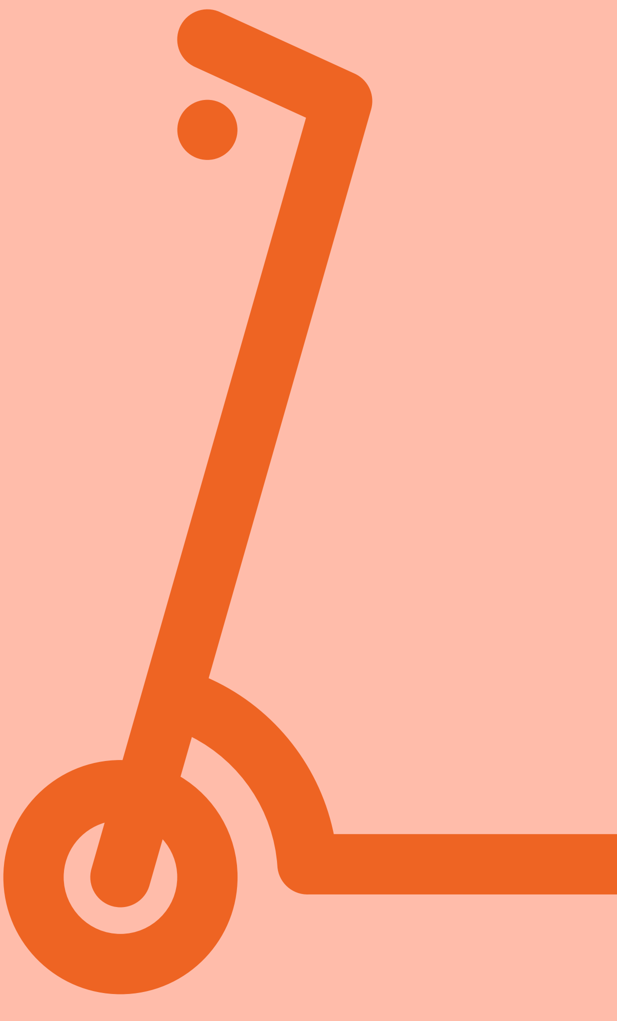
HOW LONG DO E-SCOOTERS LAST?

A NEW APPROACH TO MEASURING MICROMOBILITY LIFESPAN



BRIGHTSIDE

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EXECUTIVE SUMMARY

ENSURING SUSTAINABILITY IN THE MICROMOBILITY INDUSTRY

Cities are welcoming shared electric micromobility, including e-scooters and e-bikes, as an effective way to close the last-mile gap and serve short urban trips. Research demonstrates that micromobility is a good option for up to 60% of urban journeys in many European cities. Despite this promise, the sustainability benefits of e-scooters have been questioned due to reports about short vehicle lifespan in the industry's early days, when micromobility operators used off-the-shelf models. Though the industry has since introduced commercial-grade e-scooters, there has not been a standard methodology for assessing fleet average lifespan, a key input for lifecycle assessments (LCA)—the standard approach for determining the relative sustainability of transport modes.

As city officials take major steps to ban combustion vehicles and grow sustainable mobility options, a consistent approach to reporting on micromobility vehicle lifespan is essential. This report proposes a methodology for calculating the lifespan of shared electric micromobility using real-world data and reporting on the lifespan of the battery and vehicle separately. The analysis shows that the rate of vehicles lost or decommissioned increases over time due to wear and tear. The proposed methodology models the fleet survival curve, applies real-world data to adjust for increases in decommission rates year over year, then identifies the point at which 50% of the total fleet is lost or decommissioned to find the average vehicle and battery lifespan

Using this methodology, we estimate that Voi's e-scooter model introduced in 2021 (the V4) has a lifespan of 4.6 years (6,529 km) for the frame and 3.7 years (103.4 kWh) for the battery. This is about 5x longer than models used when the industry launched in 2018.

Our analysis finds that gains in lifespan are attributable to improvements in vehicle design, the use of modular parts (circularity), proactive maintenance practices, and sophisticated GPS technology that have improved vehicle retention. To further improve sustainability in the industry, we recommend that Voi, and all e-scooter operators, collect more granular data on the lifespan of e-scooter frames and batteries, and use this information to further improve design, maintenance, and operational practices. We also recommend that all operators adopt a similar approach to calculating lifespan, and be more transparent in sharing this information with the cities in which they operate, in order to ensure that e-scooters are embraced as an essential part of every city's sustainable transport system.

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I. INTRODUCTION

TOWARD MORE SUSTAINABLE URBAN TRANSPORTATION

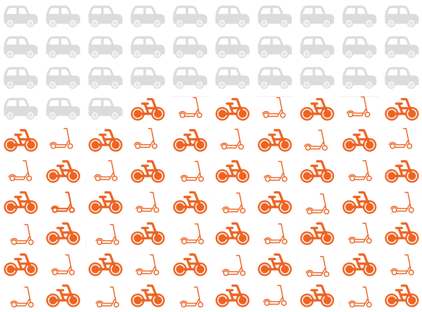
At long last, cities across the globe are taking meaningful steps to reduce carbon emissions. But while progress has been made in most sectors, a majority of cities have struggled to meaningfully reduce emissions from urban transportation. Cities are increasingly welcoming shared electric micromobility, including e-scooters and e-bikes, as an effective way to close the last-mile gap and serve short urban trips.

Research demonstrates that micromobility is a good option for a surprising number of urban journeys. For example, according to a study by transportation analytics company INRIX, up to 60% of trips in Munich and Berlin are under five kilometers, making them good candidates for micromobility. The Centre for London estimated that two-thirds of car trips in the UK capital could be completed on micromobility vehicles in 20 minutes or less. And according to Voi's 2022 Global Survey, 36% of respondents report using a car "drastically less," while 55% of users report using an e-scooter to connect to transit.

Replacing short car trips with more sustainable options can go a long way toward helping cities to achieve their goals of reducing carbon emissions and urban congestion. According to a study by Carbone 4, approximately 21% of all trips in Paris could be taken on micromobility. The report concludes that micromobility is an essential component of a sustainable transport system that could help the city to achieve a 68% reduction of emissions from energy consumption. And a report from the journal Nature found that e-scooters reduced traffic congestion, noting that removing e-scooters increased travel time in a major American city by 11%.

Despite this clear promise, some stakeholders have questioned the overall sustainability of e-scooters due to concerns over the short vehicle lifespan. Vehicle lifespan is a key factor in ensuring micromobility lives us to its sustainability promise and is circular. This report summarizes the micromobility lifespan conversation, explores the factors that contribute to lifespan, recommends a new methodology for calculating the lifespan of shared electric micromobility vehicles, and finally, presents findings about the lifespan of Voi's e-scooter fleet.

UP TO 60% OF CAR TRIPS IN EUROPEAN CITIES COULD BE TAKEN BY MICROMOBILITY



A SHORT HISTORY OF MICROMOBILITY AND THE RISING ATTENTION ON LIFESPAN

In 2008, Paris launched Velib, a **docked** bikeshare system that has since inspired hundreds of similar systems across the globe. Velib's docked model allows riders to pick up and park bicycles at designated stations distributed throughout the city. Most of the technology is embedded in the stations, instead of on the bikes. Bikes lock to the stations when not in use, requiring riders to find an open dock in order to end their ride.

The Velib system requires users to park in designated docking stations across Paris.

While docked bikeshare systems are now omnipresent in cities like Paris, New York, and London, this development did not happen overnight. Systems that use docks require city resources to site, install, and maintain infrastructure. Cities must allocate space to allow for a dense network of docking stations— usually one every 2 to 3 blocks–in order for the system to be well utilized. The use of docking stations limits the flexibility of these systems since stations are not easily installed or moved to keep up with variations in demand. On the other hand, docked systems provide predictability about where to find micromobility vehicles, and cities with docked systems report fewer public complaints about parking, as compared to dockless systems.

Enabled by smartphones and improvements in GPS technology, a new generation of **dockless** bikeshare programs emerged in China in 2016 and quickly spread to Europe and the United States. Run by private operators funded by venture capital, these dockless fleets were composed of cheap manual bikes that were lightweight, but flimsy. Bikes used in these systems were so inexpensive that operators did not maintain them, and piles of broken bikes accumulated on city street corners. City officials quickly grew tired of the clutter and lack of collaboration from dockless bikeshare operators, and soon adopted policies to restrict their use.

The first generation of dockless bikes were flimsy and poorly maintained, resulting in a short lifespan.

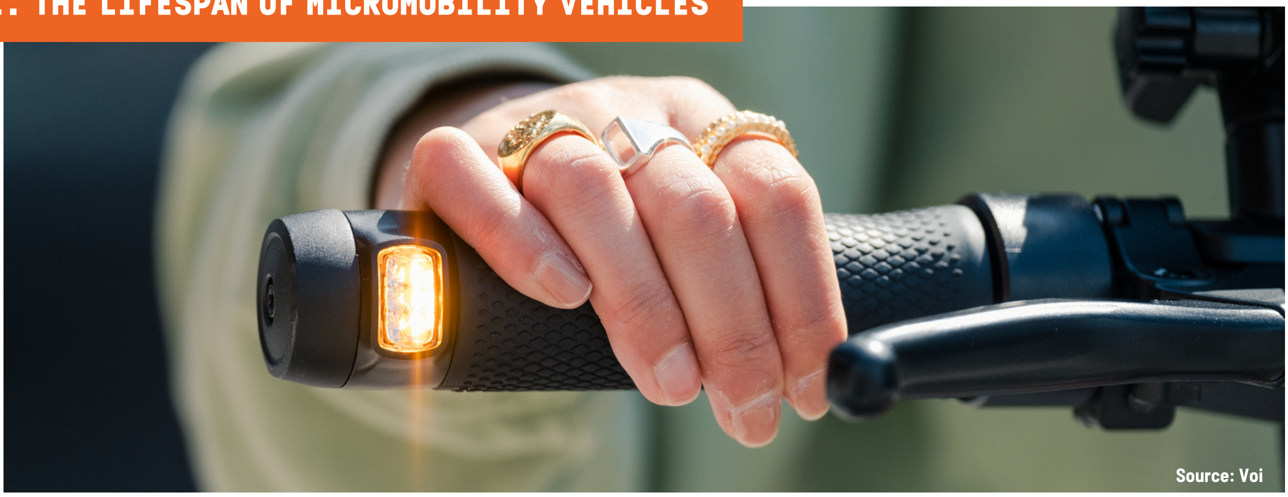
When the first generation of dockless e-scooters appeared on city streets around 2018, operating practices appeared to be similar to dockless bikes. Analyses during the industry's early days estimated that e-scooters lasted just one to three months in shared operation before being scrapped due to damage. As with dockless bikes, city officials worried that e-scooter operators would treat vehicles as disposable, rather than investing in high-quality vehicles and maintenance programs to ensure sustainability. But these same officials could not ignore the popularity of shared e-scooters, which attracted people who had never tried bikeshare and quickly demonstrated their efficacy in replacing short car trips.

Consumer model e-scooters used in the industry's early days did not last long.

Since that time, the dockless micromobility industry has matured from an unexpected upstart to a ubiquitous urban transport option. E-scooter operators have rapidly improved their vehicles, introducing more durable models purpose-built for shared use. Cities have formalized permit programs for shared e-scooters, e-bikes, e-mopeds, and adaptive modes, welcoming a wide range of options to coax more people out of cars. Cities have also started raising expectations for micromobility operators, including requiring robust vehicle maintenance practices, recycling programs for retired vehicles, and mandating the use of electric vans for charging and operations.

Some e-scooter operators have started introducing parking racks to keep e-scooters better organized.

II. THE LIFESPAN OF MICROMOBILITY VEHICLES



WHY DOES VEHICLE LIFESPAN MATTER?

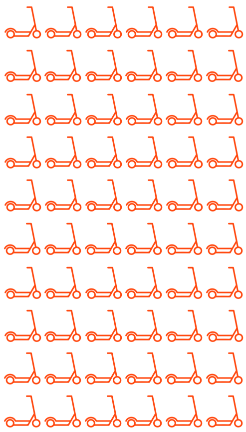
Just because a vehicle is electric does not guarantee it is sustainable. Assessing a transportation mode's sustainability impact requires quantifying both its **tailpipe** and its **lifecycle** emissions.

> Just because a vehicle is electric does not guarantee it is sustainable

The term tailpipe emissions refers to the pollutants released through the burning of fossil fuels for movement. These emissions include greenhouse gases that contribute to climate change, as well as fine particulate matter responsible for local air pollution. Electric vehicles have near-zero tailpipe emissions but do use electricity from the local energy grid, which can contribute to greenhouse gas emissions and air pollution if energy is sourced from a fossil fuel-burning power plant.

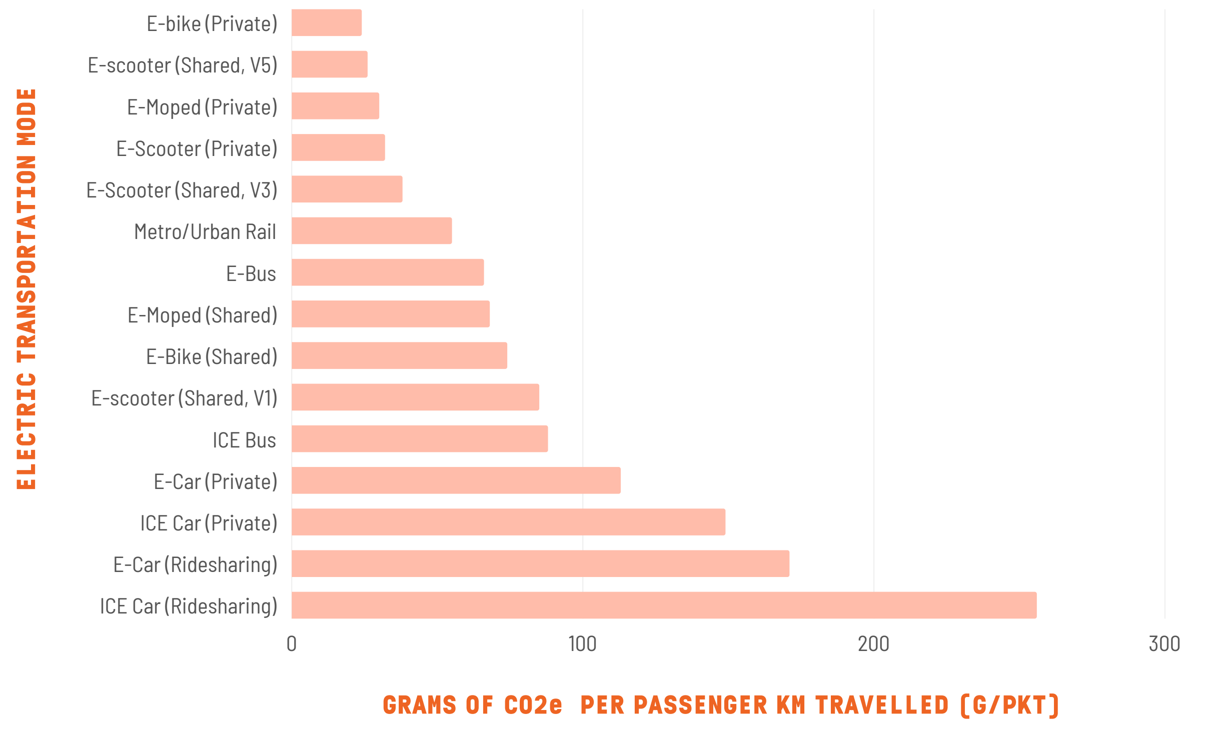
The sustainability picture becomes more complicated – but more complete – when lifecycle emissions are considered. Lifecycle emissions are measured through a lifecycle assessment (LCA) process, which considers the emissions created from manufacturing a vehicle, shipping it to market, operating and maintaining it, and disposing of it at the end of its useful life. Lifecycle assessments estimate emissions as grams of CO2e per passenger kilometer traveled (PKT), providing a common metric for comparing different forms of transportation. As electrification sweeps the transport sector, LCAs can offer policymakers a fuller picture of the sustainability benefits of various modes.

THE SAME AMOUNT OF MATERIALS :



E-scooters are remarkably efficient to operate — up to seven times more efficient than electric sedans. They also use significantly fewer materials to manufacture —up to 60 times less than the average electric car. However, if e-scooters only last a few months, even these comparatively small manufacturing emissions will drive up the carbon emissions per kilometer traveled. To be a highly sustainable mode, e-scooters must have long lifespans that amortize their lifecycle impact over many passenger trips.

FIGURE 1
LIFECYCLE EMISSIONS BY URBAN TRANSPORT MODE



Source: E-scooter (V1, V3, V5) data from Voi (2022), all other data from ITF, Assessing the Environmental Performance of New Mobility (2020), using manufacturing, fuel, and operational figures to match what is represented in the Voi numbers.

HOW IS LIFESPAN CALCULATED TODAY?

Though cities often ask for information about vehicle lifespan as part of their shared micromobility permitting processes, there is not currently a standardized methodology for calculating and reporting on lifespan. In 2019, after some reports pegged micromobility lifespan at somewhere between 23 days and a few months, companies pushed back, claiming that their vehicles lasted 24 months. By 2021, some micromobility companies, including the American company Lime and Swedish company Voi were claiming e-scooters in their fleet would last more than five years, though neither shared operational data or information about how this lifespan was calculated.

Without a consistent methodology, claims about lifespan do not mean much. Companies have a strong incentive to put forth the most generous possible lifespans to win city permits over competitors, but local transport regulators have little means of verifying those claims. This state of affairs encourages greenwashing and threatens micromobility's reliability as a low-carbon transportation mode. As city officials take major steps to remove combustion vehicles from their streets and grow sustainable mobility options, a consistent approach to monitoring and reporting on vehicle lifespan is essential.

> As city officials take major steps to ban combustion vehicles and grow sustainable mobility options, a consistent approach to monitoring and reporting on vehicle lifespan is essential

WHAT FACTORS INFLUENCE VEHICLE LIFESPAN?

Shared micromobility vehicles are subject to more abuse than personally owned ones. They spend the majority of their lifetimes outside, where they are exposed to the elements – both human and environmental. They go for multiple rides per day over cobblestones and potholes and are loaded in and out of vans and e-cargo bikes to be brought for recharging or maintenance. Between rides, they may be bumped or tipped, and occasionally, they are vandalized or stolen.

The below factors impact vehicle lifespan. They include both **intrinsic factors**, or those that are outside the operator's direct control, as well as **operational factors**, or those that are the result of choices made by operators.

Intrinsic factors that impact shared micromobility lifespan:

Frequency and duration of use

Vehicles that are ridden many times per day and for long distances will wear down faster than vehicles that are less frequently used.

Local conditions

Weather, topography, and road conditions can all impact vehicle longevity. Frequent exposure to extreme cold or extreme heat can wear out a battery faster than mild temperatures, while cobblestone roads or those filled with potholes are more likely to cause damage to components, speeding the path to an early vehicle retirement.

Use patterns

Rough riding habits can lead to a shorter lifespan. For example, some data shows that shared e-scooters deployed on college campuses require more frequent maintenance, suggesting younger riders may drive more aggressively.

Vandalism and theft

Some cities have higher rates of theft and vandalism-related crime, which often carries over to shared micromobility vehicles. Data suggests that these crimes are most common when e-scooters first arrive in a city, and they taper off over time.

Permit turnover

Most cities have taken a pilot approach to their micromobility program, offering operating permits that last for just one to two years before retendering. Losing an operating permit in a sizable market can result in early vehicle retirement unless vehicles can be allocated to a nearby city.

Operational factors that impact shared micromobility lifespan

Battery management

Well-managed lithium-ion batteries can last significantly longer than those that are not carefully managed. Practices like recharging the battery before it drops below 20% or storing batteries inside when temperatures get too high or too low can extend battery life.

Maintenance and use of modular parts

To keep e-scooters on the road longer, some shared operators have designed vehicles with modular parts that can be replaced quickly and cheaply. That includes just about everything on the vehicle: tires, fenders, the onboard computer (IoT) and sensors, wires, brakes, and more. Micromobility operators that do proactive maintenance and have local warehouses stocked with these components can significantly prolong vehicle lifespan.

New vehicle models

To attract riders and address city requests, many of the big micromobility operators have introduced new e-scooter models on an annual basis. This can accelerate fleet retirement since operators prefer that all vehicles in a city be of the same generation.

Second-life practices

A company's approach to dealing with vehicles when they are retired from a fleet can have a significant impact on lifespan. Some operators recycle vehicles when they are retired from their fleets, while others sell them to private users or other operators for continued use. Refurbishing and selling to a secondary market can extend lifespan.

HOW SHOULD LIFESPAN BE CALCULATED?

Despite rapid global expansion over the past several years, the shared electric micromobility industry is still a relatively nascent one. Third-party groups that typically propose vehicle standards, test procedures, and other guidelines are just beginning to release such recommendations for shared e-scooters and e-bikes. Because vehicle lifespan is a key metric for assessing sustainability, this report presents the first proposal for defining and calculating lifespan for shared electric micromobility. Our analysis focused on e-scooters, but we believe that the approach is also applicable to shared e-bikes, e-trikes, and other small electric vehicles.

Methodology

To explore micromobility lifespan, we started by analyzing methodologies used for other vehicles, transport services, and consumer products. We applied these frameworks to data collected from Voi, a Swedish micromobility operator servicing dozens of European cities. Voi provided data documenting roughly two years of operations in more than 50 cities, across two different generations of e-scooter models in their fleet. Voi's data allowed us to explore key trends in e-scooter deployment, use, maintenance, loss, and decommissioning rates over time.

The Voi data sources we analyzed included the following:

- **A log of the e-scooter fleet deployed**, including identification number, dates of deployment, and cause for removal
- **A log of batteries**, including dates of deployment and removal from the market
- **Number of replacement component parts** (e.g., brake pads, handle grips, tires, etc.) used in each market
- **Operational data**, including battery swaps, distance ridden, charging cycles, and maintenance/repair practices
- **Data about e-scooters sold into the secondary market**
- **Reports and warranties from vehicle and battery manufacturers**
- **Voi's lifecycle assessment models** used to assess and track sustainability and environmental impacts

We developed and tested hypotheses, while also consulting independent, internationally recognized micromobility experts, including Pierpaolo Cazzola, a transport researcher and lifecycle assessment expert who led the seminal report, *Good to Go? Assessing the Environmental Performance of New Mobility*, for the OECD's International Transport Forum, as well as Chris Cherry, a professor in Civil and Environmental Engineering at the University of Tennessee and internationally recognized expert in electric micromobility. We conducted interviews with leaders at Voi, consulted with industry experts, and surveyed best practices for modeling and reporting lifespan from micromobility operators and from adjacent industries.

Based on our research and data analysis, we recommend the following steps for calculating e-scooter lifespan.

1

RECOMMENDATION #1

A “vehicle” should be defined as the e-scooter frame and the corresponding number of batteries required to operate that frame until its end of life

We propose that “the vehicle” be defined as the e-scooter frame plus the batteries required for those operations, for three reasons. First, micromobility operators can switch out most components quickly and efficiently, but damage to a frame or battery cannot be cost-effectively repaired. Therefore, e-scooters with significantly damaged frames will usually be retired, and vehicles with damaged batteries will be assigned new ones. Second, the frame and battery account for the largest proportion of emissions and are therefore a reasonable proxy for overall vehicle lifespan. Third, while vehicle components outside the frame and battery (e.g., tires, hand grips, and fenders) must be accounted for in a lifecycle assessment, tracking the lifespan of each and every component part amid routine repairs and maintenance would require an identification number on each original and replacement part, a process which may not be feasible.

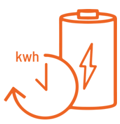
2

RECOMMENDATION #2

E-scooter lifespan should be expressed as two numbers: the total distance traveled on the e-scooter frame and total lifetime energy use of the battery

Tracking distance traveled for the e-scooter frame alongside total battery energy consumption provides the most accurate lifespan estimate, as the usage times of frames and batteries typically do not align on a one-to-one basis.

Total distance traveled (km or mi) provides the most useful information about the lifespan of vehicle frames. This data point captures the service offered by an e-scooter: how far it has moved people around a city. Distance traveled is correlated with environmental benefit: the greater the distance, the fewer average grams of CO2 emission per PKT. Distance traveled by an e-scooter can also be an indicator for reductions in tailpipe emissions from the transport modes e-scooters replace; for example, if surveying shows that 25% of all e-scooter kilometers traveled in a given city replace car journeys, the total distance traveled as reported by an e-scooter company can help a city to quickly calculate carbon emissions avoided.



Total kilowatt-hours (kWh) of electricity charged (and discharged or used) provides the most useful information about lifespan of the batteries. Batteries are often the costliest and most environmentally impactful e-scooter component. In battery manufacturer warranties, the most common convention for reporting lifespan is via throughput: the energy (expressed in kWh) that the battery discharged over its lifetime. We recommend that same approach for shared electric micromobility. Tracking and reporting on actual energy used is important for micromobility: shared e-scooter batteries tend to be retired earlier than they might in other industries due to range loss or damage, and operators should only get credit for the energy the battery actually delivered.

3

RECOMMENDATION #3

Wherever possible, fleet average lifespan should be modeled using real-world data and should correspond to the point at which 50% of e-scooter frames and batteries are expected to be retired

Shared micromobility vehicles spend the majority of their time outdoors, are used frequently, and tend to be handled more roughly than privately-owned vehicles, all of which can contribute to a lifespan shorter than what a manufacturer might project. Given the unique usage patterns, it is important to use as much real-world data as possible to track loss and decommission rates and apply this information to estimate fleet average lifespan. Even when the full lifecycle of an e-scooter has not yet been observed in the field in a particular city or for a new e-scooter model, real-world data can be used to forecast the point at which 50% of a fleet of vehicles is expected to reach the end of life—a universally accepted approach to estimating lifespan.

Use real-world data to track loss and decommission rates, and apply this information to estimate fleet average lifespan

4

RECOMMENDATION #4

When e-scooters are sold to a private owner or shared operator after retirement from a shared fleet, that extended use should count toward the lifespan calculation

Some e-scooter operators sell used vehicles to private buyers or micromobility operators in other regions, where they continue their useful life. When e-scooters are sold for continued use, the reported lifespan should extend to cover this second-life period. This extended lifetime should be calculated based on observed fleet decommission rates, the destination of e-scooters sold, and their expected second-life usage profile in as transparent and documented a manner as possible. This practice would ensure that an operator who makes the effort to find a second-life use is properly credited for the associated sustainability benefits, and may discourage operators from prematurely sending e-scooters to be recycled before the end of their useful lives.

It should be noted that operators who sell used e-scooters must carry some responsibility for ensuring proper disposal once the vehicle is fully retired. Sellers should require purchasers to share their recycling plans and/or provide instruction to private purchasers on what to do with the vehicle when it is no longer usable, including instructions on where to take it for recycling.

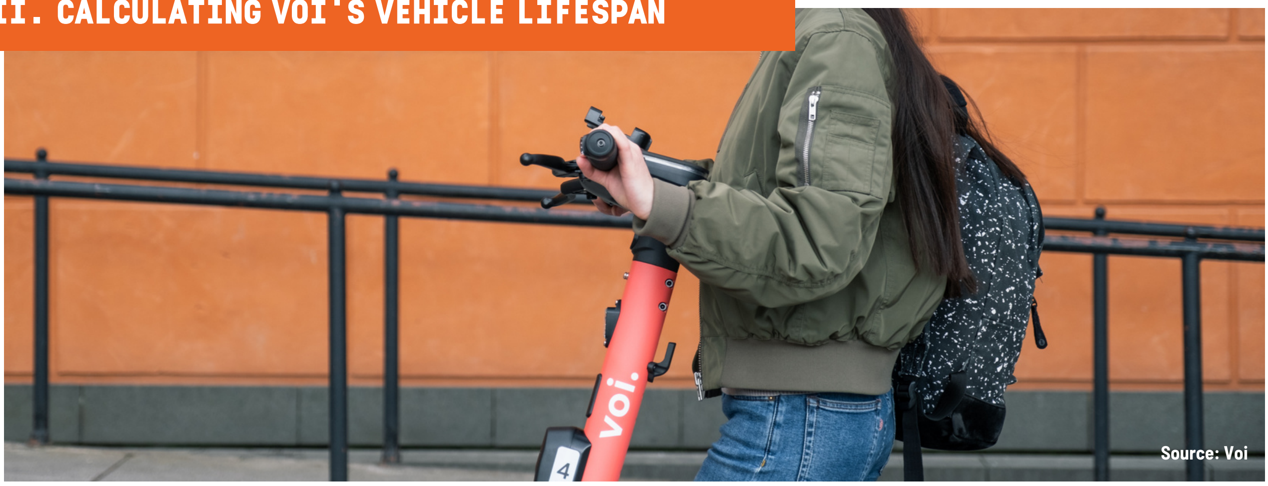
5

RECOMMENDATION #5

Track city-by-city variation in lifespan

Given the many factors that impact e-scooter lifespan across geographies, it is valuable to evaluate lifespan at the city level instead of just looking at the fleet average across all markets. Doing so can improve understanding of the factors that most impact lifespan and help operators improve their sustainability performance. For example, the average daily distance traveled can vary significantly: Voi's e-scooters in Bristol, UK travel 9.25 km, while e-scooters in Cologne, Germany travel 3.4 km. Further, the rate of loss is unique to each city: the average monthly loss rate of Voi's e-scooters in Bristol and Bath (West of England Combined Authority) is 0.03% while the rate reached 3.63% in Bordeaux, France in the early days of Voi's operations. While this city-to-city variation can provide insights for operators to extend their lifespan, it also shows that there is some amount of churn that is outside the control of the micromobility operator; even with improvements to fleet management and the addition of anti-theft technologies, e-scooter operators still experience some amount of theft.

III. CALCULATING VOI'S VEHICLE LIFESPAN



Source: Voi

Using data provided by Voi, and following the methodology described above, we estimate that the lifespan of the Voiager 4 (V4)—the dominant vehicle in Voi's fleet today—is 6,529 km (approximately 4.6 years) per frame and 103.4 kWh (approximately 3.7 years) per battery. These figures were calculated with the following steps:

STEP 1:

Calculate the average monthly churn rate for e-scooter frames

We analyzed two years of e-scooter fleet data provided by Voi's operations team. The available data tracks e-scooters by vehicle identification number and covers two generations: the Voiager 3X (V3X), launched in 2019, and the Voiager 4 (V4), which launched in 2021. This data set notes e-scooter status, including operational (still in the fleet), lost (theft or unknown missing), decommissioned (retired due to damage or other reason), or sold (sold to a private owner or third-party operator). Churn is defined as the combination of lost and decommissioned vehicles.

Our analysis shows that the rate of **loss** tends to spike in the first six months of a new e-scooter program before decreasing to a plateaued level. Across the cities analyzed, the rate of loss for Voi e-scooters in the first 6 months averaged 0.88% per month, before lowering to 0.46% for months 7 and beyond. Our analysis shows that the rate of **decommissioning** increases with time, with a notable increase after the first year in operation. The rate of decommissioning of Voi's e-scooters for month 1 through month 12 was 0.18%. At the time of analysis, the V4 had not been deployed long enough to track the rate of decommissioning past month 12, so our model applied the V3X's decommission rate. Beyond month 12, we observed that every additional month an e-scooter was in operation led to an increase in its expected decommission rate of about 0.041%. This increase in the expected decommission rate tracks with observed patterns: the longer an e-scooter remains in operation, the more wear and tear builds up. The repairs needed to keep it in the fleet begin to get costlier for the operator, thus increasing the likelihood of decommissioning monthly.

JUMP bikes sent to be recycled before the end of their useful life

Vehicles that are **sold** are treated the same as vehicles that are active in our analysis, meaning they count toward the fleet average lifespan and do not add to the monthly churn rate. Based on observed patterns from across the industry, it can be assumed that without a resale program, vehicles are more likely to be prematurely scrapped. According to Voi's business plans, the company plans to increase the percentage of the fleet that is sold, which may contribute to an increase in fleet average lifespan over time.

STEP 2:

Calculate the average monthly churn rate for batteries

As described above, e-scooter frames and batteries may have unique lifespans and should be tracked and reported on separately. Voi's available data tracks batteries as a cohort and does not include details on the status of individual batteries, limiting our ability to conduct a detailed analysis at the individual battery level. As a cohort, however, we determined the average monthly churn rate for batteries used in 2021 to be 1.69%. Voi's management team reported they expect this churn rate to improve significantly thanks to recent updates to its battery management system.

Battery performance degrades with time, but Voi's data suggests that batteries perform suitably for 500 charge/discharge cycles. If batteries were kept in operation for the full 500 cycles, that could equate to a battery lifespan of 79 months, though our analysis found a lifespan of roughly half that time. This variation underscores the importance of more detailed battery tracking.

STEP 3:

Adjust churn rate to account for fleet sold

Some shared e-scooter operators retire and scrap vehicles before the end of their useful life. However, Voi has established a program to sell its used e-scooters to private users and shared fleet operators in cities where the company does not operate. While these e-scooters and batteries have been removed from Voi's fleet, they continue to be used and this second life should be considered in calculating vehicle lifespan.

To account for this second life, we adjusted the rate of loss for e-scooters sold to private users to 0%. Since good data about loss rate of personal vehicles is not available, we assumed that while shared e-scooters are left out overnight where they are vulnerable to theft or vandalism, personal e-scooters can be assumed to be secured safely when not in use (e.g., locked or stored indoors). For e-scooters sold to other fleet operators, we kept the loss rate consistent with that shown in Voi's fleet data.

STEP 4:

Model fleet survival curve to get an estimated number of months in operation

Next, the calculated churn rates were used to model the survival curve of Voi e-scooters. This calculation helps to estimate how many e-scooter frames and batteries are expected to still be in operation over each passing month. The point at which **50% of e-scooters have churned** is deemed the expected lifespan of that fleet. According to this analysis, we estimate an expected lifespan of 55 months (4.6 years) for e-scooter frames and an expected lifespan of 44 months (3.7 years) for e-scooter batteries.

Note that without Voi's resale program, the average e-scooter lifespan would have been 5% shorter at 52 months (4.3 years) and the average battery lifespan would have been 7% shorter at 41 months (3.4 years). The measurable benefits to the lifespan of this practice of selling to second life are expected to grow as Voi continues to expand this program.

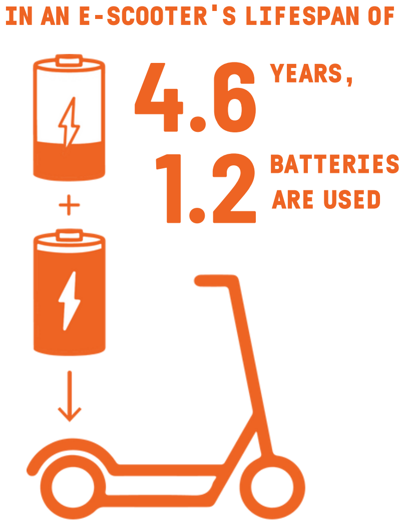
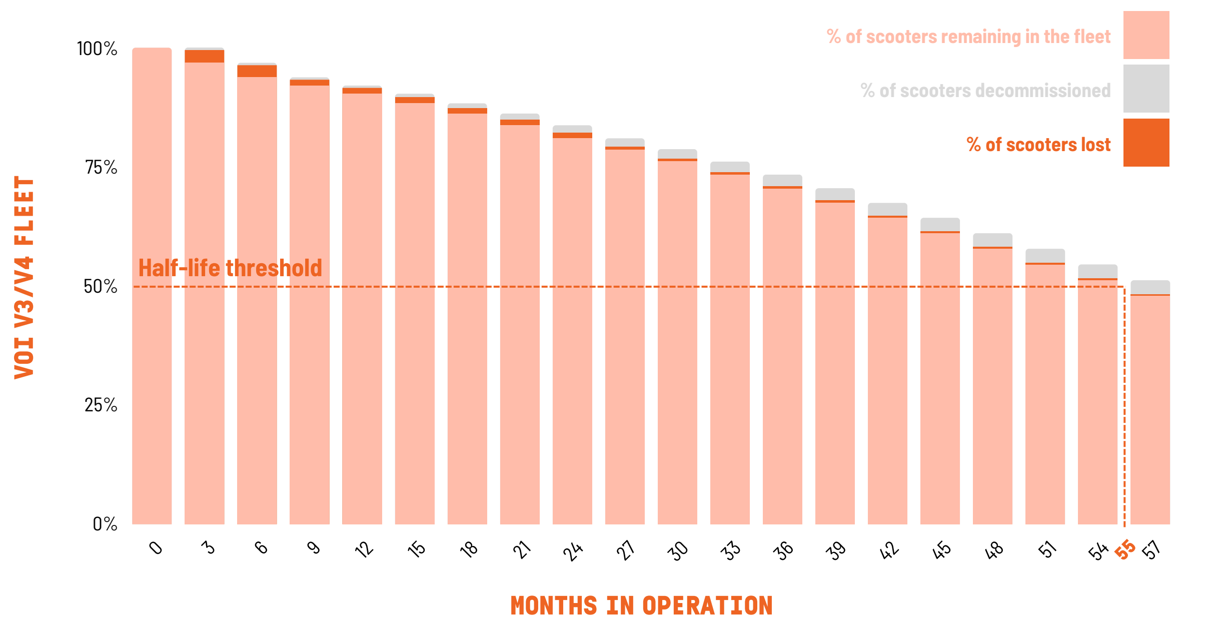


FIGURE 2

CHURN RATE FOR VOI'S E-SCOOTER FLEET



*The loss rates and decommission rates listed in the above table represent the portion of the fleet that remained at the end of the previous month that is lost or decommissioned in the subsequent month. As such, each month's loss rates and decommission rates should be considered relative to the previous month and not relative to month 0.

STEP 5:

Convert time-based estimates to km and kwh

Lastly, we converted the fleet survival curve to kilometers (km) traveled for the frame and kilowatt-hours (kWh) for the battery.

Based on the data provided by Voi, the average distance ridden per e-scooter across all markets is about 4.5 kilometers/day. E-scooters sold to other fleet operators are assumed to retain the same average daily distance, while the daily distance for e-scooters sold to private owners is expected to be lower. For the purposes of this analysis, we assumed the e-scooters sold to private users would have 50% of the average daily distance of fleet-operated e-scooters.

Altogether, the e-scooter frame's 55-month lifespan equates to 6,529-lifetime km, and the battery's 44-month lifespan equates to 5,389 km. Given this relationship, each Voi e-scooter frame requires 1.21 batteries to propel it over its full lifetime. To convert the battery lifespan to kWh, we assumed 19.19 watthour per km, an estimate based on Voi's data, making the final value for the battery lifespan 103.4 kWh.

IV. VOI'S COMPREHENSIVE APPROACH TO EXTENDING LIFESPAN


Source: Voi

According to our analysis, the e-scooters Voi launched in 2021 last 5x longer than early vehicle models. We estimate that the lifespan of the V4 is 4.6 years (6,529 km) for the frame and 3.7 years (103.4 kWh) for the battery. Consumer model e-scooters launched in early 2019 lasted about six months in a shared environment, while Voi's first custom vehicle (the V1) lasted around one year. Given this trajectory, but keeping in mind limitations in the form factor, we expect the lifespan of the V5 to be several months longer than the V4. Improvements in lifespan have been achieved through the following activities.

> The e-scooters Voi launched in 2021 last 5x longer than early vehicle models, [on average] 4.6 years for the frame and 3.7 years for the battery

IMPROVEMENTS TO VEHICLE DESIGN

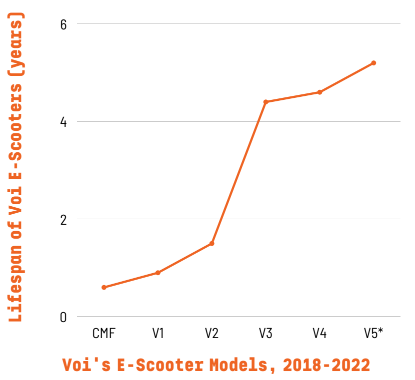
In e-scooter sharing's early days, operators used vehicles designed for personal use. In 2018, Voi launched the Ninebot CMF e-scooter, an off-the-shelf model with a narrow neck, small wheels, limited weatherization, and exposed wires and screws. These vehicles broke down quickly and were easy targets for vandalism. Their single prong kickstand left them susceptible to tipping, with each fall inflicting damage to its handlebars and handbrakes.

Today, Voi's vehicles are customized for shared use and designed in collaboration with manufacturing partners. The company has relied on repair data collected in its 60+ depots across Europe to improve each new vehicle. These data demonstrate which parts fail most often, helping the vehicle teams identify priorities for part and system redesigns that can improve longevity.

For example, front-wheel bearings have been one of the components most often needing repair, requiring replacement up to three times per year. In response, Voi redesigned the bearings for its latest e-scooter, encapsulating them with radial seals to prolong their life. Similarly, the kickstands on Voi's V4 models are made of cast aluminum, which currently requires replacement up to once per year. The Voiager 5 (V5) has a redesigned kickstand made from forged steel, and testing suggests these will be more effective at keeping vehicles upright, and last up to three times as long.

FIGURE 3

FLEET AVERAGE LIFESPAN



Source: Voi data; Electric Avenue analysis
*V5 data is a forecasted estimate

Modular parts have made e-scooters easy and inexpensive to repair

The use of **modular components** that work across vehicle models has also helped to extend the overall vehicle lifespan. While replacement parts for early consumer models were often hard to come by, Voi now keeps spare parts on hand at its service centers for its proprietary models. Having spare parts on hand streamlines the repair process and ensures vehicles can be brought back on the road quickly – decreasing the need to substitute damaged vehicles with entirely new ones.

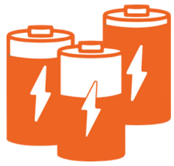
While there were dramatic advances to e-scooter technology between Voi's launch in 2018 and the release of the V3X in late-2019, vehicle design has begun to stabilize so that components are more interchangeable between models. For example, Voi's battery and the protective casing have been used across the past three generations of its electric e-scooters – meaning that extra batteries purchased one year ago can still be used in its fleet. According to Voi's vehicle team, the company hopes to keep the battery dimensions and connectors consistent across its next several vehicle generations to prevent unnecessary obsolescence and avoid the need for any battery to be recycled before the end of its useful life.

Swappable batteries reduce wear and tear from charging

Perhaps most significantly, the use of **swappable batteries versus fixed has played a big role in doubling the lifespan** between the V2 and the V3, an achievement that Voi's vehicle team believes is attributable to reducing wear and tear on the vehicle. Voi's CMF, V1, and V2 models had embedded batteries that meant the whole vehicle had to be collected, loaded into a van, driven to a warehouse, plugged into an outlet, and then loaded back into a van to be redeployed. This charging approach resulted in undue wear and tear, as e-scooters were often piled on top of one another during the transport process. With swappable batteries, introduced in the V3, depleted batteries can be exchanged for fully charged ones without having to move the e-scooter, drastically reducing wear and tear.

FLEET MANAGEMENT AND PROACTIVE MAINTENANCE

Battery management systems have optimized charging and maintenance practices



Like with mobile phones or other battery-powered devices, charging habits can go a long way toward improving performance and extending the lifespan of a battery. Voi has partnered with a battery analytics software company to improve its battery management practices. This detailed data provides Voi with recommendations for optimizing battery management. For example, this data encouraged Voi to update its operating practices to recharge batteries before they go below 20% and adapt batteries to weather conditions by, for example, using newer batteries on particularly cold days. Voi estimates that this work has helped to extend battery lifespan by up to 25%.

Proactive maintenance to avert larger issues down the line

In 2019, rider alerts were Voi's primary method for identifying vehicle repair needs. This led to faster wear and tear, as small issues would turn into bigger problems before they were addressed. Today, Voi has sensors on vehicles and has programmed its maintenance software to alert the operations team when a vehicle is due for an inspection. For example, an 'In-Field Quality Check' is automatically generated every 1000 km or 30 days and a maintenance worker is sent to closely inspect brakes, tires, and other component parts. Quick fixes (e.g. brake tightening) are performed in the field while vehicles requiring advanced repairs are transported to the nearest warehouse. In-field repairs help improve operational energy efficiency, as vehicles are only transported to the warehouse when necessary.

While Voi's V1 and V2 e-scooters were tracked in a cohort, each vehicle now has an identification number that tracks its maintenance record. The record is updated each time an e-scooter is brought in for repair.

IMPROVED VEHICLE RETENTION

Programs to limit theft and vandalism appear to have been effective

When they were first introduced, e-scooters were common targets for theft and vandalism. At its peak in 2019, Voi was losing up to 3% of vehicles monthly to theft and vandalism in cities such as Bordeaux, France. The average rate in 2021 across all markets was closer to 0.5% per month, a number that continues to decline.

Voi attributes the **decrease in theft and vandalism** to tamper-resistant design, improvements in GPS tracking, and improved fleet management. As described above, Voi's first e-scooters were consumer models, not designed for shared, free-floating use. Their onboard technology was not sufficiently secure, making it possible for thieves to hack and unlock the vehicles, thus disabling GPS. Today's vehicles have center columns that are 50 percent wider, and wheels that are 30 percent larger. The IoT has additional security features, and the GPS has its own battery, enabling Voi to continue tracking vandalized e-scooters.

Voi has also strengthened its fleet management practices through improvements in onboard technology and data collection. For example, the company has set automated data flags to alert its operations team when a vehicle appears to be "in peril," such as when it is brought outside of the geofenced operating zone. Members of the operations team are then quickly deployed, increasing the chances of recovering a vehicle before it is brought too far away from the operating zone.

FIGURE 4

VOI VEHICLE LIFESPAN

	CMF	V2	V3	V4	V5
Launch year	2018	2019	2020	2021	2022
Vehicle lifespan	8 months	16 months	55 months	55 months	60* months
Key features	Customer grade e-scooter	Partially customized e-scooter, improved suspension	Fully customized for sharing, swappable batteries, tamper proof design updates	Modular parts, improved GPS precision, improved weatherization, 50% wider neck	Improved repairability, including key components like the brake system and tires

*Note: V5 lifespan is a forecast based on design improvements. Source: Voi

VOI'S SECOND LIFE PROGRAM

Reselling vehicles has extended vehicle lifespan by more than 5%

Since April 2020, roughly 73% of Voi's retired e-scooters have been refurbished and resold. Some of these have gone on to personal use, while others are being used in shared e-scooter fleets in countries where Voi does not operate. Voi requires purchasers to commit to proper recycling of e-scooters at end of life, in line with Voi's own sustainability practices.

DISCUSSION

Shared e-scooter programs have grown quickly, expanding from just a few cities in 2018 to more than 500 cities today. The e-scooters in Voi's fleet today are notably sturdier than their predecessors, and the company's technology and operating practices have matured significantly.

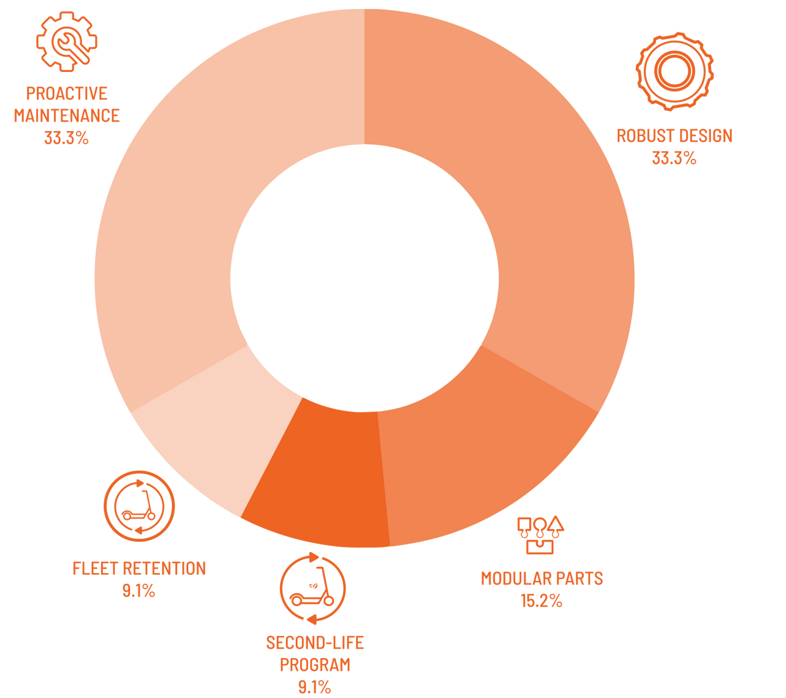
Voi has extended the average lifespan of its e-scooters by almost 5x. As discussed in the introduction of this report, extending the lifespan of e-scooters is one of the most effective ways to improve sustainability, as the fixed manufacturing emissions get spread out over a greater number of passenger-kilometers. As such, maximizing the lifespan of the scooters reduces the environmental impacts and growing the sustainability benefits offered to cities.

While available data does not allow us to directly attribute lifespan improvement in kilometers or kWh, this analysis provides some insights into the relative impact of various investments, as shown in Figure 5. Improvements in design and proactive maintenance are responsible for an estimated 33.3% of the achieved lifespan extension. Using modular parts that are kept on hand in the company's warehouses is responsible for an estimated 15.2%, while improved fleet retention and the move to resell instead of retiring early through the second-life program increased lifespan is responsible for an estimated 9.1%.

FIGURE 5

HOW HAS VOI EXTENDED LIFESPAN?

Estimated attribution of strategies to increase lifespan



While these investments have greatly increased lifespan to date, we would expect lifespan to plateau in the next couple of years due to limitations in the vehicle form factor and the operator's ability to control factors intrinsic to operating in a shared, public environment. Based on planned design improvements and updates to its proactive maintenance practices, we project that Voi's V5 model will last several months longer than the V4–up to 60 months in operation. However, other levers may have reached their limit. For example, it is not clear how much more can be done to prevent vandalism and theft of vehicles.

Additional improvements in Voi's data collection protocols are necessary if the company wants to continue to improve its sustainability performance. In particular, more detailed tracking of its batteries would provide a more accurate estimate of lifespan and help the company to identify opportunities to extend useful life, develop a refurbishing practice, and improve second-life programs.

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III. CALCULATING VOI'S VEHICLE LIFESPAN

14 _ **Note:**
This is the estimated point at which battery capacity declines to 70%, making it less reliable for shared-use purposes but still usable for private e-scooter use.

16 _ **Note:**
To simplify the model, we rounded to assume that Voi's e-scooters sold for private use were ridden 50% as much as e-scooters in a shared fleet. According to research and information published by e-scooter operators, the average trip distance on a shared e-scooter is about 2 km. There is little information available on distance ridden on privately owned e-scooters, so we assumed an average of one round trip a day for 250 days each year, or roughly 1,000 km total distance per year, for a daily average of 2.7 km.

APPENDIX

DATA SUPPORTING FIGURE 2: CHURN RATE FOR VOI'S E-SCOOTER FLEET

4_

	Loss Rate (% per month)	Decommission Rate (% per month)	TOTAL Churn Rate (% per month)
Months 1-6	0.88%	0.18%	1.06%
Months 7-12	0.46%	0.18%	0.64%
Months 13+	0.46%	[0.18 + 0.041 * (months - 12)] %	[0.64 + 0.041 * (months - 12)] %
Month 13	0.46%	0.22%	0.68%
Month 14	0.46%	0.26%	0.72%
Month 15	0.46%	0.30%	0.76%
Month 16	0.46%	0.34%	0.80%
Month 17	0.46%	0.38%	0.84%
Month 18	0.46%	0.42%	0.88%
Month 19	0.46%	0.46%	0.92%
Month 20	0.46%	0.50%	0.96%
Month 21	0.46%	0.54%	1.00%
Month 22	0.46%	0.58%	1.04%
Month 23	0.46%	0.62%	1.08%
Month 24	0.46%	0.67%	1.12%
Months 25+	0.23%	[0.18 + 0.041 * (months - 12)] %	[0.41 + 0.041 * (months - 12)] %

BRIGHTSIDE