treatment. All environmental impacts directly associated with these processes have been considered, as well as upstream emissions for provision of materials and fuels. In this study traffic infrastructure has been neglected. The analysis does not reflect a specific vehicle, but rather aims at representing defined generic reference vehicles. This is regarded as a suitable approach for comparing different modes of transport. The functional unit is the mobility service expressed as passenger kilometres (pkm) driven. Hereby, all environmental impacts of vehicles along the life cycle are allocated to average lifetime mileage and degree of capacity utilisation in Germany.

The reference vehicles are: (1) e-bike, (2) bicycle, (3) scooter, (4) petrol car, (5) bus and (6) regional train. The data basis for modelling different modes of transport was collected from ecoinvent 3.1 (Weidema et al., 2013) and results from eLCAr (Helms et al., 2016). Additionally, results from the field test have been used to adapt the LCA of the e-bike. This accounts for battery size, mileage and energy consumption. Table 2 summarizes the input data which was used for adapting the e-bike LCA.

Table 2. Input data for e-bike lifecycle assessment.

	Value	Unit
Battery size	300	Wh
Mileage	2,500	km per year
Energy consumption	0.73	kWh/100 km

Figure 7 shows the result of the climate impacts for different modes of transport measured in greenhouse gas emissions (GHG) per pkm. Since the electricity consumption of the e-bike is low, the manufacturing process was found to be far more relevant for its overall environmental impact. The e-bike has an advantage of at least 25% compared to all other motorized modes of transport. However, the highest advantage arises by shifting from car to e-bike because GHG emissions of e-bikes per passenger kilometre merely amount for 10% of the petrol car emissions. In absolute numbers this shift saves almost 150 g GHG emissions per pkm. The only negative shift in terms of additional climate impact is of course from the conventional bicycle. Nevertheless, the conventional bike itself is also not free from GHG emissions due to its manufacturing but additional components and electricity contribute to additional GHG emissions of 7,4 g per pkm for the e-bike.

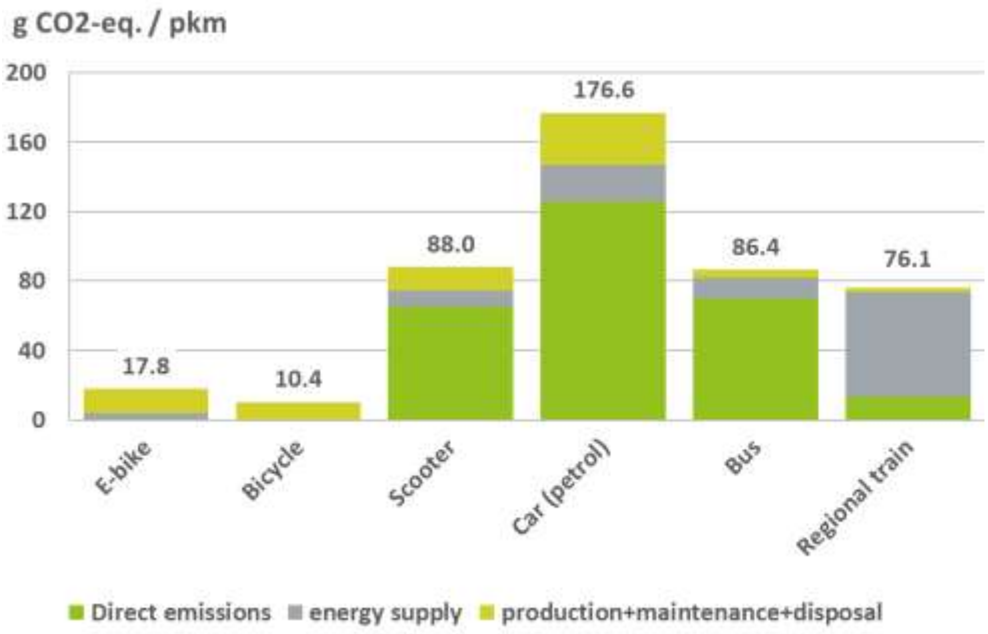

Figure 7. Greenhouse gas emissions for different vehicles.

The environmental burden of the battery in electric vehicles is often controversially discussed. This is also true for the electric bike (Wachotsch et al., 2014). The battery results in higher prices and an increased material consumption of the vehicle. Currently most e-bikes use lithium-ion (Li-Ion) batteries with considerable higher energy densities compared to older technologies such as lead or nickel based batteries. The higher energy density of Li-Ion batteries helped the e-bike concept to gain new popularity because of the significant weight reduction. Nevertheless, the production of the Li-Ion battery is associated with additional material consumption and thus environmental burdens. Nearly all Li-Ion cells for e-bikes are manufactured in Southeast Asia where national environmental regulation is less strict and quality demands differ by supplier. Low quality batteries have been used in some e-bike models and led to early replacements which caused costs for the owner and additional environmental burdens. Problems with the life expectancy have been observed during the field test but were no constant problem. Less than 20% of the participants reported technical problems with the battery. However, stockpiling has been found to contribute to a multiplication of environmental burdens caused by the battery. 13% of the participants already purchased a second (or even third) spare battery. The reported reasons were either range extensions or fear of not getting the vehicle specific battery system at a later stage.

In order to highlight the effect of an additional battery over the lifetime, a sensitivity analysis has been conducted. It also represents the recent tendency of bigger battery systems because the battery size of 300 Wh observed in the early phase of the field test does not reflect recent average sizes of new e-bike models. The base e-bike in this analysis uses a 300 Wh battery over the whole lifetime (15,000 km mileage). Figure 8 compares the conventional bicycle and the base e-bike with an e-bike with two 300 Wh batteries (or an e-bike with a single battery of 600 Wh). The results show that the battery of the base e-bike contributes 12% to the total climate impact, this share rises up to 22% for the scenario with two batteries. From an environmental perspective it is advisable to only purchase a new battery as a replacement for a deteriorated battery or if required by special use patterns. Long storage of batteries also has a negative effect on lifetime and energy capacities.

Another relevant effect on vehicle climate impacts is the lifetime mileage. Since e-bikes are associated with higher emissions as normal bicycles they should be considered as full means of transport. An integration of e-bikes into daily trips and even into commuting generally increases the mileage. If the e-bike is used just for a few leisure trips during the year it is not considered to be a full means of transport but rather a hobby equipment. This effect is illustrated by the extreme assumption of an e-bike lifetime mileage of only 1.500 km which would result in the same GHG emission per pkm as for cars which generally have a much higher mileage (176.6 g GHG emissions per pkm).

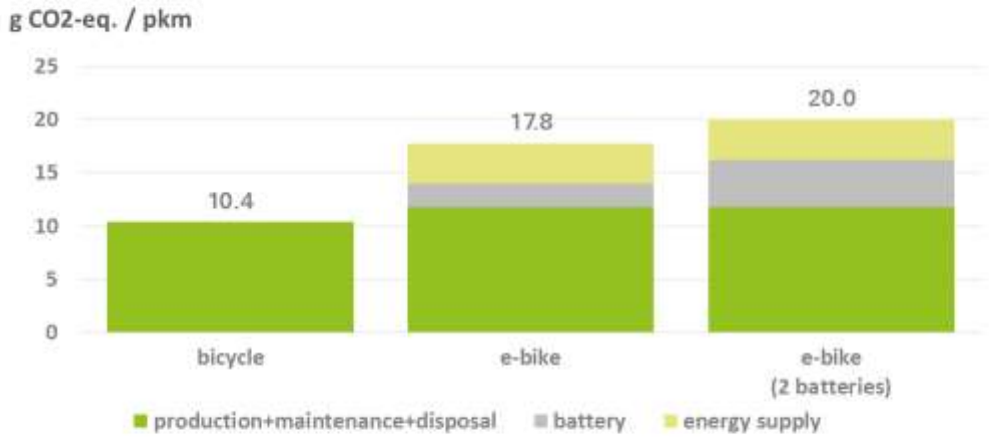

Figure 8. Sensitivity analysis of battery consumption by e-bikes.

3.3 Climate Impacts of Modal Shifting of E-bike Users

Due to modal shift induced by e-bikes, relevant car mileage can be substituted. The LCA results quantify the climate advantage of e-bikes compared to cars. But the key question to be answered at this point is how additional emissions caused by negative shifting from bicycle and walking contribute to the overall climate balance of e-bike users. Figure 9 summarises the overall average weekly GHG balance of the field test participants with e-bike compared to the previous mobility profile. The results are sorted from highest additional emissions to highest saved emissions. Significant GHG reductions owing to the observed modal shift have been achieved in the field test for most of the participants. Thus, 2,400 kg of GHG emissions have been saved by the field test participants per week. 50 kg GHG emissions have been additionally emitted due to a negative shift from bicycle and walking. In total, e-bike use saves far more emissions than it causes additionally. This even justifies the small amount of additional traffic and shifting from bicycle.

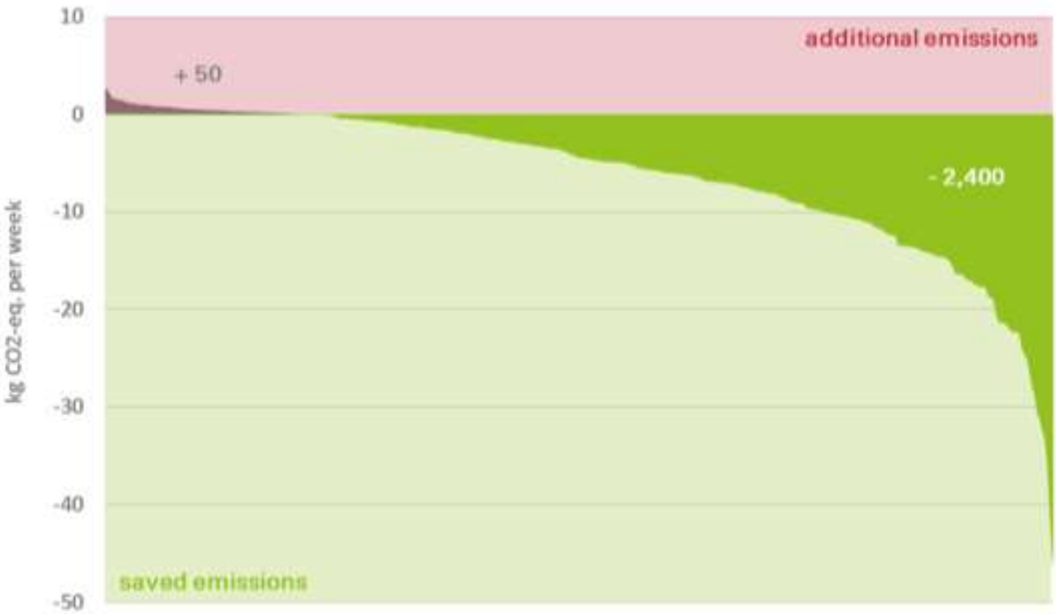

Figure 9. Average weekly GHG balance of the field test.

4 Conclusion

According to the presented results, minimization of climate relevant emissions through e-bike usage is especially large where frequent car trips are replaced. This is the case particularly for commuter traffic, where up to 80 million pkm of car trips could be substituted in Germany through the usage of e-bikes on distances up to 15 kilometres. Furthermore, e-bike-S users have been found to be replacing significantly more car trips than conventional e-bike users. In addition to promoting the modal shift, environmental impacts of e-bikes could be further reduced. Especially the lifetime of e-bike components (like the battery) highly influence the environmental impact of e-bikes. Several conclusions can be drawn from the presented results which point out the direction for relevant policy makers. Though most conclusions have been drawn for Germany, they may be valid for other European countries as well disregarding legislative constraints.

- Legislative frameworks need to be adjusted: The general differentiation between bike and motor vehicle, which is currently often made based on EU directive 2002/24 can be an obstacle for the integration, especially of e-bikes-S in the overall traffic. In Germany, for instance, bicycle lanes are not officially available to e-bike-S users. This often makes orientation difficult during cycling.
- Infrastructure needs to be improved: Environmental benefits of e-bikes are high, while costs for the improvement of their infrastructure are comparably low. E-bikes do not require any different infrastructure as

conventional bicycles. An improvement of infrastructure supports e-bikes and un-motorised bicycles likewise. Despite an official commitment towards increased share of cycling in the modal split, this is hardly reflected in the public funding yet.

- Use of e-bike batteries should be optimised: Battery treatment until sale should be improved and possibly separated from the bike sales. Considerable capacity losses can occur even before the first use of the e-bike by the end consumer. E-bike retailers suggested delivering new batteries directly from the factory together with the purchase of the bike. Also battery rental could be expanded.
- Technical upgrades should be enabled: Retailer and participants expressed the demand for upgrade possibilities, especially due to the fast innovation cycle in the battery sector. Upgrading and retrofitting should be possible even after several years of use and could be supported by the introduction of consistent standards. Consistent standards would also contribute to consumer trust and prevent stockpiling of spare batteries.
- Potential users and new segments need to be directly addressed: Currently e-bike use with a high environmental benefit (especially commuting) correlates with the level of education. More emphasis on e-bikes as a “hip” means of transport could motivate potential new users. Also currently underrepresented segments such as young adults and women could be directly addressed. One way to overcome prejudices towards e-bikes is campaigns which allow for testing of e-bikes.
- Promotion of e-bikes should not cannibalise conventional bicycles: The focus of promotion should centre on bike transportation in general. E-bikes are one option equal to bicycles as means of transport depending on the use patterns.

Bicycles – with or without electric assistance, with two or more wheels – are serious means of transport and a genuine alternative to passenger cars on short and medium distances up to 15 km. In combination with public transport even longer distances are possible. If the trend of increasing sales rates continues as the German Two-Wheeler Industry Association predicts (ZIV, 2016) over 3.5 Mio. e-bikes could be on the road by 2020. Mobility research neglected the topic for many years, despite the environmental and health benefits. In Germany, even though further projects such as Pedelection have been initiated in the past years, many research questions have not been addressed yet. Therefore, the establishment of a continuous research and improved communication towards policy makers is necessary.

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