Benign mobility? Electric bicycles, sustainable transport consumption behaviour and socio-technical transitions in Nanjing, China

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Abstract

In this paper, we ask whether electric bicycle (e-bike) use in urban China is a temporary phase or an embedded form of sustainable mobility. A survey was conducted in Nanjing in order to assess the characteristics and attitudes of electric bicycle users and other mode users (e.g. pedestrians; car drivers). Based on over 1,000 responses .a Logit Model was used to analyse current and future mode choice. The results show that electric bicycles are not necessarily displacing cars on a substantial scale, but are rather displacing the 'benign' modes of walking, traditional bicycling, and using the bus. We conclude that electric bicycles are helping to enable mobility-dependent lifestyles that may in the future be supported by cars, rather than offering a true departure from carbon-centred, motorized forms of transport.

Keywords Electric bicycles; e-bikes; Nanjing, User attitudes; regime embedding; alternative mobility.

1. Introduction

In previous research on electric bicycles (“e-bikes”) in China, it has been established that over a fairly short period of some 15 years there has been a rapid uptake of the technology in a variety of forms (roughly divided into electric bicycles and electric scooters). While adoption of the technology is gathering pace in other locations (Thomas, 2016), China remains distinct for the sheer number and pervasiveness of electric bicycles: It is the country with by far the largest industry to produce these machines and by far the largest annual market. Sales inside China now exceed 35 million units per annum, while the installed base of electric bicycles in use is thought to be well over 100 million. These are figures that totally dwarf the attempts in China or elsewhere to promote other ‘alternative’ forms of mobility, and in particular electric cars.

It seems important then to understand more about how the use of electric bicycles has grown in China, the environmental implications of such an uptake, and the prospects for future electric bicycle use. The first two areas have been covered somewhat in the literature, albeit with considerable space for further research (Cherry and Cervero, 2007; Rose, 2012; Weinert et al, 2007a; 2007c; Yang, 2010; Zhang et al., 2013). This paper therefore investigates the likely future of electric bicycles in urban China given current user behaviours and wider social attitudes.

It has also been noted that the electric bicycle phenomenon in China has occurred largely without direct state support, particularly in terms of the national government (Wells and Lin, 2015). The uptake of electric bicycles has not so far been supported by incentives for consumers, for example, or the provision of dedicated infrastructure, although it could be argued that indirect support was provided through the policy of banning scooters and motorbikes with internal combustion engines from urban areas. In this sense, the electric bicycle experience has been rather different - very much demand driven rather than supply pushed - to the idea often proposed in transition studies that more sustainable technologies, production systems and patterns of consumption need to be nurtured and accelerated by state intervention of various kinds (Ren et al, 2015). However, there is also a concern that the relative ease with which electric bicycles have become established as a mode of transport in China may also mean that they are relatively easily discarded in the future – for example as a consequence of regulatory intervention or perhaps an increase in the average economic disposable income that might result in a preference for cars in the absence of other policies.

Around the world governments have been active in promoting the uptake of electric forms of mobility and other alternative fuel vehicles in order to redress concerns over issues such as global warming, resource depletion, energy security, urban air quality, and broader themes of sustainable development (Wells, 2010; Zhang et al., 2014b). In the midst of all these efforts, electric bicycles are almost uniformly neglected – with the policy focus for road vehicles almost entirely on cars, trucks and buses.

For instance, in a wide-ranging review Fishman and Cherry (2015) argue that electric bicycles have the potential to displace cars, and bring benefits such as improved health and better air quality. However the authors also note that electric bicycle research is still 'in its infancy' and that further data will be needed to inform policy-makers and others seeking to influence future outcomes. Put another way, electric bicycles could be one of the emergent 'substantial changes' that Van Cranenburgh et al. (2012) argue will influence mobility futures in the coming decades, with profound implications for policy-making in this area. As Aguiléra and Grébert (2015) discuss, future modal choices in urban areas around the world are very variable and fluid, and in part will include electric bicycles. According to Weiss et al. (2015) electric bicycles are penetrating non-Chinese markets (in Europe for example) despite a significantly higher price than traditional bicycles, but there is much to be learned from China because of the much greater scale of experience. In so far as electric bicycles can substitute for other modes, and particularly cars, then there is anticipated to be a wide range of economic and social benefits.

Borén et al. (2016) provide an example of how these considerations regarding electrification and future mobility are being taken up at the national and local level in Sweden. Particularly in urban policy there is a growing awareness that 'smart cities' will entail transport systems unconstrained by fossil fuel dependence and offering a diversity of travel modes – a scenario into which electric bicycles can readily fit.

As a departure from these lines of research, this paper represents an attempt to explore the theoretical attributes of embeddedness via an empirical study of the attitudes of users of electric bicycles in China, specifically in the city of Nanjing, within the theoretical framing of socio-technical transitions. While previous studies have revealed the scale and pace of uptake of electric bicycles in China, along with some of the likely environmental implications in terms of issues such as battery disposal, research is lacking in terms of understanding more closely why electric bicycles were adopted in the first place, and the likely prospects for future adoption or retention of electric bicycles by existing users, pedestrians or motorists.

To proceed, the following section provides a brief discussion of socio-technical transitions and the realm of personal mobility. It is followed by an account of the research methodology adopted for the case study in Nanjing, which is essentially a statistical analysis of a large sample of electric bicycle users and the users of other modes. Thereafter the results of the Nanjing case study are described, ahead of the final section that discusses the results and links back to the main theme of seeking to understand the embeddedness of electric bicycles within the socio-technical regime of mobility in China.

2. Socio-technical transitions and the embedding of novel modes of transport

There has been a body of research into the uses to which electric bicycles are put. Interestingly, electric bicycles outside of China appear to occupy a rather different set of mobility niches (for example, extending the 'cycling lives' of the elderly), whereas in China they are used in a diverse range of applications but particularly for urban commuting and access to services. That is, electric bicycles are mainly adopted for utility use in China, which is a distinctive use characteristic (Weinert et al, 2007a; Cherry and Cervero, 2007; Wang et al., 2013; Rose, 2012; Ye et al., 2014; Zhang et al, 2014a). In contrast, in other countries electric bicycles are more likely to be in leisure use (Parker, 2006; Rooijen, 2010; Dill and Rose 2012; Schepers et al., 2014; Wolf and Seebauer, 2014). According to these studies, electric bicycles are still a niche transport application, although some effort has been made to promote the use of electric bicycles to replace cars for commuting purpose in the UK, Australian and France (Pierce et al., 2013; Johnson and Rose, 2013; Héran, 2014).

We find the notion of sociotechnical systems particularly useful when applied to the domain of electric bicycles. It is not intended here to provide a comprehensive review of socio-technical transitions theory.

However, for those unfamiliar with the theory, also sometimes called the "multilevel perspective" on socio-technical transitions and innovation, and inclusive of a sub-field known as "strategic niche management"

(Geels 2002; Schot and Geels 2008), some background may be useful Borrowing from a mix of disciplines including history, evolutionary economics, institutional theory, and science and technology studies, the approach suggests that diffusion or transition occurs through interactions between three levels: the niche, the regime, and the landscape. The niche refers to a radical innovation that may subsequently emerge and gain diffusion or widespread adoption, to move from invention and innovation to viable market introduction (Grin et al. 2010). The regime refers to the incumbent sociotechnical technical system that the niche is trying to affect or displace; such regimes contain cognitive, regulative, and normative institutions (Geels 2004). The landscape refers to exogenous developments or shocks (e.g. economic crises, demographic changes, wars, ideological change, major environmental disruption like climate change) that create pressures on the regime, which in turn create windows of opportunity for the diffusion of niche innovations.

A key concept within the framework is that of a "transition pathway." Analytically, the claim is that different kinds of interactions between niche, regime and landscape result in different kinds of alignments. Geels and Schot (2007) constructed a typology based on combinations between two dimensions: the timing and nature of multi-level interactions. This led them to distinguish four transition pathways: 1) technological substitution, based on disruptive niche-innovations which are sufficiently developed when landscape pressure occurs; 2) transformation, in which landscape pressures stimulate incumbent actors to gradually adjust the regime, when niche-innovations are not sufficiently developed; 3) reconfiguration, based on symbiotic niche innovations that are incorporated into the regime and trigger further (architectural) adjustments under landscape pressure; and 4) de-alignment and re-alignment, in which major landscape pressures destabilize the regime when niche innovations are insufficiently developed such that the prolonged co-existence of niche innovations is followed by re-creation of a new regime around one of them. The implications are that transitions are competitive, in that many niches fail, and that existing energy systems and infrastructure can dominate and suppress threatening innovations.

In sum, transitions theory using the Multi-Level Perspective (MLP) seeks to explain how technological innovations may permeate society, and to what social or economic effect. Technologies form the core of self-stabilizing 'regimes' in which economic structures and social practices are produced and reproduced. These regimes are set within a broader context or 'landscape' in which fundamental enabling characteristics (such as the availability of low-priced petroleum) act to allow regime continuity. Below the level of the regime, technological or social innovations may occur as ‘niche’ experiments and which may, ultimately, emerge to displace an existing embedded regime. The important aspect of the theory in current research is that a) transitions are understood as a process of displacement, in which a prevailing regime is at least partially destabilised and replaced by new actors clustered around new technologies, while offering new opportunities for consumers and producers; and b) that regime transition is envisaged as the means by which more sustainable practices can be nurtured, both through the protection of innovative grassroots niches and the reframing of ‘landscape’ conditions.

Another significant benefit of the theory is its emphasis on dynamic interactions between the three levels of niches, regimes, and landscapes. The success of a niche innovation (usually interpreted as an expansion of scale or increasing take-up in society) often requires external landscape changes that create pressure on regimes, opening them up so to speak. A second benefit is the theory’s focus on learning and co-evolution, which challenge overly linear explanations of change. Instead, transitions come about when multiple dimensions and levels coalesce simultaneously. The theory also focuses intently on size, stability, and structure: niches and regimes are about networks of actors that subscribe to particular rules, but these are constantly shifting in their scope, scale, maturation, and effectiveness. Also, successful niche innovations are held to need protective space where experimentation and development of new technologies can take place within a supportive environment. Moreover, expectations also play a role in articulating a future in which particular socio-technical configurations are featured (Rolffs et al. 2015).

When applied to the domain of transport and mobility, regime transition for sustainability is defined chiefly in purposeful policy intervention and market stimulation terms. In terms of personal mobility, the dominant regime is widely understood to be the private car and the ensemble of actors, practices, legal frameworks, behaviours and attitudes that have accumulated around this core technology. Some even call this the "seamless web" of technical and non-technical factors that coalesce to create regimes of automobility (Sovacool and Hirsh 2009). Other forms of mobility are of course significant, particularly in urban areas. Cowan and Hulten (1996) add that different sociotechnical trajectories can emerge and solidify for various transport systems. In the case of the rise of the automobile industry, they distinguish first the early formative years of car manufacture in which no single technological configuration dominated. Later periods follow in which a particular configuration rises to dominance; a subsequent associated consolidation of institutional power; and finally, the possibility of follow-on phases of possible dis-entrenchment and decline. Crucially, they note that technical change is not exclusively path dependent, but may also be path interdependent (as in the co-dependence of the rise of the railway and the telegraph) or path independent (such as the relatively unrelated rise of wind power and geothermal electricity).

For some, then, the possible introduction of electric cars is seen as heralding a socio-technical transition in mobility. This is perhaps a bit simplistic, as changing the means of motive power may not necessarily change much of the regime as a whole. A wider view of this transition might even challenge the significance of personal mobility in itself. It is therefore a matter of some debate whether or not electric bicycles as a core technology do indeed represent a challenge to the existing personal mobility regime, or more prosaically a deepening of it. Anecdotally, it is worth noting that in our case study city of Nanjing has expanded rapidly in physical size and population over the past 25 years or so, and in the process has also seen the development of other transport modes (such as the passenger car, and the Metro) alongside the demise of traditional modes (such as the ferry), and a road and bridge-building programme that has done much to foster the (car and bus) connectivity of the city. Hence there has been a growth in the demand or need for mobility (particularly as populations are established in the urban periphery), and a considerable growth in provision. This relationship between urbanisation and multi-mobility is to be explored in a future paper.

3. Research Methods

Intercept surveys were conducted in Nanjing City in the period from late August 2014 to early November 2014 by one of the authors and assistants. The surveys targeted both electric bicycle users and non-electric bicycle users (bicycle users, car drivers and pedestrians). Not all of the survey data is reported in this paper.

The survey of electric bicycle users consists of three parts: 1) demographic questions, 2) the previous travel modes, travel time, future choice, alternative modes, use anxiety, feelings and use preference and 3) attitudinal questions to electric bicycles and future suggestions. The surveys of bicycle users, car drivers and pedestrians comprise three parts: 1) demographic questions, 2) electric bicycle ownership information, and 3) attitudinal questions to electric bicycles.

The survey locations were chosen to provide a representative sample of electric bicycle users and non-electric bicycle users, such as the commercial centre, electric bicycle repair shops and electric bicycle communities throughout the urban areas. Conducting surveys in electric bicycle repair shops and electric bicycle communities is a very efficient way to access electric bicycle users. The advantages of choosing commercial centre are: 1) the commercial centre usually has large flow of visitors with different age groups, education backgrounds, and occupations, which maximizes the diversity of the samples, and 2) with the large stream of citizens and high density of population, we can find more potential survey participants and also increase the number of accomplished surveys. Community workers, electric bicycle maintenance technicians and office workers helped conduct the intercept surveys. In total 1,053 responses were collected.

To provide a bit more detail, car drivers were intercepted with the help of residential community workers and office workers. Firstly, the residential community workers are familiar with the citizens who live in the communities and could easily identify those who are car drivers. When the potential participants passed by the neighbourhood committees, the community workers presented the questionnaires and asked the participants to return them after they were completed. Secondly, the community workers stopped car drivers at street parking and multilevel car parking facilities to administer questionnaires. Thirdly, office workers asked citizens in the city commercial centre whether they were car drivers, and invited them to participate the survey if they were. The car drivers were therefore selected in a wide range of locations, including residential communities, street parking, multilevel car parking, office buildings, residential parking, and the city commercial centre in an effort to ensure a diverse and unbiased sample.

In aggregate the number of responses for each group is: electric bicycle users (403), bicycle users (200), car drivers (200), and pedestrians (200). One challenge of the Nanjing case study was low response rate. Many people simply refused to participate in the survey, and some abandoned the survey after answering two or three questions. If citizens refused to participate, the community workers simply asked others. The low response rate made it time-consuming to achieve a large sample size. The figures and tables in next section illustrate the data based on usable responses for each category and question.

Logit regression is applied to analyse the relationship between mode choice and electric bicycle adoption purpose, and the relationship between mode choices and electric bicycle adoption reasons. This method is particularly well-suited to the analysis of co-determining characteristics in explaining outcomes. The tested mode choices are buses, walking, metro, private cars, bicycles, and motorcycles. The electric bicycle adoption purposes include commuting, going to school, picking up children, shopping, visiting friends, travel connection to metro, leisure, and business. The electric bicycle adoption reasons are low purchase cost, low operation cost, effort-saving, flexible trip time, saving time in the traffic jams, high accessibility, environmental friendliness, and personal health. Each mode choice is paired with the electric bicycle adoption purposes listed in order to test whether a significant relationship exists between mode choice and electric bicycle adoption purpose. After that, each mode choice is paired with listed electric bicycle adoption reasons to examine the relationship between them. The results are shown in Table 2 and Table 3.

Nanjing case study

Demographically the survey showed the majority of electric bicycle users were in the 19-39 age groups, and split almost 50/50 by gender. This is consistent with other user surveys in China, and different to results found in other countries (Cherry and Cervero 2007; Weinert et al, 2007b; Wang, et al., 2013; Parker, 2006; Rooijen, 2010; Schepers et al, 2014; Dill and Rose, 2012; Johnson and Rose, 2013). Table 1 illustrates the sample characteristics for 399 responses.

Table 1 Demographics of electric bicycle users: Nanjing survey

Demographics	Categories	Percentage in the sample %	Percentage in the Nanjing* %
Gender	Male	54.55	51.52
	Female	44.95	48.48
Education	Secondary school and below	16.83	37.42
	High school	19.35	18.47
	College degree and above	63.57	35.36
	College degree	18.34	NA
	University degree	35.93	NA
	Master degree and above	9.30	NA
Income (CNY/month)	1500 and below	13.15	21.1
	1500-3000	27.79	45.5
	3000-4500	36.97	18.5
	4500 and above	22.09	14.9
Cars	Average car ownership rate per 100 households	48.83	38.7
	Households without a car	57.57	NA
	Households with one car	37.72	NA
	Households with two cars	3.47	NA
	Households with three cars	1.24	NA
Motorcycles	Average motorcycle ownership rate per 100 households	23.33	19.9
	Households without a motorcycle	77.17	NA
	Households with one motorcycle	22.33	NA
	Households with two motorcycles	0.5	NA
Bicycles	Average bicycle ownership rate per 100 households	66.54	89
	Households without a bicycle	50.13	NA
	Households with a bicycle	40.69	NA
	Households with two bicycles	7.69	NA
	Households with three bicycles	1.49	NA

(Sample size: 399 electric bicycle users)

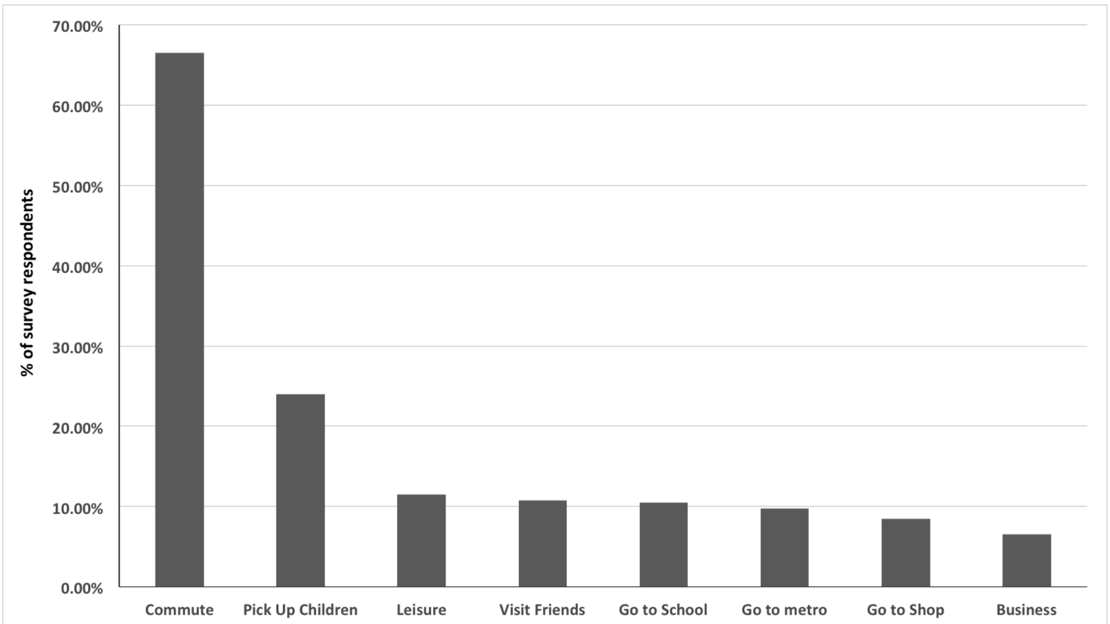
(*Source from: Statistics information network of Jiangsu, 2011; Nanjing Statistics Bureau, 2014; Nanjing Statistics Bureau, 2015; Nanjing Statistics Bureau, 2016)

Approximately 59% of participants earn more than CNY 3,000 per month. Taking into account the range of equivalent household income of Nanjing city are: below CNY 1,556 (low level); CNY 1,556 to CNY 3,040 (lower-middle level); CNY 3,040 to 6,200 (Higher-middle level); above CNY 6,200 (high level) the household income of the electric bicycle users in our study is rather high, which matches the high level of educational background of electric bicycle users. There may be some self-reporting bias in this data. Table 1 furthermore illustrates that the average household car ownership rate in electric bicycle users is 48.83%, which is somewhat more than the overall average household car ownership rate in Nanjing City (38.7%) (Nanjing Statistics Bureau, 2015). The average household motorcycle ownership rate among electric bicycle users is also higher than the average in Nanjing City (23.83% versus 19.9%) (Nanjing Statistics Bureau, 2015). In contrast, the household bicycle ownership rate of electric bicycle users is lower than the overall household bicycle ownership rate in Nanjing City (66.54% versus 89%) (Nanjing Statistics Bureau, 2014).

Travel behaviour is likely to be affected by numerous external and internal factors. The survey asked electric bicycle users to answer questions regarding trip time, trip purpose, model choice, previously used modes, primary alternative mode, reasons for electric bicycle adoption, reasons for not using electric bicycles, future choice regarding electric bicycle adoption, alternative mode choice and reasons for alternative mode choices.

The majority of electric bicycle users (47 %) stated that 20 minutes to 30 minutes is the maximum trip time, followed by 31 minutes to 50 minutes with 30% of the responses. The average of the electric bicycles users' maximum trip time is 41 minutes.

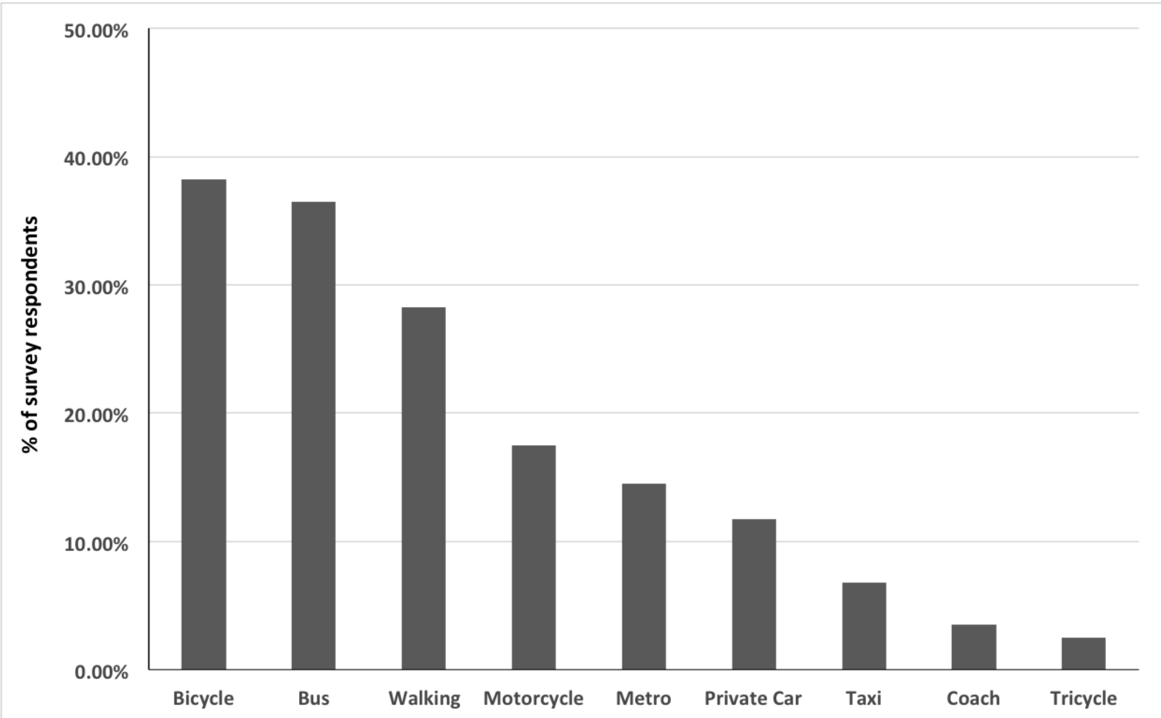
Figure 1 Trip Purpose for electric bicycle adoption: Nanjing survey



(Sample size, 394 electric bicycle users; note respondents could select more than one reason for the trip in the event of a multi-purpose journey.)

Commuting is the overwhelming majority of all trip purposes (66.5%) as shown in Figure 1, followed by picking up children (24%). The frequencies of leisure, visiting friends, going to school, accessing metro and going shopping are almost the same (10%). The result indicates that electric bicycles are mainly adopted for utility use in China.

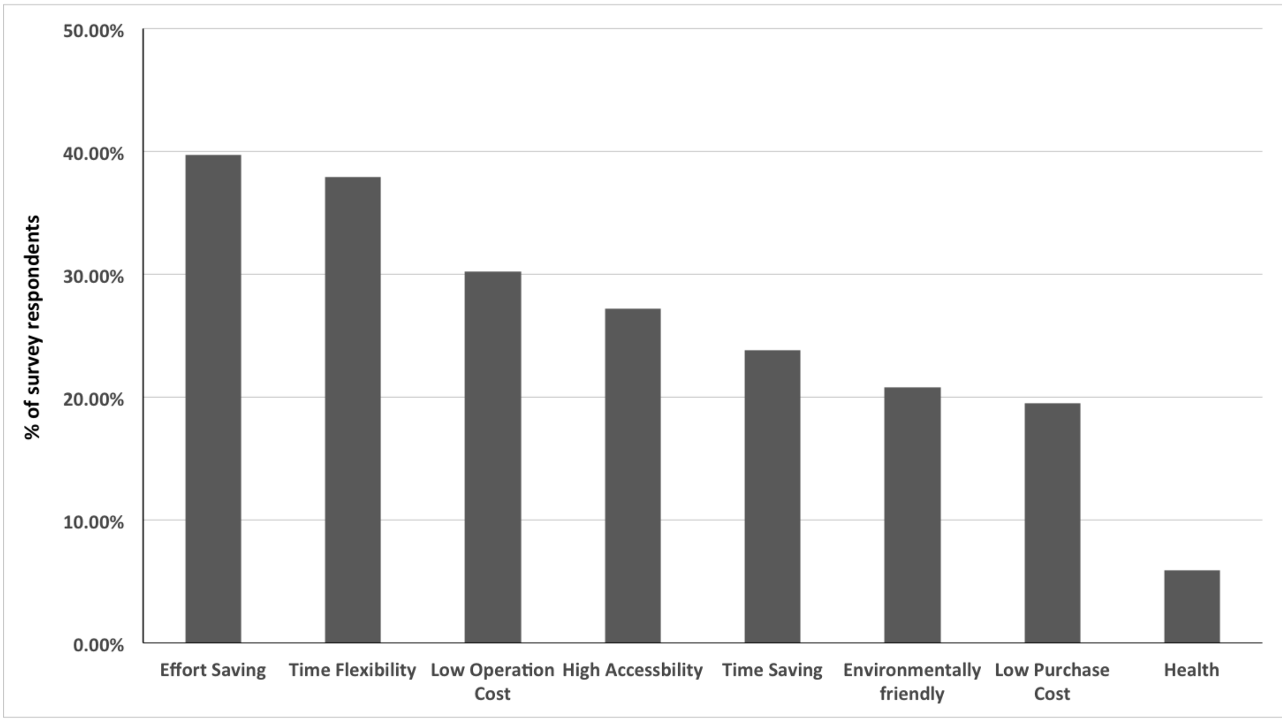
Figure 2 The mode previously used prior to electric bicycle acquisition: Nanjing survey



(Sample size, 403 electric bicycle users; note respondents could select more than one previous mode if they wished.)

Regarding the previously used transport mode of the electric bicycle users, the most frequent response was traditional bicycles (38%) (Figure 2), followed by buses (36%) and walking (28%). These results indicate that electric bicycles are regarded as an alternative mode to traditional bicycles and buses.

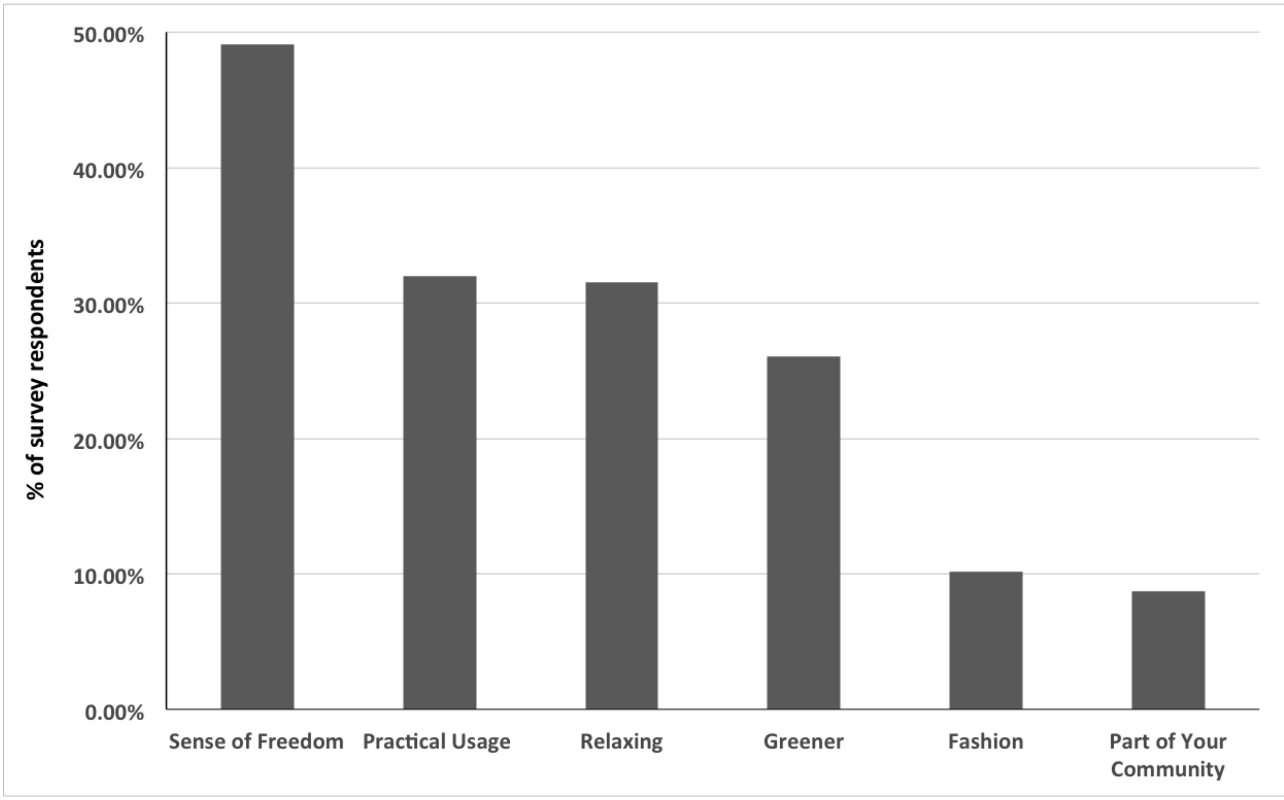
Figure 3 Reasons for electric bicycles adoption: Nanjing survey



(Sample size, 393 electric bicycle users; note respondents could select more than one reason for adoption if they wished.)

Figure 3 shows the reasons for electric bicycle adoption. Effort-saving is the most prevailing reason of electric bicycle adoption with a 40% response rate, followed by time flexibility and low operation cost. High accessibility, time-saving, environmental friendliness, and low purchase cost have response rates from 37% to 20%. The main reasons for traditional bicycles users to shift to electric bicycles are effort-saving and higher speed. For pedestrians, bus users and motorbike users, the most frequent responses were effort-saving and time flexibility. This implies that the travel priorities tend to be time saving and personal freedom. Time saving and high accessibility are main reasons that bus users and private car users shift to electric bicycles in our study.

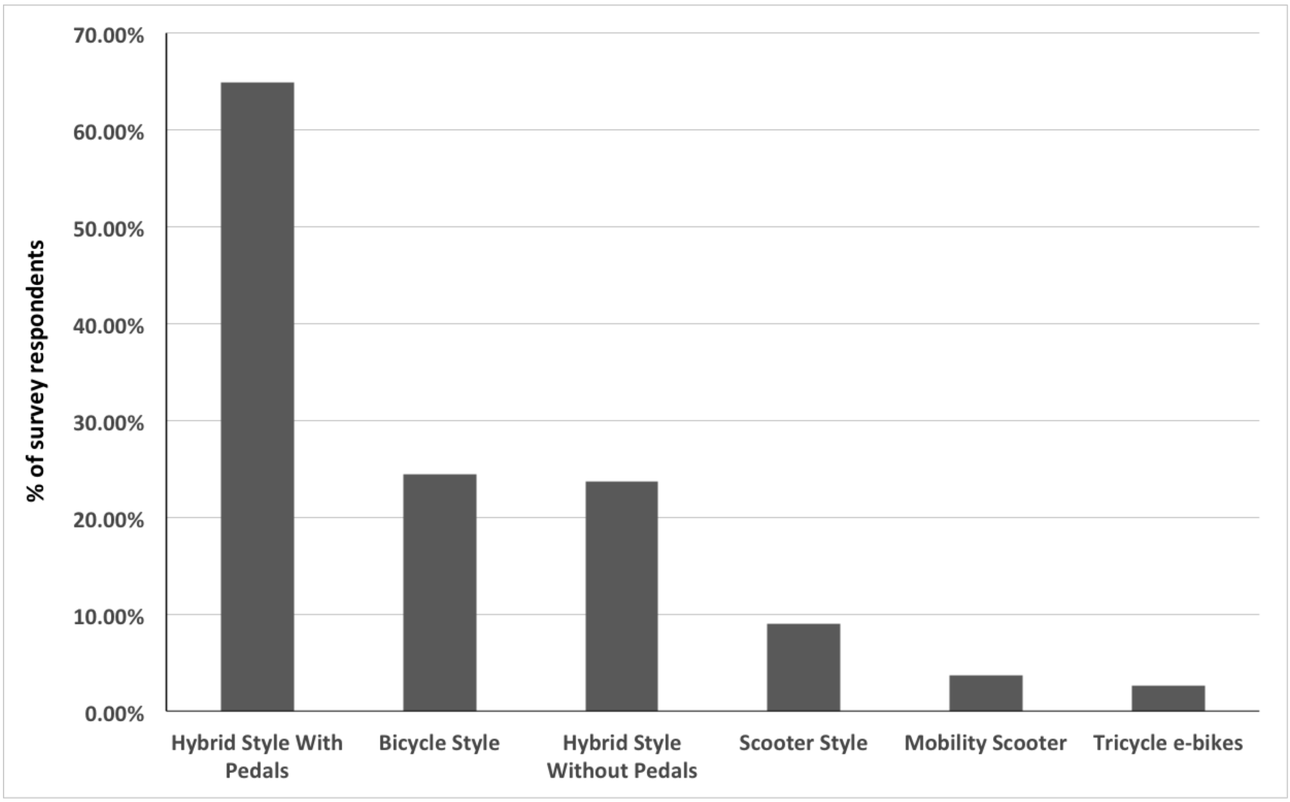
Figure 4 Attitudes for electric bicycle adoption: Nanjing survey



(Sample size, 403 electric bicycle users; note respondents could select more than one attitude if they wished.)

As shown in Figure 4, the majority of electric bicycle users believe that they would have a feeling of freedom by travelling with electric bicycles (49% of responses), followed by practical usage and having a sense of relaxation. Around 26% of electric bicycle users think that they have mitigated climate changes. Other positive associations with electric bicycle adoption are the feeling of being fashionable and feeling as a part of citizens' community. These positive associations imply an intrinsic and personal feeling about electric bicycles.

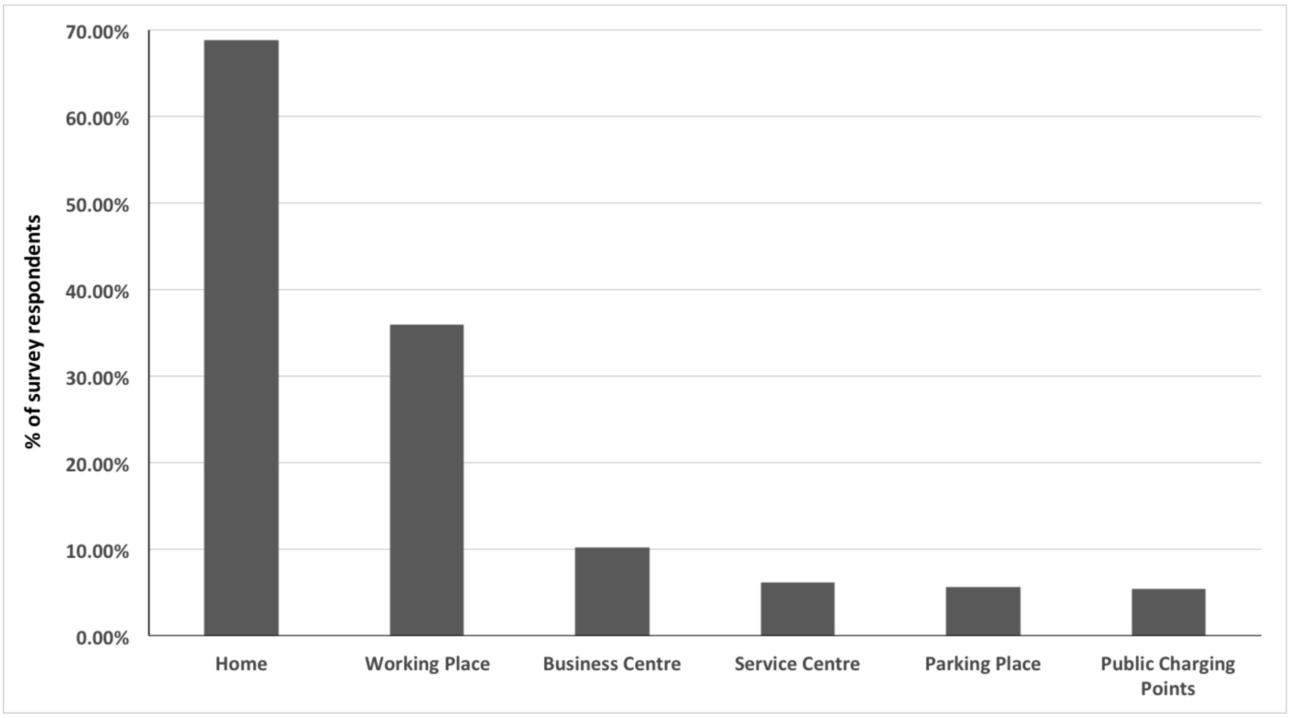
Figure 5 The types of electric bicycles which electric bicycle users current use: Nanjing survey



(Sample size, 379 electric bicycle users; note respondents could select more than one type if they wished.)

In Nanjing the most prevalent electric bicycle type is the hybrid style with pedals, which occupies more than 60% of the sample (Figure 5). The bicycle style (known in Europe as a ‘pedelec’) and hybrid style without pedals share the same portion of the sample (more than 20%). The contribution to the market share from scooter-style electric bicycles, mobility scooters and tricycle electric bicycles is trivial. The prices of electric bicycles mainly range from CNY 2,000 (GBP 200) to CNY 3,000 (GBP 300), with nearly 50% of response rate. Some 22% of electric bicycles are below CNY 2,000, while 28% of electric bicycles are above CNY 3,000. The prices of electric bicycles are closely related to electric bicycle styles. Assuming electric bicycles are equipped with lead acid batteries, the prices of different electric bicycles styles are sorted from highest to lowest as follows: mobility scooter or tricycle electric bicycles, scooter style, hybrid style, and bicycle style. It is noteworthy that if lead acid batteries are replaced by lithium-ion batteries, the price will further increase by CNY 700 (GBP 70). The result may suggest that the hybrid style electric bicycles are at the middle range of electric bicycle price. Also, the majority of electric bicycle users expect to pay CNY 3,000 or below to get an electric bicycle.

Figure 6 Battery charging place: Nanjing survey

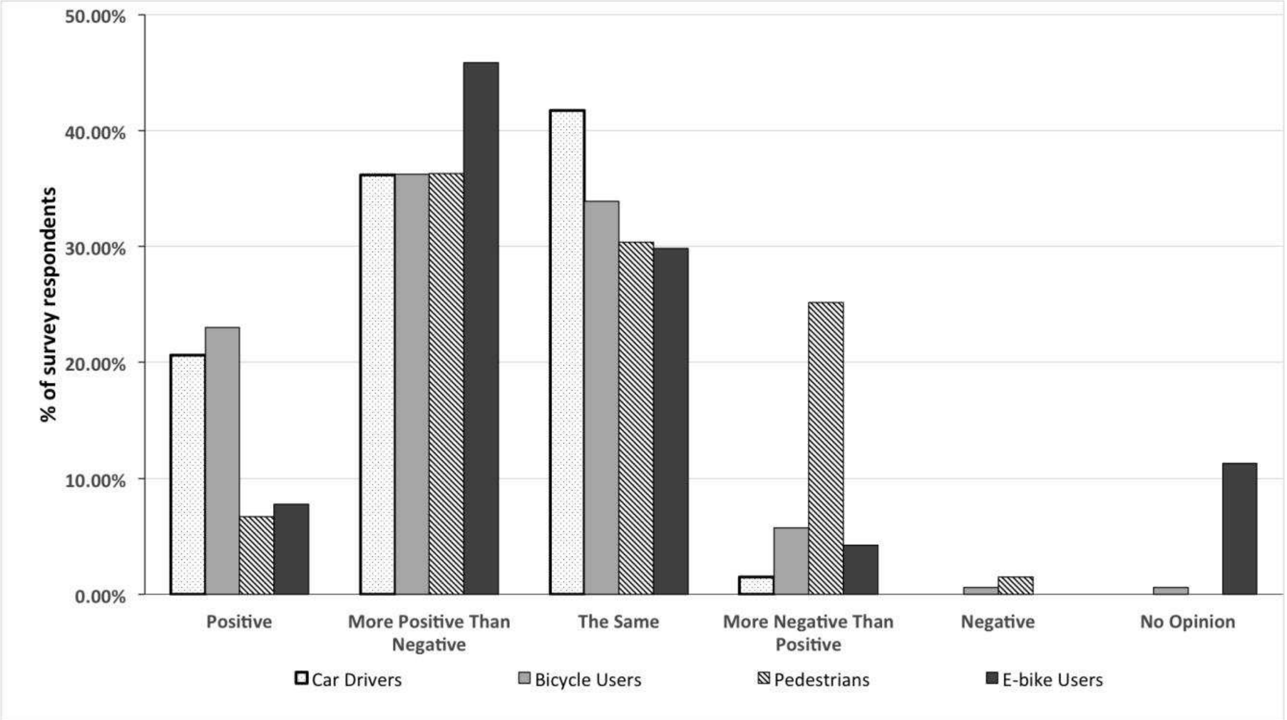


(Sample size, 395 electric bicycle users; note respondents could select more than one battery recharging location if they wished.)

As shown in Figure 6, the overwhelming majority of electric bicycle users charge their electric bicycles at home (nearly 70% response rate), followed by the workplace. Other charging places are the business centre, service centre, parking places, and public charging points with less than 10% of responses. The results indicate that electric bicycles have certain degree of flexibility in terms of charging because the battery can be pulled out of the frame. However, this result also exposes the problem that public charging services are in short supply. Electric bicycle charging time normally requires at least three to four hours. Some 50% of electric bicycle users charge the batteries during 20:00 to 24:00, which is the peak time of electricity consumption. Only 11% of electric bicycle users charge batteries during the off-peak time (0:00-5:00). Therefore, electric bicycles can be considered as a normal household appliance.

According to our survey, 70% of car drivers, nearly 60% of bicycle users, and 80% of pedestrians have electric bicycles in their households. The result indicates that electric bicycles have reached regime level in Nanjing. In other words, electric bicycles have already been widely accepted in the families in Nanjing regardless of their household income or education level. Figure 7 illustrates the attitudes of different categories of mode user to the development of electric bicycles as a mode of transport.

Figure 7 Attitudes to electric bicycle development: Nanjing survey



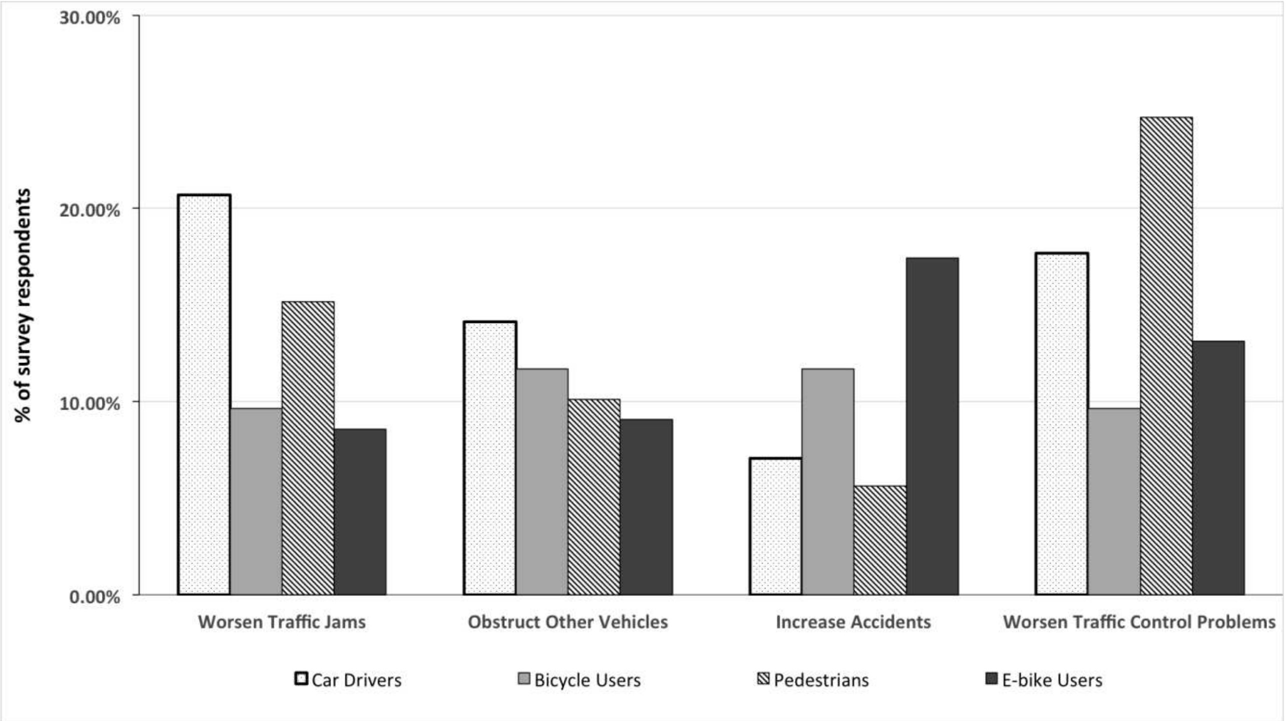
(Sample size: 199 car divers, 174 bicycle users, 135 pedestrians, 398 electric bicycle users)

The one-way ANOVA result revealed that a statistically significant difference exists among the vehicle user groups in relation to their attitudes to electric bicycle development, with F (3.,906)=14.23, p < 0.0001. The opinions of citizens on electric bicycles have a significant impact on the transport system and the prospective of electric bicycle development. In general, the attitudes of various groups of travellers to electric bicycles are positive.

The percentage of car drivers and bicycle users agreeing that electric bicycles have a positive impact on the transport system or have more positive impact than negative impact reaches 60%. In terms of negative impact, pedestrians have the highest portion (more than 20%) that tend to think that electric bicycles have more negative impacts, but few of other groups hold negative attitudes. So the pedestrians hold more negative perceptions of electric bicycle useage.

Combining the finding of this subsection and the preceding subsections, we can find that electric bicycle transition is certainly inserted as a significant feature in the entire transport system. We can see that: 1) The majority of car drivers, bicycle users, pedestrians, and electric bicycle users have positive attitudes toward electric bicycles in general, and 2) electric bicycles have been adopted widely in many aspects of the daily life setting, including commuting, going shopping, picking up children, as other transport modes in the regime level such as buses, metro, bicycles and walking. In contrast, Figure 8 explores the negative aspects of electric bicycle development as a mode of transport.

Figure 8 The negative impact of electric bicycles on the transport system: Nanjing Survey



(Sample size, 200 car divers, 198 bicycle users, 200 pedestrians, 399 electric bicycle users)

A Chi-square test verifies that there exists statistically significant differences among subsample groups (car drivers, bicycle users, pedestrians, and electric bicycle users) in relation to their opinions on positive and negative impact of electric bicycles on the transport system.

More than 40% of car drivers stated that electric bicycles provide a greener and more convenient way to access urban areas. Specially, more car drivers responded that electric bicycles are very quiet compared with responses from bicycle users, pedestrians, and electric bicycle users. In terms of worsening traffic issues, car drivers have the second largest response rate claiming that electric bicycles are more likely to worsen traffic jams and obstruct other vehicles. Nonetheless, car drivers do not believe that electric bicycles are the main factor causing accidents. The question of electric bicycle use and road traffic deaths and injuries is not explored in this paper, though data were collected on this issue.

There are more female electric bicycle users than males that were travelling by bicycle and walking previously. On the other hand, male travellers present strong preference for motorcycles. In our sample, 24.89% of male travellers previously used motorcycles, much more than females (9.13%). Therefore, female travellers preferred low-speed vehicles compared with males. This finding is also supported by the future suggestion of electric bicycle development: only 20.1% of female respondents suggested that electric bicycle speed should be increased, while 31.6% of male respondents expected to have high-speed electric bicycles.

Another significant difference between female and male respondents is in terms of metro usage. 19.9% of female electric bicycle users used the metro previously, while only 9.9% of male respondents travelled by metro before. In terms of the choice of buses and private cars, there is not much difference between female and male respondents, indicating that gender factors do not influence the transition from bus and private car users. More female respondents use electric bicycles for shopping, leisure, visiting friends and accessing the metro in our data (not shown). The result may indicate that female respondents have more diverse activities than male respondents. Also, the result could suggest that electric bicycles pervade deeper in the life setting of female respondents. In other words, the advantages of electric bicycles better fit the desired travel demand of female respondents. In addition, the electric bicycles could satisfy the demand of various trip purposes. The result may reinforce that electric bicycles have the potential to increase the mobility radius of female citizens.

Now we investigate why citizens abandoned the vehicles or modes dominant in Nanjing (Table 2), such as bicycles, public transport, walking, metro and motorcycle, to adopt an innovative vehicle. Table 2 lists the significant relationships between mode choice and electric bicycle adoption purposes, and the significant relationships between mode choice and electric bicycle adoption reasons are listed in Table 3. It is noted that Table 2 and Table 3 only list the mode choice which shows a significant relationship with electric bicycle adoption in our test, so the electric bicycle users who transferred from bicycles are not listed in the tables, because they do not have statistically significant relationship with specific electric bicycle adoption purposes and specific electric bicycle adoption reasons. The relationship significance test results are shown (see

Table 2 and Table 3):

Table 2 Travel Characteristics, vehicle transition and purpose: Nanjing survey

Previous vehicle	Transition Purpose	Correlation	P-value
Bus	Commute	0.8408	0.000466
Walking	Travel connection to metro	0.7051	0.0388
Metro	Pick up children	1.0586	0.0193
	Leisure	0.9371	0.0126

Table 3 Travel Characteristics, vehicle transition and reasons: Nanjing survey

Previous vehicle	Transition reasons	Correlation	P-value
Bus	Flexible trip time	1.0303	0.00006
	Saving time in the traffic jams	1.1774	0.0006
	High accessibility	0.7487	0.00136
Walking	Effort saving	0.4935	0.0298
Metro	Low purchase cost	1.2471	0.0000009
	Effort saving	0.776	0.0113
	Saving time in the traffic jams	0.8449	0.00707
	Environment friendliness	0.9750	0.00208
Motorcycle	Low operation cost	0.6189	0.0252

In our sample, 39% of electric bicycle users transferred from the bus, which is the second most frequent response. The electric bicycler users transferring from buses tend to use electric bicycles for the purpose of commuting. The transition reasons include flexible trip time, saving time in traffic jams, and high accessibility. In our sample, 30% of electric bicycles users shifted from walking, and they mainly use electric bicycles for travel connection to the metro. The transition motivation is to save effort, which may also imply that the number of metro stations is not sufficient to cover the urban area in Nanjing. Hence, electric bicycle adoption is also a complement to the public transport. The electric bicycler users transferring from the metro tend to use electric bicycles for picking up children, leisure and travel connections. The transition reasons are given as follows: low purchase cost, effort-saving, saving time in the peak travel times, and environmental friendliness. Firstly, electric bicycles offer personal motorised mobility with a low purchase cost. Secondly, electric bicycles provide a door-to-door service, saving the trip time from home to other destinations.

The electric bicycler users transferring from motorcycles tend to keep using electric bicycles. The main motivation is the low operation cost. In China, the average gasoline price is 6.70 CNY/L on 3rd, August, 2015 (Global Gasoline Price, 2015). Generally, the oil consumption of a 125cc motorcycle per 100 kilometres is 2.5 litres, which costs 16.875 CNY. The average travel distance of an electric bicycle carrying 48V and 12Ah battery is 44 km with full charge (Bicycle Industry Information Centre, 2011). One full charge of an electric bicycle consumes 0.6912 kWh. In this case, the electricity consumption per 100 km of the electric bicycle is 1.571 kWh. In Nanjing, the electricity price of off-peak time (21:00-8:00) is 0.3583 CNY/kWh, while the price of peak time (8:00-21:00) is 0.5583 CNY/kWh. Therefore, the highest rate of electric bicycle charging is 0.8771 CNY, and the lowest rate is 0.5625 CNY, which is nearly 30 times less than that of motorcycle operation cost. Although the travel distance may decrease if batteries are used for more than one year, the operation cost of electric bicycles is still very low compared with motorcycles.

Discussion and conclusions

It is evident that electric bicycles are not necessarily a replacement for cars on a substantial scale, but are rather displacing the 'benign' modes of walking, traditional bicycling, and using the bus. In our survey, 12% of private car users also adopted electric bicycles to improve their personal mobility in Nanjing, which may be indicative of growing congestion and the problems of parking in the city centre. Put another way, the majority of electric bicycle users are switching out of more limited modes (such as walking), or from modes that are generally regarded as environmentally benign compared with say cars (e.g. buses, traditional bicycles). Thus, there is a fairly baleful or regressive effect of electric bicycle adoption.

Furthermore, there is a very different challenge to encourage car users onto electric bicycles faced by locations outside China, with a highly entrenched automobility culture. In the context of China, however, there has arguably been a significant ‘opportunity benefit’ in that electric bicycle users may reduce the strain on public transport systems and on road networks. The additional air quality benefit for urban populations of zero emissions in use has not been calculated, but again is probably significant.

In addition, this research helps reveal the complex characteristics of electric bicycle users in Nanjing city, emphasizing the salience of user behaviour. Electric bicycle users are mainly career-age commuters and have much higher average education level than that of entire Nanjing city. The trip time of electric bicycles usually ranges from 20 minutes to 30 minutes. The most popular electric bicycle type is hybrid style with lead-acid battery. Also, electric bicycle users prefer to buy electric bicycles from local shops rather than on-line shopping.

The reasons why respondents choose electric bicycles include low cost, effort-saving, flexible trip time, time-saving in traffic jams, and high accessibility. User attitudes also affect the reason why respondents choose electric bicycles, that is, travelling by electric bicycles has sense of freedom and provides practical usage. The attitudes to the rapid growth of electric bicycles among the citizens (car drivers, pedestrians, and bicycle users) tend to be positive. Most of the citizens admit the advantages of electric bicycles such as environmental friendliness, convenience for daily use, road resource saving, and noise reduction - which is ironic given that electric bicycles seem to be substituting for more environmentally benign modes of transport. However, they also suggest that electric bicycle users should enhance their safety awareness. In terms of infrastructure, they advocate to widen bicycle lanes.

Safety and battery are the main negative factors impeding further electric bicycle transition. The two issues also underpin policy attempts to restrict or ban electric bicycles. Citizens claim that electric bicycle users have various traffic violation behaviours, including running red lights, overloading, excess speed, and sudden lane changes. Also, electric bicycle users readily come into conflict with motor vehicle users and pedestrians. In our sample, most of the electric bicycles carried lead-acid batteries, which can result in lead pollution if inadequately recycled. Also, due to the nature of lead-acid batteries, electric bicycle users claim that electric bicycles are heavy and are difficult to recharge, which can cause user anxiety in social settings.

All of these findings can contribute to further policy development, inside and outside China, with respect to supporting the growth and continued use of electric bicycles in urban areas. Electric bicycles, and related lightweight and electric power machines such as electric rickshaws or tricycle delivery vehicles, would appear to be a 'natural fit' to the transition towards a low-carbon economy, as well as much healthier urban environments. Moreover, from a resource-intensity perspective it seems certain that a 30kg electric bicycle is rather more efficient at transporting one or two passengers than a 1,400kg electric car. However, policy-makers probably need to shift priorities from the car or from mass-transit services, or at least give independent consideration to the means by which electric bicycle use can be protected – for example with dedicated electric bicycle lanes, secure public recharging facilities, secure parking provision, prioritisation at road junctions, and other measures.

In sum: electric bicycles seem to be well embedded in the current transport regime, promoting path interdependence rather than a true departure from carbon-centred, motorized forms of transport.

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