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Abstract

Electric bikes have captured a large share of trips in many Chinese cities. They provide high levels of mobility and use little energy, two things that Chinese cities need to optimize. However, these benefits come at a cost, particularly emissions from primarily coal power plants and increased lead waste from battery use. Chinese policy makers are struggling with developing appropriate policy that maximizes modal options and mobility and minimizes environmental impacts. Electric bikes use very little electricity and, as a result, emit low levels of pollution per vehicle (passenger) kilometer traveled, even compared to fully occupied buses. The most problematic issue with electric bikes is the use of lead acid batteries that have high lead loss rates during the production, manufacturing and recycling processes. Most other motorized modes also use lead acid batteries, but their rate of use is lower and thus they have lower lead emission rates per kilometer. This research investigates and quantifies the environmental implications of electric bike use in China; particularly energy use, air pollution, solid waste and water use. A framework for policy analysis is presented and potential regulatory mechanisms are discussed. This investigation can inform policy by quantifying environmental impacts so that problematic parts of the life cycle can be addressed, rather than banning electric bikes all together.

Keywords: Life Cycle Analysis, Two Wheel Vehicles, Sustainable Transportation, Lead Pollution

1. Introduction

Chinese cities have been economically developing at a phenomenal rate for the past decade. With this economic development has come an increase in urbanization and motorization, which has increased congestion and reduced urban air quality. Residents in Chinese cities are spending more time and a higher portion of their income on transportation than ever before. As a result, the industry has been developing modes that can provide low cost personal transportation that is fast, flexible and energy efficient. Particularly, electric bicycles and electric scooters have gained in popularity and their use has become widespread in many Chinese cities. In 2005, over 10 million electric bikes were sold in China, which is about 3 times the amount of cars sold.

This growth has caused concern for government officials, transportation engineers and city planners who are attempting to promote development of sustainable and efficient transportation in their cities. The environmental impacts of electric bikes are unclear and the benefits they provide to the transportation system are ambiguous. It is clear that they emit zero tail pipe emissions at their point of use and their overall energy efficiency and emissions per kilometer are lower than gasoline scooters and cars; but most electric bike users might not otherwise use cars or gasoline scooters. The environmental costs of this mode are largely related the alternative mode, should the electric bike be prohibited or restricted. While Taiwan promoted and subsidized electric bikes in the 1990’s (Chiu and Tzeng 1999), several Chinese cities are attempting to regulate or ban electric bikes because of perceived environmental and social costs (Beijing Traffic Development Research Center 2002, Guangzhou Daily 2006). This paper presents analysis of the environmental costs of electric bikes and can help inform policy that will affect millions of users.

This paper begins by summarizing the growth of electric bikes in China. The next section discusses the production processes and some of its energy use and environmental characteristics. The following section discusses the environmental impacts of electric bike use and attempt to quantify the largest sources of energy use and pollution. Initial comparisons are made between alternative modes and finally policy and industry recommendations will be presented based on this analysis.

2. Chinese Electric Bike Description and Industry Growth

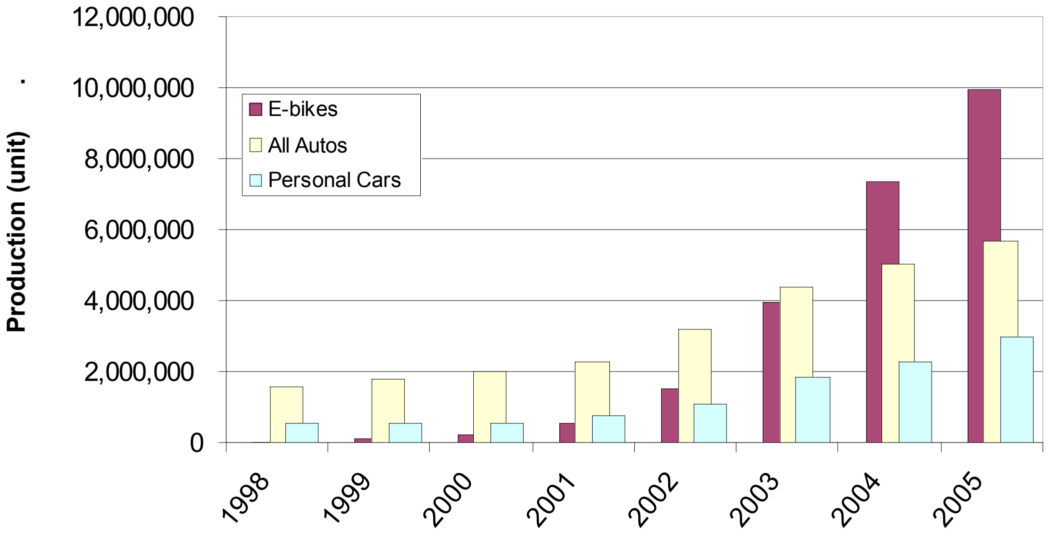
There are hundreds of models of electric bikes manufactured in China and most of them can be categorized as bicycle style electric bikes (BSEB) or scooter style electric bikes (SSEB) (Jamerson and Benjamin 2004) (Figure 1). There is a spectrum of styles between these two types that almost all electric bikes styles fall into. The SSEBs have many of the features of gasoline powered scooters such as horns, headlights, brake lights, turn signals and speedometers. BSEBs are more similar in appearance and function to standard bicycles, including functioning pedals.

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

The technology of each type of electric bike is similar. The main components of an electric bike include a hub motor, controller and battery. Almost all electric bikes in China use lead acid batteries (Jamerson and Benjamin 2004). BSEB typically have 36V batteries and 180-250W motors. SSEB typically have larger 48V batteries and higher powered motors 350-500W. Electric bikes are regulated not to exceed 20km/hr, but many can travel at speeds in excess of that limit and some are advertised to go 40km/hr. Electric bikes have a range of 40-50km on a single charge. In most cities, electric bike are allowed to operate in the bicycle lane and are considered a bicycle from a regulatory perspective (i.e. helmets and drivers licenses are not required).

The Chinese electric bike market has expanded more rapidly than any other mode in the last five to seven years, from nearly zero produced in 1998 to over 10 million in 2005. The annual production of electric bikes is shown in Figure 2. This tremendous growth has occurred in most Chinese cities, but particularly in large cities where motorcycle use is prohibited or heavily regulated, such as Shanghai. It is projected that 18 million electric vehicles will be sold in 2006 (Jamerson and Benjamin 2004) (LuYuan Electric Bike Company 2006) (Yu 2004).

Figure 2: Production of E-Bicycles and Cars for the Domestic Market in China



2.1 Manufacturing

There are hundreds of electric bike manufacturing companies in China, ranging from small assembly factories to large component makers and assembly factories.

The authors visited 5 electric bikes factories in Shanghai, Jiangsu, and Zhejiang province. These factories ranged in production output from 12,000 bikes/year to over 150,000/year. Production capability ranged from simple e-bike assembly (e-bikes are assembled from components produced by other companies off-site), while others produced some main components in-house such as the motor, controller, and frame.

Assembly of an e-bike typically requires one main assembly line where the frame is passed through various stages of assembly until fully assembled. E-bike assembly lines have the capacity to produce one e-bike every 5 minutes. Individual components and processes of the e-bike are produced and performed off-line, such as assembling wiring systems, brake systems and painting.

3. Energy Use and Emissions of E-bike Production Processes

Through interviews with factory owners and publicly reported statistics on energy use and emissions from the manufacture of raw materials, estimates are made regarding the environmental implications of the production process of electric bikes. To avoid the intensive work of calculating the environmental effect of each process in a factory, the overall energy use of all processes was obtained and included in the energy use calculation. Other estimates are made based on the weight of raw materials required to produce an electric bike. Some data are omitted because of lack of availability or the expectation that their impacts are small compared to other impacts.

There are few energy intensive processes associated with the assembly of an electric bike. Almost all energy use is in the form of electricity required to run the machinery of the factory. Perhaps the most energy intensive processes of the assembly process are steel frame construction and painting (large dryers are required). One of the larger e-bike manufacturers in China reports that in 2005, they produced 180,000 electric bikes and used 1,278,545 kWh of electricity, or 7.1kWh per bike. The processes included in this value are frame manufacturing, painting, assembly, vehicle inspection and testing, packaging and general electricity use of the factory. Another energy intensive process is the manufacture of lead acid batteries. A large scale electric bike battery manufacturer was also interviewed regarding energy consumption. The total energy consumption per 12V electric bike battery is approximately 2 kWh, so a 36V battery would require 6kWh and a 48V battery would require 8kWh.

The energy required by the assembly process is very small compared to the energy requirements of the raw material manufacturing, such as steel, plastic, and rubber. The following table is a list of electric bike components, the material they are composed of, the weight, and the energy required to produce those products. National statistics and literature on Chinese steel and lead industries are used to calculate the energy and emission intensities of these materials and combine those to identify total e-bike impacts (China Data Online 2006, Mao, et al. 2006, National Bureau of Statistics 2003, National Bureau of Statistics 2004, National Bureau of Statistics 2005, Price, et al. 2001).

TABLE 1: Material Inventory, Emissions and Energy Use

Weight of Electric Bike Materials (kg/bike)				
	BSEB		**SSEB**	
Total Steel	18.15	46.1%	26.18	46.5%
Total Plastic	5.67	14.4%	15.22	27.0%
Total Lead	10.28	26.1%	14.70	26.1%
Total Fluid	2.94	7.5%	4.20	7.5%
Total Copper	2.55	6.5%	3.46	6.1%
Total Rubber	1.14	2.9%	1.22	2.2%
Total Aluminum	0.52	1.3%	0.58	1.0%
Total Glass	0.00	0.0%	0.16	0.3%
Total Weight	41.25		65.73	
Associated Energy and Emissions of Manufacturing Processes				
Energy Use (tonne SCE)	0.178		0.260	
Energy Use (kWh)	1449		2117	
Greenhouse Gas (Tonne CO2eq)	0.599		0.865	
Air Pollution (SO2) (kg)	1.561		2.194	
Air Pollution (PM) (kg)	5.817		8.158	
Waste Water (kg)	1486		2086	
Solid Waste (kg)	4.457		7.127	

The weight of each material was estimated using weights of typical components of each style of electric bikes. These components were categorized into materials in which there are readily available data on energy use and emissions.

Several assumptions and omissions were made to develop Table 1. This table includes energy and environmental impacts due to the mining and production of steel; and the production of plastic, rubber, lead, copper and aluminum. It does not include the impacts of battery electrolyte production. It also does not include transportation impacts. The values presented in Table 1 should be considered lower bounds. The solid waste only includes solid waste of the production process, not end-of-life waste, which will be discussed later. The numbers above also include the manufacture of replacement parts, specifically five sets of batteries, three sets of tires and two motors over the lifespan of the electric bike.

4. End-of-Life Solid Waste

Because of the relatively recent appearance of electric bikes in the transportation system, little is know about the fate of electric bikes that have become obsolete or non-operational. Many of the earliest models of electric bikes were simply modified bicycles, so if components failed, the electric bike could still operate as a standard bicycle. More recent models would be inoperable if vital components failed. In order to calculate the end of life solid waste, the recyclable components of the electric bike need to be reduced from the total weight. Additionally, replacement parts must be considered; five batteries, three sets of tires and two motors.

Steel, which is the heaviest component of electric bikes also has a high recycling rate, 79.9% in 2002 (National Bureau of Statistics 2003). This is the recycling rate of the entire steel industry, and might not reflect the actual recycling rate of the steel in electric bikes. Likewise the entire copper industry has a recycling rate of 88.5% in 2002. If these materials are recycled and the other materials, including replacement parts of the electric bike enter the waste stream, BSEBs and SSEBs produce 17 and 30 kilograms of solid waste, respectively. This does not include lead waste from batteries, which will be discussed in detail in the following section.

4.1 Lead Acid Batteries

Lead acid battery pollution is one of the most cited reasons for regulation of electric bikes by policy makers. Approximately 95% of electric bikes in China are powered by lead acid batteries (Jamerson and Benjamin 2004). Based on interviews with manufacturers and service facilities, the life span of an electric bike battery is considered to be one to two years or up to 10,000 kilometers. BSEBs typically use 36V battery systems, on average weighing 14 kilograms. SSEBs typically use 48V battery systems weighing 18 kilograms. The lead content of electric batteries is 70% of the total weight, so BSEB and SSEB batteries contain 10.3 and 14.7 kilograms of lead, respectively.

This is perhaps the most problematic issue for electric bikes. This is the same problem that influenced the demise of electric car development in the United States in the mid 1990’s (Lave, et al. 1995). Because of the relatively short lifespan of electric bike batteries, an electric bike could use five batteries in its life, emitting lead into the environment with every battery. Lead is emitted into the environment through four processes: 1) Mining and smelting lead ore 2) Battery manufacturing 3) Recycling used lead and 4) Non-recycled lead entering the waste stream. Loss rates can be expressed in terms of tons of lead lost per ton of battery lead produced for each process. Lave and Hendrickson (1995) cite that, in the USA, 4% (0.04 tons lost per ton of battery lead produced) of the lead produced is lost using virgin production processes, 1% is lost during the battery manufacturing process and 2% is lost during the recycling process. So, a battery composed of 100% recycled lead emits 3% of its lead mass into the environment. A battery composed of 100% virgin material emits 5% of its lead content into the environment. In most industrialized countries, lead recycling rates exceed 90%.

China’s lead acid battery system is very different from industrialized countries. Mao et al. (2006) investigated the Chinese lead acid battery system. They found that 27.5% of the lead content of a battery is lost during the mining, concentrating, smelting and recycling process. This value can be broken down into two components, emissions of concentration and primary refining of virgin ore and secondary refining of recycled scrap, which have emission rates of 31.2% and 19.7%, respectively. In addition to these losses, 4.8% is lost during the manufacturing process. The reasons for these very high loss rates are mostly due to poor ore quality and a high proportion of lead refined at small scale factories using outdated technology. The official recycling rate of lead in China’s lead acid battery industry is 31.2%. Mao et al. (2006) estimate that the actual number is approximately double that, 62% because of informal, small scale recyclers. This value feeds into the proportion of recycled lead in each battery. The authors indicate that on average lead in a battery is made up of 22% recycled lead and 78% virgin lead.

Mao et al. (2006) use data from 1999, before electric bike batteries were a significant share of the market. Several of the values (specifically recycling rate) are estimates and could have changed since electric bikes entered the market. In 2004, electric bike batteries constituted 8% of the market, with car and motorcycle batteries comprising 74% of the total battery population (Unknown 2006). Because electric bikes use batteries quickly, some informal recycling and collection practices have developed. In most cases, an electric bike customer can exchange an exhausted battery for ¼ the price of a new battery, or around 60 RMB (US$7.50), which is a significant amount of money in most Chinese cities. The dead batteries are then collected from service centers and sent to lead recycling factories. This institution could increase the average recycling rate of all lead acid batteries. Interviews with factory owners estimate that 85-100% of electric bike batteries are recycled.

The values in Table 2 are generated using the loss rates presented above. The table outlines lead lost during production in process I, lead lost during battery manufacture in process II, and lead lost by disposal (lack of recycling) in process III. The proportion of recycled material that contributes to the content of a battery is dependent on previous years' recycling rates and the growth rate of lead demand (15-20%)(China Data Online 2006). It is assumed that all new demand is met by virgin lead production. Additionally, all lead that is lost to the environment due to recycling is also met by virgin production. The maximum amount of recycled content in lead acid batteries, assuming 100% recycling rates would be about 60% (considering loss rates from previous time periods and increased demand). Mao et al. (2006) estimate 22% recycled content of lead acid batteries, which could be considered a minimum. The manufacture loss is constant, regardless of source material and the recycling rate is estimated based on the official and estimated values.

TABLE 2: Lead Emissions

		Bus	**Car**	**BSEB**	**SSEB**
	Battery Weight (lead content) kg	90	14	10.3	14.7
I	**Lead Production Loss (% Recycled Material)**				
	0%	28.08	4.37	3.21	4.59
	22%[a]	25.80	4.01	2.95	4.21
	44%[b]	23.53	3.66	2.69	3.84
	60%	21.87	3.40	2.50	3.57
II	**Manufacture Loss**				
	4.8%[a]	4.32	0.67	0.49	0.71
III	**End-Of-Life Loss (Recycling Rate)**				
	0%	90.00	14.00	10.30	14.70
	31%[a]	62.10	9.66	7.11	10.14
	62%[b]	34.20	5.32	3.91	5.59
	85%[c]	13.50	2.10	1.55	2.21
	100%	0.00	0.00	0.00	0.00
	Scenarios (Production, Manufacture, EOL)				
	Scenario A (0%, 4.8%, 0%)	122.40	19.04	14.01	19.99
	Scenario B (22%, 4.8%, 31%)	92.22	14.35	10.55	15.06
	Scenario C (44%, 4.8%, 62%)	62.05	9.65	7.10	10.13
	Scenario D (60%, 4.8%, 85%)	39.69	6.17	4.54	6.48
	Scenario E (60% 4.8% 100%)	26.19	4.07	3.00	4.28

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

[c] Interviews with e-bike manufacturers

In the worse case scenario (A), there is no recycling (all lead is virgin material and all batteries enter the waste stream), a 10.3 kilogram (BSEB) and a 14.7 kilogram (SSEB) emit 14 and 20 kilograms of lead, respectively. As expected, these values are higher than the lead content of the battery (emissions=battery weight + manufacture loss + production loss). More realistic scenarios B and C assume moderate recycling rates reported by Mao et al. (2006). Scenarios D and E assume very high recycling rates as reported by electric bike manufacturers. The actual lead loss is likely between scenario C and D.

A conservative estimate of battery life is up to 300 cycles or 10,000 kilometers. For scenario C, this results in the emission of 710 mg/km of lead for BSEBs and 1013 mg/km of lead for SSEBs. To put this into perspective, a car running on leaded fuel that has 7.9L/100km (30 mpg) fuel economy emits 33 mg/km of lead into the environment (Lave, et al. 1995). Even if 100% of the batteries were recycled, lead emissions would still be an order of magnitude higher than an automobile running on leaded fuel. Cars and buses also use lead acid batteries, but much less frequently. For sake of comparison, bus lead emissions from battery use are included in Table 2, which are significantly higher per battery used, but lower when you consider the amount of passenger kilometers that are accrued on a battery (see Table 5).

5. Energy Use and Emissions during E-bike Operation

Electric bikes are recharged by plugging into standard wall outlets. This is a great advantage because there is no need for dedicated refueling/recharging infrastructure. Most electric bikes have removable batteries and chargers so that they can be transported into an apartment or workplace and recharged during the day or night. With their increased popularity, many apartments or workplaces are retrofitting bicycle parking areas to accommodate electric bikes by providing electrical outlets. Batteries require about 6-8 hours to charge. Charging electric bikes at night can increase the efficiency of the electric power generation network. By recharging batteries overnight, excess electricity production capacity can be used to charge batteries that will be used during the day, when electricity demand is at its peak. This has the effect of smoothing the demand peak and could potentially require little or no electricity generation capacity improvements.

Electric bikes are very cheap and efficient to operate. Most electric bikes have a range of about 50 kilometers on a single charge. Considering an average SSEB with a 350W motor and a 48V 14Ah battery, the energy requirement is 1.3kWh/100km. This is consistent with manufacturer reporting and requirements. Electricity rates in most of China are around 0.6 RMB/kWh, so the cost of operating an electric bike is 0.78RMB/100km or about $0.10/100km; far cheaper than any other motorized mode. The main expense is the purchase of batteries, which is over half of the in-use cost (Jamerson and Benjamin 2004).

Although electric bikes have zero tailpipe emissions, they do use electricity, whose generation emits high amounts of conventional pollutants and greenhouse gases. In China, the energy mix is 75% coal, 15% hydro, 8% gas and 2% nuclear (National Bureau of Statistics 2005). The emission factors of typical Chinese power plants are presented in Figure 3 (Energy Foundation China 2005).

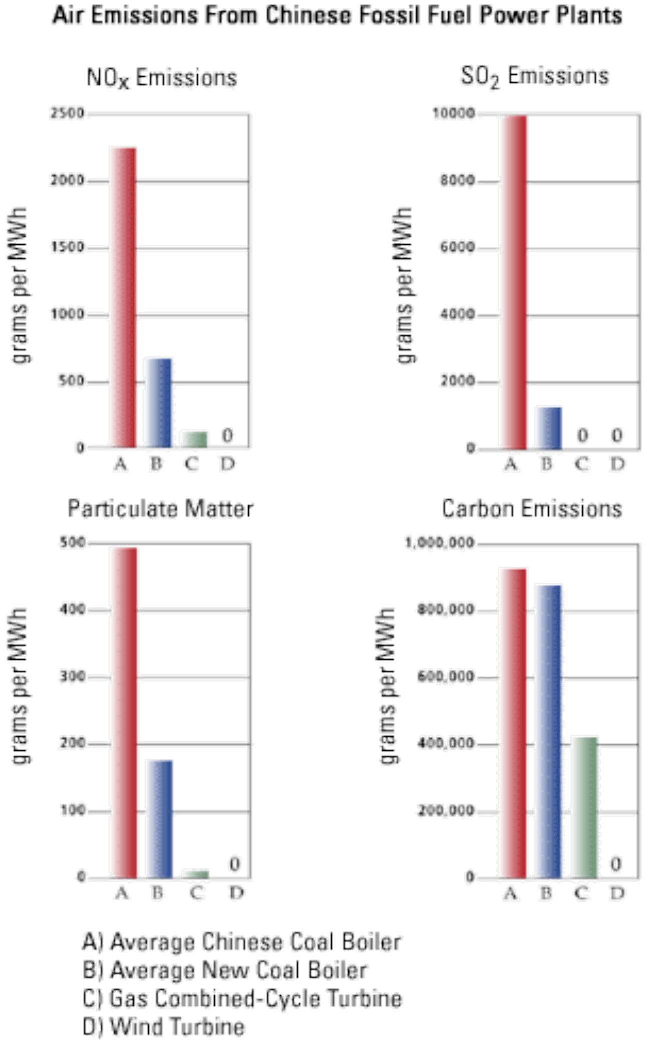


Figure 3: Emission Factors of Chinese Power Plants (Energy Foundation China 2005)

Most of China's electricity is generated by coal power plants, but the actual energy mix of a city depends on its region. China consists of 15 power grids that have limited levels of connectivity (Zhu, et al. 2005). Each of these grids has different energy mixes and each city within a power grid receives most of its electricity from its grid. In order to calculate the pollution due to electricity generation, the energy mix for the grid must be determined. Two examples of cities with high levels of electric bike usage and vastly different energy mix are Kunming and Shanghai. Kunming is located in the Yunnan Provincial Power Grid and Shanghai is located in the East China Power Network, which contains Shanghai Municipality and Zhejiang, Jiangsu and Anhui provinces. The energy mix for the Yunnan Power Grid (Kunming) is 52% hydro power and 48% coal power. The energy mix for the East China Power Network (Shanghai) is 98% coal power and 2% hydro power.

Using the emission factors from Figure 3, energy mix, assuming 1.3kWh/100km, and including an electricity transmission loss factor of 6.6% and a 6.1% in-plant use rate (National Bureau of Statistics 2005) the emission rate per kilometer traveled is generated and presented in Table 3.

Table 3: Electric bike Emissions-SSEB (g km^{-1})

	Kunming	Shanghai	All China
SO_2	0.076	0.156	0.119
NO_X	0.017	0.035	0.027
PM	0.004	0.008	0.006
CO_2	6.961	14.342	11.474

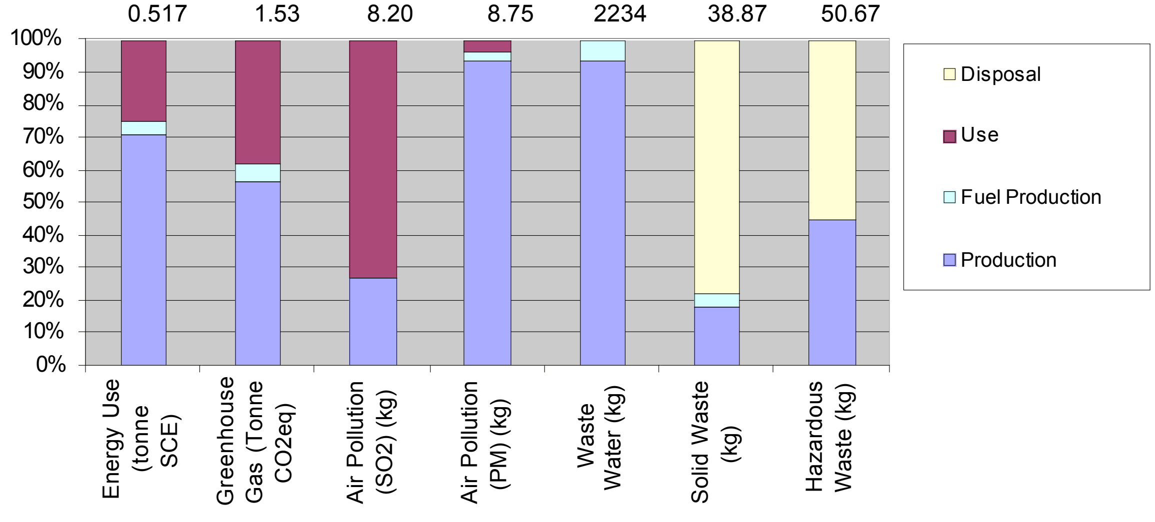
It is worth noting that these emissions, like all emissions from electric bikes are non-local. Power plants are distributed throughout the country and serve specific population centers. Exposure to most pollutants decreases significantly as population centers are located away from thermal power generating stations (Li and Hao 2003, Zhou, et al. 2006, Zhou, et al. 2003). This has significant public health benefits compared to modes with same emission rates in urban areas.

6. Life Cycle Energy Use and Emissions

Based on available data, previous research and evidence from interviews of members of the electric bike industry, life cycle energy use and emissions estimations are made. These estimations have omitted some factors for which there are no data available and that the authors perceive to contribute little to the total energy use and emissions of the electric bike. Keeping that in mind, the values presented in this and previous sections should be considered a lower bound, but include the most energy intensive processes. The total life cycle energy use and emissions include production processes (mining and manufacturing), vehicle use, and vehicle disposal.

Since electric bikes efficiently convert energy (electricity) into movement, a large portion of electric bike energy use and emissions are expended during the *production* phase, particularly on energy intensive processes such as steel and lead production, the two materials that the electric bike uses the most of during its lifecycle. The *use* phase of the life cycle emits high amounts of SO_2 as a result of electric bikes' reliance on high emitting coal power plants and this SO_2 generally oxidizes and contributes to secondary particulate formation. It is important to not that the energy use calculation does not include primary energy from coal to generate electricity, but only energy that is delivered in the form of electricity. This could underestimate the total energy use of the use phase by a factor of three in the case of exclusively coal generated electricity. Figure 4 illustrates the proportion of energy and emissions from each process of a typical SSEB. The values on top of the chart display the total energy use or emission of the total life cycle of a SSEB.

Figure 4: Life Cycle Energy and Emissions-SSEB



This is a very different picture than life cycle inventories of personal cars or buses that produce 80-90% of their environmental impacts during the *use* phase (Danielsson and Gunnarsson 2001, Sullivan, et al. 1998).

7. Modal Comparison

Life cycle impacts of transportation modes are somewhat meaningless by themselves. For the most part, transportation services are a derived demand. People do not demand transportation services for the utility derived from transportation, but they demand access to locations, goods, services etc. When identifying the environmental impacts of any policy decision, energy use and environmental comparisons should be made between the competing alternatives. Since electric bikes provide a transportation service, the assumption is that the users will make the trip by another mode if the electric bike were not available. User surveys show that predominate alternative modes of electric bike users are public buses and bicycles (Cherry and Cervero 2006, Weinert, et al. 2007). In order to identify the *net* environmental impact of electric bikes of comparisons should be made that show the difference between the same trips made by the competing modes of transportation.

7.1 Bus Emissions-Use Phase

The energy use and emissions from the *use* phase of a bus constitute a majority of the environmental impacts of the life cycle. This is because the vast majority of buses in China use diesel internal combustion engines. Local emissions, greenhouse gas emissions and energy use are highly related to fuel efficiency, vehicle power, vehicle loading, operating modes, and fuel quality. Because of these factors, most buses have very different emission per kilometer rates. The diesel powered buses examined here use about 45 liters of diesel fuel per 100 kilometers and represent an “average” public bus in China. The tailpipe emissions are highly related to the sulfur content of the fuel. During combustion, sulfur is oxidized to sulfate, which binds to fine particulates to increase the mass of particulate emissions per kilometer (ACEA, et al. 2002). Likewise, carbon monoxide emission rates increase with increased sulfur content. Conversely, increased sulfur content reduces nitrogen oxide and hydrocarbon emission rates. China imports much of its oil from the Middle East and as a result, the diesel fuel has very high sulfur levels. All of China’s diesel fuel requires a maximum sulfur concentration of 2000 ppm. Major cities like Shanghai and Guangzhou have adopted more stringent 500 ppm standards and Beijing has adopted 350 ppm standards. In 2002, China officially adopted Euro II heavy duty diesel exhaust standards and these are thought to be an optimistic estimate of current bus emission rates. Shanghai and Beijing have more recently adopted Euro III heavy duty diesel exhaust standards. Although the authors found no empirical studies of emission rates of buses operated in China, several dynamometer studies report bus emission rates for Euro II-III emission technology with different fuel qualities (Air Resource Board 2001, Air Resource Board 2002, Embarq 2006, Nylund and Erkkilä 2005). These rates are reported in Table 4.

Table 4: Emission Factors of Urban Buses (g km^{-1})

	Euro II[a]	Volvo-Sunwin[b]	MEX[c]	ARB[d]	VTT[e]	Average Value	Per-Passenger Emissions[f] (g Pax^{-1} km^{-1})
CO	6.66	1.91	19.3	4.43	1.5	7.97	0.159
CO_2		1175	1299		1350	1275	25.490
HC	1.832	0.314	0.156	0.213	0.2	0.728	0.015
NO_X	11.66	11.12	12.27	9.96	14	13.51	0.270
SO_2		0.073				0.073	0.0015
PM	0.416	0.257	1.57	0.888	0.2	0.769	0.015

[a] Euro II emission standards converted from g/kWh to g/km by using conversion factor that is the product of the engine efficiency (%), fuel energy density (kWh/L), and fuel economy of vehicle (L/km). For the Volvo-Sunwin city bus, this is a factor of 1.67. Others report a factor of 1.8 (Nylund and Erkkilä 2005).

[b] (Volvo 2006) Values adjusted from EPD document to reflect lower fuel economy than reported and multiplied emissions by ratio of Euro II standards to Euro III standards to reflect lower fuel quality and emission technology

[c] (Embarq 2006) Used values presented for 12m Volvo city bus using diesel fuel with a sulfur content of 350ppm

[d] (Air Resource Board 2001, Air Resource Board 2002) Used average values for mid-1990's bus fleet in the EMFAC2000 and speed adjusted EMFAC2001 models

[e] (Nylund and Erkkilä 2005) Euro II technology operating on diesel fuel with 50ppm sulfur content. Because of this, CO and PM rates are likely lower than buses in China and NO_x and HC rates are likely higher than buses in China.

[f] Assumes an average load factor of 50 passengers

8. Policy Discussion and Future Work

The electric bike market is expanding at an amazing rate in China. Electric bikes serve the enormous low income populations that are currently using bicycles and public transportation. They provide an alternative transportation option that has much of the mobility benefits of a personal car, but is cheaper to own and operate. Electric bikes operate free of many of the congestion problems faced by motorized modes, making them a very attractive option. They are touted as a clean form of transportation and they do not emit any local pollution, but they could increase demand on energy, they do increase power plant emissions and they introduce a large amount of lead into the environment. Electric bikes are efficient low cost modes and as a result, much of their life cycle energy is consumed during the production process. The operation of electric bikes produces a high proportion of sulfur dioxide air pollution in the life cycle, because of coal electricity generation, but few other major impacts.

When developing a policy on electric bikes, it is important to conduct a comparative analysis with other modes of transportation that are in electric bike riders' choice set. In the two cities investigated, Shanghai and Kunming, the majority of electric bike users are previous bus riders or would use a bus in the absence of an electric bike (Cherry and Cervero 2006). Crowded buses in China have low tailpipe emissions per passenger kilometer, but buses are a somewhat irreducible mode of transportation so at the margin, less ridership does not necessarily reduce overall emissions unless buses are taken off of the road because of reduced demand. The likely scenario is that electric bikes will simply reduce crowding of buses, especially during peak periods and perhaps improve their performance. Table 5 shows compares the emission rates of buses and electric bikes in China.

Table 5: Comparative Emissions of Chinese Buses and E-bikes				
	Use Phase Only			**Full Lifecycle**
	Bus ($g\ km^{-1}$)	**Bus ($g\ pax^{-1}\ km^{-1}$)**	**SSEB (all China) ($g\ pax^{-1}\ km^{-1}$)**	**SSEB (all China) ($g\ pax^{-1}\ km^{-1}$)**
CO	7.97	0.159	Unknown	Unknown
CO_2	1275	25.49	11.47	30.60
HC	0.728	0.015	Unknown	Unknown
NO_X	13.51	0.270	0.027	Unknown
SO_2	0.073	0.0015	0.119	0.164
PM	0.769	0.015	0.006	0.175
Lead (Pb)	0.248	0.005	0.862	0.862

The electric bike performs well in terms of environmental impacts compared to the bus. Sulfur dioxide emissions are considerably higher (because of high sulfur coal), but other pollutants are lower than or on the same order of magnitude of bus emissions. As mentioned before, less bus riders do not necessarily mean lower emissions since bus service will continue to operate, just with fewer riders, but long term effects could lower bus demand to more manageable levels and reduce the need of extra bus service, thus reducing vehicle kilometers traveled and emissions. When calculating emissions from electricity generation, it is important to consider the region in which policy is being developed and the influence of energy mix on the emission rates of electric bikes. The numbers presented in Table 5 represent average emissions from the electricity generation mix of all of China. Different cities have different electricity mixes, which influences the indirect emission rate of electric bikes.

It is slightly unfair to only compare marginal emission rates from the *use* phases of the bus and electric bike lifecycle, since the use phase accounts for the majority of bus impacts and the minority of electric bike impacts. A proper analysis would be to identify the average emission rate over the entire lifecycle of all modes (including bicycle). This is outside the scope of this research, and is an area of future research, which will compare buses, bicycles and electric bikes through most stages of the lifecycle. Since the major environmental impact of electric bike use occurs during the production phase, the average emission rate over the electric bike lifecycle exceeds the average in-use emission rate of buses. Also, emissions from bus tailpipes in dense urban areas likely have higher public health effects than emissions from power plants in less populated areas. Future work will investigate the differential public health effect of these different pollution sources.

The lead (Pb) emissions from battery use reported here are not “tailpipe” emissions for either mode, nor are they really incurred during the use phase, but are important for comparison sake since lead is the most problematic environmental cost for electric bikes. Lead emissions per passenger kilometer are several orders of magnitude higher for electric bikes than for buses primarily because buses use fewer (although heavier) batteries during their lifecycle and get much more mileage from each battery.

Finally, electric bikes provide a certain level of increased mobility compared to buses and bicycles. This mobility has value that can offset some of the environmental costs, balancing relative mobility gains to relative environmental costs compared to alternative modes. Chinese cities are considering regulating and banning electric bikes, with little understanding of alternative modes and environmental implications of shifting to those modes. If the mobility gains do not justify the environmental costs, a form of regulation could include charging a tax to offset the most onerous externalities, specifically a lead battery tax that could act as a “pull” incentive to encourage the electric bike industry to shift to more environmentally friendly, but more costly battery technologies. The revenue from this tax could be used to clean up the lead industry, improving the situation for all sources of lead pollution in China.

Electric bikes have established tremendous market penetration in a very short time and forecasts predict strong growth, in the absence of government intervention. Much of current policy is being made on perceived environmental costs of electric bikes, but there has been little research related to actual environmental costs. This research investigates and quantifies the major environmental impacts of electric bike use in China. Electric bikes are an extremely efficient mode and can provide great benefits to a city. If the goal of a policy maker is to improve low cost mobility in a city or reduce demand on oversubscribed bus service, electric bikes can meet those needs. If those benefits outweigh the environmental costs then the policy maker should encourage or even subsidize electric bike use. If the benefits are not great enough, the policy maker should regulate electric bike use to reduce the externalities. Future research will identify specific mobility gains by mode and perform a comparative cost and benefit analysis between modes in the choice set. Other often cited costs, such as safety, will be included in this analysis in order to take a holistic approach to address this policy question.

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References

ACEA, Alliance, EMA and JMA (2002). World Wide Fuel Charter.

Air Resource Board (2001). Heavy Duty Truck Emission Factors Development-Section 10.

Air Resource Board (2002). Urban Diesel Transit Bus Emission Inventory: Appendix E.

Beijing Traffic Development Research Center (2002). Report on How to Manage the Development of Electric Bicycles in Beijing.

C. Cherry and R. Cervero (2006). Use Characteristics and Mode Choice Behavior of Electric Bikes in China.

China Data Online (2006). http://chinadataonline.org/, Accessed 7-6-2006.

Y. C. Chiu and G. H. Tzeng (1999). The market acceptance of electric motorcycles in Taiwan experience through a stated preference analysis. Transportation Research Part D **4**.

P. Danielsson and C. Gunnarsson (2001). Design for the Environment-What, Why and How at Volvo? RAVEL Conference, 11/14/2001, Stockholm, Sweden.

Embarq (2006). Componente III Pruebas de tecnología de Autobuses.

Energy Foundation China (2005). Electric Utilities. http://www.efchina.org/programs.electricutilities.cfm, Accessed 12/12/2005.

Guangzhou Daily (2006). Guangzhou bans Electric Bikes. Guangzhou Daily. Guangzhou, China.

F. E. Jamerson and E. Benjamin (2004). Electric Bikes Worldwide Reports with 2005 update-10,000,000 Light Electric Vehicles in 2004.

L. B. Lave, C. T. Hendrickson and F. C. McMichael (1995). Environmental Implications of Electric Cars. Science **268**: 993-995.

J. Li and J. M. Hao (2003). Application of Intake Fraction to Population Exposure Estimates in Hunan Province of China. Journal of Environmental Science and Health **A38**(6): 1041-1054.

LuYuan Electric Bike Company (2006). EV in China. http://www.luyuan-ebike.com/mysite/about.files/evchina.htm, Accessed 6-7-2006.

J. Mao, Z. W. Lu and Z. F. Yang (2006). The Eco-efficiency of Lead in China's Lead-Acid Battery System. Journal of Industrial Ecology **10**(1-2): 185-197.

National Bureau of Statistics (2003). China Industrial Yearbook.

National Bureau of Statistics (2004). China Statistical Yearbook.

National Bureau of Statistics (2005). China Statistical Yearbook.

N. O. Nylund and K. Erkkilä (2005). Bus Emission Evaluation: 2002-2004 Summary Report.

L. Price, D. Phylipsen and E. Worrell (2001). Energy Use and Carbon Dioxide Emissions in the Steel Sector in Key Developing Countries.

J. L. Sullivan, R. L. Williams, S. Yester, E. Cobas-Flores, S. T. Chubbs, S. G. Hentges and S. D. Pomper (1998). Life Cycle Inventory of a Generic U.S. Family Sedan Overview of Results USCAR AMP Project.

Unknown (2006). China will change the 2006 global market for lead.

Volvo (2006). Environment Product Declaration-Volvo 8500 Low-Entry.

J. X. Weinert, C. T. Ma, X. M. Yang and C. Cherry (2007). The Transition to Electric Bikes in China: Effect on Travel Behavior, Mode Shift, and User Safety Perceptions in a Medium-Sized City. Transportation Research Record **Forthcoming**.

S. Yu (2004). The E-Bicycle Market and Prospect in China. Shanghai LEV Congress, Shanghai, China.

Y. Zhou, J. I. Levy, J. S. Evans and J. K. Hammitt (2006). The influence of geographic location on population exposure to emissions from power plants throughout China. Environment International **32**(3): 365-373.

Y. Zhou, J. I. Levy, J. K. Hammitt and J. S. Evans (2003). Estimating population exposure to power plant emissions using CALPUFF: a case study in Beijing, China. Atmospheric Environment **37**: 815-826.

F. H. Zhu, Y. F. Zheng, X. L. Guo and S. Wang (2005). Environmental Impacts and Benefits of Regional Power Grid Interconnections for China. Energy Policy **33**(14).