sustainability

MDPI

Article

An Exploration of the Decline in E-Scooter Ridership after the Introduction of Mandatory E-Scooter Parking Corrals on Virginia Tech's Campus in Blacksburg, VA

Ralph Buehler [1,*], Andrea Broaddus [2], Elizabeth White [3], Ted Sweeney [4] and Chris Evans [1]

[1] Urban Affairs and Planning, Virginia Tech Research Center, Arlington, VA 22203, USA
[2] Ford Motor Company, Palo Alto, CA 94304, USA
[3] VTTI, Virginia Tech, Blacksburg, VA 24061, USA
[4] Spin, San Francisco, CA 94107, USA
* Correspondence: ralphbu@vt.edu

Abstract: We report shared e-scooter ridership and rider perceptions on Virginia Tech's Blacksburg campus before and after introduction of mandatory e-scooter parking corrals in January 2022. The analysis relies on a panel of 131 e-scooter riders surveyed in Fall 2021 and Spring 2022. Although parking corrals were perceived favorably prior to implementation, perceptions became more negative afterwards. Respondents said corrals were not located where needed, difficult to find, fully occupied, and took too much extra time to use. After parking corrals were introduced, ridership declined 72% overall and also fell for all socio-economic subgroups. The heaviest user groups, like undergraduate males, were most likely to quit. The first study identifying desired and actual egress times for e-scooters, we found that roughly two-thirds of riders desired egress times under 2 min and one quarter under 1 min. Prior to the introduction of parking corrals, 82% of riders reported actual egress times under 2 min, and 43% under 1 min. Those who kept riding after the introduction of e-scooter corrals reported longer actual egress times and a stronger stated desire for egress times under 2 min. Communities should be careful when imposing e-scooter parking restrictions to ensure that e-scooter egress time is sufficiently low—ideally within an easy 2 min walk of popular origins and destinations.

Keywords: e-scooter; parking; parking corrals; university campus; ridership trends; policy

Citation: Buehler, R.; Broaddus, A.; White, E.; Sweeney, T.; Evans, C. An Exploration of the Decline in E-Scooter Ridership after the Introduction of Mandatory E-Scooter Parking Corrals on Virginia Tech's Campus in Blacksburg, VA. *Sustainability* **2023**, *15*, 226. https://doi.org/10.3390/su15010226

Academic Editors: Filomena Mauriello and Maria Rella Riccardi

Received: 1 November 2022
Revised: 9 December 2022
Accepted: 15 December 2022
Published: 23 December 2022

1. Introduction

Since 2018, electric scooter (e-scooter) ridership and the number of e-scooter systems has expanded rapidly in U.S. cities and on U.S. university campuses [1,2]. Combined with walking, cycling, and public transport, e-scooters have the potential to help reduce the reliance on automobiles for most trips [2–5]. E-scooter parking has been identified as a potential hindrance to the implementation of e-scooter systems [6–10]. Parked e-scooters are associated with cluttered sidewalks, blocked entrances, and obstructed ADA accessible ramps or fire hydrants [6–10]. E-scooter companies, local jurisdictions, and university campuses have reacted to community complaints about e-scooter parking problems with several policies including lock-to-requirements (where e-scooters must be locked to street furniture), e-scooter docking stations, or by limiting e-scooter parking to specified geofenced areas—so-called e-scooter parking corrals (also sometimes referred to as required parking zones (RPZs)) [6].

Published research on e-scooters has increased significantly in the last four years [5,11–26]. Those e-scooter studies have focused on motivations for riding e-scooters [5,16,19]; socio-demographics and perceptions of e-scooter riders and non-riders [2,5,9,27]; route choice and infrastructure [20]; regulations of e-scooter systems [11,13,23]; mode replacement and multimodal connections with other modes [10,14,15,17]; or benefits and costs of e-scooter systems [5,12,16,18]. Publications focusing on e-scooter parking are more limited and typically focus on perceived and actual cluttering of sidewalks. One of the first peer-reviewed studies focusing on e-scooter parking by James et al. [9] identified a low share of e-scooters that obstructed sidewalks or were parked improperly. They also reported a large discrepancy in the perception of poor e-scooter parking and actual unlawful parking. A study from San Jose State University campus found that about 72% of e-scooters were parked properly and that 90% of e-scooters, including improperly parked e-scooters, did not block pedestrian walkways [21,28]. Similarly, Klein et al. [6] studied e-scooter parking in Washington, DC and Auckland, NZ. They found little unlawful e-scooter parking. By contrast a study from Portland, Oregon, found 75% of e-scooters not being parked according to city requirements [22].

The Portland, Oregon study also found that parking compliance varied by geography and built environment—with more violations in areas with less e-scooter parking supply [22]. Similarly, James et al. [9] had found that non-compliant e-scooters were most likely improperly parked around fire hydrants, bus stops, bike parking, and light posts. Gössling [10] as well as Caspi and Smart [29] described how news outlets in the U.S. and Europe disproportionally publish stories about poorly parked e-scooters. Brown et al. [6–8,23] and James et al. [9] identified a lack of understanding of e-scooter parking regulations among riders and non-riders as a source for poor e-scooter parking and negative perceptions of parked e-scooters. Similarly, several studies identify cluttering of sidewalks as a key problem of e-scooter deployment [12,13,30]. A study of e-scooter users and non-users in Greece found that 55% of users and 58% of non-users rated dedicated e-scooter parking locations as important or very important for e-scooter riding and the reduction of negative impacts [27]. At the same time non-users identified e-scooter parking on sidewalks as a major issue for pedestrians [27]. By contrast, Buehler et al. [2] found that perceptions of e-scooter parking were positive among riders and non-riders on Virginia Tech's campus in Blacksburg, Virginia.

Klein et al. [6] suggest to distinguish between "non-compliant parking," which is illegal and "improper parking," which is legal, but perceived as illegal. They also report that responses to e-scooter parking problems fall typically in four areas: regulations, incentives, operations, and infrastructure. Regulations stipulate how e-scooters should be parked. Incentives provide future ride credit or other rewards for proper parking. Operational measures require certain user behaviors before a ride can end, including locks that necessitate e-scooters to be locked to an object or geofencing that involves e-scooters to be parked in corrals. Infrastructure includes designated e-scooter parking corrals on streets or sidewalks. Implementation of these measures usually overlaps, in practice. For example, at Virginia Tech an infrastructure measure (parking corrals) was paired with an operations measure (geofencing). In an international overview of best-practices for e-scooter regulation, Turon and Czech [13] recommend e-scooter docking stations or city wide e-scooter parking concepts that designate dedicated parking spaces in combination with ongoing supervision, enforcement, and monetary penalties for illegal parking. A case study of Paris, France found less illegal and non-compliant e-scooter parking on sidewalks after the City of Paris had announced enforcement of e-scooter parking regulations and fines for illegally parked e-scooters [31].

Karlsen et al. [32] studied the introduction of e-scooter parking corrals in Trondheim, Norway using GPS and video data. They find that proper e-scooter parking improved after installation of the corrals, but that public perception of e-scooter parking did not change. Other scholars, like Dunn [24] argue that GPS technology is not precise enough to effectively frame e-scooter parking corrals on sidewalks or streets. Similar to Karlsen et al. [32], a study from Vienna, Austria found a reduction in e-scooters cluttering the sidewalk after the introduction of 15 e-scooter parking corrals [33]. The authors found that the distance between e-scooter parking corrals should be short for riders to actually park their e-scooters in the corrals. Some cities and systems offer monetary incentives to park e-scooters in designated areas [6,23,33].

As shown above, prior research on e-scooter parking has focused on rider and non-rider perceptions of parking behavior, parking locations, cluttering of sidewalks and streets, as well as compliance with various types of regulations of e-scooter parking. There are no evaluations of impacts of corrals on overall e-scooter ridership. There is also no information about willingness to walk to access e-scooters—other than the suggestion that corrals should not be too far from each other. This paper describes e-scooter ridership as well as rider perceptions on Virginia Tech's campus in Blacksburg, Virginia before and after the introduction of mandatory e-scooter parking corrals in January 2022. The analysis mainly relies on a panel survey of 131 individuals on campus who responded to two surveys, one in Fall 2021, prior to the introduction of e-scooter parking corrals, and in Spring 2022, after the introduction of e-scooter parking corrals. We fill gaps in the existing research by investigating three questions:

(1) How did ridership of e-scooters change when mandatory parking corrals were introduced—overall, by riding intensity, and by demographic characteristics?
(2) How did actual and desired egress time from e-scooters to trip destinations change with the introduction of e-scooter parking corrals?
(3) How did riders perceive parking corrals before and after the introduction of mandatory parking corrals?

The following section of this paper introduces the study context and describes our data collection and analysis methods. Next, we present descriptive results of objective and self-reported ridership changes, overall and by demographic subgroups, before and after the introduction of mandatory parking corrals. This section also analyzes changes in actual and desired egress times from e-scooters, as well as changes in the perception of parking corrals over time. We then discuss our findings in the context of existing research, highlight limitations of our paper, and provide policy recommendations and suggestions for future research.

2. Materials and Methods

2.1. Study Background

Our analysis is part of a research partnership between the Virginia Tech Transportation Institute (VTTI) and Spin, an e-scooter mobility provider owned by Ford until April 2022—when it was sold to the micromobility provider TIER [9,34]. Between September 2019 and March 2020, as well as August 2021 and May 2022, Spin operated a fleet of up to 325 e-scooters on the Virginia Tech campus in Blacksburg, Virginia. The service was interrupted by the COVID-19 pandemic in March 2020 when the system was closed and the university moved to online teaching [34]. In August 2021 when the university returned to in-person teaching, the e-scooter sharing system resumed operation [35].

When the system was active, e-scooters could only be operated on campus—an area of about 1 square mile—but not in the adjacent town of Blacksburg. At the geofenced boundary, the e-scooter provided audible feedback and ceased to operate. Prior to the COVID-19 pandemic, every day Spin deployed its e-scooters at designated locations in the service area at 7:00 am and collected them for overnight storage and charging 30 min after dusk [2]. When the system reopened in August 2021, e-scooters were no longer collected in the evenings, but e-scooters were turned off 30 min after dusk and could not be rented. The e-scooters were reactivated for rentals at 7:00 am. During both operating phases, e-scooters were removed from campus in advance of high-traffic events (e.g., football games), during winter break, and during inclement weather. E-scooters were accessed via the Spin app, at a cost of $1 to unlock (start a trip) and a per minute charge, which was $0.15 per minute at introduction and until March 2020, and increased to $0.29 per minute at reintroduction of the system in August 2021 [34].

Due to concerns by university administration and nuisance complaints by on-campus groups about clutter and obstruction caused by parked e-scooters, Spin voluntarily decided to introduce mandatory parking corrals starting January 2022 [36]. The locations for the 49 parking corrals (see Figure 1) were mainly chosen based on trip origins and destinations of e-scooters on campus—siting parking corrals in locations with high concentrations of e-scooter trips. Spin's initial proposal for parking corral locations was adjusted with the input of campus stakeholders including Virginia Tech housing, dining services, and services for students with disabilities [36]. Spin's parking corrals were marked rectangular areas in the campus landscape, associated in Spin's backend system with a 20 m radius GPS-based geofence centered within the physically marked area. Riders with e-scooters reporting their location within the radius were permitted to end their trip.

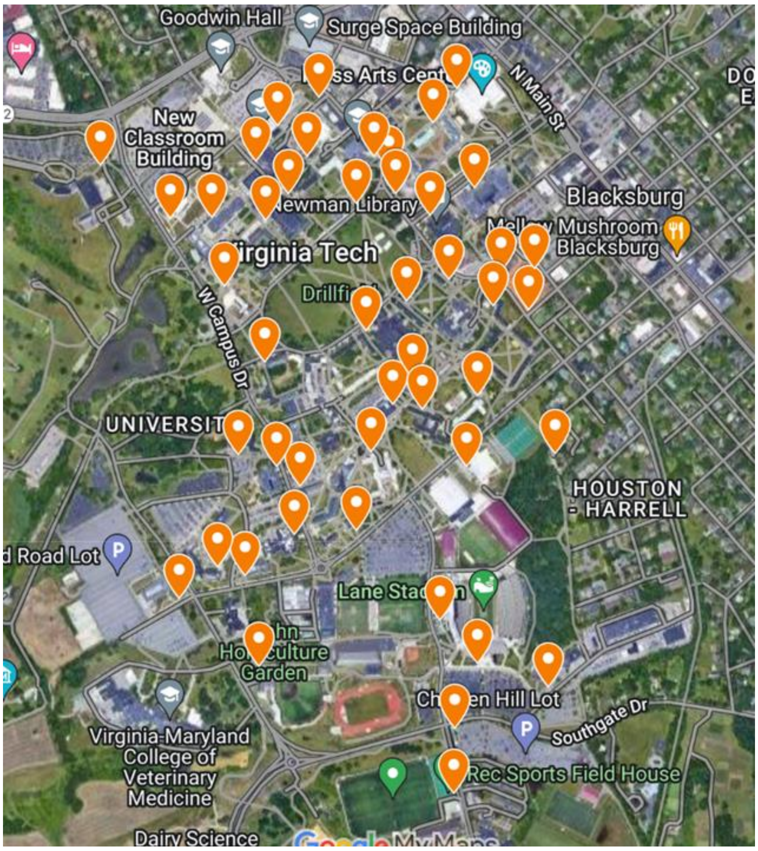

Figure 1. Location of parking corrals on Virginia Tech campus, January to March 2022. Source: google maps.

2.2. Methods

Answering our first research question, our analysis of ridership trends is based on two data sources. First, we obtained unpublished monthly ridership totals for each month of operation from Spin directly. This allowed us to compare monthly ridership trends for two periods: (1) September 2019 to March 2020, as well as (2) September 2021 to March 2022. To facilitate comparison of ridership trends between the two periods, we indexed ridership levels to 100% for September of each academic year (September 2019 = 100% for year 1 and September 2021 = 100% for year 2). The months of main interest for ridership trends were January 2022 to March 2022 when mandatory e-scooter corrals were in effect. We compared ridership trends in academic year 2021/2022 to ridership trends in 2019/2020—with a special focus on relative ridership during January, February, and March, when mandatory parking corrals were in effect in academic year 2021/2022, but not in 2019/2020.

Second, we compared self-reported ridership intensity based on responses from Spin riders participating in two waves of a panel survey: one in Fall 2021, prior to mandatory parking corrals, and one in Spring 2022 when mandatory parking corrals were in place. In each survey respondents reported their ridership intensity. We distinguished between those who did not (or no longer) ride e-scooters and those who rode at least multiple times a month or more at the time of completing the survey (defined as "regular riders"). We compared ridership intensity of the same individual prior and after the installation of mandatory parking corrals. We then identified changes in ridership for population sub-groups by gender, race/ethnicity, role on campus, on/off campus housing, income, respondent's age, and riding intensity. For each subgroup we calculated changes in self-reported e-scooter usage before and after the introduction of parking corrals. Comparing responses of the same individual in Fall 2021 and Spring 2022 allowed us to identify groups of Spin users that had reduced their e-scooter riding. Statistical significance of changes in ridership intensity was assessed using *t*-tests based on population proportions (e.g., share of respondents riding e-scooters ranging from 0–1) as well as chi-square tests for two categorical variables—for our analysis of population subgroups.

Panel participants were identified through an initial screening survey of all individuals who had ever downloaded the Spin app and signed up as a Spin user on Virginia Tech's campus in Blacksburg—no matter if they rode or did not ride e-scooters after downloading the app. As part of the sign-up process, individuals reported their email address which was used by Spin to contact them for the screening survey. The Virginia Tech team created the screening survey using the software Qualtrics, but did not have access to the email addresses of Spin users. Spin distributed the survey link to all individuals who had downloaded the Spin app at Virginia Tech's campus in Blacksburg. The survey was also advertised in campus media and on campus list-servs—clearly targeting individuals who rode Spin on campus or downloaded the app. The short screening survey collected basic demographic data and asked respondents if they would be willing to opt into a panel study of two in-depth surveys about e-scooters on campus—one survey distributed in Fall 2021 and one distributed in Spring 2022. We obtained IRB approval and offered a chance to win $50 for participants as an incentive with 20:1 odds. In total, 204 respondents opted in to participate in the two panel surveys (out of 454 responses to the screening survey).

We collected the panel data in two survey waves using the software Qualtrics: one in October and November 2021 (survey 1) as well as in January, February, and March in 2022 (survey 2). These two surveys were emailed by the Virginia Tech team directly to respondents because individuals who had opted into the panel surveys had shared their email addresses during the screening survey. The surveys were initially open for four-week periods and we reminded respondents several times about completion of the survey. A total of 131 respondents completed both surveys and were part of our final analysis (with an additional 72 respondents only completing the survey in Fall 2021, but not in Spring 2022. In spring 2022, we briefly re-opened the second wave of the panel survey in an attempt to get additional responses of the 72 non-respondents, but without success).

To answer our second research question about egress times, the panel surveys also asked riders to report their desired egress time from e-scooters to destinations, that is, how long they were willing to walk after parking the scooter, as well as their actual egress time, or how long their walk took. This allowed us to identify changes in time sensitivity for the entire sample—distinguishing those who reduced their riding and those who continued riding. For those who continued riding, we were also able to compare self-reported actual e-scooter egress time before and after the introduction of the e-scooter corrals.

Last, and to answer our third research question, the panel survey asked respondents about their perceptions of e-scooter parking corrals before and after the introduction of mandatory parking corrals on campus. Specifically, we asked about perceptions of parking corrals and cluttering of sidewalks, ease of access to e-scooters, as well as distances between e-scooters corrals and trip origins and destinations. Comparing results before and after the introduction of mandatory parking corrals allowed us to identify changes in perceptions.

3. Results

3.1. Trends in Ridership, Weather, and Deployment

Figure 2 shows trends in monthly e-scooter ridership on Virginia Tech's campus for two periods: year 1 (September 2019 to March 2020), and year 2 (August 2021 to May 2022). To facilitate comparison of trends during the two time periods, ridership levels for each period are indexed to the months of September for each year (2019 or 2021), representing 100%.

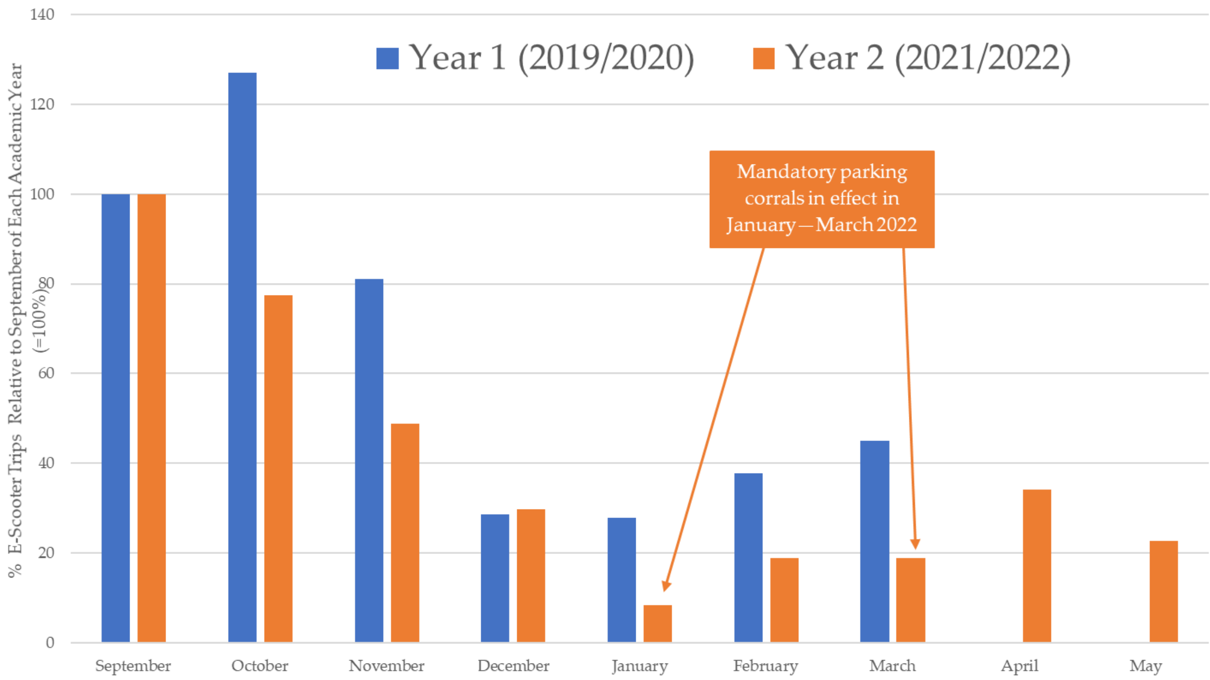

Figure 2. Trend in e-scooter trips on Virginia Tech's campus in Blacksburg, September 2019–March 2020 and September 2021–May 2022 (Note: for comparison of ridership trends, each period is indexed to September = 100% of each period).

During both periods, ridership in September and October was higher than during the other months. In year 1, ridership was lowest in December and January—roughly 30% of September ridership. Ridership in February and March 2020 rebounded to about 40 and 45% of September 2019 ridership. In year 2, ridership in December had also fallen to about 30% of September ridership—similarly to year 1. However, coinciding with the introduction of e-scooter corrals, e-scooter ridership fell further in January 2022 to only 8% of September 2021 levels. Ridership in February and March 2022 increased somewhat to roughly 19% of September 2021 levels—much lower than in year 1 when February and March represented between 40 and 45% of September 2019 levels.

Not shown in Figure 2, overall ridership levels in September of year 2 were significantly lower than in year 1 (roughly −40%). This may be related to students' still taking some online classes, a wearing-off of the novelty effect of e-scooters on campus, and nearly a doubling in cost of e-scooter rental rates per minute from $0.15 before the system closure due to COVID-19 in March 2020 to $0.29 at reopening in Fall 2021. Even after accounting for lower ridership levels in year 2, we observed ridership losses that coincided with the installation of e-scooter parking corrals from January to March 2022. In March 2022, Spin and Virginia Tech jointly decided to remove the e-scooter parking corrals. After e-scooter parking corrals had been removed, ridership in April 2022 reached 35% of September 2021 levels. While Figure 2 shows that ridership dropped significantly in the months when e-scooter corrals were implemented, it does not prove that e-scooter corrals caused these reductions in ridership. Other factors may help explain declining ridership, including weather or e-scooter deployment and availability.

A look at average temperatures and precipitation by month for the two periods shows that September 2019 was warmer (+4 degrees Celsius) and drier (−7 cm precipitation) than September 2021 [23]. Precipitation during the other months was lower in year 2 compared to year 1 (with the difference ranging between −1 and −7.5 cm per month). Average temperatures in October, November, December and February in year 2 were comparable to average temperatures in year 1, while January and March 2022 were 4- and 5-degrees Celsius cooler than March 2020, on average [37].

The number of e-scooters deployed was similar in September 2019 and September 2021 (about 200), but remained roughly 30% lower in October 2021, November 2021, December 2021, and January 2022 compared to year 1 (roughly 200 vs. 300 e-scooters). Starting February 2022, e-scooter deployment reached 80% of 2020 levels [34].

3.2. Sample Descriptive Statistics and E-Scooter Ridership Intensity

Table 1 presents descriptive statistics of our sample of 131 participants in the e-scooter rider panel survey fielded in Fall and Spring of year 2. The sample generally represents the university community with more male than female respondents, a greater share of white respondents, lower incomes, and many more undergraduate students than faculty/staff—while graduate students are somewhat underrepresented.

Table 1. Descriptive statistics of the sample (131 respondents).

Variable Name	Variable Attributes	% Total
Gender	Male	60.8
	Female	37.7
Role on Campus	Undergraduate student	82.4
	Graduate Student	9.9
	Faculty/Staff	6.9
Race/Ethnicity	Asian	10.7
	White	74.1
	African American	3.7
	Mixed race/other	11.5
Housing	On-campus	42.0
	Off-campus in Blacksburg	50.4
	Off-campus farther away	7.6
Annual Income	<15,000	55.8
	15,000–50,000	13.0
	75,000+	10.7
	Decline to say	20.6
Year Born	<1999	15.3
	1999/2000	29.1
	2001	22.1
	2002	13.7
Ride Intensity Fall 2021	Never ridden	7.0
	Ridden once	8.6
	Used to ride, but not so much anymore	29.7
	Multiple times a month	28.9
	Once a week	21.1
	Every day	4.7
Ride Intensity Spring 2022	Never ridden	6.0
	Ridden once	9.2
	Used to ride, but not so much anymore	54.6
	Multiple times a month	17.7
	Once a week	9.2
	Every day	3.1

A look at ride intensity (bottom of Table 1) reveals that 7% (fall) and 6% (spring) of respondents never rode e-scooters in-spite of downloading the Spin app. This percentage declined slightly between the two surveys—indicating that some non-riders rode an e-scooter between the two survey periods. In general, however, we find declines across all levels of riding frequency between Fall 2021 and Spring 2022: from 4.7 to 3.1% for individuals reporting to ride every day; from 21.1 to 9.1% for those reporting to ride at least once a week; and from 28.9 to 17.7% for those reporting to ride multiple times a month. The share of individuals classifying themselves as former riders increased from 29.7% to 54.6%. Not shown in Table 1, declines in ridership intensity were sharp for some rider groups. For example, 33% of those who reported riding every day in Fall 2021 did not ride anymore in Spring 2022. Similarly, 52% of those who rode at least once a week in Fall 2021 had stopped riding entirely in Spring 2022, and 50% of those riding several times a month in the Fall 2021 did not ride anymore in the Spring 2022.

Figure 3 displays the percentage share of respondents reporting reduced e-scooter riding intensity in Spring 2022 compared to Fall 2021 for each population subgroup. On average, 35.9% of respondents had reduced the riding intensity. Reduced riding is measured as a decline in riding intensity, from a higher intensity group to a lower intensity group (e.g., switching from riding every day in the Fall 2021 to less than every day in Spring 2022 or lower levels of ridership). Subgroups with the highest shares of individuals who reduced the intensity of their e-scooter riding included men (41.8% report reduced riding), Asians (−50.0%), whites (−67.0%), those who live on campus (−40.0%), and individuals born in 2001 (−41.4%) or 2002 (−44.4%).

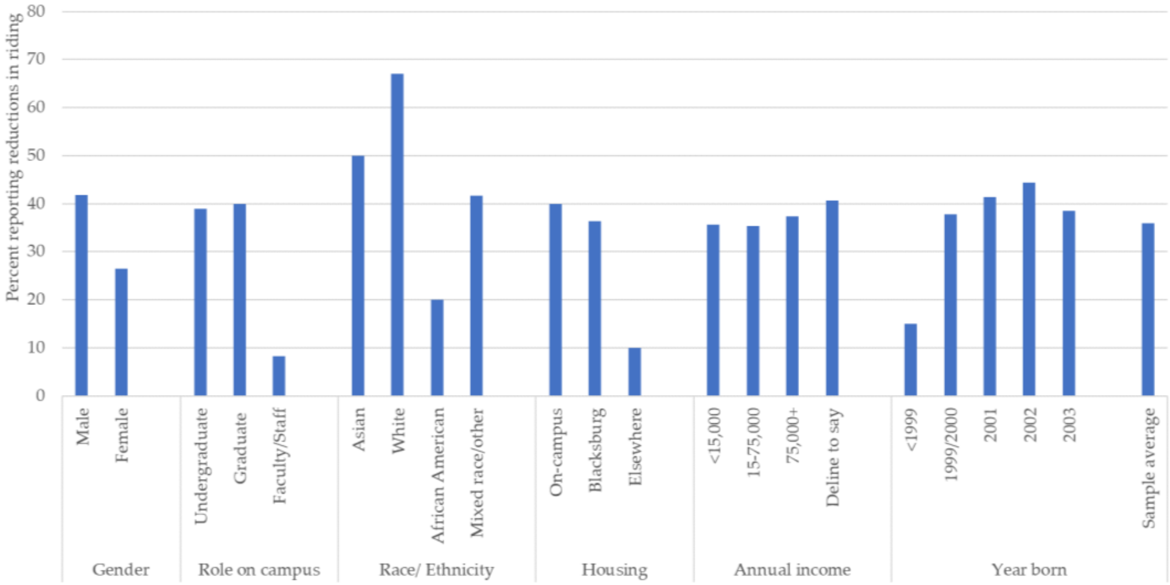

Figure 3. Share of individuals reporting reduced riding in Spring 2022 compared to Fall 2021 by socio-demographics.

In order to further investigate reductions in riding among population subgroups, we created a dummy variable identifying regular riders and non-riders. Regular riders were defined as individuals who rode multiple times a month, once a week, or every day. Non-riders were measured as respondents who stated that they used to ride, never rode, or only rode once to try out the system. Figure 4 displays the percentage share of each population subgroup that were regular riders (riding e-scooters several times per month or more) in Fall 2021 and Spring 2022. Data for Fall 2021, before the installation of e-scooter corrals, are displayed in blue colored bars. On average, 54.7% of our sample were regular e-scooter riders in Fall 2021—riding several times per month or more. Subgroups with the highest shares of regular riders in Fall 2021 were men (58.1%), undergraduate students (59.1%), students living on campus (64.2%), respondents in the lowest income group (57.1%) and those born in 2001 (60.7%) and 2002 (72.2%).

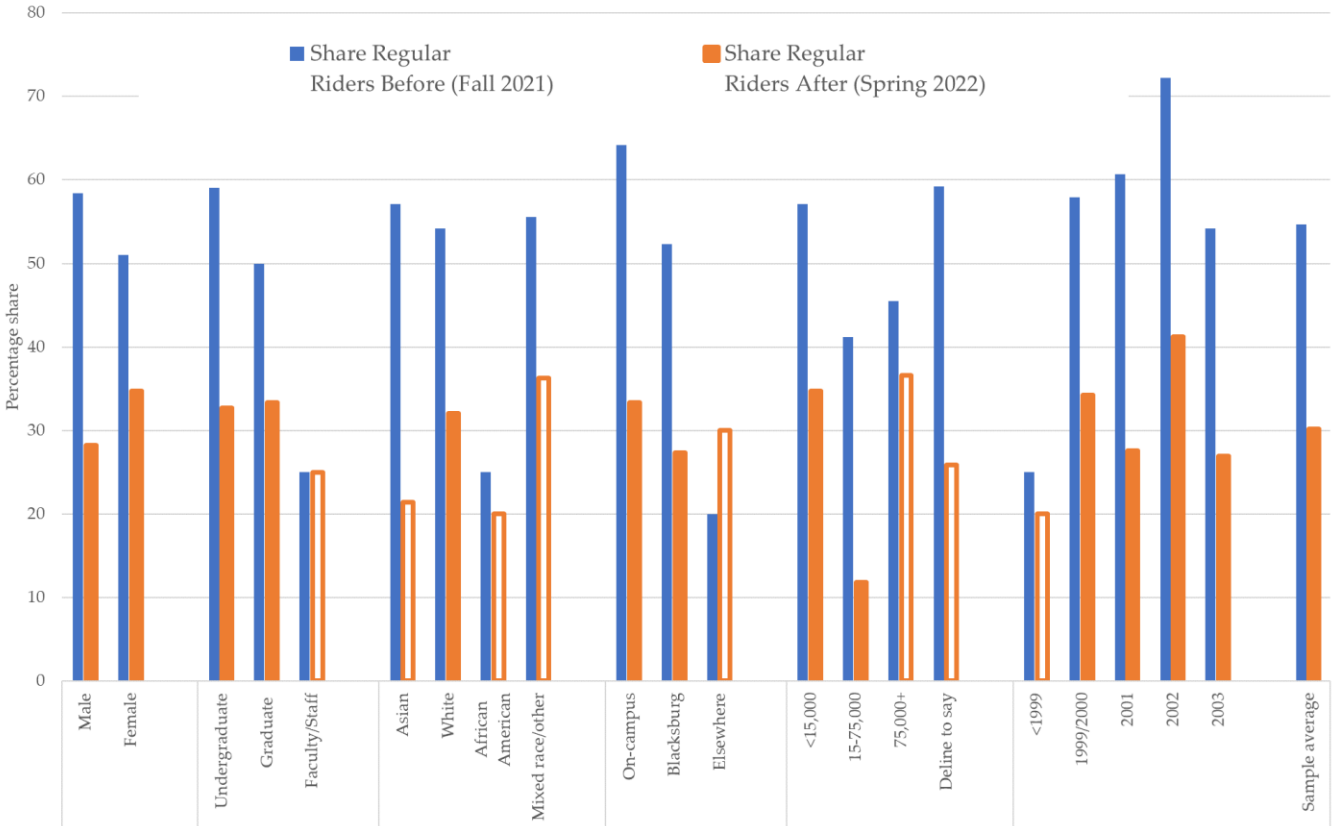

Figure 4. Percentage shares of regular riders for each sub-group (Fall 2021 and Spring 2022). Note: Solid dark-orange bars indicate a statistically significant change ($p < 0.05$) between Fall 2021 and Spring 2022. Light-orange bars that are not filled indicate changes that were not statistically significant at $p < 0.05$. Statistical significance was assessed using t-tests based on population proportions (share of individuals ranging from 0–1) as well as chi-square tests for two categorical variables.

Figure 4 also displays the share of each population subgroup that rode e-scooters several times per month or more in Spring 2022 after the installation of e-scooter corrals—in orange-colored bars. On average 30.2% of respondents were regular riders—down from 54.7% in the Fall (the drop is statistically significant at $p < 0.05$). Except for faculty/staff as well as those living off-campus outside of Blacksburg, all subgroups showed declines in the share of regular riders in Spring 2022 compared to Fall 2021. Moreover, not all reductions in the shares of regular riders between Fall 2021 and Spring 2022 were statistically significant ($p < 0.05$). For example, changes in the share of riders among faculty/staff and student living outside of Blacksburg were not statistically significant ($p < 0.05$). Drops in usage were statistically significant for: the overall sample, men, women, students, those living on campus or in Blacksburg, those reporting less than 75 k in income, and for individuals born after 1999. For those who continued to ride in Spring 2022, sub-groups with the highest shares of regular e-scooter riders in Spring 2022 were women (34.7%), individuals reporting mixed race (36.3%), individuals with high income (36.6%), as well as those born in 2002 (41.2%).

3.3. Desired and Actual E-Scooter Egress Times

Our survey asked individuals about their preferred walk time between parking their e-scooter and arrival at their destination (referred to as e-scooter egress time), and their actual walk time. Results are shown in Figure 5. The share of respondents reporting less than 2 min of actual egress time declined from 81% to 72% (from 43% to 36% for <1 min and from 38% to 36% for 1–2 min). The share of respondents reporting between 2 to 3 min egress times increased from 14% to 19%, as did the share of respondents reporting 3 to

4 min (3% to 9%). As actual egress time increased, desired egress times by riders decreased: from 56% desiring less than 2 min in Fall 2021 to 69% desiring less than 2 min in Spring 2022 (22% to 26% for less than 1 min and 34% to 43% for 1–2 min). Among those who reduced their riding in Spring 2022, 62% desired shorter egress times in the spring than in the fall.

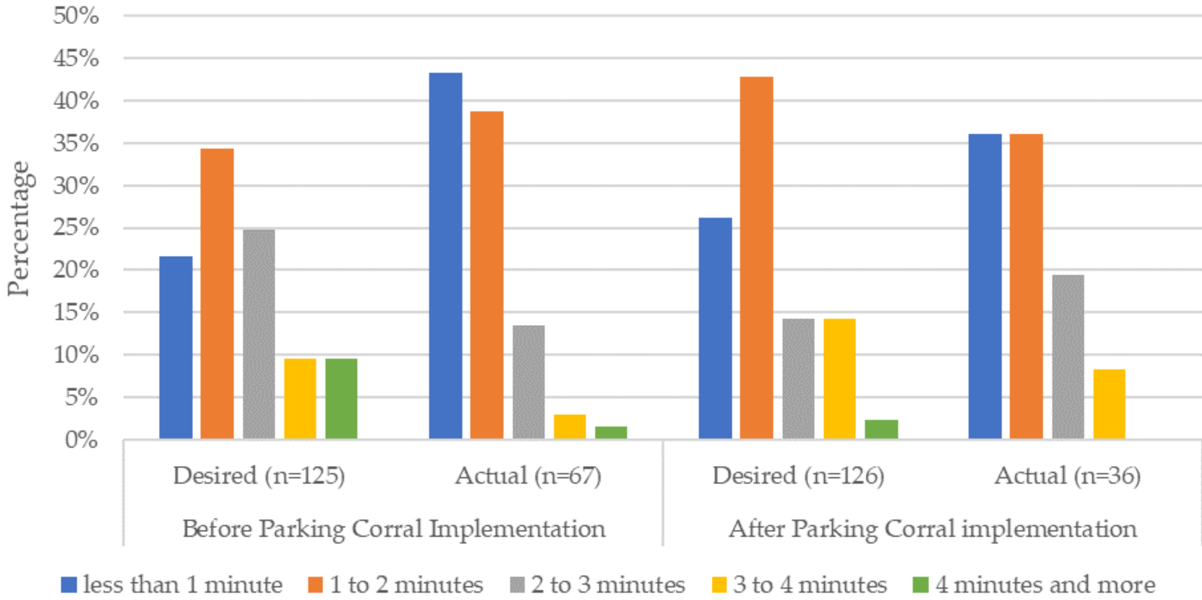

Figure 5. Comparison of desired and actual e-scooter egress times self-reported by users before (Fall 2021) and after (Spring 2022) the introduction of parking corrals.

3.4. Perceptions of Parking Corrals

We asked respondents about their perceptions of e-scooter parking corrals before and after implementation of the corrals. In Fall 2021, 30.0% expected parking corrals to help avoid blocked sidewalks, 34.9% thought the corrals would be convenient to find e-scooters, and another 34.9% stated that they expected corrals to be too far from their trip origins or destinations. In Spring 2022, responses were less favorable with 27.0% reporting less blocked sidewalks, 28.8% finding the corrals convenient, but 44.1% indicating they found the corrals to be too far from their destinations.

In Spring, we asked respondents for feedback about their experience using the parking corrals, particularly about issues with using them. The question asked, “Please tell us about any issues or problems you faced when using parking corrals,” and respondents were able to select all that applied from a list that we provided, or to report a problem in an open comment box. Responses are shown in Figure 6. Although about one-fifth of respondents reported no problems (19%), the majority experienced some trouble: the corrals were not located where the user needed them (25%), were difficult to find (20%), took too much extra time to use when parking (19%), trouble ending the trip within the app (13%), or were fully occupied when the user needed to park (4%). Several riders made comments about their trouble ending rides, for example, taking the e-scooter to the corral location but not being able to end the ride due to the app not recognizing the e-scooter’s correct location and/or not acknowledging the connection to the permitted geofence. A bad experience parking an e-scooter, especially if it caused the rider to be late arriving at their destination, could affect perceptions of e-scooters as a reliable mode.

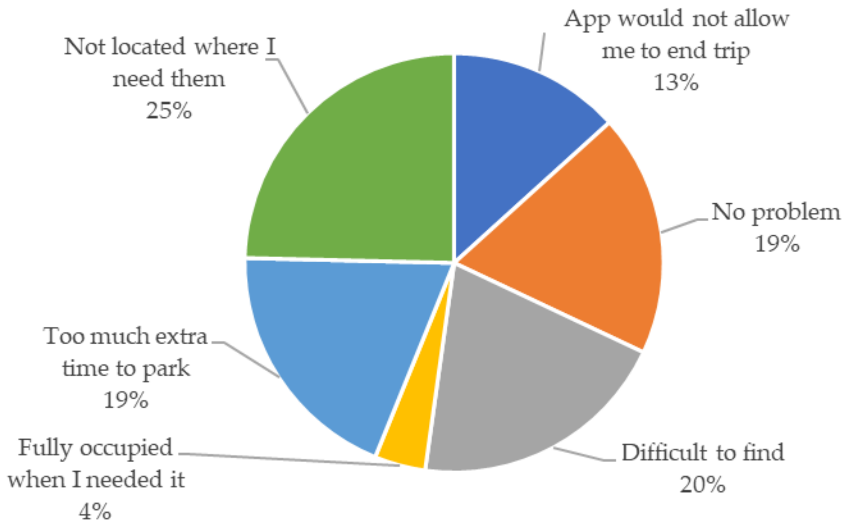

Figure 6. Problems reported by e-scooter riders after the introduction of parking corrals.

We also asked individuals who used to ride e-scooters, but reported to not ride anymore, about their reasons for reducing their riding. After the installation of corrals 5% reported reducing their riding specifically because of e-scooter parking and another 20% reported not riding anymore because of a mismatch of e-scooter availability and drop-off for the entirety of their trips. The main reason for not riding anymore was cost, stated by 25% of respondents.

4. Discussion

Answering our first research question, it appears that the e-scooter corrals were a factor explaining lower ridership levels after implementation—for all groups of users. It is difficult to isolate the effect of e-scooter parking corrals on ridership declines. Overall ridership was lower after reopening of the system in 2021 than before the COVID-related shut-down, likely due to other reasons including higher rental cost per minute, more online classes, or a weaning of the novelty effect. However, declines in ridership after the installation of the e-scooter corrals in January 2022 were steeper than previously observed seasonal changes. In both years, December ridership was roughly 70% lower than September ridership. However, ridership in January 2022 was 73% lower than December 2021 ridership, while January 2020 and December 2019 were roughly the same. Similarly, ridership levels in February and March 2022 were will roughly 37% lower than December 2021, while ridership during those two months in 2020 were 31% and 55% higher than December 2019 ridership levels.

To our knowledge, our survey was first to identify desired and actual egress times for e-scooters. Answering our second research question, egress times from e-scooters to destinations are short with 35–40% of riders reporting less than 1 min to their destination and 70–85% reporting less than 2 min. Desired egress times were equally short with roughly two-thirds desiring egress times of less than 2 min. This is in line with findings from studies in Vienna, Austria and Portland, Oregon [22,33]. The Portland, Oregon study found more parking violations in areas with less e-scooter parking supply and presumably longer egress distances [22]. The Vienna, Austria study recommended short distances between e-scooter parking corrals [33]. Assuming a walking speed between 4 and 5 km/h, an individual could cover 130–170 m in about 2 min. Because of this time sensitivity, implementation of e-scooter corrals requires close attention to the specific location of the corral and the time needed to lock e-scooters and to access final destinations [22,33].

Similar to other studies, we found positive attitudes towards e-scooter corrals prior to implementation [2,27]. Although e-scooter parking corrals were perceived rather favorably prior to implementation, perceptions turned more negative after implementation with

44% indicating that they found corrals too far from their destination—answering our third research question. Negative perceptions were accompanied by a behavioral change, as e-scooter ridership dropped on aggregate and in our sample after implementation of parking corrals. Ridership dropped for all groups. Our analysis of subgroups in a pre-post panel survey showed that groups who were among the heaviest users, like undergraduate males, quit at the highest rate. Those who kept riding reported longer actual egress times and a stronger desire for shorter egress times.

Ridership losses on Virginia Tech's campus were likely compounded by technical difficulties with geofence implementation. Spin found that while small areas can be precisely defined by geofences, in practice their accuracy is dependent upon factors outside the operators' control, such as the quality of GPS signal reception and latency. This confirms earlier doubts voiced by Dunn about the lack of precision of current GPS technology to effectively frame e-scooter parking corrals on sidewalks or streets [20]. Thus, e-scooter providers should make sure that their geofencing of parking corrals works reliably under prevailing local conditions before implementing mandatory corrals. Expanding the allowed geofence radius in the operator's system would reduce false negatives wherein a correctly parked e-scooter's GPS location does not immediately fall within the geofence radius, with some increased risk of false positives that allow parking outside of the marked corral space. Spin's anecdotal experience in other operating locations indicates that highly visible and understandable corrals, backed by 30–40 m geofence radii, may better balance rider experience with the desire to mandate orderly parking.

Spin's experience on Virginia Tech's campus is in line with prior research that suggests a high level of uncertainty about rules and regulations of e-scooter riding and parking [6,8,9]. Poorly implemented e-scooter corrals and insufficient communication about the positioning of the corrals can increase uncertainty around e-scooter rules and regulations and disincentivize riding. Moreover, Spin's implementation of geofences at Virginia Tech may be interpreted as overly strict, resulting from an intention to address parking concerns heard from university stakeholders. The scheduled April/May 2022 conclusion of Spin's research-related system deployment on the Virginia Tech campus precluded the acknowledgement of and correction of the technical issues theorized here.

E-scooter parking corrals have been implemented successfully in other locations and helped increase proper parking—the focus of a large number of prior studies on e-scooter parking [27,32]. However, on Virginia Tech's campus the change from a free-floating-system to a corral-based system likely contributed to ridership loss. Established trip durations and specific parking locations changed due the implementation of corrals leading to perceptions of longer egress times and mismatched locations of parking corrals and trip destinations.

5. Conclusions

Cities and universities have identified e-scooter parking as a major problem for the implementation of e-scooter systems. The topic has received increasing attention in the literature recently. However, most studies focus on e-scooter parking non-compliance as well as blocked or cluttered sidewalks. Designated parking areas—parking corrals—for e-scooters is one potential solution to the perceived problem. Several studies had found greater compliance with regulations after the introduction of parking corrals. This paper is first to focus on ridership trends before and after the implementation of e-scooter parking corrals. While e-scooter ridership had been declining on Virginia Tech's campus prior to the installation of parking corrals, ridership plummeted after the implementation of e-scooter parking corrals. Our paper found significant declines among all user groups—in particular, those who rode the system most prior to the implementation of e-scooter parking corrals. Thus, this paper cautions e-scooter providers to start deployment with a free-floating system and to then switch to a corral-based system.

Our study highlights the importance of egress times for e-scooter rides—with roughly two-thirds of riders desiring less than 2 min between their e-scooter and their trip origins or destinations. This implies that e-scooter corrals should be conveniently located close to areas with many trip origins and destinations—ideally within 150 m, a distance easily covered by foot in about 2 min. In addition, the Virginia Tech corral system experienced technological problems not allowing riders to end trips in designated corrals. Moreover, users had problems identifying the geographic location of drop-off and pick-up areas. Based on our study, we recommend corrals to be implemented carefully. They should be close to major trip generators and clearly visible. Moreover, technology should work smoothly. While implementation at Virginia Tech provides a cautionary tale about e-scooter corrals, other literature has shown that e-scooter parking corrals have been implemented successfully elsewhere and have helped increase proper parking.

Like most studies, our analysis also has several weaknesses. First, we rely on self-reported changes in ridership, egress time, and perceptions of the corrals. A revealed preference study tracking the actual number of trips on campus, before and after the introduction of parking corrals would be more reliable to measure actual changes in ridership of individuals. Similarly, GPS trackers or other devices could help measure actual egress times or steps taken from e-scooters, compared to self-reported times. While respondents reported problems with e-scooter corrals, observation of corral areas could have helped identify common problems and issues when parking. Second, our sample was comparatively small. We only had 131 respondents, which limited the types of statistical tests and analysis that could be carried out. A larger sample would have allowed disaggregating the dataset and ridership groups for more in depths analysis. Third, our analysis cannot prove causality in ridership decline. Factors, other than the mandatory e-scooter corrals could partly explain declines in ridership, such higher rental cost per minute in 2021/2022 than in 2019/2020, a higher share of online classes, or a weaning of the novelty effect. Fourth, a comparison with a university campus with successful e-scooter corral implementation could help identify reasons for the ridership decline at Virginia Tech. Last, studies evaluating e-scooter corrals and their impact on ridership should be replicated elsewhere to increase the generalizability of findings.

Author Contributions: Study conception and design: R.B., A.B., T.S. and E.W.; data collection: R.B., A.B., C.E., E.W. and T.S.; analysis and interpretation of results: R.B. and A.B.; draft manuscript preparation: R.B. and A.B. All authors have read and agreed to the published version of the manuscript.

Funding: The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: The project was partly funded by the Safety through Disruption (Safe-D) National UTC, a grant from the U.S. Department of Transportation's University Transportation Centers Program (Federal Grant no. 69A3551747115), and by Spin.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of Virginia Tech (IRB Number19-581; FWA00000572).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data available on request due to privacy restrictions.

Acknowledgments: The authors would like to thank Denis Teoman for his help in data cleaning; Josh Johnson for his feedback on the various drafts of the surveys; Will Vaughan for providing data on e-scooter ridership and deployment.

Conflicts of Interest: Andrea Broaddus was employed by Ford. Ford owned Spin during part of the study period. Ted Sweeney worked for Spin. Ralph Buehler and Elizabeth White received a research grant from Spin for a larger project related to this article.

References

1. NACTO. *Shared Micromobility in the U.S.: 2019*; National Associaton of City Transportation Officials: Washington, DC, USA, 2019.
2. Buehler, R.; Broaddus, A.; Sweeney, T.; Zhang, W.; White, E.; Mollenhauer, M. Changes in Travel Behavior, Attitudes, and Preferences among E-Scooter Riders and Nonriders: First Look at Results from Pre and Post E-Scooter System Launch Surveys at Virginia Tech. *Transp. Res. Rec. J. Transp. Res. Board* **2021**, *2675*, 335–345. [CrossRef]

3. Moreau, H.; de Jamblinne de Meux, L.; Zeller, V.; D'Ans, P.; Ruwet, C.; Achten, W.M.J. Dockless E-Scooter: A Green Solution for Mobility? Comparative Case Study between Dockless E-Scooters, Displaced Transport, and Personal E-Scooters. *Sustainability* **2020**, *12*, 1803. [CrossRef]
4. Bozzi, A.D.; Aguilera, A. Shared E-Scooters: A Review of Uses, Health and Environmental Impacts, and Policy Implications of a New Micro-Mobility Service. *Sustainability* **2021**, *13*, 8676. [CrossRef]
5. Sanders, R.L.; Branion-Calles, M.; Nelson, T.A. To Scoot or Not to Scoot: Findings from a Recent Survey about the Benefits and Barriers of Using E-Scooters for Riders and Non-Riders. *Transp. Res. Part A Policy Pract.* **2020**, *139*, 217–227. [CrossRef]
6. Klein, N.; Brown, A.; Thigpen, C. Clutter and Compliance: Scooter Parking Interventions and Perceptions. Working Paper, osf.io. 2022. Available online: https://www.highstreetstaskforce.org.uk/resources/details/?id=8dc111ae-406a-4549-ae37-adc608e80fab (accessed on 5 October 2022).
7. Brown, A.; Klein, N.J.; Thigpen, C.; Williams, N. Impeding Access: The Frequency and Characteristics of Improper Scooter, Bike, and Car Parking. *Transp. Res. Part D Interdiscip. Perspect.* **2020**, *4*, 100099. [CrossRef]
8. Brown, A.; Klein, N.J.; Thigpen, C. Can You Park Your Scooter There? Why Scooter Riders Mispark and What to Do about It. *Findings* **2021**, 19537. [CrossRef]
9. James, O.; Swiderski, J.I.; Hicks, J.; Teoman, D.; Buehler, R. Pedestrians and E-Scooters: An Initial Look at E-Scooter Parking and Perceptions by Riders and Non-Riders. *Sustainability* **2019**, *11*, 5591. [CrossRef]
10. Gössling, S. Integrating E-Scooters in Urban Transportation: Problems, Policies, and the Prospect of System Change. *Transp. Res. Part D Transp. Environ.* **2020**, *79*, 102230. [CrossRef]
11. Carroll, P. Perceptions of Electric Scooters Prior to Legalisation: A Case Study of Dublin, Ireland, the 'Final Frontier' of Adopted E-Scooter Use in Europe. *Sustainability* **2022**, *14*, 11376. [CrossRef]
12. Schellong, D.; Sadek, P.; Schaetzberger, C.; Barrack, T. *The Promise and Pittfalls of E-Scooter Sharing*; Boston Consulting Group: Boston, MA, USA, 2019.
13. Turoń, K.; Czech, P. The Concept of Rules and Recommendations for Riding Shared and Private E-Scooters in the Road Network in the Light of Global Problems. In *Modern Traffic Engineering in the System Approach to the Development of Traffic Networks*; Advances in Intelligent Systems and Computing; Macioszek, E., Sierpiński, G., Eds.; Springer International Publishing: Cham, Switzerland, 2020; Volume 1083, pp. 275–284. ISBN 9783030340681.
14. Kubik, A. Impact of the Use of Electric Scooters from Shared Mobility Systems on the Users. *Smart Cities* **2022**, *5*, 1079–1091. [CrossRef]
15. Field, C.; Jon, I. E-Scooters: A New Smart Mobility Option? The Case of Brisbane, Australia. *Plan. Theory Pract.* **2021**, *22*, 368–396. [CrossRef]
16. Hardt, C.; Bogenberger, K. Usage of E-Scooters in Urban Environments. *Transp. Res. Procedia* **2019**, *37*, 155–162. [CrossRef]
17. Gebhardt, L.; Wolf, C.; Seiffert, R. "I'll Take the E-Scooter Instead of My Car"—The Potential of E-Scooters as a Substitute for Car Trips in Germany. *Sustainability* **2021**, *13*, 7361. [CrossRef]
18. Severengiz, S.; Schelte, N.; Bracke, S. Analysis of the Environmental Impact of E-Scooter Sharing Services Considering Product Reliability Characteristics and Durability. *Procedia CIRP* **2021**, *96*, 181–188. [CrossRef]
19. Wang, K.; Qian, X.; Fitch, D.T.; Lee, Y.; Malik, J.; Circella, G. What Travel Modes Do Shared E-Scooters Displace? A Review of Recent Research Findings. *Transp. Rev.* **2022**, *43*, 5–31. [CrossRef]
20. Zhang, W.; Buehler, R.; Broaddus, A.; Sweeney, T. What Type of Infrastructures Do E-Scooter Riders Prefer? A Route Choice Model. *Transp. Res. Part D Transp. Environ.* **2021**, *94*, 102761. [CrossRef]
21. Fang, K.; Agrawal, A.; Steele, J.; Hunter, J.; Hooper, A. *Where Do Riders Park Dockless, Shared Electric Scooters? Findings from San Jose, California*; Mineta Transportation Institute: San Jose, CA, USA, 2019.
22. Hemphill, R.; MacArthur, J.; Longenecker, P.; Desai, G.; Nie, L.; Ibarra, A.; Dill, J. Congested Sidewalks: The Effects of the Built Environment on e-Scooter Parking Compliance. *J. Transp. Land Use* **2022**, *15*, 481–495. [CrossRef]
23. Brown, A. Micromobility, Macro Goals: Aligning Scooter Parking Policy with Broader City Objectives. *Transp. Res. Interdiscip. Perspect.* **2021**, *12*, 100508. [CrossRef]
24. Dunn, P.T. Participatory Infrastructures: The Politics of Mobility Platforms. *Urban Plan.* **2020**, *5*, 335–346. [CrossRef]
25. Jiao, J.; Bai, S. Understanding the Shared E-Scooter Travels in Austin, TX. *ISPRS Int. J. Geo-Inf.* **2020**, *9*, 135. [CrossRef]
26. Moran, M.E.; Laa, B.; Emberger, G. Six Scooter Operators, Six Maps: Spatial Coverage and Regulation of Micromobility in Vienna, Austria. *Case Stud. Transp. Policy* **2020**, *8*, 658–671. [CrossRef]
27. Nikiforiadis, A.; Paschalidis, E.; Stamatiadis, N.; Raptopoulou, A.; Kostareli, A.; Basbas, S. Analysis of Attitudes and Engagement of Shared E-Scooter Users. *Transp. Res. Part D Transp. Environ.* **2021**, *94*, 102790. [CrossRef]
28. Fang, K.; Mineta Transportation Institute; State of California SB1 2017/2018; San Jose State University; California State University Transportation Consortium; Sonoma State University. *Surveying Silicon Valley on Cycling, Travel Behavior, and Travel Attitudes*; Final Report; Mineta Transportation Institute: San Jose, CA, USA, 2020; 64p.
29. Caspi, O.; Smart, M.J. Evaluation of E-Scooter Media Coverage. *Findings* **2022**, 30193. [CrossRef]
30. Zakhem, M.; Smith-Colin, J. Micromobility Implementation Challenges and Opportunities: Analysis of e-Scooter Parking and High-Use Corridors. *Transp. Res. Part D Transp. Environ.* **2021**, *101*, 103082. [CrossRef]
31. Latinopoulos, C.; Patrier, A.; Sivakumar, A. Planning for E-Scooter Use in Metropolitan Cities: A Case Study for Paris. *Transp. Res. Part D Transp. Environ.* **2021**, *100*, 103037. [CrossRef]

32. Karlsen, K.; Johnsson, E.; Fyhri, A.; Pokorny, P. *Parking Solutions for Shared E-Scooters*; Institute of Transport Economics: Oslo, Norway, 2021.
33. Mayer, E.; Neustifter, R.; Robatsch, K.; Soteropoulus, A. Parkende E-Scooter Als Stolperfalle: Sind E-Scooter-Abstellplätze Die Lösung Des Problems? *Z. Verk.* **2022**, *68*, 201–208.
34. Virginia Tech Transportation Institute. (Blacksburg, VA, USA). VTTI E-Scooter Ridership and Deployment at Virginia Tech. Unpublished report. 2022.
35. Virginia Tech President Tim Sands Updates Blacksburg Campus on COVID-19 Status, Virginia Tech News. 2021. Available online: https://vtx.vt.edu/articles/2021/09/president-covid19-update-sept20.html (accessed on 14 October 2022).
36. Quint, N. (Virginia Tech Alterantive Transportation, Blacksburg, VA, USA). E-Scooter Corrals at Virginia Tech. Personal Communication. 15 June 2022.
37. Weatherunderground Blacksburg, VA Weather History. 2022. Available online: https://www.wunderground.com/history/daily/KBCB/date/2019-9-8 (accessed on 14 October 2022).