Freewheeling: What Six Locations, 61,000 Trips, and 242,000 Miles in Colorado Reveal About How E-Bikes Improve Mobility Options

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INTRODUCTION & MOTIVATION

Mode choices enabled by micromobility can catalyze a shift away from single-occupancy vehicles (SOVs) and improve transportation energy and emissions efficiency. E-bikes and other electrified options particularly have strong potential to upset the status quo of both standard combustion vehicles and nonelectric micromobility. Compared to conventional bikes, e-bikes can accelerate more easily (which may increase perception of safety and comfort in mixed traffic), provide shortened travel times, handle hilly terrain better, and travel longer distances with less effort [1,2].

E-bikes have higher utilization for commute trips in urban environments compared to standard bicycles, which are used more for recreation [3].

	Cargo e-Bike	Crossover SUV
Typical Fuel Fill-Up Cost	\$0.20 @ \$0.20/kW	\$50.75 @ \$3.50/gal
CO2e Emissions/Mile	0 to 3 grams	350 Grams
Annual Ownership Cost	~\$300-500	\$10,728*
Can Carry What You Need?	Usually	Usually
Good Choice for Short Trips?	Yes	Not always

Figure 1. Ownership factor comparisons between e-bikes and automobiles (Illustration by Besiki Kazaishvili, NREL)

Considering growing interest in e-bikes as replacements for other modes and as tools to support transportation energy efficiency and carbon neutrality goals, understanding demographics and trip characteristics of e-bike use is critical.

Shared e-bike systems have led to a wealth of accessibility, operational, and demand forecasting research due to open data agreements with cities as part of their permitting process. However, for personally owned e-bikes, there are few such public data sources, making evaluation of energy and carbon emissions challenging.

DATA & METHODS

The research team collaborated with the Colorado Energy Office, which initiated a mini-pilot and later larger pilot program distributing e-bikes for personal use to six programs across Colorado: Smart Commute (Denver North), Community Cycles (Boulder), City of Fort Collins, Pueblo County, Four Corners (Durango), and the Town of Vail. The programs reported approximately 200,000 combined trips completed on various travel modes across nearly 18 months (July 2021–December 2022).

Data for this study were collected using the NREL Open Platform for Agile Trip Heuristics (NREL OpenPATH), a customizable, open-source phone application, server, and visualization dashboard for collecting travel survey data. Screenshots of the interface are shown in Figure 2.

Sensed trip data summary:

- ~200,000 trips
- 235 unique users
- 92,000 trips labeled with:
  - Confirmed mode
  - Mode replaced
  - Trip purpose.

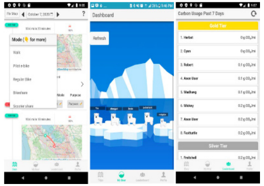

Figure 2. CanBikeCO interface (left to right): trip labels, polar bear, and leader board

The final dataset had 61,496 e-bike trips from 122 users across six programs, traveling 241,906 miles.

Energy and Emissions Calculations

Participants were prompted to enter the *replaced mode* for every e-bike trip, as the mode they would have used if the e-bike was not available. Trip-level input was used with the trip length to compute energy and emissions impacts.

Mode	Energy Intensity	CO2 emission factor	Fuel	Source notes
drove_alone	5170 BTU/PMT	157.20 lb/million BTU	gasoline	Mean per VMT of cars and trucks from the TEDB3. We don't consider the load factor since the user traveled alone
shared_ride	2585 BTU/PMT			drove_alone divided by 2. We can use a load factor of 2 instead of the 1.5 in the TEDB since we know this is a shared ride.
ridehail	7214 BTU/PMT			$car_{pmt} + car_{trip}$. See explanation in Section 3.3
train	1252 BTU/PMT = 0.37 kWh/PMT	1166 lb/MWh	electric	Commuter/light rail. Denver light rail specific number from Figure 7.03 from the TEDB
e-bike	0.022 kWh/PMT			From [28], no rebalancing due to ownership model
scootershare	0.027 kWh/PMT + 0.0041 kWh/trip			Per mile and rebalancing cost from [28]
walk	0	0	human-powered	
regular bicycle				
skateboard				
bikeshare	0 kWh/PMT + 0.09 kWh/trip			Human-powered dock-based shared bicycles; energy only for rebalancing
bus	4560 BTU/PMT	161.30 lb/million BTU	diesel	"Transit bus" from the TEDB; diesel is the most common fuel.
free_shuttle				

Figure 3. Conversion factors for the energy (kWh) and emissions (CO_2) calculations, specified per mode and person mile traveled (PMT).

RESULTS

Figure 4 shows the mode share across all observed trips in the data. Like the mini-pilot, e-bike, car, and shared car were the dominant modes, followed by walking.

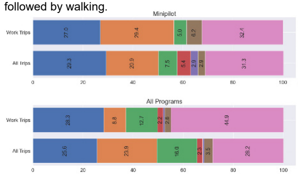

Figure 4. Composition of trip mode shares, shown between all trips and commute trips. Mini-pilot results are shown for comparison.

Figure 5 presents the trip purpose distribution for all programs. Approximately 60% of trips were made for commuting to work or returning home.

Figure 6 shows the mode shares for different programs for work and all trips. For work trips, e-bikes were preferred over car and shared car in all programs but Pueblo. This can be attributed to the **urban form and land use patterns** in Pueblo, as well as the occupational characteristics of the Pueblo program participants. Four Corners (Durango) appears to have the highest share of e-bike trips. All the participants of this program were low-income food service workers, which may explain this high use of e-bikes.

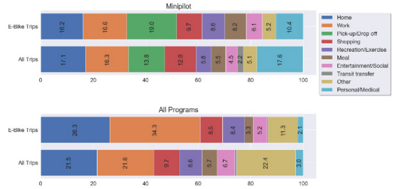

Figure 5. Composition of trip purpose, shown between all trips and e-bike trips. Mini-pilot results are shown for comparison.

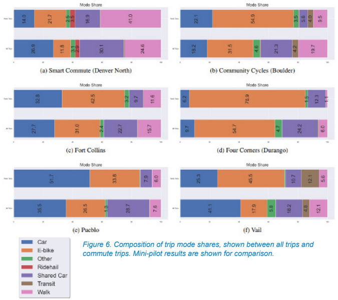

Figure 6. Composition of trip mode shares, shown between all trips and commute trips. Mini-pilot results are shown for comparison.

In the United States, most trips are shorter than 5 miles, and about half of trips are shorter than 3 miles. These distances are within easy range of e-bikes, which have maximum legal speeds between 20 and 28 miles per hour. In examining trips logged, the viability of e-bikes for trips between about 1 and 5 miles is evident. Walking dominates short trips (<1 mile) but is gradually replaced by car and e-bike trips as distance increases (Figure 7). E-bike, car, and shared car evenly split most trips 4–6 miles in length.

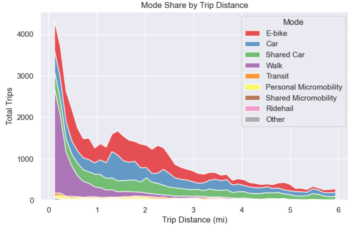

Figure 7. Mode share by trip distance

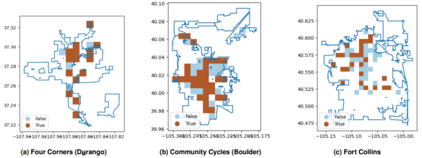

Figure 8. Geospatial analyses of e-bike use in select deployment areas; dark grid squares are where e-bike trips outnumber car trips among participants.

Dividing the program locations into a 1 x 1-km grid and counting the number of trips that started and ended in each grid pixel, there are many locations where participants used e-bikes more than cars. This effect is particularly pronounced in Durango (approximately 80%), Boulder (65%), and Fort Collins (approximately 50%) (Figure 8).

CONCLUSIONS & FUTURE WORK

Commute trips had an almost 17% higher share of e-bike trips as compared to all trips. Among the modes replaced by e-bikes, the mode most frequently replaced was cars at a rate of 34%, with personal micromobility second at 22% (Figure 9). Accounting for the difference in energy intensity between e-bike use and the mode being replaced determines the magnitude of any energy benefit and related emissions impact.

A primary motivation for the CanBikeCO program was to improve mobility options without increasing net energy use. Findings suggest that the net energy impact of e-bikes replacing other modes is strongly positive toward energy savings, estimated at 34.9 MWh over 4 years during the data collection period (Figure 10).

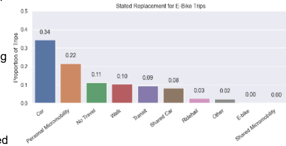

Figure 9. Stated replacement mode for e-bike trips

Replacing motorized modes, primarily SOV replacements, have estimated benefits that greatly outweigh additional energy expended for non-motorized replacement and induced e-bike trips.

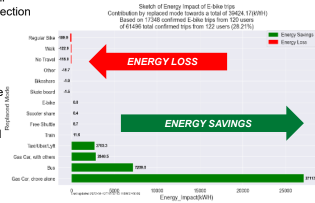

Figure 10. Energy impacts of the modes stated to be replaced by e-bikes

A more robust comparison of sociodemographic and geographical factors impacting e-bike use would be gained by including stated preference data from a highly variable set of choices—for example, by surveying a range of travel costs and times for the same trip and tracking user choice as those parameters change. In a similar vein, this study directly targeted low-income individuals. It is thus difficult to draw conclusions from these data on how income affects personal e-bike usage, which would be a valuable insight to e-bike ridership. Overall, findings suggest favorable energy outcomes from personally owned e-bikes. Future work might build on these findings by testing the impact of personally owned e-bikes on aggregated national data under various adoption scenarios.

REFERENCES

[1] Helaine M. Alessio et al. 2021. "Metabolic and cardiovascular responses to a simulated commute on an e-bike." *Translational Journal of the American College of Sports Medicine* 6 (2): e000155. http://dx.doi.org/10.1249/TJX.0000000000000155.
[2] John MacArthur, Jennifer Dill, and Mark Person. 2014. "Electric bikes in North America: Results of an online survey." *Transportation Research Record* 2468 (1): 123–130. https://doi.org/10.3141/2468-14.
[3] Ziwen Ling et al. 2017. "Differences of cycling experiences and perceptions between e-bike and bicycle users in the United States." *Sustainability* 9 (9): 1662. https://doi.org/10.3390/su9091662.

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