January 6, 2021

California Air Resources Board (CARB)
1001 I Street, Sacramento, CA 95814

RE: Potential Future Changes to the LCFS Program

Dear Chair Liane M. Randolph,

As a subsidiary of Ford Motor Company, Spin is an industry leader in offering shared micromobility solutions, including e-scooters and e-bikes. Over the last four years, Spin has greatly expanded the availability of e-scooters and e-bikes for hire in over 113 cities and universities across North America and Europe. Each day, hundreds of thousands of Americans rely on Spin e-scooters and other microbility options to conveniently get to work, school, or visit local retail businesses in their communities. In the context of COVID-19, the value of micromobility as a vital transportation option has also become more apparent. By eliminating the highest risk factors for coronavirus transmission, electric scooters offer two distinct safety advantages compared to other modes of shared transportation: The ability to 1) ride alone and 2) stay outdoors. These public-health advantages explain why many U.S. cities quickly declared electric scooters an "essential service" and integral part of their local transportation ecosystem.

Beyond the value to riders, shared micromobilty also offers broader potential as a sustainable transportation alternative to gasoline-based cars and motor vehicles. This is particularly true in cities, where the majority of trips are short-distance (e.g. less than 3 miles) and congestion and pollution from cars is a persistent and growing issue. Fortunately, within the micromobillity industry, there is a growing recognition that more must be done to improve the underlying sustainability of all elements of operations. At Spin, for example, these efforts include using 100% renewable electricity to charge our fleets (i.e. e-scooters and e-bikes), replacing gas vans with electric vans and other sustainable vehicles such as e-cargo bikes and electric low-speed vehicles to serve operational needs, and using swappable and long-range batteries to reduce the need for transporting scooters to our warehouses for charging, so e-scooters and e-bikes can remain on the street available for use.

In reference to CARB's public workshop on changes to the LCFS Program, we have included some relevant data (see attached file) to help inform the development of new energy economy ratios (EERs) for "battery-electric micromobility applications." Specifically, our data includes a recent Life Cycle Analysis (LCA) of our latest e-scooter vehicle completed by the Massachusetts Institute of Technology, along with aggregated mode shift survey results from our riders in California. These mode shift surveys shed light on the decision making behind why people chose to use shared e-scooters and e-bikes over other transportation options, including private cars, rideshare Apps, public transportation, and walking. Encouragingly, over 27% of our respondents said they decided to ride an e-scooter rather than a private car or rideshare option (e.g. Lyft or Uber). Still, we recognize that significantly more mode shift away from cars is needed. Spin recently published a report (see attached file) on the factors that we believe can enable and encourage such mode shift and what we are doing to promote greater mode shift.

Looking ahead, we strongly support the creation of new energy economy ratings (EERs) for micromobility to help achieve CARB's stated objective of accelerating the transition to zero-emission vehicles (ZEVs). As your staff continues the consultation process, we encourage you to reach out for additional data and technical input as needed. At the moment, we are working with researchers from UC Davis to conduct additional mode shift research based on our data and to better understand what drives mode shift so we can enable greater mode shift to happen in the future. Such inputs may be useful for your team to inform the development of EERs for micromobility by leveraging the latest industry and independent research available.

Thank you for your consideration, and we look forward to continue working with your team on this important issue. If you have any follow up questions or additional data needs, please do not hesitate to contact us directly.

Sincerely,

Brit Moller

Brit Moller
Director of Public Policy
Spin ("Skinny Labs Inc.")

Hui Wen Chan

Hui Wen Chan
Director of Sustainability
Spin ("Skinny Labs Inc.")

SPIN

Micromobility:

From Tailpipe Emissions to a More Sustainable World through Mode Shift

Contents

Executive Summary

The COVID-19 global health crisis created a groundbreaking shift in the way people travel. In the height of the pandemic, all modes of transportation came to a virtual standstill as lockdowns dramatically decreased travel worldwide. However, essential workers and others who still needed transport sought safe, single-person, socially distanced forms of transportation, creating a significant shift in travel behavior.

The Impact of COVID-19 on Transportation and Sustainability

Throughout the pandemic, micromobility enabled transport resiliency by providing riders with safe and reliable alternative transportation modes, and where cities needed to scale back public transit due to safety and reduced ridership, micromobility provided a transportation lifeline to many essential workers.

The shift in transportation patterns from reduced car trips and increased use of micromobility options during the early days of the pandemic contributed to significant gains in sustainability, with record drops in air and noise pollution as car trips in urban areas fell dramatically.

Although these sustainability gains were impressive, they were short-lived. Transportation sector emissions are already returning to pre-pandemic levels as car trips have recovered and even surpassed pre-pandemic levels in some cities.

The pandemic allowed cities a glimpse into a different 'normal', with cleaner air, more shared space, and less vehicle congestion. As we emerge from the pandemic, it is clear that micromobility is a key player in facilitating this new normal by offering sustainable modes of transportation that can help with recovery efforts, meeting community needs, tackling climate change, and building a more sustainable transport ecosystem.

Sustainability in Micromobility

The climate crisis facing cities today requires new strategies that promote sustainable transportation solutions. The transportation sector is the leading cause of CO_2 emissions in major cities and the fastest growing source of emissions, with cars being the main driver of the sector's emissions. Micromobility can play a crucial role in helping cities mitigate climate change by offering more sustainable transport modes that reduce car use and emissions. But this requires the micromobility industry to operate sustainably.

The micromobility industry has come a long way over the past few years on sustainability. When scooters were first introduced, they were not as durable as today's generation of scooters and the operational activities of the micromobility companies were not as sustainable as they should be. Over the past two years, micromobility companies have focused on improving the sustainability of their vehicle fleets and their operations. Scooters have become more durable and operators have adapted their operating choices – switching to renewable electricity for charging, recycling and harvesting materials, and switching operations fleets to electric vehicles. These choices have dramatically brought down the environmental impact of the scooter sector, as illustrated by the results of Spin's recent life cycle assessment of its latest generation of e-scooters.

Micromobility has the potential to transform urban environments into less car-centric cities by providing a sustainable first and last mile complement to public transport and a superior alternative to cars for shorter trips. However, being sustainable is not sufficient for creating positive change. In order for micromobility to live up to its full potential as a sustainable mode of transport that contributes to decarbonization, we need more mode shift away from cars for short trips. Safety, infrastructure, equitable access, and supportive policies are all essential ingredients to driving mode shift.

Mode Shift for the Journey to a Sustainable Future

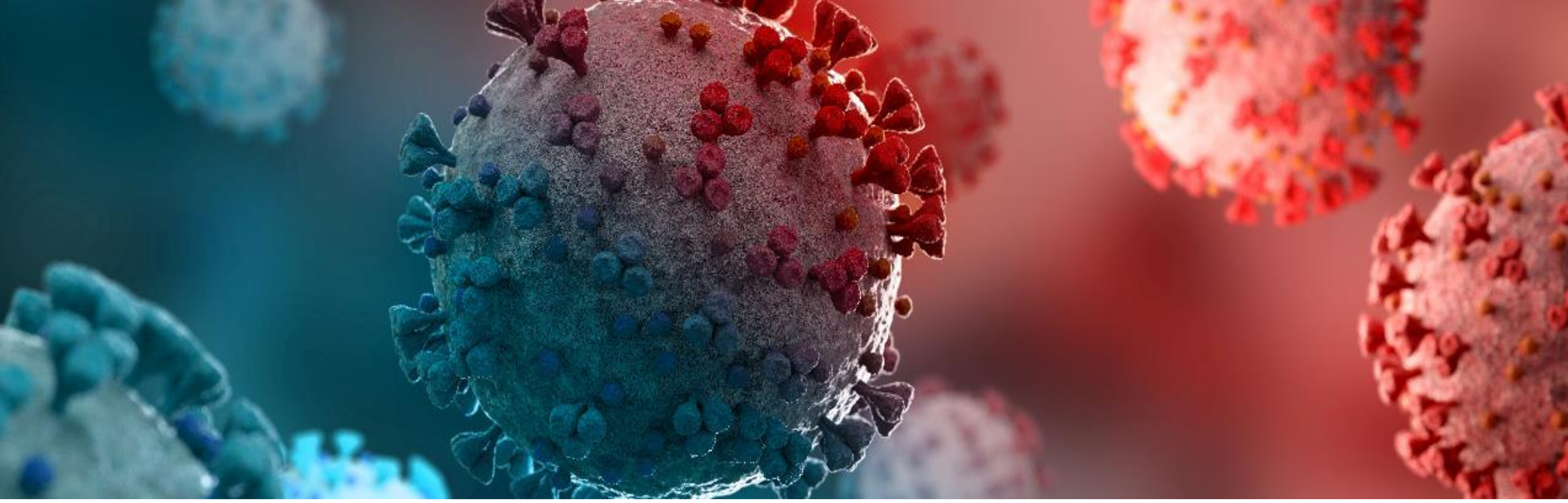
Last month, the UN Intergovernmental Panel on Climate Change (IPCC) published its Sixth Assessment Report, which warned that changes to the climate are not only well underway, but are also widespread, rapid, and intensifying. Urgent actions to reduce greenhouse gas emissions and limit global warming are needed if we want to build a more sustainable future. As cities turn their attention to tackling climate change, the sustainability of micromobility solutions becomes even more important. Society has reached a pivotal moment where change can happen and we can see a future for cities where mobility is not just about one mode of transit and instead meets the needs of all people and our planet.

This paper highlights the sustainability gains that micromobility can offer cities and communities. However, the sustainable benefits that micromobility can offer cannot be fully realized without accelerating its adoption and displacing car trips. To achieve higher utilization and mode shift, micromobility operators, cities, and communities must focus on driving changes in the key pillars of: 1) safety, 2) equity, inclusion, and access; and 3) supportive policies and regulations.

Improved safety outcomes for micromobility users, including safer places to ride, are an important prerequisite for mode shift. Several micromobility companies have recently adopted explicit Vision Zero goals as part of their safety programs. The Vision Zero approach traditionally targets safety through the three E's: engineering, education, and enforcement. Recently, in recognition of the fact that Black and Indigenous populations and neighborhoods are significantly more affected by traffic violence, many practitioners have added a fourth "E", equity, and begun rethinking the "enforcement" element of Vision Zero to address the disproportionately negative impact policing has had on these same communities.

The transportation sector has a huge influence on equity, especially in urban areas. Micromobility partners can help cities achieve equity and access goals through providing efficient sustainable transportation modes and lifting barriers to access of transportation services. However, providing access to micromobility services does not automatically translate to adoption and impact. Investment in safe and sustainable infrastructure in underserved communities is key to achieving transportation equity.

The last pillar to drive mode shift is effective and outcomes-based policies and regulations. Regulations and policies are drivers of municipal agendas for social change and environmental sustainability. Creating the right policies and regulatory frameworks are key to accelerating wider micromobility adoption. Municipalities should develop the following features to foster successful, accountability-focused frameworks: (1) Public-Private Collaboration, (2) Outcome-based Accountability, and (3) Locally-based Policy.



Introduction: The Impact of COVID-19

The COVID-19 global health crisis created a groundbreaking shift in the way people travel. In the height of the pandemic, all modes of transportation came to a virtual standstill, as lockdowns dramatically decreased travel worldwide. Nevertheless, essential workers and others who needed transport sought safe, single-person, and socially distanced forms of transportation, marking a significant change in travel behavior. While the usage of micromobility modes dropped considerably during the pandemic, along with other transit modes, the shift in transportation habits drove new adoption and utilization of micromobility modes, such as e-scooters, bikes, e-bikes, and e-mopeds. Notably, approximately 50% of micromobility operators reported an increase in first-time riders.

Micromobility use has grown rapidly over the past few years. Micromobility operators provide transportation over short distances via lightweight, usually single-person vehicles, such as bicycles and scooters. As the pandemic persisted, cities and communities came to view micromobility options not only as recreation, but also as an essential part of their transportation ecosystem. Throughout the pandemic, micromobility enabled transport resiliency by providing riders with a safe and reliable alternative to traditional transportation modes, particularly offering a lifeline to essential workers in cities, where public transit was scaled back due to safety and reduced ridership. The importance of this impact on transport resilience cannot be underestimated. As the world continues to deal with disruption, whether another pandemic or the effects of climate change, cities and communities will increasingly need more transportation options – including micromobility – in order to ensure greater transport resiliency.

The shift in transportation patterns from reduced car trips, as well as the increased use of micromobility options during the early days of the pandemic contributed toward significant gains in sustainability, with record drops in air and noise pollution due to fewer car trips in urban areas. Comparing average normal pollution levels to those during the pandemic, the NASA Center for Climate Simulation discovered that nitrogen dioxide levels fell between 20-50% in 50 of 61 cities sampled.[1] A study published in ScienceDirect's Environmental Research discovered that New York City had a 23% city-wide improvement in fine particulate matter ($PM_{2.5}$) during the shutdown, which lasted between March 15 and May 15, 2020, compared to average levels between 2015 and 2018.[2] With respect to noise pollution, an overall reduction of 2.6 decibels, representing almost half of the amount of normal noise pollution, was measured from data across four states by a joint study between Apple and the University of Michigan that collected data across four states from smart watches and phones during the initial COVID-19 global lockdown.[3]

New York City pollution levels improved 23% during the COVID-19 shutdown months

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Although these gains in sustainability were impressive, they were short-lived. Emissions from the transportation sector have already returned to pre-pandemic levels due to the recovery of car travel post-lockdown, even surpassing pre-pandemic levels in some cities, with passengers seeking socially distanced transport options. Single occupancy vehicles, especially for short distances, are not sustainable, resulting in the rapid loss of sustainability gains, achieved during the pandemic. Micromobility adoption must play an important role in a sustainable transit ecosystem by facilitating the greater use of public transportation over private single-occupancy vehicles. Mode shift to micromobility will enable cities to tackle the challenges of climate change, and meet their sustainability goals, making permanent the gains that the disruptions from COVID-19 showed were possible. Spin has partnered with Marsh, the leading global risk firm, to examine these critical issues and to understand what cities need to achieve change.

Reimagining the Future of Urban Space

Streets, historically dedicated to car travel and parking, account for more than 80% of urban public space.[4] In addition to changing the way people travel, the COVID-19 pandemic offered communities an opportunity to reimagine the future use of city streets by reallocating public space toward economic, social, and recreational activities, as well as alternative and sustainable methods of transportation. Communities are becoming increasingly urban, with the UN predicting that over two-thirds of the world's population will live in cities by 2050. The most recent U.S. census showed population growth for the 10 largest American cities, ranging from 1.9%–11.2% growth. Cities, such as Los Angeles, New York, San Francisco, Chicago and Atlanta, already struggle with traffic and congestion.

Communities will need to reimagine the allocation of streets, in response to increasing urban populations and changing mobility demands of urban residents, placing greater priority on safe, affordable, sustainable, and convenient transport options for non-car users. This process accelerated during the pandemic, as cities came to view micromobility transportation options as not only a form of recreation, but also as an essential part of their transportation ecosystem. Spin data showed that average trip length increased by 26%, compared to pre-pandemic levels, with some cities increasing their median ride distance by 60%, indicating that scooters are being used for more than just first and last mile transportation needs. This shift from recreational to essential transport focused attention on the need for urban communities to redevelop space and infrastructure for these newer modes of transportation.

The need for investments in temporary and permanent initiatives to support social distancing created the opportunity to reimagine the future of cities. The ability to reimagine our public spaces opened new avenues for multi-modal transportation. One such example was the conversion of car lanes to space dedicated to bicyclists, micromobility users, and walkers.

Significantly, in some cases, the pandemic initiated transportation experiments that led to permanent changes in allocation of space, fostering support for economic recovery. A combination of closed streets and micromobility can lead to higher spending at local businesses and increased tourism, illustrating that not only can micromobility enable significant sustainability gains, but also encourage community recovery from the pandemic.

The 15 Minute City

In order to maintain the momentum created by the pandemic, cities and their transportation partners must think boldly and creatively to reshape cities to be more sustainable and people-centric. One such approach that has captured growing attention is the 15-minute city. The concept of a 15-minute city centers around making it easy for residents to access all elements of their daily life – work, home, leisure, and essentials like food, education, and healthcare – within 15 minutes or less, through a combination of reliable public transport, and shared public or private mobility.

As a result of drastic changes in cities over the past year, with evolving streets landscapes and shifting transportation habits and patterns, Spin launched an initiative to create 15-minute cities in order to help cement the progress towards building more sustainable and livable communities. Spin's goal is to make it as convenient to get around by walking, biking, scooting, as well as utilizing public transit and other shared forms of mobility as by car.

Behavioral science studies show that unsustainable car-driving behaviors are difficult to change because using cars has become habitual.[5] The COVID-19 pandemic offered cities a unique scenario, where the habits of many travelers were disrupted and open to change, making this the perfect time to make progress toward the achievement of a more sustainable and livable future.

Continuing the Momentum

The pandemic gave cities a glimpse into a different 'normal', with cleaner air, more shared space, and less vehicle congestion. As we emerge from the pandemic, it is clear that micromobility will be a key player in facilitating this new normal by offering sustainable modes of transportation, which will help with recovery efforts, meeting community needs, and tackling climate change. The pandemic demonstrated that micromobility offers cities a reliable and popular alternative to less sustainable modes of transportation, critical to the development of a resilient and sustainable transportation system.

As cities turn their attention to tackling climate change, the sustainability of micromobility solutions becomes even more important. Transportation accounts for approximately 20% of global greenhouse gas emissions and, in places like the U.S., transportation has displaced the utility sector as the largest contributor to emissions. Road transport accounts for approximately 75% of transportation emissions.[6,7] Crucially, reducing transit-oriented emissions is imperative to tackling the climate crisis, requiring shifts towards more sustainable transportation modes, like e-scooters, bikes, and electric cars.

Society has reached a pivotal moment for change. We can see a future for cities, where mobility is not just about one mode of transit but rather meets the needs of all people and our planet. This paper highlights the sustainability gains that micromobility can offer cities and communities. However, such benefits cannot be fully realized without accelerating micromobility adoption and displacing car trips. Hence, this report also addresses the key pillars to driving mode shift: (1) Safety; (2) Equity, Inclusion, and Access; and (3) Supportive Policies and Regulations. Throughout the paper, we highlight examples from the micromobility sector, with a focus on how Spin is advancing sustainability by addressing these pillars to enable mode shift.

Sustainability isn't enough without adoption.

Sustainability

The climate crisis facing urban communities today requires new strategies to promote sustainable transportation solutions. The transportation sector is the leading cause of CO_2 emissions in major cities, as well as the fastest growing source of emissions, with cars being the main driver of the sector's emissions. Micromobility can play a crucial role in helping cities to mitigate climate change by offering more sustainable transport modes, which reduce car use and emissions. By providing critical transportation services at significantly lower levels of emissions, micromobility can enable greener, healthier, safer, more equitable, and livable cities.

Reducing Emissions

Due to rising greenhouse gas (GHG) emissions, driven by human activities, our planet is rapidly warming. July 2021 was the planet's hottest month on record, according to the National Oceanic and Atmospheric Administration.[8] This follows NOAA's report that 2020 tied for the hottest year on record.[9] A recent UN Intergovernmental Panel on Climate Change Report warns that the impacts of global warming are now unavoidable.[10] Even if countries started significantly cutting emissions today, global temperatures would still rise by approximately 1.5 degrees Celsius above pre-industrial levels within the next two decades. This will result in more life-threatening extreme weather events, rising of sea levels, and loss of animal and plant species. However, societies can deter the effects of climate change by achieving net zero emissions by 2050. Reaching net zero requires counterbalancing all GHG emissions released in the atmosphere by removing a commensurate amount of emissions from the atmosphere.

In order to reduce emissions in the transportation sector, an emphasis on mode shift is crucial. Micromobility services can facilitate the transition away from cars, as well as reduce emissions. In 2020, the North American Bikeshare and Scootershare Association (NABSA) estimated that 36% of micromobility trips replaced car ones in North America. These trips cumulatively offset approximately 29 million pounds of CO_2 emissions.[11] Continued improvements could offer even more gains. Given the significance of these potential effects, it is critical that the transportation sector and cities collaborate now.

If mode share for e-bikes rises to 11%, a 7% decrease in CO_2 emissions from the urban transport sector by 2030, is possible, the equivalent of taking 134 million cars off the road.

Micromobility transit options provide an ideal first and last mile complement to public transportation. The NABSA study reported that 50% of micromobility riders use shared micromobility to connect to transit. 16% of total micromobility trips connected to public transportation. Spin's own data from six U.S. cities showed that an even greater share of trips – approximately a quarter of trips in each city – were used to connect with public transit.

Furthermore, micromobility offers residents additional transportation modes ideal for shorter trips. 48% of car trips in the U.S. are under three miles,[12] a distance that can easily be covered by more sustainable micromobility options. In fact, micromobility transport solutions could replace 50-70% of short-distance car trips.[13]

Micromobility transport options could replace 50-70% of short-distance car trips

Sustainability is not solely a story of mode shift. Indeed, the operational infrastructure supporting micromobility – from the operations vehicles, required to deploy, rebalance, and maintain scooters and bikes, to the electricity required to charge them – is an equally important part of the conversation. The charging of electric scooters is one of the industry's main sources of energy consumption, with additional miles driven to pick up scooters, transport them for charging, and redistribute them accounting for 43% of scooters' emissions impact.[14] Increasingly, micromobility operators are choosing to charge their vehicles with renewable electricity and use cleaner hybrid and electric vehicles, as well as e-cargo bikes to maintain their fleets, rather than gas-guzzling vans and trucks. Utilizing electric vehicles, powered by clean energy, removes the need to burn fossil fuels in the deployment of micromobility fleets, thus eliminating further emissions in local cities. Since 2020, Spin has been using 100% renewable electricity for all of its charging. Spin also committed to fully electrifying its operations vehicles by 2023. In the U.S., Spin was the first micromobility company to deploy full-sized electric vans in its operations.

The manufacturing of micromobility vehicles is another significant source of emissions. A critical component of improved sustainability includes managing supply chain impacts. Micromobility operators are partnering with suppliers to lower manufacturing impacts.

Designing Products for Sustainability

Shared micromobility vehicles are rapidly evolving, with major gains in sustainability. One of the biggest drivers of sustainability is product lifespan. While early models were not designed for shared use and much less durable, newer models are now designed to handle heavy fleet usage, heavy wear and tear, and adverse weather, significantly increasing the average lifespan of the vehicles. In addition, vehicles are more modular and easily repairable. Sophisticated sensors and diagnostics allow micromobility operators to optimize performance, monitor hardware problems, and enable faster maintenance and repairs, all of which extend the longevity of the vehicles. Today, many micromobility operators, including Spin, are reporting vehicle lifespans of at least 2-3 years, a significant improvement over earlier vehicle models whose lifespans were measured in mere weeks or months. Improved durability and longer lifespans decrease the frequency of having to replace parts and scooters, in turn reducing demand for the valuable resources needed to manufacture new parts and vehicles, and minimizing emissions from end-of-life processing.

Moreover, the micromobility industry has introduced new vehicles, which have swappable batteries instead of integrated batteries, allowing for greater operational efficiencies and sustainability benefits. Swappable batteries can be replaced on the street when depleted, making it more efficient and sustainable to operate and maintain. Studies estimate that driving requirements for operational vehicle are reduced between 50%-75% when deploying scooters with swappable batteries, compared to integrated batteries.[15,16,17] These savings are a result of being able to service more scooters per trip per operations vehicle, as only the batteries need to be collected for charging rather than the whole scooter. Furthermore, swappable batteries make it possible for operators to use smaller operations vehicles, such as e-cargo bikes, to do battery swaps and rebalance scooters. The need to transport scooters back to a warehouse only when repairs are needed likewise reduces the wear and tear of vehicles, in turn extending their lifespan.

Lastly, micromobility companies are designing for sustainability, through material selection. There is growing use of recycled and low-carbon materials in scooters. European micromobility companies, including Tier, Dott, and Voi, committed to using at least 20% recycled content in all new scooters, beginning in 2021.[18]

From End-of-Life to Second Life

Responsible treatment of scooters at the end-of-life prevents additional waste from ending up in landfill. A number of micromobility operators, including Spin, are harvesting parts for repairs to extend the life of their vehicles. In addition, operators are working with recyclers to recycle worn parts and vehicles, which can be mined for materials to reenter the production cycle and be manufactured into other goods. Spin has partnered with R2 certified recyclers to ensure that at least 98% of their vehicles are recycled and mined for valuable materials.

Micromobility companies are also looking to second life opportunities for their vehicles and batteries to improve their sustainability. Several operators, such as Bird, Tier and Voi, refurbish and sell used scooters to consumers and other fleet operators. Moreover, companies are developing second life opportunities for their batteries, which outlast the scooters. For example, Lime has partnered with Gomi to repurpose batteries into portable speakers. Spin is likewise developing partnerships with companies to resell scooters and repurpose used batteries.

E-Scooter
Life Cycle Assessment

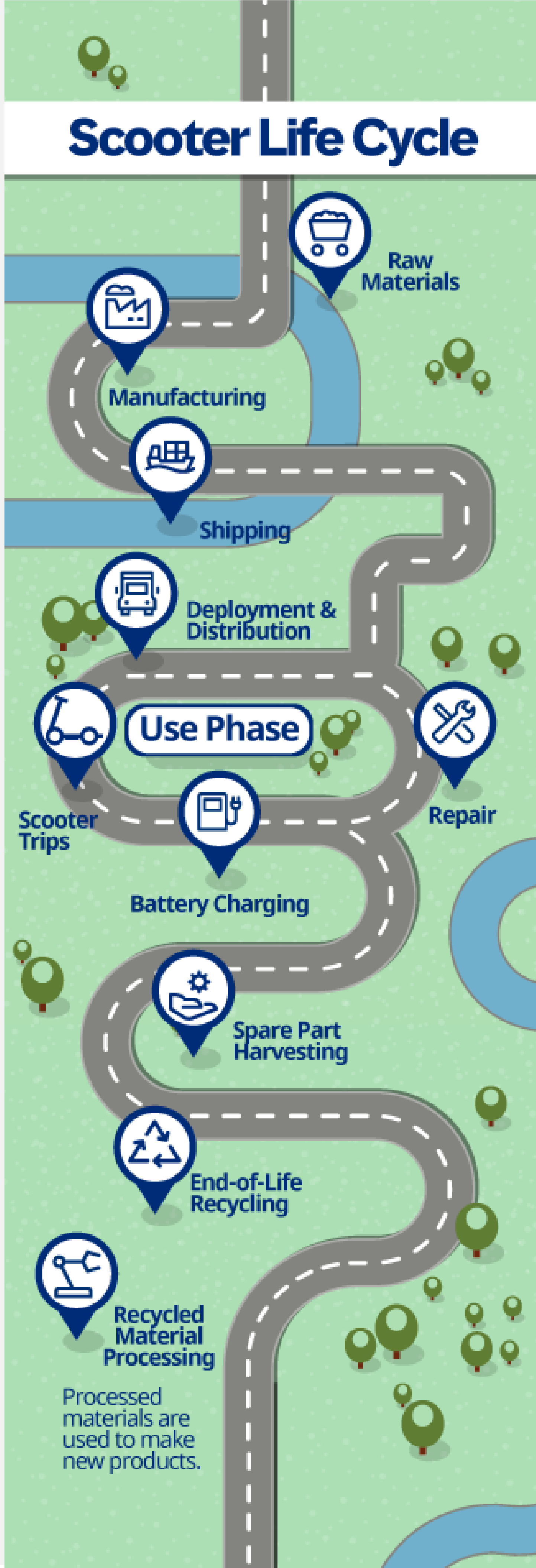
Life cycle assessment (LCA) is a technique used by a wide range of industries to assess potential environmental impacts, including GHG emissions, associated with a product or process.

The main steps of performing an LCA include:

1. Compiling a cradle-to-grave inventory, spanning the full life cycle of a product from raw material extraction all the way to its final disposal, of relevant energy and material inputs and environmental releases;
2. Evaluating the potential environmental impacts associated with identified inputs and releases; and
3. Interpreting the results to assist in making more informed decisions to reduce the environmental impacts of the product or process.

An LCA, which measures the environmental footprint of a product, can help companies better understand the relative impacts of each phase of their product's life cycle. It also helps identify the areas with the highest environmental impacts and the greatest potential for emissions reductions. A number of micromobility providers have reported using LCAs to assess the environmental impacts of their vehicles. Some cities have also requested such an assessment from micromobility operators, to substantiate sustainability claims.

Spin recently completed an LCA of its S-100 7th Edition scooter, which has a swappable battery, in partnership with the Sustainability and Health Initiative for NetPositive Enterprise (SHINE) at the Massachusetts Institute of Technology (MIT) Materials Systems Laboratory. In this report, we use Spin's LCA to illustrate how product and operational improvements have reduced emissions and improved the sustainability profile of e-scooters.



Results were compared to an LCA study of an earlier scooter model with a non-swappable battery conducted by MIT in 2019, prior to business and operational decisions that Spin has taken to improve the efficiency of its operations and the sustainability of its scooter and service. The LCA looked at the following stages: raw material extraction, manufacturing, shipping, use (i.e., scooter trips, deployment and distribution, battery charging, and repair) and end-of-life.

Cradle-to-Gate Impacts: Raw Material Extraction, Manufacturing and Shipping

The raw material extraction and manufacturing phases capture the environmental impacts of producing the scooter and are based on a parts-level bill of materials and information from the EcoInvent 3.4 life cycle inventory (LCI) database. Following production, the scooters are shipped from China, where they are manufactured, to Spin's markets, where they are deployed, via ocean freight and trucks. These activities happen prior to the scooters reaching Spin and are often referred to as "cradle-to-gate."

Use Phase

The use phase captures the environmental impacts during the life of the scooter, while it is being operated. This is where the impacts of Spin's decisions on how to operate and charge its scooter fleet are reflected. Environmental impacts associated with the use phase were based on data of Spin's operational activities in San Francisco, California from January 2020 to June 2021. These activities included scooter maintenance (including repairs), battery charging, and scooter deployment and distribution using a fleet of operational vehicles. The impacts of a longer vehicle lifespan (estimated to be approximately 7,300 kilometers) and the operational efficiencies from using swappable batteries are also reflected in this phase.

Spin uses 100% renewable electricity for its charging and has begun using electric operations vehicles. The LCA reflects a hybrid operating fleet with 50% electric vehicles and 50% diesel vehicles. Scooters are repaired and maintained by harvesting used spare from decommissioned scooters to extend their life and reduce unnecessary waste.

End-of-Life

The end-of-life phase captures how the scooters are disposed – for example, in a landfill or recycled. Although Spin reuses parts to repair and maintain its scooters and extend their life, scooters and parts will eventually reach their end of life when worn or damaged. To divert waste from landfill, Spin partners with R2 certified recyclers, who ensure that at least 98% of scooter materials, including batteries, metals, and the motor, are mined and recovered, and sent downstream for processing into new manufactured goods. This reduces the need for new primary materials, resulting in positive environmental impacts.

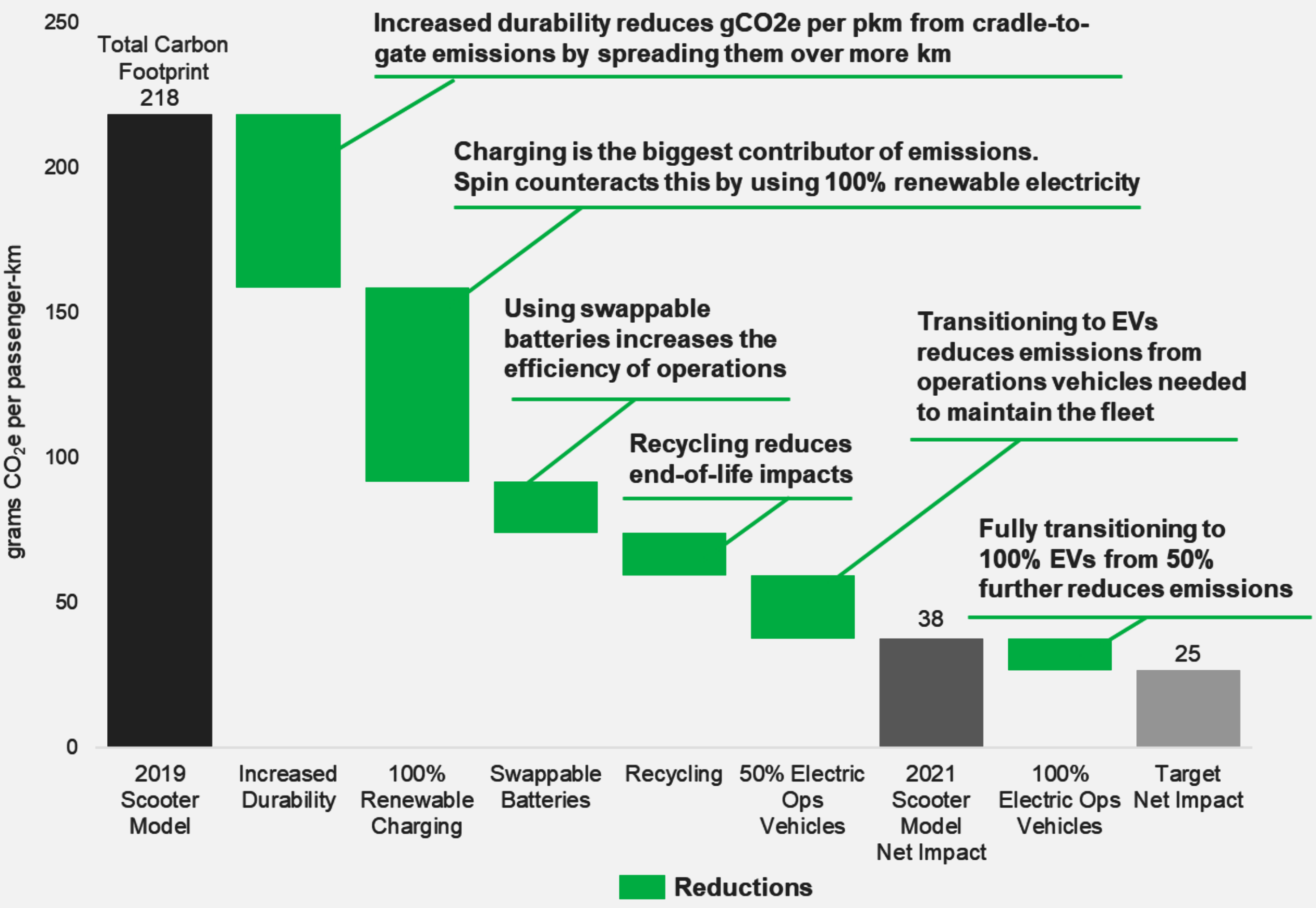
Results

The results of the LCA were normalized to a standardized personal transportation metric called the passenger-kilometer (passenger-km or pkm), which is equivalent to transporting one person for one kilometer. Expressing the results in passenger-km allows us to compare the impacts of a single person riding an electric scooter to other modes of transport over the same distance, such as driving a private passenger car.

Based on Spin's LCA, the net carbon impact of riding Spin's scooters is 38 grams CO_2 equivalent (g CO_2e) per passenger-km, which is almost 85% less than riding in an average gas-powered car carrying only one passenger in the U.S., which emits 251g CO_2e per pkm.[1] Once Spin completes its transition to a 100% electric operations fleet, the LCA estimates that the net carbon impact of riding Spin's scooters will be further reduced to 25g CO_2e per pkm.

Battery charging is the dominant contributor to the scooter's carbon footprint. Spin counteracts this by purchasing 100% renewable electricity to power its facilities and charging infrastructure. This results in a much smaller impact from battery chargingase. To reduce emissions even further, Spin is transitioning its entire operations fleet to 100% electric vehicles by 2023, and working to further increase the durability and lifespan of its scooters. As scooter durability and lifespan increase, the use phase, associated with battery charging and the operations vehicle fleet, will become even more important. Not surprisingly, operational decisions to use electric vehicles and renewable energy are fundamental to providing a sustainable and carbon-free micromobility service.

Carbon Emission Reduction from Material and Operational Improvements



[1] Based on data from the US Environmental Protection Agency, which reports that an average passenger vehicle emits 404g CO_2e per mile (251g CO_2e per km).

Sustainability of the Micromobility Industry

Spin's LCA illustrates that the scooter industry has progressed significantly over the last few years. When the industry started, scooters were not as durable as those today, and its operational activities were not as sustainable. Over the past two years, micromobility companies have focused on improving the sustainability of their vehicle fleets and their operations. Scooters have become more durable, and operators have adapted by switching to renewable electricity for charging, recycling and harvesting materials, and changing operations fleets to electric vehicles. These choices have dramatically decreased the environmental impact of the scooter sector. In addition, major scooter companies, including Spin, are purchasing carbon offsets to neutralize their carbon footprint.

Micromobility companies should continue to leverage LCAs to identify areas for future vehicle design and operational improvements. As a part of Spin's work with SHINE, they are working to use the information gleaned from their LCA and carbon accounting – their environmental footprints – to understand how they can further create "handprints" – positive changes, compared with business-as-usual, in response to areas of concern – through business decisions that drive sustainability and mode shift to build a more sustainable transit ecosystem.

Enabling Healthier, Safer, and More Livable Cities

Micromobility has the potential to transform urban environments into less car-centric cities by providing a sustainable first and last mile complement to public transport, and a superior alternative to cars for shorter trips. The adoption of e-scooters and other micromobility modes, including e-bikes and bikes, can help cities reduce congestion and emissions. These impacts will only grow, as the sustainability of e-scooters and other micromobility transport modes continues to improve. Furthermore, it can contribute to reducing CO_2 emissions in major cities to help meet UN climate goals. However, being sustainable is not sufficient for creating positive change. In order for micromobility to reach its potential as a sustainable mode of transport that contributes to decarbonization, we need more mode shift away from cars for short trips. Safety, infrastructure, equitable access, and supportive policies are all essential ingredients to driving mode shift.

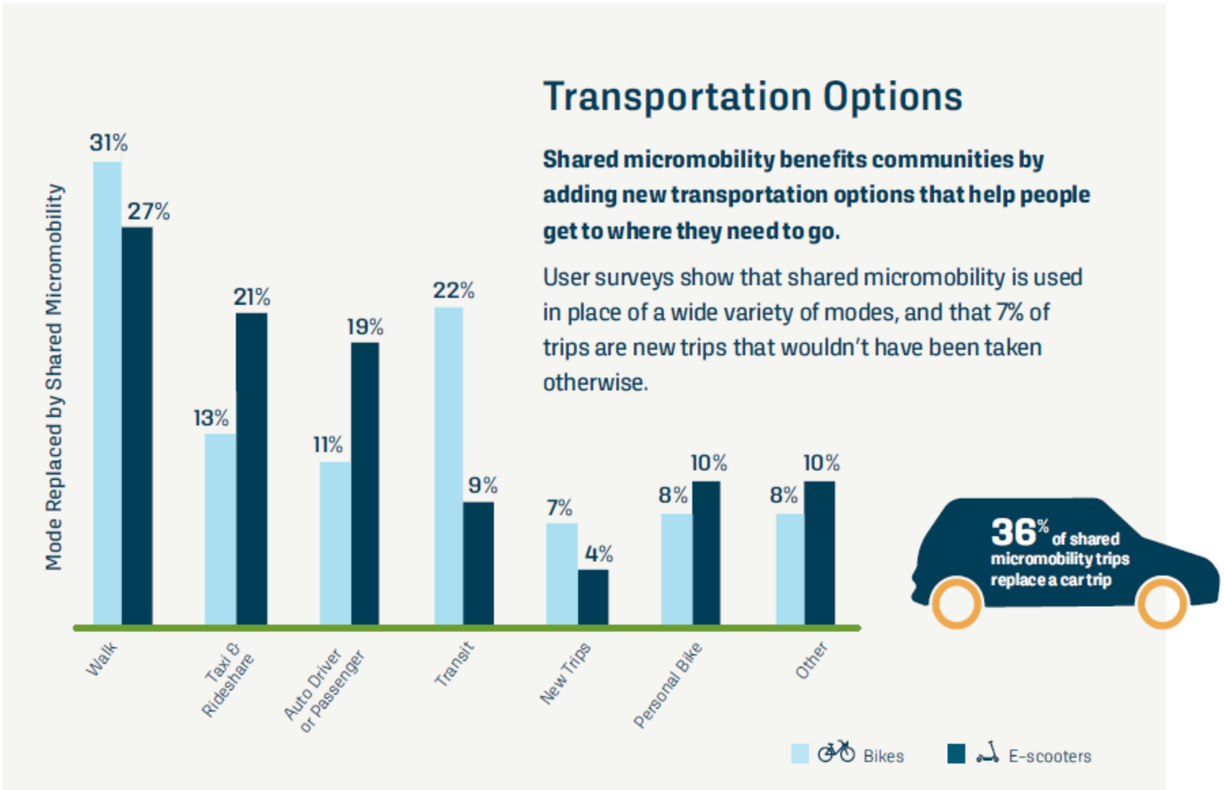
Mode Shift

Micromobility has offered cities sustainable and reliable modes of transportation during the COVID-19 pandemic. However, in order to build upon the gains achieved during the pandemic, the micromobility sector must continue to drive greater utilization and mode shift away from cars for short trips.

The Pillars of Mode Shift

In order to achieve this, micromobility operators, cities, and communities must focus on driving changes in the key pillars of: 1) safety, 2) equity, inclusion, and access; and 3) supportive policies and regulations. The sections that follow detail these concepts.

Broad access to e-scooters and other micromobility vehicles can catalyze change in urban mobility habits. In Portland, Oregon, 34% of shared e-scooter users said that they would have driven a personal car or hailed a taxi (19%), Uber or Lyft (15%), if they had not taken an e-scooter for their most recent trip.[19] NABSA’s 2020 State of the Industry Report reports that 36% of micromobility trips replaced a car trip in North America.



Source: NABSA 2020 State of the Industry Report

However, access to scooters alone is not enough. Micromobility operators must drive an acceleration of mode shift toward more sustainable methods of transportation, through a focus on providing tools that encourage shifts in behavior. The goal of the micromobility industry is to encourage people to adopt a car-free or at least a car-light life, using micromobility solutions in combination with complementary sustainable alternative modes, including walking, cycling, and public transit. Changing the habits of younger generations, prior to car adoption, and ensuring micromobility is a safe, convenient, reliable, and affordable option, are key to this mission.

1. Safety: Safety First, People Always

Safety is paramount to enabling mode shift. It applies not just to micromobility users, but to all road users. Improved safety outcomes for micromobility users, including places to ride, are an important prerequisite for mode shift. Safety is a top concern for automobile users in considering barriers to shifting active modes of transportation, including walking and biking.[20] When cities have invested in significant infrastructure for riding, mode shift away from cars has followed.

Vision Zero Approach

The gold standard for rider safety is the Vision Zero approach, which argues that all road fatalities are predictable and preventable and the goal of transportation system design should be zero traffic fatalities. Several micromobililty companies have recently adopted explicit Vision Zero goals as part of their safety programs, including Voi, which has adopted the goal of zero fatalities or serious injuries by 2030, and Spin, which employs the Vision Zero concept to develop and evaluate safety initiatives.

The Vision Zero approach traditionally targets safety through the three E's: engineering, education, and enforcement. Recently, in recognition of the fact that Black and Indigenous populations are significantly more affected by traffic violence, as well as the disproportionately negative impact policing has had on these communities, many practitioners have added a fourth "E," equity.

Engineering

Engineering is the first line of defense to reduce traffic fatalities and serious injuries, and includes the design of scooters and bikes, roadway infrastructure, and motor vehicles. In a critical shift, “safety by design” principles now drive the industry. Designing the next generations of scooters and micromobility programs for safety can propel greater adoption and be a key driver of sustainability gains in micromobility.

Vehicle and Program Design

Micromobility companies have incorporated a number of features into their vehicles to reduce both conflict with pedestrians and the risk of injuries to riders and non-riders. For example, Spin’s newly launched S-100T includes several innovative features designed to keep riders and non-riders safe:

- Smart Parking & Sidewalk Riding Self-Enforcement: Spin’s Insight Level 2 technology uses a combination of on-board computer vision, AI, audible rider feedback, and GPS to detect and prevent improper parking and sidewalk riding;
- Status Light: 360º status light alerts riders about reduced speed zones, no-ride zones, and geofences;
- Braking System: Three discrete braking systems allow a complete stop in under 15 feet;
- One-second Geofence Detection: Sensors enable faster adherence to city compliance requirements, such as no-ride or slow-speed zones;
- High Visibility Lights: Lights visible from 500 feet away that are the same brightness as those of a car;
- Dual-Leg Kickstand: Prevents tipping, and keeps sidewalks clear and safe for non-riders.

Furthermore, micromobility companies have added in-app features to improve safety. One such feature is a test to prevent intoxicated riding. Riding while under the influence of drugs or alcohol risks serious injury and can result in a Driving While Intoxicated (DWI) offense. A 103-person study by the Trauma Surgery & Acute Care Open found that of the 79% of patients who were tested for alcohol, at three trauma centers for e-scooter related injuries, 48% had a blood-alcohol level greater than 0.08, above the legal limit for drivers in most states.[21] To address such risks, Spin recently added an intoxicated riding test to its app. The test prompts riders to complete a series of tasks within the app in order to measure their reaction time before allowing them to check out the scooter. Other micromobility companies, such as Bird and Lime, have also added similar tests to prevent drunk riding.[22,23] These technological innovations can reduce the potential risks posed by intoxicated e-scooter riders to themselves and others to improve safety.

Another example of an in-app feature is slower modes for new and inexperienced riders. Spin offers both a Slow First Ride and Slow Mode to give inexperienced riders a chance to get comfortable with micromobility vehicles at slower speeds with less risk of injury. Likewise, Voi offers riders a beginner’s mode, which limits vehicle speeds.

Micromobility operators should continue to regularly evaluate these features to improve safety outcomes in the markets where they operate.

Infrastructure

Street redesign, which creates more space for riders and pedestrians, represents a major opportunity for improved safety outcomes and influencing mode shift. A study of 690 cyclists by the American Journal of Public Health found that protected lanes reduce bicyclist injury risk by up to 90%.24 For e-scooter riders, dedicated bike lanes also reduce injury risk. The Insurance Institute for Highway Safety (IIHS) discovered that 80% of injuries to e-scooter riders occur in the absence of bike lanes or multi-use trails.25 Bike lanes can furthermore reduce rider-pedestrian conflict by encouraging riders to stay off the sidewalk. In Philadelphia, the Bicycle Coalition found that sidewalk riding dropped from 19.8% on streets with no bike lane to 8.6% on streets with a bike lane, and 2.4% on streets with a buffered bike lane.[26]

WeCLAIM, winning proposal from Spin's Better Barrier Challenge

The pandemic drove gains in conversion of car lanes to those dedicated to bicyclists and walkers in several major cities, which included:

- Montreal, announcing more than 199 miles (320 km) of new pedestrian and bike paths;
- Seattle, permanently closing 19 miles (30 km) of streets to most vehicles;
- Brussels, announcing it would turn 25 miles (40 km) of vehicle traffic lanes into bike lanes;
- Paris, announcing the conversion of 31 miles (50 km) of streets to bike lanes;
- Bogota, adding 47 miles (76 km) of cycle lanes.

Increased infrastructure drives adoption of cycling as a transportation mode. A recent study found that cycling increased up to 48% in cities that added bike infrastructure. High-density cities with access to public transportation saw the greatest increases.[27] In a post-pandemic world, it is essential that cities continue to support investments in infrastructure to enable wider adoption and mode shift.

Spin supports the creation of safer places to ride through its Spin Streets program, which directly supports the design and installation of protected bicycle lanes, pedestrian amenities, and other roadway redesigns to improve the public realm. After Spin installed the first protected intersection in Salt Lake City, the city included multiple bike lanes and protected intersections in its 2021-2022 capital plan. Moreover, Spin has partnered with transportation data companies to offer Mobility Data for Safer Streets – a program that provides local municipal and community partners with information to target investments in sustainable infrastructure, where it will have the greatest impact.

Mobility Data for Safer Streets

Data is key to several of the mode shift pillars, including safety. Micromobility operators can use data to facilitate and track initiatives to improve inclusivity and access in underserved neighborhoods. Micromobility operators can enable innovation with data driven insights and support cities and communities that may lack access to such data to achieve their safety and infrastructure goals. For example, Spin's Mobility Data for Safer Streets initiative ("MDSS") awards partners with a unique suite of data sources, software tools and physical equipment to gather, analyze, understand, and present data for streets advocacy. If a transportation advocacy organization or neighborhood coalition wants to advocate for a transportation project, evaluate a completed project, or study speed limits and traffic calming effectiveness and the city has not completed a full assessment or does not have the necessary data tools to do so, the MDSS initiative provides access to the data tools to support the required project evaluation.

Furthermore, infrastructure investments can help create dedicated space for riders to park scooters, and prevent sidewalk clutter. For example, Spin works with public agencies and private community partners to establish Spin Hubs – docks that provide e-scooter charging and parking – at corporate campuses, hospitals, hotels, apartment complexes, and the public right-of-way. In San Francisco, the Spin Hub outside the CalTrain station offers riders a safe and convenient place to park a scooter and connect to transit. Swiftmile, an e-scooter charging station operator, also partners with cities and micromobility operators to install mobility hubs to facilitate charging and parking needs.[28] To encourage parking at dedicated micromobility charging hubs or parking spaces, some micromobility operators are offering incentives such as discounts or rewards to their riders.

First Protected Intersection in Salt Lake City

With the United States' announcement of $1 trillion in spending to improve and modernize the nation's aging infrastructure, the time to act is now. The Infrastructure Investment and Jobs Act includes funding for Vision Zero safety programs and micromobility infrastructure, like pedestrian and bike lanes, as well as shared mobility as an eligible use.[29]

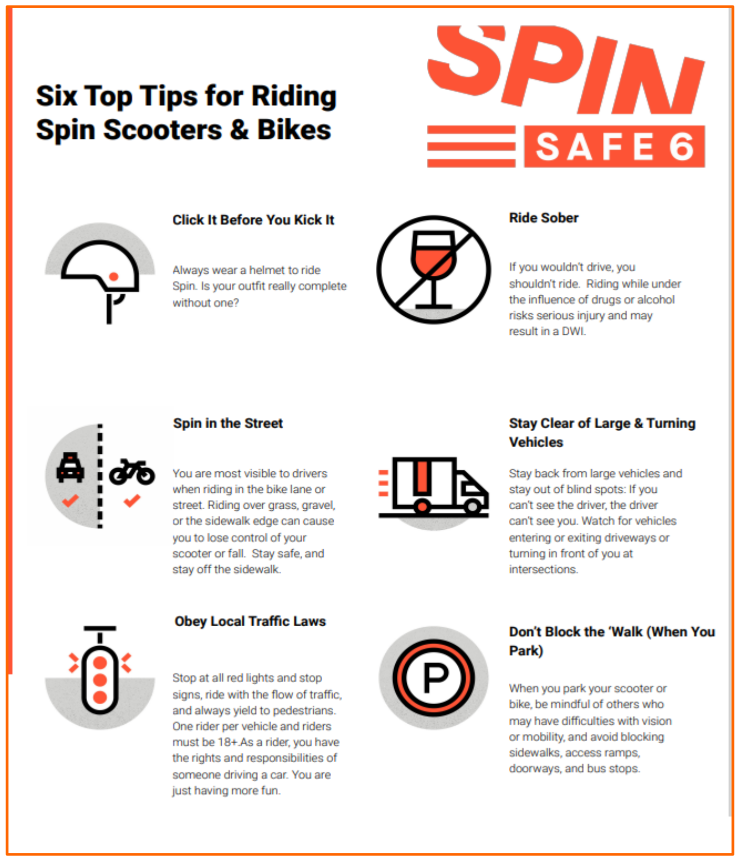
Motor Vehicle Design & Retrofits

Often considered beyond the scope of Vision Zero programs, motor vehicle design, including retrofits such as truck side guards, can also have a significant impact on safety outcomes for all road users. Side guards are rails or flat surfaces installed on trucks between or in front of the wheels on trucks that prevent a pedestrian or rider from being pulled under the wheels of a truck in the event of a crash. Large vehicles, including trucks and buses, are overrepresented in causing fatal injuries to pedestrians, cyclists, and scooter riders. Studies have found side guards to reduce the risk of fatal injuries in 75% of crashes, and 90% of crashes involving a semi-trailer – reducing risk for drivers of smaller motor vehicles as well as more vulnerable road users. [30] The United Kingdom and Japan, as well as several American cities have made side guards mandatory.

The USPS recently set a new high bar for pedestrian safety in the design of its new Oshkosh Defense mail truck. The new vehicle includes 360-degree cameras, front- and rear-collision avoidance systems, a low front-end, enhanced driver visibility with an oversized windshield, and built-in side guards.

Education

Raising awareness of best safety practices, alongside the causes of accidents, is the second strategy of Vision Zero to influence safe rider and driver behavior. Spin employs a variety of educational tools to reach riders, including direct digital communications, interactive quizzes, in-app messaging, social media, on-vehicle messaging, and in-person events. In order to maximize the effectiveness of its messaging, Spin focuses on the highest-impact behaviors, applicable in all markets in its outreach to riders, known as the Spin Safe Six: helmet use, slowing down near and yielding to pedestrians, following local traffic rules, parking responsibly, riding sober, and staying clear of large and turning vehicles.



Because inexperienced riders make up approximately two-thirds of all reported scooter injuries, with one-third occurring on the very first ride, Spin is developing a series of skills-based training programs to target correct handling of the scooter. In university and college markets, Spin will launch its Campus Safety Toolkit, which includes training for Student Safety Ambassadors about safety and skills, in the fall of 2021.

Although rider education is important, most casualties, including the overwhelming majority of fatal injuries, are a result of automobile drivers. Spin partners with Ford's Driving Skills for Life, DriveTech, Rac, and other global automotive safety organizations to educate drivers on how best to avoid crashes and share the road safely with people on scooters and bikes. In the U.S., Spin works with the Vision Zero Network to promote safe driving and riding.

Enforcement

Enforcement of local traffic and operator rules should be considered last when developing micromobility systems. As Leah Shahum, the founder of the Vision Zero Network, wrote in 2016, “No amount of police presence can overcome road designs and policies that simply don’t work well enough.”[31] The enforcement of local traffic laws and operator rules can take on many forms, from interaction with local police to behavior detection and response systems enacted by operators themselves.

Increasingly, micromobility companies are shifting to automated enforcement, such as AI-driven ID checks, to enforce age restrictions and automated vehicle slow-downs in restricted areas. When designed thoughtfully, with equity implications in mind, such an approach can improve equity outcomes and rider compliance, as well as reduce the cost burden to municipalities.

Spin pioneered self-enforcing parking and sidewalk riding technology with its recently launched Spin Insight Level 2 powered by Drover. Spin Insight Level 2 combines onboard forward-facing cameras, AI, GPS, and accelerometers to determine whether riders are following local rules when parking. The technology can also detect when users are riding on sidewalks or bike lanes, and be integrated with responsive messaging, speed controls, or penalty/incentive programs to encourage rider compliance and improve safety outcomes. Similarly, Voi and Tier are piloting startup Luna’s AI technology to improve rider and parking compliance.[32,33] Link now offers a Pedestrian Defense system to detect and prevent non-compliant riding.[34]

Equity is also a key consideration when developing enforcement strategies. In the United States, Black and Indigenous people are significantly more likely to be killed or seriously injured in a traffic crash (24% more and 164% more likely to suffer a fatal traffic injury than white Americans, respectively).[35] At the same time, racial discrimination in traffic enforcement across the U.S. has been well-documented in academia[36] and the national press[37] as an ongoing problem with severe consequences. Beginning in the spring of 2021, Spin has partnered with the Vision Zero Network in the U.S. to offer a series of workshops for municipal leaders and transportation practitioners to rethink traffic enforcement, with equity in mind. The workshop participants discussed how traditional methods of traffic enforcement can perpetuate unjust and unsafe practices, affecting communities of color, and alternative approaches to move forward.

The Virtuous Cycle: Mode Shift Enhances Safety, Enhanced Safety Drives Mode Shift

In the last century, street design has prioritized motor vehicles, particularly the speed of motor vehicle transport over the safety of all other road users, including pedestrians, cyclists, and e-scooter riders. This prioritization led to some of the safety challenges, described in the prior section, and inadequate infrastructure investment in more sustainable transportation methods, such as micromobility. However, the COVID-19 pandemic has created a window of opportunity to accelerate change.

Designs that increase safety for micromobility users have also been shown to reduce crashes with injuries for other road users. For example, the installation of protected bicycle lane infrastructure in New York City has been shown to reduce injuries to pedestrians by 22%, and motorists by an astonishing 25%. This same project increased cycling by an average of 59%.[38]

In addition to the direct effect of improved road design, reducing the number of cars on the road reduces risk to all other road users. A report from May 2021, based on data from Nashville, Tennessee, found that 80% of e-scooter rider fatalities involve cars. There is a strong similarity between car crashes involving e-scooters and those involving cyclists.[39] An OECD analysis of crash data in Bogota, Paris, and London, reinforces this point, with data showing that car crashes cause 4-7x more deaths among vulnerable road users than among vehicle occupants.[40] In comparison, non-riders represent no more than 10% of the total fatalities in collisions involving e-scooters or bicycles. These studies illustrate the importance of investments by communities in infrastructure, such as protected bike lanes, to ensure safety, and encourage the adoption of more sustainable modes of transportation.

Reducing reliance on cars is key to improving the overall safety of the transportation sector. A Portland study found that when vehicle miles decrease, serious injuries and fatalities do similarly. A Portland Bureau of Transportation Study found that 34% of Portland's riders replaced car trips with e-scooter trips.[41] An increase in e-scooter use, in turn a mode shift away from cars, has the potential to contribute to an overall reduction in serious injuries and fatalities.

2. Equity, Inclusion and Access: Micromobility as a Catalyst for Democratizing Access to Transportation

Transportation enables access to essential services, employment, and opportunities. Therefore, the sector has a huge influence on equity, especially in urban areas. Spending projects for transportation must be equitable in order to ensure access for all urban residents. Micromobility partners can help cities achieve equity and access goals by providing efficient and sustainable transportation modes.

Infrastructure Promotes Equity

Mobility operators can supply transport options to the city's underserved residents, but in order to ensure uptake by underserved populations, who need more transportation solutions, cities must simultaneously invest in the necessary infrastructure that facilitates safety and adoption. Providing access to micromobility services does not automatically translate to adoption and impact. Hence, investment in safe and sustainable infrastructure in underserved communities is an important element to achieving transportation equity. If people have a safe place to ride, they will be more likely to do so. If there is not a dedicated bike lane, or the streets are not paved, then residents are much less likely to use micromobility services.

The Fourth National Climate Assessment, conducted by the U.S. Global Change Research Program, reported that underserved communities have higher rates of many health conditions, face greater exposure to environmental hazards, and endure longer recoveries from natural disasters, all conditions that will be further exacerbated by climate change.[42] Access to more sustainable transportation modes can reduce air pollution and emissions from tailpipes, mitigating the effects of climate change and improving health outcomes for communities.

Historically, infrastructure investment has favored car users. Migration patterns to suburbs have resulted in poor public transport options to underserved neighborhoods. For example, streets with sidewalks on one or both sides of the street are significantly more common in high-income areas (89%) than underserved communities (49%).43 To address historical inequities, infrastructure investments in underprivileged neighborhoods must be greater than, not just equal to, investments in affluent ones. Community benefits are significantly higher on infrastructure spending that promotes transportation inclusion and access for populations who are the least served and most in need. During COVID-19, as Spin's ridership generally decreased due to shelter-in-place orders, ridership in underserved areas and among Spin Access program users generally increased, showing that micromobility provided a transportation lifeline to many essential low-income workers. Governments at the federal, state, and local levels must allocate critical spending to fund infrastructure in underserved communities, and expand transit options for residents.

Lifting Barriers

Micromobility can lift barriers to access of services. Access to reliable and affordable transportation is core to the concept of the 15-minute city and to improving economic mobility and quality of life for all urban residents. Equitable access impacts the lives of potential users by connecting them to more job opportunities and reducing the time to travel to those opportunities. NABSA's 2020 State of the Industry Report found that Studies across 9 cities indicate that 44% more jobs were accessible within 5 minutes or less when pairing shared micromobility service with public transportation and walking.

44% more jobs were accessible within 5 minutes or less when pairing shared micromobility service with public transportation and walking.

In a city, like Pittsburgh, where 65% of low income residents lack access to a vehicle and residents without a vehicle can only access about 40% of the region's jobs within a 90-minute commute, providing additional transportation options can greatly enhance access to jobs and other opportunities. Move PGH is Spin's groundbreaking mobility-as-a-service (MaaS) program with the City of Pittsburgh, designed to address key equity and access issues. As part of the program, Spin intends to work with the City of Pittsburgh, local non-profit organizations, and researchers at a local university and the Urban Institute, on a Guaranteed Basic Mobility pilot program to cover the cost of Move PGH transportation options for up to 50 low-income Pittsburgh residents over one year. During the trial period, the researchers will measure the impact on participants' economic mobility, health and well-being, and travel behavior, to determine how to make the pilot program sustainable long-term, as well as expand to more participants, and identify opportunities for implementation in other communities. Early ridership data from the Move PGH pilot program indicates that scooters can help connect people to reliable and affordable transportation, particularly in underserved communities.

Case Study: Improving Transportation Equity in Chicago

When the City of Chicago announced their 2020 micromobility program, the city made clear that ensuring equitable access was a top priority. The Chicago Department of Transportation (CDOT) required all operators to deploy half of their scooter fleet in designated Equity Priority Areas and continue to ensure access by rebalancing scooters to those areas throughout the day. As a result of this requirement, 23% of trips over the course of the pilot program originated in Equity Priority Areas. According to CDOT's evaluation report on the 2020 pilot program, Spin was the only operator to fully comply with this requirement.

CDOT's analysis found that riders in these Equity Priority Areas were 1.6 times more likely to report they used e-scooters as transportation to and from work. This data illustrates how micromobility can provide vital transportation in historically underserved communities.

Affordability is a barrier to equitable access. Transportation equity requires that transportation be both accessible and affordable for all residents. This vision of equitable transportation led Spin to create Spin Access, which gives free or discounted rides to low-income residents. Other micromobility companies, such as Bird and Lime, also provide similar discount programs for low-income residents.[44,45]

In addition to its Spin Access program, Spin is partnering with cities and community organizations to introduce programs that expand micromobility services to low-income residents at low or no cost. In Portland, Spin worked with the Portland Bureau of Education to supplement transit service during the pandemic. The city waived their street use surcharge of $0.25 per scooter trip and the scooter right of way fee, allowing Spin to reduce its prices by 50%, making trips affordable to lower income Portland residents, who utilize the service for commuting and other essential trips.In partnership with the City of Grand Rapids and five local community organizations, Spin introduced the Spin Community Pass pilot program. The city purchased 650 three-month passes for residents who face transportation barriers, such as limited income or lack of access to a credit card or smartphone. Each pass gives riders up to five free 30-minue rides a day over a three-month period on any available Spin scooter, enabling these residents to travel for work, run essential errands, or connect with public transit. Riders also receive a free helmet to use the scooter safely.

Another barrier to equitable access is a requirement for smartphones, credit cards, or drivers' licenses to access micromobility services. Roughly a quarter of low-income households do not own a smartphone and 43% lack broadband access.[46] If micromobility operators assume that all users have a smartphone, many underserved residents will be unable to access micromobility options. Micromobility operators have recognized this limitation, and are incorporating alternate ways to access services in their discount programs, such as text-to-unlock, and cash or prepaid debit payment methods. A third barrier to the equitable use and adoption of micromobility is the perception of shared scooters. Early adopters of shared micromobility tended to be young, educated, and higher-income city residents. From the equity lens, this barrier equates to the difference between whether something is available and whether it is an option for you. Micromobility offers residents in underserved communities increased transportation access, however residents must see micromobility operators as options for them before they will adopt and use them. The industry has made great strides over the past two years, through education and outreach efforts, but perception barriers remain a factor.

New Form Factors Including Adaptive Vehicles

Micromobility companies are introducing new form factors (e.g., e-bikes and e-mopeds), and adapting their vehicles (e.g., adaptive scooters with seats, baskets, and wheelchair attachments) to meet the diverse needs of residents, including those with disabilities and those who may want to travel slightly longer distances or use vehicles that can carry items. These new form factors and adaptive scooters, which make micromobility modes an option for a wider audience, will accelerate the adoption of micromobility transportation.

The introduction of new form factors can drive increased access and inclusion. Shared micromobility naturally favors non-disabled residents. Micromobility operators are addressing these challenges, through physiologically inclusive and adaptive options. Furthermore, a recent industry study from NABSA indicated that women are 13% less likely to use scooters, but an increase in bikeshare usage by women has led to greater parity in bike usage.[47] Spin has introduced e-bikes in several of their city and campus markets, like Providence, Rhode Island, Fort Collins, Colorado, and Penn State University, and will be rolling out e-bikes in additional cities and campuses shortly. Efforts like this will further drive micromobility adoption by women who may feel less comfortable with a scooter versus a bike. The micromobility industry has likewise focused on the introduction of e-mopeds as an additional option.

Importance of Partnerships

The case studies highlighted in this section illustrate the importance of public-private partnerships in achieving equity. These partnerships enable the leveraging and pooling of resources to improve city planning, and investment decisions that lead to equitable transportation in cities and communities.

Equally critical are partnerships between operators and local organizations. These partnerships enable micromobility operators to build trust and credibility in the community. Residents are more likely to trust and adopt the products and services provided by operators, who work with local organizations. Through work with community groups, operators can reach residents and foster trust, while advancing the goals of bringing greater transportation options to underserved communities.

Using Technology to Improve Access: Mobility-as-a-Service

Mobility-as-a-Service (“MaaS”) has the potential to revolutionize micromobility adoption and facilitate greater multi-modal transportation. MaaS, specifically the integration of micromobility transport options into transit maps (e.g., Google, Moovit, Transit, and local transit agency apps), can make multi-modal mobility seamless for residents by providing convenient mobility, which encourages multi-modal transport, rather than cars. MaaS allows users to choose from all available transportation modes on a single platform, improving ease of use. Convenient multi-modal trip planning, as well as the purchase of tickets for all legs of the trip, makes it easier for users to adopt micromobility as a first to last mile solution, which connects to transit. Spin’s integration into transit apps will make e-scooter use more convenient and seamless, accelerating adoption and usage, and the correlated impact on sustainability.

MaaS provides convenient and flexible multi-modal transportation options. For example, in July 2021, Spin launched the Move PGH program in the City of Pittsburgh, a first-of-its-kind public-private partnership providing residents with access to a menu of transportation options all in one seamless experience. This included: a new fleet of shared low-speed electric scooters provided by Spin, trip planning and booking, expanded carshare services, a fleet of electric mopeds, carpool matching and commuting services facilitation, electric charging for e-scooters, and real time transit and mobility information at mobility hubs. Residents can access these options digitally, through the Transit App and at 50 Mobility Hub locations, making the experience more seamless for passengers as in-app integration streamlines the connection between micromobility and transit, for instance allowing riders to get off at a train station and quickly find an e-scooter for the last leg of their journey. This collaboration between Spin and the City of Pittsburgh offers an enhanced experience, through an app that is already widely used and familiar to Pittsburgh residents, encourages adoption, and provides for ease of use, potentially setting the standard for collaboration between micromobility providers, and cities and communities worldwide.

3. Effective Policies and Regulations: From Pilots to Permanent Micromobility Programs

The last pillar that drives mode shift is the achievement of effective and outcomes-based policies and regulations, matched to local municipal agendas for social change and environmental sustainability. Creating supportive policies and regulatory frameworks are essential to accelerating wider micromobility adoption and access, as well as meaningful reductions in personal car usage.

Developing Effective Policies and Regulations

Municipalities should develop the following features to foster successful, accountability-focused micromobility policies and regulations: (1) Public-Private Collaboration, (2) Outcome-based Accountability, and (3) Locally-based Policies.

First, mutual benefits can be realized by taking a collaborative and interactive approach to regulation and policymaking. To that end, municipalities have developed pilot programs, and formed partnerships with micromobility companies to better understand operational logistics and best practices. Collaborative policymaking creates a micromobility system that is suited to the unique needs of each municipality, as well as feasible for micromobility companies to provide safe, affordable, reliable, and accessible forms of green transportation.

Second, outcomes-based accountability is critical to effective policies and regulations. Often times when municipalities design new or young micromobility programs, accountability metrics are overlooked in the policymaking and planning process. This is a missed opportunity to improve priority outcomes around safety and sustainability, while avoiding some of the most common pitfalls that plague markets, where operator performance is not continuously tracked, reported, or enforced.

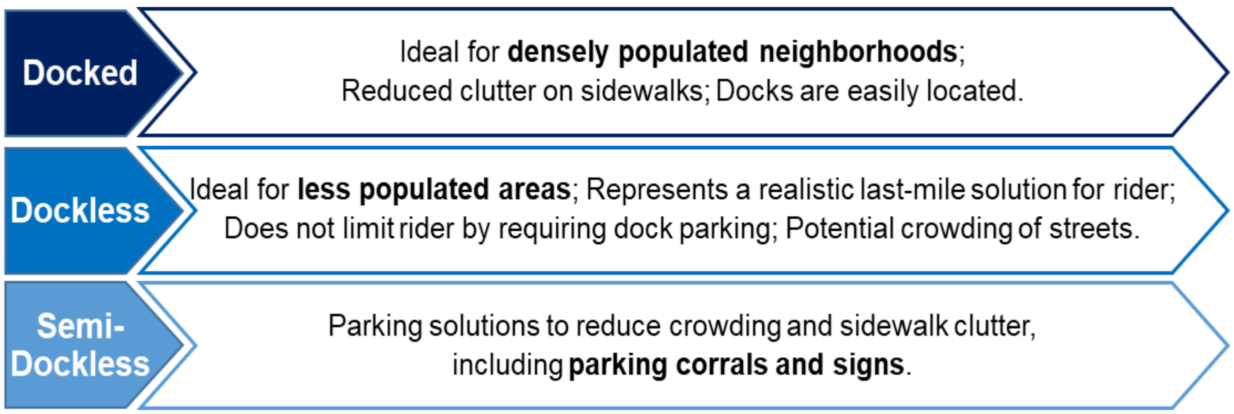
For example, the City of Chicago's 2020 pilot program aimed to measure key outcomes, such as:

1. Safety of riders and non-riders
2. Equity and engagement
3. Reduction of single occupancy vehicle trips
4. Operations, maintenance, and environmental impact
5. Evaluation and public survey

Chicago's pilot program set clear outcomes and then followed-up with a thorough evaluation, illustrating best practices for other pilot programs.

An outcomes-based approach to accountability is also one of the most effective ways municipalities can create positive buy-in from communities and achieve meaningful progress on local priorities. Operator oversight and compliance enforcement can take many different forms, including quarterly report cards, which rigorously track key results and metrics. In such a highly competitive industry, with numerous micromobility companies vying for a limited number of permit spots, locally-based report cards serve an important function: they provide a clear and transparent way to better hold operators accountable to often lofty promises, made in competitive request for proposal (RFP) responses. By tracking progress on fulfilling RFP commitments, municipalities can incentivize good behavior and compliance in key areas, such as safety and sustainability, when compliance determines fleet increases (i.e., number of scooters per operator) or future permit renewals and extensions.

Finally, policies should be tailored to the needs of the local market. A micromobility system's operating model, fleet size, and parking rules should all be based on local needs and topography – there are no one-size-fits-all regulations to address these issues. For example, depending on the characteristics of different neighborhoods, municipalities can consider a docked, dockless or semi-dockless model.



In addition to locally-based policies, which support mode shift to micromobility, regulations can be used to fix potential problems from rapid micromobility growth. For example, fleet size caps represent a way local markets can tailor regulations to meet local demand based on population density and neighborhood characteristics (e.g., busy commercial areas vs. residential neighborhoods), and minimize sidewalk clutter.

From Pilots to Permanent Micromobility Programs

Pilot programs help municipalities build upon micromobility regulations based on the analysis of program results and community feedback. This informs the design of permanent micromobility programs and future RFP processes.

Resident and community group feedback is critical to implement successful pilot programs, and strengthen policies and regulations before a permanent program is finalized. Furthermore, municipalities can use pilot programs to achieve goals around safety, sustainability, and accessibility by including requirements on parking, fleet size, and deployment zones.

Two relevant criticisms of pilot models include:

1. Open permit pilots: A limited vendor model leads to better outcomes, since municipalities can set high performance standards for micromobility companies to demonstrate how they will provide the best service in order to receive permits.
2. Length of pilot: Short-term pilots, which range from three to six months, are most beneficial to working out the growing pains of a new micromobility transportation system. Once the testing period ends, municipalities should evaluate the pilot, update regulations as needed, and create a long-term program with two- to five-year contracts. This approach enables municipalities to build

working relationships with operators and ensure that they provide a high-quality transportation service, which meets local community needs.

By adopting outcome-based accountability approaches and collaborating on policy and regulation, cities can help micromobility programs flourish. In this regard, cities have a once-in-a-generation opportunity to drive social change and environmental sustainability with effective micromobility policy.

Zoning and Land Use for People-Centric Cities and Streets

Complimentary land use changes are likewise needed to encourage people-centric street design, which prioritizes the safety for all users of city streets. Land use regulations, such as zoning, that support density, mixed-use, and reduced parking requirements are imperative to support mode shift.

One key tool, to repurposing infrastructure to accelerate mode shift, is reducing the enormous amount of space in urban areas – both public and private – dedicated to vehicle parking. Parking requirements force real estate developers to set aside minimum amounts of land for vehicle parking. In Los Angeles, 200 square miles are dedicated to vehicle parking, more than four times the total size of the city of San Francisco.[48] A UCLA report found that in San Francisco, minimum parking requirements have increased both the number of cars and trips taken due to the one parking space per home requirement in affordable housing, which more than doubles the likelihood of residents owning a car. [49] Reduction of parking and vehicle lanes also provides cities the ability to offer increased safety infrastructure for other modes of transport and road users.

Minneapolis is one city, which is rethinking parking. The city council voted unanimously to eliminate minimum parking requirements. The co-author of the ordinance explained:

"We want more people to be able to live, work, and play in Minneapolis without a car—it's better for our climate, it's healthier for people's lives, and it makes Minneapolis a more affordable place to live by reducing the cost of transportation. By removing minimum parking requirements and instead encouraging a variety of strategies to increase walking, biking, and transit use, we will not only reduce the cost of new housing but also spur the creation of more walkable neighborhoods."

Furthermore, legislative efforts can foster people-centric cities and streets. In April 2021, a California legislator introduced a bill that eliminates parking requirements for new construction buildings located near public transportation and in walkable neighborhoods.[50]

Parking Day – Worldwide Celebration

On the third Friday in September each year, the world celebrates Park(ing) Day. Launched in 2005, Park(ing) Day encourages people across the world to creatively repurpose street parking into parks, as well as places for art, play, and activism, to encourage dialogue about the design and building of cities, providing for urban public space. Spin supported Park(ing) Day 2021 by providing 30 organizations across 27 cities globally $1,000 each toward creating a Park(ing) Day installation. Infrastructure initiatives like this will drive less car-centric cities and improve safety for all urban residents.

Conclusion

Micromobility is Key to Sustainable, Resilient Cities and Communities

The changes caused by the COVID-19 pandemic demonstrated that the gains provided by mode shift to micromobility transport options can enable a more sustainable and resilient transportation system. As the world continues to grapple with an evolving risk landscape – from pandemics to climate change – resiliency takes on a more crucial role in any organization, city or community.

COVID-19 highlighted the importance of transportation resiliency, especially in urban areas. When health mandates and reduced ridership forced cities to shut down or reduce public transit service, micromobility served as a key enabler of transportation resiliency, providing a lifeline to essential workers and others with urgent need for safe, socially-distanced transportation. Spin is committed to helping its city and community partners meet their transportation resiliency needs, in both the continued recovery from the COVID-19 pandemic and whatever future crises may come.

Given the climate crisis facing the world, emissions reduction and climate resilience have taken on increasing importance globally. 85% of respondents to a recent Marsh Risk Resilience study rated Environmental, Social and Governance factors, including climate, as either important or very important, a powerful statement regarding the increasingly important role that climate resiliency plays in the overall resilience planning of organizations, cities and communities.

85% of respondents to Marsh's risk reliance study rated ESG as either important or very important.

Mode shift to micromobility is part of the solution to reduce transportation-related emissions, build a more sustainable transportation system, and mitigate climate change. Moreover, it can help create a path towards greater climate resiliency, in addition to addressing and managing climate risks. Cities, communities, businesses, and other organizations can capitalize on the strategic opportunities presented by the shift to a lower-carbon and resource-strained world. This includes redesigning our cities to be less car-dependent, and more people-centric and sustainable.

Resiliency in the context of micromobility is broader than just climate resiliency. There is resiliency of the transportation system itself, resiliency of communities, as well as the need to develop sustainable and scalable policies to ensure long-term success and viability of micromobility programs. First, building a resilient transportation system serves both climate resilience and general disaster preparedness. During the COVID-19 pandemic, cities relied on micromobility options as an essential part of their transportation ecosystem, as riders looked for safe, socially-distant means of transportation. It also offered residents a lifeline to access work, and obtain critical services, such as food and medical care. The lessons learned from the pandemic, regarding micromobility and its contribution to transportation resiliency, can help cities better prepare for, and more effectively combat whatever their next challenge may be.

Second, micromobility enables the resiliency of communities, through improvements in access and equity. The COVID-19 pandemic established micromobility as much more than a recreational form of transport for the affluent: specifically, as a real lifeline for underserved communities, where access to transportation options is often limited. Access to safe, reliable, and affordable transportation is key to enabling resiliency, and improving quality of life for all urban communities. Through community partnerships, micromobility operators can continue to accelerate the introduction and expansion of new modes of transport to residents in underserved communities, who often lack access to transport options to access jobs and basic needs.

Finally, communities need sustainable and scalable micromobility policies to ensure the long-term success and viability of these transport options. Responsible deployment of micromobility is crucial to long-term resiliency and sustainability benefits, as well as avoiding cities cluttered with unused scooters. To achieve this, responsible policies need to support the creation of pilot programs and the building of operator capacity to guarantee a sustainable future for the industry. Achieving resiliency requires policies, which recognize this opportunity for micromobility, allow for responsible and phased growth and implementation, and enable long-term success for our communities and for our planet.

As the World Economic Forum concluded, “until businesses and investors embrace an approach where resilience is a consistent thread ... running through ESG, they will remain ill-equipped to rebound most effectively from the crises that inevitably lie in our future.” Micromobility served as a critical enabler of transportation resiliency at a time of world crisis. The importance of this impact on transport resilience cannot be underestimated. As the world continues to deal with disruption, be it another pandemic or the impacts of climate change, cities and communities will increasingly need further transportation options – cars, public transit, shared rides and micromobility options – in order to ensure transport resiliency.

Such resiliency is even more crucial in the face of climate change. In order to support micromobility as a cornerstone of cities and communities resiliency planning efforts, mode shift must be accelerated. To achieve greater micromobility adoption, public-private partnerships must make rapid improvements in safety, infrastructure, equity, access, and supportive policies and regulations as this report highlighted. If cities and micromobility operators act now to make permanent the gains driven by the COVID-19 pandemic, and streamline progress, healthier, greener, safer, and more livable streets for all will be within our reach.

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SPIN

The Life Cycle Assessment of Spin Shared Electric Scooter Model S-100 and Adaptive S-100 in the San Francisco Market

Final Report

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Statement:

This life cycle assessment (LCA) study about Spin's S-100 7th Edition (S-100) shared electric scooter was completed in compliance with the ISO guidelines for LCA. The scope of this work does not include comparative assertions and is not intended to be used to support marketing claims. An ISO panel review has not been performed for this assessment. This report is being submitted to the San Francisco Municipal Transportation Agency (SFMTA) as a condition for Spin's permit application, in accordance with Appendix 6: Sustainability Guidelines and Requirements of SFMTA's Powered Scooter Share Permit Program. This publication is based on information obtained during research conducted in 2021.

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1 Introduction

Shared vehicles and micromobility is reshaping current transportation systems. Shared stand-up electric scooters are single person vehicles with a small electric motor and a deck on which a single rider stands. Spin, a micromobility company, offers dockless shared stand-up electric scooters in many cities as an option for short-term rental and short-distance travel with the objective of reducing traffic congestion and the negative environmental impacts of transportation in cities. An accurate assessment of the impacts of the latest scooter technology requires proper identification and modeling of the alternative scenarios for deployment of innovative vehicle technology and services in specific real-world contexts.

In this study, we use a life cycle assessment (LCA) to quantify the environmental impacts of shared dockless electric scooters, making use of actual, internal data on use-related parameters for the case study cities. The goal of this study is to identify the key drivers of environmental impacts. The broad system boundaries encompass electric scooter manufacturing, shipping, deployment and consumer use, battery charging, and end with estimates of environmental impacts from the final recycling and disposal of the vehicle.

2 Life cycle assessment

LCA is a technique to assess potential environmental impacts associated with a product or process by:

1. Compiling a cradle-to-grave inventory of relevant energy and material inputs and environmental releases;
2. Evaluating the potential environmental impacts associated with identified inputs and releases; and
3. Interpreting the results to assist in making more informed decisions. LCA holds the promise of identifying inefficiencies in the system, which can be addressed to foster the long-term health of the industry.

The guidelines for conducting an LCA are provided in a suite of ISO standards (ISO, 2006a, 2006b).

Broadly, an LCA consists of four stages:

1. Define the goal and scope – including appropriate metrics (e.g., greenhouse gas emissions, water consumption, hazardous materials generated, and/or quantity of waste);

2. Conduct life cycle inventories (collection of data that identifies the system inputs and outputs and emissions to the environment);
3. Perform impact assessment; and
4. Analyze and interpret the results.

An important aspect of LCA is to define the specific reasons that it is being undertaken.

2.1 Goal of the study

The goal of this study was to provide a comprehensive, attributional life cycle assessment (LCA) of Spin's latest model of the electric scooter called the S-100 7th Edition. The study addresses manufacturing and Spin's operational strategy in San Francisco, California.

Spin's S-100 7th Edition scooters in San Francisco are deployed with a cable lock system and Spin Level 2 Insight, which is powered by Drover AI's PathPilot technology via a camera module mounted on the vertical post of the scooter (this model is referred to as the S-100 in this report, shown in Figure 1a). The impacts from the Level 2 Insight module and cable lock system are included in the scope of this study. Furthermore, as Spin is also deploying an accessible version of the S-100 in San Francisco, this LCA also includes impacts associated with the seat post, seat cushion, and basket in Spin's adaptive scooter (this model is referred to as the Adaptive S-100, shown in Figure 1b).

Figure 1a: Side view of S-100.

Figure 1b: Side view of Adaptive S-100.

The intended application of the study is submission to the SFMTA as a condition for Spin's permit application. The target audience includes decision makers at Spin, who are using the results to identify opportunities to reduce environmental impacts and/or consumption of natural resources and to support other internal decisions.

This assessment relied on scenarios to describe user profiles and operational strategies. Results are normalized to a standardized functional unit for personal transportation (the person-kilometer), which can support subsequent comparisons of the electric scooter with alternative modes of transport. This study identified hotspots and established a baseline assessment of environmental impacts for Spin's shared dockless electric scooters. We anticipate that results presented will be further used for improving Spin's hotspots and operations' data measurement.

No comparative assertions will be made with competing products; however, the cradle-to-grave impacts were benchmarked with existing generic Ecoinvent data.

2.2 Scope of the study

The scope of the study was a cradle-to-grave assessment with the geographic scope being China for electric scooter manufacturing, and San Francisco, California for electric scooter operations. The temporal horizon for the study was the entirety of 2020 and up to June 2021. Spin was able to provide total electricity consumption through electric utility bills. It is assumed that electricity consumption can be mainly attributed to charging scooter batteries; however, the precise allocation cannot be determined. Existing literature instead relies on battery capacity and average depletion rate to determine the electricity consumption per passenger-km (de Bortoli, 2021, Severengiz, et al., 2020, Hollingsworth, 2019). Both approaches have their own advantages: utility bills reflect real consumption data; engineering estimates calculation pinpoints electricity consumption directly intended for battery charging. Therefore, both methods were implemented in the study and presented as separate scenarios in the results section.

Spin aims to transition the entire operational van fleet in San Francisco to electric vehicles with the intention of charging with 100% renewable energy. However, due to availability of vehicles on the market it is expected that the transition will occur gradually over 2021-2023. Therefore, the study presents three scenarios: 1) an operations fleet with no electric vehicles 2) an operations fleet comprised of 50% electric vehicles and 50% diesel vehicles—and 3) an operations fleet of 100% electric vehicles.

2.3 Functional unit

The main function of an electric scooter is to provide short-term rental and short-distance travel for one person. A summary of the performance characteristics of the scooter and battery are reported in Table 1. This life cycle assessment is a cradle-to-grave analysis of the manufacturing and operation of the S-100 electric scooter. The functional unit is:

Transportation of 1 passenger over distance of 1 kilometer, or 1 passenger-kilometer (pkm)

This allows comparison between alternative modes of transportation, which is consistent with our goal and scope. Sustainability performance measurement was based on a comprehensive list of environmental impact categories, which are bundled together as the ReCiPe 2016 Midpoint (H) impact assessment method, with characterization factors based on a hierarchist cultural perspective, which is considered a default model (Huijbregts et al., 2016).

Table 1: S-100 performance characteristics.

Parameters Item	[redacted]
Maximum speed	[redacted]
Endurance	[redacted]
Battery	[redacted]
Maximum slope	[redacted]
Road	[redacted]
Net weight	[redacted]
Charge time	[redacted]

Since the impacts have different units for each impact category, it is not possible to interpret category-level characterization results to determine which categories may be of higher concern for the product system. To contextualize the results and to support such a determination, the cradle-to-grave impacts will be benchmarked with generic Ecoinvent datasets for urban transport.

2.4 System boundary

This LCA is a cradle-to-grave analysis of the manufacturing and operations of Spin's S-100 electric scooter and Adaptive S-100 electric scooter. Figure 2 displays the schematic of the cradle-to-grave system boundaries including: (1) materials and assemblies, (2) electric scooter manufacturing, (3) charging, (4) vehicle transport, and (5) use and end of life. The main inputs for scooter chassis manufacturing included: aluminum alloy, steel, rubber, and plastic materials, all included in "Raw material inputs" in Figure 2. The scooter powertrain is composed of assemblies including Li-ion battery, electric motor, wiring, adapter, charger, printed wiring boards (PWBs), and integrated circuits (ICs). The manufacturing step included energy for powertrain and chassis assembly, water use, and building and equipment infrastructure.

Charging included regionalized electricity production, Li-ion battery charging, and charging station infrastructure. Operations vehicle miles associated with deployment, rebalancing, recharging, and maintenance are all included and are based on data for large passenger vehicle fuel consumption and kilometers traveled. The average scooter in a fleet undergoes maintenance as repair needs arise, with replacement parts often sourced from other decommissioned scooters.

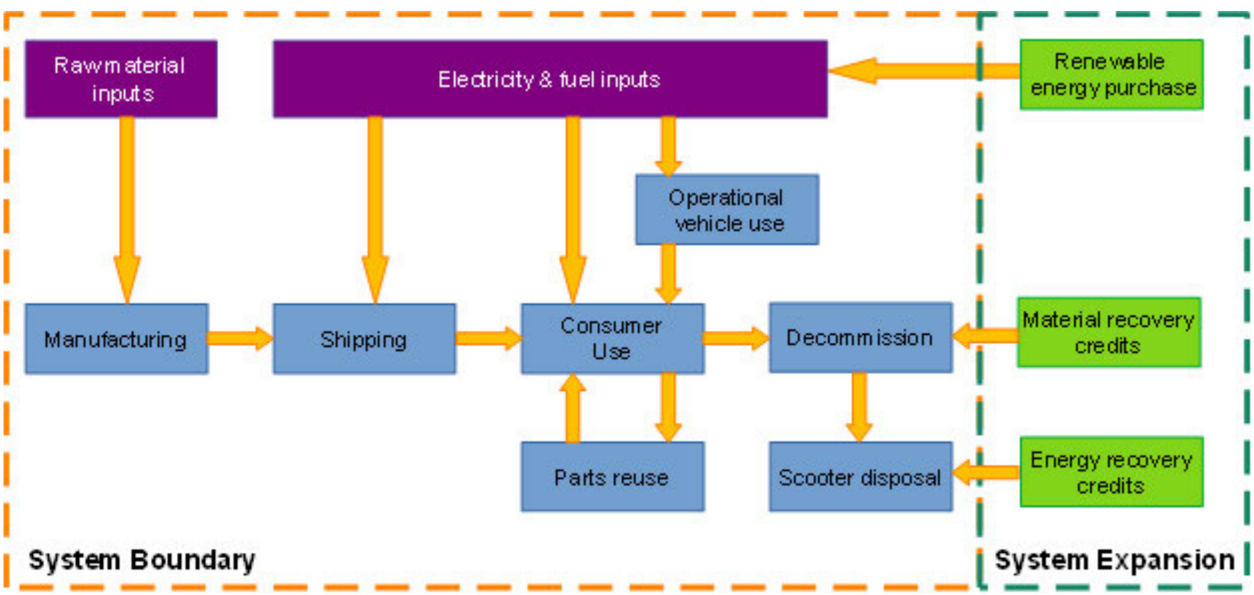

Figure 2: System boundary of Spin scooter, orange boundary being the Spin life cycle phases, and green boundary being the system expansion for credits.

All scooters will be decommissioned at the end of their useful life. Most of the scooter material is recoverable. Thus, system expansion is performed to credit the assumed displacement of primary materials upon recycling. A portion of the non-recoverable material such as plastics is assumed to be incinerated for energy (US EPA, 2018). Therefore, system expansion is similarly performed to give credit for the electricity and heating energy generated.

Spin participates in a 100% renewable electricity purchasing program provided by CleanPowerSF in San Francisco. The program guarantees that all electricity consumed by Spin's facility is backed by *Renewable Energy Certificates* (RECs), generated by renewable energy providers. However, the ISO standard on conducting LCA does not provide guidance on incorporating RECs into the life cycle impact of products or services. While this study is being performed in accordance with the ISO standard, considering the absence of guidance on this point, this study takes precedence from the GHG Protocol, a highly regarded standard on organizational carbon accounting (GHG Protocol, 2015). The standard states: "...companies should always report their own internal emissions in separate accounts from offsets used to meet the target, rather than providing a net figure" (GHG Protocol, 2015). Therefore, impacts from electricity consumption will be displayed as impacts from the standard regional electrical grid (location-based), as well as benefits from supplying the equivalent amount of electricity from a 100% renewable source (market-based).

According to Spin, up to 80% of the scooter is readily reusable in repairs and maintenance upon decommissioning and disassembly, extending the life of the rest of the fleet. However, it is recognized that reused parts alone cannot meet the needs of all maintenance work, thus new parts are also ordered from the factory. Manufacturing specifications suggest that with wear-and-tear from regular use, only the tires likely need to be replaced throughout a vehicle's lifetime. However, accidents and misuse sometimes necessitate premature replacement of otherwise durable components. Due to the sparse, *ad hoc* nature of such internal purchasing activities, only the replacement of tires is considered in the maintenance phase.

A 1% cut off threshold for mass and energy was adopted for this study. Inputs to the system that represent less than 1% of the mass or less than 1% of the energy required for a specific unit process in the system were not subject to detailed analysis; however, if the data were readily available, they were included. An exception to this exclusion was made in cases where small quantities of materials were associated with significant environmental impact—these are included where identified. Effects embodied in system manufacturing facility infrastructure were also included.

Spin aims to transition to 100% electric vehicles for operations such as deployment, battery swapping, and rebalancing. Chargers will be installed in all Spin warehouses, where 100% renewable electricity (backed by RECs) is supplied by CleanPowerSF; however, there may be occasional need to "top-off" the electric battery away from Spin facilities. While topping off may be needed on occasion, it was viewed by Spin that such occurrence will be rare and can be considered outside the system boundary.

2.5 Limitations and Model Assumptions

These results cannot be considered as representative of the entire electric scooter manufacturing industry in China nor of all operations in the U.S.; however, these results are representative of Spin's scooter manufacturing supply chain and they accurately represent the environmental performance of Spin's operations in San Francisco.

The COVID-19 pandemic had a seismic impact on the way and the degree to which people traveled in the year 2020 and into 2021. While internal data is analyzed for all of 2020 and up to June 2021, it should be recognized that the data reflects markets that had substantial travel restrictions. While the total fleet travel distances were severely reduced, it was found that when data points such as electricity consumption and operational vehicle distance were normalized to their corresponding passenger-km, the calculated values did not substantially deviate from partial data available up to June 2021.

Spin is currently transitioning to an entirely swappable battery fleet. In comparison to traditional fixed battery scooters, it is estimated that operational vehicle driving requirements could be reduced by 50% up to 75% (de Bortolli 2021, Severengiz 2020, ITF 2020). Operational savings come largely from being able to service more scooters per trip per vehicle, since only the batteries need to be collected for charging rather than the whole scooter. However, operational data was only available for a non-swappable fleet. It was not possible to collect empirical comparative data since the transition in San Francisco did not occur until July 2021, after the study was already underway. Due to this circumstance, a conservative estimate of 50% reduction in operational vehicle miles was applied in accordance with available literature (de Bortoli 2021, Severengiz 2020, IT 2020). A scenario with a non-swappable battery fleet is also presented for comparison.

According to internal data, swappable batteries additionally allow for the modularization of the battery charger component. Instead of having a charger module for every vehicle, a single charger can service many batteries. The total number of chargers required in a fleet can be reduced to as few as 30% of the number of vehicles deployed in a market. Therefore, the average material requirements for chargers will be reduced by 70% for a swappable scooter fleet.

Spin is also rolling out a *Route & Deployment Optimization* (RDO) tool. The purpose of the tool is to improve demand forecasting and increase ridership. Additionally, the tool optimizes the route in which these deployment points can be accessed. Initial testing indicates that RDO can boost ridership as well as reduce operational vehicle usage. [redacted] increase in riders, this information is immaterial in the assessment, as it would only change the amount of time it takes for an average scooter to deplete the assumed lifetime pkm. Unless the RDO is empirically shown to lower the operational vehicle distance per serviced scooter, it is not incorporated in the study.

According to Spin, [redacted] of a decommissioned scooter is reusable by volume. Therefore, it is assumed that harvested parts from previously decommissioned scooters will fulfill much of the later material demands of the maintenance phase, extending the overall lifespan of an average scooter in a fleet. However, this study captures the *eventuality* that every scooter will enter the waste stream regardless of the number of times scooter parts may enter the maintenance phase. According to Spin, all decommissioned scooters are sent to R2 certified partner recyclers for recycling and disposal. [redacted]. The non-recyclable materials, such as plastics, are incinerated at waste-to-energy facilities or disposed in landfills (US EPA, 2018). At the recycler, certain materials are more readily recyclable than others, which will be discussed in the life cycle inventory.

As the deployment history of the new swappable scooter models is relatively recent, there is no empirical data on how durable they are in terms of time horizon or lifetime pkm. There are several methods to estimate the lifetime pkm presented in the study; however, in light of the lack of sufficient empirical data, the baseline scenario will instead rely on a distance used numerous times in the literature of 7,300 km (Severengiz et al., 2020, de Bortoli, 2021). The range of impacts for different, non-base lifetime pkm assumptions will also be presented in the study.

3 Life cycle inventory

The life cycle inventory (LCI) stage of an LCA requires gathering of inputs and outputs for each element of the system and for each process and product option. In this research, each system was divided into linked unit processes:

- the electric scooter production and end-of-life;
- transport to US locations from China;
- vehicle options for transporting, distribution, and rebalancing scooters and ensuring availability on the streets;
- scooter charging and warehouse infrastructure; and
- the use phase.

The primary focus of this study was on processes within the direct control of scooter operations, and to assess the environmental implications of the current vehicle platform and operational strategy. The LCI model provides a framework to validate reductions through the ability to create a benchmark of performance.

Our modeling of the effects of the Spin S-100 and Adaptive S-100 dockless electric scooter system included the full scope of processes in the supply chains of all inputs to the systems with potential environmental significance:

- mining and processing of raw materials;
- production of electricity and other energy carriers;
- production, maintenance and ultimate disposition of vehicles;
- and the supportive infrastructure (roads, factories, etc.).

We used the Ecoinvent 3.4 LCI database, which is transparent at the unit process level, in order to identify hotspots, i.e., processes that make a significant contribution to one or more impacts of interest in the research (Ecoinvent, 2017). The consistency in use of Ecoinvent 3.4. enabled us to assess the influence of data uncertainties on results and conclusions (Ecoinvent, 2017).

Protection of confidential business information requires an aggregation of the data that were acquired from the surveys and internal data. In addition, it is important to determine the most appropriate statistical analysis for evaluating the average values for the whole population. In this study, internal data about scooter daily kilometers traveled were used to calculate scooter lifetime use-related parameters. The data for operational vehicle kilometers traveled for deployment and redistribution were sourced from monthly vehicle distances. Scooter and vehicle operations data were provided for the entirety of the year 2020 and up to June 2021 to insure the lowest level of uncertainty and the highest accuracy.

When not available from primary sources, data for some of the inputs/outputs from the European Ecoinvent 3.4 database as well as data from existing electric scooter and electric bike LCAs and other industry provided data sets were adopted.

3.1 Material composition of a scooter

To create an accurate materials inventory for an electric scooter, we used an individual part-level bill of materials (BOM). The individual part materials were matched with existing Ecoinvent 3.4 datasets. Manufacturing processes, energy, water, waste generation, and on-site emissions are based on existing Ecoinvent dataset *electric bicycle production | electric bicycle | Cutoff, U.* The majority of the total mass of the scooter is comprised of aluminum, the battery, and the motor, as shown in Table 2. The majority of the aluminum was assumed to be cast, except for the steering tube, which was assumed to be wrought. The polycarbonate/ABS-based components were injection molded.

In addition to the main scooter BOM, accessories / attachments—seat post, seat cushion, basket, lock and AI camera—are also shown with corresponding Ecoinvent datasets used in the study.

Table 2: Material composition of S-100 and corresponding Ecoinvent datasets.

BOM Material	Amount	Ecoinvent 3.4 datasets
Scooters		
[redacted]	[redacted]	[redacted]
		[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
		[redacted]
		[redacted]
		[redacted]
		[redacted]
		[redacted]
[redacted]	[redacted]	[redacted]
		[redacted]

Cables	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
		[redacted]
		[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
Accessories / Attachments		
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
Manufacturing / Waste (Ecoinvent proxy)		
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
		[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

3.2 Shipping from manufacturer to market

All scooter models are shipped from the manufacturer in Shanghai to the Port of Oakland via standard transoceanic freight. Port-to-port distances were found to be 36,600km. Then, the scooters are

[redacted]

delivered to the local market via standard shipping truck. The trucking distance to San Francisco was approximately 103 km. The distance and mode of shipping are summarized below in Table 3.

Table 3: Summary of shipping mode and distances.

	Ocean Freight	Truck
Shanghai to San Francisco	36,600 km	103 km

3.3 Life expectancy measured in passenger-km and time horizon

While the scooter manufacturer claims that the new generation of scooters, which are purpose-built for the shareable market, can last up to [redacted] the real-world use case may be lower due to wear-and-tear from rough handling. However, this new generation of purpose-built scooters, such as the S-100, are able to withstand heavy fleet use much better than the original models, which were existing consumer models modified to fit the needs of micromobility operators. Spin also repairs and maintains their vehicles to extend the empirical lifespan of their scooters. The original models were thought to last approximately 6 months or even as low as 3 months due to misuse and wear-and-tear (MIT, 2019).

The base case presented in the study is for a lifetime pkm of 7,300km, which is supported by two literature sources (Severengiz et al., 2020, de Bortoli, 2021). This lifetime pkm is calculated from assumed daily distance and durability in years—10 pkm per day and 2 years, respectively. The manufacturer's lifetime pkm of [redacted] will be the maximum scenario. These assumptions are summarized below in Table 4. As a reference, the lifetime pkm used in a previous Spin study is also presented.

Table 4: Summary of lifetime pkm and sources of estimates.

Scenarios	Lifetime pkm	Description
1. Max estimate	[redacted]	[redacted]
2. Base estimate	7,300 pkm	10 pkm / day / scooter over 2 years (Severengiz et al., 2020, de Bortoli, 2021)
3. Legacy	2,850 pkm	2019 Spin LCA study (MIT, 2019)

3.4 Electricity production

In the United States, the environmental impacts of electricity production vary for different locations due to site-dependent electricity production characteristics, i.e., fuel mix. The Ecoinvent 3.4 database contains ten process-based attributional LCA models for U.S. regional assessment of electricity production (called eGrids) including WECC, MRO, SPP, TRE, RFC, NPCC, SERC, FRCC, ASCC, and HICC (Ecoinvent, 2017). According to the electrical power grid map of the United States, the markets for this study all belong to the WECC eGrid region (EPA, 2014). The grid mix for the WECC eGrid according to the Ecoinvent dataset is shown in Figure 3.

Spin conducts direct renewable purchasing from the electric utility provider, where available. CleanPowerSF in San Francisco offers a 100% renewable purchasing option where the supply mix is shown in Figure 4. As noted, electricity consumption results will be presented with impacts from using the traditional grid, as well as benefits from instead sourcing from a 100% renewable source in accordance with the GHG Protocol guidance (Greenhouse Gas Protocol, 2004). Reporting net values are discouraged, as it hides the relative difference in impact between the traditional and renewable supply mix.

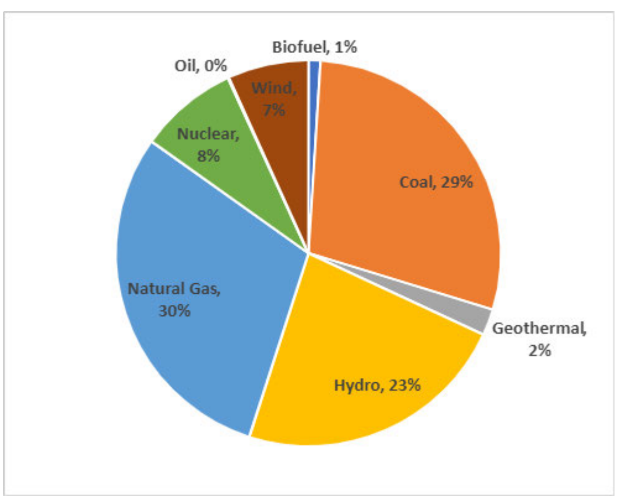

Figure 3: WECC eGrid fuel source mix per Ecoinvent 3.4.

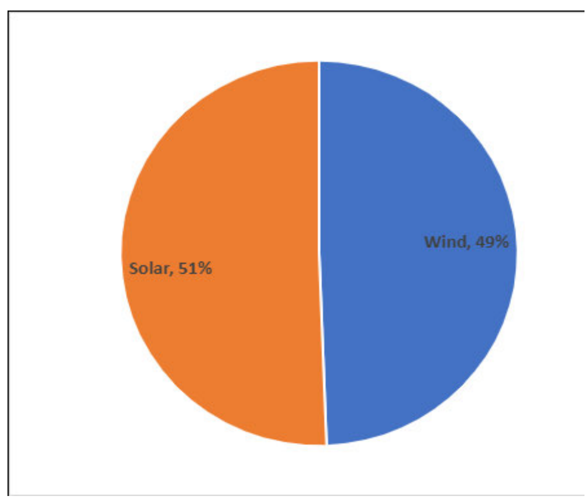

Figure 4: CleanPowerSF SuperGreen renewable supply mix.

3.5 Electricity consumption of battery charging

Electricity consumption for battery charging was based on monthly electricity utility bills. The available monthly electricity use in kWh was aggregated for 2020 through June 2021 and divided by the aggregate of scooter pkm for the corresponding months to arrive at the average kWh electricity per pkm of scooter use.

When pkm per month is plotted against the corresponding kWh per month, it shows a rather weak relationship (Figure 5). As the total pkm per month increases, it was thought that the total electricity consumption would also increase similarly. However, the total electricity consumption from the utility bill appears to be peaking at approximately [redacted]. This suggests either that the electricity consumption reflected in the utility bill is not accurately capturing the battery charging needs, or that the overhead energy needs at the charging warehouse overshadows any variability in charging needs due to differences in total monthly pkm.

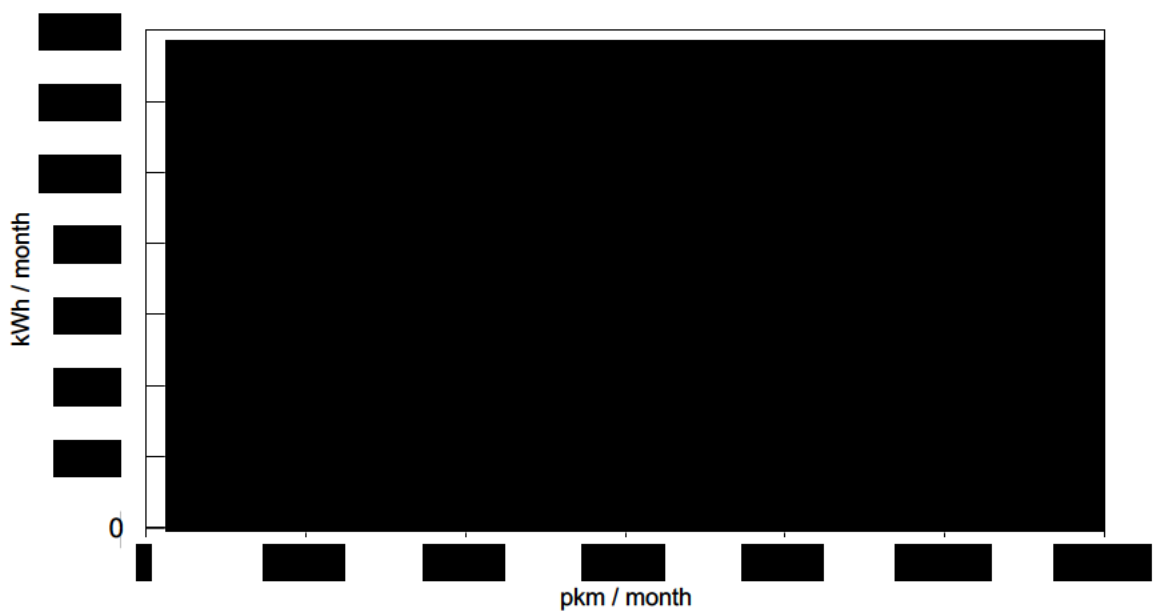

Figure 5: Spin data for pkm per month plotted against corresponding kWh per month.

Another scenario is presented where electricity demand for charging the Li-ion battery was calculated using engineering estimates based on average scooter use and battery charging capacity. The total electricity consumption over lifetime is divided by the total pkm over lifetime to calculate the kWh consumed per pkm. This approach leads to a substantially reduced electricity demand of [redacted] kWh / pkm; the difference in impacts will be presented in a separate scenario. The electricity consumption calculation using utility bills and engineering estimates are summarized in Table 5.

Table 5: Summary of electricity consumption per pkm calculation.

Market	2020 – June 2021 Total scooter pkm	2020 to June 2021 Total electricity consumption	Per pkm electricity consumption from utility bills	Per pkm electricity consumption from engineering estimates
San Francisco	[redacted]	[redacted]	[redacted]	[redacted]

3.6 Operational vehicles for charging, deployment, and redistribution

Similar to the calculation of electricity consumption, monthly operational vehicle distances were available for 2020. While individual vehicle data were available, such granularity was not relevant to the study, thus was aggregated. The aggregate 2020 total vehicle km (vkm) was normalized by the corresponding total scooter passenger km (pkm) for 2020 to calculate the overall vkm per pkm for 2020 to June 2021. The calculation is summarized in Table 6 below.

Table 6: Calculation summary of operational vehicle km per pkm.

Market	2020 to June 2021 Total scooter pkm	2020 to June 2021 Total vehicle km	Overall vkm / pkm
San Francisco	[redacted]	[redacted]	[redacted]

The monthly vehicle usage is plotted against the corresponding total monthly pkm in Figure 6. Similar to electricity consumption, the total pkm does not appear to be the only factor influencing total vehicle usage. There may be elements of inefficiencies at low pkm, where there are less scooters deployed, and operation vans must travel farther to service each scooter. Moreover, differences in ridership due to seasonality is not captured in Figure 6.

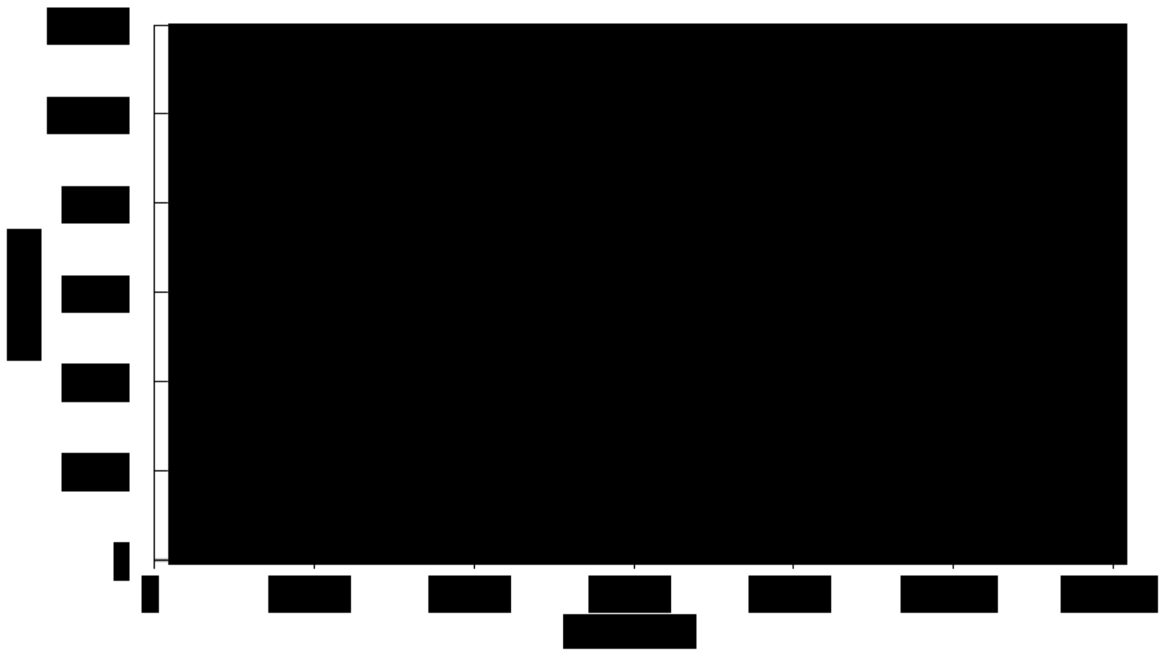

Figure 6: Spin data for vehicle-km per month plotted against corresponding monthly total pkm.

3.7 Scooter maintenance requirements

When scooters are sent for repair they are subjected to a diagnostic test. Possible outcomes are replacing broken parts or decommissioning the scooter and subsequent recycling or disposal. Smaller parts that are typically replaced are screws, bell, kick stand, throttle, brake lever, brake lights, headlights, fender, and stickers. Some of the larger parts that can be replaced include electric motor, front fork, base board, battery, and handlebar assembly.

As noted in Section 2.5, a decommissioned scooter has up to [redacted] reusable parts in volume—unless water or fire damage occurred. Therefore, it was assumed that a majority of maintenance needs would be addressed by existing replacement parts. However, new replacement parts are required occasionally. Empirical data on replacement frequencies for scooter parts are not available. However, manufacturer design specifications are provided, and corroborated via communication with the Spin team. The manufacturer's specifications are summarized in Table 7.

Table 7: Manufacturer's design specifications for scooter parts.

Part	Design Specifications
Deck	[redacted]
Wheels	[redacted]
Motor	[redacted]
Battery	[redacted]

According to the specifications in Table 7, a scooter under a baseline scenario would need to change its tires once at [redacted], then approximately [redacted] of the environmental impact of the second set of tires need to be accounted for in the consumer use phase.

3.8 End of life recycling, reuse, and disposal

As noted in Section 2.5, we aim to capture the inevitable material path for all scooters: that they will *eventually* enter the recycling and waste stream. While we recognize that much of the scooter parts are reusable, we assume that the maintenance phase has been implicitly captured in the lifetime durability assumption of an average scooter.

According to Spin, all unrepairable, non-reusable scooters will be sent to a recycler for proper handling of the end-of-life stage. All parts, including motors and batteries, are broken down to their base materials for recovery. Some materials are not readily recyclable, such as the polycarbonate-ABS blend plastic and printed wiring boards.

Up to [redacted] of recycled materials, including all metals, batteries, and motor are assumed to be recovered, and the subsequent displacement of primary materials is credited to the Spin life cycle through system expansion.

3.9 Model assessment

Our goal was to provide an open and transparent assessment, in terms of data, data sources, assumptions, and methodology, respecting the constraints of data confidentiality, for the environmental footprint for electric scooter manufacturing including the use-phase scenarios. This allows the results of this study to be compared with those from other LCA studies. Specifically, for a valid comparison, there must be equivalence in the functional unit, system boundaries, scope, and assumptions including allocation procedures. By providing an open, transparent study, these comparisons become feasible. All computational modules are fully documented with reference citations to data sources. All formulas are checked by both the author of the module and at least one additional team member.

3.10 Data quality

The hierarchy of criteria for acceptance of data is as follows:

- primary data collected as part of the survey of manufacturers;
- data from previous peer reviewed projects;
- data published in peer reviewed journals that are generally regarded reliable sources of information;
- data that have been presented at conferences or otherwise are publicly available (e.g., internet sources).

To the greatest extent possible, we used current data as provided by Spin and other electric scooter research and peer reviewed data from secondary sources such as Ecoinvent 3.4 LCI database (Ecoinvent, 2017). Data were requested/collected respecting geographic relevance specifically to base our model on U.S. data. We used monthly aggregate data from Spin directly adjusted for units or scaled if necessary.

4 Life cycle impact assessment

The intention of this study is to provide a comprehensive environmental life cycle impact assessment (LCIA), which addresses all phases of electric scooter manufacturing and use phase. The environmental impact categories were selected based on the ReCiPe 2016 Midpoint (H) LCIA framework (Huijbregts et al., 2016), which is among the most recent LCIA frameworks available. The environmental impacts included fine particulate matter formation, fossil resource scarcity, freshwater ecotoxicity, freshwater eutrophication, global warming, human carcinogenic toxicity, human non-carcinogenic toxicity, ionizing radiation, land use, marine ecotoxicity, marine eutrophication, mineral resource scarcity, ozone formation-human health, ozone formation-terrestrial ecosystems, stratospheric ozone depletion, terrestrial acidification, terrestrial ecotoxicity, and water consumption, as shown in Table 8.

Table 8: The ReCiPe 2016 Midpoint (H) collection of impact categories (Huijbregts et al., 2016).

Impact category	**Reference unit**
Fine particulate matter formation	kg PM2.5 eq
Fossil resource scarcity	kg oil eq
Freshwater ecotoxicity	kg 1,4-DCB
Freshwater eutrophication	kg P eq
Global warming	kg CO_2 eq
Human carcinogenic toxicity	kg 1,4-DCB
Human non-carcinogenic toxicity	kg 1,4-DCB
Ionizing radiation	kBq Co-60 eq
Land use	m^2a crop eq
Marine ecotoxicity	kg 1,4-DCB
Marine eutrophication	kg N eq
Mineral resource scarcity	kg Cu eq
Ozone formation, Human health	kg NO_x eq
Ozone formation, Terrestrial ecosystems	kg NO_x eq
Stratospheric ozone depletion	kg CFC11 eq
Terrestrial acidification	kg SO_2 eq
Terrestrial ecotoxicity	kg 1,4-DCB
Water consumption	m^3

4.1 Cradle-to-gate life cycle impact assessment results of electric scooter manufacturing

The LCIA results for cradle to scooter manufacturing gate using the ReCiPe Midpoint (H) method are presented in Table 9. Previous work by (Hollingsworth et al., 2019) reported results for: (a) global warming, (b) respiratory effects, (c) acidification, and (d) eutrophication. Note that the cradle-to-gate results in Table 9 do not capture activities beyond the factory gate; thus, use phase and end-of-life activities are not considered.

Table 9: The LCIA ReCiPe Midpoint (H) results for manufacturing of S-100 scooter.

Impact Category	**Reference unit**	**Scooter**	**Drover Camera**	**Lock**	**Seat and Basket**
Fine particulate matter formation	kg PM2.5 eq/scooter	[redacted]	[redacted]	[redacted]	[redacted]
Fossil resource scarcity	kg oil eq/scooter	[redacted]	[redacted]	[redacted]	[redacted]
Freshwater ecotoxicity	kg 1,4-DCB/scooter	[redacted]	[redacted]	[redacted]	[redacted]
Freshwater eutrophication	kg P eq/scooter	[redacted]	[redacted]	[redacted]	[redacted]
Global warming	kg CO_2 eq/scooter	[redacted]	[redacted]	[redacted]	[redacted]
Human carcinogenic toxicity	kg 1,4-DCB/scooter	[redacted]	[redacted]	[redacted]	[redacted]
Human non-carcinogenic toxicity	kg 1,4-DCB/scooter	[redacted]	[redacted]	[redacted]	[redacted]
Ionizing radiation	kBq Co-60 eq/scooter	[redacted]	[redacted]	[redacted]	[redacted]
Land use	m2a crop eq/scooter	[redacted]	[redacted]	[redacted]	[redacted]
Marine ecotoxicity	kg 1,4-DCB/scooter	[redacted]	[redacted]	[redacted]	[redacted]
Marine eutrophication	kg N eq/scooter	[redacted]	[redacted]	[redacted]	[redacted]
Mineral resource scarcity	kg Cu eq/scooter	[redacted]	[redacted]	[redacted]	[redacted]
Ozone formation, Human health	kg NOx eq/scooter	[redacted]	[redacted]	[redacted]	[redacted]
Ozone formation, Terrestrial ecosystems	kg NOx eq/scooter	[redacted]	[redacted]	[redacted]	[redacted]
Stratospheric ozone depletion	kg CFC11 eq/scooter	[redacted]	[redacted]	[redacted]	[redacted]
Terrestrial acidification	kg SO2 eq/scooter	[redacted]	[redacted]	[redacted]	[redacted]
Terrestrial ecotoxicity	kg 1,4-DCB/scooter	[redacted]	[redacted]	[redacted]	[redacted]
Water consumption	m3/scooter	[redacted]	[redacted]	[redacted]	[redacted]

Figure 7 below shows contribution analysis for selected impact categories in the ReCiPe 2016 Midpoint (H) framework from cradle to scooter manufacturing gate for the selected categories. The approach taken here is intended to provide the electric scooter industry with insight into which scooter components are more important for a comprehensive variety of impact categories, so that they can directly influence or manage these impacts.

A majority of the impact for all ReCiPe categories tend to be from five materials: aluminum, battery, cables, charger, and motor. The sum of these five contributors exceeded [redacted] across all impact categories. The Drover camera, lock, seat, and basket, appear to be overall minor factors for all ReCiPe environmental impact categories, with no individual impact exceeding 10% of total.

Electricity and heat at the manufacturing stage comprises all energy used for assembling the scooter and building use. Because on-site data from the scooter factory production site in China were not available, we used the data from Ecoinvent 3.4 database for manufacturing of an electric bicycle (Ecoinvent, 2017).

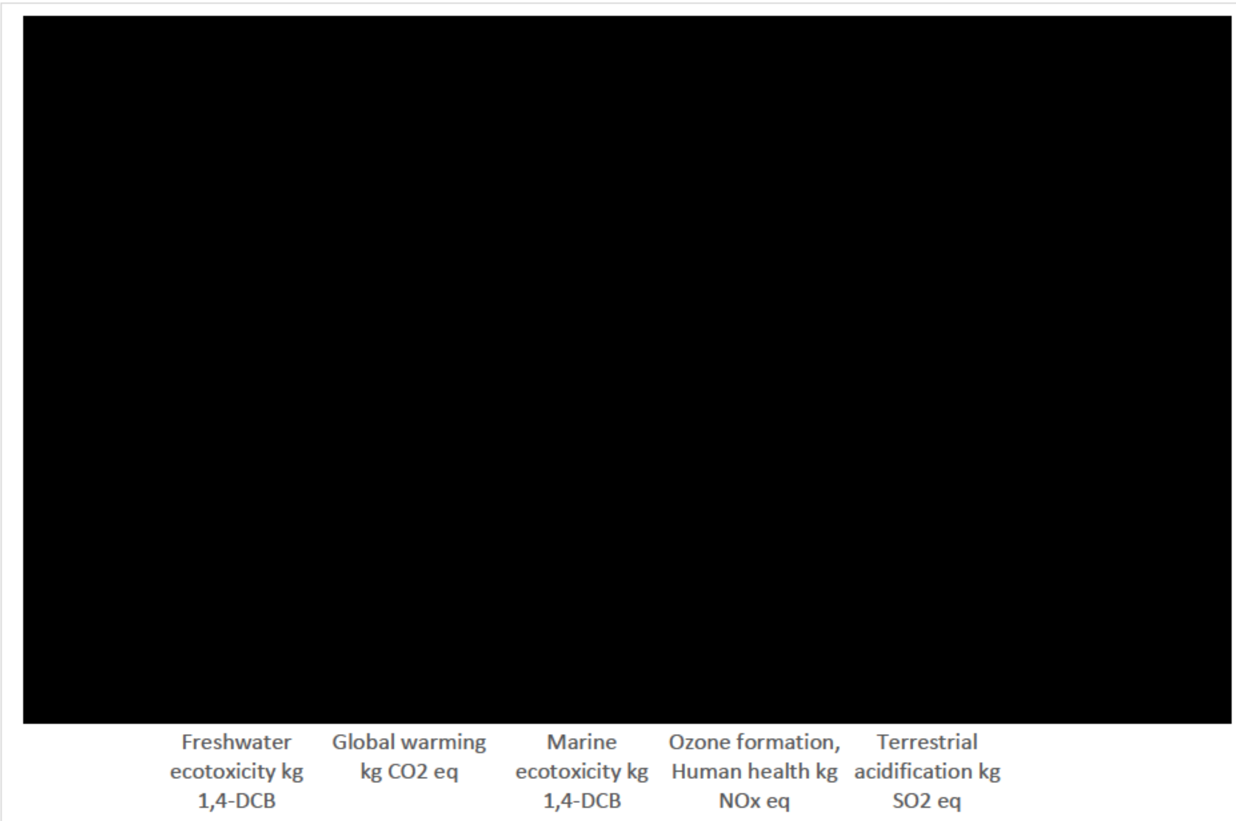

Figure 7: Relative contributions of materials and manufacturing categories for S-100 electric scooter.

4.2 Cradle-to-grave impacts of base scenario

The base scenario lifetime distance of 7,300 pkm was used to normalize the impact of the vehicle, as well as the associated disposal and recycling credits. As described previously, the impacts from battery charging and operational vehicle usage calculations are already attributed to a pkm basis. The full set of impacts are presented below in Table 10. Credits from renewable energy purchases were presented in separate columns in accordance with the GHG Protocol (The Greenhouse Gas Protocol, 2004). The total, net impacts per pkm are presented in the right-most column of Table 10.

Table 10: Full cradle-to-grave impacts of base scenario S-100 scooter on a per pkm basis, Global Warming highlighted in blue.

Impacts	Scooter Mfg	Shipping	Charging	Van Transport	Disposal	Recycling	RECs, Charging	RECs, Op EV	Total
Fine particulate matter formation kg PM2.5 eq	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Fossil resource scarcity kg oil eq	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Freshwater ecotoxicity kg 1,4-DCB	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Freshwater eutrophication kg P eq	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Global warming kg CO2 eq	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Human carcinogenic toxicity kg 1,4-DCB	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Human non-carcinogenic toxicity kg 1,4-DCB	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Ionizing radiation kBq Co-60 eq	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Land use m2a crop eq	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Marine ecotoxicity kg 1,4-DCB	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Marine eutrophication kg N eq	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Mineral resource scarcity kg Cu eq	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Ozone formation, Human health kg NOx eq	[redacted]	[redacted]		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Ozone formation, Terrestrial ecosystems kg NOx eq	[redacted]	[redacted]		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Stratospheric ozone depletion kg CFC11 eq	[redacted]	[redacted]		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Terrestrial acidification kg SO2 eq	[redacted]	[redacted]		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Terrestrial ecotoxicity kg 1,4-DCB	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Water consumption m3	[redacted]	[redacted]		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 10 shows that the total cradle-to-grave Global Warming impacts for the base scenario is [redacted] $kgCO_2$-eq / pkm ([redacted]) for the S-100 with the Drover camera and lock. The addition of the seat and basket increases the Adaptive S-100's cradle-to-grave Global Warming impact by [redacted] gCO_2-eq / pkm to a total of [redacted] gCO_2-eq / pkm. Spin's operating decisions to use renewable energy and responsibly recycle scooters at the end of life to enable material recovery upon scooter decommissioning led to substantially lower impacts. Without such actions, the global warming impacts from scooter manufacturing, battery charging, van transport, and disposal would total [redacted] gCO_2-eq for the S-100 with the Drover camera and lock.

Figure 8 is a "waterfall" chart depicting the incremental impact from manufacturing and the use phase and the beneficial activities such as recycling and renewable energy purchases that counteract the impacts.

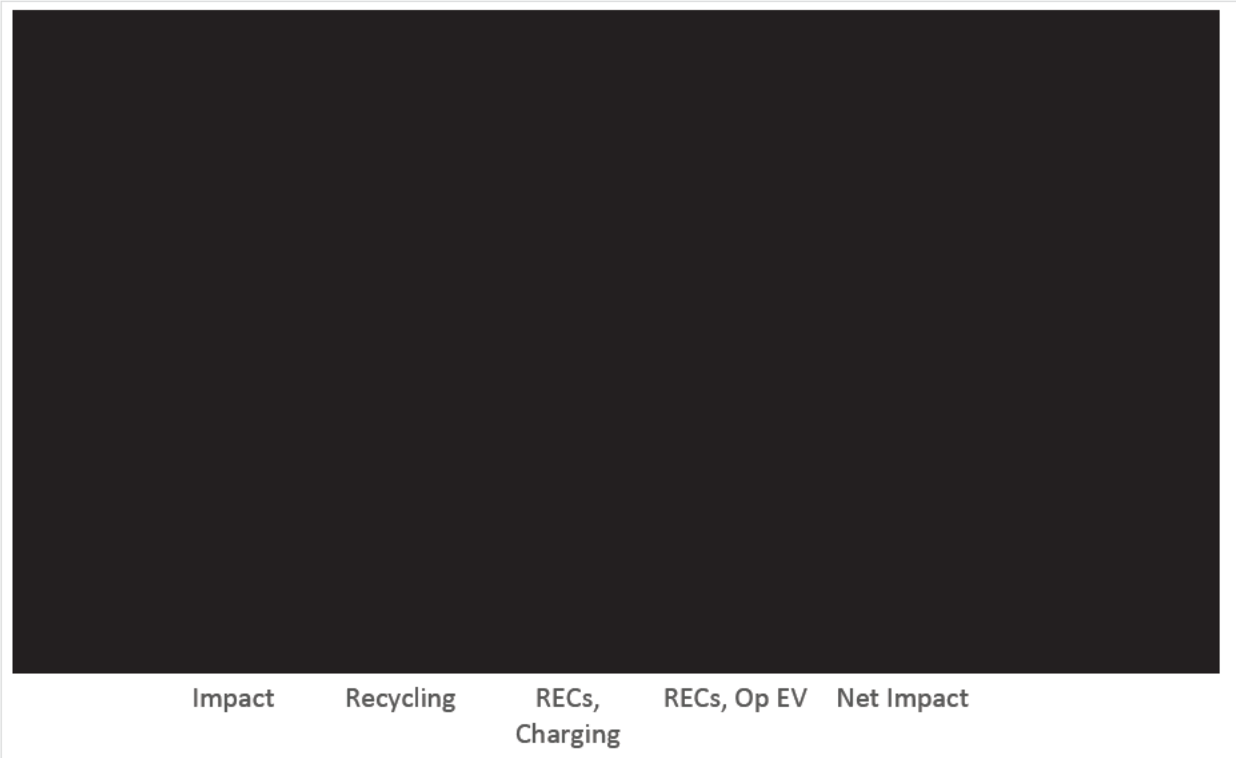

Figure 8: Waterfall chart of cradle-to-grave Global Warming impacts of base scenario.

4.3 Cradle-to-grave impacts of scenario analyses

The various scenario options described so far are summarized below in Table 11. There are three main scenarios to analyze. Scenario 2 involves two sub-scenarios, EV van fleet makeup and swappable battery, and the impacts from all the possible iterations will be presented. The baseline parameter is underlined and bolded in Table 11.

Table 11: Scenario options assessed in the study including legacy scenario. Underlined scenarios will be the default choice presented unless otherwise noted.

Scenarios	**Legacy**	**Baseline**	**Non-baseline scenarios**
1) Lifetime pkm	2,850 pkm	7,300 pkm	Max: [redacted] km
2a) EV van fleet	0%	50%	100%
2b) Swappable battery	No	Yes	No
3) Charging calculation	Utility bills	Utility bills	Engineering estimate

Lifetime pkm, EV van fleet, and swappable battery scenarios were created due to uncertainties in available operational data. However, the battery charging scenario was assessed due to differences in methodology from existing literature, which uses an engineering estimate approach, and utility bill data available at Spin. Each set of scenarios will be presented with resulting differences in the cradle-to-grave impacts.

In addition to baseline and non-baseline scenarios, a “legacy” set of impacts from a prior Spin study will be presented as well. The legacy scenario is sourced from a 2019 study on a previous Spin scooter model in the Portland market. The subsequent impacts will only present global warming potential for scenario comparison purposes. Note that the following graphs will show a stacked version of the waterfall chart shown in Figure 8. The beneficial activities such as recycling and renewable energy purchases will instead be displayed as negative value bars, extending below the 0 gCO_2-eq line. The net total value is calculated by subtracting the negative bars from the “positive” impacts.

4.3.1 Lifetime pkm distance scenarios

Scenario analysis of lifetime pkm was analyzed for Global Warming from cradle-to-grave. Figure 9 shows that there is a substantial reduction in total impacts compared to the legacy scenario, which was an LCA on the Portland market in 2019. Also, recycling after decommissioning was not incorporated in the legacy study. As seen in Figure 9, nearly half of the raw material and manufacturing Global Warming impacts are eventually offset with material recovery. The impact of scooter manufacture may be greatest in the low scenario, but the assumption of the eventual recycling leads it to have lower impacts than the legacy scenario. Similarly, the impacts from battery charging and van transport are offset by the use of 100% renewable energy. Note that the base scenario is that 100% of electricity is sourced from renewable purchases, but the operational fleet is only comprised of 50% electric vans.

Figure 9: Cradle-to-grave Global Warming impacts of various lifetime pkm for S-100 scooter in San Francisco.

4.3.2 Electric van fleet makeup and swappable battery fleet

The scenario analyses for electric vans in the operations fleet and swappable batteries will be combined since both scenarios pertain to the operational vehicle usage. The operational vehicle usage seemed to be much lower in impacts in the current study. The data from the legacy study showed that there were fewer months of data available in the original study, and thus the average value was more sensitive to outliers. Moreover, the legacy study applied an additional upscaling factor to correct for unreported van trips, which further increased the assumed van travel per pkm. Such a correction factor was not applied in the current study since Spin did not indicate such corrections were needed in the current data. Finally, the legacy study had 0% electric vans for operations.

As expected, 100% EV fleet with swappable scooters led to the lowest cradle-to-grave impacts. As described in Section 2.5, there is currently no Spin-specific empirical data available comparing the operation efficiency per pkm between servicing non-swappable and swappable scooters since swappable scooters have only been introduced to their fleet very recently. However, multiple literature sources cite reductions ranging from 50% to as much as 75% compared to non-swappable; this study applies a conservative reduction of 50%. The intermediate scenarios of 50% EV with swappable and 100% EV with non-swappable had comparable impacts. On the other end of the spectrum, the scenario 0% EV with non-swappable scooters had the highest impacts, with the exception of the legacy scenario.

There is a reduction in scooter manufacturing impacts in the swappable scenarios because of the modularization of the charger component. This allows raw material impacts from the charger to be reduced to 30% compared to non-swappable scenarios.

Note that Spin aims to transition to full electric vans, therefore, 0% EV scenarios are presented for analytical purposes only.

[redacted]

Figure 10: Cradle-to-grave Global Warming impacts of EV fleet composition and battery swappability for S-100 scooter in San Francisco.

4.3.3 Battery charging calculation methodologies

Figure 11 shows the differences in net total impacts between electricity consumption data based on Spin utility bills and engineering estimates of battery depletion rates. Compared to the legacy scenario, both current scenarios are substantially lower in Global Warming impacts. Paradoxically, using engineering estimates, where electricity consumption calculations are substantially lower, did not lead to a drastic reduction in cradle-to-grave impacts. This is due to the model assumption that 100% of electricity consumed is from renewable sources. Therefore, the higher electricity consumption impact is ultimately offset by an equally high amount of benefits from renewable energy purchases from the utility. The engineering estimate scenario has slightly lower total impacts; however, the offsetting effects from the RECs lead to only a minor reduction overall.

[redacted]

Figure 11: Cradle-to-grave Global Warming impacts of battery charging calculations for S-100 scooter in San Francisco.

4.3.4 All material and operational improvement scenarios combined

Figure 12 shows that when all material and operational improvement scenarios are combined, the impact per pkm impacts for global warming can be reduced to as low as [redacted] gCO_2eq for the S-100 with the Drover camera and lock and [redacted] gCO_2eq for the Adaptive S-100 with the Drover camera, lock, seat, and basket. While Spin aims to reach 100% electric vans for all markets, this is a future target due to high demand and limited supply of electric vans in the United States currently.

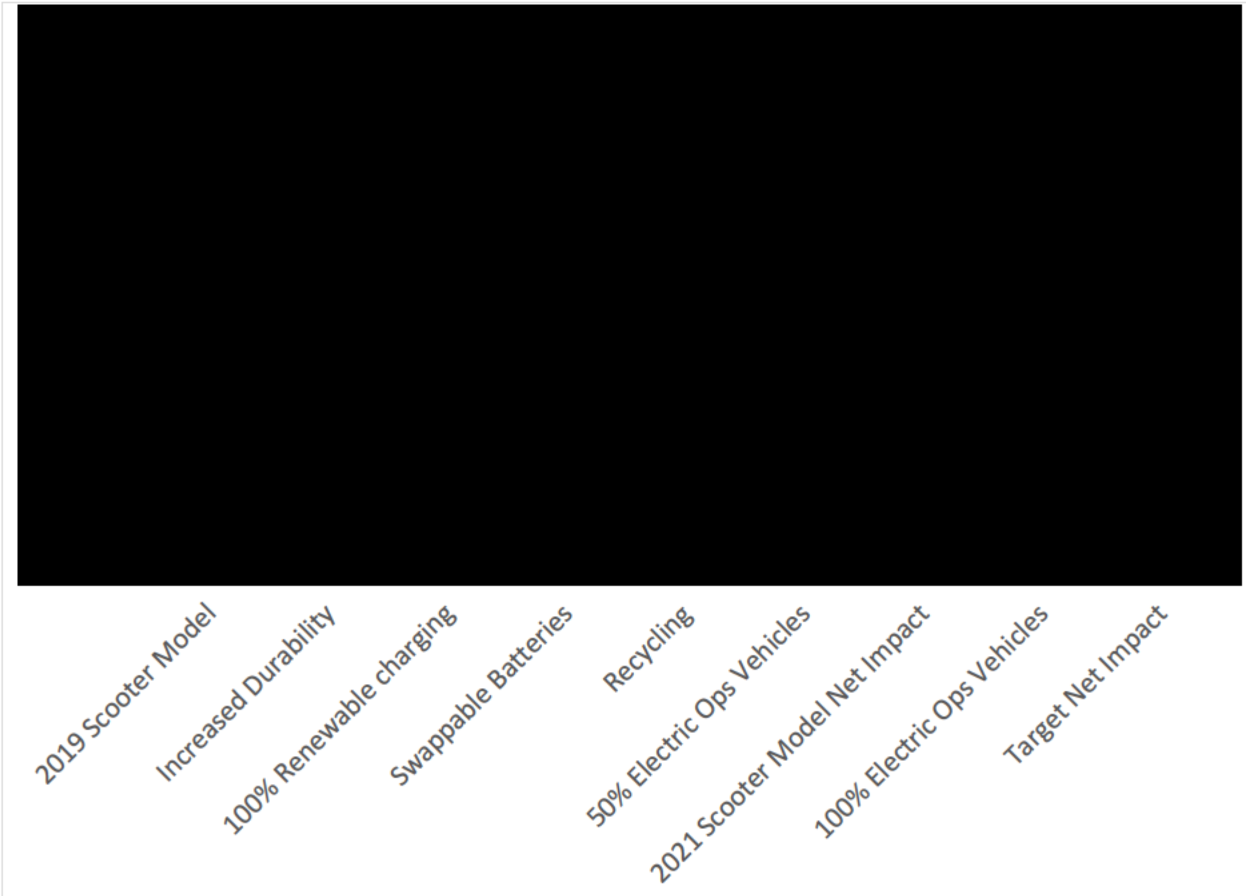

Figure 12: Waterfall chart of all material and operational improvements. Green bars showing the reductions from legacy 2019 scooter model.

4.4 Comparing with other Urban Transport Data in Ecoinvent Database

In the Ecoinvent database, there were six urban transport datasets that were selected for comparing with baseline cradle-to-grave impacts of Spin scooters.

Table 12: Ecoinvent processes for urban transport compared to Spin scooter.

Ecoinvent unit process	**Description**
transport, passenger car, medium size, petrol, EURO 4 | transport, passenger car, medium size, petrol, EURO 4 | Cutoff, U - RoW	Car, gasoline, internal combustion engine (IEC)
transport, passenger car, electric | transport, passenger car, electric | Cutoff, U	Car, electric
transport, regular bus | transport, regular bus | Cutoff, U – RoW	Bus, diesel engine

transport, passenger, motor scooter | transport, passenger, motor scooter | Cutoff, U - RoW	Motor scooter (moped), internal combustion engine
transport, tram | transport, tram | Cutoff, U - RoW	Train, electric (e.g., urban subway, streetcars)
transport, passenger, bicycle | transport, passenger, bicycle | Cutoff, U - RoW	Bicycle, manual pedal powered

The environmental impact results of the Ecoinvent processes summarized in Table 12 are presented on a per km basis in Table 13. Datasets for bus and tram assume an average level of occupancy per km of transport. Spin scooter, car, moped, and bicycle assume a single passenger.

Table 13: Impacts of various urban transport modes compared with Spin scooter on a per km basis, Global Warming highlighted.

Impact Category	Car, ICE	Car, electric	Bus, diesel	Tram, electric	Moped, ICE	Bicycle, Pedal	S-100 (w/ Drover & lock)	Adaptive S-100 (w/ Drover & lock)
Fine particulate matter formation kg PM2.5 eq	3.70E-04	7.40E-04	2.10E-04	2.10E-04	1.20E-04	2.94E-05	[redacted]	[redacted]
Fossil resource scarcity kg oil eq	0.1153	0.0600	0.0364	0.0232	0.0349	0.0035	[redacted]	[redacted]
Freshwater ecotoxicity kg 1,4-DCB	2.62E-02	3.41E-02	1.17E-03	2.53E-03	2.76E-03	1.54E-03	[redacted]	[redacted]
Freshwater eutrophication kg P eq	6.96E-05	2.70E-04	7.40E-06	4.63E-05	8.12E-06	4.90E-06	[redacted]	[redacted]
Global warming kg CO_2 eq	0.3665	0.2274	0.1080	0.0981	0.1131	0.0146	[redacted]	[redacted]
Human carcinogenic toxicity kg 1,4-DCB	1.61E-02	2.29E-02	1.79E-03	5.64E-03	2.73E-03	2.28E-03	[redacted]	[redacted]
Human non-carcinogenic toxicity kg 1,4-DCB	0.3187	0.8060	0.0206	0.0644	0.0861	0.0461	[redacted]	[redacted]
Ionizing radiation kBq Co-60 eq	8.26E-03	3.75E-02	1.99E-03	9.66E-03	1.63E-03	4.30E-04	[redacted]	[redacted]
Land use m2a crop eq	7.96E-03	6.08E-03	3.15E-03	1.75E-03	9.90E-04	4.90E-04	[redacted]	[redacted]
Marine ecotoxicity kg 1,4-DCB	0.0351	0.0471	0.0016	0.0035	0.0040	0.0021	[redacted]	[redacted]
Marine eutrophication kg N eq	4.81E-06	1.69E-05	8.35E-07	3.16E-06	7.66E-07	5.10E-07	[redacted]	[redacted]
Mineral resource scarcity kg Cu eq	1.85E-03	2.22E-03	1.40E-04	2.70E-04	2.50E-04	2.10E-04	[redacted]	[redacted]
Ozone formation, Human health kg NOx eq	5.00E-04	4.80E-04	1.04E-03	2.70E-04	7.30E-04	3.22E-05	[redacted]	[redacted]
Ozone formation, Terrestrial ecosystems kg NOx eq	5.40E-04	5.60E-04	1.05E-03	2.90E-04	1.00E-03	3.31E-05	[redacted]	[redacted]
Stratospheric ozone depletion kg CFC11 eq	1.98E-07	9.21E-08	3.96E-08	3.57E-08	3.59E-08	3.71E-09	[redacted]	[redacted]

Terrestrial acidification kg SO2 eq	8.50E-04	8.90E-04	5.20E-04	3.60E-04	2.80E-04	6.00E-05	[redacted]	[redacted]
Terrestrial ecotoxicity kg 1,4-DCB	1.9150	2.0033	0.1727	0.1720	0.4509	0.0299	[redacted]	[redacted]
Water consumption m3	1.46E-03	1.62E-03	3.00E-04	7.00E-04	3.20E-04	1.10E-04	[redacted]	[redacted]

Table 13 shows all of the impact categories available in the ReCiPe methodology. Graphing the Global Warming methodology shows a wide range of impacts per km of transport.

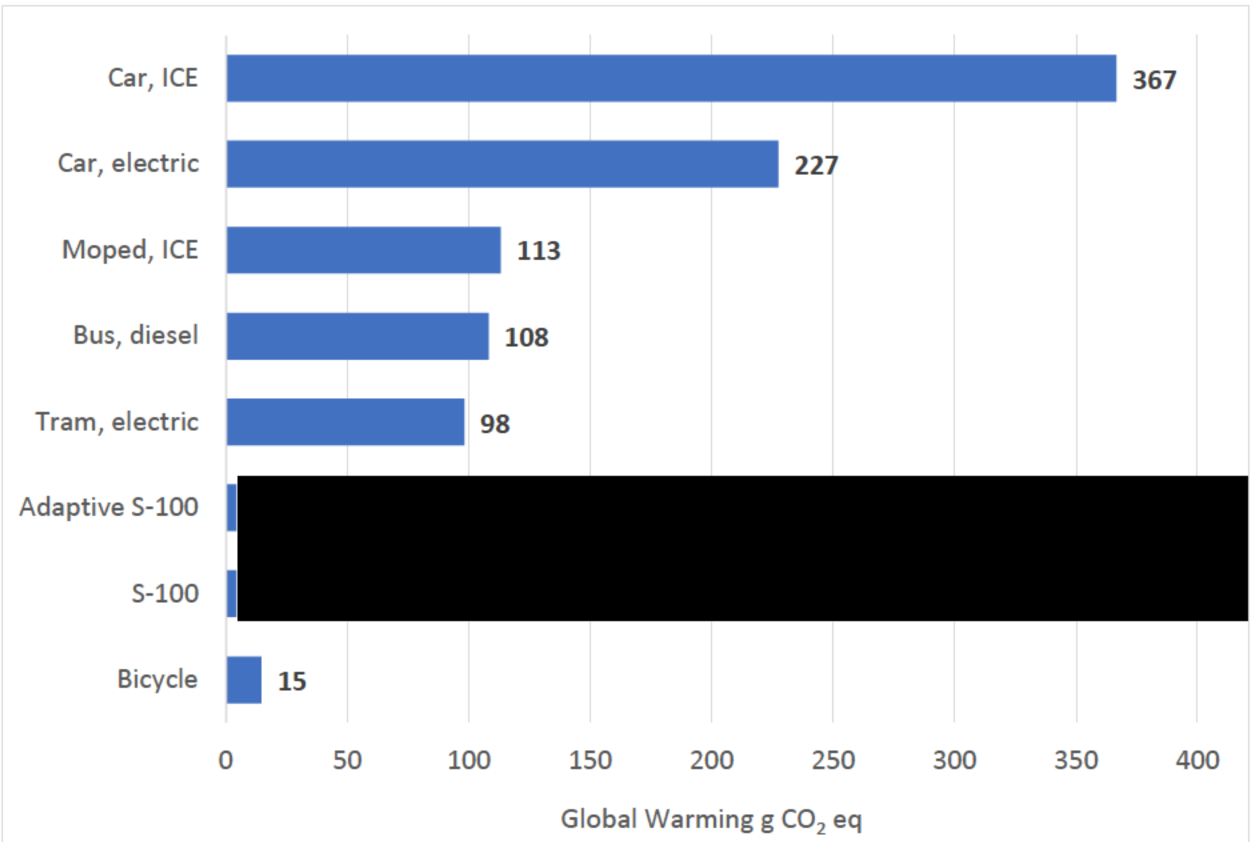

Figure 13: Global Warming impact per km of urban transport.

Figure 13 above shows that gasoline-powered cars have the highest Global Warming impact per km of transport. However, it should be highlighted that electric cars are also twice as impactful per km as the moped, which is the third most impactful. According to the Department of Energy, average occupancy of a passenger car was approximately 1.5 (DoE, 2017). While both gasoline and electric cars remain the highest impact transport modes, using an occupancy higher than 1 would result in lower impacts per km. Mopeds, bus, and trams all have comparable per km impacts. Because buses and trams are high-capacity vehicles, increasing average ridership assumptions could potentially lead to substantially lower impacts.

Spin scooters have the lowest Global Warming impact among technology-assisted urban vehicles. The only vehicle with lower per-km impacts is the bicycle, which is manually pedaled.

5 Conclusion

A cradle-to-gate analysis revealed that the main contributors to impacts were primarily the aluminum, lithium-ion battery, cables, and electric motors. Accessories such as the seat, basket, and the Drover AI camera were found to have generally minor impacts. Recycling at end-of-life led to approximately half of the impacts of raw material acquisition to be offset by displacing future primary material production.

Using life cycle assessment, we quantify the cradle-to-grave environmental impacts of this mobility option. We find that the cradle-to-grave Global Warming impact for the base scenario described, and the S-100 with the Drover camera and lock is [redacted] kgCO_2-eq per passenger-km, or [redacted] CO_2 equivalent and [redacted] CO_2 equivalent for the Adaptive S-100 with the Drover camera, lock, seat, and basket. This baseline impact is expected to vary from market-to-market due to a multitude of factors, such as actual lifetime durability of the scooters in terms of distance, deployment of swappable scooters, electric vans for operations, and overhead electricity consumption at sites where batteries are charged. If all of the reduction activities are realized, the per passenger-km can be reduced to [redacted] grams CO_2 equivalent for the S-100 and [redacted] CO_2 equivalent for the Adaptive S-100.

Figure 13 shows that dockless scooters have the potential to substantially reduce urban transport by displacing other modes such as single-occupied gasoline cars.

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		Q1) When did you decide to take this scooter for this trip?			Q2) If not by scooter, how would you have taken the trip that just ended?									Q3) Did you connect with public transit before or after your SPIN trip?		Q4) What factors influenced you to choose a scooter for this trip? Choose all that apply.									
City	**# of Complete Responses**	**Spur of the moment (when I saw the scooter)**	**Shortly before starting the trip**	**Planned earlier in the day or the days before**	**Private Car**	**Ride Share (e.g., Uber, Lyft, Taxi, etc.)**	**Walk**	**Public Transit**	**Personal Bike**	**Bike share**	**I wouldn't have made this trip**	**Other**	**% total car trips displaced (private care + ride share)**	**Yes**	**No**	**Faster option**	**Easiest, most convenient option**	**Least expensive option**	**I don't own a car**	**Public transit is too far/too slow**	**Best option due to COVID-19**	**It's fun**	**Safer than alternative options**	**Less polluting / more environmentally friendly**	**Other (please specify)**
Los Angeles	1,758	55.3%	27.2%	17.5%	16.3%	14.9%	43.7%	11.4%	3.5%	3.5%	4.9%	1.8%	31.2%	36.1%	63.9%	54.7%	34.9%	17.9%	25.4%	17.1%	10.9%	36.1%	8.2%	14.6%	6.0%
Sacramento	3,259	59.1%	24.4%	16.5%	19.3%	12.6%	51.2%	4.4%	3.4%	2.8%	5.0%	1.4%	31.9%	23.4%	76.7%	54.5%	33.3%	11.8%	11.1%	9.0%	5.6%	42.1%	5.9%	10.4%	5.4%
San Diego	3,733	52.2%	34.6%	13.2%	8.3%	4.2%	74.4%	4.6%	2.8%	1.4%	3.3%	1.1%	12.5%	24.2%	75.8%	70.4%	35.5%	7.2%	14.3%	9.1%	3.5%	32.8%	3.8%	6.3%	3.0%
San Francisco	4,367	51.2%	32.5%	16.3%	12.2%	17.1%	46.8%	11.6%	2.9%	4.5%	3.7%	1.2%	29.3%	26.8%	73.3%	62.3%	40.3%	17.6%	17.8%	17.0%	7.8%	40.3%	5.2%	13.6%	4.7%
Santa Monica	2,204	53.3%	29.2%	17.6%	19.0%	14.4%	48.4%	4.4%	4.0%	4.0%	4.2%	1.6%	33.4%	23.2%	76.8%	55.7%	36.1%	14.8%	12.4%	11.6%	7.1%	40.6%	6.0%	12.6%	4.4%
	Avg	**54.2%**	**29.6%**	**16.2%**	**15.0%**	**12.6%**	**52.9%**	**7.3%**	**3.3%**	**3.2%**	**4.2%**	**1.4%**	**27.7%**	**26.7%**	**73.3%**	**59.5%**	**36.0%**	**13.9%**	**16.2%**	**12.8%**	**7.0%**	**38.4%**	**5.8%**	**11.5%**	**4.7%**