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Electric Bike Use in China and Their Impacts on the Environment, Safety, Mobility and Accessibility

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ABSTRACT

Chinese cities have a long legacy of bicycle use due to relatively low incomes, dense urban development, and short trip lengths. Because of tremendous economic growth resulting in increased motorization and spatial expansion of cities, trips are becoming longer and more difficult to make by bicycle. As a result, electric powered two-wheelers have risen in popularity over the past five years. Touted as environmentally friendly vehicles, they are capable of traveling 40-50 kilometers on a single charge and emit zero tailpipe emissions. However, many cities are banning electric two-wheelers from city streets, citing safety and environmental problems. They do have significant environmental impacts because they use lead acid batteries and electricity, which is predominantly generated from coal power plants, but they also have significant mobility benefits that are seldom considered. This research investigates the tremendous growth of electric two-wheelers in China and compares their environmental and safety impacts to those of alternative modes of transportation; such as traditional bicycles, public transportation, or personal cars. This research also analyzes the benefits of electric two-wheelers in terms of increased mobility and accessibility to opportunities due to their increased speed and range. Electric two-wheelers tend to be more energy efficient and produce less air pollution per kilometer traveled than many other modes. Also, to the extent that they displace car trips, they improve the safety of the transportation system in Chinese cities. While electric two-wheelers do have some problems that need to be addressed (namely excessive lead acid battery pollution), they provide large benefits and can be a successful strategy toward a sustainable transportation future.

1 INTRODUCTION

China's historically dense cities, low incomes and nearly perfect job-housing balance have made most cities very walkable and bikable. China's rapid economic growth and transition to a market economy has caused an increased demand for travel in most Chinese cities. Much of this new demand is met by various motorized modes, particularly public transportation and personal automobiles for those who can afford them. Still, a very high proportion of trips are made by un-motorized or semi-motorized modes. One mode of transportation that has indigenously developed in China is the electric bike. Electric bikes provide higher mobility and range than traditional bicycles and flexibility that cannot be found with public transportation modes. Several researchers have tracked the market development of this mode (Chiu and Tzeng 1999; Jamerson and Benjamin 2004; Weinert, Ma et al. 2006) . This paper will present research results from a study aimed at investigating the main impacts electric bikes have on the transportation system, particularly, safety, environmental performance and mobility.

Electric bike use in China has grown tremendously over the past decade, from several thousand electric bikes sold in the late 1990s to over ten million sold in 2005. Electric bikes fall into two categories in China, bicycle style electric bikes (BSEB), which resemble traditional bicycles and scooter style electric bikes (SSEB), which resemble scooters (Figure 1). This growth rate is unparalleled by any mode in China and most cities have attempted to accommodate this mode to the extent possible. Two national regulations were developed to classify and control electric bikes. The National Road Transportation Law classifies electric bikes as "bicycles" that can operate in the bicycle lane and is not subject to laws governing other motorized modes, such as license, insurance and helmet requirements. The General Technical Standards limits size and speed so that electric bikes can operate safely in the bicycle lane. These standards are poorly enforced and most SSEBs do not adhere to the maximum weight or speed requirements (China Central Government 1999; China Central Government 2004). A recent movement among the industry has been to reclassify electric bikes as Light Electric Vehicles (LEV), which will give them more latitude to develop larger and faster two and four wheeled vehicles (Ni 2005).

Figure 1: Bicycle Style and Scooter Style Electric Bikes (image source: www.forever-bikes.com)

Many cities are facing difficult policy decisions related to electric bike regulation. Several cities, including Beijing, Guangzhou and Fuzhou have or are attempting electric bike bans. Many policy makers feel that electric bikes are too fast to safely operate in the bicycle lane and too slow to safely operate in the traffic lane. Electric bikes are touted as environmentally friendly vehicles by proponents, but they do use electricity generated coal power plants and they also operate on lead acid batteries, introducing large amounts of lead into the environment through production and disposal processes. While electric bikes have perceived costs in terms of environmental impacts and safety, they also have benefits in terms of increased mobility and accessibility to goods and services in the urban area. Moreover, the *net* benefits and costs of electric bikes are relative to the mode that the user would otherwise use if electric bikes were banned. That is, if an electric bike user would otherwise choose a car; there could be net environmental and mobility advantages in choosing an electric bike as an alternative. If they would otherwise choose a bicycle, then electric bike use could result in net environmental advantages, but mobility disadvantages.

This paper will investigate some of these effects in order to inform the development of sustainable transportation policy in Chinese cities. The first part of the paper will discuss user characteristics and mode choice behavior of electric bike users in two case study cities, Shanghai and Kunming. The next part will discuss the results of environmental life cycle analysis performed on electric bikes, public buses, and bicycles. Next, potential safety impacts will be investigated. The following section will discuss the accessibility gains in Kunming compared to bus and bicycle. The final section will discuss the overall sustainability implications of this mode and suggest appropriate ways to develop policy related to electric bikes.

2 ELECTRIC BIKE USER CHARACTERISTICS

In order to identify the environmental and social impacts of electric bike use and regulation, the users must be identified and characteristics of their travel behavior and potential mode shift must be understood. An intercept survey of electric bike and traditional bicycle users was carried out in two cities (Shanghai and Kunming) that identify the important demographic and travel factors (Cherry and Cervero 2007). In Shanghai and Kunming, electric bike users take more trips and travel farther than bicycle users. Interestingly, in Shanghai and Kunming, over 50% of electric bike riders state that they would switch to public bus for their trip if electric bikes were not available. In Shanghai and Kunming, 12% and 21% would switch to bicycle, respectively. A similar study in Shijiazhuang found a different pattern, over 60% of electric bike users would switch to bicycle and only 30% would switch to bus (Weinert, Ma et al. 2007). This difference could reflect the difference in bus service quality between the cities. In all three cities, bus and bicycle dominate as alternative modes, so any analysis should compare these modes together.

3 ENVIRONMENTAL IMPACTS

Electric bikes are extremely efficient and emit near zero emissions at the point of use. This could be considered a positive development as most Chinese cities battle poor urban air quality and the contribution of transportation related pollution is steadily increasing. Electric bikes do use electricity and most of China’s electric power is generated by coal power plants. Moreover, the emission rates from power plants is highly variable across China, as some power grids rely almost exclusively on coal power, while other rely heavily on hydro power. This results in different emission rates depending on where electric bikes are used. Electric bikes also use lead acid batteries, which emit lead into the environment through various production processes. In order to identify the effects of electric bike use in China on energy and the environment, the relative effects must be considered between modes. Lifecycle analyses were conducted on electric bikes, traditional bicycles and buses all produced and operated in China. Impacts from mining, manufacturing, use and disposal are included in the following sections. The following analyses are excerpts from (Cherry, Weinert et al. 2007) and represent an "average" bus (12m Volvo-Sunwin), bicycle, SSEB and BSEB. The next sub-sections discuss the production phase, use phase, and lead pollution of the three modes.

3.1 Production Phase

The production phase includes raw material extraction, processing, manufacturing and assembly. Some processes were omitted for which there was no reliable data or that were too minor to significantly influence the results. Energy and emission intensities (e.g. kWh/kg or grams PM/kg) were calculated from statistical yearbooks and summed across all components of the vehicle (National Bureau of Statistics 2003; National Bureau of Statistics 2004; National Bureau of Statistics 2005; China Data Online 2006). Vehicle material inventories were derived from interviews or websites of vehicle manufacturers. The energy use and emissions of the production processes are reported in Table 1.

Table 1: Energy Use and Emissions of Bus, Bicycle, and Electric Bike Production Phase [a]

	Energy Use (kWh)	CO_2eq (Metric Tonne)	SO_2 (kg)	PM [b] (kg)
Bus	278918	69.77	273.37	1062.61
Bicycle	360	0.09	0.27	1.17
BSEB	1453	0.60	1.56	5.82
SSEB	2119	0.87	2.19	8.16

[a] Production Phases include: Mining, Petroleum Extraction, Refining, Manufacture and Assembly of raw materials that make up the physical vehicle. It does not include impacts of fuel production and use consumed during the vehicle's use phase

[b] PM is only from combustion processes and does not include PM emissions from industrial non-combustion sources.

3.2 Use Phase

The three modes rely on different motive power sources, with different fuels. Each of these sources has different energy efficiencies and different dominate pollutants. Buses burn fossil fuels in internal combustion engines. Electric bikes utilize electricity from a variety of sources, including hydropower, fossil fuel generation, and some nuclear power. China's energy mix is approximately 75% coal, 8% gas, 15% hydro power and 2% nuclear. The energy mix varies significantly by region (Zhu, Zheng et al. 2005), which in turn affects the emission rates. Bicycles are human powered and the energy required to propel a bicycle is derived from food consumption. However, it is unclear if bicyclists consume proportionally more food than non-bicyclists (Ulrich 2006). Bicyclists are generally thinner, indicating that they burn more calories bicycling than they consume specifically for bicycling (Bell, Ge et al. 2002). Table 2 shows emission rates and energy use during the use phase of the vehicle lifecycle.

Table 2: Energy Use and Emissions of Bus, Bicycle, and Electric Bike Use Phase [a] [b]

	Energy Use (kWh)	CO2eq (Metric Tonne)	SO_2 (kg)	PM (kg)	CO[c] (kg)	HC[c] (kg)	NO_X[c] (kg)	Pb[d] (kg)
Bus	6252503	2352	520	2196	7973	728	13513	248.18
Bicycle[e]	615	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BSEB [f]	661	0.51	4.61	0.44	Unkn	Unkn	Unkn	35.50
SSEB [f]	859	0.66	5.99	0.58	Unkn	Unkn	Unkn	50.67

[a] The use phase includes fuel extraction, processing and combustion either through internal combustion engines (bus) or power plant electricity generation (e-bike).

[b] The impacts of a vehicle during the use phase are directly related to the assumed lifespan of the vehicle, informed by interviews with manufacturers. The assumed lifespans are as follows: Bus-1,000,000 km, Electric Bike-50,000 km, Bicycle-20,000 km

[c] The author found no data related to CO, HC, and NO_x emission factors for electricity generation in China

[d] Pb (Lead) pollution is considered under the "use" phase because batteries are used as a type of "fuel" for electric bikes and battery life is significantly influenced by use. Bus batteries are included for comparison purposes and all Lead is emitted during the production, recycling, and disposal phases. This is discussed more in the following section.

[e] Bicycle impacts are largely zero during the use phase and do not consider the energy and emissions required by the production of food. Energy use here reports the total energy required to pedal a bicycle for the total lifespan of the bicycle.

[f] Emissions from electric bikes are related to energy mix in the power grid in which a city is located. The emissions presented here represent all of China's average energy mix, but some cities' electricity is almost exclusively coal generate, while others rely heavily on hydropower

The environmental impact of each mode is very different, due to differences in fuel and propulsion technologies. The *use* phase constitutes about 95% of energy use for buses, 65% for bicycles and 30% for electric bikes. This is partially due to the low useable lifespan of bicycles and electric bikes. In general, most of the impacts of buses occur during the use phase, most of the impacts of bicycles and electric bikes occur during the production phase. One notable exception is the SO_2 emissions from electricity generation.

3.3 Lead Pollution

Lead pollution is the most problematic environmental problem with electric bikes. They use approximately one battery set every 10,000 kilometers. Lead is emitted into the environment through mining and smelting (Phase I), battery manufacturing (Phase II), recycling and disposal processes (Phase III). (Mao, Lu et al. 2006) found that high levels of lead are lost to the environment through all of these processes and even if China could achieve 100% recycling rates of lead acid batteries, up to 30% of the lead would be emitted into the environment as solid, water, or airborne waste. Often these emission sources are in rural or industrial areas. This lead will eventually impact human systems and cause developmental disorders associated with lead poisoning. It is important to note that these are not tailpipe emission. Lead loss rates from each process and various recycling scenarios are presented in Table 3.

TABLE 3: Lead Emissions

		Bus	Bicycle	BSEB	SSEB
	Battery Weight (lead content) kg	90	0	10.3	14.7
I	**Lead Production Loss (% Recycled Material)**				
	0%	28.08		3.21	4.59
	22%[a]	25.80		2.95	4.21
	44%[b]	23.53		2.69	3.84
	60%	21.87		2.50	3.57
II	**Manufacture Loss**				
	4.8%[a]	4.32		0.49	0.71
III	**End-Of-Life Loss (Recycling Rate)**				
	0%	90.00		10.30	14.70
	31%[a]	62.10		7.11	10.14
	62%[b]	34.20		3.91	5.59
	85%[c]	13.50		1.55	2.21
	100%	0.00		0.00	0.00
	Scenarios (Production, Manufacture, EOL)				
	Scenario A (0%, 4.8%, 0%)	122.40		14.01	19.99
	Scenario B (22%, 4.8%, 31%)	92.22		10.55	15.06
	Scenario C (44%, 4.8%, 62%)	62.05		7.10	10.13
	Scenario D (60%, 4.8%, 85%)	39.69		4.54	6.48
	Scenario E (60% 4.8% 100%)	26.19		3.00	4.28

[a] Official Estimates from (Mao, Lu et al. 2006)

[b] Estimates including the informal recycling sector, which is composed of about 300 small enterprises and accounts for about 50% of the lead demand. (Mao, Lu et al. 2006)

[c] Interviews with e-bike manufacturers

During the production phase (Phase I), the lead emissions are related to the amount of virgin material from which a battery is produced. Even if 100% of batteries were recycled, this would only account for 60% of future lead demand because of market growth and lead losses. The official proportion of batteries recycled is 31%, which constitute 22% of the total input into new batteries. It is conceivable that up to 62% of batteries are recycled through informal, unregulated operations, which would increase the composition of new batteries to 44% recycled material (Mao, Lu et al. 2006). If batteries have a 100% recycling rate, about 60% of the lead demand would be met and the other 40% would come from virgin material. Scenarios A-E calculate the emission of lead using different recycling rates. The most realistic case is Scenario C, where 62% of all batteries are recycled; resulting in 44% recycled lead in new batteries and 66% originating from virgin sources. Under this scenario, lead is emitted into the environment that is equivalent to 69% of the battery's lead content, so a battery with 10 kilograms of lead would represent 6.9 kilograms of lead pollution.

3.4 Total Lifecycle Environmental Impact Per Passenger Kilometer

While lifecycle energy use and emissions of buses are much higher than those of electric bikes or bicycles, this is offset their longer lifespan and higher load factors. When comparing impacts, it is important to compare the average emissions per passenger kilometer traveled. Table 4 represents the environmental impact of both the production and use phases, per passenger kilometer traveled on various alternative modes. Cars were included in this table, drawing from literature (Sullivan, Williams et al. 1998) to show the orders of magnitude differences compared to the more sustainable modes. While personal cars represent a small proportion of the alternative mode of electric bike users, the magnitude of a marginal shift to cars could outweigh larger shifts to buses or bicycles. Bicycles outperform all modes from an environmental perspective. Per capita energy use is higher for buses than alternative modes, but buses have lower emissions of certain other pollutants than electric bikes, namely SO_2 and PM. Overall, electric bikes are very energy efficient and have low CO_2 and NO_X emissions, compared to buses and bicycles; and electric bikes are cleaner than cars on all metrics with the exception of Lead (Pb).

Table 4: Lifecycle Environmental Impact Per Passenger Kilometer Traveled[a]

	Energy Use (kWh/100 pax-km)	CO2 (g/pax-km)	SO2 (g/pax-km)	PM (g/pax-km)	CO (g/pax-km)	HC (g/pax-km)	NOX (g/pax-km)	Pb[b] (g/pax-km)
Car[c]	140	306	0.689	0.277	10.06	1.67	1.32	0.299
Bus	13.06	48.4	0.022	0.065	0.159	0.015	0.270	0.005
Bicycle	4.88	4.70	0.014	0.059	Unkn	Unkn	Unkn	0.000
BSEB	6.12	22.08	0.123	0.125	Unkn	Unkn	0.027[d]	0.710
SSEB	8.42	30.44	0.164	0.175	Unkn	Unkn	0.020[d]	1.013

[a] Assuming lifespan of 1,000,000 km, 20,000 km, and 50,000 km and average load factors of 50 pax, 1 pax, and 1 pax for bus, bicycle and electric bike, respectively.

[b] Assuming one battery every 10,000 km for electric bikes and one battery every 3 years or 250,000 kilometers for buses.

Note: some fields are Unknown (Unkn) because data are not available for the emission of these pollutants from production processes and/or power plant emissions

[c] Sullivan et al. 1998-LCA of Generic US Car

[d] Only *Use* phase emission rate, no production processes included

Note: some fields are Unknown (Unkn) because data are not available for the emission of these pollutants from production processes and/or power plant emissions

One important note is the regional nature of the electric bike pollution compared to the local/urban nature of bus emissions. Use emissions from remote power plants are easier to regulate and control than bus emissions. Also, bus tailpipe emissions are emitted into dense urban areas, whereas power plant emissions are generally dispersed throughout rural areas. The public health effects of electric bike emissions from power plants are likely lower than the public health effects of the same emissions out of the tailpipe of a vehicle in an urban area.

Although buses have much larger batteries and thus emit more lead per battery used, they travel more passenger kilometers on each battery than electric bikes. Because electric bikes often require battery replacement, the emission rate is 2-3 orders of magnitude higher than bus lead battery emission rates. While these are not tailpipe emission rates, they do enter human systems and impact public health.

4 SAFETY IMPACTS OF ELECTRIC BIKES

Many cities cite safety concerns when developing electric bike policy. Safety is one of the main reasons that Guangzhou recently imposed a ban on electric bikes (Guangzhou Daily 2006). When Beijing officials attempted to ban electric bikes, they also cited safety concerns, while electric bike proponents posited that electric bikes are safer than other modes (Ribet 2005). Detailed primary crash data are largely unavailable to the public in most Chinese cities. One of the issues raised is the safety of electric bikes in bicycle lanes. They operate faster than bicycles, but slower than cars, so they safely fit in neither lane. Regulations require maximum speeds of 20 km/hr and maximum weight of 40 kg, in an effort to improve safety and make electric bikes more like bicycles, but these standards are poorly enforced and manufacturers are forced to reduce quality to meet low weight requirements. Another issue is conflicts with larger vehicles. While a collision with a motor vehicle will almost certainly result in injury or death of an electric bike user, it is important to distinguish that increased fatalities by a certain mode do not necessarily imply that that mode is dangerous. It could be that electric bikes are simply vulnerable road users. Some 60% of fatalities in China are vulnerable road users (pedestrians and two-wheeled vehicle users).

If electric bike users all shifted to automobiles, perhaps the overall transportation fatality rate would be worse. In 1998, large and small motor vehicles were the cause of 90% of Shanghai’s 24,000 accidents (Zacharias 2002). Vulnerable road users caused the remaining 10% of accidents, but likely paid the highest costs. From the survey data presented in section 2, 30-60% of users would shift to public transit if electric bikes were banned (depending on the city). While public transit riders are generally safe, they would have to walk to transit stops and be exposed to traffic during that walk. From the survey data, a large portion of the electric bike population would shift to bicycle. The risk involved in riding a bicycle could be higher than an electric bike. Now that electric bikes are becoming more prevalent, some data are showing that electric bikes are not as dangerous as one might expect. The China Bicycle Association cited that the 2002 crash rate (crashes/vehicle population) for electric bikes in Shanghai is 0.17%, while the crash rate for cars is 1.6% (Ribet 2005). Of course a crash on an electric bike might be much more damaging than a crash in a car, and minor electric bike crashes could go unreported. Policy makers need to consider not only crash rates, but fatality rates, expressed in terms of fatalities per vehicle kilometer traveled. Table 5 shows 2004 safety data in Zhejiang Province (bordering Shanghai to the south) and Jiangsu Province (bordering Shanghai to the west).

Table 5: Safety Data from Zhejiang and Jiangsu Provinces

	Fatalities[a]	Injuries[a]	Veh pop[b] (million)	Vkt/yr[c] (million)	Fatality Rate (fatalities/m-vkt)
Zhejiang Province					
Passenger vehicle	3731	29884	1.81	18100	0.206
Bicycle	1194	7148	24.9	53012	0.023
Electric bike	129	1660	1.5	3255	0.039
Jiangsu Province					
Passenger vehicle	2153	8180	1.13	11300	0.191
Bicycle	210	507	41.9	89205	0.002
Electric bike	65	538	4.2	10307	0.007

[a] Secondary source Zhejiang Public Security Bureau, Zhejiang Bicycle Association, Jiangsu Public Security Bureau

[b] Zhejiang, Jiangsu and China Statistical Yearbooks 2005

[c] 10,000 vkt/year/veh assumed for motor vehicles and average of Kunming and Shanghai survey data for bicycle (2129 km/bike/yr) and e-bike (2454 km/ebike/yr).

These figures are supported by 2005 data provided by the Kunming Public Safety Bureau citing a crash rate of 0.05% for electric bike users, with five fatalities. Using a conservative estimate of 171,000 electric bikes and 2400 vkt/year results in a fatality rate of 0.012 fatalities/m-vkt.

These data show that, at the margin, electric bikes are slightly more dangerous than bicycles but much safer than cars. The safety impacts compared to riding a bus are unclear, since the bus trip includes walk access. While bus riders might be safe while on the bus, the most hazardous part of the journey is likely the walk to and from the bus stop.

Since motor vehicles are the cause of most accidents and also the most unsafe mode of transport, a shift from bicycle or electric bike to motor vehicle will likely cause a significant increase in transportation related fatalities. Occupants of passenger vehicles will be victims of road fatalities and vulnerable road users will also be victims of more heavy vehicles on the roadway.

Many opponents of electric bike use in cities suggest that electric bikes are unsafe and point to total fatalities as evidence of their safety record. Electric bike users and manufacturers often feel safer than other modes, particularly bicycles. Electric bikes are easier than bicycles to control and maneuver in heavy traffic because of their low center of gravity, acceleration characteristics, and superior brake systems. One serious safety concern is the speed differential between bicycles and electric bikes operating in the bicycle lane. While high electric bike speed might reduce the differential between electric bikes and cars, it might cause conflict in the bicycle lane. More careful analysis is needed to identify the impacts of the speed differential in the bicycle lane.

5 ACCESSIBILITY ADVANTAGES OF ELECTRIC BIKE USERS

All modes of transportation have certain environmental and social costs. A society can tolerate those costs if the benefits are tangible and outweigh the costs. The primary benefit of any transportation mode is the mobility and accessibility increases it provides to the user. If a mode has the same mobility and accessibility characteristics, but higher environmental externalities of an alternative, then this might be seen as an inferior mode. In the case of the electric bike, it certainly emits more pollution and has a slightly worse safety record than a bicycle or a bus, but it provides much higher levels of mobility and thus accessibility in Chinese cities. Mobility and accessibility is dependent upon the urban form, distribution of land uses, and transportation infrastructure. Ease of movement or operating speeds of various modes can describe differences in mobility. Accessibility is defined as the number of opportunities available within a certain travel time. Accessibility can be improved in two ways, by proximity or mobility. Proximity is a function of urban form (i.e. jobs-housing balance) and mobility is determined by transportation system operations and vehicle performance characteristics. Accessibility to jobs has been identified as a major contributor to poverty in developing countries and is an essential impact to consider in the development any transportation policy (World Bank 2002). To identify the mobility and accessibility changes of electric bike users, analyses were carried out in Kunming and Shanghai.

5.1 Mobility Increases

In order to identify the differences in mobility between modes, the average operating speed of electric bikes, bicycles and buses must be identified. The average operating speeds of buses in Kunming and Shanghai is just over 10 km/hr (including stops) (Fudan News 2004; Xinhua Net 2005). In Kunming, this is down from 16 km/hr in 2003 (Kunming University of Science and Technology 2005). Most electric bikes have maximum operating speeds of around 30 km/hr and bicycles can also approach this maximum speed. In order to identify the true mobility increases, average operating speeds (including signal delay) were measured using a floating vehicle methodology, with speed measurements captured with a handheld Global Positioning System (GPS) interfaced with a Geographic Information System (GIS). A speed measurement is collected every second. Under the floating vehicle methodology, the measurement vehicle “floats” in a traffic stream or platoon of vehicles, adopting the average speed and balancing the number of vehicles that are overtaken by the number of vehicles that overtake the measurement vehicle. This results in an approximate median speed distribution. From March to May 2006 speed studies were conducted for bicycles and electric bikes during the morning and evening peak travel periods on all major roads in Kunming and a subset of major commute routes in Shanghai. The speed distributions are shown in Figure 2-3, with the dashed lines indicating average speed, not including stops and the solid lines indicating average speed including stops. There is little difference between the speeds in both cities, implying that these results may be transferable to other cities.

Figure 2: Histogram of Speed Observations in Kunming

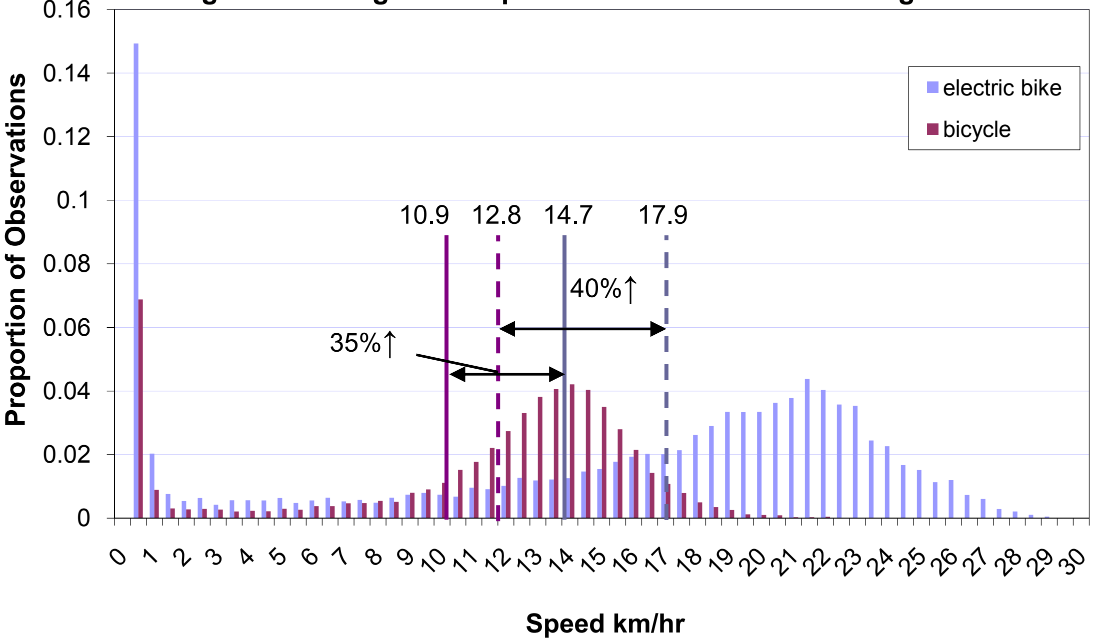
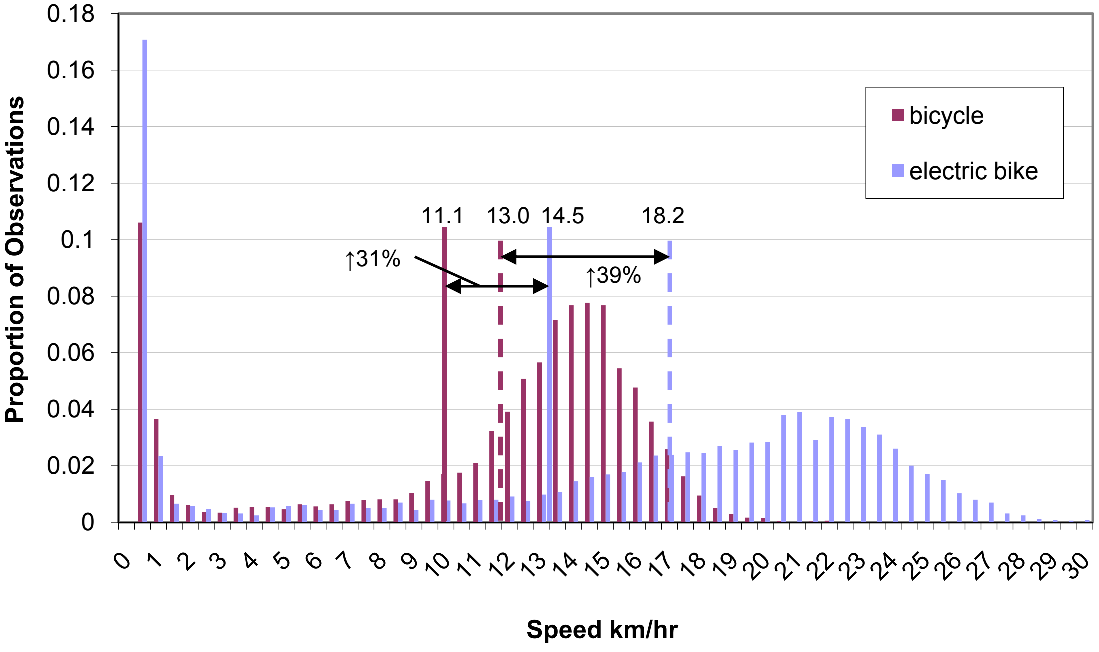


Figure 3: Histogram of Speed Observations in Shanghai



The figures show that electric bike users do in fact travel significantly faster than bicyclists. The average speed (not including stops) is about 18 km/hr, or 40% higher than the average speed of bicycles (13 km/hr). Since electric bikes are faster than bicycles, they spend a higher proportion of their travel time stopped at signals and the overall average speed drops to about 14.5 km/hr and 11 km/hr for electric bikes and bicycles, respectively.

5.2 Job Accessibility Gains: The Case of Kunming

The mobility improvements of electric bikes, represented by average operating speeds, will certainly improve the accessibility of shopping, service and job opportunities in Kunming's urban area. The map presented in Figure 4 illustrates the accessibility differences by different modes within 20 minute travel time from an origin in the city center. Each point represents 3,000 jobs and it is clear that bus access is by far the mode with the poorest accessibility. Within 20 minutes, electric bikes can reach most of the job opportunities in the urban area, bikes reach a smaller proportion and buses reach a very small proportion.

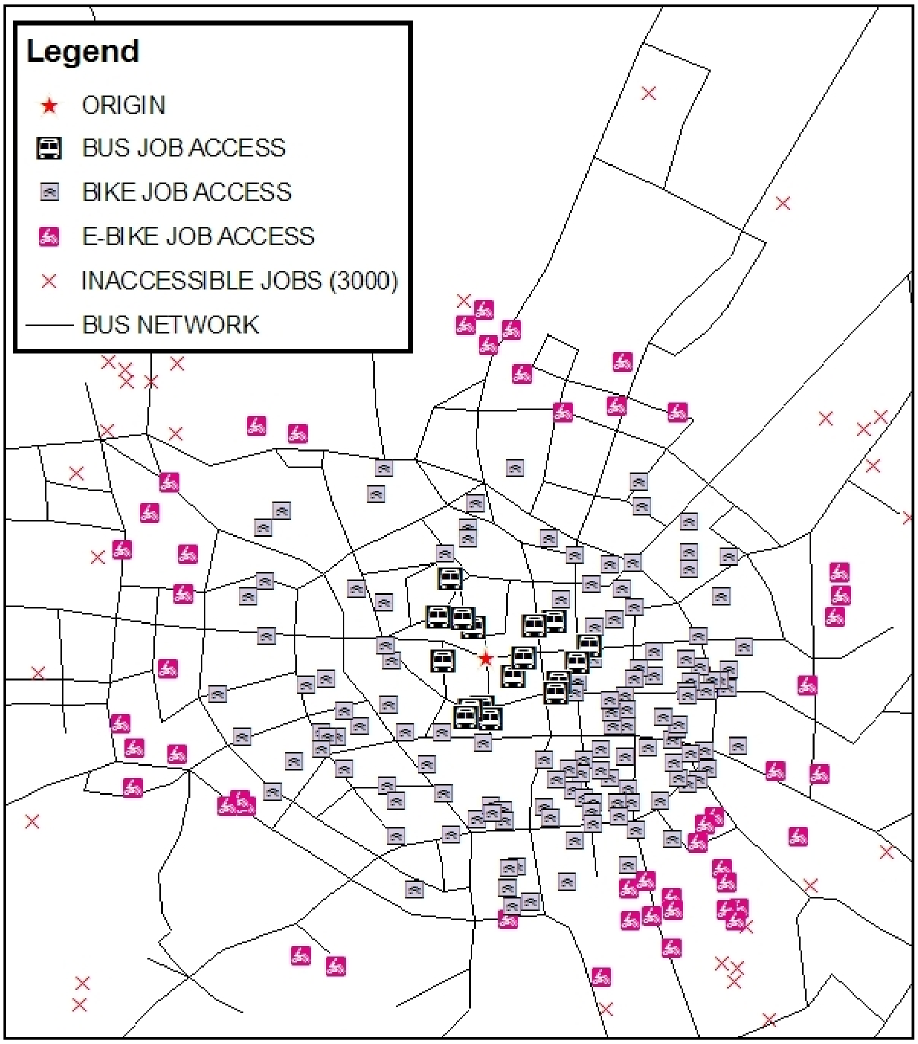


Figure 4: Mode Specific Jobs Access Within 20 minutes of Kunming City Center

Buses operate on a limited network, but could have higher operating speeds on certain corridors. Figure 4 illustrates a bus operating at 10 km/hr and about half of the 20 minute trip time is lost during access, wait, and egress times. As trip distances extend, a higher proportion of the time is spent moving and the bus’ disadvantage in reduced.

While this map is an interesting illustration, to calculate the true accessibility gains of electric bikes in Kunming, one has to calculate the number of jobs accessed at different time increments from all residential locations. To quantify accessibility, an accessibility index has been developed that measures relative accessibility as the proportion of activities reached by competing modes (Cervero 2005). From a given origin, if a traveler can reach 20 jobs by bicycle and 30 jobs by electric bike within a certain time frame, then the accessibility index would be 1.5, or electric bikes provide 50% more accessibility than bicycles. Using GIS tools, accessibility indices are calculated in ten minute increments for all 695 residential locations, each representing 3000 residents. Table 6 shows the accessibility indices for electric bikes compared to buses and bicycles. Bus is included twice, the current 10kph operating speed and the 16kph operating speed of a couple of years ago. This illustrates the drop in accessibility as a result of reduced operating speeds.

Table 6: Job Accessibility Indices Between E-bike and Alternatives

	Cumulative jobs accessed from all residential origins (x3000)					
	10 min	*20 min*	*30 min*	*40 min*	*50 min*	*60 min*
Bicycle	12508	43984	80814	115223	146332	171103
Bus (10kph)	0	3002	17938	42587	68878	99021
Bus (16kph)	0	8672	44753	90246	132313	165930
E-bike	21985	69673	116736	157266	183590	195956
	Accessibility Index					
	10 min	*20 min*	*30 min*	*40 min*	*50 min*	*60 min*
E-bike/Bicycle	1.76	1.58	1.44	1.36	1.25	1.15
E-bike/Bus (10kph)	Inf	23.21	6.51	3.69	2.67	1.98
E-bike/Bus (16kph)	Inf	8.03	2.61	1.74	1.39	1.18

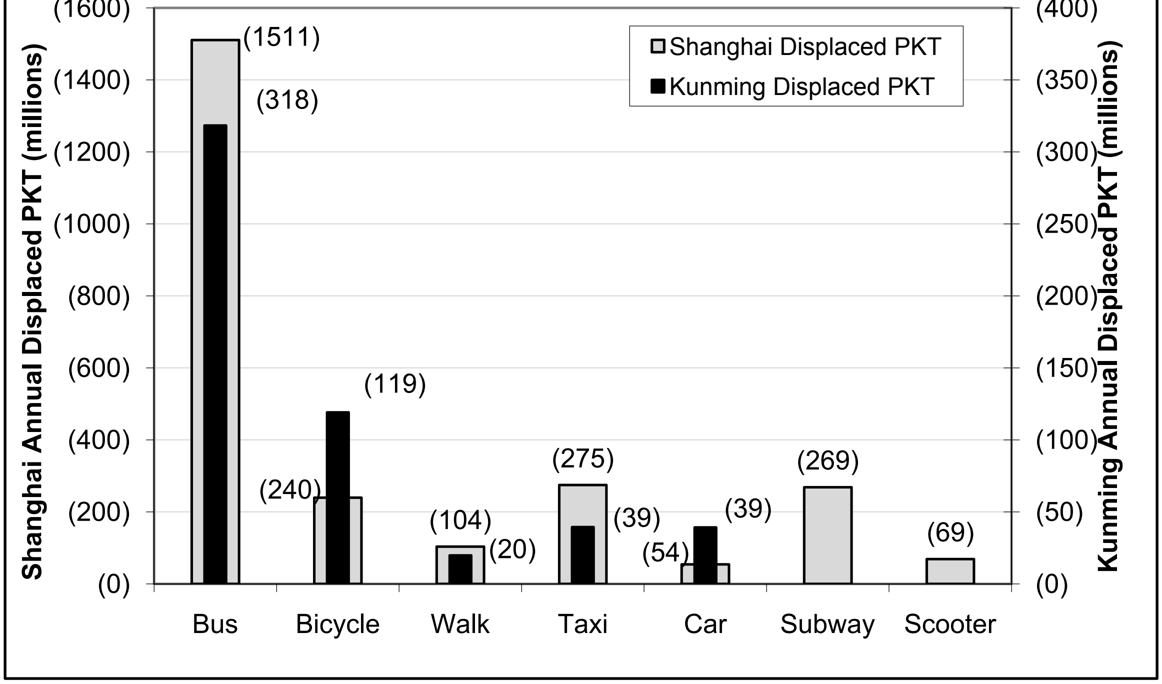
Because of electric bikes’ higher operating speeds and door to door performance, they provide the highest level of accessibility by far. Electric bikes have the highest accessibility advantage over alternative modes for short trips. Notably, electric bikes provide access to 23 times more jobs than buses within a 20 minute travel time. Electric bikes also provide 58% more accessibility to jobs than a bicycle within 20 minutes. This is significant, because 70% of all trips made by bicycle and electric bike fall within this time category. As trips become longer, vehicles begin to reach most of the jobs in the region and the higher speed of electric bikes does not result in increased job access. The jobs reached within 60 minutes are similar across modes (except the slow bus), because all modes can reach most jobs in the region within one hour.

The reduced speed of buses over the past several years has had a major effect on jobs accessibility. In 2003, the job access by bus within 30 minutes was 2.5 times what it is now. This is a significant reduction and reduces the competitiveness of public transportation compared to personal transportation modes.

6 APPLICATION TO CASE STUDIES-KUNMING AND SHANGHAI

The above sections outline relative advantages or disadvantages of electric bike use compared to alternative modes. Suppose that a city were to ban electric bikes, which is the popular form of regulation. The impacts of the ban would depend on the shift to alternative modes. Based on yearly passenger kilometers traveled (PKT) of electric bike users from the surveys discussed briefly in section 2 and electric bike population (1,000,000 in Shanghai and 230,000 in Kunming), the displaced PKT by alternative modes can be calculated. This is presented in figure 5:

Figure 5: Displaced PKT by Mode-Shanghai and Kunming



Applying city specific lifecycle environmental impacts to the distribution of the alternative modes results in net increases and decreases of emissions of various pollutants. The net environmental impacts of an electric bike ban are shown in Table 7, where the yearly displaced emissions are calculated as the net increase or decrease in emission rates between two modes, multiplied by the yearly displaced PKT and summed over all alternative modes. Negative numbers represent decreased emissions if electric bikes were banned; for instance there would be large decreases of lead emissions as a result of an electric bike ban. Positive values represent increases in certain pollutants as a result of an electric bike ban, for instance CO_2 emissions increase if electric bikes are banned.

Table 7: Net Environmental Impact of Electric Bike Ban-Yearly Displaced Emissions						
Impact Per Electric Bike Removed						
	CO_2	NO_X	SO_2	PM	Lead(Pb)	Energy
	(kg/yr)	(g/yr)	(g/yr)	(g/yr)	(g/yr)	(kWh/yr)
Kunming	**121**	**791**	**6.2**	**-149**	**-2050**	**538**
Shanghai	**109**	**773**	**-137**	**-152**	**-1908**	**495**
City-Wide Impact of Electric Bike Ban						
	CO_2	NO_X	SO_2	PM	Lead(Pb)	Energy
	tonne/yr	tonne/yr	tonne/yr	tonne/yr	tonne/yr	GWh/yr
Kunming	**27,648**	**181**	**1.4**	**-34**	**-469**	**123**
Shanghai	**108,546**	**774**	**-137**	**-152**	**-1908**	**495**

While there are increases in some pollutants in the event of a ban, the public health impacts of banning electric bikes would likely be negative, or there would be more air pollution related deaths because the negative public health impacts of increased NO_X emissions would outweigh the positive public health impacts of decreased PM and SO_X emission, based on dose response relationships (Health Effects Institute 2004).

The safety impact can be estimated by mapping the road fatality rates presented in section 4 to the displaced PKT in Figure 5. The small amount of displaced PKT that would otherwise use auto modes (car and taxi) would contribute to an increased number of roadway fatalities if electric bikes were banned from Shanghai or Kunming. Shanghai would see a net increase of 7-50 roadway fatalities and Kunming would a net increase of 5-13 roadway fatalities.

The biggest benefit that electric bike users face is the increased mobility provided by this mode, especially compared to the bus. If electric bikes are banned and all trips are made by the best stated alternative mode, Shanghai and Kunming electric bike users would save 107 and 126 hours of travel time per year, respectively. This time savings could significantly improve the productivity and earning potential of electric bike users.

If electric bikes were banned in Kunming or Shanghai, there would be definite degradations in local public health due to air pollution and roadway safety, mostly from the small portion of users that would shift to automobile modes. In addition, former electric bike users would spend more time traveling, reducing their productivity. The only advantage that is quantified in this paper is the reduction of lead pollution, which could result in significant, but non-local benefits in public health. This implies that cities benefit from electric bike use and the most challenging environmental externality is non-local, so cities should embrace electric bikes and national policy should be developed to mitigate externalities associated with lead production and recycling.

7 COST EFFECTIVENESS OF MOBILITY

Ultimately, sustainable transportation policy for a city would be one that maximizes mobility and access to the city, but minimizes user and social costs. Electric bikes provide high levels of mobility with very low user costs. Moreover, the only negative externality that is worse than all other modes is lead pollution from the use of lead acid batteries. There are alternative battery technologies that can be used, which will increase the cost of electric bike use, but mitigate the lead pollution problem. Nickel Metal Hydride and Lithium Ion batteries are alternatives are more environmentally benign but would increase the purchase price of an electric bike by 20-25%, and increase the operating cost by about 100% (Jamerson and Benjamin 2004). Even with these increased costs, the cost-effectiveness of travel is still lower than any other modes. Figure 6 shows the cost effectiveness of traveling 100 kilometers by various alternative modes, including internal costs (travel time, out-of-pocket costs) and external costs (pollution remediation, safety, public subsidy).

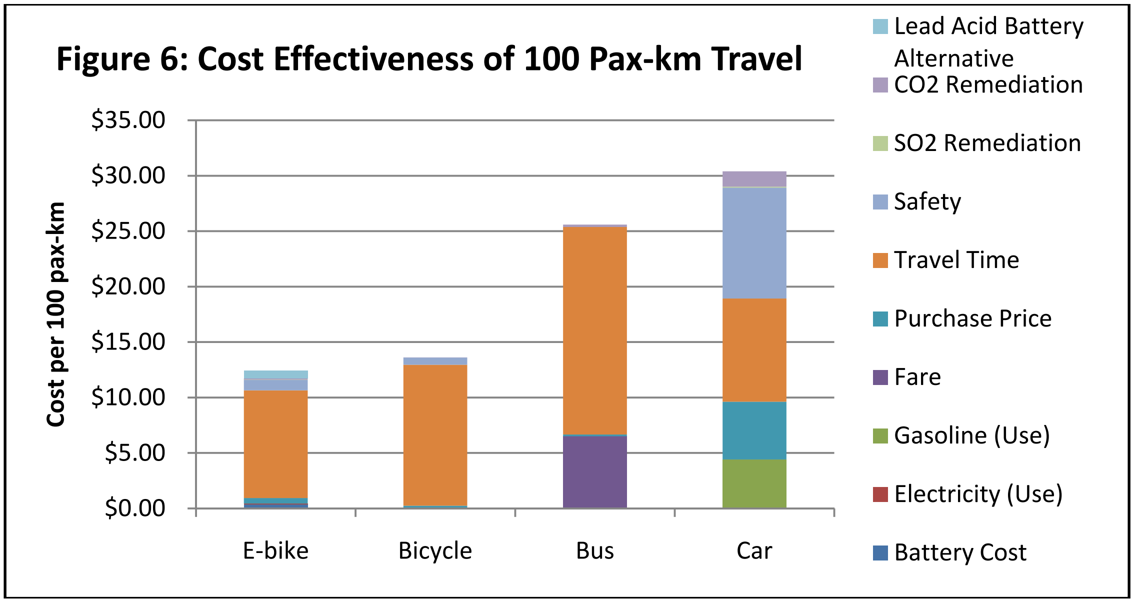


Figure 6: Cost Effectiveness of 100 Pax-km Travel

Notes:

[a] Electricity rate: $0.08/kWh from (Weinert, Ma et al. 2007) and (Metschies 2007)

[b] It is assumed that bus fare covers all operating costs in China, including fuel, maintenance and labor, but not including vehicle capital costs.

[c] Purchase price assumes E-bike, Bicycle, Bus and Car cost $275, $50, $85,000, and $10,000, respectively and have useable lives of 50,000, 20,000, 50,000,000, and 197,000, passenger kilometers respectively (Sullivan, Williams et al. 1998; People's Daily Online 2002; Volvo 2006).

[d] Travel time savings uses speeds and trip lengths derived in from section 5 and average trip lengths from survey data, average hourly wage of ebike user $1.40

[e] Midpoint Value of Statistical Life (VOSL) estimates from (Liu 1997; Feng 1999; Brajer and Mead 2003), about $500,000

[f] Cost effectiveness study of SO_2 remediation (Li, Guttikunda et al. 2004), $1.24/kg. These improvements also have more minor co-benefits of reducing NO_X and PM, not accounted for here.

[g] Approximate value of a metric tonne of CO_2 from Clean Development Mechanism (CDM) framework, $45/kg

[h] Cost of remediating all lead pollution from lead acid battery use in electric bikes by shifting to alternative battery technology (NiMH), $0.69/100km. Not relevant for cars or buses because of different battery technology requirements.

The biggest “cost” of travel is the time spent traveling. For 100 km of travel, bus riders internalize a high cost of travel in the time spent on a slow mode. Car drivers on the other hand spend less in travel, but much of the cost of travel by car is external, mostly safety impacts in which the car driver does not explicitly pay. Considering this subset of costs, electric bikes are comparable with bicycles in providing the lowest cost mobility.

8 CONCLUSIONS AND POLICY RECOMMENDATIONS

The fate of electric bikes in Chinese cities is being closely watched by academics, environmentalists, policy makers, industry and users. Ultimately, any regulatory action on electric bikes affects everyone living in Chinese cities and to some extent affects the global population as China’s transportation trends are having greater influence on resource consumption and climate change. Opponents of electric bikes point to some of electric bikes’ largest impacts when arguing against them, including lead pollution, safety issues, conflict with other modes (namely cars), and “image”. They ignore important improvements in mobility and accessibility that vastly improves the quality of living of users of this low-cost mode. Proponents of electric bikes often defend their safety record and suggest that electric bikes are clean modes of transportation with low noise levels and zero tailpipe emissions. Neither group compares electric bikes to the set of best alternatives to determine the *net* impact. However, both groups make valid points and this research attempts objectively quantify the most significant of these impacts; namely environmental impacts, safety, mobility, and accessibility.

Electric bikes are relatively energy efficient and emit no tailpipe emissions, which is a big advantage in Chinese cities. They do emit pollution from regional power plants, most of which are coal powered. Electric bikes are unique because the emission rate depends on the region in which the electric bike is used. Different regions have different energy mixes, so electric bikes operated in southern China emit less than electric bikes in northern China because of southern China’s relative reliance on hydro power. When compared to buses, electric bikes perform well during the use phase, but when comparing lifecycle emissions, electric bikes do not perform so well on some metrics, particularly PM and SO_2 emissions. Electric bikes have low usable lifespans, so all of the impacts of production of the vehicle are spread over a low number of passenger kilometers (about 50,000). Buses are much larger and have more environmental impacts per vehicle, but those impacts are spread over a large number of passenger kilometers (about 50,000,000). The impacts of the production processes are not borne by the users of the system, but the residents nearby industrial facilities, often in other provinces. Environmentally, bicycles perform best of all modes, with low energy use and greenhouse gas emissions, but comparable NO_X and SO_2 emissions as buses over the lifecycle.

The biggest and most cited environmental problem with electric bikes is lead pollution. The reason lead acid batteries are used in electric bikes is because the externalities of lead pollution are not included in the price. More expensive alternative technologies are available. Instead of banning electric bikes because of lead pollution, a more appropriate policy would be to increase the cost, through pricing mechanisms to encourage the industry to shift to alternative battery technologies, or subsidizing alternative battery technologies.

Electric bikes are not as unsafe as they might seem. They are still small vehicles whose speed is restrained, either through regulation or interaction with other vehicles. Fatality rates are nearly as low as bicycle fatality rates and much lower than cars. It is likely that most of those fatalities are the result of collisions with motor vehicles and most of those collisions are likely caused by motor vehicle. It is important to distinguish between a mode that is unsafe and a mode that is vulnerable. While the initial response might be to ban the vulnerable mode, this would effectively transfer more people to modes that truly reduce the safety of the transportation system. As technology advances and people become more accustomed to electric bikes, safety will likely improve

The biggest benefit of electric bikes is increased mobility and thus accessibility to all types of opportunities in the urban area. Buses have very low levels of mobility, especially for short trips where most of the travel time is spent accessing bus stops and waiting. Electric bikes provide very cost effective personal mobility that is unmatched by any mode in the transportation system. While this mobility might lead to longer trip lengths, and thus more externalities compared to an alternative mode, it also leads to more opportunities of urban low income individuals. Bicycles also perform well because of their flexibility and segregation from congested traffic lanes.

To develop sustainable transportation policy related to electric bikes, one must look at the most significant benefits and costs. The importance of these benefits and costs vary from city to city and policy makers must be willing to accept some costs in order to realize the benefits of any mode. Buses are the most efficient users of road space, provide the highest people moving capacity and low emission levels, but they are inflexible and inappropriate for short trips. Thus, mobility and accessibility are diminished. Bicycles have the lowest environmental externalities, and have medium levels of mobility. Electric bikes have very high levels of mobility and can provide access to opportunities throughout the city, but emit medium to high levels of most pollutants. Since most of the environmental impacts are borne during the production processes, national policy should be developed that mitigates the environmental impacts of production, especially lead acid batteries. While electric bikes perform worse that buses or bicycles on most environmental metrics, they are perhaps the best performing mode of personal motorized transportation. As incomes increase, perhaps electric bikes could delay or replace the use of more environmentally damaging and less safe modes, such as cars or motorcycles. It is important to understand and predict the impact of mode shift now and in the future if electric bikes are no longer in the choice set. Policy makers need to determine local, regional, and national priorities for sustainable development and determine if electric bikes are suitable for meeting those goals. If the priority is to minimize emissions of certain pollutants at the cost of mobility, then electric bikes should be regulated in some form. If policy makers are willing to accept some pollution to increase access to opportunities throughout the city, then electric bikes should be encouraged. To the extent that electric bikes reduce or delay auto trips, they should be encouraged.

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