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LIFE CYCLE ASSESSMENT OF COMBINED SHARING SYSTEMS WITH DIFFERENT LIGHT ELECTRIC VEHICLES IN URBAN AREAS CONSIDERING NOVEL CHARGING INFRASTRUCTURE AND MODAL SHIFT

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INTRODUCTION

Light electric vehicles (LEV) are considered a space-saving and environmentally friendly alternative for passenger transport in urban areas. However, they require a charging infrastructure, which comes with its own requirements and opportunities in the form of exchangeable batteries and decentralized solutions for shared mobility. LEV-Sharing accounts for less than 0.3% of the daily passenger traffic volume in Berlin and even less when considering the German average. The full modal split is shown in Figure 1.

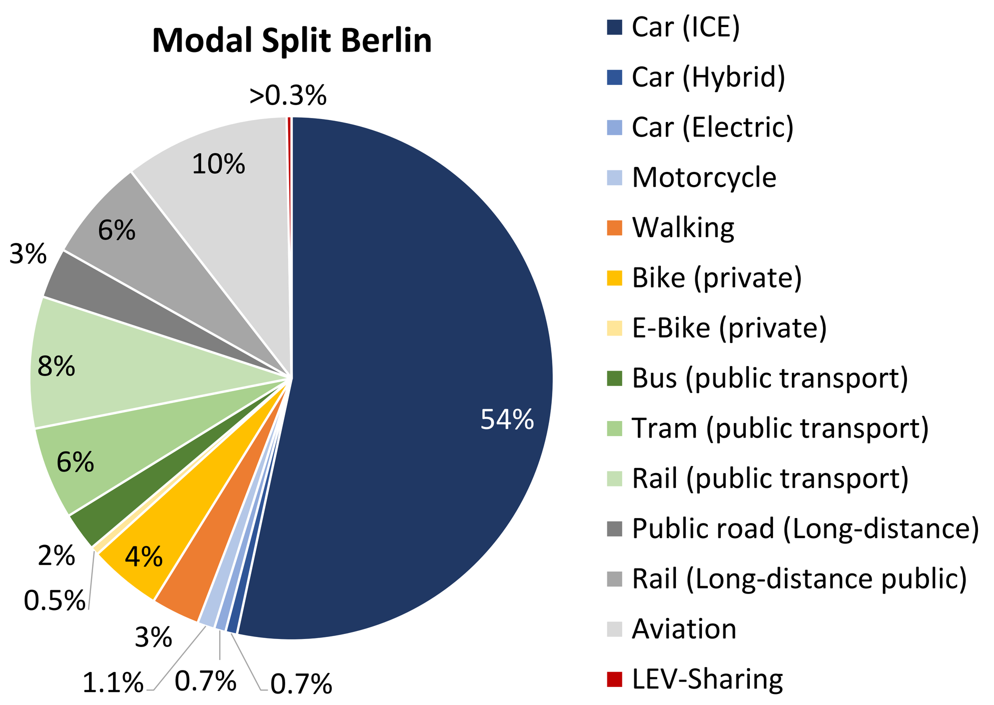

Figure 1: Modal split Berlin by shares of person-kilometers travelled with different means of transport according to data from the MiD Regional Report. Berlin-Brandenburg (2020) [1], BMVU (2021) [2], Eurostat (2022) [3], VDV (2019) [4], Statista (2022) [5].

What is LEV sharing?

[9]

In this study, the light electric vehicles e-scooters (up to 20 km/h), e-bikes (up to 25 km/h) and e-mopeds (up to 45 km/h) are investigated. They are distributed by a sharing service provider in a defined operation area (i.e., city center) and can be rented with a mobile application.

METHOD

LEV-Sharing systems, consisting of e-scooters, e-bikes and e-mopeds with battery swapping stations (BSS) that are provided for user-based battery swapping (UBBS), are analyzed. For the quantification of the environmental relief potential, the global warming potential (GWP_{100}) is evaluated. The methodology of life cycle assessment (LCA) is applied. A model is developed that can be used to evaluate different scenarios for the design of LEV-Sharing systems. The entire life cycle (Cradle-to-Grave, see Figure 2) is considered with the functional unit passenger-kilometer (pkm). To determine the environmental relief potential, the substitution of transport modes by the LEV-Sharing system is considered (modal shift). Different scenarios for the design of LEV-Sharing systems in the city Berlin are evaluated (Table 1) and their environmental relief potentials are discussed (Figure 3).

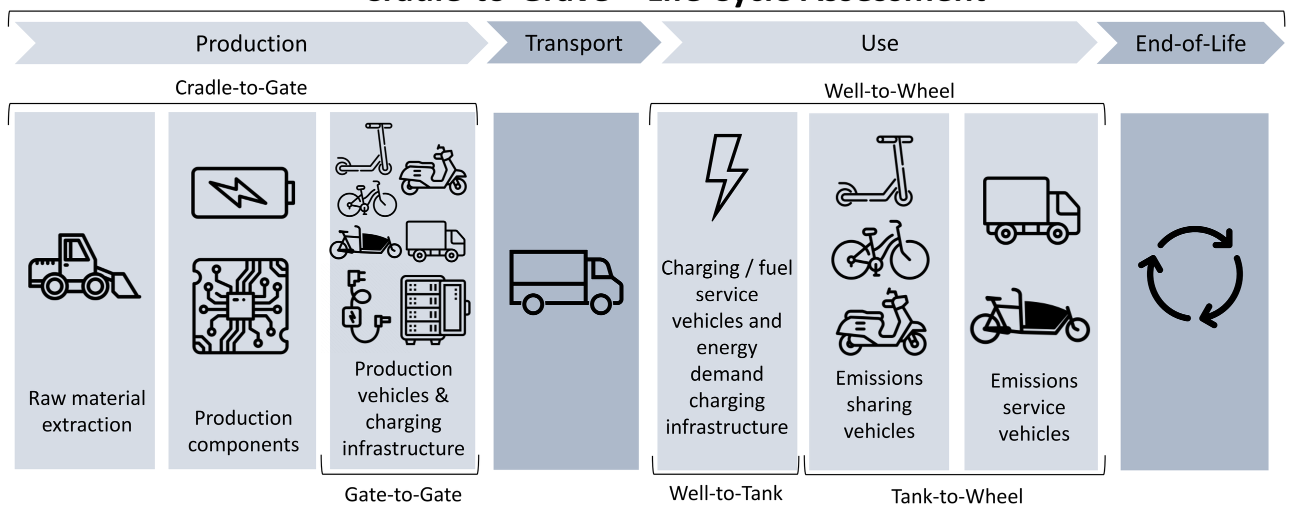

Figure 2: Scope Cradle-to-Grave LCA for LEV-Sharing systems. Pictograms from Flaticon [9].

Parameter	1. Base Case Grid Mix	2. E-Service Green Mix	3. BSS Grid Mix	4. BSS Green Mix	5. Focus Pedelec	6. Focus E-Moped
E-Scooters	10.000	10.000	10.000	10.000	3.913	3.462
E-Bikes	3.000	3.000	3.000	3.000	10.000	1.038
E-Mopeds	1.500	1.500	1.500	1.500	587	10.000
Charging	Grid Mix Germany	Green Energy Mix Germany	Grid Mix Germany	Green Energy Mix Germany	Grid Mix Germany	Grid Mix Germany
Service Diesel-Van	79.2 %	0 %	44 %	0 %	79.2 %	79.2 %
Service E-Van	5.4 %	38.7 %	3 %	21.5 %	5.4 %	5.4 %
Service E-Cargo Bike	5.4 %	52.3 %	3 %	28.5 %	5.4 %	5.4 %
Service UBBS	10 %	10 %	50 %	50 %	10 %	10 %

Table 1: Selected parameters for the considered scenarios.

RESULTS

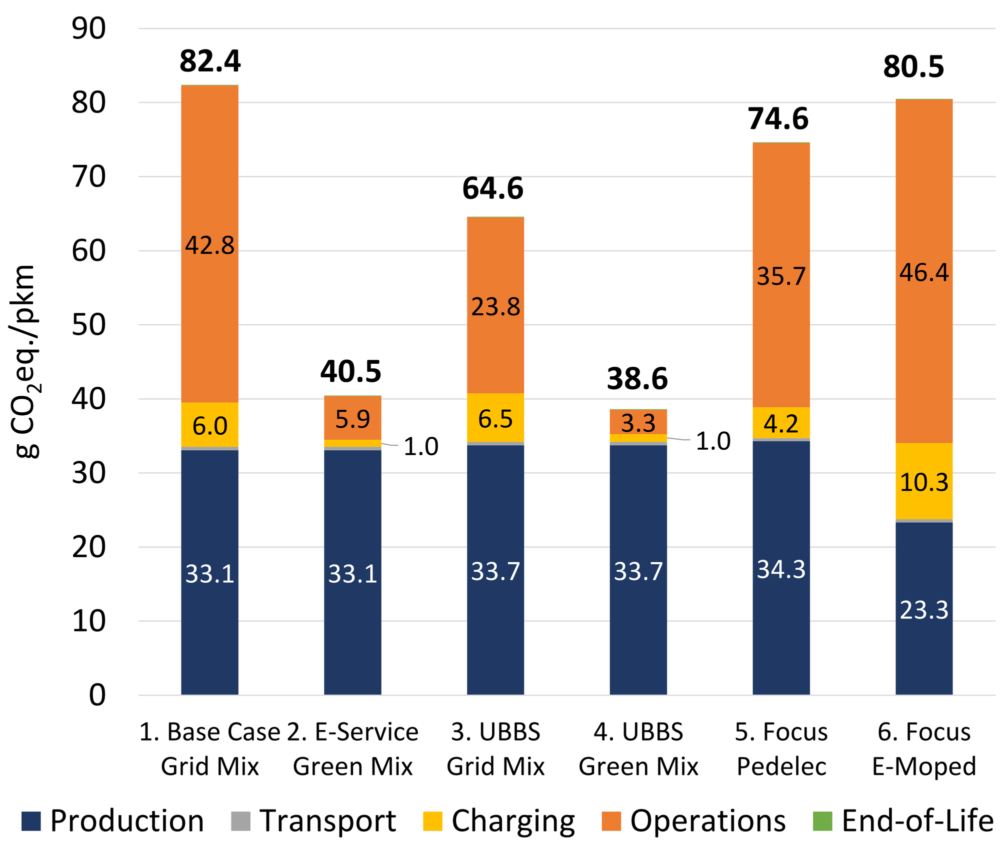

Figure 3: Impact assessment for combined LEV-Sharing systems in Berlin considering different scenarios for the GWP subdivided according to life cycle stages.

The design of the sharing system influences their greenhouse gas (GHG) balance significantly with operations being the biggest lever for cutting down on GHG emissions followed by production. The transportation of the products only accounts for less than 1% of their GHG emissions over the product life cycle.

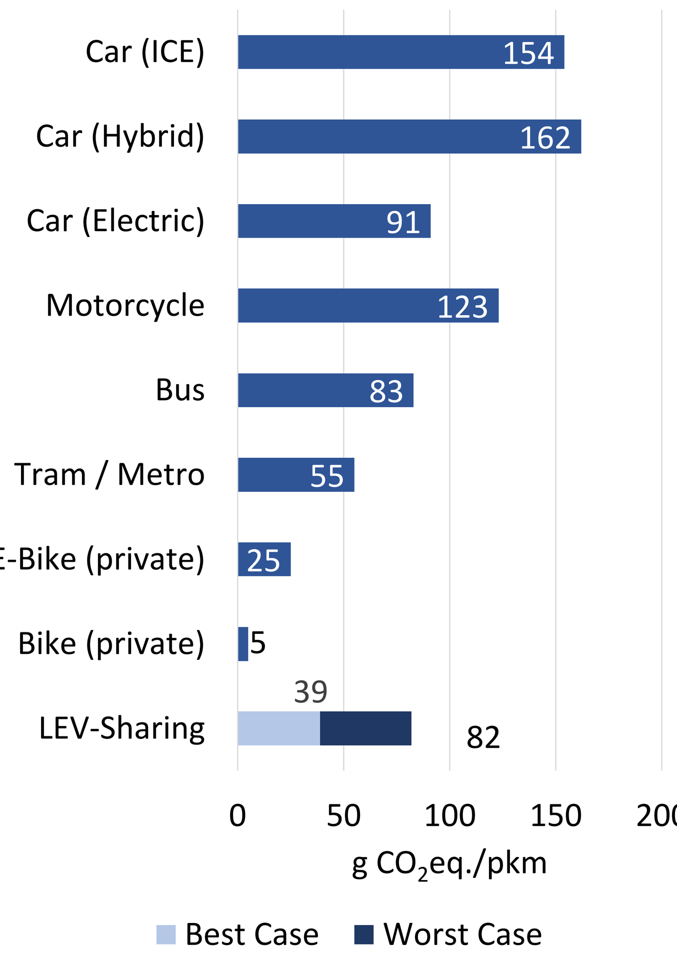

Figure 4: GWP comparison of LEV-Sharing with alternative means of transport. Data from UBA Germany (2021) for ICE car, bus, tram and metro [6], UBA Austria (2021) for PHEV car and BEV car [7] and Weiss et al. (2015) for motorcycle, bike, and e-bike [8].

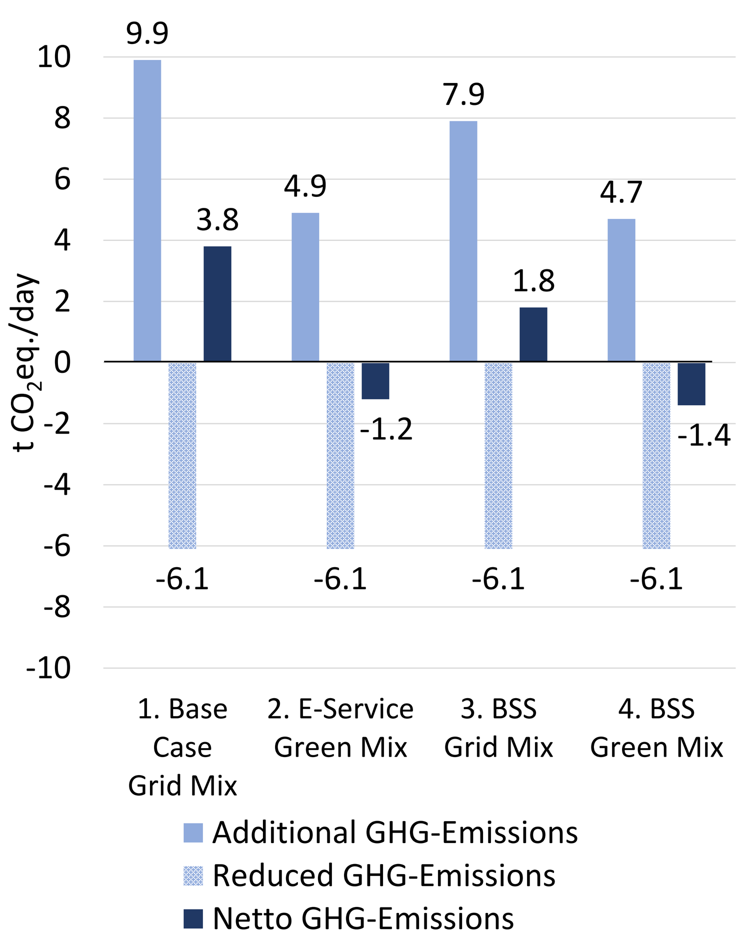

Figure 5: Change in GHG emissions in Berlin's transport sector through different scenarios for LEV-Sharing systems. Additional, reduced and net GHG emission in the scenarios 1-4 when 15% car-, 42% public transport-, 27% bike-, 5% e-bike- and 11% walking-distances are substituted. Substitution patterns based on Reck et al. [9].

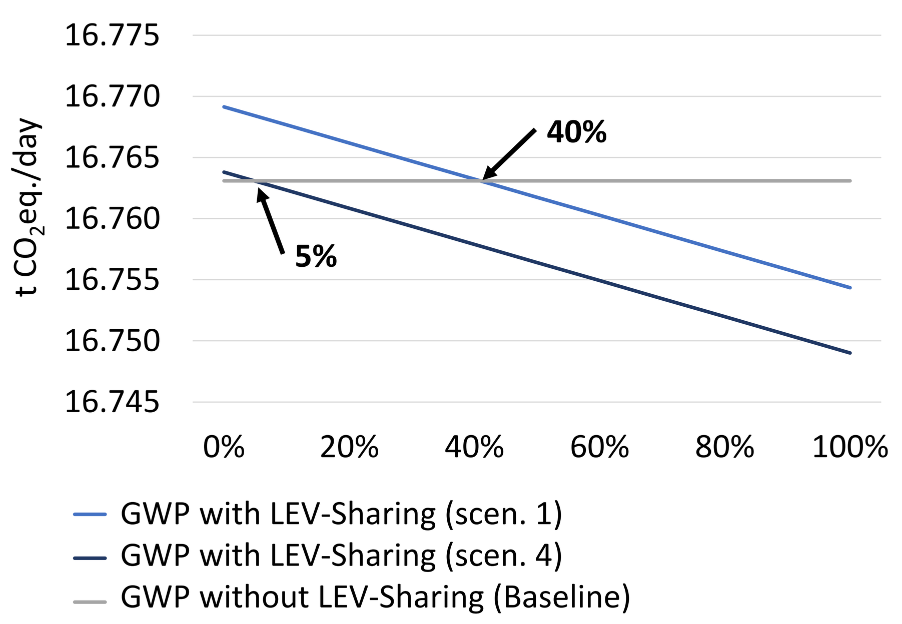

Figure 6: Comparison of daily GHG emissions without LEV-Sharing to daily GHG emissions with LEV-Sharing in scenarios 1 and 4 with a variation of the share of substituted car trips. The share of substituted car trips is varied on the x-axis of this graph while the remaining share consists of a substitution mix of public transport, bike, e-bike and walking.

Without LEV-Sharing, emissions amounting to 16,763 t CO_2eq./day are generated for passenger transport in Berlin. If less than 40% of the pkm traveled with the scenario-1-LEV-Sharing-system substitute car kilometers, the daily GHG emissions with the LEV-Sharing system are higher than without the LEV-Sharing system. With a scenario-4-LEV-Sharing-system, only more than 5% of the pkm traveled with the LEV-Sharing system need to substitute car kilometers to achieve a net saving in GHG emissions.

CONCLUSION AND RECOMMENDATIONS

Combined LEV-Sharing systems with UBBS have a GHG reduction potential of up to 13 g CO_2eq./pkm (scenario 4) if 15% car, 42% public transport, 27% bicycle, 5% e-bikes and 11% walking routes are substituted. However, LEV-Sharing can also increase GHG emissions by up to 32 g CO_2eq./pkm for the same substitution mix when it relies on diesel fueled service vans and non-renewable energy sources (scenario 1). The following recommendations are given to maximize the GHG saving potential:

1. Encouraging modal shift from passenger cars to LEV-Sharing! Combined with public transport, LEV-Sharing systems can be an attractive alternative to cars in urban areas.
2. Maximize the service life and usage intensity of LEVs! If LEVs are used intensively, emissions from production and service trips are allocated to more kilometers driven and emissions per functional unit (pkm) decrease. Second-use applications, such as battery reuse for low-voltage applications, can also reduce production emissions to more use cases, improving the GHG balance.
3. Use renewable energy sources in all life cycle stages! Specially for charging of the LEVs and their service vehicles.
5. Electrify the service fleet! E-vans and e-cargo bikes are similarly efficient in terms of their GHG balance when powered with green electricity.
6. Implement Battery Swapping Stations to enable users to swap batteries and power them with renewable electricity.
7. The production is responsible for a major share of GHG emissions within LEV-Sharing systems with aluminum being the hotspot:
   - Use secondary aluminum wherever possible
   - Perform energy-intensive production operations such as aluminum extraction, with renewable energy sources.
   - For some components alternative raw materials can be used, for example: steel wire rims instead of aluminum or magnesium rims.

A net reduction of GHG emissions is achieved if more than 5% of the pkm traveled by the combined LEV-Sharing system substitute travels by passenger car and UBBS, electric service vehicles and renewable electricity sources are used. In direct comparison to passenger cars LEV-Sharing systems can reduce GHG emissions by 115 g CO_2eq./pkm. If the deployed service fleet consists mainly of diesel vans, the electricity mix of Germany is used to charge the LEVs, and little novel charging infrastructure is deployed, more than 40% of the passenger kilometers traveled must substitute passenger car routes to enable a reduction in GHG emissions.

Disclaimer Currently, LEV-Sharing systems do not yet contribute to significant savings or increases in GHG emissions in the transport sector, as they are only used for a very small proportion of passenger transport. The GHG relief potential for Berlin is up to 1.4 t CO_2eq./day (scenario 4). This corresponds to an environmental relief potential of 0.01% of the daily GHG emissions of Berlin's passenger transport sector.

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