Transport Reviews

ISSN: 0144-1647 (Print) 1464-5327 (Online) Journal homepage: http://www.tandfonline.com/loi/ttrv20

E-bikes in the Mainstream: Reviewing a Decade of Research

Elliot Fishman & Christopher Cherry

To cite this article: Elliot Fishman & Christopher Cherry (2016) E-bikes in the Mainstream: Reviewing a Decade of Research, Transport Reviews, 36:1, 72-91, DOI: 10.1080/01441647.2015.1069907

To link to this article: https://doi.org/10.1080/01441647.2015.1069907

Published online: 30 Jul 2015.

Submit your article to this journal

Article views: 1841

View related articles

View Crossmark data

Citing articles: 27 View citing articles

Full Terms & Conditions of access and use can be found at
http://www.tandfonline.com/action/journalInformation?journalCode=ttrv20

Transport Reviews, 2016
Vol. 36, No. 1, 72–91, http://dx.doi.org/10.1080/01441647.2015.1069907

E-bikes in the Mainstream: Reviewing a Decade of Research

ELLIOT FISHMAN*§ AND CHRISTOPHER CHERRY**

**Institute for Sensible Transport, Suite 13/39 Park Crescent, Fairfield, Melbourne Victoria 3078, Australia; **Department of Civil and Environmental Engineering, University of Tennessee-Knoxville, 321 JD Tickle Bldg, Knoxville, TN 37996-2313, USA*

(*Received 5 November 2014; revised 29 June 2015; accepted 2 July 2015*)

ABSTRACT *Electric bicycles (e-bikes) represent one of the fastest growing segments of the transport market. Over 31 million e-bikes were sold in 2012. Research has followed this growth and this paper provides a synthesis of the most pertinent themes emerging over the past on the burgeoning topic of e-bikes. The focus is* transport *rather than* recreational *e-bike research, as well as the most critical research gaps requiring attention. China leads the world in e-bike sales, followed by the Netherlands and Germany. E-bikes can maintain speed with less effort. E-bikes are found to increase bicycle usage. E-bikes have the potential to displace conventional motorised (internal combustion) modes, but there are open questions about their role in displacing traditional bicycles. E-bikes have been shown to provide health benefits and an order of magnitude less carbon dioxide than a car travelling the same distance. Safety issues have emerged as a policy issue in several jurisdictions and e-bike numbers are now approaching levels in which adequate safety data are able to be collected. Research on e-bikes is still in its infancy. As e-bike usage continues to grow, so too will the need for further research, in order to provide the necessary data to inform policy-makers and industry.*

1. Introduction

There is a growing interest in the bicycle's role in Western urban transport systems (Fishman, 2014; Handy, van Wee, & Kroesen, 2014; Pucher & Buehler, 2012). Combining more bicycle-friendly cities with rapid advances in technology has resulted in a dramatic increase in the purchase and use of e-bikes (MacArthur, Dill, & Person, 2014). Commercially available e-bikes originated in Japan in the early 1980s (Rose, 2012), but technological and cost factors limited market attractiveness until the early 2000s (Jamerson & Benjamin, 2013). Improved battery and motor technology, component modularity, as well as economies of scale improvements have meant e-bikes can now travel longer distances, are faster, and are more affordable than ever. In the past decade more than 150 million e-bikes have been sold (Jamerson & Benjamin, 2013), the largest and most rapid uptake of alternative fuelled vehicles in the history of motorisation.

§Corresponding author. Email: info@sensibletransport.org.au

© 2015 Taylor & Francis

The dramatic growth in e-bike use has several important implications for researchers and practitioners across a variety of fields, including transport planning, engineering, traffic safety, public policy, and the bicycle market. A growing body of research since the mid-2000s examines a wide variety of questions related to e-bikes. This paper sets out to review a decade of research on the burgeoning topic of e-bikes, focusing on emerging themes in e-bike research, as well as the most critical research gaps requiring further study. This paper is organised around several topical themes, with geographic difference included within those theme areas. The following sections describe: categories and definitions, demographics, global markets, purchase motivation, impacts on trip frequency and mode choice, health, environment, and safety. The last section summarises key findings across these topics.

1.1. *Review of the Literature*

Relevant papers were collected via a scan of Scopus and Google Scholar databases, using the terms 'electric bike', 'electric bicycle', 'e-bike', and 'pedelec', conducted between May and November 2014. This review is limited to vehicles that are classified as bicycles in most contexts, they have two wheels, they have a mode of human assistance (even if not required for electric power assistance), and they are relatively low speed. This review includes small electric scooters that are prevalent in China and regulated as bicycles, but does not include electric motorcycles capable of high speeds and without pedal assistance. The next section describes these definitions and regulations that bound this review. Most research published in the late 2000s focused on growth in the Asian market. Most North American and European research has been published in the past five years. The grey literature was also scanned, especially for industry reports, which may not be identified in academic search engines. This review was restricted to English language publications, and emphasises on transport rather than recreational e-bike research.

E-bike research varies by subject and geography. Eastern (e.g. China) studies tend to focus on operations, safety, and market growth revolving around large volumes of e-bikes. Western studies (e.g. North America and Europe) tend to focus on emerging markets, health, and behaviour of nascent markets. This paper focuses on both geographic and topical themes in the literature aiming to answer important questions about safety, mode shift, behaviour, demographics, and technological trends. The paper's purpose is to provide the policy-maker, researcher, and industry participant with a succinct distillation of the latest research concerning e-bike usage, impacts, and trends.

2. Categories, Design, and Performance of Electric Two-Wheelers

A wide variety of e-bikes are commercially available, with varying performance and design characteristics (Cherry, Weinert, & Xinmiao, 2009; Rose, 2012). There is a spectrum of e-bike designs, from bicycle-style e-bikes (BSEBs) to scooter-style e-bikes (SSEBs). This section provides brief definitions, characteristics, and operating performance of different variations of e-bikes.

There are a few clear defining lines between the different e-bike technologies (Figure 1). The underlying technology is the same, with three main components: battery, controller, and motor. The distinctions are mainly related to performance

Figure 1. Range of e-bike designs, from BSEB (a) to SSEB (f).
Source: Luyuan.com

(e.g. speed), cosmetic design, and two main control modes (throttle control or pedal assist). The spectrum of designs from BSEB to SSEB is illustrated in Figure 1, where the top-left (a) vehicle is clearly a BSEB and the bottom right (f) vehicle is clearly an SSEB. The biggest design change occurs between (c) and (d), but both vehicles have common features (i.e. flat footboard and pedals) and the key differences are purely cosmetic. Most pedals on SSEBs do not provide much function and are generally included for regulatory purposes. BSEBs can be solely electric powered or require pedal assistance. The motor power generally ranges from 200 W to 1000 W, weight range from 20 kg to 45 kg, electric range can be as high as 150 km, and speeds are generally less than 45 km/h. The predominant European and North American bike designs include derivatives of Figure 1(a), while China's market includes all styles of e-bike shown in Figure 1. In some Chinese cities, the vast majority of e-bikes fall in the style of vehicles shown in Figure 1(d)–(f), where those styles of e-bikes are relatively rare in North America and Europe. As such, most e-bike research in North America and Europe follows the same themes as bicycle research. Research in China often parallels approaches seen in research of larger powered two-wheelers.

It is important to note that the term 'e-bike' is synonymous with BSEBs and SSEBs in the literature. Unless explicitly stated otherwise, e-bike will be used in this paper to refer to all electric two-wheelers shown in Figure 1. In general, references to e-bikes in the European, North American, and Australian context refer to BSEBs (i.e. the bicycle has functional pedals, but is assisted by an electric motor), consistent with the distinction made by MacArthur et al. (2014). References to e-bikes in the Asian context can include any e-bike shown in Figure 1. With improvements in battery and motor technology, there is a trend for e-bike design to more closely resemble traditional bicycles. In most countries, e-bikes that require pedalling to activate the motor (pedelecs) are legally classified as bicycles. Regulations vary across countries, regions, and even between jurisdictions in the same urban area, with some classifying them equivalent to motorcycles, sometimes intentionally and sometimes because regulations have failed to keep up with technology. A very brief synthesis of complex regulations is as follows, and is presented in Table 1 (adapted from Macarthur and Kobel (2014)). In China, e-bikes are classified, through national technical industrial standards, as bicycles if they weigh less than 45 kg, travel less than 20 km/h, and have pedals. The vehicles are regulated at the factory and regulations can be loosely enforced with most e-bikes exceeding top speed and weight. Some cities impose added local use restrictions. In the USA, e-bikes are regulated by the Consumer Product Safety Commission and are required to travel lower than 32 km/h solely on electric power and have top motor power of 750 W. The European Commission regulates throttle-controlled e-bikes through a type of approvals process, with two main categories, 'powered bicycles' (speed $<$ 25 km/h, motor power $<$ 1000 W) and 'moped' (speed 25–45 km/h, motor power 1000–4000 W). Pedelecs (speed $<$ 25 km/h, motor power $<$ 250 W) are regulated as bicycles. So-called *Speed-pedelecs* (S-Pedelecs) are classified as mopeds and generally require additional licencing and rider regulations. Interested readers are encouraged to refer to Macarthur and Kobel (2014) and Reed Business Information (2014).

3. Demographics of E-bike Users

As with other transport modes, e-bike users are diverse. A number of studies have examined the demographic characteristics of e-bike users in different cities and countries.

3.1. *North America and Europe*

Qualitative research conducted in California found participants (e-bike users in the Sacramento area) were older, better educated, and had higher incomes than

Table 1. Main performance regulations of global e-bike markets (modified from Macarthur and Kobel (2014)

Region	Motor power limit (W)	Top speed (km/h)	Notes
USA	750	32	Operable pedals required. S-pedelecs are allowable above 32 km/h since they require human power. States are allowed to regulate use differently
Canada	500	32	Electric power above 3 km/h
Australia	200–250	–	Operable pedals required. Pedelecs allowed 250 W power. Throttle e-bikes allows 200 W power
European Union (pedelec)	250	25	Pedelecs classified as bicycles
European Union (powered cycles)	250–1000	25	Requires pedals. Generally throttle powered
European Union (moped)	1000–4000	45	S-pedelec must weigh $<$ 35 kg. Motor power must be $<$4 times human power
China	–	12	Pedals required, but often removed by consumer/retailer. Must weigh $<$ 45 kg. Cities can regulate use differently. Inconsistent enforcement of design standards
Japan	250	24	Pedelec only, power tapers from 15 to 24 km/h

the general California population (Popovich et al., 2014). In the first comprehensive North American study of e-bike users (MacArthur et al., 2014), respondents were 85% male, 71% were over 44 years old, and 90% were Caucasian. Some 34% had a graduate degree. Almost all respondents (94%) rode a traditional bike as an adult prior to using their e-bike. An Austrian study (Wolf & Seebauer, 2014) found e-bike owners to be disproportionately older than the general population, and consequently more likely to be retired. In contrast to other studies, Wolf and Seebauer's (2014) sample were more likely to own a car, and have lower educational and income levels than the general population. To some extent this may simply reflect the fact that the Austrian study participants were recruited using traditional mail surveys, whereas most of the other studies reported in this section relied on online surveys, which may attract a younger demographic.

3.2. *Asia and Australia*

Cherry and Cervero (2007) examined traditional and e-bike users in China and found e-bike users had significantly higher income and educational attainment than traditional bike users, suggesting e-bikes are a motorisation stepping stone as China's economy grows. A study on Australian e-bike users (Johnson & Rose, 2013) received 529 respondents, of which 71% were male and just over half were aged between 41 and 60 years. Interestingly, 47% earned considerably more than the population average, and had high car ownership rates (94%) (Australian Bureau of Statistics, 2013). Similarly, respondents had achieved higher levels of education than the general Australian population ($>70\%$ having a tertiary degree). A common weakness in the studies identified above is *self-selection bias* since the survey methods rely on e-bike owner response. More research is required using sampling techniques capturing a more representative sample of the general e-bike user population.

4. Global E-bike Sales

An estimated 31 million e-bikes were sold in 2012 with forecasts to reach 47.6 million by 2018 (MacArthur et al., 2014). E-bike sales data are limited due to definition challenges across jurisdictions and lack of public registration processes. Available data show China accounts for some 93% of global e-bike sales in 2012 (Table 2) and has resulted in approximately twice as many people owning e-bikes as cars (Ji, Cherry, Bechle, Wu, & Marshall, 2012). E-bikes sold in China are almost exclusively throttle-controlled, requiring no pedaling effort on behalf of the rider and often take the form of SSEBs.

4.1. *Asian E-bike Sales*

The rate of e-bike sales growth in China outstrips other personal modes (Ji et al., 2012). Weinert, Ma, and Cherry (2007) identify that credibility to e-bikes was granted through legislation that governed standards for e-bike size and performance characteristics. Moreover, e-bikes were formally classified as bicycles (China Central Government, 2004), and thereby avoided the licencing and helmet regulations associated with some other powered two-wheelers, as well as allowing their use on standard bicycle infrastructure. Perhaps the most

Table 2. Global e-bike sales (estimates)

	2011	2012	2013	2014	2015
China	31 000 000	29 000 000	31 600 000	34 200 000	36 800 000
India	79 000	29 000	39 000	40 000	70 000
Japan	409 000	385 000	400 000	420 000	440 000
Europe	1 234 500	1 483 000	1 759 000	2 016 000	2 318 000
Taiwan	33 500	31 000	33 500	36 000	39 500
SE Asia	50 000	65 000	75 000	80 000	90 000
USA	80 000	100 000	200 000	250 000	300 000
Total	32 886 000	31 093 000	34 106 500	37 042 000	40 057 500

Sources: Taken from Electric Bikes Worldwide Reports (2013), China data from 2011, and China Bicycles Association. Other sources report 2012 ranging from a low of 22 million to a high of 31 million. EBWR concludes 2012 small sales dip with growth to 2015. India data from Naveen Munjal of HeroEco (includes e-bikes and SSEB that are called scooters in India. Japan data from Japan Bicycle Promotion, Institute and Masao Ono Tokyo R&D Co. Ltd. European data from Hannes Neupert, ExtraEnergy. Taiwan data from Victor Ko KYMCO (with e-moped 25 km/h max., 40 kg weight classed as e-bike). SE Asia data from Prakit Lertyaovarit, Bangkok Cycle. The USA data from a survey of 54 companies and total was extrapolated from a small number of survey returns. Several USA companies were reporting strong sales beginning in 2013 suggesting that this may be a 'breakout' year for EB sales in the USA and is reflected in the 2013 to 2015 estimates.
Disclaimer from EBWR: EBWR sales tables are estimates based on information from a variety of sources, domestic/overseas. 2013, 2014, and 2015 numbers are EBWR estimates based on extrapolating trends. There is no official record of EB/ES sales in most countries. A caveat on China EB numbers: these include SSEBs that have pedals, or sometimes only provisions for pedals. These are legally e-bikes in China but also can be regarded as light motor scooters.

pertinent policy prompting the growth in e-bikes in China came from a ban on petrol-powered scooters and mopeds in many cities (Yang, 2010).

E-bike sales in other developing Asian countries have been slow relative to China. Many Asian cities rely on gasoline two-wheelers that have higher speeds and cargo-carrying capacity than most e-bikes. Most Asian cities do not have robust dedicated bicycling infrastructure, which benefits e-bike riders in China. Moreover, lack of marketing, experience, maintenance infrastructure, and higher up-front costs of e-bikes diminish overall market share (Cherry & Jones, 2009; Jones, Cherry, Vu, & Nguyen, 2013). Some Indian and South Asian markets have experienced growth in the industry. Developing Asian countries collectively sold fewer than 200 000 e-bikes in 2012 (Jamerson & Benjamin, 2013).

Japan is a unique case in the Asian e-bike market. As technological innovators, many of the key early e-bike developments (batteries and motors) came from Japanese companies. E-bike sales in Japan are approaching half a million annually, far exceeding all other Asian markets combined, except China (Jamerson & Benjamin, 2013).

4.2. *European E-bike Sales*

Germany and the Netherlands are the two leading e-bike markets in Europe, accounting for 44% and 21% of all EU sales. The next closest countries, in terms of gross sales, are France, Italy, and Austria, each with 5% of EU sales (Association of the European Two-Wheeler Parts' and |Accessories' Industry, 2013). European e-bike sales grew almost 10-fold between 2007 and 2012 (European Two-Wheel Retailers' Association, n.d.). In the Netherlands, 16.9% of new bicycles sold are e-bikes (Association of the European Two-Wheeler Parts' and Accessories' Industry, 2013). The Economist (2013) reports that in France traditional bike sales fell 9% in 2012, but e-bike sales increased 15%.

Table 3 illustrates the total and normalised (per 1000 people) e-bike sales in EU member states (and Switzerland) during 2012. The Netherlands and Denmark have among the highest e-bike sales per capita in Europe, and are also the countries with the highest rate of general cycling (Pucher & Buehler, 2008). In these countries, infrastructure and safety barriers have been overcome and therefore offer the most fertile market for the introduction of the e-bike. In Switzerland e-bike sales accounted for one in every seven bicycles sold in 2011, with total volumes increasing 25% on the previous year. It is now estimated that e-bikes account for just over 5% of the national bicycle fleet in Switzerland (Bike Europe, 2015). Some distortion may exist in these Swiss sales figures, because of cross-border purchases, given favourable currency rates.

4.3. *E-bike Sales in North America and Australia*

E-bikes in North America are somewhat difficult to track because about half of the e-bikes in the market are 'retrofit' kits, where cyclists convert their conventional

Table 3. E-bike sales in the European Union & Switzerland, 2012

Country	E-bike sales	Country share (%)	Population[a]	E-bike sales per 1000 people	Total bike sales (all types)	E-bike percentage of total bike sales (%)
The Netherlands	175 000	21	16 779 575	10.4	1 035 000	16.9
Switzerland	50 000	–	8 039 060	6.2	330 313	15.1
Denmark	30 000	4	5 602 628	5.4	550 000	5.5
Austria	45 000	5	8 451 860	5.3	410 000	10.9
Germany	380 000	45	82 020 578	4.6	3 966 000	9.6
Belgium	25 000	3	11 161 642	2.2	450 000	5.6
Luxembourg	1000	0	537 039	1.9	10 000	10.0
Sweden	11 000	1	9 555 893	1.2	555 000	1.9
Czech Republic	10 000	1	10 516 125	1.0	350 000	2.9
Slovenia	2000	0	2 058 821	1.0	250 000	0.8
Finland	5000	1	5 426 674	0.9	330 000	1.5
Italy	46 000	5	59 685 227	0.8	1 606 000	2.9
France	46 000	5	65 633 194	0.7	2 835 000	1.6
Lithuania	2000	0	2 971 905	0.7	115 000	1.7
Spain	30 000	4	46 704 308	0.6	780 000	3.9
Great Britain	30 000	4	63 896 071	0.5	3 600 000	0.8
Ireland	2000	0	4 591 087	0.4	95 000	2.1
Slovakia	2000	0	5 410 836	0.4	300 000	0.7
Poland	5000	1	38 533 299	0.1	992 000	0.5
Greece	1000	0	11 062 508	0.1	320 000	0.3
EU 27	**854 000**	**100**	**492 448 575**	**1.7**	**18 879 313**	**4.2**

Note: The Bold signifies EU totals and averages.
Source: EU e-bike sales (Association of the European Two-Wheeler Parts' and Accessories' Industry, 2013)
[a]EU Population (European Commission, 2013) and Swiss data (Bike Europe, 2015; Hummel, 2015)
NB: Hungary, Bulgaria, Cyprus, Estonia, Latvia, Malta, and Romania recorded zero e-bike sales and have therefore not been included. Swiss data are from 2013.

bicycle to an e-bike by adding a motor, battery, and controller kit (MacArthur et al., 2014). Combing through customs and import data, Benjamin (2014) estimates that about 200 000 e-bikes were bought into the USA in 2013. No systematic sales data are captured on e-bike sales in Australia (Johnson & Rose, 2013) and therefore the authors are unable to report even an approximate figure on the number of e-bike sales there.

5. E-bike User Benefits and Motivations for Purchase

A key benefit of e-bikes is that they can maintain speed with less effort (Popovich et al., 2014). This helps to overcome some of the most commonly cited barriers to traditional bike riding. Online surveys from 553 e-bike owners in North America (MacArthur et al., 2014) and 529 e-bike owners in Australia (Johnson & Rose, 2013) suggest the increased speed and reduced physical exertion are motivating factors for e-bike purchase, allowing riders to arrive at their destination in a comfortable state (Popovich et al., 2014). Heinen, van Wee, and Maat (2010) review factors associated with bicycle commuting and note that topography, distance, and time limitations can act as barriers to bicycle riding (non e-bike). E-bikes potentially mitigate each of these factors. High temperatures, poor air quality, and precipitation can also push riders towards e-bikes instead of bicycles (Campbell, 2012). There is some evidence that e-bikes provide mobility to those with physical limitations that prohibit cycling (Langford, 2013; MacArthur et al., 2014; Rose, 2012). A consistent theme emerging from interviews with Californian e-bike owners is that the electrical assistance offered by e-bikes had made cycling *fun* again (Popovich et al., 2014). E-bikes enable longer trips for a greater variety of trip purposes (Langford, Cherry, Yoon, Worley, & Smith, 2013). The aforementioned Austrian study found that motivation for e-bike use differs according to trip purpose. For those using e-bikes predominately for transport purposes, the social context (positive to e-bikes) and environmental beliefs are important determinants, whereas for leisure use, health is a more important motivator (Wolf & Seebauer, 2014).

One of the most frequently cited benefits of e-bikes is the potential to act as a replacement for motor vehicle use. This appears to be a key motivation for e-bike purchase from Australia and North America (Johnson & Rose, 2013; MacArthur et al., 2014; Popovich et al., 2014). While much of the research relies on self-reported behaviour and is subject to response bias, research suggests e-bikes may reduce the number of trips taken by car.

6. Travel Behaviour Impacts

Where e-bikes are used as a replacement for motor vehicle trips, potential benefits may arise through reductions in congestion, emissions, and improvements to health through physical activity and lowering local air pollution (Gojanovic, Welker, Iglesias, Daucourt, & Gremion, 2011; Rose, 2012). This section reviews research examining the impacts of e-bikes, in terms of changes in travel behaviour, health, and the environment.

6.1. *Impact on Riding Frequency and Distance*

The previously reported study of e-bike users in North America (MacArthur et al., 2014) found e-bikes may increase cycling participation. Some 55% of the sample indicated they rode weekly or daily prior to owning an e-bike and since e-bike ownership, 93% ride weekly or daily. Despite potential self-selection bias, or short-term novelty of e-bikes, this result would appear too large to discount entirely. E-bike riders in a mixed e-bike and conventional bikeshare system rode 13% farther than their conventional bikeshare counterparts (Langford et al., 2013). A recent Norwegian study randomly selected 66 individuals who were given an e-bike and compared their use to a control group of 160 individuals (Fyhri & Fearnley, 2015). The researchers found cycling trips increased from 0.9 to 1.4 per day and distances increased from 4.8 km to 10.5 km following the provision of the e-bike. The control group showed no increase. The increase among the e-bike group was greatest for women.

Cherry and Cervero (2007) examined e-bike usage in two major Chinese cities, Kunming and Shanghai. E-bike users were found to travel greater distances than those using traditional bicycles (Kunming + 22%, Shanghai + 9%). This study also found travel speed was between 10 and 15% higher for e-bikes, but mean travel times were similar, supporting literature on constant travel time budgets (Marchetti, 1994). A more recent study by the same authors found that e-bike tour distances increased by over 50% between 2006 and 2012 (Cherry, Yang, Jones, & He, 2014).

6.2. *Impact on Mode and Vehicle Choice*

In China, e-bikes are a mainstream mode with dramatic potential to replace other motorised modes. In Kunming, up to 25% of e-bike riders substitute car-based trips and nearly 60% replace public transport (bus) trips. Only a small fraction (7%) of e-bike trips substitute bicycle trips (Cherry et al., 2014). This finding is somewhat consistent across different cities with high-quality transit systems, including Shanghai (Cherry & Cervero, 2007) and Jinan (Montgomery, 2010). By contrast, e-bikes substitute more than 60% of bicycle trips in Shijiazhuang (Weinert, Ma, Yang, & Cherry, 2007).

Two other studies, one in Taiwan (Chiu & Tzeng, 1999) and one in Vietnam (Jones et al., 2013), investigated two-wheeler purchase decisions using the stated preference method. Chiu and Tzeng (1999) found that there is a significant potential for e-bike adoption, especially among women. Jones et al. (2013) found that in the context of stiff competition with traditional motorcycles, relatively low performing e-bikes (i.e. SSEBs) have little chance for high market penetration without substantial performance and price incentives.

A recent evaluation of the first e-bike sharing programme in North America found displaced car trips accounted for 11% of all e-bike trips and 0% of all bicycle trips in that system (Langford et al., 2013). Most of the displaced trips for that programme were walk trips, since it was a campus-based system.

MacArthur et al. (2014) found replacing car trips was cited by almost 65% of respondents as one of their primary reasons for beginning to use an e-bike. In recent Australian research, 60% of respondents to an online survey cited replacing some car trips as a main motivation for e-bike purchase, followed by 49% who said they were motivated by being able to ride with less effort (Johnson & Rose, 2013). Neither of those two surveys documents actual car substitution. The recent Norwegian study referred to earlier found that those provided with an e-bike increased the proportion of trips done by bike from 28% to 48% (Fyhri & Fearnley, 2015).

The research to date on the impact of e-bikes on cycling and car use suggests that e-bikes facilitate more frequent cycling, and trips of greater distance. In North America and Australia and some Chinese studies, e-bikes appear to be used as a replacement for some car trips, although little data exist to understand the precise magnitude of this effect. An ongoing effort by several researchers aims to generate more naturalistic use data that can result in detailed substitution analysis.

7. Health Impacts of E-bikes

Several studies have emerged over the previous decade seeking to measure the impact of e-bikes on health. For the purposes of this review, the meaning of the term 'health' is restricted to improved health from increased *physical activity*.

Simons, Van Es, and Hendriksen (2009) conducted a study in the Netherlands on 12 healthy, physically active subjects, who rode a 4.3 km route three times using an e-bike while measuring physiological performance. The first circuit was undertaken without any power assistance, the second while the e-bike was on eco mode, and the final circuit was completed using the most electrical assistance. The researchers measured physiological variables such as heart rate and oxygen consumption as well as power applied through the pedals. The results showed that all three power settings provided a useful contribution to meeting minimum physical activity requirements. Even with electrical assistance, riders achieved the necessary physical activity intensity (between 3–6 Metabolic Equivalent of Task, or METs[1]) to help reduce the chance of sedentary lifestyle diseases. Not surprisingly, riders under the most powerful assistance setting achieved a higher average speed, which had the effect of reducing overall riding time. While this does have the effect of reducing the duration of physical activity, there is some evidence to suggest that those riding e-bikes tend to spend more time on their bikes than if they did not have an e-bike available (MacArthur et al., 2014).

Gojanovic et al. (2011) set out to examine whether e-bikes were able to provide sufficient physical activity for the user to gain health benefits. Conducted in a hilly part of Lausanne, Switzerland, 18 sedentary participants (12 female) performed four set trips at their own pace. The first trip involved a 1.7 km uphill walk, the second a predominately uphill 5.1 km trip on a conventional bicycle, an e-bike with a standard power settings and with a high power setting. The walking and e-bike (high power setting) resulted in average METs of 6.5 and 6.1, respectively (no significant difference). The e-bike using the standard power setting and the traditional bike resulted in an average MET of 7.3 and 8.2, respectively. These results led the authors to conclude that e-bikes are effective in providing health-enhancing physical activity in a topographically challenging environment.

Similarly, in Sperlich, Zinner, Hebert-Losier, Born, and Holmberg (2012), eight sedentary females were required to cycle at their own pace along a 9.5 km route, once on an e-bike and again on a conventional bike (the order was randomised). Measures of physical exertion were lower when using an e-bike compared to a traditional bike, but the level of enjoyment and speed was higher. Despite the lower levels of physical activity recorded by participants on e-bikes, the energy expenditure was found to be within the range necessary for health enhancement. de Geus, Kempenaers, Lataire, and Meeusen (2013) found positive physiological changes in 20 people following a 6-week period of e-bike use.

Finally, Langford (2013) investigated the 19 users of a bicycle and electric bike-sharing system in Knoxville, Tennessee, USA, on a fixed 4.4 km hilly course using laboratory, GPS, and onboard power metres to measure physical exertion. This research found that energy expenditure per unit time for e-bike trips is 11% less than that for regular bicycle trips and 8% more than for walking trips. Average cruising speed for the three modes was 5.1 km/h for walking, 14.4 km/h for bicycle, and 16.4 km/h for e-bike. Walking trips, while requiring less energy per unit time, take longer to complete and, in this case, require a greater amount of total energy from the user, consistent with other active transport research (Fishman, Böcker, & Helbich, 2015). Considering the performance advantages of e-bikes over the course of the trips studied, the total energy demanded for e-bike trips was 21% less than required for regular bicycles trips and 62% less than for walking trips.

Overall, the clear theme emerging from research on e-bikes and physical activity is that they provide a lower level of physical activity than traditional bikes, but still achieve a level necessary for health enhancement. Moreover, there appears to be some added enjoyment experienced by e-bike users, although these are in experimental conditions, and it is not clear whether enjoyment levels are sustained when using an e-bike on a more consistent basis (i.e. without the novelty factor).

8. Environmental Impacts of E-bikes

The environmental impacts of e-bikes are dependent to a large degree on the mode they replace (Cherry & Cervero, 2007). E-bikes that replace fully non-motorised modes (i.e. walking or bicycle) result in net negative impact on the environment. However, e-bikes are generally very energy efficient because of their light weight and electric drive technology, with most e-bikes consuming less than 2 kWh/100 km, about one-tenth the energy consumption of a small electric car (Ji et al., 2012) and around 40 less[2] carbon dioxide (from power plants) than a standard car travelling the same distance (Ji et al., 2012).

In perhaps the most comprehensive study of its type, Cherry, Weinert, and Xinmiao (2009) assessed the environmental impact of e-bikes in China and compared them with other, competing modes of transport, including environmental costs associated with vehicle production. The results indicate that e-bikes offer a considerable environmental improvement (in terms of most emissions) compared to car use and similar emissions intensity, on a per passenger kilometre basis, to that of bus travel. Moreover, the source of emissions is usually far from population centres, relative to conventional vehicles, so health impacts from conventional pollution are even lower than the emission factors suggest. In China, the health effects of emissions from power plants are lower by a factor of five compared to equivalent tailpipe emissions (Ji et al., 2012). Cherry et al. (2009) conclude that environmental gains occur where e-bikes are used as a replacement for motorised vehicles.

Even where the power sector has among the highest emission factors (e.g. China and Australia), emissions of CO_2 and other conventional pollution from e-bikes are relatively low. Other countries, where e-bikes are gaining popularity (e.g. the Netherlands and Germany), have power sector emission factors that are approximately half those of China and Australia (International Energy Agency, 2012), further reducing emission rates of e-bikes. In summary, the emissions of e-bikes are inconsequential and likely better than the set of alternative modes, even in large numbers and if the power sector is dominated by coal (e.g. China).

It is estimated that 95% of e-bikes in China (mostly 'e-scooters') use lead-acid batteries, though other batteries have been entering the market in recent years (Jamerson & Benjamin, 2013). E-bikes have been a large driver of the increase in lead consumption in China (Van der Kuijp, Huang, & Cherry, 2013) and associated battery manufacturing, recycling, and disposal — processes found to be a major source of environmental contamination. Lead poisoning is associated with a range of adverse impacts on humans including developmental disorders, lowering of IQ, and reduced life expectancy (Sanders, Liu, Buchner, & Tchounwou, 2009). Lithium Ion (Li-ion) batteries can increase vehicle and environmental performance (Rose, 2012; Weinert, Burke, & Wei, 2007) and there is a general trend towards Li-ion batteries. Improving the environmental efficiency of the lead industry and transitioning to different battery technologies will improve the challenges with battery-source pollution.

9. E-bikes and Safety

Safety concerns are perhaps the greatest driver of e-bike regulation globally. An increasing body of research in recent years focused on the safety issues related to e-bikes. Much of this work has taken place in China, where e-bike numbers are high enough to identify safety trends. China-oriented safety studies generally cover both SSEBs and BSEBs. Safety studies outside Asia almost exclusively cover BSEBs.

9.1. *Perceived Safety and Behaviour*

There is some evidence that e-bikes change the perception of safety, compared to riding traditional bikes. In a North American survey of e-bike owners 60% feel safer riding an e-bike and 42% said the e-bike had assisted in avoiding crashes. The reasons given to explain this apparent effect ranged from increased acceleration to clear an intersection, keeping up with traffic, and improved balance at higher speeds (MacArthur et al., 2014). A similar perception-oriented analysis in China found that women feel safer traversing intersections on e-bikes but that there were reservations about increases in e-bike speed in mixed use bicycle lanes (Weinert, Ma, Yang, et al., 2007). Another study found that only about half of e-bike riders thought that riding an e-bike was safer than riding a bicycle (Lin, He, Tan, & He, 2008). A more recent study by Yao and Wu (2012) investigated user behaviour in relation to crash history and found that e-bike riders who have been involved in at-fault crashes generally have lower safety attitudes and risk perception, and are therefore more likely to engage in aberrant behaviour, which includes making errors, impulsive and aggressive behaviour, and rule violation.

In the USA, the improved performance of e-bikes prompts e-bike riders to *state* that they are more likely to obey traffic rules (e.g. stopping at stop signs) compared to a traditional bicycle (Popovich et al., 2014). However Langford, Chen, and Cherry (2015), using GPS equipped e-bikes and bicycles in a bikesharing system, found that e-bike and bicycle riders behave very similarly at traffic control devices, violating at about equal rates.

9.2. *Empirical Analyses of E-bike Safety Behaviour in China*

There are few opportunities for extensive e-bike crash analysis outside of China. Within China, most safety research has focused on two key approaches to analysis (1) conflict and aberrant behaviour, generally at intersections using video-based observations and (2) crash and injury data from hospital and crash records.

The main articles that investigate e-bike-related behaviour at intersections generally arrive at the same conclusion; intersections have high levels of aberrant behaviour among all road users and e-bike riders tend to be worse than other road users. One of the first studies (Wu, Yao, & Zhang, 2012) that investigated intersection behaviour found that red light running among cyclists and e-bike riders in China was very high (56%) and that many demographic and situational factors contributed to red light running. Across all categories, e-bike riders ran red lights at a higher rate (63%) than bicyclists (50%) but controlling for confounding variables, the authors could not find a statistical difference between e-bike and bicycle red light running behaviour that could be owed to the vehicle type itself. They suggest several possible reasons for this, including the general acceptance of red light running, little legal differentiation between bicycles and e-bikes, and a small sample that simply could not statistically account for the differences. A similar study by the same authors (Zhang & Wu, 2013) investigated the effect of installed sun shades on red light running (i.e. the hypothesis being that riders are more likely to stop to wait under the shades). This time, with a larger sample, they found that e-bike riders were 1.8 times more likely to run the red light than bicyclists, controlling for other variables. One possible explanation is that e-bike performance characteristics entice riders to take more risks at intersections. Beyond simply running red lights immediately, e-bike riders also wait for a shorter duration at a red signal phase before ultimately running the red light, controlling for other variables (Yang, Huan, Abdel-Aty, Peng, & Gao, 2015).

Du et al. (2013b) observed over 18 000 e-bike riders at multiple intersections in Suzhou with the aim of identifying unsafe riding behaviour. They focus on a host of unsafe riding behaviour (even if not prohibited by regulation) that include talking on the phone, helmet use, wrong-way riding, riding outside the bicycle lane, and red light running. The authors found a relatively high rate of risky behaviour, with one in four infringing on intersection regulations, although the red light running rate was only 5% and consistent with studies of general bicycle riders (Johnson Newstead, Charlton, & Oxley, 2011). It is unclear however if this rate is of all e-bike riders or only those facing red lights.

Bai, Liu, Chen, Zhang, and Wang (2013) focused on video conflict analysis at intersections. This study is the first that acknowledges high amounts of rule-breaking behaviour (inputs) of all road users and focuses on outcomes (i.e. near-misses). The authors categorised risky behaviour, similar to earlier studies, and found that about 7% of e-bike riders violated red lights, slightly more than bicyclists. Categorising 16 types of conflicting movements, they found that automobile drivers failing to yield are responsible for over three-quarters of the conflicts. E-bike and bicycle riders are about evenly responsible for the other quarter of the conflicts. However, the conflict rates are higher with e-bikes than bicyclists, regardless of fault.

E-bikes in China share bicycle infrastructure, resulting in some concerns regarding differential speed performance. Three studies investigated speed and all found e-bikes cruising speeds were 40–50% faster than bicycles despite share facilities (Cherry & He, 2010; Lin et al., 2008; Yang et al., 2014). This speed differential is a safety concern among regulators, though there is little empirical evidence of added risk.

9.3. *Empirical Analysis of E-bike Crash Data in China*

Crash data in China are subject to concerns over reliability, yet there have been few recent studies using crash data from police records. Feng et al. (2010) examining police crash data from 2004 to 2008 found the rapid rise in e-bike use had resulted in a corresponding increase in injury burden. The rates of mortality and injury per 100 000 population increased by 6.5 times and 3.7 times, respectively between 2004 and 2008. However, they found that both injuries and fatalities per 100 000 registered e-bikes decreased slightly over the same period. The researchers found overall declining casualty rates across other modes. The authors recommend that current regulations need improvement and that better enforcement is required to boost safety levels.

A more recent study focused on over 500 non-fatal hospitalisations over seven months in rural Suzhou (Du et al., 2013a). During this period, e-bike riders accounted for about 25% of all hospitalised injuries, which is more than half of all injuries from road crashes. About half of all e-bike rider injuries were the result of a collision with a motor vehicle and 46% of all riders suffered head injuries, resulting in the policy recommendation to encourage or mandate helmet use. The authors suggest that the current increase in e-bike injuries could be replacing relatively low bicycle injury rates. Hu, Lv, Zhu, and Fang (2014) follow a similar approach to earlier studies, focusing on hospitalisation records of 205 injured bicycle and e-bike riders (including six deaths) in Hefei between 2009 and 2011. One-third of e-bike riders suffered severe injuries, while only 17% of bicyclists suffered severe injuries. Nearly two-thirds of the hospitalisations resulted from a violation of traffic rules. Being struck by a large motor vehicle increases the odds of severe injury by 2.5, compared to small motor vehicles.

One of the major gaps in the safety literature in China is the lack of research attributing fault or causal crash analysis on rising e-bike casualty burden. E-bike riders fall into a class of vulnerable road users that have characteristics (e.g., speed) that likely increase exposure and risk relative to bicyclists, but whose riders are largely injured by heavy vehicles.

9.4. *Empirical Analysis of E-bike Crash Data in Europe*

E-bikes are beginning to reach sufficient levels of market penetration to observe crashes in some European countries. Two recent studies focus on investigating crash or hospitalisation data. Papoutsi, Martinolli, Braun, and Exadaktylos (2014) investigated hospitalisation data for e-bike riders in Switzerland. The authors investigated 23 crashes that were reported to the emergency department (ED). Just over one-quarter of the reported crashes results in head injuries, with upper extremities being the second highest injured region. Interestingly, most of the crashes reported were as a result of being caught in a tram rail, not a result of motor vehicle collision. The authors found that crashes tend to be less severe in Switzerland than China, in part due to wider use of helmets and the relatively low number of e-bike crashes involving motor vehicles.

Schepers, Fishman, den Hertog, Wolt, and Schwab (2014) compared the safety outcomes of e-bike and bicycle use in the Netherlands, using data from ED, as

Table 4. Major themes and findings

E-bike theme	Major findings in the literature
Categories, design, & performance	E-bike style varies widely, from those that largely resemble standard bicycles to those that appear more like scooters, without functional pedals (often added for regulatory rather than propulsive purposes). In Europe, North America, and Australia, e-bikes generally share more similarities to regular bicycles, whereas in Asia, they more often resemble a scooter. Interpreting research in these geographic areas must be bounded in the context of e-bike type, which is often difficult to distinguish
Demographics of users	A number of studies (in China, North America, and Australia) have found that e-bike users report higher income and educational attainment than regular cyclists and in some cases, the general population. E-bike users in Western countries tend to be older than regular bicycle riders. A common weakness in research on the demographics of e-bike users is *self-selection bias*
Sales	It is estimated 31 million e-bikes were sold in 2012, with about 90% of these coming from Chinese consumers. E-bikes are a fast-growing category within the bike industry. The Dutch purchase more e-bikes per capita than any other European country. Many of the countries with high e-bike sales (on a per capita basis) also have high rates of general cycling. E-bike sales in Europe are experiencing a stronger growth trend than regular bike sales, and now account for up to one in six of all bike sales A major gap exists concerning reliable e-bikes sales data from North America and Australia
User motivations and benefits	The ability to maintain speed with less effort was found to be the central motivation for e-bike use, especially in hilly and hot conditions. Additionally, experienced, older riders who now find a regular bike too physically demanding are drawn to e-bikes. Examination of Chinese and North American e-bike users shows they often have longer travel distances than regular bike users, although further research is required to determine whether the longer travel distance was stimulated by e-bike availability or if e-bike users choose e-bikes because their trip distances are longer
Impacts on transport behaviour	E-bike users appear to ride more frequently and further, although self-selection bias makes it difficult to determine the degree to which this is representative of the e-bike user population in general. Research in China, North America, and Australia shows that e-bikes have a greater capacity to replace car use than standard bicycles. The precise degree to which car use is reduced however is currently unknown and remains a pertinent topic for future research
Physical activity impact	Studies on the physical intensity of e-bike use consistently found subjects met the requirements to reduce sedentary lifestyle disease (between 3 and 6 METs). Given that e-bike users appear to ride more frequently and for greater duration than regular bicycle riders, e-bikes may contribute to boosting overall physical activity levels, although more research is required, especially using randomised controlled trials over an extended period (e.g. six months or more)
Environmental impact	When used to replace motorised transport, e-bikes offer a clear environmental benefit. E-bike travel emits an order of magnitude less carbon dioxide (from power plants) than a car travelling the same distance and emit fewer emissions than buses, on per person kilometre basis Many of the e-bikes in China rely on lead-acid batteries yielding significant increases in lead consumption and environmental pollution. The trend towards Lithium batteries promises both performance and environmental benefits over lead-acid batteries

(*Continued*)

Table 4. Continued

E-bike theme	Major findings in the literature
Road safety	Most Chinese and North American research found e-bike users have higher levels of *perceived* safety. However current evidence suggests e-bike users are exposed to greater risks than regular bicycles, though the precise nature and magnitude of this effect is largely unknown and likely depends on the type (i.e. performance) of the e-bike, among other factors Chinese studies of e-bike users at intersections have found higher levels of aberrant behaviour. E-bike crash risk in China appears to be higher than for regular bicycles and this is broadly consistent with the findings of recent Dutch research
Future research	Government agencies should consider creating *e-bikes* as a separate option on travel surveys and hospital admission forms. This will help develop an important data source, in order to improve the knowledge base on usage and safety. More research is required on the influence of e-bikes on travel behaviour, enabling further understanding of the impacts e-bikes may have on health, congestion, emissions, and safety. More research is needed to accurately assess vehicle use and mode substitution of e-bike users, likely moving away from static surveys to more naturalistic assessment approaches

well as surveys of cyclists without any known crash experience. In total, 294 e-bike and 1699 bicycle crash victims were included in the study, as well as 791 e-bike users and 517 bicycle riders without any known crash involvement (control group). The authors conclude that after controlling for age, gender, and the amount of cycling, e-bike use is associated with a fairly small increase in risk of ED treatment due to a crash, but that for those treated at an ED, e-bike users are no more likely than bicycle riders to be admitted to hospital (i.e. crashes are equally severe). Females were less likely to be treated at an ED, although there is some uncertainty about the accuracy of self-reporting between the sexes that make gender comparison problematic. Those aged 50–56 years were less likely to require ED treatment than those aged 16–49 years. The age group with the highest likelihood of ED treatment included those 65 years and older. Overall differences in safety outcomes were not dramatic between e-bike and bicycle riders. Finally, the authors note that e-bikes may trigger modal shift and this may have wider impacts on transport safety generally, particularly if the shift substitutes motor vehicles.

10. Conclusion

Several themes emerged from this review of the e-bike literature. E-bike use has grown dramatically over the past decade and there is little evidence to suggest this growth will slow in the coming decade, as market penetration is low in most countries. Table 4 provides a synthesis of the key findings of this review.

Despite the growth in e-bike research over recent years, several important gaps in knowledge are apparent. Government agencies have generally not yet integrated *e-bikes* as a travel mode option as part of travel surveys, hospital admissions, and police crash databases. As e-bike use continues to grow, it will become more important to offer 'e-bike' as an option on standardised forms related to transport, providing much needed data on the level of e-bike use at the population level. This will help address the low sample size associated with many of the current e-bike studies. Including e-bike questions on population surveys will also serve to enhance understanding of any demographic difference between e-bike owners and the general population.

A number of sub-topics could not be covered in this review and these include e-bike regulation, technological issues, bikeshare integration, and freight/cargo e-bike potential. Moreover, research on the effectiveness of government policy promoting e-bike use was not included, nor was research examining safety issues between e-bike users and pedestrians on shared paths.

In order to better understand the impact of e-bikes, comprehensive studies are needed to quantify the influence of e-bikes on travel behaviour. E-bike research can benefit from the movement towards more naturalistic data collection techniques that are occurring throughout the transport field, relying on better technology to gather more detailed use information. This will help provide the necessary details to model the impact of current and future e-bike use on health, climate change, local air and noise pollution, congestion, transport costs, and safety. Importantly, safety issues associated with e-bike use need to include the impact on *all* road users, rather than just injury burden on e-bike riders themselves.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes

1. A physiological measure expressing the energy cost of physical activities and defined as the ratio of metabolic rate (and therefore the rate of energy consumption) during a specific physical activity to a reference metabolic rate, set by convention to 3.5 ml O_2 kg^{-1} min^{-1}.
2. This will vary according to electricity generation factors and vehicle type.

References

Association of the European Two-Wheeler Parts' and Accessories' Industry. (2013). *European bicycle market 2013 edition*. Retrieved from http://www.coliped.com/docs/issuu/European Bicycle Market & Industry Profile - Edition 2013.pdf

Australian Bureau of Statistics. (2013). *Census 2011*. Retrieved June 13, 2013, from http://www.abs.gov.au/websitedbs/censushome.nsf/home/data?opendocument&navpos=200

Bai, L., Liu, P., Chen, Y., Zhang, X., & Wang, W. (2013). Comparative analysis of the safety effects of electric bikes at signalized intersections. *Transportation Research Part D: Transport and Environment*, *20*(0), 48–54. doi:10.1016/j.trd.2013.02.001

Benjamin, E. (2014). *The USA electric bike market numbers*. Retrieved from http://electricbikereport.com/usa-electric-bike-market-numbers/

Bike Europe. (2015). Switzerland 2011: Strong E-bike Trend Continues. Retrieved June 17, from http://www.bike-eu.com/sales-trends/artikel/2012/5/switzerland-2011-strong-e-bike-trend-continues-1019846

Campbell, A. A. (2012). *Factors influencing the choice of shared bicycles and electric bicycles in Beijing – a stated preference approach* (Masters thesis). University of Tennessee, Knoxville.

Cherry, C., & Cervero, R. (2007). Use characteristics and mode choice behavior of electric bike users in China. *Transport Policy*, *14*(3), 247–257. doi:10.1016/j.tranpol.2007.02.005

Cherry, C., & He, M. (2010). Alternative methods of measuring operating speed of electric and traditional bikes in China-implications for travel demand models. *Journal of the Eastern Asia Society for Transportation Studies*, *8*(2010), 1424–1436.

Cherry, C., & Jones, L. (2009). Electric two-wheelers in India and Vietnam: Market analysis and environmental impacts. Asian Development Bank.

Cherry, C., Yang, C. H., Jones, L., & He, M. (2014). Dynamics of electric bike use in Kunming China. Transport Policy (in Review).

Cherry, C. R., Weinert, J. X., & Xinmiao, Y. (2009). Comparative environmental impacts of electric bikes in China. *Transportation Research Part D: Transport and Environment*, *14*(5), 281–290. doi:10.1016/j.trd.2008.11.003

China Central Government. (2004). National Road Transportation Law.

Chiu, Y.-C., & Tzeng, G.-H. (1999). The market acceptance of electric motorcycles in Taiwan experience through a stated preference analysis. *Transportation Research Part D: Transport and Environment*, *4*(2), 127–146. doi:10.1016/S1361-9209(99)00001-2

Du, W., Yang, J., Powis, B., Zheng, X., Ozanne-Smith, J., Bilston, L., . . . Wu, M. (2013a). Epidemiological profile of hospitalised injuries among electric bicycle riders admitted to a rural hospital in Suzhou: A cross sectional study. *Injury Prevention*, *20*(2), 128–133.

Du, W., Yang, J., Powis, B., Zheng, X., Ozanne-Smith, J., Bilston, L., . . . Wu, M. (2013b). Understanding on-road practices of electric bike riders: An observational study in a developed city of China. *Accident Analysis & Prevention*, *59*(0), 319–326. doi:10.1016/j.aap.2013.06.011

The Economist. (2013). Two (motorised) wheels better, *The Economist*. Retrieved from http://www.economist.com/news/business/21586591-sales-are-booming-large-scale-urban-hire-schemes-remain-some-way-two-motorised-wheels

European Commission. (2013). *Eurostat population database*. Brussels: European Commission. Retrieved from http://epp.eurostat.ec.europa.eu/portal/page/portal/population/data/database

European Two-Wheel Retailers' Association. (n.d.). Contribution for the European Commission's stakeholders' consultation on the European Strategy on clean and energy efficient vehicles. Retrieved from http://ec.europa.eu/enterprise/sectors/automotive/files/pagesbackground/competitiveness/contribution_etra_en.pdf

Feng, Z., Raghuwanshi, R. P., Xu, Z., Huang, D., Zhang, C., & Jin, T. (2010). Electric-bicycle-related injury: A rising traffic injury burden in China. *Injury Prevention*. doi:10.1136/ip.2009.024646

Fishman, E. (2014). *Bikeshare: barriers, facilitators and impacts on car use* (PhD thesis by Publication). Queensland University of Technology, Brisbane.

Fishman, E., Böcker, L., & Helbich, M. (2015). Adult active transport in the Netherlands: An analysis of its contribution to physical activity requirements. *PLoS ONE*, *10*(4), e0121871. doi:10.1371/journal.pone.0121871

Fyhri, A., & Fearnley, N. (2015). Effects of e-bikes on bicycle use and mode share. *Transportation Research Part D: Transport and Environment*, *36*(0), 45–52. doi:10.1016/j.trd.2015.02.005

de Geus, B., Kempenaers, F., Lataire, P., & Meeusen, R. (2013). Influence of electrically assisted cycling on physiological parameters in untrained subjects. *European Journal of Sport Science*, *13*(3), 290–294. doi:10.1080/17461391.2011.606845

Gojanovic, B., Welker, J., Iglesias, K., Daucourt, C., & Gremion, G. (2011). Electric bicycles as a new active transportation modality to promote health. *Medicine & Science in Sports & Exercise*, *43*(11), 2204–2210. doi:10.1249/MSS.0b013e31821cbdc8

Handy, S., van Wee, B., & Kroesen, M. (2014). Promoting cycling for transport: Research needs and challenges. *Transport Reviews*, *34*(1), 4–24. doi:10.1080/01441647.2013.860204

Heinen, E., van Wee, B., & Maat, K. (2010). Commuting by bicycle: An overview of the literature. *Transport Reviews*, *30*(1), 59–96. doi:10.1080/01441640903187001

Hu, F., Lv, D., Zhu, J., & Fang, J. (2014). Related risk factors for injury severity of e-bike and bicycle crashes in Hefei. *Traffic Injury Prevention*, *15*(3), 319–323. doi:10.1080/15389588.2013.817669

Hummel, P. (2015). *Swiss surprise: Sales drop in e-bikes*. Retrieved 16th June, from http://www.bike-eu.com/sales-trends/nieuws/2014/5/swiss-surprise-sales-drop-in-e-bikes-10110129

International Energy Agency. (2012). *CO2 emissions from fuel combustion: Highlights*. Paris: International Energy Agency. Retrieved from http://www.iea.org/co2highlights/co2highlights.pdf

Jamerson, F. E., & Benjamin, E. (2013). *Electric bikes worldwide reports. Electric bikes worldwide reports*. Retrieved from http://www.ebwr.com/

Ji, S., Cherry, C. R., Bechle, M. J., Wu, Y., & Marshall, J. D. (2012). Electric vehicles in China: Emissions and health impacts. *Environmental Science and Technology*, *46*(4), 2018–2024. doi:10.1021/es202347q

Johnson, M., Newstead, S., Charlton, J., & Oxley, J. (2011). Riding through red lights: The rate, characteristics and risk factors of non-compliant urban commuter cyclists. *Accident Analysis & Prevention*, *43*(1), 323–328. doi:10.1016/j.aap.2010.08.030

Johnson, M., & Rose, G. (2013). *Electric Bikes – cycling in the New world city: An Investigation of Australian Electric Bicycle Owners and the Decision Making Process for Purchase.* Paper presented at the Australasian Transport Research Forum, Brisbane.

Jones, L. R., Cherry, C. R., Vu, T. A., & Nguyen, Q. N. (2013). The effect of incentives and technology on the adoption of electric motorcycles: A stated choice experiment in Vietnam. *Transportation Research Part A: Policy and Practice*, *57*(0), 1–11. doi:10.1016/j.tra.2013.09.003

Langford, B. C. (2013). *A comparative health and safety analysis of electric-assist and regular bicycles in an on-campus bicycle sharing system*. PhD thesis, University of Tennessee. Retrieved from http://trace.tennessee.edu/utk_graddiss/2445/

Langford, B. C., Chen, J., & Cherry, C. (2015). Risky riding: Naturalistic methods comparing safety behavior from conventional bicycle riders and electric bike riders. *Accident Analysis and Prevention*, *82*, 220–226. doi:10.1016/j.aap.2015.05.016

Langford, B. C., Cherry, C., Yoon, T., Worley, S., & Smith, D. (2013). North America's first e-bikeshare. *Transportation Research Record: Journal of the Transportation Research Board*, *2387*(1), 120–128. doi:10.3141/2387-14

Lin, S., He, M., Tan, Y., & He, M. (2008). Comparison study on operating speeds of electric bicycles and bicycles: Experience from field investigation in Kunming, China. *Transportation Research Record: Journal of the Transportation Research Board*, *2048*(1), 52–59.

MacArthur, J., Dill, J., & Person, M. (2014). Electric Bikes in North America: Results from an online survey. *Transportation Research Record: Journal of the Transportation Research Board*, *2468*, 123–130. doi:10.3141/2468-14

Macarthur, J., & Kobel, N. (2014). *Regulations of E-Bikes in North America. NITC-RR-564. National Institute for Transportation and Communities sponsored by the U.S. Department of Transportation*. Portland, United States. Retrieved from http://ebike.research.pdx.edu/sites/default/files/NITC-RR-564_Regulations_of_E-Bikes_in_North_America_2.pdf

Marchetti, C. (1994). Anthropological invariants in travel behavior. *Technological Forecasting and Social Change*, *47*, 75–88. doi:10.1016/0040-1625(94)90041-8

Montgomery, B. N. (2010). Cycling trends and fate in the face of bus rapid transit. *Transportation Research Record: Journal of the Transportation Research Board*, *2193*(1), 28–36. doi:10.3141/2193-04

Papoutsi, S., Martinolli, L., Braun, C. T., & Exadaktylos, A. K. (2014). E-bike injuries: Experience from an urban emergency department—A retrospective study from Switzerland. *Emergency Medicine International*, *5*. doi:10.1155/2014/850236

Popovich, N., Gordon, E., Shao, Z., Xing, Y., Wang, Y., & Handy, S. (2014). Experiences of electric bicycle users in the Sacramento, California area. *Travel Behaviour and Society*. doi:10.1016/j.tbs.2013.10.006

Pucher, J., & Buehler, R. (2008). Making cycling irresistible: Lessons from the Netherlands, Denmark and Germany. *Transport Reviews*, *28*(4), 495–528. doi:10.1080/01441640701806612

Pucher, J. E., & Buehler, R. E. (2012). *City cycling*. Cambridge, MA: MIT Press.

Reed Business Information. (2014). EU Regulations for e-bikes, pedelecs and speed pedelecs. Bike Europe. Brussels.

Rose, G. (2012). E-Bikes and urban transportation: Emerging issues and unresolved Questions. *Transportation*, *39*(1), 81–96. doi:10.1007/s11116-011-9328-y

Sanders, T., Liu, Y., Buchner, V., & Tchounwou, P. B. (2009). Neurotoxic effects and biomarkers of lead exposure: a review. *Reviews on Environmental Health*, *24*(1), 15–46. doi:10.1515/REVEH.2009.24.1.15

Schepers, J. P., Fishman, E., den Hertog, P., Wolt, K. K., & Schwab, A. L. (2014). The safety of electrically assisted bicycles compared to classic bicycles. *Accident Analysis and Prevention*, *73c*, 174–180. doi:10.1016/j.aap.2014.09.010

Simons, M., Van Es, E., & Hendriksen, I. (2009). Electrically assisted cycling: A new mode for meeting physical activity guidelines? *Medicine and Science in Sports and Exercise*, *41*(11), 2097–2102. doi:10.1249/MSS.0b013e3181a6aaa4

Sperlich, B., Zinner, C., Hebert-Losier, K., Born, D.-P., & Holmberg, H.-C. (2012). Biomechanical, cardiorespiratory, metabolic and perceived responses to electrically assisted cycling. *European Journal of Applied Physiology*, *112*(12), 4015–4025. doi:10.1007/s00421-012-2382-0

Van der Kuijp, T. J., Huang, L., & Cherry, C. R. (2013). Health hazards of China's lead-acid battery industry: A review of its market drivers, production processes, and health impacts. *Environmental Health*, *12*(1), 61.

Weinert, J., Ma, C., & Cherry, C. (2007). The transition to electric bikes in China: History and key reasons for rapid growth. *Transportation*, *34*(3), 301–318. doi:10.1007/s11116-007-9118-8

Weinert, J. X., Burke, A. F., & Wei, X. (2007). Lead-acid and lithium-ion batteries for the Chinese electric bike market and implications on future technology advancement. *Journal of Power Sources*, *172*(2), 938–945. doi:10.1016/j.jpowsour.2007.05.044

Weinert, J. X., Ma, C., Yang, X., & Cherry, C. R. (2007). Electric two-wheelers in China: Effect on travel behavior, mode shift, and user safety perceptions in a medium-sized city. *Transportation Research Record: Journal of the Transportation Research Board*, *2038*(1), 62–68. doi:10.3141/2038-08

Wolf, A., & Seebauer, S. (2014). Technology adoption of electric bicycles: A survey among early adopters. *Transportation Research Part A: Policy and Practice*, *69*(0), 196–211. doi:10.1016/j.tra.2014.08.007

Wu, C., Yao, L., & Zhang, K. (2012). The red-light running behavior of electric bike riders and cyclists at urban intersections in China: An observational study. *Accident Analysis & Prevention*, *49*(0), 186–192. doi:10.1016/j.aap.2011.06.001

Yang, C.-J. (2010). Launching strategy for electric vehicles: Lessons from China and Taiwan. *Technological Forecasting and Social Change*, *77*(5), 831–834. doi:10.1016/j.techfore.2010.01.010

Yang, J., Hu, Y., Du, W., Powis, B., Ozanne-Smith, J., Liao, Y., . . . Wu, M. (2014). Unsafe riding practice among electric bikers in Suzhou, China: An observational study. *BMJ Open*, *4*(1), e003902. Retrieved from http://bmjopen.bmj.com/content/4/1/e003902.long

Yang, X., Huan, M., Abdel-Aty, M., Peng, Y., & Gao, Z. (2015). A hazard-based duration model for analyzing crossing behavior of cyclists and electric bike riders at signalized intersections. *Accident Analysis & Prevention*, *74*(0), 33–41. doi:10.1016/j.aap.2014.10.014

Yao, L., & Wu, C. (2012). Traffic safety for electric bike riders in China. *Transportation Research Record: Journal of the Transportation Research Board*, *2314*(1), 49–56. doi:10.3141/2314-07

Zhang, Y., & Wu, C. (2013). The effects of sunshields on red light running behavior of cyclists and electric bike riders. *Accident Analysis & Prevention*, *52*(0), 210–218. doi:10.1016/j.aap.2012.12.032