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Techno-Economical and Ecological Potential of Electrical Scooters: A Life Cycle Analysis

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In Germany, mobility is currently in a state of flux. Since June 2019, electric kick scooters (e-scooters) have been permitted on the roads, and this market is booming. This study employs a user survey to generate new data, supplemented by expert interviews to determine whether such e-scooters are a climate-friendly means of transport. The environmental impacts are quantified using a life cycle assessment. This results in a very accurate picture of e-scooters in Germany. The global warming potential of an e-scooter calculated in this study is 165 g CO_2-eq./km, mostly due to material and production (that together account for 73% of the impact). By switching to e-scooters where the battery is swapped, the global warming potential can be reduced by 12%. The lowest value of 46 g CO_2-eq./km is reached if all possibilities are exploited and the life span of e-scooters is increased to 15 months. Comparing these emissions with those of the replaced modal split, e-scooters are at best 8% above the modal split value of 39 g CO_2-eq./km.

Keywords: *e-scooter, e-mobility, micromobility, urban mobility, shared mobility, first and last mile connectivity, LCA.*

1. Introduction

Since June 2019, Germany has permitted micro-electric vehicles on its roads (Bundesministerium der Justiz und für Verbraucherschutz, 2019). The German Minister of Transport, Andreas Scheuer, commented on the new law in a press release: "We want new ways of modern, eco-friendly and

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clean mobility in our cities. E-scooters have enormous future potential! In conjunction with local public private transport, they are a real additional alternative to the car […]" (BMVI, 2019).

Fostering sustainable mobility in cities is an important strategy for mitigating greenhouse gas emissions: on the one hand, cities have been identified as the main driver to reduce greenhouse gas emissions (Mi et al., 2019); on the other hand, transportation is the only sector in Germany that did not contribute to greenhouse gas reductions between 1990 and 2019 (BMU, 2019). Road traffic was the main contributor to the transport sector's greenhouse gas emissions with 96 percent (BMU, 2019). These constant emission values are especially remarkable considering Germany's overall greenhouse gas reduction of 37.5 percent in the same period (BMU, 2020). Introducing modern and clean urban transport is therefore a logical step to further mitigate emissions.

Modern mobility in growing cities is characterized by individualism, connectivity and neo-ecology (Zukunftsinstitut, 2020a). This is manifested in recent urban transport concepts such as ride sharing and micromobility. Micromobility is booming and expected to reach a market volume of 100 to 150 billion US dollars in Europe by 2030 (McKinsey & Company, 2019). E-scooters, in particular, represent a promising, but also controversially discussed option for clean and modern micromobility, as envisioned by the German Transport Minister Scheuer (BMVI, 2019).

E-scooter sharing concepts have recently been introduced in many of the world's major cities and are often considered a pathway to reducing vehicle ownership and therefore climate-friendly (Axsen and Sovacool, 2019). However, doubts have been raised about the sustainability of electric scooters (Hollingsworth et al., 2019). More research is needed to understand their impacts on the environment (Shaheen et al., 2020) and how shared micromobility solutions, such as e-scooters, interact with public transport (ibidem). Results from the e-bike sharing market indicate that bike usage is increasing as a mode to access public transport (Goeverden and Correia, 2018), but it is not clear whether this finding also applies to e-scooter sharing schemes.

Since data on e-scooters and their usage are sparse, the few available analyses on their sustainability display diverging results. This study aims to collect missing data and to determine whether electric stand-up scooters in a sharing model contribute to an environmentally sustainable mobility with reduced CO_2-eq. emissions in inner-city areas in Germany.

In order to fulfil this objective, we carried out a life cycle assessment (LCA). This LCA aimed to calculate a range for the e-scooter's global warming potential (GWP). The first step was to derive the required input data; the technical information about the latest generation of free-floating e-scooters obtained by reviewing the literature and data sheets and expert interviews. Further, we collected typical user profiles and data on the use of e-scooters in Germany through a user survey. For better comparability with other studies pursuing a similar objective, our study focuses on the ecological sustainability of e-scooters. The other two of the three pillars of sustainability, economic and social sustainability (Aachener Stiftung Kathy Beys, 2015), were only considered as side-effects of ecological sustainability.

The paper is structured as follows: section 2 describes the findings from the literature review, including the definition of e-scooters as well as the results available from studies of user behaviour. Section 3 focuses on the methods applied in this study, the user analysis and the life cycle assessment. In Section 4, we present the results by combining and interpreting the results of the life cycle assessment and the user survey. Section 5 discusses the results and the methodology. In Section 6, we summarize the findings of this study and its contribution to science.

2. State of the art

Although e-scooters have been on the German market for several months now, and some of them have been on the market in other countries for even longer, there is only limited peer reviewed literature available on them. The concept of e-scooter sharing "allows individuals access to scooters by joining an organization that maintains a fleet of scooters at various locations" (Shaheen, 2019, p. 3). Due to the novelty of the "e-scooter sharing" system and the rapid change associated with new technologies, the few documents found are rarely cited. Often, the keyword "e-scooter" yields publications referring to other electric means of transport also called e-scooters, such as seated electric scooters. Some management consulting companies or analysts offer their own analyses, but these data are not validated scientifically. In particular, there are hardly any independent survey results so far on the actual use of stand-up e-scooters. These are only beginning to be collected via application projects (6t-bureau de recherche, 2019; Populus, 2018; Portland Bureau of Transportation, 2018; Reinz-Zettler, 2019). This chapter summarizes our findings on the available technical data, user data and LCA and includes, for the above named reasons, references to grey literature.

2.1 *Definition e-scooter:*

Electric kick scooters (umbrella term: micromobility), also called e-scooters, are stand-up scooters that set in motion by one or two steps. The electric motor then switches on and powers the scooter. The e-scooters are defined in Germany by the BMJV (Federal Ministry of Justice and Consumer Protection) : "For the purposes of this regulation, micromobility electric vehicles are motor vehicles with electric drive and a maximum design speed of no less than 6 km/h and no more than 20 km/h" (Bundesministerium der Justiz und für Verbraucherschutz, 2019). People who collect and charge the e-scooters are commonly called "juicers".

2.2 *User behaviour towards e-scooters:*

The 6T-Research Office investigated user behaviour of free-floating e-scooters in France (6t-bureau de recherche, 2019). This study found that 42% of users use the e-scooters three times a month or less. 23% of all journeys were intermodal (ibidem). However, 44% of the trips made using e-scooters replaced walking (ibidem).

A study published by Earnest and Young in early 2020 found that 12% of all e-scooter rides replace cars, taxis or ride-hailing trips (Holm Møller et al., 2020a; Holm Møller et al., 2020b). In Brussels, e-scooters replaced 29.2% of car trips (Moreau et al., 2020).

The Civity Management Consultants GmbH & Co. KG (hereinafter referred to as "civity") mapped the spatial and temporal availability of e-scooters in Germany from providers operating in Germany by "regularly polling the publicly accessible interfaces in September" (Tack et al., 2019). These data include the number of e-scooters in use and the routes per day. An e-scooter in Karlsruhe, for example, is used about 4.9 times a day. Ingolstadt has the most frequent use of e-scooters with 5 trips per day, and Potsdam the least with 1.5 trips per day. The average distances covered are 1.96 km for Tier, 1.81 km for VOI and 1.75 km for Lime. From this data, it is possible to estimate that an e-scooter in Karlsruhe covers roughly 10 km per day.

In the study "civity Matters No. 1", civity (2014) determined the average one-way distances for different means of mobility. 0.9 km are covered by foot, 3.4 km by bicycle, 4.9 km by tram, 5.4 km by bus, 9.5 km by car and 12.9 km by urban railway (Weigele et al., 2014). This implies that, for an average distance of 3.4 km, a person will use a bicycle, but will walk if the distance is around 0.9 km. The average one-trip distance for e-scooters at just under 2 km therefore lies between walking and cycling modes.

2.3 *Development of e-scooters over time and short description of the e-scooter used in this LCA:*

The first rental e-scooters offered in the USA included the Xiaomi and Segway-Ninebot (Hawkins, 2019). Xiaomi initially intended the M365 model to be a consumer model that would not withstand continuous use or harsh weather conditions (Hawkins, 2019). This is reflected in its very short lifespan in sharing schemes. For this reason, the various e-scooter sharing providers are now developing their own models; some of them are already on the market. One example is the company VOI, with the "Voiager 2" and "Voiager 3" e-scooters (Moreau et al., 2020; VOI Technology AB., 2019).

According to Tier Mobility (hereinafter referred to as "Tier"), the e-scooters they use in sharing operations are very similar to the "ES200D-C" e-scooters offered by Okai Vehicle Co, Ltd. The ES200D-C e-scooter is used as the standard for this work. The e-scooter pictured in Figure 1 is very similar to the ES200D/ES200D-C.

Figure 1. *E-scooter used by TIER Mobility (similarities to the ES200D-C) (TIER Mobility, 2019b; TIER Mobility, 2019a)*

New to the market are the e-scooters with swappable batteries used by Tier (TIER Mobility, 2019b) and VOI (Holm Møller et al., 2020a). As these have only recently been added to the e-scooter fleet, they are not considered for the bill of materials in this study, but are considered as a way to reduce the GWP of e-scooters. Specific details used in the LCA can be found in the Life Cycle Inventory in the appendix.

2.4 *Overview of life cycle assessments of e-scooters*

E-scooters are a very recent addition to the mobility market, so very few LCAs have been carried out so far. Hollingsworth et al. (2019) conducted a study with free-floating e-scooters in the USA. Their results suggest that a rental e-scooter emits 126 g CO_2-eq. per passenger kilometre over its entire lifetime. The authors find that material and manufacturing are the main cause of emissions (50%), followed by the daily collection and redistribution of the e-scooters (43%). The authors conclude that a more efficient collection and distribution process could reduce the greenhouse gas emissions to 91.9 g CO_2-eq. per person-kilometre. If a longer lifetime of two years is assumed, emissions could be reduced even more to 88.1 g CO_2-eq. per person-kilometre.

One of the most relevant sources in the study of Hollingsworth et al. (2019) is a life cycle assessment of shared free-floating e-scooters by the energy analyst Matt Chester published in his blog (Chester, 2019). In line with the results of Hollingsworth et al. (2019), Chester (2019) suggests that materials and manufacturing are responsible for most of the life cycle CO_2-eq. emissions, followed by the collection and distribution process. Chester (2019) calculates a best-case scenario of 200 g CO_2-eq. per person-kilometre.

A recent peer-reviewed study by Moreau et al. (2020) follows a similar approach to the research described in this article. They study the GWP of e-scooters deployed in Brussels, the capital of Belgium. The authors find that one e-scooter emits 131 g of CO_2-eq. per kilometre in the current e-scooter scheme (Moreau et al., 2020). Their study builds in parts on data provided by Hollingsworth et al. (2019) and supports their results. The results of Moreau et al. (2020) show that many people (42%) used a personal e-scooter at least once. In contrast, our study does not research the use of personal scooters, but focuses on e-scooters in a sharing scheme.

Finally, Earnest and Young published a study about micromobility in early 2020 (Møller et al. 2020). The authors partnered with VOI and conducted a user analysis and LCA based on VOI data. It is important to note that the authors focus on the new e-scooter models of VOI, which were distributed in cities at the end of 2019 and were still being rolled out in early 2020 and will gradually replace the existing e-scooters in cities. A major change in these new e-scooters is the swappable battery. In order to charge the e-scooter, only the batteries have to be transported, which can be done by using electrified transporters or cargo-e-bikes. The e-scooters themselves only have to be collected for re-distribution and maintenance. In the study by Earnest and Young, this leads to a major decrease in the e-scooter carbon emissions. Assuming a lifetime of 24 months for the new e-scooter fleet, Møller et al. (2020) calculate carbon emissions of 35g CO_2-eq./person-kilometre for the VOI e-scooter fleet in Paris. This represents a major improvement with 72% fewer emissions than the study of Hollingsworth et al. (2019).

In summary, based on literature research, the GWP of a shared e-scooter is likely to be between 100 to 200 g CO_2-eq. per kilometre. Møller et al. (2020) present a non-peer reviewed best-case scenario of 35g CO_2-eq./km.

Independent of the above-mentioned studies, there is a LCA of e-scooters carried out by "Carbone 4" for "Bird". However, this is a white paper and its results should be viewed with caution. The results for GHG emissions in this study are very different from the results of the previously mentioned studies.

Our study differs to the above-mentioned study by Moreau et al. (2020) as shown:

- The legal aspects of driving and owning an e-scooter are different between Belgium and Germany. Germany requires a specific registration (as mentioned in the eKfV), whereas this is not the case in Belgium, which makes it much more attractive to own an e-scooter there. This legal issue results in the larger number of personal e-scooter owners who took part in the survey in Brussels.
- People from all over Germany, including rural areas, took part in the survey. Our main focus is on Germany. We use Karlsruhe and its urban area as a reference point for a mid-sized German city. Karlsruhe had a congestion index of 22% in 2019 according to (TomTom, 2020a). The study of Moreau et al. (2020) focuses on Brussels, a capital city with a high congestion index of 38% (TomTom, 2020b).
- In 2020, 98.1%of the Belgian population live in an urban area, compared to Germany, where 77.5% of the population reside in an urban area (United Nations, Department of Economic and Social Affairs, Population Dynamics, 2018).
- In this study, we explored how changes in battery manufacturing could impact the GWP of e-scooters in Germany.

3. Data and methods

E-scooters have now been available on the global market for two and a half years. In Germany, the rental providers have been available since June 2019. Despite the increasing and now relatively long presence of rental providers, there is not yet much data available on the rental business in Germany and the e-scooters themselves. For this reason, we conducted our own survey and interviews. In order to investigate this topic in more detail, the purpose of the survey and the interviews can be divided into two sub-questions:

1. How are e-scooters accepted by the population in Germany and how are they typically used? (user analysis)
2. How environmentally sustainable is the production, transport, use and end-of-life of e-scooters?

We aim to answer these questions using two survey procedures and one calculation:

1. An online questionnaire, which is distributed over a large sample (quantitative)
2. A semi-structured interview with selected experts from the field of e-scooter sharing providers (qualitative)
3. A life cycle assessment, which is calculated based on the data collected in "2.", data from ecoinvent V3.5 and various studies on specific materials.

3.1 *Data and user behaviour*

The survey's field phase lasted two months from November to December 2019. We distributed the survey through various channels, one of which was the "electrive.net" newsletter of 18 November 2019. In it, the survey was referred to in the form of a "join-in tip". In addition, we distributed the link to the survey via the Twitter account of Fraunhofer ISI, via e-mail at Reutlingen University and other channels such as Facebook, Twitter and LinkedIn. Due to our use of social media to broadcast the survey, we do not have reliable information on the total number of persons that received it or the response rate.

We received answers from 964 participants, of which 410 completed the survey. We analysed only fully completed surveys in the evaluation. About 60% of the participants that completed the survey reside in the German federal state of Baden-Württemberg and about 14% in the Stuttgart conurbation. These figures are estimates, as not all participants revealed their ZIP code. Other participants were distributed all over Germany, big cities such as Hamburg, Berlin, or Münster were other hotspots, but also more rural areas.

We chose the above-mentioned channels in order to reach a predefined target group consisting mainly of persons under 30. 65% of the survey participants were in this age group. The reason for choosing this target group was that a population survey by PricewaterhouseCoopers AG (2015) had revealed that 82% of the under-30s stated that they had already used a Share Economy offer in Germany. In making this selection based on the distribution method, it is clear that older population groups and population groups with a lower activity level on the internet or social networks are underrepresented.

Further, the survey is also not completely representative, since the method of distribution cannot guarantee that all "characteristic values of characteristics such as gender, age, education, occupation, etc. are represented with frequencies that are proportional to those in the population" (Faulbaum, 2019, p. 464). However, we did not intend to draw conclusions about the population; our question is of an experimental nature and aims to provide insights into the behaviour of the group of e-scooter users. Therefore, compromises can be made with regard to representativeness (Faulbaum, 2019). Despite this limitation, the survey was able to produce findings similar to those obtained in comparable studies and generates important new information on the e-scooter community in Germany.

In addition to the survey, we conducted a semi-structured written interview with the e-scooter provider VOI Technology and a semi-structured telephone interview with the German e-scooter sharing provider Tier Mobility. We also contacted other providers like Lime, Jump, Bird[1] and Circ and suggested interviews, but did not receive a response.

3.2 *Life cycle assessment of e-scooters*

In order to be able to make a statement on the environmental footprint of the e-scooters, we prepared a detailed LCA based on the theoretical foundation of Hauschild et al. (2017). We also followed the guidelines of EN ISO 14040:2006. We used ecoinvent 3.5 (ecoinvent Association, 2020) as the database to calculate the LCA.

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[1] A Bird representative answered a few questions

The four different phases in a LCA are the definition of objectives and scope, stock analysis, impact assessment and interpretation (Hauschild et al., 2017). For the impact assessment method, we followed the IPCC 2013 standard. The functional unit for the calculation is the CO_2-eq. emissions per passenger-kilometre travelled (g CO_2-eq./km). Figure 2 shows the system boundary diagram used for our LCA. We followed the system boundary diagram used by Hollingsworth et al., (2019).

E-scooter specifications
The considered e-scooter is based upon the ES200D/ES200D-C model distributed by Zhejiang Okai Vehicle Co, Ltd. "Sharing e-Scooter on Alibaba, Zhejiang Okai Vehicle Co., Ltd.". This model has a battery with a capacity of 460.8 Wh, weighs 4.4 kg and consists of 88 units of 18650 NMC 111 batteries, assumed to have the same battery cells as previously researched models (Hollingsworth et al., 2019).

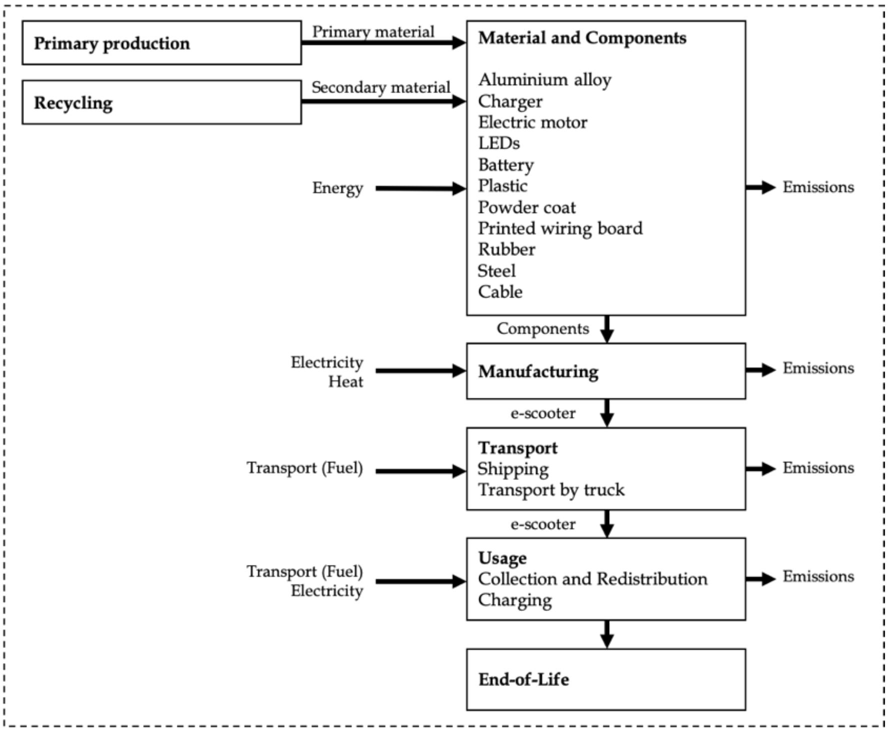

Figure 2. *System boundary diagram (according to Hollingsworth et al. (2020))*

Material and components
Data on the bill of material are taken from the study by Hollingsworth et al. (2019) or the ecoinvent database and other studies published on the GWP of batteries (Dahllöf et al., 2019 ;Romare and Dahllöf, 2017; Emilsson et al., 2019). The majority of the material and component data in the study of Hollingsworth et al. (2019) refers to the Xiaomi M365 model, which is a smaller and lighter model than the e-scooters (ES200D) analysed in our study. We assume that the current models are heavier due to the more robust frame construction. For this reason, we scaled up the weight of the aluminium from 6 kg to 12.6 kg based on the data sheet from Tier (TIER Mobility, 2019a). The battery and frame account for 74% of the total mass of the e-scooter, as the biggest change in the new e-scooter design is its more robust design.

Manufacturing
The production of an electric bicycle in China is used as a proxy, following the recommendations by Hollingsworth et al. (2019) and Moreau et al. (2020). Values for energy expenditure were also taken from the corresponding data sheet. For battery production, we used data from the studies mentioned in "Material and components".

Transport

It was assumed that the e-scooters would be shipped from Shenzhen to Germany (60 g CO_2-eq/tkm; Forschungsinformations-System (2019)) and then transported from the port of Hamburg to Karlsruhe by truck (160 g CO_2-eq/tkm; Forschungsinformations-System (2019)).

Usage

In our calculation, use includes production of the electricity required to charge the e-scooters and the "collection and redistribution" of the e-scooters. We calculated five scenarios for the latter point of the sensitivity analysis, while scenario 2 can be considered as a base case. Data for scenario 2 are taken from the semi-structured interviews and are similar other studies (Chester, 2019; Hollingsworth et al., 2019; Moreau et al., 2020).

1. Efficient juicer scenario (1.5 km per e-scooter, collected with an average fossil fuelled car)
2. Standard juicer scenario (2 km per e-scooter, collected with an average fossil fuelled car)
3. Inefficient juicer scenario (5 km per e-scooter, collected with an average fossil fuelled car)
4. E-scooters are collected by the service provider with a fossil fuelled transporter (50 km to collect 35 e-scooters)
5. E-scooter batteries are swapped using an e-cargo-bike (20 km to change 15 batteries, e-scooters will not be redistributed)

In scenarios 1 and 3, we varied the distance per e-scooter covered by the car for "collection and redistribution" compared to scenario 2. In scenarios 4 and 5, a fixed service provider takes care of the collection, loading and redistribution. In scenario 4, the transport provider collects the e-scooters with transporters, an option mentioned in an article by Raddatz (2019). In scenario 5, the e-scooters are equipped with exchangeable batteries; the batteries are distributed using e-cargo-bikes. This scenario was described as a future option by e-scooter sharing providers in our semi-structured interviews.

In order to yield comparable results to the LCA of Hollingsworth et al. (2019), we assumed that the vehicles performing the "collection and redistribution" exist, within our system they are only used to collect the e-scooters, outside the system they are also used for other purposes. We therefore only consider the tailpipe emissions of these vehicles. We base the CO_2-eq. emissions of a normal car (120.4 g CO_2/km) or transporter (158.1 g CO_2/km) on data from the European Environment Agency (2019).

We modelled the number of kilometres travelled with the e-scooters over different scenarios of the e-scooters' lifetime, with lifetime ranging from 3 months to 15 months. In the standard (juicer) scenario, the e-scooter service life is given as 6 months with an average of 4.9 rides per day (Tack et al., 2019) and 2.4 kilometres per ride, which corresponds to approximately 2117 km for a typical lifetime mileage. In our LCA, with increasing lifetime, the lifetime mileage increases linearly. This value is taken from our survey as the average distance travelled by e-scooter in Germany.

End-of-life

For the disposal of the e-scooter, substitute values from ecoinvent were taken from the e-bike market. The system model used here is the ecoinvent, allocation cut-off by classification. Values for battery recycling are based on the study by Romare and Dahllöf (2017) and the updated version Dahllöf et al. (2019). These authors assume that existing recycling is focused on incineration with pyrometallurgy and that all production emissions can be allocated to the vehicle for the foreseeable future as there is currently no second life market for batteries.

Sensitivity Analysis
The sensitivity analysis explores the impacts of differences in the input parameters for the life cycle stages. These sensitivities include changes in battery production and cell chemistry, battery recycling, the juicer scenario (to scenario 5), charging the e-scooter using green electricity, and increasing the lifetime to 15 months.

4. Results

This section presents and interprets the results of the survey, the LCA and the interviews. Individual results are presented to start with and then evaluated and discussed in context.

4.1 Results on user behaviour
The evaluation of the survey provides answers to the first sub-question from chapter 3 "*How are e-scooters accepted by the population in Germany and how are they typically used?*"

Half of the survey participants have already used a vehicle sharing scheme, whether bicycle/ car/ scooter/ e-bike/ e-scooter or other. However, 73% of respondents stated they had never used an e-scooter for a broad range of individual reasons. The main reasons were that such offers did not exist in their place of residence or e-scooters were not needed. For some users, the environmental impact of e-scooters was a very important factor in the decision against usage. On average, respondents stated that their average distance to work was 19 km.

We asked those participants who had already used an e-scooter about themselves. About one third of the e-scooter sharing scheme users live in large cities, where rental e-scooters are available. Most of the participants stated that they used shared e-scooters, only 8% said they had their own personal e-scooter.

The e-scooters were mainly used out of curiosity. A lack of bicycle paths did not have a strong influence on their use. If e-scooters were used in conjunction with public transport, they served as a supplement. E-scooters were mainly used for leisure (Figure 3).

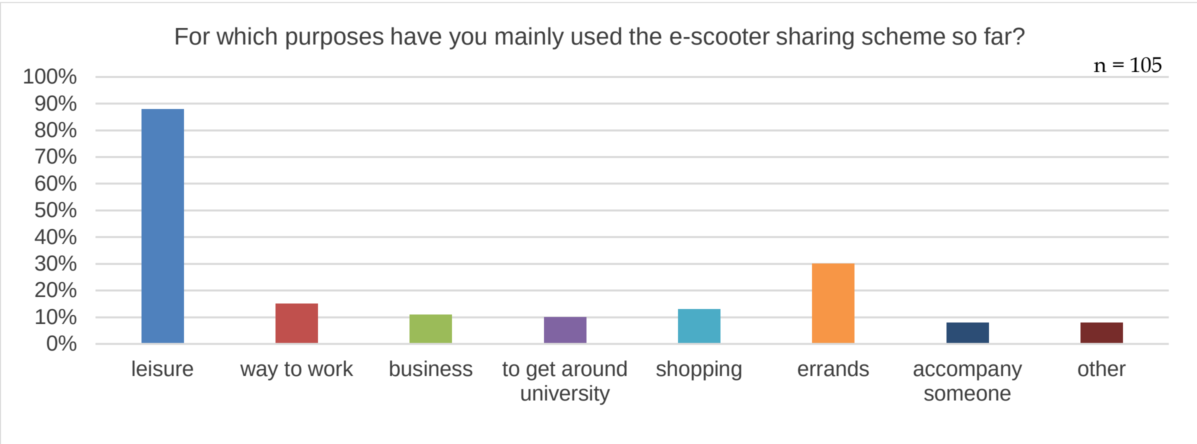

Figure 3. *Routes for which e-scooters are used*

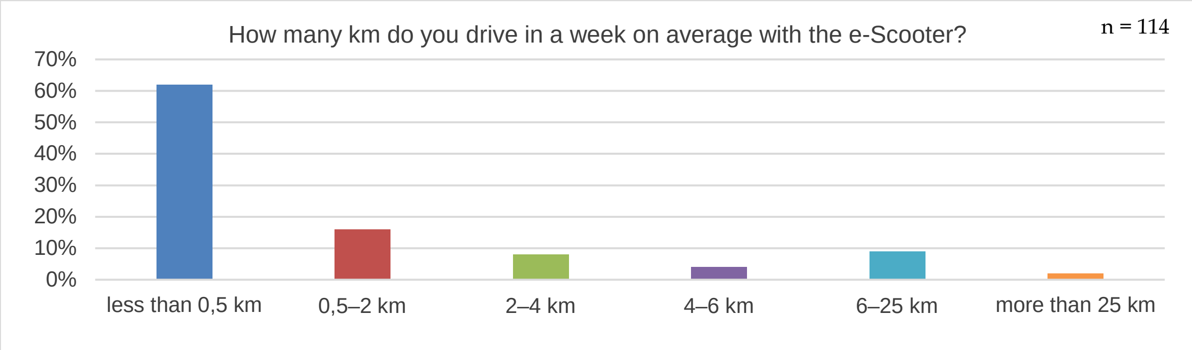

Figure 4. *Average weekly distance driven by e-scooters*

The distribution of the average distances driven is important for the ecological evaluation. 94% of the users used an e-scooter one to three times per month. Therefore, the average weekly distance can be assumed to be equal to the distance of one trip, an assumption that we will take as an input parameter in our LCA. Figure 4 shows that 62% of the distances covered by e-scooters were less than half a kilometre, and 91% of all distances covered were shorter than 10 km. On average, the users drove about 2.4 km with an e-scooter. We use this distance later to calculate the total lifetime mileage. The value for the median is "less than 0.5 km".

Furthermore, we asked the survey participants which modes of transport their use of the e-scooter replaced. On an average route, an e-scooter mainly replaced walking, to a lesser extent public transport and, in equal proportions, cars and bicycles (Figure 5).

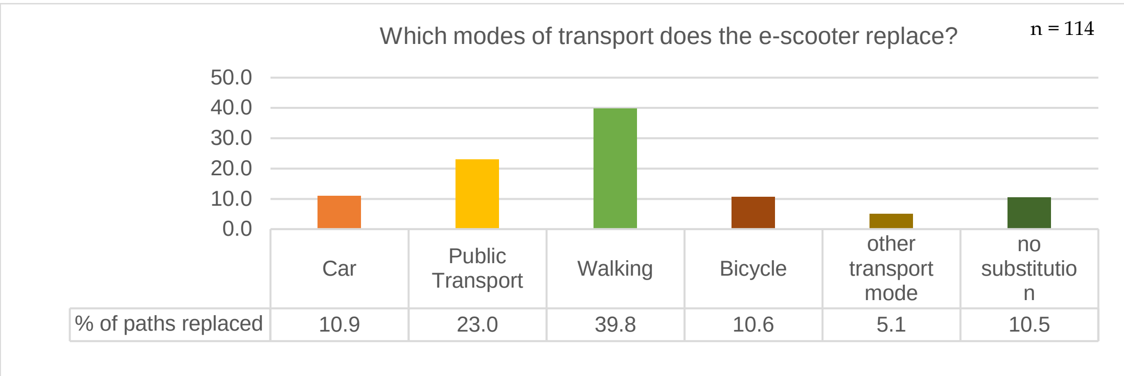

Figure 5. *Modes of transport replaced by the e-scooter*

The e-scooter replaced 39.8% of otherwise walked routes. Related to one kilometre, this is a distance of 398 metres. Assuming the example distance of one kilometre is covered proportionally with the above-mentioned means of transport and their average emissions, the approximate emissions are 39 g CO_2-eq./km, as shown in Figure 9. Corresponding GWPs can be found in Appendix 1.

4.2 Results of the life cycle analysis

This chapter answers the second sub-question from chapter 3 "*How environmentally sustainable is the production, transport, end-of-life and use of e-scooters?*" based on the standard case described in chapter 3.2. The standard case assumes a service life of 6 months, 2117 km as the typical lifetime mileage, and juicers drive 2 kilometres for redistribution and collection per scooter with an average car. This calculation results in total emissions of 165 g CO_2-eq./km. Figure 6 illustrates the distribution of the GWP across individual life cycle stages. "Charging" and "Collection and redistribution" summarize the use phase of the e-scooters.

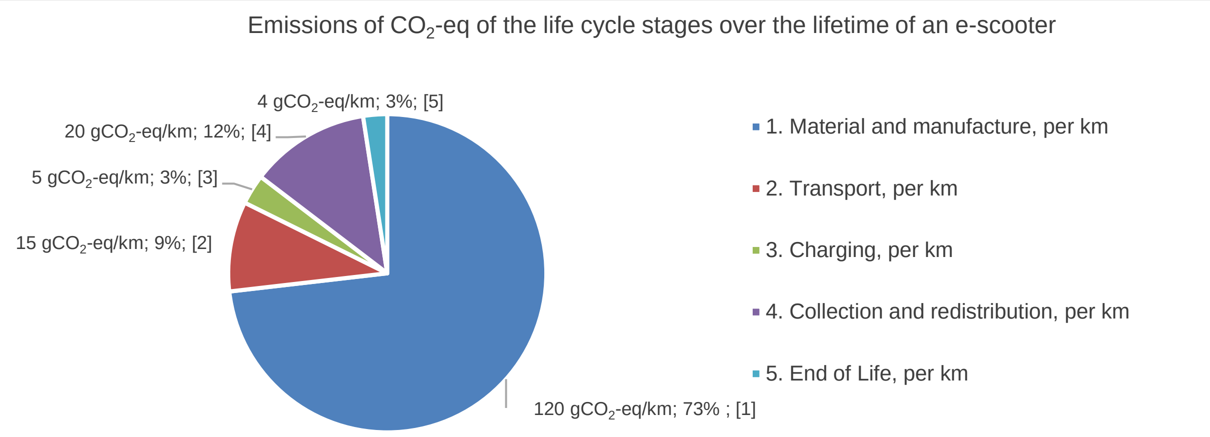

Figure 6. *Calculation of the GWP of an e-scooter in the standard scenario*

In the following, the life cycle stages are described ranked from the highest to lowest emissions of CO_2-eq.:

- "Material and manufacturing" (production) is the main cause of the high GWP of an e-scooter. When breaking production down further, it can be shown that the production of the aluminium frame and the battery cause the most emissions.
- In "Collection and Redistribution", the main emissions are from the cars with internal combustion engines used for collecting the e-scooters. These cause 12% of the total emissions.
- "Transport" of the e-scooters from China to Germany is not discussed in detail in this study, because the parameters and transport routes are fixed and not easily changed.
- In the standard case, "Charging" (electricity used to charge the e-scooters) only accounts for 2% of the total emissions. We assumed that the e-scooter is charged with the average grid power mix in Germany (German electricity mix: 474 g CO_2-eq./kWh; (Icha et al., 2019)).
- "The End-of-Life process" does not cause large emissions. As shown in Figure 5, this process is only responsible for 3% of the e-scooter's total GWP on average.

4.3 Sensitivity Analysis

We analysed the impact of different e-scooter lifespans. Figure 6 shows the GWP dependent on lifetime mileage. The GWP decreases considerably with increasing lifetime mileage. This underlines the importance of long lifetimes for e-scooters. Here, we assumed that usage remains the same, only the lifetime in months increases.

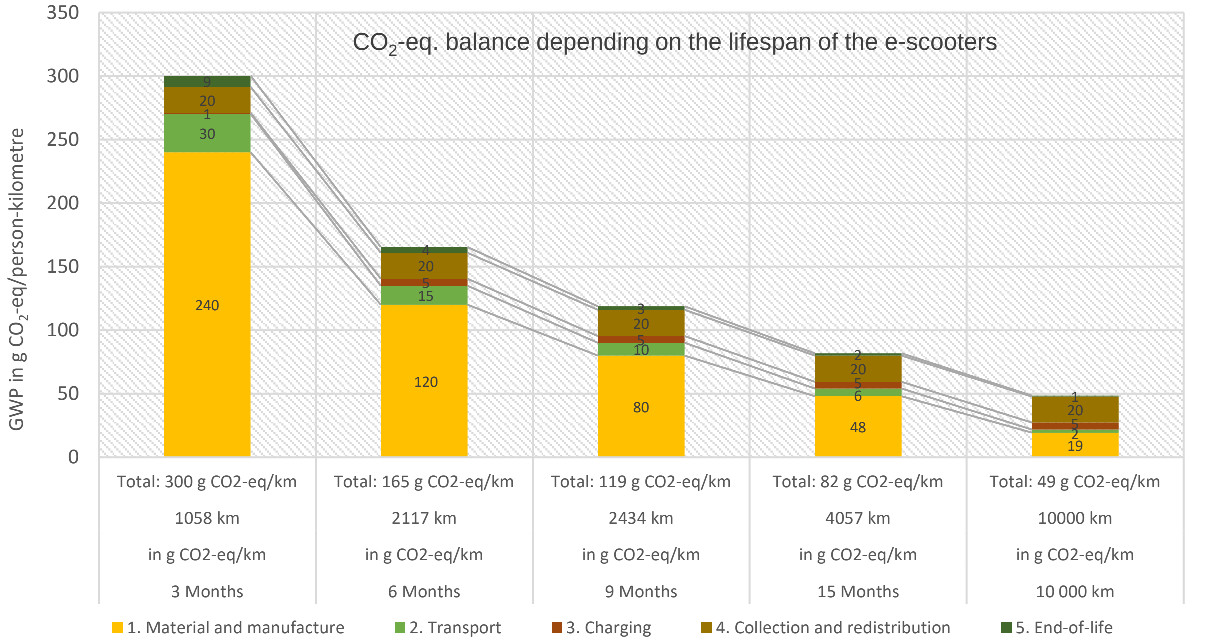

Figure 7. *Different lifetime scenarios*

Figure 7 shows the path to the lowest GWP. The CO_2-eq. emissions range from 300 g CO_2-eq./km in the worst case to 46 g CO_2-eq./km in the best case.
Additionally, as stated in chapter 3.2, other potential improvement options were analysed based on the standard case. Figure 8 lists the individual options and their effect on the GWP.

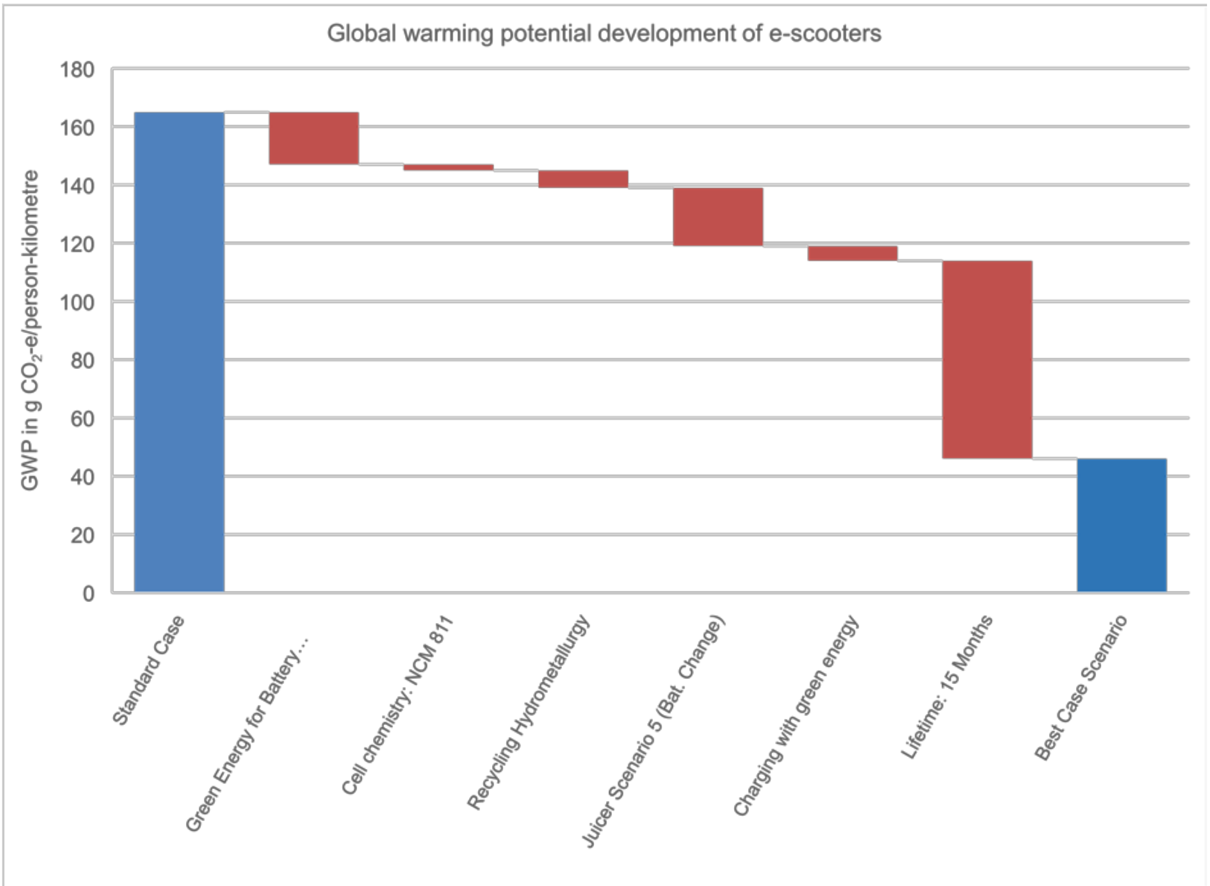

Figure 8. *Effect of improvement options on the GWP*

Recycling has high potential to reduce the GWP. The life cycle assessment can also be improved by charging the scooters with green energy instead of the average grid power mix. If the extreme case with a mileage of 10 000 km is considered, the difference is as much as 10%. Charging and recycling are strongly influenced by the conditions in the country where the e-scooters are used. However, the biggest leverage is provided by the lifespan of e-scooters. If user behaviour remains the same (number of trips and km per route), an increased service life of 15 months can reduce the GWP by 68 g CO_2-eq./km. Thus, in a best-case scenario, the emissions of greenhouse gases could be reduced by a total of 72% per e-scooter.

4.4 Comparison of emissions from standard case, best case and mixed means of transport

Due to the current situation, in which e-scooter providers are striving to act climate-neutrally (TIER Mobility, 2019c; Hjelm, 2019; Wachunas, 2019), we consider the standard case and the "best case" scenario for the comparison with the mixed means of transport (in Figure 9 "E-scooter eco-friendly production and high usage"). From the survey, we derived a modal split with the GWP of 39 g CO_2-eq./km. With reference to sub question 2 of chapter 3, "*How environmentally sustainable is the production and use of e-scooters?*", e-scooters are compared with the mix of existing means of transport.

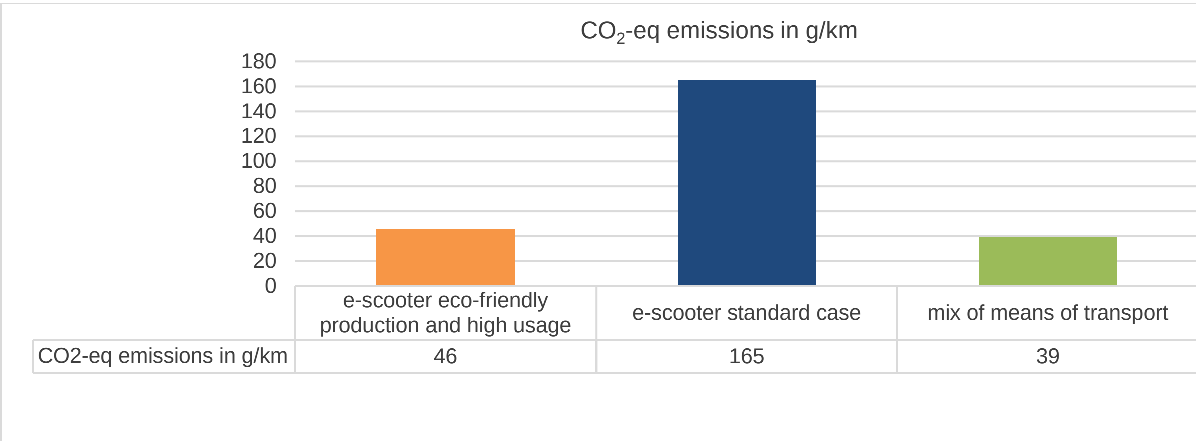

Figure 9. *Global Warming Potential of e-scooters and of the replaced modal split*

Figure 9 shows that the GWP of the modal split substituted by e-scooters in the standard case is significantly lower than the emissions of the e-scooters. Even in the "best case" (e-scooter eco-friendly production and high usage with all the improvements described in the sensitivity analysis), the emissions of the e-scooter are still 8% higher than the emissions of the replaced mix of transport. The "mix of transport means" represents the average emissions per km of the forms of mobility replaced by the e-scooter, as shown in Figure 5. More information regarding the calculation of the modal split can be found in the appendix.

5. Discussion of the results

The result of the life cycle assessment indicates that, given their current production, redistribution and use in the standard case, e-scooters do not represent an eco-friendly sustainable alternative for inner-city mobility. According to our survey, e-scooters rarely replace more climate-damaging means of transport. However, it must be emphasized that this market is still growing and subject to rapid change.

The sensitivity analysis of different improvement options suggests that there is still a considerable potential to lower the GWP in the LCA from making e-scooter production more energy efficient. We found that e-scooter production causes considerable CO_2-eq. and is the main driver of greenhouse gas emissions and the very high GWP of the e-scooters. Since reliable data are scarce, additional assumptions have to be made, which is why different studies have different GWP results. However, despite these uncertainties, almost all studies agree that the environmental sustainability of e-scooters is heavily dependent on the e-scooters' production and actual use (Chester, 2019; Hollingsworth et al., 2019; Holm Møller et al., 2020a; Moreau et al., 2020).

In our questionnaire, most respondents gave "fun rides" or "curiosity" as the reason for using e-scooters. Since these motives do not correspond to a real need for mobility, e-scooters do not benefit the mobility system in terms of carbon neutrality or climate protection. Those ways, where the e-scooter is no substitution for another form of transport are calculated proportionally in Figure 9 as ways with zero emission, reducing the emissions. However, this could also be only a temporary effect based on the novelty of e-scooters, which becomes less important over time.

Considering whether e-scooters can substitute other means of transport such as e.g. passenger cars (question 22: Which modes of transport does the e-scooter replace in your case?), it is possible that inaccuracies occurred in the self-assessment. Still, the result is within the range of other studies (Hollingsworth et al., 2019; Tack et al., 2019). Contrary to Moreau et al. (2020), most e-scooter users in Germany use shared e-scooters, only very few actually own an e-scooter.

Comparing the results of this study with other LCAs, the e-scooter's GWP in our calculation is in the middle of the range, higher than the study by Hollingsworth et al. (2019) and lower than the calculation published by Chester Energy (Chester, 2019). Compared to more recent studies from beginning of 2020, it is in the range of the LCA from Moreau et al. (2020), but 78% higher than the result published by Holm Møller et al. (2020a). These differences can be explained by the differences in the input parameters.

Holm Møller et al. (2020a) consider a change in the charging system (swappable battery) and a lifespan which is four times longer than the one considered in our study. When estimating a longer e-scooter lifetime of 24 months and including the improvements considered in the best-case scenarios, the results of our study are similar to those of Holm Møller et al. (2020) and VOI. This indicates how much the environmental benefits of e-scooters are affected by their design and use and their great potential in a sharing ecosystem which should not be underestimated. The ecological backpack of the e-scooter is still very high in both studies. However, in the analysis by Holm Møller et al. (2020a), it is spread over a longer lifetime, more driven kilometres and the GWP intensive charging scenario is also eliminated.

The user profiles are similar in all LCAs. Similar distances and lifetimes (except for Holm Møller et al. (2020a)) are assumed in the majority of LCAs. Our LCA uses 2.4 km as the average trip length, based on the survey results for the estimated average trip distance per week and the usage of e-scooters per month. Our calculated distance is close to the average trip distance found in the other, above-mentioned studies(Hollingsworth et al., 2019; Tack et al., 2019). Our LCA uses a different type of e-scooter, which is more robust and has a larger battery compared to earlier studies (Chester, 2019; Hollingsworth et al., 2019). Holm Møller et al. (2020a) and Moreau et al. (2020) use a similar model. This additional material increases the share of production in the overall GWP and the material costs but, according to the rental company, leads to a longer service life.

The increase in "Manufacturing" due to a more robust frame and bigger battery also affects the percentage share of "collection and redistribution". In our study, a small percentage share is allocated to the process "collection and redistribution". In absolute terms, however, this value should not be neglected, as those emissions are produced where the e-scooters are used.

In the area of "Usage", no wear and tear of the battery was included in the calculation for reasons of simplification. It was assumed that the capacity of the battery would not decrease. However, this factor should not be neglected in the future, especially as it may become more important with increasing mileage of the e-scooters. In addition, no wear and tear or repairs were included in the phase of operation due to the lack of data. This limitation could be overcome by studying the batteries used in the e-scooters and their durability over time.

A further limitation of our LCA is that we only included the tailpipe emissions of the collection vehicles. Similar to other LCAs on e-scooters, we defined the lifecycle emissions of the collection vehicles as being outside our system's boundary, since the focus of this study is on e-scooters.

It should also be mentioned that the study only considered the current conditions in Germany, with a focus on the federal state of Baden-Württemberg. The focus is on passenger transport in cities. Deliveries and other transport are not considered.

6. Conclusions

The trend towards the diversification of mobility offers is clearly noticeable (Zukunftsinstitut, 2020b). As passenger transport in cities steadily increases, it becomes more and more important for this to be ecologically sustainable. The McKinsey study (McKinsey & Company, 2019), the Carbone 4 report (Schuller and Aboukrat, 2019) and research published by Holm Møller et al. (2020a) highlight the advantages of e-scooters and their potential as a solution for individual passenger transport with a low GWP.

However, our survey found that these potential ecological advantages are not currently realized in the majority of e-scooter use cases. With an average distance of 2.4 km and a median of just 0.5 km ("less than 0.5 km" in the survey), e-scooters operate in a distance range usually covered by bicycles or on foot, i.e. for which no environmentally harmful means of transport are used. So far, the sharing providers cannot replace cars in city centres and relieve inner-city traffic congestion in a climate-neutral way. The study by Holm Møller et al. (2020a) also addresses this point, that e-scooters only replace 12% of car trips. In contrast to the opinion voiced by the German Minister of Transport (see chapter 1), e-scooters do not yet contribute to an eco-friendly and clean mobility, when used as suggested by the survey within this research. Our research finds that they produce more CO_2-eq./km than the means of transport they normally replace.

If e-scooters were more widely used and replaced more carbon-intensive transport means, they might benefit cities. However, our research showed that this mode of transport does not interest those who have not used it before and may not in the future.

It can be assumed that the range of 46 g CO_2-eq./km - 300 g CO_2-eq./km is realistic. This study assumed the value of 165 g CO_2-eq./km in the standard case. We found that the aluminium frame as well as the production of the battery are the decisive factors for the high GWP.

This does not imply that e-scooters cannot be an ecologically sustainable form of mobility. Their GWP could be lowered by implementing the measures presented in our sensitivity analysis. Increasing the lifetime of the e-scooters, changing the charging system (swappable batteries), and using electricity with a low GWP for production and charging have the biggest impact on the GWP of the e-scooters.

If providers are able to lower the GWP of e-scooters to the very low GWP calculated by Holm Møller et al. (2020a), e-scooters could benefit urban mobility. However, to prove this, we recommend carrying out another independent LCA and user analysis once new e-scooters and battery swapping become the standard in cities where free-floating e-scooter fleets are operated by sharing-providers. In terms of their ecological potential, e-scooters are better than cars. If more cars were substituted by e-scooters, this would significantly improve the CO_2-eq. savings. These potentials could be investigated in further research, especially once the use of e-scooters becomes more common.

The results of this study contribute to the evaluation of e-scooters in road traffic. We collected new data on user behaviour in Germany. The substitution potentials show a progress in research as well as the calculation of the life cycle assessment of the e-scooters used in Germany. E-scooter providers are aware of improvement options and are trying to reduce CO_2-eq emissions. The conditions in cities can differ significantly, which make them more or less suitable for e-scooter use. Further research is recommended on how city centres could benefit from developing public transport. The starting point here is the finding that e-scooters replace some routes otherwise covered by public transport. We suggest e-scooter providers and public transport should work on a joint concept of how these means of transport could complement each other. Our study shows that, from an ecological perspective, it should be avoided that people give up walking or cycling to use e-scooters instead. Furthermore, other options such as shared e-bike schemes could also be examined more closely, as such schemes may have advantages in terms of the life cycle assessment. Solutions to before mentioned problems in combination with eco-friendlier e-scooters could have a positive impact on the sustainability of urban mobility. Additionally, since e-scooters have now been around for longer, further research could quantify their lifetime and how many kilometres they are driven more precisely which would increase the accuracy of the LCA.

References

6t-bureau de recherche, 2019. Uses and users of free-floating electric scooters in france. 6t-bureau de recherche, France.

Aachener Stiftung Kathy Beys, 2005-2020, 2015. Lexikon der Nachhaltigkeit | Wirtschaft | Drei Säulen Modell. *Lexikon der Nachhaltigkeit*.
https://www.nachhaltigkeit.info/artikel/1_3_a_drei_saeulen_modell_1531.htm (accessed 1.7.20).

Axsen, J., Sovacool, B.K., 2019. The roles of users in electric, shared and automated mobility transitions. *Transportation Research Part D: Transport and Environment 71*, 1–21. https://doi.org/10.1016/j.trd.2019.02.012

BMU, 2019. Klimaschutz in Zahlen. Emissionsentwicklung 2019. Stand 03/2020. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Berlin.

BMU, 2020. Climate Action in Figures. Facts, Trends and Incentives for German Climate Policy 2019 edition. Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), Berlin.

BMVI, 2019. BMVI - Elektrokleinstfahrzeuge demnächst Thema im Bundesrat https://www.bmvi.de/SharedDocs/DE/Pressemitteilungen/2019/025-scheuer-elektrokleinstfahrzeuge.html (accessed 4.25.20).

Bundesministerium der Justiz und für Verbraucherschutz, 2019. Verordnung über die Teilnahme von Elektrokleinstfahrzeugen am Straßenverkehr.

Chester, M., 2019. It's a Bird…It's a Lime…It's Dockless Scooters! But Can These Electric-Powered Mobility Options Be Considered Sustainable Using Life-Cycle Analysis? | Chester Energy and Policy. *Chester Energy and Policy. Providing insights and analytics in the energy technology and energy policy arenas*. https://chesterenergyandpolicy.com/2019/01/28/its-a-bird-its-a-lime-its-dockless-scooters-but-can-these-electric-powered-mobility-options-be-considered-sustainable-using-life-cycle-analysis/ (accessed 10.16.19).

Dahllöf, L., Romare, M., Wu, A., 2019. Mapping of lithium-ion batteries for vehicles, 2019:548. ed, TemaNord. Nordic Council of Ministers, Copenhagen. https://doi.org/10.6027/TN2019-548

ecoinvent Association, 2020. ecoinvent, Switzerland.
https://v35.ecoquery.ecoinvent.org/Search/Index (accessed 1.4.20).

Emilsson, E., Dahllöf, L., IVL Swedish Environmental Research Institute, 2019. Lithium-Ion Vehicle Battery Production. *Status of 2019 on Energy Use, CO2 Emissions, Use of Metals, Products Environmental Footprint, and Recycling*. IVL Swedish Environmental Research Institute 2019.

European Environment Agency, 2019. Average CO2 emissions from new cars and new vans increased in 2018. European Environment Agency. https://www.eea.europa.eu/highlights/average-co2-emissions-from-new (accessed 11.12.19).

Faulbaum, F., 2019. *Methodische Grundlagen der Umfrageforschung*. Springer Fachmedien Wiesbaden, Wiesbaden. https://doi.org/10.1007/978-3-531-93278-1

Forschungsinformations-System, 2019. Umwelt- und Klimabelastung der Seeschifffahrt im modalen Vergleich. Forschungsinformations-System. https://www.forschungsinformationssystem.de/servlet/is/334495/ (accessed 12.18.19).

Goeverden, K. van, Correia, G., 2018. Potential of peer-to-peer bike sharing for relieving bike parking capacity shortage at train stations: an explorative analysis for the Netherlands. *European Journal of Transport and Infrastructure Research*; Vol 18 No 4 (2018). https://doi.org/10.18757/ejtir.2018.18.4.3259.

Hauschild, M.Z., Rosenbaum, R.K., Olsen, S.I. (Eds.), 2017. *Life cycle assessment: theory and practice.* Springer, Cham, Switzerland.

Hawkins, A.J., 2019. Bird has a new electric scooter: it's durable, comes in three different colors, and you can buy it. The Verge. https://www.theverge.com/2019/5/8/18535698/bird-one-electric-scooter-ride-share-own-price (accessed 9.29.19).

Hjelm, F., 2019. Voi Technology. Sustainability Statement. https://www.voiscooters.com/wp-content/uploads/2019/09/Voi-Technology-Sustainability-Statement-.pdf

Hollingsworth, J., Copeland, B., Johnson, J.X., 2019. Are e-scooters polluters? The environmental impacts of shared dockless electric scooters. *Environmental Research Letters 14*. https://doi.org/10.1088/1748-9326/ab2da8

Holm Møller, T., Simlett, J., Mugnier, E., 2020a. Mikromobilität: Städte in eine nachhaltige Zukunft führen. EYGM Limited, United Kingdom.

Holm Møller, T., Simlett, J., Mugnier, E., 2020b. Micromobility: Moving cities into a sustainable future. EYGM Limited, United Kingdom.

Icha, P., Geschäftsstelle der Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat) am Umweltbundesamt, Kuhs, G., 2019. Entwicklung der spezifischen Kohlendioxid-Emissionen des deutschen Strommix in den Jahren 1990 - 2018, Klima | Energie. Umweltbundesamt, Germany.

McKinsey & Company, 2019. Micromobility's 15,000-mile checkup. McKinsey & Company, USA. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/micromobilitys-15000-mile-checkup

Mi, Z., Guan, D., Liu, Z., Liu, J., Viguié, V., Fromer, N., Wang, Y., 2019. Cities: The core of climate change mitigation. *Journal of Cleaner Production* 207, 582–589. https://doi.org/10.1016/j.jclepro.2018.10.034

Moreau, H., de Jamblinne de Meux, L., Zeller, V., D'Ans, P., Ruwet, C., Achten, W.M.J., 2020. Dockless E-Scooter: A Green Solution for Mobility? Comparative Case Study between Dockless E-Scooters, Displaced Transport, and Personal E-Scooters. *Sustainability* 12, 1803. https://doi.org/10.3390/su12051803

Populus, 2018. The Micro-Mobility Revolution: The introduction and adoption of electric scooters in the United States, *Populus Insights*. Populus, San Francisco, CA United States.

Portland Bureau of Transportation, 2018. *2018 E-Scooter Findings Report*. Portland Bureau of Transportation, Portland, USA.

Raddatz, B., 2019. Nachts, wenn der Transporter in Berlin auf E-Scooter-Suche geht. https://www.rbb24.de/wirtschaft/beitrag/2019/07/e-tretroller-berlin-reportage-einsammeln-spandau-lagerhalle.html (accessed 5.7.20).

Reinz-Zettler, J., 2019. E-Scooter – eine Lösung für unsere Verkehrsprobleme?! Ergebnisse der Nutzerbefragung zum ersten E-Scooter Feldtest in Deutschland. Bayern Innovativ.

Romare, M., Dahllöf, L., 2017. The Life Cycle Energy Consumption and Greenhouse Gas Emissions from Lithium-Ion Batteries. IVL Swedish Environmental Research Institute 2017.

Schuller, A., Aboukrat, M., 2019. White paper: The Role of e-scooters and Light Electric Vehicles in Decarbonizing Cities (Study report). Sep. 2019, Carbone 4.

Shaheen, S., Cohen, A. 2019. Micromobility Policy Toolkit: Docked and Dockless Bike and Scooter Sharing. https://doi.org/10.7922/G2TH8JW7

Shaheen, S., Cohen, A., Chan, N., Bansal, A., 2020. Sharing strategies: carsharing, shared micromobility (bikesharing and scooter sharing), transportation network companies, microtransit, and other innovative mobility modes, in: *Transportation, Land Use, and Environmental Planning*. Elsevier, pp. 237–262. https://doi.org/10.1016/B978-0-12-815167-9.00013-X

Sharing e-Scooter auf Alibaba, Zhejiang Okai Vehicle Co., Ltd., n.d. www.alibaba.com. www.alibaba.com/product-detail/European-Hot-sale-GPS-tracking-scooter_62339995256.html (accessed 11.12.19).

Tack, A., Klein, A., Bock, B., 2019. E-Scooter in Deutschland. Ein datenbasierter Debattenbeitrag. E-Scooter in Deutschland. http://scooters.civity.de/index.html (accessed 9.17.19).

TIER Mobility, 2019a. myTIER Online Shop - eScooter mit Straßenzulassung. myTIER. https://mytier.app/ (accessed 12.25.19).

TIER Mobility, 2019b. TIER Mobility launches operations with swappable batteries as the first e-scooter provider worldwide – TIER. https://www.tier.app/de/tier-mobility-launches-operations-with-swappable-batteries-as-the-first-e-scooter-provider-worldwide/ (accessed 3.20.20).

TIER Mobility, 2019c. TIER Mobility commits to full carbon neutrality – TIER. Press Releases. https://www.tier.app/de/tier-mobility-commits-to-full-carbon-neutrality/ (accessed 1.7.20).

TomTom, 2020a. Karlsruhe traffic report | TomTom Traffic Index. https://www.tomtom.com/en_gb/traffic-index/karlsruhe-traffic/ (accessed 5.17.20).

TomTom, 2020b. Brussels traffic report | TomTom Traffic Index https://www.tomtom.com/en_gb/traffic-index/brussels-traffic/ (accessed 5.17.20).

Umweltbundesamt, 2019. Emissionsdaten. Umweltbundesamt. https://www.umweltbundesamt.de/themen/verkehr-laerm/emissionsdaten (accessed 1.15.20).

United Nations, Department of Economic and Social Affairs, Population Dynamics, 2018. World Urbanization Prospects - Population Division - United Nations. *World Urbanization Prospects: The 2018 Revision*, Online Edition. https://population.un.org/wup/Download/ (accessed 5.1.20).

VOI Technology AB., 2019. Voi Fahrzeuge - Unsere Flotte auf den Straßen. Unsere Fahrzeuge. https://www.voiscooters.com/de/voi-fahrzeuge/ (accessed 10.16.19).

Wachunas, J., 2019. Lime President Reinforces Commitment To 100% Renewable Energy, Carbon Neutrality. 2nd STREET | Lime. https://www.li.me/second-street/lime-reinforces-commitment-100-renewable-energy-carbon-neutrality (accessed 5.1.20).

Weigele, S., Brockmeyer, F., Frohwerk, S., Bürger, K., Schliebs, M., 2014. civity Matters No. 1. civity Management Consultants GmbH & Co. KG, Hamburg, Germany.

Weiss, M., Dekker, P., Moro, A., Scholz, H., Patel, M.K., 2015. On the electrification of road transportation – A review of the environmental, economic, and social performance of electric two-wheelers. *Transportation Research Part D: Transport and Environment 41*, 348–366. https://doi.org/10.1016/j.trd.2015.09.007

Zukunftsinstitut, 2020a. Mobilität Glossar https://www.zukunftsinstitut.de/artikel/mtglossar/mobilitaet-glossar/ (accessed 1.20.20).

Zukunftsinstitut, 2020b. Megatrend Mobilität. https://www.zukunftsinstitut.de/dossier/megatrend-mobilitaet/ (accessed 1.20.20).

Appendices

Appendix A

Table 1. Average global warming potential of replaced means of transport

Mode of transport:	Emissions	Source
Car	220. 5 g CO_2-eq.	Umweltbundesamt (2019)
Public transport	58 g CO_2-eq.	Umweltbundesamt (2019)
Bicycle	5 g CO_2-eq.	Weiss et al. (2015)
Other mode of transport	25 g CO_2-eq. (Assumption for eBike)	Weiss et al. (2015)

Appendix B

Table 2. Life Cycle Inventory

Flows into e-Scooter production	**Flow property**	**Amount**	**Unit**
Aluminium alloy, AlMg3	Mass	12.6	kg
Aluminium, cast alloy2	Mass	0.256	kg
Battery cell, produced	Mass	4.4	kg
Used Li-ion battery	Mass	4.4	kg
Charger, for electric scooter	Mass	0.65	kg
Electric motor, for electric scooter	Mass	2	kg
Electricity, medium voltage, at grid	Energy	68.9	kWh
Heat, district or industrial, natural gas	Energy	13.6	MJ
Heat, district or industrial, other than natural gas	Energy	0.193	MJ
Light emitting diode	Mass	0.016	kg
Polycarbonate	Mass	0.266	kg
Powder coat, aluminium sheet	Area	0.35	m2
Printed wiring board, mixed mounted, unspec., solder mix, at plant	Mass	0.059	kg
Steel, low-alloyed	Mass	1.349	kg
Synthetic rubber	Mass	2	kg
Tap water	Mass	0.744	kg
Transistor, wired, small size, through-hole mounting	Mass	0.062	kg
Welding, arc, aluminium	Length	0.75	m
End of Life Flow			
Electric scooter - produced	Number of Items	Items	1
Municipal solid waste	Mass	4.5	kg
Wastewater, average	Volume	0.0007	m3
Water	Mass	0.0001	kg
Used Li-ion battery	Mass	0.8487	kg