The Net Sustainability Impact of Shared Micromobility in Six Global Cities

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Declaration of interest

☐ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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CRediT author statement

Konstantin Krauss: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Project administration, Funding acquisition. **Claus Doll:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Funding acquisition, Supervision. **Calvin Thigpen:** Conceptualization, Methodology, Validation, Data Curation, Writing - Review & Editing, Supervision.

Abstract

Shared micromobility, i.e. shared e-scooters and e-bikes, has become a widely used service, particularly for urban travelers. While previous work has primarily focused on who uses these for which purposes, the discussion about the consequences of usage has just begun, such as the effect for transportation sector emissions. Previous studies have captured snapshots of shared micromobility's net sustainability impact from 2018 through 2021, with a trajectory of improvement that nonetheless fell short of reducing carbon emissions. To provide a 2022 update, we collect survey data from shared micromobility riders in six cities across the globe (Berlin, Dusseldorf, Paris, Stockholm, Melbourne and Seattle; n=4,167). To calculate the emission impact, we adapt existing life cycle assessment data to the characteristics of the cities surveyed and apply information of a shared micromobility provider. The largest shift effects are from walking, PT, ridehailing, and private vehicles to shared micromobility. In all six cities studied, shared micromobility shows emission reductions compared to the modes replaced. This effect is more positive for shared e-scooters than shared e-bikes, due to differences in their relative embedded carbon and life spans. Shared micromobility providers have opportunities to further decarbonize by continuing to move to all-electric operations, decarbonizing material extraction, increasing the vehicles' lifespans, and leveraging partnerships with PT agencies and shared mobility services like ridehailing to increase mode shift from motor vehicles. Our results also point to the importance of cities implementing solutions like protected bike lanes or travel cost and time increases for individual motorized transport.

Keywords: shared micromobility, LCA, emission

Highlights

- Analyzing emission effects of shared e-scooters and e-bikes in six cities worldwide
- Local adaptation of LCA numbers for all transportation modes
- Emission reduction potential mostly due to replacing ridehailing and car trips
- Shared e-scooters reduce carbon emissions to a greater extent than shared e-bikes
- Pricing and regulating car travel support positive net impacts most

1 Introduction

As policymakers examine opportunities to decarbonize the transportation sector to meet climate goals, a key challenge is evaluating the merits and impacts of proposed solutions. A potential solution introduced in the last years was dockless, shared micromobility: small vehicles such as e-bikes, e-scooters, and other light-weight electric vehicles used for short distance trips. This represented a key operational departure from previous generations of bikeshare: vehicles are rented by smartphone and can be more flexibly parked in a variety of locations, in contrast to previous generations being constrained to parking at a docking station. Vehicles are equipped with electric motors to partially (e-bikes) or entirely (e-scooters) propel the rider (Fishman, 2016). Given the flexibility, convenience, and ease of use of these vehicles, their popularity grew quickly, with ridership exceeding that of traditional docked bikeshare systems (NACTO, 2019). From the beginning, the shared micromobility industry has emphasized the benefits of shared e-scooters and e-bikes as a first- and last-mile complement to public transport (PT) (Fishman, 2016; EEA, 2020; Christoforou et al., 2021) and as an environmentally sustainable transportation service. This latter claim has seen substantial scrutiny - researchers have asked: does the introduction of shared micromobility reduce the emissions of a city's transportation system?

An important determinant of the environmental impact of shared micromobility is the distribution of modes that it replaces, i.e. mode shift. Research suggests that the largest mode shift is from walking (Christoforou et al., 2021) followed by PT (Laa and Leth, 2020), but competition with taxi or ridehailing has been found as well (Guo and Zhang, 2021). Shared e-scooters are also found to replace car trips, and therefore offer a new strategy to reduce car dependence (Wang et al., 2022). To what extent shared micromobility complements PT is still subject of debate, with evidence found for complementing (Krier et al., 2021; Merlin et al., 2021; Radzimski and Dzięcielski, 2021), against complementing (Moran et al., 2020; Luo et al., 2021) and no impact at all (Ziedan et al., 2021). One explanation to these different findings is that the degree of competition or complement is city-dependent (Wang et al., 2022). Additionally, the infrastructure, i.e. cycling infrastructure or distance to the next bus station, plays a crucial role to increase the shared systems' usage (Maas et al., 2020). Using trip-based data, previous work has focused on describing usage patterns within cities (Bai and Jiao, 2020; Caspi et al., 2020; Almannaa et al., 2021) and, to a lesser extent, between cities (Li et al., 2022).Analysis of the differences in usage between shared e-bikes and e-scooters suggests that the former are more frequently used for commuting than the latter (McKenzie, 2019).

Assessing the sustainability impacts of shared micromobility requires accounting for emissions and other impacts associated with the full life cycle. This is typically conducted using a Life Cycle Assessment (LCA), a standardized, systematic methodology applied to different products and services. As applied to transportation modes, LCA examines vehicles by analyzing each distinct part, e.g. body, electronics, batteries, fuel used, service operations and infrastructure usage. For these components, LCA distinguishes life cycle phases, such as production, manufacturing, shipment, use and disposal, as well as impact categories. Out of the many sustainability impact categories commonly addressed by LCA including acidification, eutrophication or noise, this study solely concentrates on the global warming potential measured in carbon dioxide equivalents (CO_2e).

Recently, studies have sought to combine the effects of mode shift with the lifecycle emissions of all relevant modes to estimate a single "net impact" outcome, and in combination they provide a picture of the trajectory of shared micromobility's sustainability impacts. A study in North Carolina, US found the mode shift of shared e-scooters resulting in additional emissions after considering lifecycle emissions (Hollingsworth et al., 2019). This pattern was found in subsequent work as well, ranking electric micromobility modes between active modes and cars powered by internal combustion engines (Bortoli, 2021). Due to shifts mainly from lower emitting modes, related work conducted in Paris, France found shared e-scooters to generate an additional 13,000 tons of CO_2ein one year and would have to emit less than 56 g CO_2e per passenger kilometer (pkm) in order to be climate-positive (Bortoli and Christoforou, 2020). A study in Zurich, Switzerland identified a substantial difference in the environmental impacts between private and shared micromobility: private micromobility modes were found to reduce net emissions whereas their shared versions resulted in negative environmental implications (Reck et al., 2022). In this study, personal e-bikes were found to perform best with a reduction of net emissions by 54 g CO_2e per pkm. Personal e-scooters were estimated to achieve a reduction of 16 g CO_2e/pkm while on the other hand, shared e-bikes generated additional 25 g CO_2e/pkm and shared e-scooters 51 g CO_2e/pkm. Recently, work focusing on Germany found shared e-scooters currently generate net carbon emissions but state that there is a likely path towards a positive impact (Weschke et al., 2022).

The comparability of LCA results is limited by scope, appraisal methods, and technical progress in vehicle production, recycling, and energy use. Despite these methodological differences, we observe a rapid improvement in life cycle emissions in the relatively young micromobility industry in several of these aspects (see below and ITF-CPB, 2020). Studies on the topic of shared micromobility's environmental impact have had two key challenges to address: keeping up with the current hardware and operations in a rapidly-evolving and maturing industry, and balancing detailled, local research against generalizable, global results. The lifecycle emissions of shared scooters have decreased by 70% over two years, and by even more in comparison to the hardware models initially deployed in cities (Lackner et al., 2021). In large part, these drastic improvements are due to improved lifespans from a reported 30 days in early 2019 (Griswold, 2019) to two years or longer in late 2020 (ITF-CPB, 2020). Simultaneously, shared micromobility providers have improved their operational efficiency and introduced measures to reduce the carbon intensity of their operations. The other difficulty is in striking a balance between reflecting the nuances of the local context with the general patterns at a regional or global scale. On the one hand, some studies have focused on individual cities (Hollingsworth et al., 2019; Bortoli and Christoforou, 2020; Reck et al., 2022), which yields results that are reflective of the characteristics and relevant regulations of that city, and on the other hand, other research has provided global or regional assessments (ITF-CPB, 2020; Lackner et al., 2021), which are useful for describing broad trends but miss the key differences between local settings.

Given the rapid evolution of the industry and the importance of developing precise yet generalizable estimates of shared micromobility's environmental impacts, this study aims to present a snapshot of case studies in multiple cities around the globe, spanning both shared e-bikes and e-scooters. It is a snapshot that represents the current knowledge about the industry's emission effects. It is a case study because we use LCA numbers from the provider, Lime, which is based on the best available data and methods, such as current parts reuse schedules and vehicle decay rates for shared Generation 4 e-scooter and e-bike services in Europe (Anthesis, 2022b). Hence, the work is specific regarding time, space, and the provider we use the information from. In addition, we examine avenues for improvement, particularly the possible impact of policy instruments aimed to induce more sustainable mode shift. To achieve these goals, we use a survey of shared micromobility users and combine their mode shift with LCA data that we adapt to the cities of interest. In keeping with our approach to yield accurate local insights to facilitate global comparisons, we implement the same survey instrument across multiple cities and use city-specific LCA numbers. We include six cities spanning five countries and three continents. We adapt existing LCA methodology (ITF-CPB, 2020; Brown, 2021) to the surveyed cities by integrating their modal splits, source of energy production and infrastructure specifications.

The remainder of this work is structured as follows: first, we elaborate on the methods used, which includes a survey collecting user data and secondary data regarding LCA numbers. Second, we present the results regarding the local LCA numbers, the consequent net impacts and the policy instrument evaluation. Third, we discuss these results in the context of previous work as well as explore implications for policy and practice and avenues for future research.

2 Survey instrument

To capture mode choice behavior, we sent a survey to Lime riders between May 13th and June 13th 2022 yielding 4,167 responses for analysis. To enable comparisons across different transport systems and city characteristics, Lime e-scooter and e-bike riders were surveyed in Berlin and Dusseldorf (Germany), Melbourne (Australia), Paris (France), Seattle (US), and Stockholm (Sweden, not offering shared e-bikes). The population of interest was all people who took a ride on a Lime e-bike or e-scooter, and the sampling frame was the people who had provided Lime with a valid email address and took a ride through the Lime smartphone app within the study period. A random sample of eligible riders were invited by email to participate in the study. The questionnaire was made available in each country's official language (example in English for Paris in A.1). Respondents were incentivized to take part by providing three free “unlocks” (the initial cost to rent a shared micromobility vehicle) for the first 500 respondents in each city.

The questionnaire is adapted to the micromobility mode of their recent trip and structured in four parts: their last trip, their general mobility behavior, policy instrument scenarios, and socio-demographic information. Items about the last trip cover the intermodal connection to other modes, the main trip purpose, and the mode they would have used if the shared micromobility mode had not been available. This final "mode shift” question is used in conjunction with subsequent LCA analyses. The general mobility behavior section asks riders about their mobility tools and their general usage of modes in everyday life. The policy instrument section includes different scenarios (in terms of shifting to shared micromobility from other modes): better cycling or parking infrastructure as well as higher costs and travel times for other modes. Finally, the socio-demographic section asks for the respondents’ age, gender, their relation to the city of their last trip, and their household size and income. Information about the riders’ most recent “reference” ride is associated with the response for each respondent and includes the distance travelled, the mode used (e-bike or e-scooter), as well as the time and city where the trip was taken. Where possible, we use survey items tested in previous studies and adapted them to our context (Caspi et al., 2020; Laa and Leth, 2020; PBOT, 2020; Almannaa et al., 2021; Christoforou et al., 2021; Reck, 2021; Wang et al., 2022). Additional questions that had not been used in previous studies were developed by the authors and carefully reviewed and tested by pre-testers in all languages. The complete questionnaire was reviewed and pretested by native speakers living in the respective country to adapt the questions to the local specifics.

Table 1 gives an overview about the sample. With 30% and 23% respectively, Berlin and Paris have the highest shares in the sample while Stockholm (10%) and Melbourne (7%) have the smallest. Respondents are predominantly under 40 (68%) with people between 18 and 29 years showing the highest share (37%). Regarding gender, the sample is predominantly male (65%). Further, the sample is slightly skewed toward higher-income people, with 64% earning more than their respective national median income. 82% hold a driver’s license and 55% a PT season ticket. On average, respondents own one car and bike and no e-bike or e-scooter.

Table 1: Sample description

	Total sample (n=4,167)	Berlin (n=1,228)	Dusseldorf (n=585)	Melbourne (n=305)	Paris (n=952)	Seattle (n=690)	Stockholm (n=407)
Socio-demographics							
Share of total sample		29.5 %	14.0 %	7.3 %	22.8 %	16.6 %	9.8 %
Share of e-scooter trips		85.9 % (n = 1,055)	92.3 % (n = 540)	87.9 % (n = 268)	65.1 % (n = 620)	64.2 % (n = 443)	100.0 % (n = 407)
Age							
18-29	37.0 %	29.5 %	37.8 %	42.8 %	47.6 %	35.5 %	32.7 %
30-39	31.2 %	36.6 %	28.2 %	32.1 %	24.8 %	34.8 %	27.5 %
40-49	18.6 %	20.9 %	19.3 %	17.6 %	15.7 %	17.2 %	20.2 %
50-59	10.6 %	10.9 %	12.5 %	6.9 %	9.1 %	9.2 %	15.1 %
> 60	2.6 %	2.2 %	2.3 %	0.7 %	2.8 %	3.2 %	4.5 %
Gender							
Female	29.3 %	29.5 %	26.9 %	27.2 %	32.2 %	30.5 %	24.3 %
Male	64.9 %	63.5 %	68.8 %	65.6 %	63.1 %	61.5 %	73.2 %
Diverse	5.8 %	7.0 %	4.3 %	7.2 %	4.6 %	8.0 %	2.5 %
Annual household income before taxes							
Below national median	35.9 %	46.8 %	46.8 %	43.3 %	40.5 %	28.5 %	20.3 %
Above national median	64.1 %	53.2 %	53.2 %	56.7 %	59.5 %	71.5 %	79.7 %
Mobility tools							
Driver's license	82.0 %	78.4 %	82.4 %	85.9 %	78.5 %	91.2 %	81.6 %
PT season ticket	55.0 %	53.0 %	54.4 %	63.9 %	60.2 %	58.1 %	37.6 %
Number of private cars in household (median)	1	1	1	1	1	1	1
Number of bikes in household (median)	1	2	2	1	1	1	1
Number of e-bikes in household (median)	0	0	0	0	0	0	0
Number of e-scooters in household (median)	0	0	0	0	0	0	0

3 LCA estimation

Average global life cycle emissions for all modes but shared micromobility are based on the review and calculations by the International Transport Forum (ITF) (ITF-CPB, 2020). The ITF report is accompanied by a calculation model detailing the assumptions, formulae, and results for 131 detailed vehicle categories, technical specifications, and performance parameters. Of these, we first select 24 average-case privately-owned and shared vehicle categories and add missing categories (e.g. carshare). Second, the ITF results on greenhouse gas (GHG) emissions per pkm for 2018 were updated to 2022 along the four life cycle phases - vehicle manufacturing, fuel use, operational services, and infrastructure - for each of the six cities investigated. Finally, the LCA results by vehicle classes are summarized by the modes and services included in our survey. This was done using average fleet compositions of electric e-scooters, carshare, taxi/ridehailing, and bus.

3.1 Updating of ITF LCA estimates to the sample cities and to 2022

The generic LCA values by ITF (ITF-CPB, 2020) and the accompanying models for 2018 are largely based on the Greenhouse gases, Regulated Emissions and Energy use in Transportation (GREET) model and the International Energy Agency (IEA) Global Electric Vehicle (EV) Outlook 2019 (iea, 2022). To update the GHG emission estimates per pkm to 2022 and to adjust them to the six cities investigated for all modes but shared micromobility, the following assumptions are taken along the four life cycle components:

For vehicle components, we distinguish the manufacturing of batteries and other vehicle parts. Battery production gets less carbon intense over time as the global GHG intensity of electricity production decreased by 20% in the past decade (iea, 2022). This is due to increased recycling and second use as well as producers using less energy-intensive production forms and materials. The International Council on Clean Transportation (ICCT) (Bieker, 2021) assumes a localization of battery production and a 20% decline in life cycle carbon intensity from 2021 to 2030. This improvement rate is applied to the time span 2018 to 2022.

For fuel components, the share between electric and fossil fuel-powered driving is provided by ITF (ITF-CPB, 2020). We apply this to the cities considered. For electric driving we adjust the average 2018 grid mix carbon intensity of 563 g CO_2e/kWh to regional carbon intensities of 300 gCO_2e/kWh for Europe and 450 g CO_2e/kWh for the US. For Australia, we use the global average carbon intensity as specific values are not available. For fossil fuel driving, we assume a 1.5% improvement in fuel economy per year for the US and Australia, but keep this constant for the comparably fuel efficient European internal combustion engine (ICE) vehicle fleet (Bieker, 2021).

For the infrastructure components, ITF-CPB (2020) applies average infrastructure lifetime GHG emissions per lane/ track to more or less equal traffic volumes of all vehicle classes without taking account of different vehicle sizes and weights. To partly correct for this approach, we assign passenger car equivalents (PCEs) to each vehicle class expressing their capacity need on urban roads: 0.3 for bikes and e-scooters, 0.5 for mopeds, 1.0 for all types of cars and vans, 1.5 for minibuses and 2.0 for urban buses (FGSV, 2015). To account for city differences in the load of the infrastructures we divide the resulting congestion figures by cities' relative congestion level taken from the TomTom Traffic Index 2021 (TomTom, 2022).

For operational services, activities around shared e-scooters, e-bikes, and cars require extra service vehicle travel. For this study, we use the ITF assumptions of 0.14 service vehicle km per revenue vehicle-km with an average GHG intensity of 210 g CO_2e/vkm.

For Lime e-scooters and e-bikes we used the recent LCA values provided by Anthesis (2022b), which is the Lime-specific version of reports providers have published in recent years (Anthesis, 2022a; Business Wire, 2022; Voi, 2022). These use the outputs of the Lime duration analysis for Generation 4 vehicles for Paris, Stockholm and the DACH region[1] with lifespans over 5 years and maintenance and part replacement regimes over that period. For materials, we assume substantial recycling benefits around 80%, which is much higher than for other modes like cars due to Lime's integrated operations. Final LCA values for Lime e-scooters range from 19.7 g CO_2e/pkm for Paris (with 100% electric vehicles for servicing) to 25.5 g CO_2e/pkm for DACH (with 50% fossil fuel vehicles for servicing). As Lime does not have localized LCA estimates for Seattle and Melbourne, we used DACH values for the vehicle, fuel and operations components in these two cities. This is because DACH values assume a mix of electric and combustion vehicles for servicing. Infrastructure emissions are added from the locally adapted ITF values as described above.

3.2 Aggregation of vehicle data to modes and services

For all vehicle and service categories considered by ITF-CPB (2020) , private and shared non-motorized, ICE and battery electric vehicles (BEV) are considered. Hybrid electric, plug-in hybrid and fuel cell electric vehicles are disregarded to reduce the complexity of results. Carshare with ICE and BEV cars is derived from private cars using 25% higher per passenger annual mileage, 20% higher fuel efficiency, plus an additional 10% fuel use for operational services. The summarized set of vehicle and service categories is composed using the adjusted ITF estimates along the following principles to match the modes listed in with the user questionnaire:

- private e-scooters, bikes, e-bikes, ICE mopeds/motorcycles, BEV mopeds/motorcycles, shared bikes and e-bikes: use of the original ITF vehicle categories plus Lime Generation 4 shared e-scooters and e-bikes;
- shared mopeds: simple average of ITF categories ICE and BEV mopeds;
- private car, ICE and BEV: use of the central categories by ITF averaging across several technical options;
- shared e-scooters: mix of first generation (40%) and new generation (60%) categories;
- carshare: weighted average of ICE (77%) and BEV (23%) categories (example percentages shown for Germany);
- taxi/ridehailing: weighted average of categories ridehailing/ridesourcing with car ICE (0.9%) and car BEV (1.3%) and taxi ICE (88%) and taxi BEV (10%) (example percentages shown for Berlin; individual fleet composition according to local fleet mix);
- bus: mix of ITF categories ridesourcing with van and minibus, ICE and BEV (2% each), public bus ICE (83%) and public bus BEV (9%) (numbers for Germany; individual estimates per city);
- subway: use of the original ITF vehicle category.

Lime figures are applied to the assessment of survey results for the Lime vehicles, while the mode that was substituted is assigned the adjusted ITF numbers.

[1] DACH: German-speaking countries Germany (D), Austria (A) and Switzerland (CH).

3.3 Net Impact: fusing survey and LCA data

To combine the survey data and the secondary, adapted LCA estimates, we use the item asking respondents to indicate the mode they replaced by using the shared e-scooter or e-bike. We distinguish five categories of replaced modes: (1) motor vehicles, i.e. personal car (EV or ICE), personal motorcycle (EV or ICE), carshare, and shared moped; (2) taxi or ridehailing; (3) PT, i.e. bus or subway; (4) micromobility, i.e. personal bike, personal e-bike or pedelec, personal e-scooter, shared bike, and shared e-scooter, with the latter two meaning one of another provider; and (5) walking. Further, a sixth category captures respondents who would have used a different mode that was not listed or they would not have made the trip at all if a Lime e-scooter or e-bike was not available (induced trip).

To compute the emission effect of shared micromobility modes, we use the formula presented in Equation 1. The emission effect of the last trip using the shared micromobility mode is the difference between the micromobility mode's per-pkm emissions and the replaced mode, multiplied by the distance travelled.

$$E_{ijk} = (e_i - e_j) * d_k \text{ , with}$$

E is the trip-level emission effect

e is the mode-specific passenger kilometer emissions

d is the distance of reference trip, while **Equation 1**

i is the shared micromobility mode used (e-scooter or e-bike)

j is the mode replaced, and

k is the respondent

4 Results

4.1 LCA estimates for the study cities

Comparing the 2022 LCA results indicates that in many cases the adjusted ITF-CPB (2020) values do not vary by large degrees across the six cities. Figure 1 shows the average by LCA component (colored bars) and the uncertainty of total GHG emissions per pkm driven by methodological issues and city characteristics (black error bars). For methodological uncertainties we apply a general deviation of +/- 25%. We use these numbers for subsequent analysis. Only the completely electrified modes private cars BEV, metro/light rail and to some extent private e-bike vary considerably between cities, reflecting the differences in the carbon intensity of national electricity production. The French and Swedish electricity mixes perform much better in this respect compared to the coal-driven electricity generation in Australia and partly in North America. For BEV cars and rail-based transit the variations in LCA results across cities can thus exceed the average values, i.e. vary more than +/-50%. The numbers per pkm indicate that Lime Generation 4 e-scooters have carbon impacts between a private e-bike and the subway. The most relevant categories of GHG emissions of e-scooters are vehicle manufacturing and operational services. The same holds for shared e-bikes: even without batteries, their "environmental backpack" (i.e. vehicle production-related emissions) dominates their LCA outcome and makes them comparable to subways. Ridehailing with ICE vehicles show the worst GHG emission balance due to cruising and servicing("deadheading").

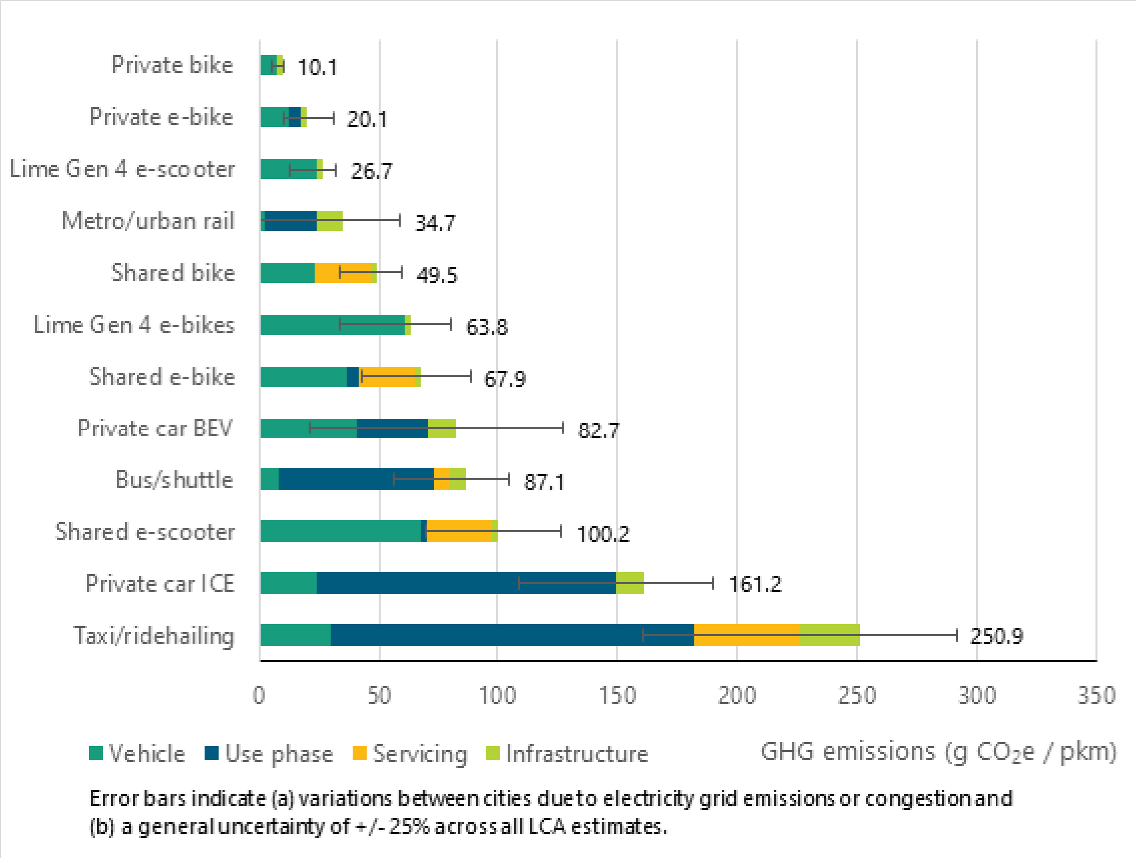

Figure 1: Average LCA results for selected combined modes by life cycle components in g CO2e per pkm applied in this study (source: own calculations).

4.2 Comparing ITF and Lime LCA numbers

Anthesis (2022b) considered the classical impact categories of ozone depletion, global warming, smog, acidification, eutrophication and fossil fuel depletion. LCA phases included vehicle manufacturing, assembly, transport, use phase, operational services, and end of life treatment. For Paris the use phase of Lime Generation 4 e-scooters (0.11 g CO_2e/pkm) accounts for 0.6% of total emissions only, primarily due to 100% renewable energy for charging the shared vehicles and 100% electric service vehicles. With assumed measures for improving the sustainability of shared Generation 4 e-scooters, Lime LCA values range at around 20% of results for second generation e-scooters by ITF-CPB (2020) of 97.8 g CO_2e/pkm reflecting industry practices from 2020 to 2021. Sensitivity analyses with 20% lost vehicles due to vandalism and theft for Paris, which do partly not enter the recycling stream, show per-pkm emissions for e-scooters and e-bikes to increase by 25%.

Overall, these LCA results are optimistic as they assume that the long lifespans indicated by current survival models hold true over the coming years. These values thus reflect a positive case for an ambitious sustainability management regime of a single operator and may not be reflective of an industry average.

4.3 Mode Shift Effects of Shared Micromobility in 2022

As a first step, we investigate potential shift effects of respondents if the currently used e-scooters or e-bikes were not available. Figure 2 shows the results for shared e-scooters and Figure 3 for shared e-bikes. The difference between shared e-scooters and shared e-bikes is substantial. While the largest effect for shared e-scooters is replacing walking trips, this is less clear for shared e-bikes, for which subway and walking dominate.

Shift effects vary by city. 40% (Paris) to 64% (Seattle) of shared e-scooter trips replace walking (Figure 2). The next most commonly-replaced trips are by subway (between 1% in Seattle, which has a small light rail system, and 30% in Paris), taxi and ridehailing (4% in Berlin to 12% in Melbourne), and bus (5% in Dusseldorf and Paris to 15% in Stockholm). Only a small fraction of shared e-scooter trips replace a private BEV trip (up to 0.7%) while a larger proportion replaces private ICE car trips (1% to 7%). Only 1% to 4% of shared e-scooter trips replace personal cycling trips.

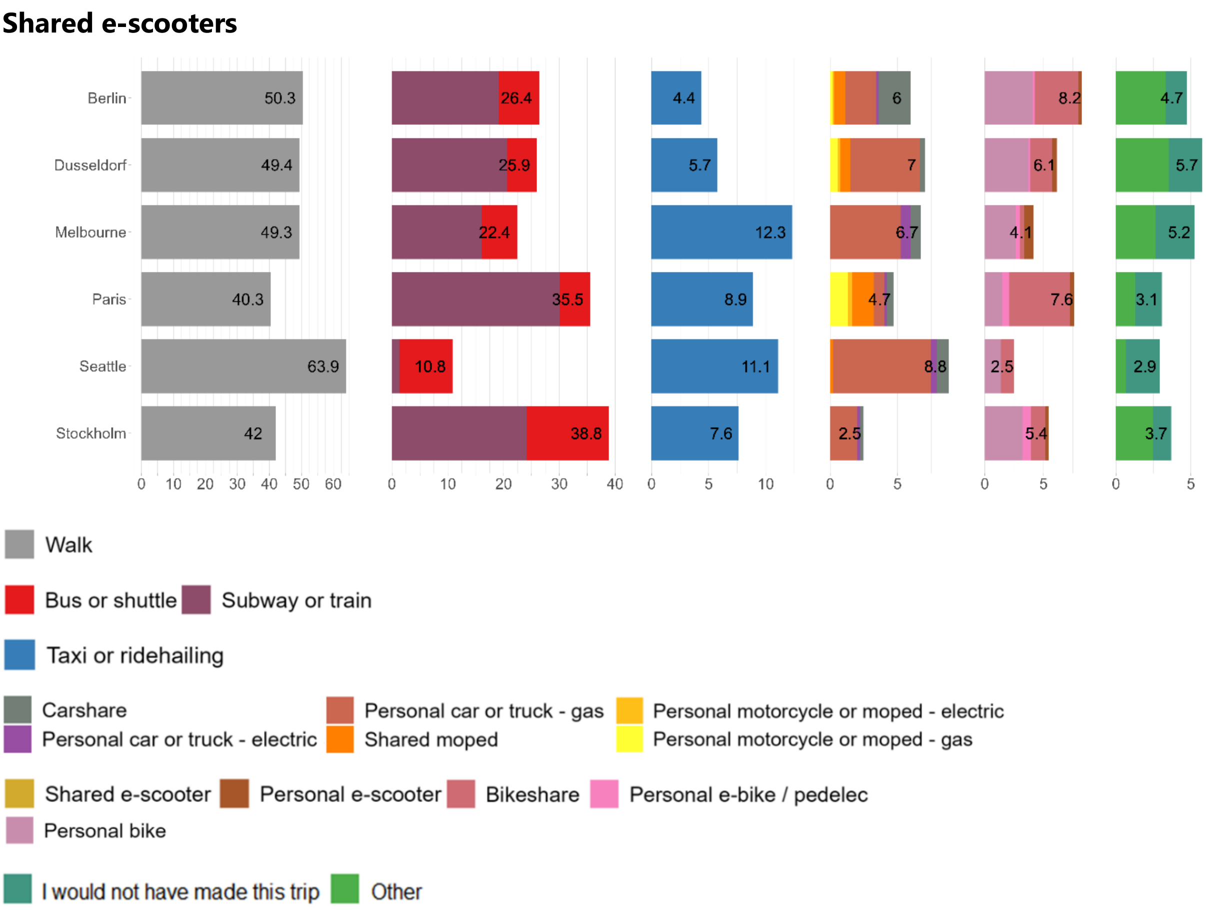

Figure 2: Modes respondents replaced to use shared e-scooters in each city

For shared e-bikes, the picture looks different (Figure 3). Replaced walking trips account for 28% (Berlin) to 49% (Seattle), less than in the case of shared e-scooters. Large effects are also observed for subway trips, being replaced in 2% (Seattle) to 33% (Berlin) of the cases, which is also less than shared e-scooters. 6% (Berlin) to 14% (Melbourne) of shared e-bike trips replace taxi or ridehailing. Buses are replaced in 4% (Dusseldorf) to 11% (Seattle) of trips. While for shared e-scooters, the effect of replacing shared e-bike trips is very low, this effect is larger in the case of shared e-bikes replacing shared e-scooter trips: 2% (Dusseldorf) to 15% (Paris).

Shared e-bikes

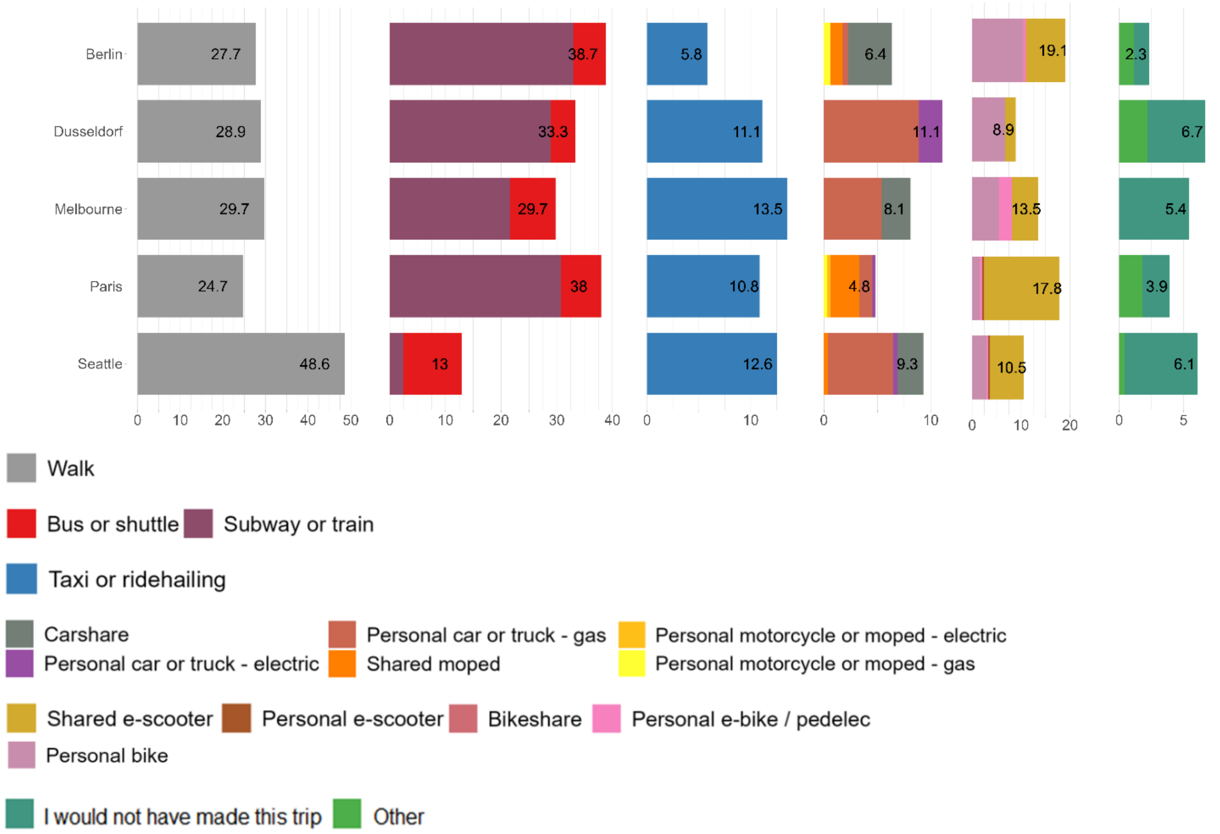

Figure 3: Modes respondents replaced to use shared e-bikes in each city

4.4 Net emission effects of shared micromobility

Figure 4 shows the differences between the LCA emissions per pkm of the shared micromobility mode and the modes people would have used if shared e-scooters or e-bikes would not have been available. In all instances but shared e-bikes in Berlin, shared micromobility modes reduce the carbon emissions of cities' transportation system. The largest effects for shared e-scooters is observed in Melbourne (-42.4g/pkm) and Seattle (-37.7g/pkm). In these two cities the LCA figures for PT and BEV used a considerably higher CO_2 intensity of electricity compared to the European cities. Dusseldorf (-22.1g/pkm), Paris and Stockholm (-20.7g/pkm) have similar levels of emissions reductions for e-scooters, while e-scooters in Berlin show smaller reductions (-14.8g/pkm). In all cities, the net carbon impact of shared e-bikes is less beneficial than shared e-scooters. Large emissions reductions are estimated for Dusseldorf (-20.4g/pkm), Paris (-15.4g/pkm), Seattle (-15.2g/pkm), and Melbourne (-13.7g/pkm), while emission increases are estimated for Berlin (+13.0g/pkm). As can be seen from Figure 3, Berlin has smaller shares of shared e-bike trips replacing individual motorized modes, which is the main explanatory factor for the addition of emissions from shared micromobility operation in this city. The error bars show that the net impact does change when the uncertainties in the LCA numbers are integrated, even leading to possible negative effects for shared e-bikes in Melbourne and Seattle and positive effects for shared e-bikes in Berlin.

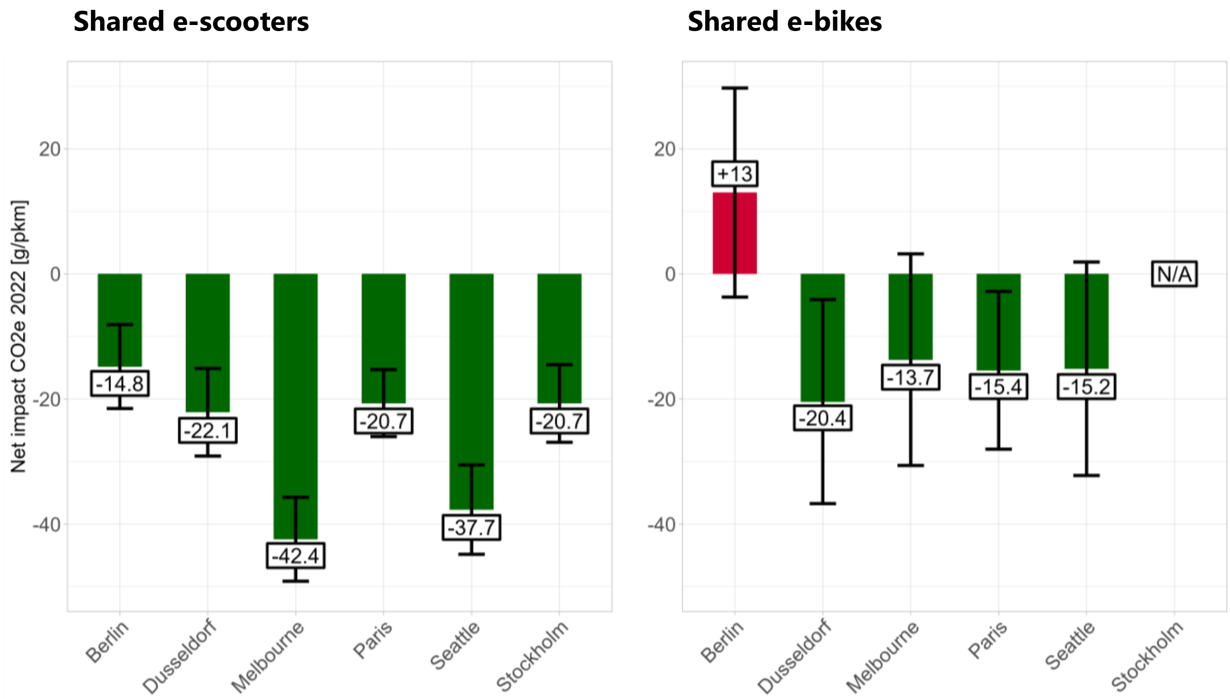

Figure 4: Differences in CO2e emissions between replaced and used mode per passenger kilometer and city (error bars show +/- 25% uncertainties of the Lime shared e-scooter and e-bike LCA numbers)

A deeper analysis at the mode level helps to further explain the effects observed at the city level. Figure 5 shows the net impact of shared micromobility usage for each of the modes respondents replaced, averaged across all surveyed cities. We present net impact as the average g CO_2e per trip to convey simultaneously how mode-specific LCA differences and average trip distances combine to generate differences between modes. As can be seen, the largest impacts originate from ridehailing or taxi services (-679.3 and -541.0g CO_2e per trip for shared e-bikes and e-scooters respectively), personal combustion cars (-334.6 and -272.9g) and carshare services (-213.0 and -203.6g). In ten (e-scooters) or eight (e-bikes) out of the 15 replaced modes, the shared micromobility services reduce emissions in the cities surveyed. On the other hand, we also observe some modes where shared micromobility increases emissions. These are largest for induced trips (+199.3 and +65.6g) and personal bikes (+180.0 and +40.9g). Further negative effects stem from shifts from personal e-bikes (+126.3 and +18.8 g) and walking (+109.9 and +39.4g).

These results show that the crucial factor for the net impacts of shared micromobility is the ratio of trips replacing ridehailing, personal ICE car, and carshare trips in comparison to induced, active mode, and PT trips. For example, although Seattle shows the highest share of replaced walking trips, it also has the highest share of replaced ridehailing trips. The substantial emissions reductions due to ridehailing replacement is sufficient to tip the scales despite the large walking replacement. Similar patterns are observed in Melbourne and Dusseldorf. Berlin, however, shows relatively larger shares of personal bikes and subway replaced by shared micromobility modes. Since the share of taxi and ridehailing is not as large in this case, shared e-bikes modes do not reduce emissions while shared e-scooters do.

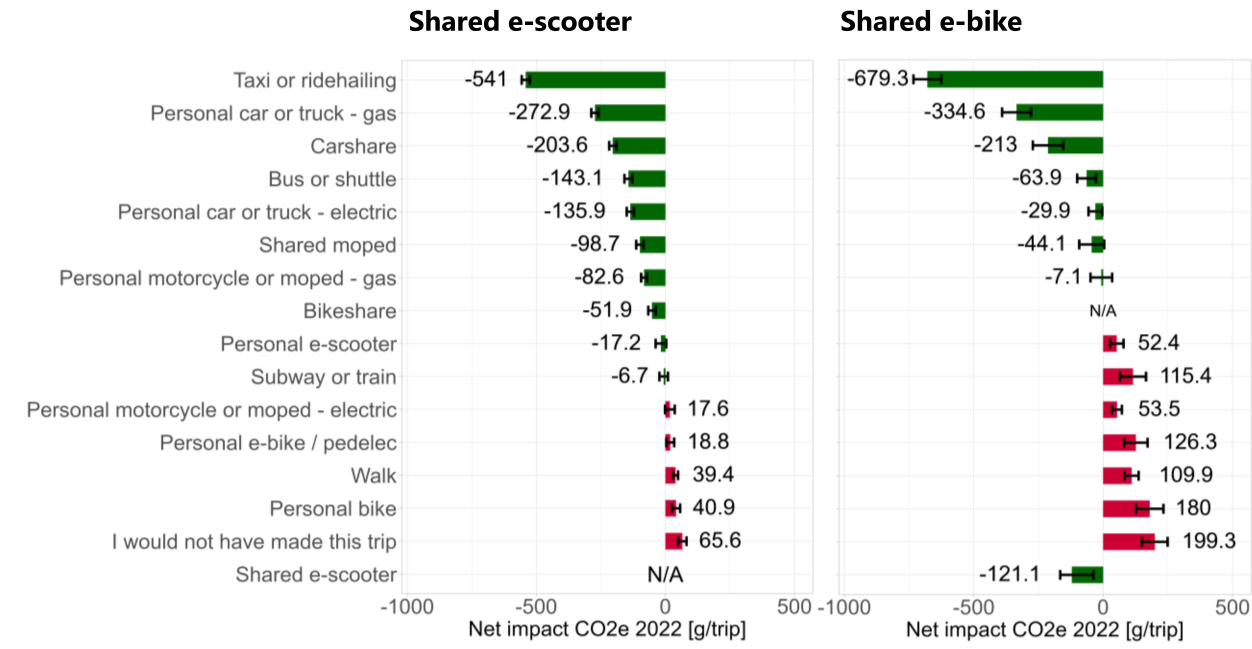

Figure 5: Differences in net emissions by modes replaced

To better understand the overall impacts of shared micromobility across all trips, not just the survey sample, we scale the usage numbers from the sample up to all trips made by Lime users in the study period in each city (Figure 6). To calculate these numbers, we use the share of the kilometers travelled per mode (e-scooter or e-bike) from the survey and transfer this to the total kilometers travelled by Lime services in each city and the survey period. In all cities shared micromobility modes reduce emissions. The biggest impact is observed for Paris (-66.1t) and Seattle (-10.6t), followed by Stockholm and Berlin (-9.5t), Melbourne (-6.2t) and Dusseldorf (-3.9t). In all cities, shared e-scooters reduce overall emissions more than shared e-bikes (the latter increase emissions in Berlin by 1.3t). The relatively large impact for Paris can be traced back to the heavy usage of Lime services in this city, which is in kilometers more than four times as high as in Berlin, the city with the second highest usage in the period surveyed. The error bars show that when integrating the uncertainties, the net impact does vary but the total effect does not change signs.

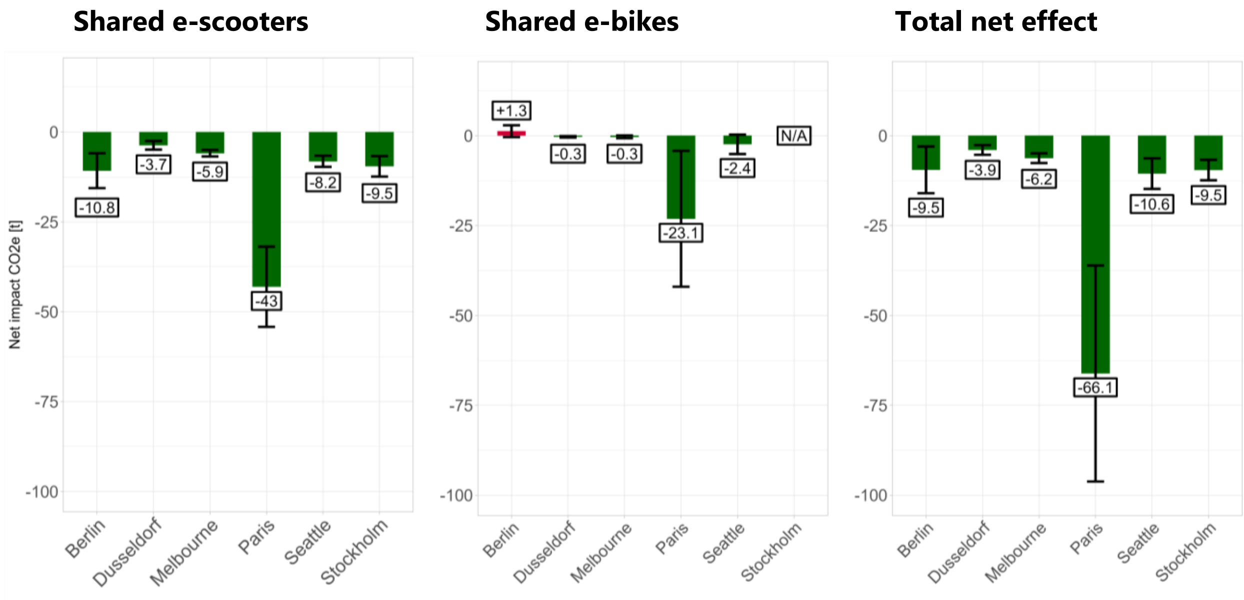

Figure 6: Net emission effect of shared micromobility aggregated on city-level (error bars show +/- 25% uncertainties of the Lime shared e-scooter and e-bike LCA numbers)

4.5 Policy instrument analysis

For the policy analysis, we ask respondents about their likely change of mode use patterns after presenting to them a selected combination of infrastructure, regulatory and pricing measures: (1) better cycling infrastructure, (2) price increases and (3) longer travel times in alternative modes. Participants are asked to estimate increased or decreased use of e-scooters replacement for private cars, taxi/ridehail and PT in response to the policy instrument scenarios (Table 2).

The responses suggest that all three policy interventions would lead to changes in peoples' intention to use shared micromobility. The levels and replaced modes, however, are specific to the policy schemes. Strongest reactions are obtained with increased travel times for alternative modes. Slowing down ridehail services would cause 47% of current micromobility customers to use shared e-scooters and e-bikes at least twice as often, followed by nearly 38% with decreasing car speeds.

The cost of alternative modes is the second-most important role for the use of shared micromobility. In this case the readiness to use shared micromobility more than twice as often is 42% for ridehail and 29% for private cars. 20%-37% of current shared micromobility users would not change their behavior.

Poor cycling infrastructure is one of the most commonly-cited barriers (Handy et al., 2014) to more use of micromobility. If cycling infrastructure were improved, 26%-32% of micromobility users would use micromobility twice as often or more, while around 40% would not change their behavior. Ridehail is the mode most likely to be replaced and PT is replaced least.

Table 2: Policy measures and intended change of usage regarding shared micromobility

Survey item	Replaced mode / subject to intervention	More than twice as often	Somewhat more often	Same as before	Less than before
Travel time: Use of shared e-scooters/e-bikes with more travel time needed for … [4]	Car	38.1%	28.9%	28.0%	5.0%
	Taxi/ridehail	47.4%	27.7%	18.6%	6.4%
	PT	49.3%	31.1%	15.2%	4.4%
Travel costs: Use of shared e-scooters/e-bikes with cost increases for … [3]	Car	29.1%	28.6%	36.6%	5.8%
	Taxi/ridehail	42.0%	29.8%	20.2%	7.8%
	PT	41.6%	28.7%	24.4%	5.3%
Better cycling infrastructure: Use of shared e-scooters/e-bikes to replace… [2]	Car	27.0%	29.4%	43.6%	
	Taxi/ridehail	31.8%	30.1%	38.1%	
	PT	25.6%	30.3%	44.1%	

Notes:

1 Shares not always add to 100% due to rounding.

2 Survey question: Imagine that the quality of cycling infrastructure was improved by building more protected bike lanes. How often would you use shared [e-scooters/bikes] as a replacement for…?

3 Survey question: Imagine that the cost of different transportation options has increased. How would that influence your use of shared [e-scooters/bikes]? -

4 Survey question: Imagine that the travel time of different transportation options has increased. How would that influence your use of shared [e-scooters/bikes]?

5 Implications for policy and practice

5.1 Industry Opportunities

In addition to the importance of city policies to manage micromobility usage, micromobility providers have room to further decarbonize their services and to encourage further mode shift from motor vehicles. As identified in this study and others (Ding et al., 2019; ITF-CPB, 2019; Fernando et al., 2020; Bortoli, 2021; Lackner et al., 2021) the key opportunities for decarbonization are in electrifying operations, reducing the carbon intensity of material extraction and manufacturing e.g. through recycling and by expanding vehicle use phase and usage intensity. For generating greater mode shift from cars, three strategies seem particularly promising: providing balanced availability of shared micromobility where needed most, directly and indirectly encouraging taxi and ridehail travelers to switch to micromobility for short trips, and coordinating shared micromobility operations with public transit to further enhance micromobility's role as a first- and last-mile complement to transit.

Availability of shared micromobility needs to be balanced in a way that minimizes barriers for users, specifically for those using individual motorized vehicles, while also not leading to overabundance resulting in increased mode shift from walking. Implementing mobility hubs where travelers can seamlessly change modes and can be certain to have vehicles available can be one possibility. Among many barriers to riding, a lack of vehicle availability was cited by many survey respondents (32% stated finding a shared micromobility vehicle was moderately or extremely challenging). Many cities impose caps on the number of shared micromobility vehicles that can be deployed, ranging from roughly 7,000 e-scooters in Seattle to 15,000 in Paris (The Seattle Times, 2021; The

Local, AFP, 2022). Yet in comparison, motor vehicle registrations in these cities can dwarf shared micromobility fleets by 70 to over 100 to 1 (Statista, 2022a, 2022b). Sufficient parking and bike lane infrastructure can be one way to support mode shifts from (private) cars. Paris for instance created 2,500 dedicated micromobility parking spaces (ELTIS, 2022).

Reducing taxi and ridehailing usage is key to the net sustainability impact of shared micromobility, so companies should partner with ridehail companies to identify additional opportunities to nudge travelers from ridehail to micromobility when possible. Nearly half of ridehail trips are under three miles (UBER, 2019, p. 165), which is at the upper end of the typical trip distance for shared micromobility. Though this is a large proportion of all ridehail trips, the feasibility of encouraging travelers to instead consider micromobility is constrained by a multitude of factors, such as weather, luggage or other mobility conditions of the passengers. Encouraging mode shift from cars to micromobility thus requires a multifaceted approach, including reliable intermodal travel information, safe and secure infrastructures and alleviating the barrier of availability of shared micromobility. The net impact will also change in the future as taxi and ridehail operators progressively electrify their fleets, which will decrease the emission difference towards shared micromobility.

In a similar vein, partnering with PT agencies to coordinate operations could further enhance the car-replacement potential of shared micromobility. Many transit and micromobility companies already offer integrated smartphone applications with multimodal routing, trip planning and booking, allowing travelers to better identify an available e-scooter or e-bike near their transit stop to use for the first or last mile. But there are greater opportunities for transit and micromobility operators to coordinate, for example to expand micromobility operations in more peripheral, suburban or residential areas around transit stops or mobility hubs to serve as a first- and last-mile solution and by mutually opening back and systems for direct booking by mobility partners (Clausen et al., 2022).

Occupancy rates and vehicle lifetimes matter substantially. Vehicle manufacturing-related carbon emissions account for 50-60% for micromobility modes and subways. Serving more passengers with the same vehicle is crucial for the per-pkm carbon emissions. Keeping vehicles longer in service and increasing occupancy rates in PT as well as replacing ridehailing by its pooled counterpart ridepooling supports efficiency.

5.2 Policy implications

This study shows that in all six cities surveyed, the presence of shared e-scooters and e-bikes by only one specific provider reduces the carbon emissions of the transportation system. We find that the effect of shared micromobility on urban transportation emissions relies heavily on the extent to which these services shift people from individual motorized modes, i.e. ridehail and taxi services and private (combustion) cars. If this share surpasses a threshold, the overall net impact can be positive. Thus, the locally dominant mobility behavior of travelers is critical. Additionally, the local preconditions for mobility (e.g. carbon intensity of electricity generation) are crucial for the effect of shared micromobility. For policy, we draw the following two conclusions:

First, if providers fulfill their sustainability commitments, micromobility cannot be seen as major polluter, particularly compared to the status quo of using private ICE cars. The LCA results, especially for new generation vehicles and operations, show that modern micromobility service can operate well below most motorized forms of urban mobility. Further, their net carbon impact on city-level is found to be negative for shared e-scooters in all six cities and for shared e-bikes in four of five cities. There is also potential for shared micromobility usage instead of cars and taxis/ridehailing if infrastructure is provided that enables safe and easy use of shared micromobility services. New generation shared e-scooters and e-bikes can thus support cities' low carbon strategies if they are integrated in PT strategies and if shifts from walking and non-electrified bikes are minimized. This is particularly interesting as the adaptation of micromobility fleets does not require investments of the cities and can be implemented quickly compared to decades of planning PT offers.

Second, taxi and ridehailing services are the crucial modes for shared micromobility to replace. Their current emission numbers are the highest in transportation systems. However, policy announcements in the EU suggest a rapid electrification of taxi fleets with 80% zero emission vehicles by 2030. Even as shared micromobility continues to reduce vehicles' lifecycle emissions, future net carbon impacts of micromobility will thus be highly sensitive to the carbon reductions achieved by these services. Thus, the effect of shared micromobility should be closely evaluated along developments of other modes.

The assessment of policy instruments in this study found, that the most effective instruments to support micromobility use are those coming along with rather low costs and short implementation times. In descending order of effectiveness these are speed limits for cars, raising costs for motorized travel and finally investing in better cycling infrastructure. If these instruments are applied according to transport modes' carbon footprint shifts from private cars and taxi/ridehail to micromobility without attacking PT, cycling and walking could be encouraged at low costs. This strategy is crucial as our results suggest that longer travel times and higher prices push more people out of transit than out of cars and taxi/ridehail.

6 Discussion and outlook

This study combines contemporary LCA numbers for urban mobility services with mode shift statements from a survey of Lime users. By distinguishing six cities, we provide new insights into the impact of shared micromobility on carbon emissions in urban settings around the world. Most crucial for the overall emission impacts of shared micromobility modes are the local preconditions for energy generation and the mobility behavior of travelers. Shared micromobility need to shift substantially from individual motorized transport while minimizing shifts from PT or active modes.

Although we focus on the net impact of shared micromobility, we acknowledge that urban impacts are more complex than climate change alone. In this study, we exclude acidification due to air pollution, noise, public space use, and potential health benefits. Particularly for public space use, we suspect this would constitute additional benefits for shared micromobility modes compared to the prevailing usage of private cars.. In particular in a future where most urban mobility is electrified with zero carbon electricity, the GHG impacts from vehicle use becomes less relevant for judging the sustainability of mobility services.

An important aspect for transport planners is a trend of travelers expecting more flexibility in their travel options. Driven by on-demand services in many areas of contemporary life, people expect easy access, constant availability, flexibility and reliability from mobility services as well. Shared micromobility can satisfy this demand, though the risk of induced demand needs to be monitored. Therefore, cooperation among shared modes and PT is necessary and integration of these modes into mobility platforms can be a promising way forward. Developing services and business models that can succeed outside dense urban areas is an opportunity for all shared mobility providers.

This work is subject to two crucial aspects, which make the work a snapshot case study for one specific provider and its users in six selected cities with the respective emission effects: first, the results and implications cannot simply be transferred to other cities or contexts. This is due to the focus on the selected cities and the application of provider-specific LCA numbers for shared micromobility services, which make the work a case study for this specific context and do not represent an industry-wide evaluation for the environmental impact of shared micromobility services. Second, we use stated mobility preferences of shared micromobility users of one provider. Hence, we do not draw on revealed information and the sample is limited to Lime users. As we thus have not observed the real shift behavior of people for one specific group only, the results may not be generalizable to other shared micromobility services and users.

This study has limitations, most notably related to the survey period and the omission of Lime trips booked via the Uber app. The survey was conducted in the late spring for most of the cities, which makes shared micromobility usage more attractive. To provide a complete picture, a survey in winter would be beneficial. Further, this study does not include individuals who took a Lime trip through other platforms such as Uber due to methodological limitations of reaching these audiences. Given the volume of Lime trips made through the Uber app, and the likely mode shift from ridehail to shared e-scooters and e-bikes that many of these trips represent, it is probable that this reports' estimates of mode shift from ridehail are conservative, which implies further potential to reduce the respective net carbon impact.

7 Conclusion

This study found that the latest generation of shared e-scooters and e-bikes can reduce carbon emissions in transportation systems in six cities surveyed around the world. By fusing mode shift survey data with lifecycle emissions data for all modes considered, we compute a single net carbon impact figure for each city and each micromobility mode. Shared e-scooters can reduce carbon emissions more than shared e-bikes, and crucial to both modes' emissions reductions potential is the potential to replace the highest-emitting modes like taxi/ridehailing and personal cars. Extrapolating to a month of trips in each city, we estimate that Lime's shared micromobility services reduce carbon emissions during the time of survey. We find that shared micromobility providers and cities have substantial opportunities to further enhance the sustainability benefits of shared micromobility. Industry should further extend vehicle lifespans, continue to decarbonize manufacturing by contributing to a circular economy, and use partnerships to induce favorable mode shift from taxi/ridehailing and personal cars. Providers and city planners should jointly work towards a better connection of micromobility and PT by for instance establishing mobility hubs and reliable intermodal travel planning tools for seamless transfers. On the other hand, the shift effects from PT and walking to shared micromobility should be kept at a minimum. In the long run, urban design concepts like the 15-minute city or Barcelona's superblocks may be effective, and we also encourage cities to continue building comprehensive networks of bicycle infrastructure and to consider implementing congestion pricing schemes to disincentivize car use.

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A.1 Survey instrument

The following questionnaire uses the city of Paris as an example. The questionnaire for the other five cities were adapted to the local context.

Fraunhofer Institute for Systems and Innovation Research ISI ("Fraunhofer ISI") and Lime have jointly developed this survey to better understand the consequences of shared micro-mobility for a future transportation system. The survey will take about 10 minutes to complete.
As a thank you for taking part in the survey, Lime will provide the first 500 respondents with a promo code at the end of the survey for 3 free unlocks in Paris (promo terms apply)!
Participation in the survey is voluntary. You can interrupt participation in the survey at any time and continue or cancel it at a later date. The survey serves exclusively the purpose stated above and in the Privacy Notice. The data is evaluated anonymously, so that no conclusions can be drawn about your person, and all your information will be treated with the strictest confidence. It will be used exclusively for research purposes and statistical evaluations. If you choose to participate, Lime will share the following information with Fraunhofer ISI: (i) your responses to the survey questions; (ii) city where your trip took place and the mode you used; (iii) start time, end time, distance and price of your trip; and (iv) whether you're a LimePrime or Lime Access user. Lime will not share any name, contact details, or payment information with Fraunhofer ISI. In aggregate, Fraunhofer ISI will use survey responses to analyze the emission effects of shared micro-mobility services for scientific work and publications. For more information and how we process your data, see our Privacy Notice. If you have any questions, please do not hesitate to contact us at *[e-mail address]*.

Do you consent to participate in this study?

- ◯ Yes, I consent to participate in this study
- ◯ No, I do not consent to participate in this study

Thanks for your time!

End of Block: Introduction

Start of Block: Recent Trip

Your Recent Trip

In the following questions, we will ask you about your recent Lime trip *ending on {DATE} at {TIME}*.

Why did you take this trip?

- ◯ Commuting to work or school
- ◯ Shopping or errands
- ◯ Leisure activity (e.g. dining, concert, gym)
- ◯ Business/work-related travel (e.g. client meetings, out of town travel)
- ◯ "Joy ride" (e.g. riding for fun, no particular destination)
- ◯ Get home
- ◯ Other

On this trip, did you use Lime immediately *after* using another service, as part of the same journey?

- ◯ Yes, I used Lime *after* public transport
- ◯ Yes, I used Lime *after* another shared service (e.g. carshare, bikeshare, ridehail)
- ◯ No

On this trip, did you use Lime immediately *before* using another service, as part of the same journey?

- ◯ Yes, I used Lime *before* public transport
- ◯ Yes, I used Lime *before* another shared service (e.g. carshare, bikeshare, ridehail)
- ◯ No

Display This Question:
If rode an e-bike on their most recent trip.

On this trip, how long did it take you to get to the shared e-bike you used?

- ◯ Less than 1 minute
- ◯ 1 - 2 minutes
- ◯ 3 - 5 minutes
- ◯ More than 5 minutes

Display This Question:
If rode an e-scooter on their most recent trip.

On this trip, how long did it take you to get to the shared e-scooter you used?

- ◯ Less than 1 minute
- ◯ 1 - 2 minutes
- ◯ 3 - 5 minutes
- ◯ More than 5 minutes

Display This Question:
If rode an e-bike on their most recent trip.

On this trip, why did you choose to ride a Lime e-bike?

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
Affordable - Lime was a low-cost option.	◯	◯	◯	◯	◯
Fast - I wanted or needed to get to my destination quickly.	◯	◯	◯	◯	◯
Sustainable - I wanted to choose a less polluting travel option.	◯	◯	◯	◯	◯
Fun - Riding Lime is enjoyable.	◯	◯	◯	◯	◯
Convenient - It was easy to find and use a Lime to get to my destination.	◯	◯	◯	◯	◯
Flexible - I could choose how to travel while on-the-go.	◯	◯	◯	◯	◯
Reliable - I knew I could depend on a shared e-bikes to get where I needed to go.	◯	◯	◯	◯	◯

Display This Question:
If rode an e-scooter on their most recent trip.

On this trip, why did you choose to ride a Lime e-scooter?

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
Affordable - Lime was a low-cost option.	○	○	○	○	○
Fast - I wanted or needed to get to my destination quickly.	○	○	○	○	○
Sustainable - I wanted to choose a less polluting travel option.	○	○	○	○	○
Fun - Riding Lime is enjoyable.	○	○	○	○	○
Convenient - It was easy to find and use a Lime to get to my destination.	○	○	○	○	○
Flexible - I could choose how to travel while on-the-go.	○	○	○	○	○
Reliable - I knew I could depend on a shared e-scooters to get where I needed to go.	○	○	○	○	○

Display This Question:
If rode an e-bike on their most recent trip.

[Randomized display order of groups of modes]

How would you have made this trip if a shared e-bike had not been available? Choose the most likely option.

- ○ Personal car or truck
- ○ Personal motorcycle or moped
- ○ Taxi or ridehailing (e.g., Uber)
- ○ Carshare (e.g., Virtuo, GetAround)
- ○ Shared moped (e.g. Revel, CityScoot)
- ○ Subway or train
- ○ Bus or shuttle
- ○ Personal bike
- ○ Personal e-bike / pedelec
- ○ Personal e-scooter
- ○ Shared e-scooter (e.g., Lime, Dott, Tier, Voi)
- ○ Walk
- ○ I would not have made this trip
- ○ Other

Display This Question:
If rode an e-scooter on their most recent trip.

[Randomized display order of groups of modes]

How would you have made this trip if a shared e-scooter had not been available? Choose the most likely option.

- ○ Personal car or truck
- ○ Personal motorcycle or moped
- ○ Taxi or ridehailing (e.g., Uber)
- ○ Carshare (e.g., Virtuo, GetAround)
- ○ Shared moped (e.g. Revel, CityScoot)
- ○ Subway or train
- ○ Bus or shuttle
- ○ Personal bike
- ○ Personal e-bike / pedelec
- ○ Personal e-scooter
- ○ Bikeshare
- ○ Walk
- ○ I would not have made this trip
- ○ Other

End of Block: Recent Trip

Start of Block: Car transmission

What type of car would you have used instead?

- ○ electric car
- ○ gasoline/diesel car

End of Block: Car transmission

Start of Block: Moped or motorcycle transmission

What type of moped or motorcycle would you have used instead?

- ○ electric moped/motorcycle
- ○ gasoline moped/motorcycle

End of Block: Moped or motorcycle transmission

Start of Block: Travel Patterns

Travel Patterns

The following questions refer to your general mobility behavior.

Do you have a driver's license for cars?

- ◯ Yes
- ◯ No

Do you have a public transport pass/season ticket? Select all that apply.

- ◯ Yes, for local services
- ◯ Yes, for national services
- ◯ No

How many of the following types of vehicles are available to you in your household?

	0	1	2	3	4	5	6 or more
Personal car or truck	◯	◯	◯	◯	◯	◯	◯
Motorcycle or moped	◯	◯	◯	◯	◯	◯	◯
Bike	◯	◯	◯	◯	◯	◯	◯
E-bike or pedelec	◯	◯	◯	◯	◯	◯	◯
E-scooter	◯	◯	◯	◯	◯	◯	◯

Do you plan to change the number of vehicles in your household in the next 3 months?

	No change	Reduce	Replace	Add
Personal car or truck	◯	◯	◯	◯
Motorcycle or moped	◯	◯	◯	◯
Bike	◯	◯	◯	◯
E-bike or pedelec	◯	◯	◯	◯
E-scooter	◯	◯	◯	◯

How often have you travelled by each of the following modes of transportation in the last 3 months, for any purpose?

	Daily or almost daily	Several times per week	Once per week	Several times per month	Once per month or less	Never
Personal car or truck	○	○	○	○	○	○
Public transport	○	○	○	○	○	○
Taxi or ridehailing (e.g., Uber)	○	○	○	○	○	○
Ridepooling (e.g., UberPool)	○	○	○	○	○	○
Motorcycle or moped	○	○	○	○	○	○
Personal bike, e-bike, or e-scooter	○	○	○	○	○	○
Shared bike, e-bike, or e-scooter (e.g., Lime, Dott, Tier)	○	○	○	○	○	○
Walk	○	○	○	○	○	○

Display This Question:
If rode an e-bike on their most recent trip.

How often do you use shared e-bikes to get to public transport?

- ○ Never
- ○ Some trips (about 25%)
- ○ Many trips (about 50%)
- ○ Most trips (about 75%)
- ○ Every trip

Display This Question:
If rode an e-scooter on their most recent trip.

How often do you use shared e-scooters to get to public transport?

- ○ Never
- ○ Some trips (about 25%)
- ○ Many trips (about 50%)
- ○ Most trips (about 75%)
- ○ Every trip

Display This Question:
If rode an e-bike on their most recent trip.

How has the use of shared e-bikes affected your frequency of use of...?

	I did not use this before, and do not use it now	I use it much *less* often	I use it somewhat *less* often	I have not changed my use	I use it somewhat *more* often	I use it much *more* often
Personal car or carshare (e.g., Virtuo, Get-Around)	○	○	○	○	○	○
Personal motorcycle / moped or shared moped (e.g., Revel, CityScoot)	○	○	○	○	○	○
Taxi or ridehailing (e.g., Uber)	○	○	○	○	○	○
Bus or shuttle	○	○	○	○	○	○
Subway or train	○	○	○	○	○	○
Personal bicycle or e-bike	○	○	○	○	○	○
Walk	○	○	○	○	○	○

Display This Question:
If rode an e-scooter on their most recent trip.

How has the use of shared e-scooters affected your frequency of use of...?

	I did not use this before, and do not use it now	I use it much *less* often	I use it somewhat *less* often	I have not changed my use	I use it somewhat *more* often	I use it much *more* often
Personal car or carshare (e.g., Virtuo, GetAround)	○	○	○	○	○	○
Personal motorcycle / moped or shared moped (e.g., Revel, CityScoot)	○	○	○	○	○	○
Taxi or ridehailing (e.g., Uber)	○	○	○	○	○	○
Bus or shuttle	○	○	○	○	○	○
Subway or train	○	○	○	○	○	○
Personal bicycle or e-bike	○	○	○	○	○	○
Walk	○	○	○	○	○	○

End of Block: Travel Patterns

Start of Block: Current and Future Transportation Options

In the following questions, we will ask you about your travel experiences.

Display This Question:
If rode an e-bike on their most recent trip.

How challenging have the following factors been for you when trying to take a ride or when riding a shared e-bike? (Please select all that apply.)

	Not challenging at all	Slightly challenging	Moderately challenging	Very challenging	Extremely challenging
Cost - The shared e-bike was too expensive to use.	○	○	○	○	○
Availability - I could not find a shared e-bike.	○	○	○	○	○
Parking - It was difficult to park or unclear how to park.	○	○	○	○	○
Belongings - I was carrying bulky items, gear, or food/drinks.	○	○	○	○	○

Display This Question:
If rode an e-scooter on their most recent trip.

How challenging have the following factors been for you when trying to take a ride or when riding a shared e-scooter? (Please select all that apply.)

	Not challenging at all	Slightly challenging	Moderately challenging	Very challenging	Extremely challenging
Cost - The shared e-scooter was too expensive to use.	○	○	○	○	○
Availability - I could not find a shared e-scooter.	○	○	○	○	○
Parking - It was difficult to park or unclear how to park.	○	○	○	○	○
Belongings - I was carrying bulky items, gear, or food/drinks.	○	○	○	○	○

How would you rate the quality of cycling infrastructure (e.g. quality of bike lanes, safety when cycling, parking facilities) in Paris?

- Extremely bad
- Somewhat bad
- Neither good nor bad
- Somewhat good
- Extremely good

In the following questions, we will ask how you would react to a few different scenarios. Please imagine the scenarios as best as you can.

Display This Question:
If rated cycling infrastructure as Extremely bad, Somewhat bad, or Neither good nor bad
And If used Personal car or truck, Public transport, Taxi or ridehailing (e.g., Uber), or Motorcycle or moped at least Several times per month or more frequently.
And If rode an e-scooter on their most recent trip.

Imagine that the quality of cycling infrastructure was improved by building more protected bike lanes.

How often would you ***use shared e-bikes as a replacement*** for...?

	The same as before	Somewhat more often	Twice as often	Three times as often	More than three times as often
... personal car or truck	○	○	○	○	○
... taxi or ridehailing (e.g. Uber or Lyft)	○	○	○	○	○
... personal moped or motorcycle	○	○	○	○	○
... public transport	○	○	○	○	○

Display This Question:
If rated cycling infrastructure as Extremely bad, Somewhat bad, or Neither good nor bad
And If used Personal car or truck, Public transport, Taxi or ridehailing (e.g., Uber), or Motorcycle or moped at least Several times per month or more frequently.
And If rode an e-scooter on their most recent trip.

Imagine that the quality of cycling infrastructure was improved by building more protected bike lanes.

How often would you ***use shared e-scooters as a replacement*** for...?

	The same as before	Somewhat more often	Twice as often	Three times as often	More than three times as often
... personal car or truck	○	○	○	○	○
... taxi or ridehailing (e.g. Uber or Lyft)	○	○	○	○	○
... personal moped or motorcycle	○	○	○	○	○
... public transport	○	○	○	○	○

Display This Question:
If used Personal car or truck, Public transport, Taxi or ridehailing (e.g., Uber), or Motorcycle or moped at least Several times per month or more frequently.
And If rode an e-bike on their most recent trip.

Imagine that the *cost* of different transportation options has *increased*.

How would that influence your use of shared e-bikes?

	Less than before	The same as before	Somewhat more often	Twice as often	Three times as often	More than three times as often
If a **personal car or truck** cost me twice as much to use, I would use shared e-bikes...	○	○	○	○	○	○
If a **taxi or ridehailing (e.g. Uber or Lyft)** cost me twice as much to use, I would use shared e-bikes...	○	○	○	○	○	○
If a **personal moped or motorcycle** cost me twice as much to use, I would use shared e-bikes...	○	○	○	○	○	○
If **public transport** cost me twice as much to use, I would use shared e-bikes...	○	○	○	○	○	○

Display This Question:
If used Personal car or truck, Public transport, Taxi or ridehailing (e.g., Uber), or Motorcycle or moped at least Several times per month or more frequently.
And If rode an e-scooter on their most recent trip.

Imagine that the *cost* of different transportation options has *increased.*

How would that influence your use of shared e-scooters?

	Less than be-fore	The same as before	Somewhat more often	Twice as often	Three times as often	More than three times as often
If a **personal car or truck** cost me twice as much to use, I would use shared e-scooters...	○	○	○	○	○	○
If a **taxi or ridehailing (e.g. Uber or Lyft)** cost me twice as much to use, I would use shared e-scooters...	○	○	○	○	○	○
If a **personal moped or motorcycle** cost me twice as much to use, I would use shared e-scooters...	○	○	○	○	○	○
If **public transport** cost me twice as much to use, I would use shared e-scooters...	○	○	○	○	○	○

Display This Question:
If used Personal car or truck, Public transport, Taxi or ridehailing (e.g., Uber), or Motorcycle or moped at least Several times per month or more frequently.
And If rode an e-bike on their most recent trip.

Imagine that the *travel time* of different transportation options has *increased*.

How would that influence your use of shared e-bikes?

	Less than before	The same as before	Somewhat more often	Twice as often	Three times as often	More than three times as often
If driving a **personal car or truck** took twice as long, I would use shared e-bikes...	○	○	○	○	○	○
If taking a **taxi or ridehailing (e.g. Uber or Lyft)** took twice as long, I would use shared e-bikes...	○	○	○	○	○	○
If riding a **personal moped or motorcycle** took twice as long, I would use shared e-bikes...	○	○	○	○	○	○
If taking **public transport** took twice as long, I would use shared e-bikes...	○	○	○	○	○	○

Display This Question:
If used Personal car or truck, Public transport, Taxi or ridehailing (e.g., Uber), or Motorcycle or moped at least Several times per month or more frequently.
And If rode an e-scooter on their most recent trip.

Imagine that the *travel time* of different transportation options has *increased.*

How would that influence your use of shared e-scooters?

	Less than before	The same as before	Somewhat more often	Twice as often	Three times as often	More than three times as often
If driving a **personal car or truck** took twice as long, I would use shared e-scooters...	◯	◯	◯	◯	◯	◯
If taking a **taxi or ridehailing (e.g. Uber or Lyft)** took twice as long, I would use shared e-scooters...	◯	◯	◯	◯	◯	◯
If riding a **personal moped or motorcycle** took twice as long, I would use shared e-scooters...	◯	◯	◯	◯	◯	◯
If taking **public transport** took twice as long, I would use shared e-scooters...	◯	◯	◯	◯	◯	◯

Display This Question:
If rode an e-scooter on their most recent trip.

Imagine that the maximum speed for *e-scooters* had been reduced from the current 20 km/h to 10 km/h instead.

Of all of the trips you've taken using shared e-scooters in the last 12 months, what percent would you still have made?

◯ 0% (none)
◯ 25%
◯ 50%
◯ 75%
◯ 100% (all)

Display This Question:

If used Personal car or truck, Public transport, Taxi or ridehailing (e.g., Uber), or Motorcycle or moped at least Several times per month or more frequently.

And If rode an e-bike on their most recent trip.

Imagine that you could always find an available shared e-bike within a 1 to 2 minute walk (100 to 150 meters).

How many of the trips you currently take using other transportation options would you take by shared e-bikes instead?

	Percent of trips that you would switch to shared e-bikes
	0 10 20 30 40 50 60 70 80 90 100
Personal car or truck	
Public transport	
Taxi or ridehailing (e.g. Uber or Lyft)	

Display This Question:

If used Personal car or truck, Public transport, Taxi or ridehailing (e.g., Uber), or Motorcycle or moped at least Several times per month or more frequently.

And If rode an e-scooter on their most recent trip.

Imagine that you could always find an available shared e-scooter within a 1 to 2 minute walk (100 to 150 meters).

How many of the trips you currently take using other transportation options would you take by shared e-scooters instead?

	Percent of trips that you would switch to shared e-scooters
	0 10 20 30 40 50 60 70 80 90 100
Personal car or truck	
Public transport	
Taxi or ridehailing (e.g. Uber or Lyft)	

Display This Question:

If used Personal car or truck, Public transport, Taxi or ridehailing (e.g., Uber), or Motorcycle or moped at least Several times per month or more frequently.

And If rode an e-bike on their most recent trip.

Imagine that there were enough shared e-bike parking locations that you could always park your shared e-bike within a 1 to 2 minute walk (100 to 150 meters) of your destination.

How many of the trips you currently take using other transportation options would you take by shared e-bikes instead?

Percent of trips that you would switch to shared e-bikes

	0	10	20	30	40	50	60	70	80	90	100
Personal car or truck											
Public transport											
Taxi or ridehailing (e.g. Uber or Lyft)											

Display This Question:

If used Personal car or truck, Public transport, Taxi or ridehailing (e.g., Uber), or Motorcycle or moped at least Several times per month or more frequently.

And If rode an e-scooter on their most recent trip.

Imagine that there were enough shared e-scooter parking locations that you could always park your shared e-scooter within a 1 to 2 minute walk (100 to 150 meters) of your destination.

How many of the trips you currently take using other transportation options would you take by shared e-scooters instead?

Percent of trips that you would switch to shared e-scooters

	0	10	20	30	40	50	60	70	80	90	100
Personal car or truck											
Public transport											
Taxi or ridehailing (e.g. Uber or Lyft)											

End of Block: Current and Future Transportation Options

Start of Block: Background Information

Background Information

To better understand your travel choices, the following questions ask for general information about you and your household.

What is your relationship to Paris? Please select all that apply.

- I *live* in Paris
- I *commute* to Paris
- I am a *business traveller* in Paris
- I *attend school* in Paris
- I live nearby and came for a *visit*
- I do not live nearby and came as a *tourist*
- Other

How many people live in your household, yourself included?

	0	1	2	3	4	5	6 or more
Children (less than 18 years)	○	○	○	○	○	○	○
Adults (18 years or older)	○	○	○	○	○	○	○

Please check the category for your annual household income before taxes for 2021. Consider all sources of income.

- Less than €10,000
- €10,001 to €20,000
- €20,001 to €35,000
- €35,001 to €50,000
- €50,001 to €70,000
- €70,001 to €100,000
- More than €100,000
- Prefer not to answer

How do you currently describe your gender identity?

- Male
- Female
- Transgender male
- Transgender female
- Gender nonconforming, genderqueer, or gender questioning
- Different identity
- Prefer not to answer

What year were you born?

▼ Prefer not to answer ... 1920

End of Block: Background Information

Start of Block: Promo Codes

Thank you for taking the time to complete the survey, your response has been recorded.

As a token of our appreciation, we are sharing a promo code for a discount on your next 3 Lime rides:

To redeem code, open Lime app, select Wallet to add a promo code, and enter and apply code. Code valid for €1 off your next 3 rides. You must apply the code to your account before June 13, 2022 at 11:30 PM. Discount is valid from when you apply the code to your account until it expires on August 31, 2022 at 11:30 PM. Code valid in Paris only. Quantities are limited and applied on a first-come-first-served basis. Limit one redemption per person. Promotional value, coupon code, and other discounts cannot be combined, stored, or transferred, and are not valid with LimePrime, Ride Pass, Lime Access, or for guests on Group Rides. To use promo code, you must be eligible to use Lime products and services, have a Lime account, agree to Lime's User Agreement, and must be the direct, intended recipient of this email. Lime may update these terms at any time and may revoke any promotion or discount, for example if a Lime account has been flagged for any suspicious or fraudulent activity. Promotions and discounts are not necessarily applied in chronological order. Any unused portion of any discount for an eligible trip will not carry over to your next eligible trip.

End of Block: Promo Codes

A.2 LCA Data by City

Table 3: Detailed LCA data by city and life cycle phase (g CO_2e / pkm)

Mode and vehicle type	City	Vehicle production	Fuel / use phase	Servicing operations	Infra-structure	TOTAL
Lime Gen 4 e-scooter *	Berlin	25.5			2.1	25.5
	Düsseldorf	25.5			3.3	25.5
	Paris	19.7			2.0	19.7
	Stockholm	22.6			2.7	22.6
	Seattle	25.5			3.3	25.5
	Melbourne	25.5			2.7	25.5
Lime Gen 4 e-bikes *	Berlin	64.9			2.1	64.9
	Düsseldorf	64.9			3.3	64.9
	Paris	49.4			2.0	49.4
	Stockholm	57.5			2.7	57.5
	Seattle	64.9			3.3	64.9
	Melbourne	64.9			2.7	64.9
Shared e-scooter	Berlin	67.4	3.1	27.0	2.1	97.5
	Düsseldorf	67.4	3.1	27.8	3.3	98.3
	Paris	67.4	0.6	26.5	2.0	94.5
	Stockholm	67.4	0.1	27.0	2.7	94.4
	Seattle	67.4	3.7	27.9	3.3	99.1
	Melbourne	67.4	6.0	27.9	2.7	101.3
Private bike	Berlin	7.5	0.0	0.0	2.1	7.5
	Düsseldorf	7.5	0.0	0.0	3.3	7.5
	Paris	7.5	0.0	0.0	2.0	7.5
	Stockholm	7.5	0.0	0.0	2.7	7.5
	Seattle	7.5	0.0	0.0	3.3	7.5
	Melbourne	7.5	0.0	0.0	2.7	7.5
Private e-bike	Berlin	12.4	5.6	0.0	2.1	18.0
	Düsseldorf	12.4	5.6	0.0	3.3	18.0
	Paris	12.4	1.1	0.0	2.0	13.5
	Stockholm	12.4	0.1	0.0	2.7	12.5
	Seattle	12.4	6.8	0.0	3.3	19.2
	Melbourne	12.4	10.9	0.0	2.7	23.3
Shared bike	Berlin	23.3	0.0	23.2	2.1	46.6
	Düsseldorf	23.3	0.0	23.9	3.3	47.3
	Paris	23.3	0.0	22.8	2.0	46.1
	Stockholm	23.3	0.0	23.2	2.7	46.5
	Seattle	23.3	0.0	24.0	3.3	47.3
	Melbourne	23.3	0.0	24.0	2.7	47.3
Shared e-bike	Berlin	36.7	5.6	23.2	2.1	65.5
	Düsseldorf	36.7	5.6	23.9	3.3	66.2

	Paris	36.7	1.1	22.8	2.0	60.6
	Stockholm	36.7	0.1	23.2	2.7	60.0
	Seattle	36.7	6.8	24.0	3.3	67.5
	Melbourne	36.7	10.9	24.0	2.7	71.6
Private car ICE	Berlin	23.9	125.6	0.0	9.1	149.5
	Düsseldorf	23.9	125.6	0.0	14.4	149.5
	Paris	23.9	125.6	0.0	8.6	149.5
	Stockholm	23.9	125.6	0.0	11.9	149.5
	Seattle	23.9	125.6	0.0	14.4	149.5
	Melbourne	23.9	125.6	0.0	11.9	149.5
Private car BEV	Berlin	40.8	33.9	0.0	8.9	74.7
	Düsseldorf	40.8	33.9	0.0	14.1	74.7
	Paris	40.8	6.5	0.0	8.4	47.3
	Stockholm	40.8	0.9	0.0	11.7	41.7
	Seattle	40.8	41.1	0.0	14.1	81.9
	Melbourne	40.8	65.9	0.0	11.7	106.7
Taxi/ridehailing	Berlin	30.0	152.2	44.1	19.4	226.3
	Düsseldorf	30.0	152.2	44.1	30.7	226.3
	Paris	30.0	150.4	43.6	18.2	224.1
	Stockholm	30.0	150.1	43.5	25.3	223.6
	Seattle	30.0	152.6	44.3	30.7	226.9
	Melbourne	30.0	154.2	44.7	25.3	228.9
Bus/shuttle	Berlin	8.6	64.9	7.1	5.2	80.7
	Düsseldorf	8.6	64.9	7.1	8.3	80.7
	Paris	8.6	62.8	6.9	4.9	78.4
	Stockholm	8.6	62.4	6.9	6.8	78.0
	Seattle	8.6	65.4	7.2	8.3	81.3
	Melbourne	8.6	67.3	7.4	6.8	83.3
Metro/urban rail	Berlin	2.0	24.9	0.0	8.1	27.0
	Düsseldorf	2.0	24.9	0.0	12.7	27.0
	Paris	2.0	4.8	0.0	7.6	6.8
	Stockholm	2.0	0.6	0.0	10.5	2.7
	Seattle	2.0	30.2	0.0	12.7	32.3
	Melbourne	2.0	48.4	0.0	10.5	50.4

Values adopted from ITF-CPB (2020) besides * values adopted from Anthesis (2022b, totals for vehicle production, use phase and service operations only)