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Potentials of Light Electric Vehicles for Climate Protection by Substituting Passenger Car Trips

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Summary
The presented study focuses on the theoretical potential of substitutability of passenger car trips in Germany by varied small and light electric vehicles (LEVs) based on the “Mobilität in Deutschland 2017” (“Mobility in Germany 2017”) dataset, for the year 2030. By conducting a life cycle assessment of these exemplary LEVs and passenger cars, potential emission savings were analysed. In the considered baseline scenario, it is found that 44 % emissions could be reduced with 50% passenger car mileage being substituted by LEVs.

Keywords: Emissions, EV, LCA, light vehicles

1 Introduction

With 16 % of worldwide emission emerging from transport related activities [1], transforming transportation with new vehicle concepts and mobility modes play a vital role in reaching target climate goals and reduction of emissions of noise, pollutants and improve living conditions. Light electric vehicles (LEV) show great promise in this regard owing to their efficiency and low ratio of vehicle weight to payload resulting in low energy consumption and thus greenhouse gas emissions per driven kilometer. When situated in a multi and inter modal environment, they have great potential to replace car trips and thus reduce emissions.

Todays’ market offers a large variety of LEV models, from electric scooters and e-bikes up to two-, three- and four-wheelers that fall under categories L1e to L7e according to EU regulation 168/2013 [2]. LEV address diverse target groups and applications and accordingly differ regarding design and technical features. Common characteristics of all LEVs are that they are battery-electric and have a much lower weight and energy consumption per kilometer travelled compared to passenger cars with electric or other drive systems. The study analyses the following selection of LEV categories: e-scooters, e-bikes, “e-bike+” that allow transport of cargo or children, speed pedelecs (L1e), mopeds (L1e), motorcycles (L3e), and three types of microcars differing in maximum speed and number of wheels (L5e, L6e, L7e). Section 2.1 provides detailed information on each category.

In order to quantify the theoretical potential of emission reduction, this study models a scenario in 2030, in which a major modal shift away from trips with full-sized passenger cars to LEVs has taken place. For the analysis, todays mobility patterns are maintained, with only a few trips still made by car, such as very long trips or trips with many occupants. The study uses Germany as an example of a national savings potential, as cars play there an important role both as a means of mobility and as a sector of the economy.

2 Methodology

2.1 LEV Properties

For the potential analyses and calculation of life cycle emissions, technical characteristics per evaluated vehicle categories are required, such as the maximum design speed, which determines the use on highways. In addition, values are needed that are derived on the basis of technical properties, as they do not result directly. This is the case for the maximum trip length for which a trip is considered to be substitutable. The so-called "relevant trip length" defines a trip length that is well drivable with a specific LEV category on the basis of literature and expert assessments. It is shorter than the technical electric range.

Most parameters such as maximum design speed, weight, battery capacity, technical electrical range and seating capacity are based on exemplary models for the analyses. The data was taken from manufacturer information and sales websites as far as available or calculated on the basis of technical data. The energy consumption per kilometer is either taken from the sources described or calculated with electric range and battery capacity if not provided. As vehicles differ considerably regarding maximum design speed, there are no standardised test cycles for assessing the energy consumption per kilometre that apply to all categories. This is considered tolerable, as the trip duration is also not necessarily kept constant for the replaced trips. The lack of standardised driving cycles, different handling of manufacturer specifications and the high influence of user behaviour complicate the estimation of energy consumption. In contrast to the technical parameters, which are based on today's technological status, for modelling a scenario for the year 2030, an increased lifetime mileage compared to today's vehicle mileage is assumed, resulting from expected technological progress. Although it is likely that other technical parameters also improve, these were left at the current level in order to make a conservative estimate. Table 1 provides an overview of the values used for the further potential analysis.

Table1: LEV properties (see [3])

	Max. speed (km/h)	Technical electric range (km)	Battery capacity (kWh)	Weight (kg)	Energy consumption (kWh/100km)	Lifetime Mileage (km)
E-Scooter	20	65	0.6	20	0.8	16,000
E-bike	25	120	0.4	25	0.3	50,000
E-bike+	25	70	0.4	51	0.6	50,000
Speed pedelec	25	70	1.2	29	1.7	70,000
Moped	45	100	2.7	100	2.7	70,000
Motorcycle	120	130	8.5	231	7.7	100,000
Microcar45	45	110	6.1	440	5.5	70,000
Microcar90	90	200	14.4	571	7.2	160,000
Microcar125	125	256	25	454	10.0	160,000

The maximum design speed indicates the speed used within the analyses. According to EU regulation 168/2013 [3], for the categories evaluated in the study, it is limited to 45 km/h for light two-wheel vehicles (L2e-B) and for microcars (L6e), to 90 km/h for microcars of category L7e (depending on sub-categories) and is not limited for vehicles belonging to category L3e or L5e.

For each category that was used for analysing the trip substitution potential and for assessing life cycle emissions, an exemplary LEV model that is (soon) available on the market serves as basis for definition of the technical parameters. The selection process of LEV categories and respective exemplary models for deriving LEV properties aimed for (1) covering a broad spectrum of properties and capabilities in order to satisfy a full range of use cases and thus offering a high trip substitution potential, (2) capturing the differences between LEV categories and models, (3) limiting the number of selections to maintain an achievable modelling effort leading to comprehensible and memorable results and (4) choosing models with low CO_{2eq} expected emission values, e.g. having a battery capacity corresponding to a required range, and not significantly higher. According to these aims, the technical parameters defined for each category do not represent average values of models available on the market or sold units in each category, but offer values for each category that are realistic on the one hand (as based on existing models) and oriented towards sustainability on the other hand, which does not necessarily correspond to average values of each category. The sustainability aspect refers in particular to choosing vehicles with rather low weight and battery capacity. A certain exception is the exemplary model of the L5e category, as here a model with three seats and a relatively high maximum design speed was aimed for and no vehicle was found that combines these characteristics with a relatively small battery capacity.

2.2 Trip Substitution

This study uses data from the German national travel survey "Mobilität in Deutschland 2017" [4], which surveyed 156,000 households, resulting in a dataset containing 960,000 trips. The dataset itself provides weighting and extrapolation factors that can be used to calculate the daily mobility pattern of the entire German population. Based on this data, this study analyses the theoretical substitutability of car trips by LEVs of various categories considering their constraints. Real-world market-ready LEVs were taken as reference for using technical properties of 9 types of LEVs ranging from e-scooters, speed bikes to microcars as described in section 2.1. Their constraints regarding relevant travel distance, occupants, trip purposes, weather, age of driver etc. were compared with the characteristics of the surveyed car trips. The relevant travel distance describes the distance that is assumed to be comfortably driven with a LEV per day and is lower than the technical electrical range. Microcars have a higher relevant travel distance and are appropriate for most street types and all weather conditions and therefore offer a broader range of suitability than e-bikes, for example (Table 2). Regarding trip purposes, some trips dedicated to shopping, accompaniment of other persons as well as professional trips are excluded and considered as unsuitable for LEVs. Only if all constraints that characterize a trip are fulfilled, a LEV will be classified as suitable for this trip.

Since everyday trips are seldom independent of each other but usually belong to trip chains of an individual, substitutability was not only tested for individual trips but also on the level of the associated trip chain. With this approach, daily car trips in Germany that could be substituted by a LEV were determined. Finally, identified trips are translated into substituted vehicle km for one day according to the trip single lengths reported in the MiD dataset.

Table2: Trips substitution criteria (see [3])

<table>
<tr><th></th><th>Relevant travel distance (round trip, km)</th><th>Number of occupants</th><th>Street category</th><th>Max. age of driver (years)</th><th>Weather conditions</th><th>Impairments (suitability)</th></tr>
<tr><td>E-Scooter</td><td>8</td><td rowspan="2">1</td><td rowspan="5">excl. highway</td><td rowspan="6">18-70</td><td rowspan="6">All, without heavy rain, snowfall, or icy roads</td><td rowspan="6">none</td></tr>
<tr><td>E-bike</td><td>30</td></tr>
<tr><td>E-bike+</td><td>30</td><td>1 + 3 children</td></tr>
<tr><td>Speed pedelec</td><td>60</td><td>1</td></tr>
<tr><td>Moped</td><td>60</td><td rowspan="2">2 (excl. children)</td></tr>
<tr><td>Motorcycle</td><td>90</td><td>all</td></tr>
<tr><td>Microcar45</td><td>80</td><td rowspan="2">2</td><td>excl. highway</td><td rowspan="3">18-99</td><td rowspan="3">all</td><td rowspan="3">Walking impairment</td></tr>
<tr><td>Microcar90</td><td>140</td><td rowspan="2">all</td></tr>
<tr><td>Microcar125</td><td>140</td><td>3</td></tr>
</table>

2.3 Life Cycle Assessment and Emission Reduction Potential

Quantifying emissions savings by LEVs versus conventional passenger cars both during vehicle use phase and production requires a life cycle analysis (LCA) comparison. Scarce data and research for new LEV types and models for components and vehicle use behavior presents a challenge for analyzing potential emission reduction. Based on an analysis of currently available LEVs and prototypes, a representative set of technical characteristics has been defined for every LEV category (see Table 1). Range and battery capacity represent upper boundaries of current vehicles as we assume the technical characteristics to be representative for the year 2030 to which we refer in our analysis.

The LCA analysis of LEVs is based on modelling the production and vehicle use greenhouse gas (CO_{2eq}) emissions of e-scooters, e-bicycles, e-mopeds and small 4 wheelers. Models using the material and energy flow software Umberto and the ecoinvent 3.7 [5] database are created using material flow details from available literature. The data for vehicle characteristics and material composition of the vehicles is taken from various data sources. For e-scooters, several authors analysed the production and use and data for this study is taken from [6] and [7]. In case of e-bikes, we used data and the bill of materials from [8]. For the e-mopeds and motorcycle we refered to [9] and [10]. For microcars, less information on representative vehicles of these classes is available. Therefore, we assumed that the generic microcars that we consider in our study have a similar material composition as a small electric vehicle which is available in [11]. We adapted all vehicle material data to the technical characteristics of the generic LEVs in Table 1. While aluminium is the dominant material for e-scooter, the share of steel increases with the vehicle size (Fig. 1) The lithium ion battery is assumed to be a NMC type for all vehicles. The production of these batteries is adapted from the production process in the GREET Model [14] and combined with background data of the ecoinvent database. Lifetime mileage (see Table 1) plays a crucial role in the emission reduction potential and care is taken by accounting for uncertainty emerging from literature derived vehicle use as well as suitable battery and material properties.

The production of the passenger cars was calculated according to data from the ecoinvent 3.7 database [5]. We distinguish mid-class passenger cars with different drive-trains, such as gasoline or diesel vehicles, cars using compressed natural gas (CNG), hybrid and plug-in hybrid electric vehicles as well as battery electric vehicles (BEV). The vehicle life time mileage for all drive train types is assumed to be 200,000 km. Emissions for the vehicle operation were taken from the handbook of emission factors [13]. Such emissions from the use of conventional fuels in internal combustion engines do not occur for purely electric vehicles, that is all LEVs and BEVs. The electricity mix for the vehicle use is taken from [14]. The report describes pathways for the electricity system in Germany until 2035. From this we derived an electricity production mix for the year 2030 with a renewable share of 74 %. Conventional electricity production in this scenario consists mainly of natural gas and to a smaller share of coal and lignite. A second scenario having a higher share of renewable energies (76 %) and significantly lower share of lignite is derived from this report and used for a sensitivity analysis.

In order to calculate the overall emission saving potential for the passenger car substitution, we analyse which LEVs are suitable for the trips identified from MiD (see section 2.2) and chose the LEV with the lowest CO_{2eq} emissions as a substitute for the passenger car. The passenger car emissions are averaged according to a reference fleet for 2030 [15] containing a BEV share of 35 % in the new vehicle fleet and 14 % in the stock. Using this information, the difference of CO_{2eq} emissions between the average car and a LEV trip (emissions per km times trip length, 2030 scenario, Germany) is calculated using the following formula:

$$Emission\ Reduction\ Potential\ (\%) = \frac{\sum_i l_i * (E_c - E_{LEV_{lowest,i}})}{\sum_i l_i * E_c} * 100 \qquad (1)$$

Where

i = trip in MiD dataset
l = trip length
E_c = Stock weighted LCA emission of passenger car
$E_{LEV\ lowest}$ = LCA emission of least emitting substitutable LEV for given trip

As shown in Eq. 1, when estimating the emission reduction potential from LEV substitution, the least LCA based emission producing LEV was selected when multiple LEVs satisfied a trip's constraints. This value is based on trips made on a representative day as reported in section 2.2 Finally, the daily trips are aggregated and upscaled for one year.

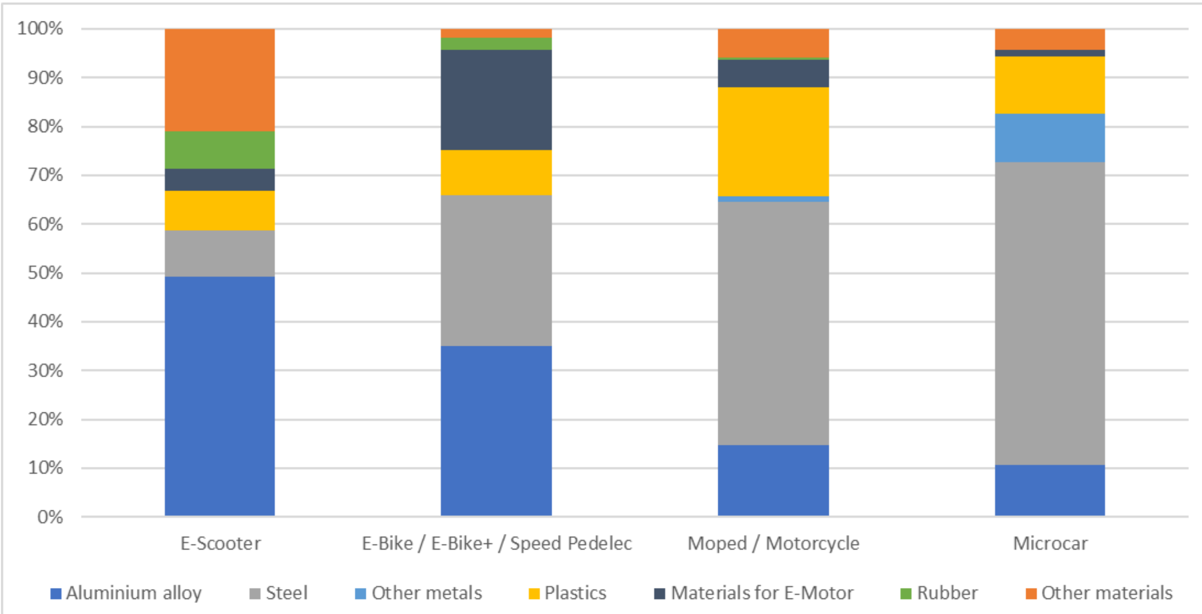

Figure 1: Weight share of vehicle materials and components

3 Results

3.1 Potential of Substituting Car Trips and Mileage

Fig. 2 shows the maximum potential of mileage substitution by the considered LEVs with a baseline range of these vehicles. A maximum of 76% of all trips accounted by the dataset can be substituted which accounts for 50 % of the mileage driven in Germany (Fig. 2).

The difference between the trip substitution potential and the substitution potential in terms of car mileage is mainly based on the fact that a significant proportion of car mileage in Germany results from long distance car trips (see [16], which could not be substituted by LEV due to their limited range. Due to their different characteristics, there is a considerably difference in the car mileage each LEV could substitute. While the e-scooter, as the simplest LEV model in these calculations, could only substitute under 1% of all car mileage in Germany, e-bikes already could substitute up to almost 20% of car mileage. Two wheeled LEV models of the category Moped and Motorcycle offer a substitution potential which ranges from around 25 to 33% of car mileage. With the four-wheeled microcars, LEV models offer characteristics quite similar to small ordinary combustion engine cars, which is also reflected in the results: up to around 50% of all car mileage in Germany could be substituted by these types of LEVs.

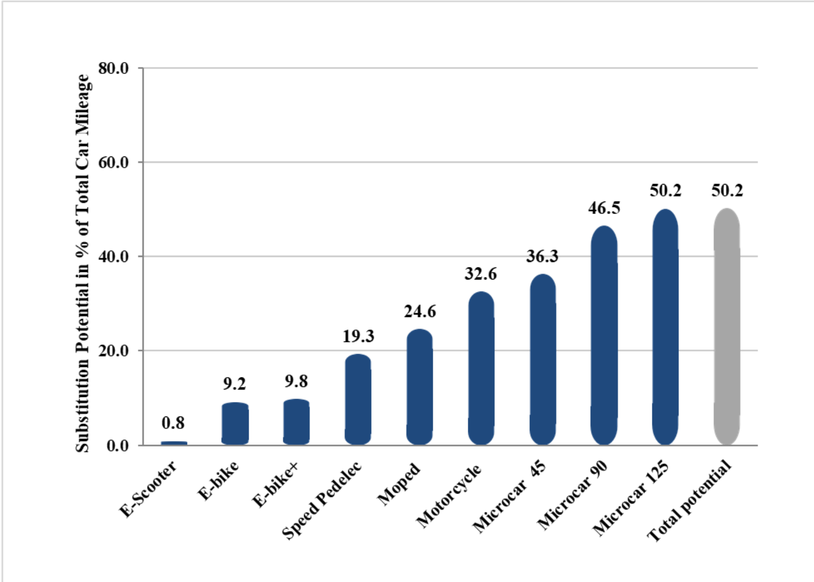

Figure 2: Maximum mileage substitution potential as a percentage of passenger car trips

3.2 Emission Reduction Potential

Battery size and capacity are found to play a decisive role in the overall greenhouse gas emissions. Emissions from battery and materials are directly related to battery capacity and vehicle weight. Consequently, microcars and motorcycles cause considerably more greenhouse gas emissions than smaller 2-wheeler LEVs (Fig. 3). The microcars with the largest batteries (microcar 125 km/h) have around 16 times higher greenhouse gas emissions in their production stage than an E-bike. More than half of these microcar emissions stem from the production of the traction battery. Comparing the technical electric range of more than 250 km possible with this battery and the assumed relevant travel distance of 140 km per day, an optimization of battery size in relation to the vehicle use bears some emission reduction potential.

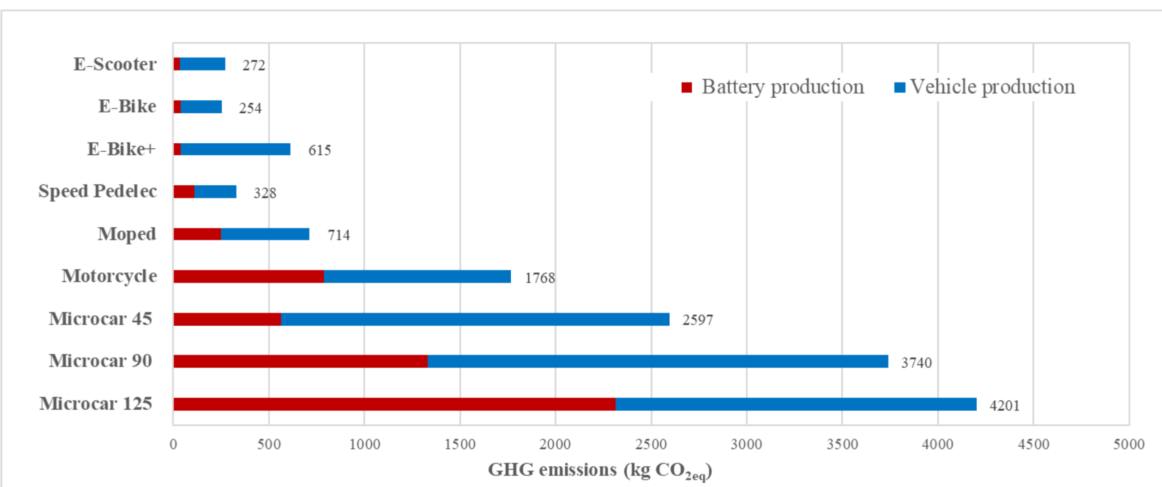

Figure 3: LEV Production emission for baseline scenario

For a per kilometer greenhouse gas emission comparison with passenger cars, lifetime mileages of the vehicles are highly relevant, as they reflect the different technical characteristics as well as the different utilities of the vehicle types. Due to the higher lifetime mileages of microcar 90 km/h and microcar 125 km/h, the greenhouse gas emissions on a per km basis are closer to the smaller LEVs which have a lower lifetime mileage (Fig. 4).

For the vehicle use stage, apart from the direct emissions of fuel combustion, the indirect emissions of the traction electricity supply are decisive for the results. The greenhouse gas emissions for the baseline energy mix of 2030 amount to around 240 g CO_{2eq} per kWh. Compared to the emissions from fossil fuel combustion and production, the emissions from the traction electricity supply lead to significantly lower emissions in the case of electric vehicle. This applies for BEVs in comparison to other drive-trains for the passenger car and also for the LEVs. Due to their lower energy consumption for operation, the LEVs in the worst case still cause only half of the greenhouse gas emission emissions of a BEV and less than a quarter of conventional gasoline or diesel passenger cars (Fig. 4).

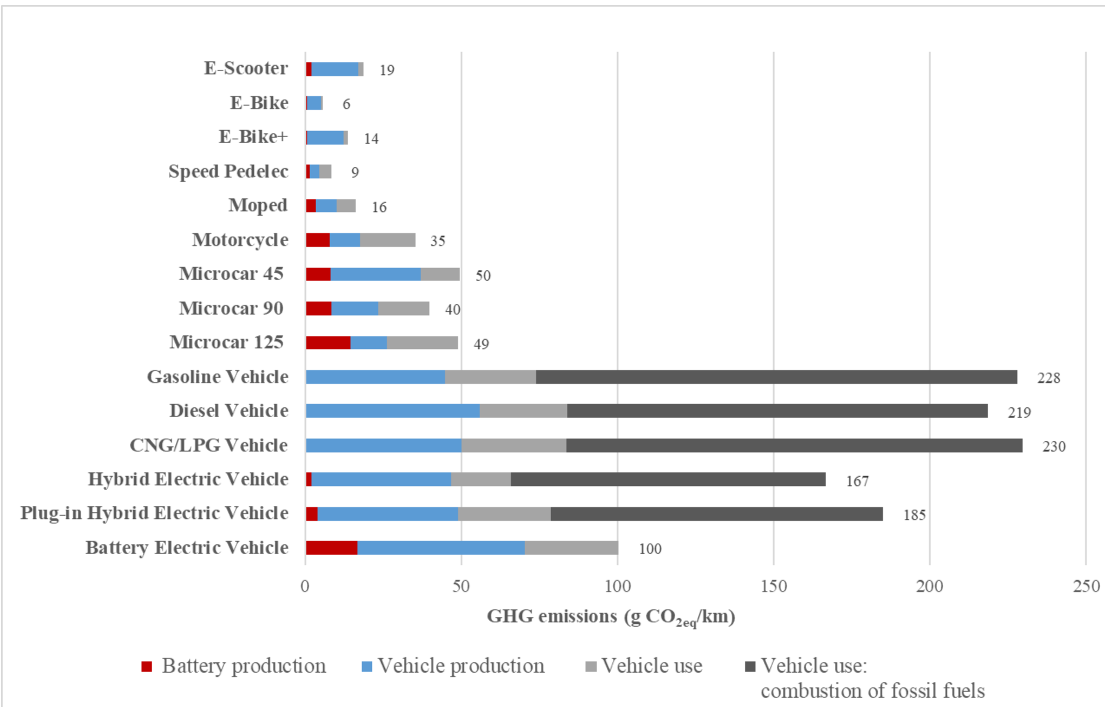

Figure 4: LCA Emissions of LEVs and Passenger cars for Baseline Scenario

When analyzing the substitutable trips with low emission LEVs the average greenhouse emissions of the LEVs (substituted mileage weighted average) is 24 g CO_{2eq} /km including vehicle production. This is only 12 % of the replaced passenger car greenhouse gas emissions of 203 g CO_{2eq}/km. The average passenger car emissions represent the vehicle stock composition as described in section 2.3. This difference results in a high emission reduction potential. With the identified mileage substitution potential of 50 % (see section 3.1), an overall saving of 44 % would be achieved compared to the use of passenger cars on these trips. In absolute number this amounts to 157 kilo tonnes CO_{2eq} per day compared to 356 kilo tonnes CO_{2eq} per day. This is equivalent to a reduction of 57 Mio tonnes CO_{2eq} per year (Fig. 5). Overall, all LEV types contribute to this emission reduction potential with a slightly higher potential for small 2-wheeler compared to microcars, mopeds and motorcycles (Fig. 5).

When evaluating the reduction potential that are be allocated to the transport sector, only emissions on a tank-to-wheel basis would be considered. The analysis of the emission reduction potential with the tank-to-wheel system boundary leads to savings of 40 kilo tonnes CO_{2eq} per year (Fig. 5) with E-bikes having the highest contribution.

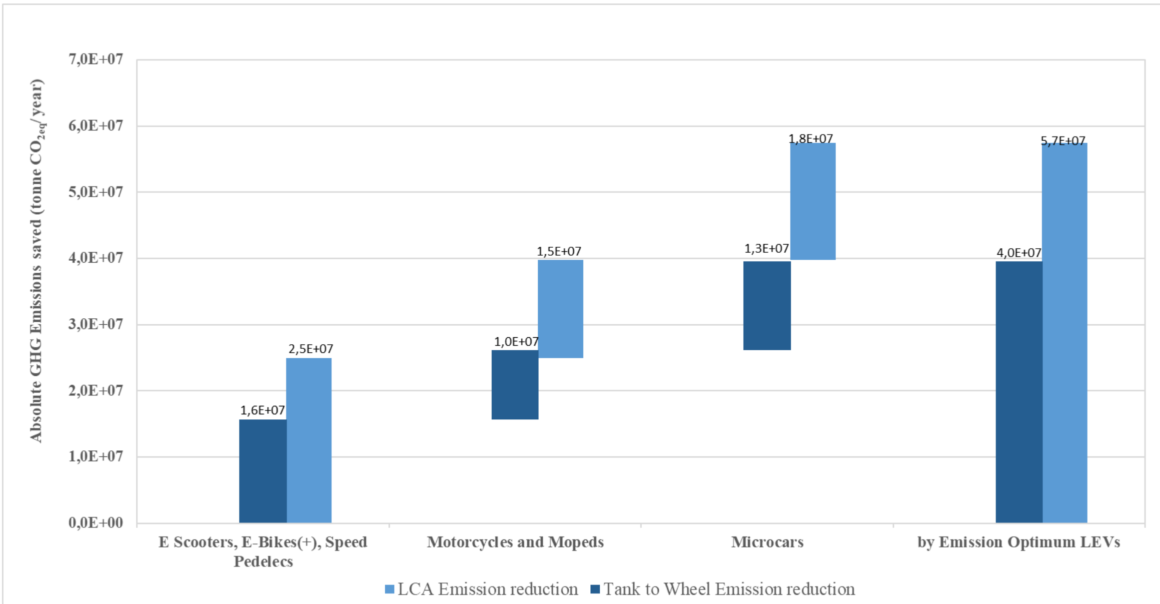

Figure 5: Emission reduction potential by LEV categories

3.3 Sensitivity Analysis

A sensitivity analysis was done with respect to influencing parameters like vehicle range, lifetime mileage and energy mix possibilities. Fig. 6 shows the variation in the LCA based emission reduction potential by substituting emission optimum LEVs for passenger car trips. The variation is shown as a function of a common range multiplier applied to the range of all LEVs when considered for trip substitution and an energy mix carbon intensity multiplier which affects the emissions generated during LEV vehicle use. The alternative energy mix is related to around 140 g CO_{2eq} per kWh compared to 230 g CO_{2eq} per kWh of the baseline electricity mix. For the sensitivity analysis, a range between these two electricity mixes has been used. The multipliers are applied to the baseline vehicle scenario parameters as explained in Table 1 and Table 2.

As can be seen, the emission reduction potential varies from 33 % to 51 % of the total passenger car and motorcycle emissions calculated from the MiD dataset when both multipliers are varied from 0.6 to 1.4 times the baseline scenario value. The gradient of the resulting surface is more aligned towards the range multiplier direction; i.e. higher percentage change of emission reduction potential by change in range multiplier as more trips can be substituted by lower emitting LEVs. The effect of this seems larger than reducing the carbon intensity of the energy mix to as low as 60 % of the assumed base scenario. On an average across this variable space, with a 10 % increase in range, the emission reduction potential increases by approximately 2 % whereas for a 10 % decrease in carbon intensity of the energy mix, the emission reduction potential increases by approximately 0.3%. It should be noted that rate of change of emission reduction potential is not constant with respect to the range multiplier since it is also a function of the trip distribution in the MiD dataset and the parameters of the LEVs considered for substitution.

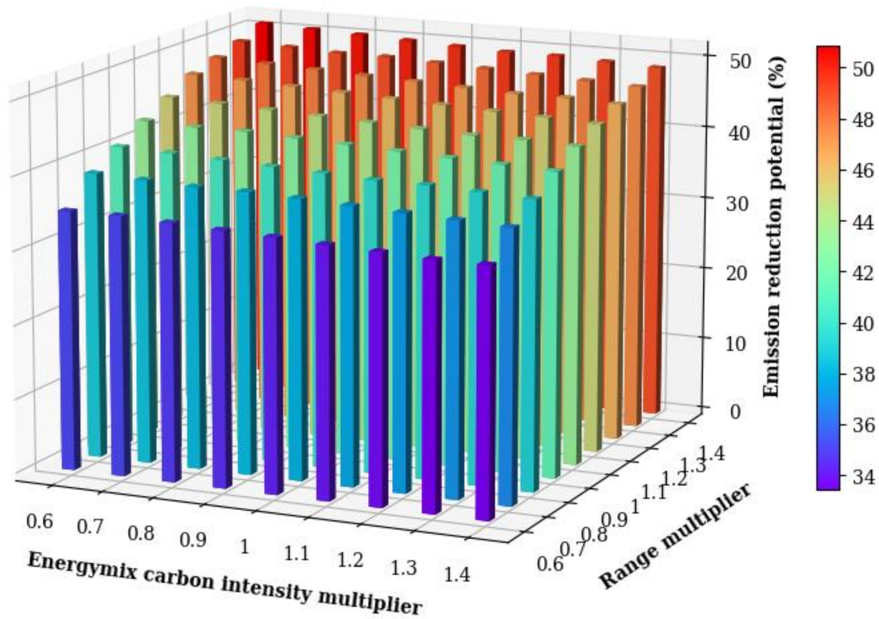

Figure 6: Sensitivity of the results to the carbon intensity of the energy mix and to the relevant travel distance

4 Discussion and Conclusions

The analysis quantifies a significant theoretical potential for decreasing greenhouse gas emissions with LEVs and is a first step which sets the ground for future scientific work evaluating approaches and obstacles to realising the emissions reduction potential of LEVs. It thereby shall give way to further research on LEVs and would urge both policy makers and general users to steer towards comprehensive measures that have to be taken to encourage a switch from cars to LEVs.

The potential for trip substitution and reduction of greenhouse gas emissions might seem high at first glance, however given that 60 % of the car mileage results in Germany from trips under 50 km and some LEV can cover even longer trips, the result with 50 % mileage replacement potential and respective emission reduction is plausible. Conservative assumptions were made regarding technical properties, substitutability of trips and replaced vehicles. Evaluation of data from the German Kraftfahrtbundesamt on new battery electric cars registered Germany in the recent years show a trend towards batteries with higher capacity than today. As long as battery technology does not improve significantly regarding production-related greenhouse gas emissions, the life cycle impacts of electric cars would tend to worsen and the relative potential of LEVs to reduce greenhouse gases would improve. Furthermore, it would be interesting to expand the scope of the study and analyse the extent to which LEVs can support modal shift and multimodal mobility. For instance, long car trips could be partly covered by using a - privately owned or shared - LEV in combination with long-distance trains and thereby further reduce emissions. A mix of mobility solutions will be necessary for future sustainable mobility, as LEV are no stand-alone solution for substituting car trips and reduce car ownership. Extensive sustainability effects would be achieved with a holistic mobility approach, integrating LEV in a system together with a high share of public transport, active modes, low private care ownership, attractive vehicle sharing offers and other sustainable mobility components such as reducing the number of trips by approaches such as the city of short distances.

The analyses quantify as a first step a theoretical potential to substitute car trips and thereby reduce greenhouse gas emissions, not considering aspects of user acceptance, nor possible changes in mobility behaviour, infrastructure or political framework conditions. Future research should therefore evaluate paths towards greater use of LEVs with specific measures to promote a sustainable and safe use of LEVs and investigate social aspects, such as user acceptance and preferences in mode choice as well as technological aspects such as improved vehicle safety.

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References

[1] IEA, *Global CO2 emissions by sector,* [Online], available: https://www.iea.org/data-and-statistics/charts/global-co2-emissions-by-sector-2019, accessed on 2021-12-22

[2] Regulation (EU) No 168/2013 of the European Parliament and of the Council of 15 January 2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles (Text with EEA relevance), available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02013R0168-20201114, last accessed 2022/04/12https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02013R0168-20201114, last accessed 2022/04/12

[3] M. Brost, L. Gebhardt, S. Ehrenberger, I. Dasgupta, R. Hahn, *The Potential of Light Electric Vehicles for Climate Protection through Substitution for Passenger Car Trips - Germany as a Case Study,* project report 2022, available online: https://elib.dlr.de/186036/1/2022-03-24_LEV4Climate_DLR_LEVA-EU_report.pdf

[4] Federal Ministry of Transport and Digital Infrastructure (BMVI), *Mobillitaet in Deutschland (Mobility in Germany)* [Online]. Available: http://www.mobilitaet-in-deutschland.de/publikationen2017.html, accessed on 2021-12-22

[5] G. Wernet, C. Bauer, B. Steubing, J. Reinhard, E. Moreno-Ruiz, B. Weidema, *The ecoinvent database version 3 (part I): overview and methodology*. Int. J. Life Cycle Assess. 21 (2016), www.ecoinvent.org

[6] S. Severengiz, S. Finke, N. Schelte, N. Wendt, *Life Cycle Assessment on the Mobility Service E-Scooter Sharing*, 2020 IEEE European Technology and Engineering Management Summit, E-TEMS 2020.

[7] H, Moreau, L.J. Meux, V. Zeller, P. D'Ans, C. Ruwet, W.M.J. Achten, *Dockless e-scooter: A green solution for mobility? Comparative case study between dockless e-scooters, displaced transport, and personal e-scooters*. Sustainability (Switzerland) 12(5) (2020). https://doi.org/10.3390/su12051803

[8] R.J. Bonilla-Alicea, B.C. Watson, Z. Shen, L. Tamayo, C. Telenko, *Life cycle assessment to quantify the impact of technology improvements in bike-sharing systems,* Journal of Industrial Ecology, 24:138–148 (2020)

[9] P. Kerdlap, S.H. Gheewala, *Electric Motorcycles in Thailand - A Life Cycle Perspective*, Journal of Industrial Ecology 20 (6) 2016

[10] B.L. Cox, C.L. Mutel, *The environmental and cost performance of current and future motorcycles,* Applied Energy 212 (2018) 1013–1024

[11] E. Helmers, J. Dietz, M. Weiss, *Sensitivity Analysis in the Life-Cycle Assessment of Electric vs. Combustion Engine Cars under Approximate Real-World Conditions,* Sustainability 2020, 12

[12] Q. Dai, J. Kelly, J. Dunn, P. Benavides, *Update of bill-of-materials and cathode materials production for lithium-ion batteries in the GREET® model,* Memo 2018 www.greet.es.anl.gov

[13] INFRAS, *Handbook Emission Factors for Road Transport (HBEFA)*, Bern / Vienna / Dessau / Borlänge / Oslo / Ispra, 2017

[14] T. Drees, H. Medert, M. Meinecke, C. Halici, *Netzentwicklungsplan Strom 2035 (2021), zweiter Entwurf | Übertragungsnetzbetreiber CC-BY-4.0,* 2021

[15] Kopernikus-Projekt Ariadne, *Ariadne-Report: Deutschland auf dem Weg zur Klimaneutralität 2045 - Szenarien und Pfade im Modellvergleich*. https://doi.org/10.48485/pik.2021.006, 2021

[16] C. Nobis, T. Kuhnimhof, *Mobilität in Deutschland – MiD Ergebnisbericht*, Studie von infas, DLR, IVT und infas 360 im Auftrag des Bundesministers für Verkehr und digitale Infrastruktur (FE□Nr. 70.904/15). Bonn, Berlin. www.mobilitaet-in-deutschland.de, 2018

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