Silicon Valley Clean Energy

City Chrysalis E-bike Program Evaluation

SUBMITTED TO: Silicon Valley Clean Energy

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Abstract

Silicon Valley Clean Energy (SVCE) conducted the City Chrysalis pilot program to assess the impact of e-bike usage on four participants in Santa Clara County. Data from this pilot program was provided to ADM Associates, Inc. (ADM) who assessed health outcomes, the impact of weather on e-bike use, and the costs/benefits associated with e-bikes as compared to other modes of transportation. While statistically significant health outcomes were not identified, the pilot program demonstrated the clear potential of e-bikes to improve cardiovascular health. Of the dimensions of weather assessed, outside air temperature was the only variable with a statistically significant association with e-bike distance and duration. A 1°F increase in outside air temperature correlated with a .68 mile decrease in e-bike distance ($p = 0.02$) and a nine-minute decrease in e-bike duration ($p = 0.002$). Lastly, a cost-benefit analysis found that e-bikes emit substantially less CO_2 than cars or public transportation, and cost far less than cars. Moreover, for e-bike trips less than 45 minutes in length, riding an e-bike takes a similar amount of time as driving a car and substantially less than taking public transport. These findings suggest the benefits of e-bikes far outweigh the costs, and future iterations of this program could yield even more precise and meaningful conclusions. Especially in the face of growing carbon emissions and climate change, e-bikes powered by renewable energy offer a sustainable path for local transportation.

Study Overview

Program Summary

Silicon Valley Clean Energy (SVCE) is a public, not-for-profit, community-owned agency that provides clean energy in Santa Clara County. As a part of their commitment to community engagement, SVCE initiated the Innovation Onramp program which provides grant funding to support innovation aimed at achieving deep decarbonization in Santa Clara and beyond.

Through this program, SVCE has funded City Chrysalis, a pilot program to study the benefits and challenges of using electric bikes (e-bikes) for daily transportation. This pilot program was administered by Outthink and involved outfitting four low income residents with a Rad Power e-bike, safety equipment, a CycloTrac bike GPS tracker, and a personal Fitbit. The pilot took place in the City of Gilroy, a member agency of SVCE.

The CycloTrac Boomerang bike GPS tool was used to track e-bike routes and riding patterns, while the Fitbit tracked key health data such as resting heartrate, activity level, and sleep quality. Data from these two tools were shared with ADM with the goal of using them to conduct a cost-benefit analysis. In combination with the qualitative narrative produced by ADM based on ethnographic participant interviews, this quantitative report presents a comprehensive assessment of the impact of the City Chrysalis pilot program.

Participant Information

Candidates for this pilot program were recruited through local affordable housing managers and social organizers. Of 30 applicants, four were selected based on reported travel habits, car usage, and personal stories. We will refer to these participants as Paul, Jacob, Samantha, and Charlie.

- Paul is a 55-year-old male with diabetes who needed to lose 60 pounds before he could receive reconstructive knee surgery.
- Jacob is a 65-year-old male with prediabetes, who is recovering from a heart attack and triple bypass surgery in 2020.
- Samantha is a 46-year-old female with asthma, who struggles to keep up with her family on weekend bicycle outings.
- Charlie is a 73-year-old male with prediabetes who suffered a stroke in 2019 and had colon cancer surgery in 2020.

Each of the participants received either a RadCity 3 Step-thru or RadCity 4 e-bike, as well as a helmet, pannier bags, a light, and a U-lock with cables. As detailed above, participants also received a CycloTrac Boomerang bike GPS tracker and a Fitbit Charge 4 health watch to monitor e-bike travel and participant health, respectively.

Fitbit Data	**Activity Intensity:** Time in each active zone (fat burn, cardio, and peak), altitude tracking (# of floors climbed), calories burned, distance traveled, activity intensity (light, moderate, and very active), sedentary time, steps taken, exercise duration and type **Cardiovascular Health:** Resting heart rate, heart rate, blood oxygen infrared to red signal ratio, VO2 max (maximal oxygen consumption) **Other:** Sleep duration, sleep score data, social data (i.e., achievement badges earned)
E-bike Tracking	GPX data files that tracked user trips, distances, durations
In-depth interviews	ADM staff conducted in-depth interviews with all four participants to better understand how pilot participants use their e-bikes and the impacts they have had on their lives.

Carbon Impact

E-bikes demonstrated markedly lower carbon intensity than internal combustion engine (ICE) vehicles and public transit. Local public transit is currently focused on compressed natural gas (CNG) and diesel buses and electric light rail, with limited bus electrification. It is expected that this would converge as the VTA transitions to electric buses.

E-bikes
- 2,005 miles/year
- 22 lbs. carbon emissions per-rider

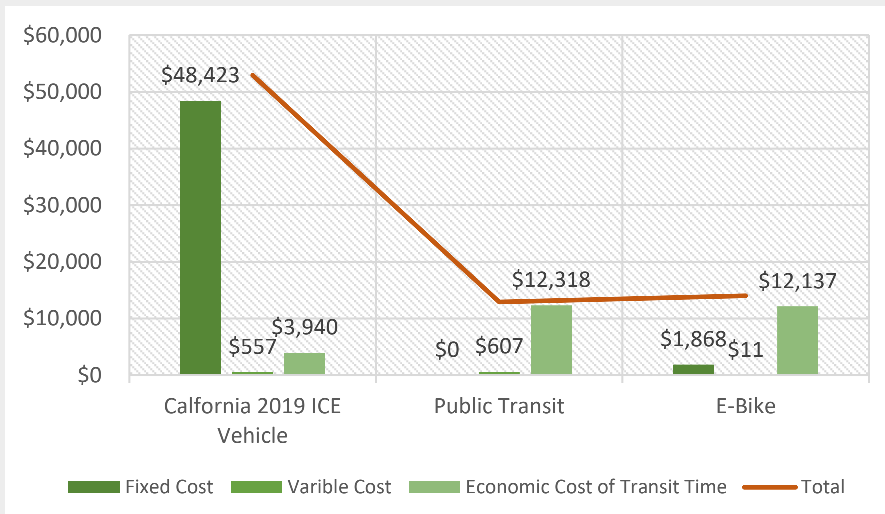
Average California ICE vehicle
- 1,080 lbs. carbon emissions per-user (including passengers)

Public Transit (Bus & Light Rail)
- 311 lbs. carbon emissions per rider

User Costs

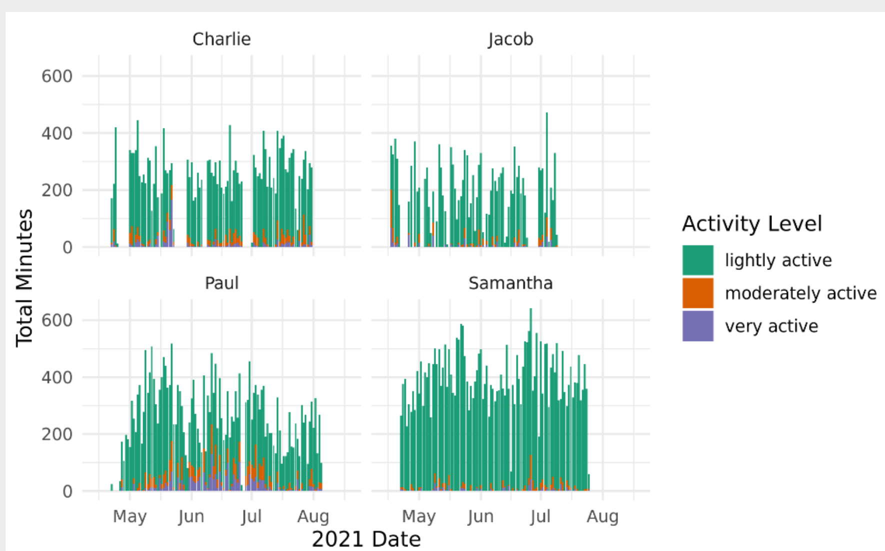
ADM analyzed fixed, variable, and economic costs associated with transit to satisfy the 2,005 annualized miles travelled by the Pilot participants.

The major cost incurred from E-bike use relative to ICE vehicles is the economic cost of time in transit; financial costs (fixed and variable) were significantly lower than ICE vehicles, though higher than public transit.



Health Impact

The FitBit data characterized participants' activity levels as "lightly", "moderately", or "very" active, and heart rate zones divided into "fat burn", "cardio", and "peak". While minor differences in e-bike usage exist across participants, e-bikes were mostly used for lightly strenuous activity. This finding is supported by the ethnographic interviews where that most participants indicated using their e-bikes for trips to the store and daily errands.



"It's better than a vehicle, don't have to waste money on gas…perfect for the buses…you'll save money, doing errands, groceries, going by the post office." – E-bike user 'Samantha'

Summary

Program Offering

Figure 1. Equipment Provided to Pilot Participants & MSRP

Data Received

Fitbit Data

SVCE provided ADM Fitbit data for each participant. Fitbit data was a combination of TXT and CSV files tracking the following health metrics:

- **Activity Intensity**: Time in each active zone (fat burn, cardio, and peak), altitude tracking (# of floors climbed), calories burned, distance traveled, activity intensity (light, moderate, and very active), sedentary time, steps taken, swimming data, exercise duration and type
- **Cardiovascular Health**: Resting heart rate, heart rate, blood oxygen infrared to red signal ratio, VO2 max (maximal oxygen consumption)
- **Other**: Sleep duration, sleep score data, social data (i.e., achievement badges earned)

Most of these Fitbit datasets included health metrics from dates between mid-April 2021 (~04/17/2021) and early August 2021 (~08/05/2021). However, during that timeframe, data quality varied across datasets and participants. Some datasets, such as the sleep and exercise tracker were missing substantial data for certain participants. For example, Samantha only recorded 20 nights of sleep data across the 110 days between April and August 2021. Such missing data may suggest participants wore their Fitbits with varying degrees of consistency or the data ADM received may have been a subset of all available data. Outside of missing data, the accuracy of Fitbit health metrics is also subject to question. A recent study in JMIR Formative Research suggested that the mean absolute percentage error of the

Fitbit Charge 4 heart rate tracker was just less than 10%, with a particularly high bias when individuals are climbing stairs or squatting.[1] The Fitbit Charge 4 tracks a variety of other metrics that are likely as difficult as heart rate to accurately estimate using a smart watch. Despite missing data and potential inaccuracies in health metrics, the Fitbit data we received were sufficient to draw broad conclusions on the impact of e-bikes on participant health.

GPX Files

ADM also received GPX data from SVCE; these files included e-bike route information for all participants' trips between April 22, 2021 and October 1, 2021. Of note, these files did not contain any reference to participant name, and while we attempted to match e-bike trips to participants using Fitbit distance data, the resulting matches were imprecise. As such, our e-bike trip analyses were conducted on a cohort level (i.e., including all four participants) as opposed to a participant level. Despite missing participant tags, the GPS data we received were of high quality with the 431 unique trips containing a mean of 269 waypoints and a median of 246 (including the origin and destination). Given that the mean trip length was 66 minutes and 8.26 miles, on average a GPS waypoint was noted once every 16 seconds/54 meters, suggesting high precision in the GPS dataset. While the GPS data ADM received were certainly precise, it seems they were different than the GPS data used in the City Chrysalis report. The report SVCE published outlined how the pilot program yielded 626 trips for a total of 4,281 miles travelled while the data ADM received included 431 trips for a total of 3,561 miles.[2] All analyses conducted in subsequent sections will assume City Chrysalis involved 431 unique trips over 162 active trial days.

In-Depth Participant Interviews

ADM staff conducted in-depth interviews with all four participants of the e-bike pilot project. The goal of the in-depth participant interviews was to better understand how pilot participants use their e-bikes and the impacts they have had on their lives. Interviews provided participants the opportunity to talk about their experiences with the e-bikes, and provide rich detail regarding how, when, and why they choose to ride their e-bike.

Data Analysis

Analyses for both the Fitbit and GPX data were conducted using R statistical software version 4.2.0 (2022-04-22). The aforementioned GPX, TXT, and CSV files were imported into R and participant-specific data were merged into metric-specific datasets (i.e., heart-rate data across participants were merged into a single file). Fitbit data did not require any additional calculations, so after cleaning and merging the datasets, figures (faceted by patient) were produced to highlight key health trends across the pilot program. In contrast, the GPS data only included the time, latitude/longitude, and elevation of each waypoint on each trip; therefore, data manipulation was necessary for our cost-benefit analysis.

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[1] Nissen, et al., Heart Rate Measurement Accuracy of Fitbit Charge 4 and Samsung Galaxy Watch Active2: Device Evaluation Study, 2022

[2] Silicon Valley Clean Energy, City Chrysalis Report, 2022

First, the distance between each leg of each trip was calculated using the distHaversine() function from the geosphere package. This function calculates the shortest distance between two points (in meters) assuming a spherical earth, ignoring ellipsoidal effects. With distance travelled between each waypoint for each trip calculated, we then proceeded to calculate the duration, speed, and elevation change of each leg. With these leg-specific calculations completed, we aggregated our calculations into per-day and per-trip buckets. We then used the per-day buckets in a linear regression model to assess the impact of weather conditions on e-bike travel. Lastly, we employed per-trip buckets for cost, emissions, and temporal cost-benefit calculations.

To discern the effects of weather on e-bike usage, ADM conducted a linear regression. Dependent variables included e-bike trip distance, duration, and whether a trip was taken.

Independent variables included:

- Daily dry bulb temperature[3];
- Precipitation;
- Solar irradiance; and
- Particulate matter 2.5 (PM 2.5), as a proxy for air quality.

In addition to raw versions of these variables, ADM produced bucketed categorical variables (e.g., less/greater than 60 °F). ADM sourced local dry bulb temperatures from the National Oceanic and Atmospheric Administration using the extract_isd_ids() function from the rnoaa package. Precipitation meanwhile was extracted from the same database using the cpc_prcp() function. Solar irradiance data were imported from the National Aeronautics and Space Administration using the get_power() function in the nasapower package. Lastly, PM 2.5 data were downloaded from the Environmental Protection Agency via the epa_downloadData() function within the PWFSLSmoke package.

Lastly, ADM analyzed how e-bike travel compares to cars and the Santa Clara Valley Transportation Authority (VTA), the local public transportation service. For both emissions and cost calculations ADM assumed participants used a RadCity 3 Step-thru e-bike. This e-bike was compared to an "average California car" per the NREL's 2019 California Vehicle Survey.[4] This vehicle is not a specific car model, but rather it represents the average emissions/costs for a vehicle across California in 2019. The Santa Clara VTA produces sustainability and financial reports which were used to inform the emissions and cost estimates for public transportation.

Participant In-Depth Interviews

Interviews lasted approximately 60 minutes; two interviews were completed over Microsoft Teams using video and audio functions, while the other two interview were conducted over the phone with audio only. All interviews were recorded with permission from the participants. The interviews focused on five main topic areas: neighborhood safety, project engagement, e-bike usage, benefits, and net promoter score. ADM staff summarized key findings across the interviews, as well as provided individual user stories. Individual user stories have been included as an appendix.

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[3] I.e., standard temperature measurement, where temperature is measured independent of humidity.

[4] National Renewable Energy Laboratory, California Vehicle Survey, 2019

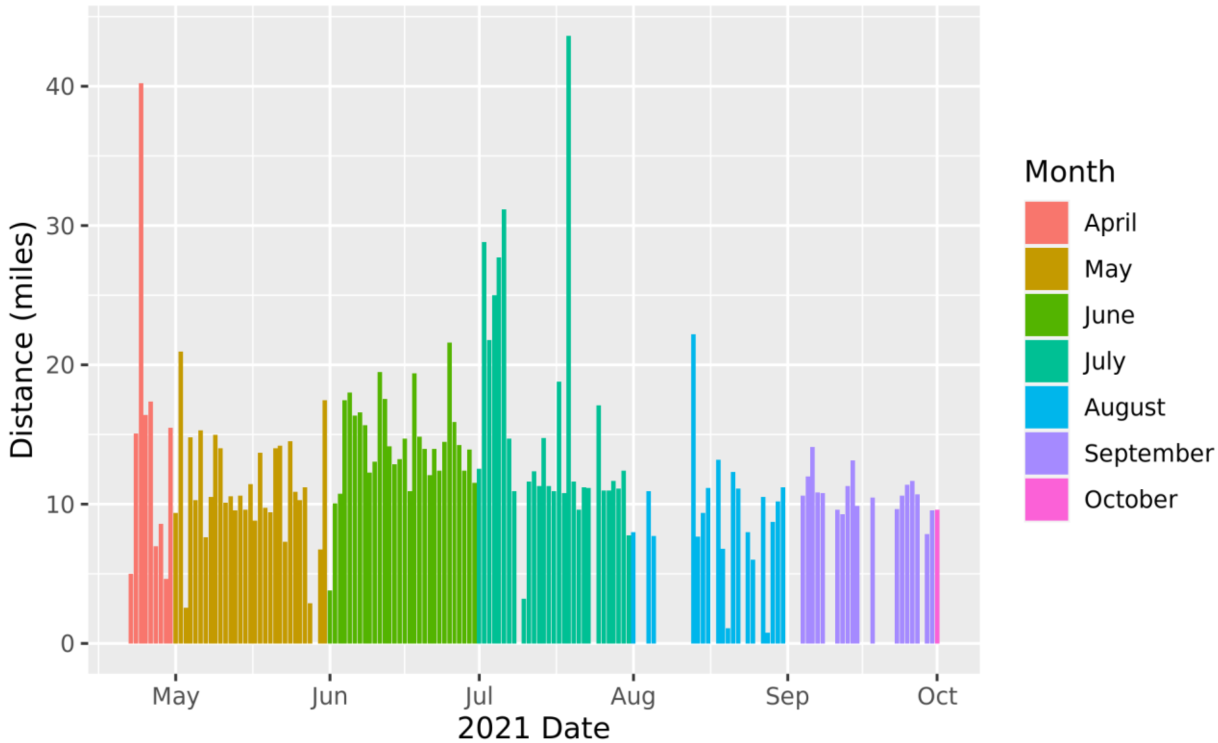
Results

E-bike Trip Overview

Study Period	4/22/2021 – 10/1/2021
Total Trips	431 unique trips Trips taken on 136 out of 162 days in study period Totaled across all four participants, there were 2.7 trips per day (.7 trips per user)
Trip Distance	Mean: 8.26 miles Median: 7.64 miles High outliers removed: One trip excluded by distance (110 miles, next longest trip was 43 miles)
Trip Duration	Mean: 1.1 hours Median: .9 hours High outliers removed: Two trips excluded by duration (23.8 and 20.2 hours, next longest was 5.2 hours)

Figure 2 presents e-bike trip distance organized by date, excluding the 110 mile outlier. April, May, and June all have consistent e-bike usage both in terms of frequency and distance. Although frequency in July seems to decrease, the distance travelled spikes. By August and September, trip frequency and distance both decrease. Possible explanations for this decrease include changes in weather, participant fatigue, and/or the spread of COVID-19.

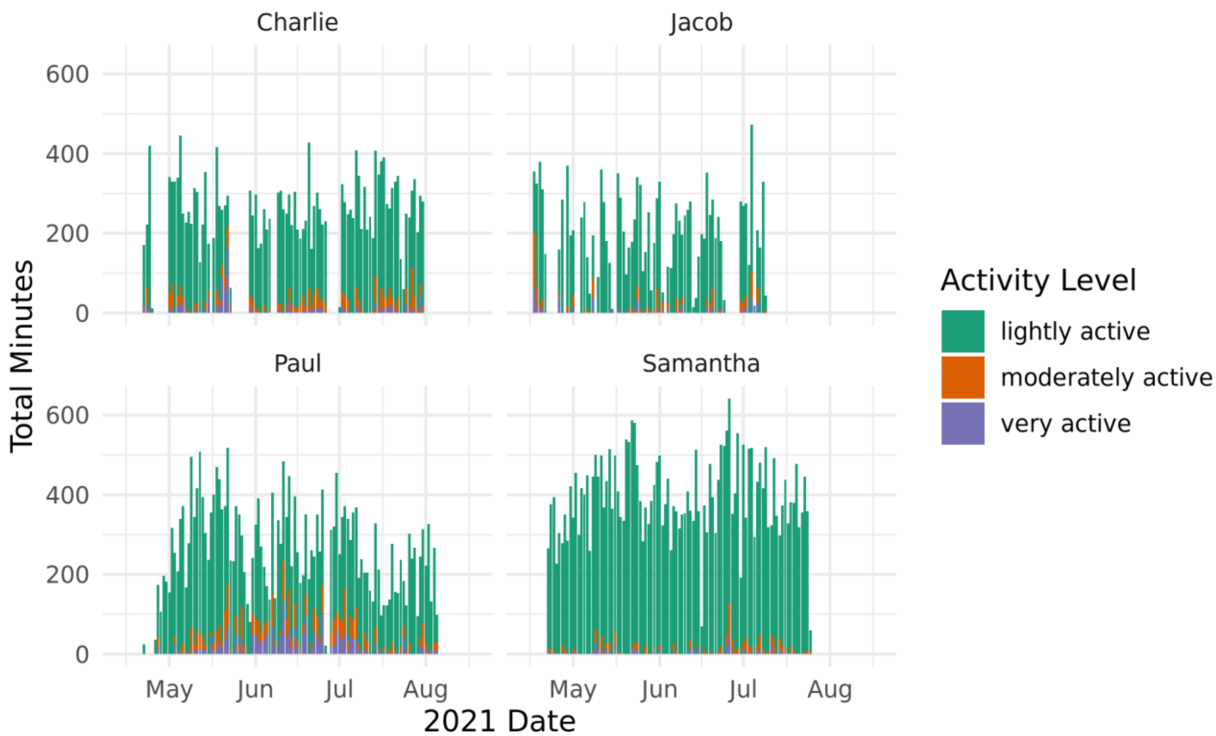
Figure 2. E-bike Trip Distance by Date (Excluding Outliers > 90 miles)



Participant Health Analysis

Figure 3 and Figure 4 highlight the activity level and heart rate zone participants experienced each day. Both measures are bucketed by intensity level, with activity levels divided into light, moderate, and very active, and heart rate zones divided into fat burn, cardio, and peak. The vast majority of participants' exercise fell into the light and fat burn categories; however, Paul had a mix of moderate and very active days throughout the summer months. Generally, these figures seem to suggest that while minor differences in e-bike usage exist across participants, e-bikes are mostly used for lightly strenuous activity. This finding is supported by the ethnographic interviews conducted by ADM which suggest that most participants used their e-bikes for trips to the store and daily errands.

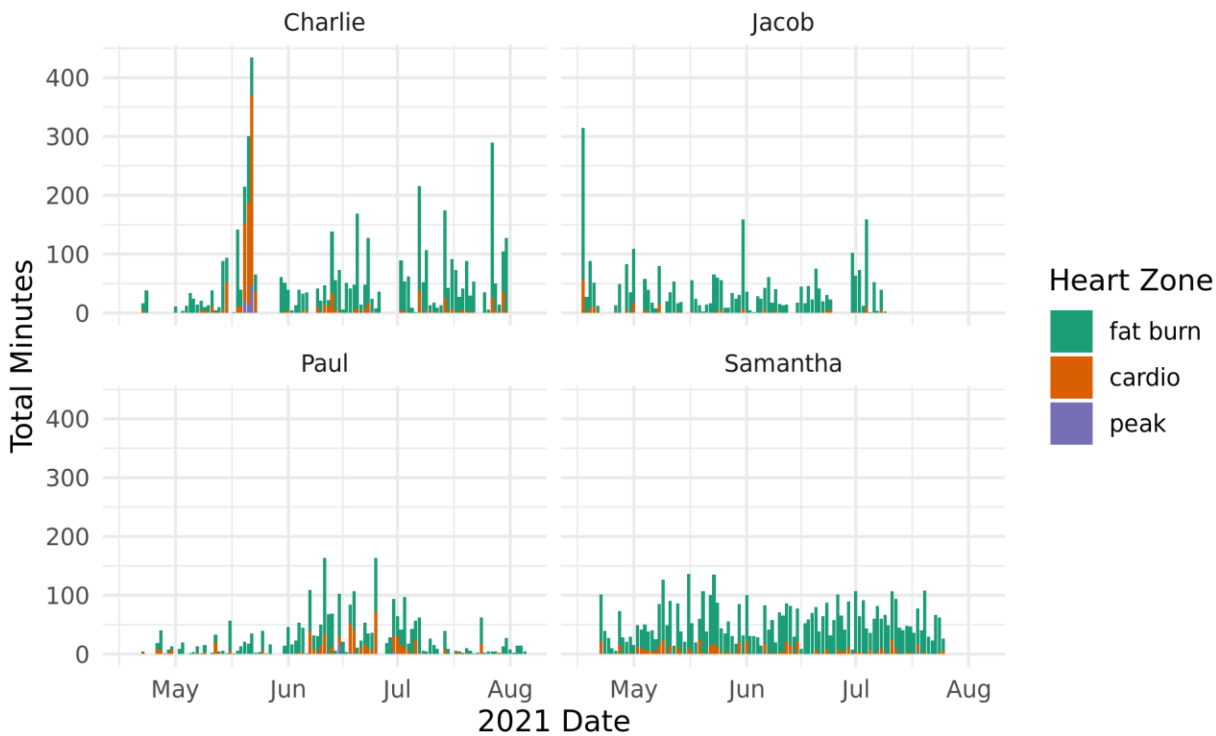
Figure 3. Fitbit Active Level by Month & Name



In addition to activity level trackers, the Fitbit Charge 4 also keeps track of the infrared to red light signal ratio, which can be used to assess participant blood oxygen level. Oxygenated hemoglobin absorbs more infrared light than red light, while deoxygenated hemoglobin does the opposite. The Fitbit assesses the amount of light that is transmitted (not absorbed) and calculates an infrared to red light ratio. The further away from zero this ratio is, the more infrared light is being transmitted meaning the more deoxygenated hemoglobin there is in the body.[5] As evident in Figure 5, the dramatic day-to-day variation in mean infrared to red signal ratio suggests that Fitbit pulse oximetry is somewhat inaccurate. However, the general trend of average participant infrared to red signal ratio staying close to zero indicates participants maintained high blood oxygen saturation. Paul, the most physically active participant, seemed to improve his blood oxygen saturation over the course of the summer.

[5] Chan, Chan, & Chan, Pulse oximetry: Understanding its basic principles facilitates appreciation of its limitations, 2013

Figure 4. Fitbit Active Zone by Month & Name



Participants' Fitbits also collected data on their maximal oxygen consumption or VO2 max. Generally, a higher VO2 max correlates with better physical fitness. As demonstrated in Figure 6, Jacob experienced a marked increase in VO2 max from an initial reading of ~44 in April up to ~50 (L/min) in July. Samantha and Charlie maintained a consistent maximal oxygen consumption levels, while Paul experienced a steep decline from early May to June. The dramatic variation in Paul's VO2 max suggests the participant may have experienced a significant confounding life event (e.g., cardiac arrest) or the Fitbit may have been reading VO2 inaccurately in early May. While four participants do not provide sufficient data to draw in-depth conclusions on the impact of e-bike usage on VO2 max, e-bikes appear to have the potential to maintain and improve cardiovascular health.

Figure 5. Participant Mean Infrared to Red Signal Ratio by Date & Name

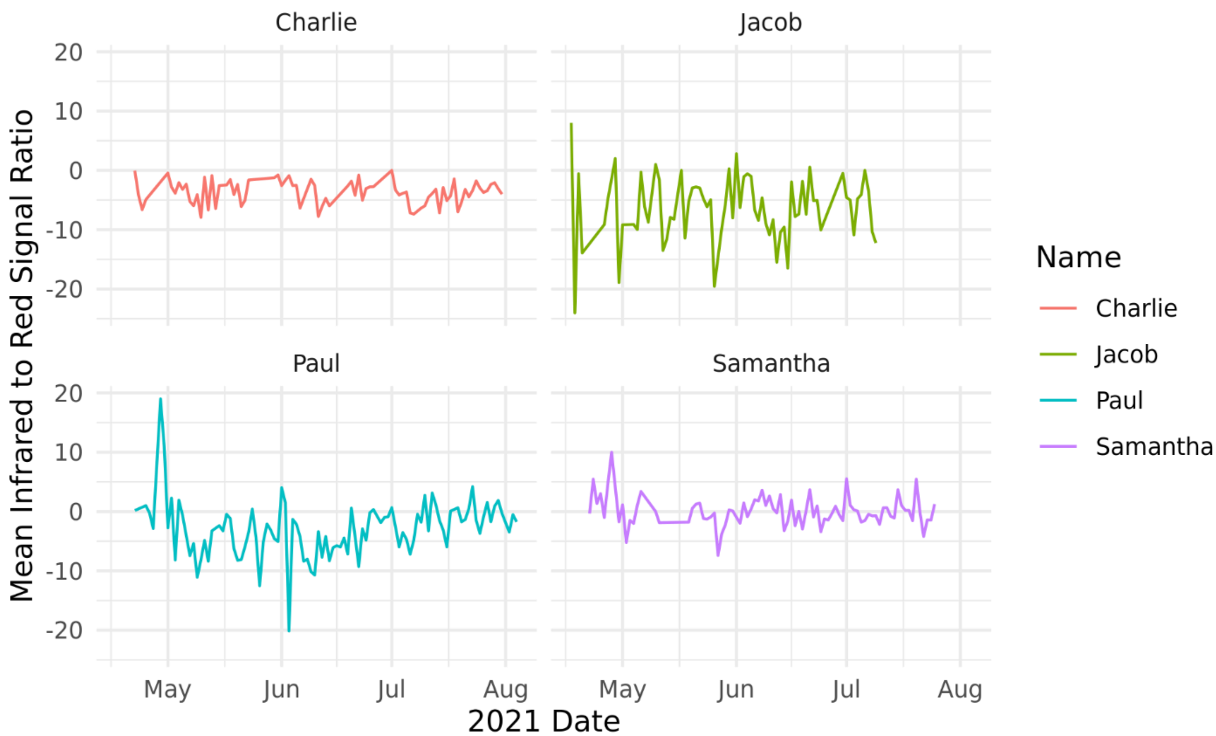
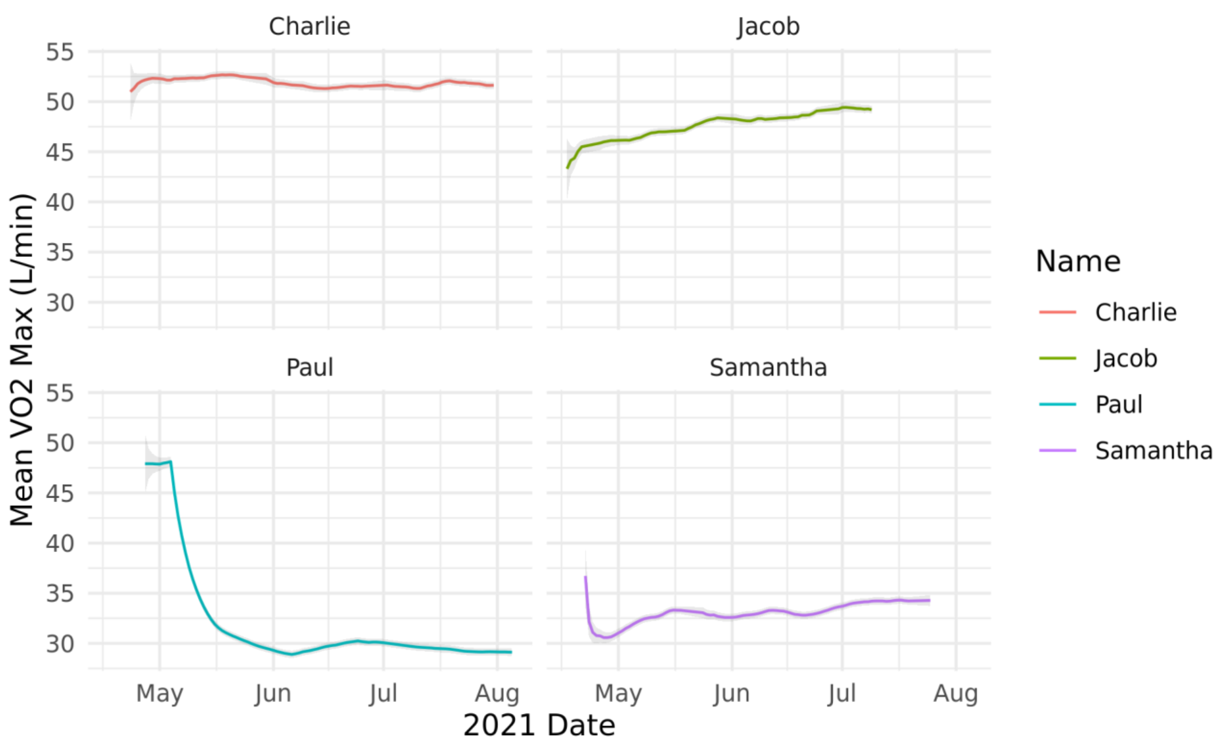


Figure 6. Average VO2 Max by Date Faceted by Name (w/ Error)



In addition to oxygen consumption, the Fitbit Charge 4 also tracked participant heart rate and resting heart rate. Mean daily heart rates and resting heart rates are presented in Figure 7 and Figure 8 respectively. Both datasets show a similar trend of heart rate staying consistent for Samantha, Charlie, and Paul and decreasing slightly for Jacob. These heart rate trends match those outlined in the VO2 max section, suggesting e-bikes have the potential to improve many aspects of cardiovascular health. Of note, ethnographic interviews revealed that Jacob used his e-bike exclusively for exercise (between 8-20 miles at a time), while all other participants used their e-bikes for a mix of exercise and daily activities. Jacob's focus on aerobic e-bike exercise is evident in the data and suggests that e-bikes may simply facilitate broader lifestyle and exercise goals. Our evidence suggests that e-bikes may be used as a tool for building endurance (especially so for the elderly or those recovering from health conditions), as they allow riders to travel substantial distances with relative ease.

Figure 7. Mean Heart Rate by Date Faceted by Name

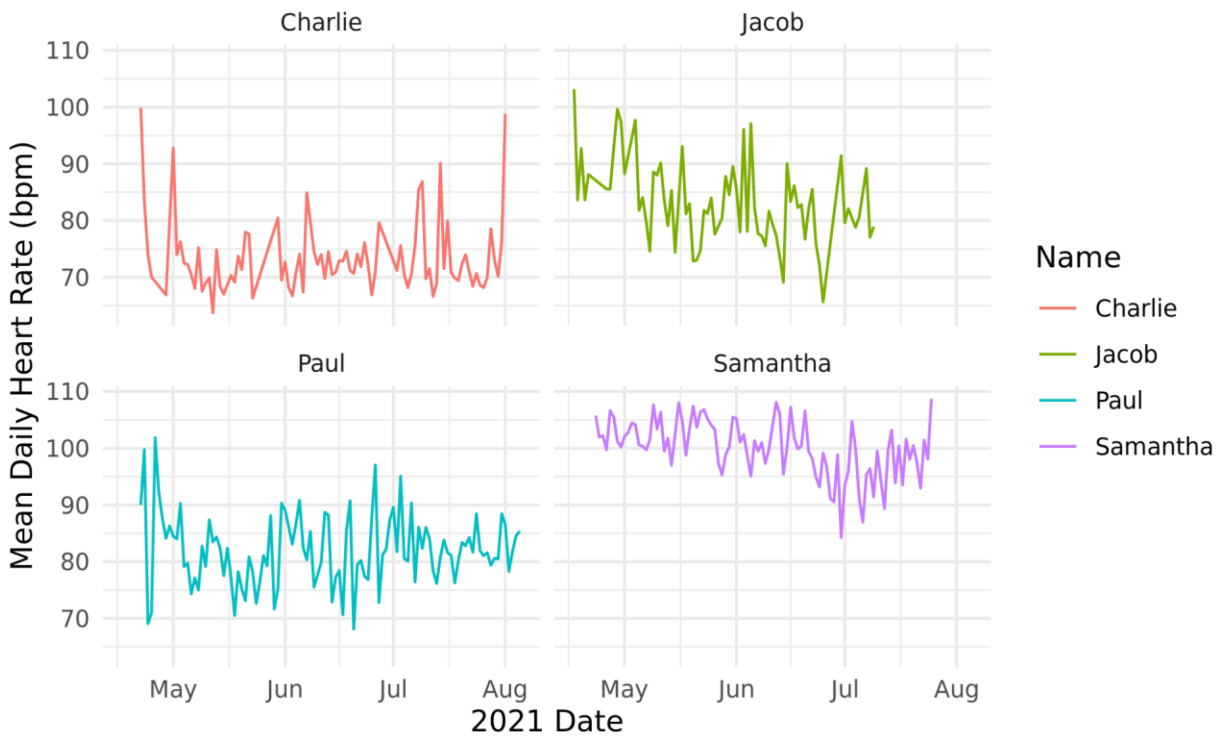
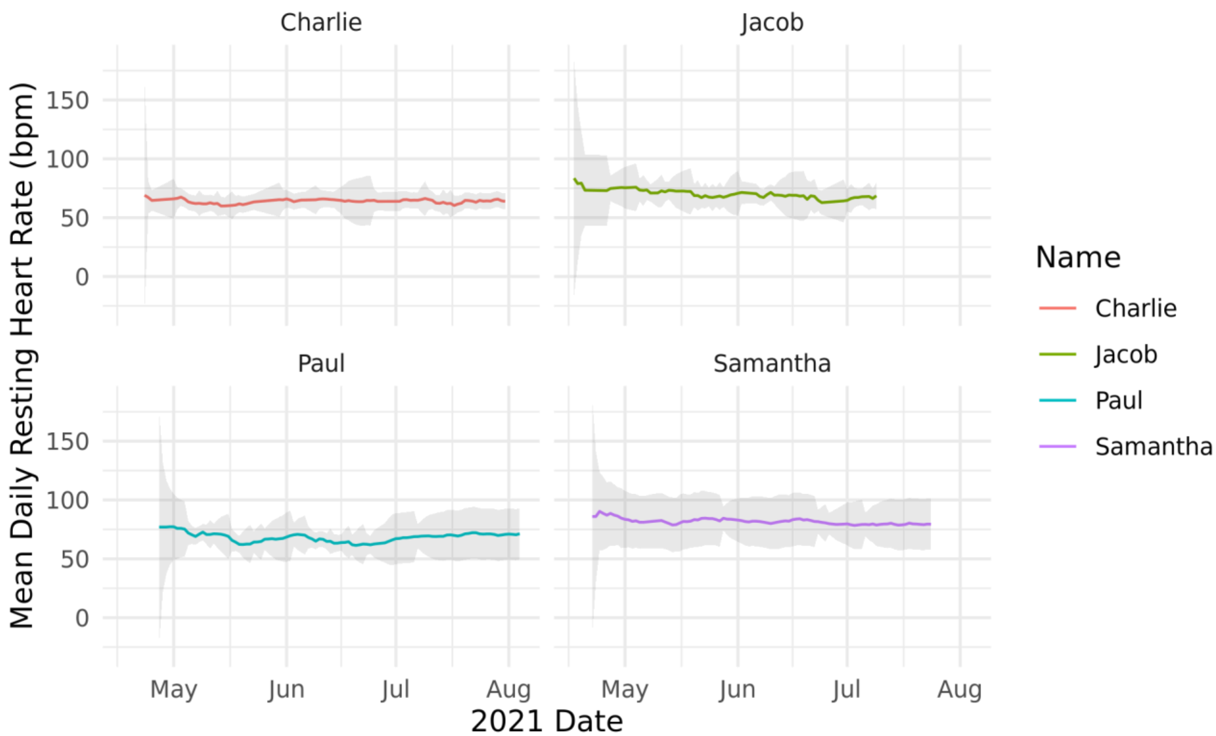


Figure 8. Mean Resting Heart Rate by Date & Name (w/ Error)



A final dimension of health data that the Fitbit tracks is sleep quality. The Fitbit Charge 4 tracks both sleep time and a proprietary sleep score. Sleep score is calculated as the sum of individual scores in sleep duration, quality, and restoration and is out of a total of 100. A score of 90-100 is excellent, 80-89 is good, 60-79 is fair, and less than 60 is poor. Of note, Fitbit outlines that an average sleep score is between 72 and 83.[6] Neither sleep time nor sleep score, demonstrated meaningful trends, as there is substantial variation day-to-day and, especially in the case of Samantha and Paul, missing data.

While the Fitbit data ADM received was sparse for some metrics, as a whole it seems to suggest that the participants in the City Chrysalis pilot used e-bikes for primarily light aerobic activity with high frequency. Per the ethnographic interviews this activity was a mix of exercise and daily errands. While using these e-bikes, participants' cardiovascular health either remained constant or improved slightly. Sleep seemed unaffected by e-bike usage; however, sparse data made drawing conclusions regarding sleep time/quality difficult. Overall, e-bikes seem to have the potential to improve participant health; however, larger sample sizes, lengthier studies, and comparison to controls are necessary.

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[6] Fitbit, What's sleep score in the Fitbit app, 2022

Regression Analysis

ADM conducted a linear regression to assess the impact of weather conditions on our dependent variables: e-bike trip distance, duration, and frequency. More specifically, the weather conditions included in the models were daily measures at the average geography (longitude/latitude) of all trips taken that day. These independent variables were bucketed into temperature, precipitation, solar irradiance, and air quality. Temperature variables included dry bulb temperature and a categorical temperature variable splitting temperature into > 60°F and ≤ 60°F. Precipitation variables included total daily precipitation, a categorical precipitation variable (i.e., did it rain or not), and a categorical variable tracking whether or not it rained the day before. ADM only had one solar irradiance variable that tracks the daily average downward thermal infrared radiative flux. Lastly, for air quality, ADM used a continuous PM 2.5 variable, as well as a categorical variable tracking whether the PM 2.5 > 12.1 or not. Per the EPA's Technical Assistance Document for the Reporting of Daily Air Quality, a PM 2.5 from 12.1-35.4 corresponds to a moderate AQI.[7] The maximum PM 2.5 during the pilot timeframe was 34.7.

The results of the regressions are presented in Table 1.

Collectively, the results of the linear regression models seem to suggest that the daily lag of precipitation was the only independent variable that had a statistically significant impact on e-bike distance and duration. PM2.5 affected trip distance but not duration. Moreover, no independent variables appear to have an impact on e-bike frequency, i.e., whether or not individuals take a trip on their e-bike. These findings are generally supported by the ethnographic interviews. Jacob reported that air quality was not a concern; however, he avoided riding his bike when it was very hot outside. Of note, while precipitation did not have a statistically significant effect, many participants outlined safety concerns about riding in the rain in their interviews. There are several explanations for the lack of an association between weather conditions and e-bike usage. First, it is possible that the trips participants were taking were often vital errands (i.e., biking to the grocery store), so participants had to take the trip regardless of the weather. This hypothesis seems unlikely, as at least two of the four participants had cars and the VTA is readily available as an alternate form of transportation.

[7] Environmental Protection Agency, Technical Assistance Document for the Reporting of Daily Air Quality - the Air Quality Index (AQI), 2018

Table 1. Multiple Linear Regression Model Results

Dependent Variable	Independent Variable	Estimate	P value
Trip Distance	Daily dry bulb temperature	-0.71	0.392
	Categorical temp variable	-11.68	0.221
	Precipitation	-4.28	0.168
	Categorical precipitation	3.72	0.642
	Categorical precipitation – daily lag	-13.50*	0.067
	Solar irradiance	0.10	0.560
	PM 2.5	-1.34*	0.078
	Categorical Air Quality	14.74	0.253
Trip Duration	Daily dry bulb temperature	-0.06	0.473
	Categorical temp variable	-1.19	0.215
	Precipitation	-0.44	0.164
	Categorical precipitation	0.14	0.859
	Categorical precipitation – daily lag	-1.37*	0.065
	Solar irradiance	-0.01	0.628
	PM 2.5	-0.10	0.208
	Categorical Air Quality	0.72	0.582
Trip Frequency	Daily dry bulb temperature	-0.00	0.919
	Categorical temp variable	-0.12	0.263
	Precipitation	-0.03	0.478
	Categorical precipitation	0.08	0.382
	Categorical precipitation – daily lag	-0.11	0.206
	Solar irradiance	-0.00	0.813
	PM 2.5	-0.01	0.474
	Categorical Air Quality	0.08	0.591
*Significant at 90% confidence **Significant at 95% confidence			

Alternatively, having received a free e-bike and knowing they were a part of a pilot program, participants may have felt an obligation to use their e-bike frequently, which could partially explain the lack of correlation between weather and e-bike use.

Daily dry bulb temperature varied from 51.6°F to 81.0°F with a mean of 65.0°F, precipitation ranged from 0 to 9.0 with a mean of 0.13 inches, daily solar irradiance had a range from 268.0 to 368.7 with a mean of 316.8 W/m^2, and, PM 2.5 air quality varied from -2.5 to 34.7 (as outlined above, 35.4 is the upper bound for a moderate AQI) with a mean of 5.9 µg/m^3.

It should be noted that Gilroy has significantly hotter weather than most of SVCE's service territory. Despite this, there was no identifiable correlation between outside air temperature and E-bike use. With Santa Clara County's generally mild climate, this pattern could be expected to continue in other Member Cities that do not have a climate as warm as Gilroy's.

Cost-Benefit Analysis

ADM conducted a cost benefit analysis to assess the differences in emissions, costs, and time associated with e-bikes, cars, and public transportation (the VTA). For each of these dimensions, we calculated the emissions, costs, and time associated with the e-bike trips participants had taken in the pilot program, an average per trip, and an annualized total. Broadly, we found that e-bikes emit substantially less CO_2 than cars or public transportation, have far lower costs than cars, and on average are only slightly slower than cars. We delve further into the specifics of each facet of this cost-benefit analysis below.

The emissions calculations ADM conducted focus exclusively on CO_2; however, it is important to acknowledge that cars and public transportation both produce methane, nitrous oxide, and hydrofluorocarbon emissions – all of which have more substantial global warming potential than carbon dioxide.[8] As such, all emissions calculations should be considered conservative. To calculate carbon dioxide emissions, we used the EPA's estimate that a gallon of gasoline emits 19.59 lbs. of CO_2 and a peer reviewed study's estimate that an e-bike emits .000022 lbs. of CO_2 per mile.[9,10] Then, using the milage per gallon of our modal cars we were able to convert carbon dioxide emissions per gallon to .89 lbs./mile. Moreover, instead of simply assessing the emissions of each car, we calculated the emissions per person, assuming an average car occupancy of 1.54 people.[11] After applying that divisor, we converted our calculations from emissions per mile to emissions per mile, given that our GPS data tracked distance in meters. This yielded the following person emissions: E-bike – .11 lbs./mi., average California car – .54 lbs./mi.

The VTA meanwhile has broad statistics on emissions and passenger transport usage in their 2020 Sustainability Annual Report and 2020 Comprehensive Annual Financial Report, respectively. The VTA outlined that their buses released 34,213 metric tons (75,426,754 lbs.) of CO_2 in 2020.[12] The Comprehensive Annual Financial Report meanwhile detailed that annual ridership was 35.5 million for a total of 184.3 million person miles traveled.[13] When we divide the total emissions released by person miles travelled we find that the VTA averages .39 lbs./mile of carbon dioxide emissions. While this emission total may seem dramatically high for public transportation, it is important to note that the COVID-19 pandemic likely decreased VTA ridership, making the CO_2 emissions per person substantially higher. Starting in March 2020, VTA ridership was reduced 80-90% on buses, with only 8 passengers allowed on board a 40-foot bus.[14] As of May 2021, the VTA implemented capacity limits of 34 passengers per car of a light rail, and 15, 18, and 26 passenger limits for 30-, 40-, and 60-foot buses

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[8] Environmental Protection Agency, Greenhouse Gas Emissions from a Typical Passenger Vehicle, 2018

[9] Environmental Protection Agency, Greenhouse Gas Emissions from a Typical Passenger Vehicle, 2018

[10] McQueen, MacArthur, & Cherry, The E-bike Potential: Estimating the Effect of E-bikes on Person Miles Travelled and Greenhouse Gas Emissions, 2019

[11] Office of Energy Efficiency and Renewable Energy, Average Vehicle Occupancy Remains Unchanged from 2009 to 2017, 2018

[12] Valley Transportation Authority, Sustainability Annual Report FY 2020, 2020

[13] Santa Clara Valley Transportation Authority, Comprehensive Annual Financial Report, 2020

[14] Valley Transportation Authority, VTA increases capacity on transit vehicles starting May 26, 2021

respectively.[15] Working with these updated guidelines, ADM calculated the emissions associated with the VTA, assuming an average of 23 passengers per ride, as .16 lbs./mile of carbon dioxide. Using these emissions per mile, ADM calculated pilot program emissions, emissions per trip, and annualized emissions, all of which are outlined below in Table 2. Of note, for annual calculations we assumed an average of 243 e-bike trips per year, since across the four participants there were 431 trips over 162 days for an average of 0.67 trips per person per day.

Table 2. Carbon Dioxide Emissions by Mode of Transportation

Description	Units	Pilot Program	Average Trip	Annualized
Time on e-bike	Hours	476	1.1	268
Distance traveled	Miles	3,561	8.26	2,006
E-bike CO2 emissions	Lbs./person	39.68	0.09	22.05
Average 2019 California car CO2 emissions	Lbs./person	1,918.02	4.45	1,080.26
VTA 2020 CO2 emissions	Lbs./person	1,457.25	3.37	820.12
23 individuals per VTA 2020 CO2 emissions	Lbs./person	553.36	1.28	310.85

With e-bikes demonstrating the lowest carbon dioxide emissions, ADM proceeded to conduct a cost comparison of these three modes of transportation. Calculations were split into variable (i.e., regular costs associated with refueling/recharging) and fixed (i.e., one-time or annualized purchases) costs and were assessed across the same three scenarios (pilot program, average trip, and annualized) as emissions. The only variable e-bike cost was the cost associated with recharging the battery. SVCE's "example bill" Tier 2 usage cost is $.28159/kWh.[16] Per the Rad Power Bikes website, the RadCity 3 Step-Thru has a .672 kWh battery and an expected battery range between 25 and 45 miles.[17,18] Using this information ADM calculated an average e-bike variable cost per mile of $0.0055. E-bike fixed costs meanwhile include $1,599 for the e-bike itself, an annual e-bike maintenance cost of $159 and, assuming a 5-year life cycle for the e-bike battery, a $110 annual battery maintenance cost.[19,20,21]

Car variable costs included both a car maintenance cost per mile and a gas cost per mile. The car maintenance cost per mile was calculated as $0.098 based on a AAA 2021 driving costs report.[22] Car gas costs per mile were calculated based on car-specific MPG and the Bay Area price of gas in April 2021, per

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[15] Valley Transportation Authority, VTA increases capacity on transit vehicles starting May 26, 2021

[16] https://www.svcleanenergy.org/wp-content/uploads/2019/08/Sample-Bill-8.01.2019-Sparky-Joule.pdf

[17] Rad Power Bikes, RadCity 3 Step-Thru Specs & Details, 2022

[18] Rad Power Bikes, Take Charge: See How Far Your Bike Battery Can Take You, 2020

[19] Rad Power Bikes, RadCity 3 Step-Thru Specs & Details, 2022

[20] Summit Bicycles, Summit Certified Bike Service & Repair, 2022

[21] Rad Power Bikes, Rad External Battery Pack, 2022

[22] AAA, Your Driving Costs, 2021

the Bureau of Labor Statistics, $3.943.[23] This gas price yielded a variable gas cost of $.179 per mile for the average US car. Car fixed costs were calculated as a simple mean of new and used car costs. Used car costs were calculated using Kelly Blue Book, resulting in a fixed cost of $45,766 for the California average car. In addition to the cost of purchasing a car we included an annual California car insurance estimate of $2,125 as an additional fixed cost.[24] The combination of these variable and fixed costs are outlined below in Table 3. This table highlights how e-bikes have the lowest variable costs and the second lowest total costs after public transportation. Considering the downside of public transportation having a more limited range of possible destinations than either an e-bike or car, e-bikes seem to be a cost-effective option. Moreover, were we to split the purchasing price of an e-bike ($1,599) across multiple years (i.e., 5 years), the annualized cost of an e-bike would be reduced to $589, which is less expensive than the VTA. Of note, our estimates of VTA costs assume participants would purchase single ride passes for each trip, given that an annual pass costing $990 would be more expensive than buying 268 single rides in a year.

Table 3. Variable and Fixed Costs by Mode of Transportation

Description	Units	Pilot Program	Average Trip	Annualized
Time on e-bike	hours	476	1.10	268
Distance traveled	miles	3,561	8.26	2,006
E-bike variable costs	USD	14	0.03	$11
E-bike fixed costs	USD	-	-	$1,868
E-bike total costs	USD	-	-	$1,876
Average 2019 California car variable costs	USD	988	2.29	$557
Average 2019 California car fixed costs	USD	-	-	$47,891
Average 2019 California car total costs	USD	-	-	$48,423
VTA total costs	USD	1,078	2.50	$607

The final dimension of the cost-benefit analysis ADM conducted was an assessment of the difference in trip time between e-bikes, cars, and public transportation. E-bike trip time was calculated by the CycloTrac affixed to each bike. Car and public transportation timing meanwhile was calculated using the Google Directions API. The Directions API is a web service provided by Google that uses an HTTP request to return JSON or XML-formatted directions and timings between locations. ADM employed the mp_directions() function from the mapsapi R package to interphase with the Directions API and extract the timing for each trip. To match the e-bike trip route as closely as possible, we extracted the first and last GPS datapoints as the origin and destination and tracked all others as intermediate waypoints. The Directions API has a limit on the number of waypoints per API call and only allows waypoints to be used for car transportation (not public). As such, for our car API calls, we limited the number of waypoints included in our call to 9 that were evenly spaced between the origin and destination. For our public transportation API calls, since waypoints were not a valid option, we split each trip into four smaller trips: origin to waypoint 1, waypoint 1 to 2, 2 to 3, and waypoint 3 to destination. In this manner we

[23] Bureau of Labor Statistics, Average energy Prices, San Francisco-Oakland-Hayward - April 2022, 2022

[24] Car Insurance, How much is car insurance in California, 2022

were able to estimate the total time each trip would have taken via car and public transportation. Results of these analyses for the pilot program, an average trip, and on an annualized basis are presented below in Table 4. Of note, 118 of the 431 VTA trips we assessed using the Directions API were missing data for at least one of the four legs of the trip. Given that the VTA timing estimate for those trips would have been a drastic underestimate, those trips have been removed from our temporal analysis. These trips we excluded had a mean distance of 11 miles and mean duration of 72 minutes. The remaining trips totaled 2,241 miles over 341 hours, with an average of 7.5 miles over 66 minutes. Overall, Table 4 highlights how driving is the fastest mode of transportation; however, especially for shorter trips, e-bikes are a close second. Indeed, while there may be an average time difference between driving and e-bikes of 45 minutes across all trips, for trips less than or equal to 30 minutes, that time difference is reduced to 8 minutes. This suggests that for short trips, (i.e., errands or trips to the grocery store) an e-bike is almost as fast as a car at a far lower cost with nearly no emissions. For longer trips, a car may be the quicker option; however, e-bikes are slightly faster than VTA public transportation, by an average of one minute per trip.

To estimate the economic impact of time spent in transit, ADM assumed household income for a two-person household meeting 80% of the Area Median Income of Santa Clara County converted Santa Clara County ($94,200[25]) into hourly values by dividing by 2,080, assuming a 40-hour workweek. This assigns an economic value per hour of $45.29.

We note that the costs presented in Table 4 are strictly financial and economic costs borne by end-users, and do not include the cost of environmental impacts (carbon, PM2.5, etc.) associated with emissions reductions.

Table 4. Trip Time by Mode of Transportation

Description	Units	Pilot Program	Average Trip	Annualized
Time on e-bike	hours	341	1.1	268
Distance traveled	miles	2,241	8.3	2,006
Time difference between e-bikes and driving	hours	234	0.75	181
Time difference between e-bikes and VTA	hours	-5	-0.02	-4
Time diff. between e-bikes and driving (e-bike trips ≤ 60 min)	hours	51	0.27	65
Time diff. between e-bikes and VTA (e-bike trips ≤ 60 min)	hours	-68	-0.36	-87
Time diff. between e-bikes and driving (e-bike trips ≤ 45 min)	hours	29	0.20	48
Time diff. between e-bikes and VTA (e-bike trips ≤ 45 min)	hours	-52	-0.36	-87
Time diff. between e-bikes and driving (e-bike trips ≤ 30 min)	hours	12	0.13	32
Time diff. between e-bikes and VTA (e-bike trips ≤ 30 min)	hours	-27	-0.30	-73

[25] https://covid19.sccgov.org/sites/g/files/exjcpb766/files/Documents/santa-clara-county-2021-area-median-income-ami-chart.pdf

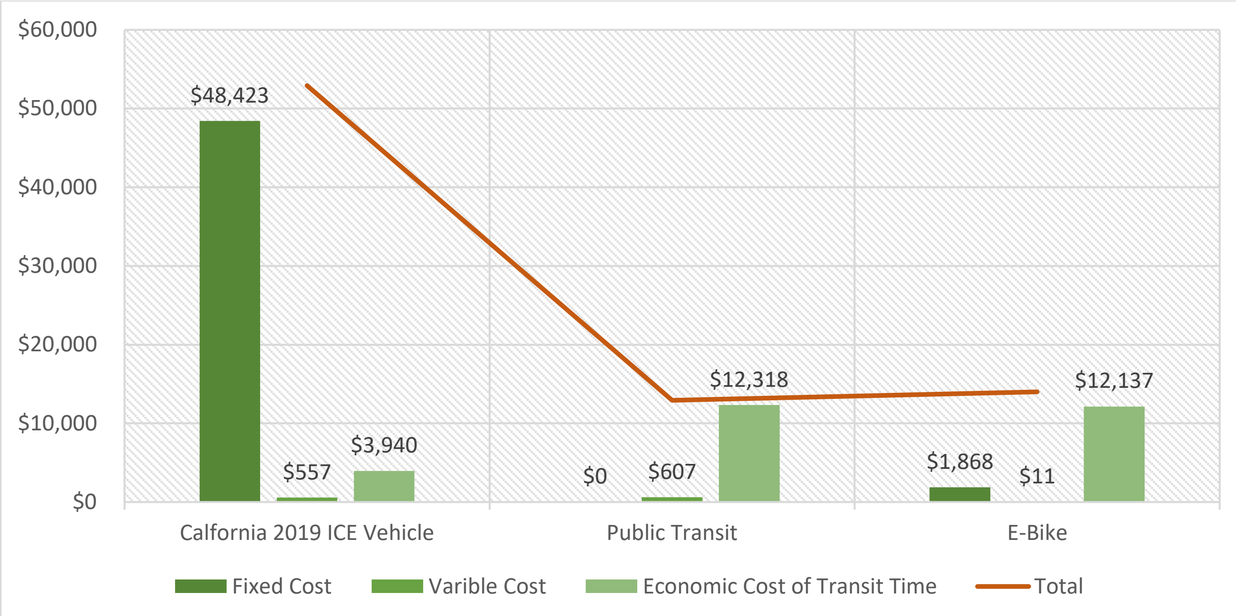

Figure 9. Cost Comparison of Transit Modes – 2,005 Miles of Travel

These three dimensions of the analysis broadly highlight the cost-effectiveness of e-bikes. They produce a low level of emissions, they are substantially less expensive than cars, and have similar trip times to cars over shorter routes. The City Chrysalis pilot program seems to have demonstrated the clear benefits of e-bike usage. From increasing participant physical activity, with clear potential to improve key health metrics, to reducing emissions and costs, e-bikes provide riders with an easy way to traverse their community that is robust across weather conditions. While hot temperatures may cause a slight decrease in e-bike trip distance and duration, the benefits of such e-bike programs far outweigh the costs.

Participant Interviews

The interviews focused on four primary topics: 1) neighborhood safety, 2) project engagement, 3) benefits, and 4) net promoter score. Although interviewees answers varied, some common themes emerged within in each topic.

Neighborhood Safety

> *"I'm not only getting my exercise and getting my daily errands, but I'm helping my community by monitoring the roads and the lights that needed to be placed"*

All participants indicated that their neighborhoods were mostly safe. While some noted that certain parts of town were safer and more welcoming than others, participants generally felt safe in their neighborhood. Participants also agreed that the key components to making a neighborhood bicycle friendly include bicycle lanes, proper signage, slow speed limits, and sidewalks.

Project Engagement

All the participants learned about the e-bike pilot project via their apartment complex. Some saw flyers, while others attended an information session. Most of the participants had never ridden an e-bike before joining the pilot project, and only one participant had previously owned or considered buying an e-bike. In general, the participants were interested in using an e-bike for exercise and getting around town. Prior to joining the pilot project, driving was participants most common means of transportation, although some of the participants had bicycles.

When riding their e-bikes, participants were not perturbed by cold weather, however many expressed safety concerns about riding in the rain. Participants were split in their level of concern over it came to riding in poor air quality conditions. All participants stored their e-bikes in their apartments and charged them after every ride or after every other ride.

Benefits

"I was stuck in a rut and not getting off the couch...this bike has helped me take my life back…I'm on this bike and I'm outside..."

Universally, participants acknowledged the immense impact their e-bike has had on their physical and mental health. All the participants were interested in joining the pilot project because of the potential health impacts, and they have been surprised by the degree of change. The participants talked about how the e-bikes have enabled them to exercise longer and more frequently; they also talked about feeling less discouraged when riding, because they have the pedal assist to help them up tough hills. Some participants also observed changes in important health indicators like resting heart rate and blood pressure. A few participants commented on the mental health benefits of the e-bike, explaining that it has provided them an outlet to clear their minds and escape the drab of daily life.

Table 5. Self-Reported Benefits of E-Bikes

Benefits	Quote
Physical strength	*"Riding the bike has built up muscles in my legs. It has helped with leg issues. I couldn't walk upstairs and now I can."* *"That bike, I've been able to take the physical part of my life back"*
Exercise	*"Got my exercise, when my asthma kicked in and I couldn't do it, there was that assistance. Let me keep up with my family."* *"But my Rad City Bike, I would feel it punch in. That would make me excited…now I'm going further. I'm going further and further."* *"For my underlying condition, it's been like a good therapy for me. I can tell the difference…It's done a lot of good for my health. I feel it feel, I actually feel it physically."*
Mental Health	*"I'm a little bit more outgoing, a little bit more out there. I feel like it's helped me."* *"At the age of 65, I felt like a little kid;"* *"[I have] become more brave... Amazed by changes in my mental blockage."* *"Became my source of enjoying day-to-day life."*
Transportation	*"Why would I get into a car to do that."* *"It's better than a vehicle, don't have to waste money on gas…perfect for the buses…you'll save money, doing errands, groceries, going by the post office."* *"Because they're not only fun, they're reliable."*

Net Promoter Score

All participants gave the e-bikes a net promoter score of 8-10 on a scale of 0-10, indicating they are highly likely to recommend an e-bike to friends, family, and colleagues. Across the four participants, the Net Promoter Score was 75, which is considered an excellent Net Promoter Score.[26] Although two participants alluded to some stigma they faced or felt when they first entered the pilot, those negative perceptions quickly faded away when people saw how much the e-bike was impacting their lives.

[26] Washington University in St. Louis, Net Promoter Score, 2018

Discussion

Using Fitbit health data, CycloTrac GPS data, and in-depth interviews, evaluators were able to assess the relationship between program participation and participants' health outcomes, CO_2 emissions, direct costs, and time to destination across different modes of transportation. Evaluators also explored the relationship between weather and e-bike usage.

The data reveal that e-bikes have the potential to improve participants cardiovascular health, encourage physical activity, and support mental health. We found that e-bike usage occurs independent of most weather events, with dry bulb temperature serving as the only significant variable with a weak, negative relationship to trip distance and duration. Lastly, the data suggest that e-bikes have drastically lower emissions than cars or public transportation, annualized costs similar to public transportation (and far lower than cars), and times to destination that are similar to cars for shorter trips

Collectively, these findings indicate the pilot program was successful and suggest a second iteration of this program would be worthwhile. A variety of limitations exist in this pilot program that could be addressed in a new study. First, a group of four participants is a small sample size, which makes drawing meaningful conclusions difficult. A larger sample size (10 or 20 people) could reveal more in-depth findings with a higher likelihood of significance. Not only would more participants provide improved data, but it would also give us the opportunity to assess whether age-dependent trends exist in the data. While the age range of 46 to 73 in this study is sufficient for a pilot, a broader age range with more data points could add an interesting dimension to future analyses. Moreover, if participants were trained on how to use their Fitbits (i.e., when to charge them, how to ensure good skin contact for accurate health readings) we could determine the health impacts of e-bikes far more precisely. Furthermore, if the subsequent e-bike study included both a pre-e-bike period of Fitbit data collection, as well as demographically matched controls who did not receive e-bikes, we could employ statistical tests of significance to assess the effects of e-bike usage in a much more systematic manner.

In addition to improved controls, lengthening the study time could also provide meaningful results. This pilot program focused exclusively on late spring, summer, and early fall, meaning seasonal trends associated with e-bike usage are unknown. A year-long follow up study could reveal interesting trends. In addition to tracking seasonal variation, it might also be interesting to assess the impact of geography of e-bike findings. While SVCE may exclusively focus on Silicon Valley, partnering with other clean energy programs across the state/country could provide worthwhile insights into the impact of geography on e-bike usage. Lastly, conducting regular interviews with e-bike participants to assess their thoughts and feelings on e-bikes could be useful. When comparing e-bikes to other modes of transportation, having such qualitative data could help answer questions like, do pannier bags provide enough space for grocery shopping? Not only could such further study provide insights into e-bike use cases and limitations, but it could also help determine how e-bikes effect participants' mood and daily routine.

The City Chrysalis pilot program revealed the advantages and cost-effectiveness of e-bikes in Santa Clara County. ADM would highly recommend a follow-up study to build on these findings and explore novel dimensions of e-bike usage. In the face of mounting climate change and bourgeoning populations, clean, space-efficient, and cost-effective means of transportation like e-bikes are invaluable. Pilot programs such as City Chrysalis provide a clear impetus for increased e-bike usage and more broadly a shift to clean, renewable energy.

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Appendix A: Individual User Stories

Participant #1 Charlie

Charlie is retired and currently living in a senior living community, away from the business and traffic of downtown. Overall, Charlie feels safe in his neighborhood; some areas are not as welcoming or bike friendly, but he typically rides his e-bike along the levy trail, nearby parks, and through farmland to his friends' ranches. Charlie has observed other residents riding their bikes around town, predominately for exercise and pleasure on the same pedestrian trails and parks that he rides.

Charlie first learned about the e-bike pilot through a conversation with his social worker. After suffering through a bout of health issues over the past five years, including a leg injury, stroke, and cancer, Charlie was looking for a way to become more active and improve his health. He commented on how the timing of this pilot could not have been better, as he was looking into buying an e-bike to replace the regular bike he had been using. Charlie was particularly interested in the pedal assist functionality of e-bikes, as he felt as though he was not able to go as far or get as much exercise on his regular bike. Although Charlie was interested in purchasing an e-bike prior to his enrollment in the program, even going so far as to buy a used e-bike at a garage sale, he was unable to afford the newer and more advanced models.

When asked about how he uses the e-bike, Charlie commented that "he can't get enough" and "it's been a lifesaver." He excitedly explained that he rides about 22 miles a day and has already ridden 1800 miles on the e-bike. Charlie said that he uses his e-bike for everything; he rides for exercise 1-2 times a day, grocery shopping 2-3 times a week, and visiting friends and family once a week. His rides range from 4-5 mile trips to the store, 10-mile morning/evening rides, and 26-mile longer rides on the weekends. Charlie feels comfortable bringing his e-bike on the bus or train and locks it to bike racks when running errands or going out to eat. Charlie does not mind riding in the cold: "I like the nip. I like all the seasons. I just go with it." Charlie avoids riding in the rain, as he prefers to "play it safe" and avoid accidents; he also prefers riding when it is light outside.

At home, Charlie stores his e-bike in his apartment. He charges the bike after every ride, so it is ready to go for the next ride. Charlie appreciates the rack and saddle bags that came with the bike and is looking into getting another rack for more storage. He is also considering buying another battery so he can bring his e-bike on longer rides.

Charlie is incredibly appreciative of the e-bike, and frequently commented on the immense impact it has had on his life, particularly his physical health. He talked about how he "feels strong and doing more things." Previously, he had felt stiff and his muscles ached, but with the e-bike he feels as though he has gotten some of his mobility back.

> *"Riding the bike has built up muscles in my legs. It has helped with leg issues. I couldn't walk upstairs and now I can. Before I to take one step at a time and use my left leg to help my right leg up."*
>
> *"For my underlying condition, it's been like a good therapy for me. I can tell the difference…It's done a lot of good for my health. I feel it feel, I actually feel it physically."*
>
> *"I can't get enough. It's a must."*

Moreover, from a mental health perspective, Charlie also noticed a change. He noted that *"as you get older, if you don't use it, you lose it,"* but the e-bike has kept him *"productive and moving and that's why [he'll] never give up riding."*

When asked how likely he is to recommend an e-bike to a friend or colleague, Charlie said he highly recommends e-bikes to anyone, giving it an 8-10 on a scale of 0-10. When asked if there are considerations for why he might not recommend riding an e-bike, he commented that he *"cannot see why anyone would not want to."*

Participant #2 Samantha

Samantha lives in an apartment complex with her husband and two children. She has lived in the building for about ten years and overall thinks it is a good community. The building is geared towards low-income individuals and provides variety of community resources and services to residents. While Samantha believes more things could be done around town to improve safety, she acknowledges that progress is being made *"a little at a time".*

Samantha first learned about the pilot project during a presentation at her apartment. At first, she was hesitant about applying, as she had a beach cruiser at the time and knew there was some stigma regarding e-bikes. However, Samantha was still interested in the e-bike program and decided to give it a chance. When asked what her specific motivations for joining were, Samantha explained:

> *"Transportation was an issue, but wasn't really an issue. I wasn't working at the time, so I didn't always have gas money to get to the store and get around. Something that caught my attention also is that my family does a lot of bike rides and I had a beach cruiser, but I'm asthmatic, so I can go and go, but I get tired. I have a husband who's a mountain biker and then I have my two teens who skateboard, they're young and they have the energy that I didn't have at the time. I'd have to stop and they'd have to wait for me. So I had gotten rid of my bike and follow them in my car. So it was something I couldn't do for my family."*

Samantha did not know much about e-bikes before joining the pilot project and was not thinking of buying one. Upon her acceptance in the pilot, many of her friends told her the e-bike was *a "sissy bike. It's not a real bicycle. You're not getting your stuff out of it"*. However, once she got her e-bike she realized her friends' perceptions were not true:

"Once I got this bike, it just did so many things, I really enjoyed it. Got my exercise, when my asthma kicked in and I couldn't do it, there was that assistance. Let me keep up with my family."

Now, Samantha uses her e-bike for everything: going to the grocery store, exercise, etc. In general, Samantha rides about 7-10 miles a day. Moreover, the e-bike gives her a chance to improve her community, as she provides the program organizer feedback about road conditions and safety. Since receiving the e-bike, Samantha has noticed infrastructure improvements throughout her community; there are now more bike racks and bike lanes, as well as better lights and signs indicating bicycle traffic.

"I'm not only getting my exercise and getting my daily errands, but I'm helping my community by monitoring the roads and the lights that needed to be placed".

Prior to receiving the e-bike, Samantha would drive almost everywhere. She would walk for exercise but used a car for errands and grocery trips. When deciding whether to use her e-bike or drive to her destination, Samantha considers distance, number of errands, and whether she has her kids in tow. If she is by herself and only needs to go to one or two places for a few things, she will use her e-bike. Additionally, weather plays a role. Although it has not rained since she got her e-bike, Samantha does not think she will ride as much in the rain. Also, due to her asthma, she avoids biking during periods of bad air quality. The cold does not bother Samantha, she just puts on a beanie and scarf.

Samantha locks her e-bike on the racks outside stores when running errands and then stores the bike in her apartment when she is at home. The e-bike has a rack and saddle bags that she uses for groceries and errands, as well as a messenger bag she uses as a backpack. Samantha would like to add a water bottle holder to make hydration easier. She charges the bike at least once a week, when the bars go down to level two, as she does not want to be stranded.

When asked about the impact the e-bike has had on her life, Samantha says:

> *"It's awesome. It's so awesome, in the beginning I was iffy, but I would totally recommend it to all. I'm not young I'm 46 years old, so being able to ride a bike and have the assist and being able to go out and continue to do family things. It's awesome, or just to get on it and go to the grocery store or enjoy a bike ride through town. It's just so awesome."*

In terms of mental and physical health, Samantha has seen an improvement. On her old bike, Samantha could no ride as far, she said *"my self-esteem was low. [I'd think] I can't do it, but I want to do it, but I'm not capable of doing it. Now [with my e-bike] I'm able to be like 'hey want to go on a ride, let's go'. I'm a little bit more outgoing, a little bit more out there. I feel like it's helped me".* Moreover, the e-bike has helped with her asthma: "*I do not have to worry about being out of air…getting more exercise, pushing myself a little but more, expand my lungs and breathing techniques"*. She also commented that she has kept her weight stable, which she is proud of.

When asked how likely she is to recommend an e-bike to a friend or colleague on a scale of 0-10, with zero being not all likely and 10 being very likely, Samantha says 10. She elaborated with:

> *"It's better than a vehicle, don't have to waste money on gas…perfect for the busses…you'll save money, doing errands, groceries, going by the post office. The post office doesn't always have parking, but with a bike you just go right up".*

Participant #3 Paul

Paul lives in an apartment complex; he moved to the area right before the pandemic hit. Although he noted that parts of the surrounding area are not as safe and the people are not as friendly as in his previous town, the people in his building and immediate community are nice. Paul also commented on what makes a neighborhood bike friendly; he listed wide roads, slow speed limits, plentiful bike lanes, and ample signage. He noted that although his neighborhood has bike lanes, the speed limit is 45 miles per hour in many places, and there are not sidewalks everywhere. He went on to explain that although he sees some people riding bikes along the levy trail, he does not see as many people on bikes as he would expect. He lamented over society's reliance on cars over bicycles: *"everybody wants to jump into the suburban and burn up the ozone to drive 5 miles. It's sad".*

Paul first learned about the pilot project via flyers posted in his apartment building. Although he had never ridden an e-bike before, Paul loves bikes and became interested. Prior to joining the pilot, Paul rode his mountain bike; he used it for commuting to and from the train to get to work, occasionally meeting up for weekend rides with friends, and riding with his son. Paul had never considered an e-bike, as he heard the negative perceptions and stigma surrounding e-bikes. However, once he learned more about the e-bike and the pedal assist functionality, he became interested. He talked about how he was *"looking for a release…something I could do to achieve those goals…I'm morbid obese and once you get to this weight, no one wants to be obese…goals were anyway I could get off the couch. I still rode my mountain bike…but it only goes so far".* Moreover, he saw the e-bike as an opportunity to reduce his carbon footprint.

Once Paul got his e-bike, *"it was a whole new world [for him], it wasn't cheating".* He loved the pedal assist aspect because while he still needed to move his legs and pedal, the pedal assist helped him get up more hills and ride further than he was previously able to do:

> *"Where I would take my mountain bike and there was a steep hill, that would burn me out to make me want to go home. But my Rad City Bike, I would feel it punch in. That would make me excited…now I'm going further. I'm going further and further".*

Additionally, Paul talked about how he stopped using his car to go to the store or visit friends and family: *"why would I get into a car to do that".* Paul uses the bike every day; over the course of the week, he logs about 120 miles between trail rides for exercise (10-15 miles per day), visiting friends and family (10 miles a few times a week), and running errands (5-10 miles a few times a week). He notes that at least 50-60 miles would have been in a car if not for the e-bike, *"but [he doesn't] even think about the car"* anymore.

Although Paul does not mind riding his bike in the cold nor rain, *"I'm not made out of sugar, I'll ride the bike in the rain. I'm not going to melt",* he does not like riding in wind or bad air quality. When running errands, Paul locks the e-bike to a bike rack using the provided lock and cable; he also feels comfortable knowing the bike has a GPS that can be used for tracking. At home, the e-bike lives in his apartment and he charges it once a day to ensure it never gets down to its last battery bar.

When asked about the benefits the e-bike has had on his life, Paul gets emotional:

> *"That bike, I've been able to take the physical part of my life back. Nobody wants to morbid obese and you know die of a heart attack or have legs cutoff from diabetes…I was stuck in a rut and not getting off the couch...this bike has helped me take my life back…I'm on this bike and I'm outside..."*

Paul goes on to explain what an impact the e-bike has had on his health both physically and mentally. He notes that in three months, his resting heart rate reduced from 79 to 69, his diabetes remained stable, and his blood pressure went down. Over the summer, his bike had a flat tire for a few days and Paul talks about how he felt *"stir crazy"* and was *"going nuts and could not sleep"* because he was not able to ride his bike. Paul indicates that the bike added to the quality of his life and helped him achieve his goals: *"you set goals, personal goals: yeah, I'm going to walk, I'll do this, but I just would have done this [gestures to clicking remote]*".

Paul cannot emphasize enough how much the e-bike has helped him *“take [his] life back…[he] see[s] the numbers going down, it save[d] [his] life”.* In addition to the health benefits, he also likes that the e-bike helps him to reduce his carbon footprint and has provided him the opportunity to see beautiful things. When asked he is to recommend an e-bike to a friend or colleague on a scale of 0-10, with zero being not all likely and 10 being very likely, Paul says 10. He cannot think of anything that would make him not recommend an e-bike; he elaborated with:

> *“Because they’re not only fun, they’re reliable. They can be used to substitute for errands, short distance you would use a car for… They’re made a little heavier, so the ride is really smooth”.*

Participant #4 Jacob

Jacob lives in a senior citizen apartment complex. When talking about his community of Gilroy, Jacob explains that the town has two areas, the north side is mountainous with ranches and trails, while the southside has more businesses, apartments, and lower income homes. He says that it is mostly a farming community with wonderful people, but it is not always a safe area, indicating there have been break-ins in his building. Although Jacob feels safe riding his bike on the trails and in parks, he does not feel safe riding his bike downtown due to traffic and the railroad crossing in the middle of town.

Jacob first learned about the pilot through his social worker. He describes himself as 65 years old with a heart and kidney conditions, diabetes, and depression. He explains that he was nervous at first, because he had never ridden any type of bicycle in his life, let alone an e-bike. Jacob commented that he never previously considered an e-bike due to cost. Despite his trepidation, Jacob applied for the pilot project because he knew he needed to get more exercise:

> *“When I got introduced to project, I was very scared because at my age I had never had ridden a bicycle, let alone electric one. I got a little shaky, but post heart surgery I needed physical activity because I had lost muscle mass”.*

Now that Jacob has the e-bike and has learned how to ride it, he uses it 4-5 times a week. He talks about how he never had the opportunity to have a bicycle *and “at the age of 65, [he] felt like a little kid”*; it has been so much fun for him to ride.

On average, Jacob rides about 8-20 miles at a time, and his rides are strictly for exercise. He says he never intentionally uses the e-bike to run errands, as he is concerned about his own safety riding downtown, as well as the bicycle’s safety being locked up outside. In regard to weather conditions, Jacob brings warm layers if he knows he’ll be riding in the late afternoon; he does not consider air quality to be a major concern, but he avoids riding when it is very hot outside. So far Jacob has not encountered rain, but he plans to avoid rainy rides for the sake of safety. When not in use, Jacob’s e-bike lives in his apartment. He charges it after every use because he wants to make sure it has a charge when he wants to use it. Jacob does not share the e-bike with anyone: *“I will not share this bicycle with nobody. It’s my favorite toy in my entire life. I’m taking care of it dearly”.*

Jacob heavily emphasized the large impact the e-bike has had on his health, particularly his mental health. He talked about how the e-bike has allowed him to overcome *“severe physical and mental obstacles”* and how it has built up his confidence: *“[I have] become more brave... Amazed by changes in* *my mental blockage".* He commented on the strong positive influence the e-bike has had on his state of mind, and *"became [his] source of enjoying day of life".* Moreover, the e-bike has contributed to physical health improvements. He explained how *"this e-bike as main tool for physical exercise"* and *"very soon [he] saw the positive outcomes by getting the exercise [he] needed".* Riding the e-bike helped alleviate some of the negative side effects of his medications helping him to *"not be handicapped by medication".* Additionally, he explains:

> *"It has added days if not months to my life because of the positive impact on my mental state of mind and physical muscle. It has greatly helped me to not only motivate myself to become more physically active, it has encouraged me mentally as well as get excited about life because I have something positive to focus my mind and get out of the isolation and enjoy the sunshine, enjoy the sightseeing, and enjoy the beautiful nature around me. If it was not for the e-bike, I would have missed lots of beautiful places."*

When asked he is to recommend an e-bike to a friend or colleague on a scale of 0-10, with zero being not all likely and 10 being very likely, Jacob says "I recommend 11 to anybody". The e-bike has greatly improved his health and he believes that e-bikes can help older generations to become physically active and an opportunity for fun among younger generations.

Appendix B: Other Models Examined

ADM evaluated simple linear regression models for key variables. This was not used in the final analysis.

The only models with statistically significant outcomes were a simple model of daily dry bulb temperature on distance and duration and a simple model of our categorical temperature variable on distance and duration. These models suggest that higher temperatures are associated with decreased trip distance and duration. A 1°F increase in dry bulb temperature is associated with a .68 mile decrease in e-bike distance ($p = 0.02$) and a 0.15 hour decrease in e-bike duration ($p = 0.002$). Meanwhile, the categorical temperature variable (> 60°F vs, ≤ 60°F) was associated with a 9.82 mile in e-bike distance ($p = 0.024$) and a 2.09 hour decrease in e-bike duration ($p = 0.003$).

Table 6. Simple Linear Regression Model Results

Model Description	Dependent Variable	Independent Variable	Estimate	P value
Simple Temperature	Trip Distance	Daily dry bulb temperature	-.68**	0.020
	Trip Duration	Daily dry bulb temperature	-0.15**	0.002
	Trip Frequency	Daily dry bulb temperature	-0.01	0.105
Simple Categorical Temp	Trip Distance	Categorical temp variable	-9.82**	0.024
	Trip Duration	Categorical temp variable	-2.09**	0.003
	Trip Frequency	Categorical temp variable	-0.14*	0.067
Simple Precipitation	Trip Distance	Precipitation	-2.16	0.234
	Trip Duration	Precipitation	-0.37	0.220
	Trip Frequency	Precipitation	-0.01	0.691
Simple Categorical Precipitation	Trip Distance	Categorical precipitation	-1.43	0.734
	Trip Duration	Categorical precipitation	-0.67	0.335
	Trip Frequency	Categorical precipitation	0.02	0.793
Simple Lag Precipitation	Trip Distance	Categorical lag precipitation	-5.64	0.183
	Trip Duration	Categorical lag precipitation	-1.11	0.112
	Trip Frequency	Categorical lag precipitation	-0.07	0.388
Simple Solar Irradiance	Trip Distance	Solar irradiance	-0.11	0.133
	Trip Duration	Solar irradiance	-0.03**	0.004
	Trip Frequency	Solar irradiance	-0.00	0.165
Simple PM 2.5	Trip Distance	PM 2.5	-0.60*	0.078
	Trip Duration	PM 2.5	-0.10*	0.067
	Trip Frequency	PM 2.5	-0.01	0.436
Simple Categorical Air Quality	Trip Distance	Categorical Air Quality	-1.71	0.781
	Trip Duration	Categorical Air Quality	-0.70	0.490
	Trip Frequency	Categorical Air Quality	-0.01	0.944
*Significant at 90% confidence **Significant at 95% confidence				