IETI Transactions on Engineering Research and Practice

http://ieti.net/TES

2021, Volume 5, Issue 2, 18-30, DOI 10.6723/TERP.202112_5(2).0003

ERGONOMIC ASPECTS OF E-BIKE TRANSPORT

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Abstract: The paper analyzes the ergonomic aspects of e-bicycle transport considering it from two aspects: the development of cycling in the function of passenger transport, as well as in the function of goods transport in urban city areas. Based on the analyzed ergonomic aspects of e-bicycle transport, it is possible to come to conclusions related to the planned and continuous development of cycling.

Keywords: e-bike; transport; ergonomic aspects.

1. INTRODUCTION

In the last few years, cycling has experienced a great expansion of use. The significant increase in the use of motor vehicles and their impact on the ecology, economy and health of the population has led to an increase in interest in the promotion of cycling as an alternative mode of transport. Having in mind the above, in many European cities, the "agenda" includes the planned and continuous development of cycling, and this is considered from two aspects: the development of cycling in the function of passenger transport, as well as in the function of transporting goods in urban areas.

The topic of this paper is the research on ergonomic aspects of e-bicycle as a mode of transportation usage. In order to provide the comprehensive review on the subject of investigation, a thorough search of available online databases was conducted. Multiple searches were performed using different search strategies. The research was conducted using electronic databases (Web of Science, Science Direct, etc.), as well as, web search engine Google Scholar. Also, individual journals (Transportation Research Record, Accident Analysis & Prevention, Journal of Transport Engineering, ITE Journal, etc.) were covered. This paper discusses literature review as a methodology for conducting research related to bicycle traffic, cargo bicycles, e-bikes and cargo e-bikes, with special reference to e-bikes in traffic and transport. Thus, the synthesis of research findings, evidence on a meta-level and uncovering areas in which more research on ergonomic aspects of e-bicycle transport is needed were analyzed and presented.

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2. BICYCLES AND E-BICYCLES IN TRAFFIC AND TRANSPORT

Based on research conducted in the project "Cycle logistics", it is estimated that 51% of all trips made by motor vehicles in European cities, which involve the transport of goods, can be replaced by bicycles or cargo bicycles [47].

Cycling in China, according to studies, can replace up to 60% of travel by other modes of transport [58], to the dominant replacement of bus travel [4], depending on the quality available by public transport services [21]. More than two thirds of all bicycle trips (about 69%) are "private" trips (shopping, travel, etc.), while one third (about 31%) are commercial transport (deliveries, services and business trips). By analyzing the purpose of "private travel" it can be concluded that, as much as 40% is done for shopping, 21% of travel is done for services and work, 17% of travel is done for leisure, 12% for work or school, and 10% for the purpose of delivery of goods. Daily deliveries make up 85% of the trip. In urban areas, supermarkets are usually located in the area of "basin" of bicycle traffic. About 10% of travel refers to consumer products (e.g., clothes), and only 5% refers to goods such as furniture, equipment, etc. A survey conducted in Graz in 2009 indicates that 80% of goods in a sample of 1,600 purchases could be transported in a bicycle basket, 14% of goods would have to be transported in a bicycle trailer due to the quantity, and for 6% of goods, ~~purchase of~~ a car was necessary to transport goods home.

According to the above mentioned, it can be concluded that 99% of cycling takes place mainly within the inner-city zone. Analyzing the transport of shipments by bicycles and cars, it can be concluded that the delivery by bicycles is most represented at a distance of 3 km, while the delivery of shipments by car is most represented at a distance of 6 km [18]. Between 19% and 48% of the kilometers traveled, in order to deliver goods, which are currently performed by motor vehicles can be replaced by cargo e-bikes. Shipments at "short" and "medium" distances (less than 15 km), within the inner-city zone, are especially unpopular for carriers who transport by motor vehicles, due to the high risk of congestion, which can lead to losses [18].

Ergonomic aspects of bicycle and e-bicycle transport have been considered in the literature through several aspects. Physical and spatial aspects are often mentioned to explain differences in cycling participation between countries or cities [3]. Other important factors are: climate, topography, city size, urban appearance, cycling infrastructure, population density or other population characteristics such as the share of youth and students in the total population, and ethnicity. But often, a combination of several factors is the case. Over the past decades, studies have focused on e-bike design and performance, sales trends, user demographics, safety, the environment, with only recently attention focused on shopping motivation, impact on travel behavior, health, and to other benefits [15].

2.1. Ergonomic Aspects of E-bike Transport

Ergonomic aspects of transport are analyzed from the aspect of:

- E-bikes observed according to the:
- geographical position of countries and cities;
- culture of countries and cities;
- purpose of the trip;
- length of the trip;

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- climatic factors and weather conditions;
- age of the user;
- gender of the user;
- psychological factors of the users: attitudes, social norms and habits;
- socio-economic factors of users;
- safety of e-bikes in traffic and transport;
- cycling infrastructure;
- e-bikes in terms of distances, roads and infrastructure;
- terrain configuration and the quality of the surfaces;
- e-bikes observed through income or education of users;
- e-bikes viewed through political support for promotion purposes.

2.1.1. E-bikes Observed According to the Geographical Position of Countries and Cities

Bicycle use varies from country to country, from modest to enormous use. Many available research papers on cycling highlight clear differences between the role of cycling in the transport system of different countries, and even in different regions or cities within the same country [15]. For example, Pucher and Buehler [39] claim that the share of cycling in the total number of trips is about 1–2% for countries such as the USA, Canada, Australia or the United Kingdom, while countries such as Germany have a share of 10%, Denmark 18 %, and the Netherlands as much as 27%. The importance of distance in cycling is reflected in the relationship between the size of the city as well as the city and the way of sharing transportation. In the Netherlands, small and medium-sized cities have the largest share in cycling [28], probably as a result of the proximity of the destination.

Although the reasons for such percentages are multiple, Pucher and Buehler [39] and other authors claim that the historical development of countries and cities, as well as their different policies, explain many of the differences we see today in the application of bicycles.

Differences in bicycle use between countries can be observed in relation to cycling culture, the purpose of bicycle use, the position of bicycle riders in traffic, and in relation to the measures taken to make bicycle riders safer [57].

2.1.2. E-bikes Observed According to the Culture of Countries and Cities

Inconsistent results regarding the effects of e-bike mobility from different studies conducted can be partly explained by the cultures of different countries. For example, in countries characterized by cycling culture, such as Denmark and the Netherlands, there are already optimized bicycle trips, because a larger percentage of the population already uses a bicycle [21], in some other countries such as Serbia, Macedonia, Hungary and Montenegro there are no optimized cycling trips because of a small percentage of bicycle usage.

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2.1.3. E-bikes Observed According to the Purpose of the Trip

In a study conducted by Gruber [18] it was found that 42.7% of respondents use an e-bike for the purpose of travel, while 36.5% use a bicycle for the purpose of shopping.

2.1.4. E-bikes Observed According to the Length of the Trip

By analyzing the research of Gruber [18] it can be concluded that e-bike riders in 33% of cases ride e-bike up to 5 km, from 5 km to 10 km exceed 37.3% of respondents, the distance from 10 to 15 km exceeds 14.1% of respondents, from 15 to 20 km exceeds 7.6% of respondents. This result indicates that e-bikes are suitable for long-distance travel, with the e-bike becoming a strong competitor to "medium" and "short" distances. E-bikes can encourage relatively long journeys. Engelmoer [14] suggests that, on average, e-bikes travel longer distances compared to bicycles (9.8 km vs. 6.3 km). Helms et al [23] state that the average e-bike ride is 11.4 km (compared to 7.1 km cycling).

2.1.5. E-bikes Observed According to Climatic Factors and Weather Conditions

Bad weather, seasonal restrictions, such as temperature and rainfall, or poor road conditions can negatively affect cycling. Stinson and Bhat [49] and Guo et. al. [19] state that cycling is more popular in the USA in summer, compared to other seasons. In Australia, Nankervis [32] finds that more people ride bicycles during summer and autumn, compared to winter and spring. The "decline" of cycling during the winter varies by region [49]. Regions with low winter temperatures, such as Canada and the U.S. Northeast and Midwest, have fewer cyclists riding bicycles during ~~the~~ winter, compared to regions with milder winters.

Not only do people ride a bike less in the winter, but according to Bergström and Magnusson [1], the maximum cycling distance is reduced from 20 km in summer to 10 km covered by bicycles in winter. The same study showed a similar effect for shorter distances, with only 25% of people traveling by car in summer when the travel distance is up to 3 km, while in winter this percentage is 40%.

It should be borne in mind that the seasons do not refer only to the weather conditions, but also to the hours of daylight. According to Heinen et. al. [22]. Stinson and Bhat [49] and Gatersleben and Appleton [17] darkness has a negative effect on cycling. In particular, women cyclists are more careful to ride a bike during the day, compared to men [1-4].

While cyclists consider rain to be the most negative weather aspect, a number of other weather-related factors affect bicycle use, including temperature. Researches indicate that during one year, on average, there are over 100 rainy days. In addition to rainy days, cycling is also affected by temperature.

As for another climate-related factor, temperature, [38] indicates that other factors play a more important role. They base their claim on the fact that Canadians ride bicycles more than Americans, despite the colder climate. An increase in temperature results in an increase in the percentage of cycling [34]. Nankervis [32] finds that cyclists perceive colder temperatures, which are more

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uncomfortable than higher temperatures. Surprisingly little is known about the effect of wind on cycling, despite the fact that wind affects the amount of effort a cyclist puts in while riding [33].

Heinen et. al. [22] considers that future research should focus not only on climate and weather conditions, which cannot be changed, but also on measures and facilities that could reduce the negative effects of weather.

2.1.6. E-bikes Observed According to the Age of the User

The findings suggest that the use of e-bikes erases differences in the age of the rider and in the frequency of cycling use [21]. Namely, the results indicate that the use of e-bikes by young people, generally has positive effects on the environment, as a consequence, while in the elderly the use of e-bikes increases mobility and thus contributes to their health and well-being. Older people use an e-bike for the purpose of re-riding, while younger people use an e-bike to increase the distance traveled on an e-bike. Younger people are mostly e-bike riders who use an e-bike for the purpose of performing daily tasks, while older people are e-bike riders who use an e-bike for recreational purposes. Research has confirmed that older people are more likely to replace walking with e-bikes, while younger people are more likely to replace traveling by car [21].

2.1.7. E-bikes Observed According to the Gender of the User

Women are underrepresented as bicycle riders, compared to men, in many countries [13]. Most research concludes that men ride bicycles more than women [11]. Howard and Burns [24] indicate that women cross 6.6 km on average, while men cross 11.6 km. This may be related to locations and activity choices that vary by gender. Haustein and Møller [21] found that e-bike riders are more often women, more often belong to age groups older than 50 years and are less likely to be among people younger than 18 and up to 40 years as well as and somewhat better educated.

Cauwenberg et. al. [53] came to the conclusion that there are some significant gender differences in the elderly in the purpose of using e-bikes. Cycling, for recreational purposes, was significantly more prevalent among men, as many as 69.1%, compared to women, with 58.3%, while using e-bikes for visiting purposes was significantly more prevalent among women, (52.1%), compared to men, with a percentage of 39.4%. Use of e-bike for social activities (going to a sports club, etc.) was also more common in women, with 43.2%, while in men this percentage is 33.9%.

2.1.8. E-bikes Observed According to the Psychological Factors of the Users: Attitudes, Social Norms and Habits

Heinen et. al. [22] state that recent research has focused on the influence of attitudes and other psychological factors on travel behavior and the choice of mode of transportation.

People's attitudes towards car use are generally more positive than people's attitudes towards bicycle use [11]. Furthermore, Dill and Voros [11] show that a positive attitude towards cycling increases the probability that the bicycle is used or ridden.

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Heinen et. al. [22] indicate that social norms do play an important role. It is assumed that there is a link between other social aspects, such as the public image of cycling and the general attitudes towards cycling within the culture of a particular country or region and the use of e-bikes [37]. Dill and Voros [11] state that colleagues at work who ride a bicycle can influence colleagues who do not ride a bicycle to start using a bicycle, which is likely to happen. Besides, if employers offer financial support for the use of bicycles, which can be considered as evidence of a positive attitude towards cycling, there is a greater chance that employees will ride a bicycle. Gatersleben and Appleton [17] report that individuals who do not travel by bicycle see more obstacles to cycling than cyclists. Compared to non-cyclists, cyclists see more opportunities to ride a bike. Moreover, the use of bicycles in childhood can influence the behavior of adults in the role of bicycle riders [11]. Surprisingly, however, there is no evidence of a relationship between cycling in adulthood and their past behavior - cycling to school.

Not only do individuals' cycling habits influence their cycling behavior. Verplanken et. al. [55] and Ministerie van Verkeer en Waterstaat [29] found that the habit of using other modes of transport negatively affects the use of bicycles.

2.1.9. E-bikes Observed According to Socio-economic Factors of Users

Car ownership has a strong negative impact on the share of cycling [34]. Stinson and Bhat [49] conclude that not owning a car increases the frequency of cycling. Some research participants state that they need a car to work as a reason for not to riding a bicycle [30].

A person's working status affects the use of a bicycle. Among employees, part-time workers travel more often by bicycle to work than full-time workers, perhaps because they live closer to their place of work. Having a high social status and having a young family reduces the likelihood of using bicycles [45].

2.1.10. Safety of E-bikes in Traffic and Transport

Very little is known, especially in Europe, about the safety of e-bike riders, the way they behave in traffic, as well as, the mechanism of accidents [7]. The possibility of accidents, as well as injuries are the main obstacles for cycling [37].

In 2005, 44% of deaths of cyclists in Europe were among cyclists over the age of 60, with more than 60% of cyclists over the age of 60 in Finland and Sweden. The highest number of deaths in children was observed in the age group from 6 to 14 years. Injuries can be more serious in rural than urban roads, where higher vehicle speeds can make overtaking maneuvers particularly dangerous [51]. On city roads, motor vehicles most often encounter cyclists at intersections. In contrast, on rural roads, motor vehicle drivers are most likely to interact with bicycles during overtaking maneuvers, while riding significantly faster than bicycle drivers [54].

When it comes to cycling, most traffic accidents and injuries, are the result of falls or collision with one vehicle. Motor vehicle accidents involving cyclists increase the risk of hospitalization by almost four times and account for more than 90% of deaths, including 95% of child deaths.

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Countries with many bicycles in traffic have a low mortality rate (Germany and the Netherlands), while countries with less bicycles have a high mortality rate [57]. Cherry [10] investigating the safety of e-bikes in China, came to the conclusion that e-bike riders have a slightly higher mortality rate compared to conventional bicycles riders.

2.1.11. Cycling Infrastructure

The most common problem for cyclists around the world is our modern traffic system, which is designed mainly from the perspective of car users, resulting in a lack of a network of road infrastructure intended for cyclists. The system often does not consider the following characteristics: the cyclist is vulnerable (in case of a traffic accident), flexible (in the form of behavior), unstable (can fall off a bike), inconspicuous (difficult to see), has different abilities (due to the large population using the bike), motivated to reduce energy consumption, with cyclists often feeling like intruders in the traffic system rather than as an integral part of the system. These key characteristics can also occur in a combination of several "factors". Roads should be designed and maintained in accordance with the requirements of cyclists, and riders should be taught to treat cyclists as legitimate road users [16].

The issue of cycling infrastructure is related to traffic safety. We identify two types of security: objective and subjective security. Objective safety is "real" safety for cyclists, measured in terms of the number of bicycle incidents per million inhabitants. Subjective security refers to how individuals perceive security, and is generally measured in terms of the stated security experience of users or other participants [22]. Klobucar and Fricker [25] argue that the effect of cycling infrastructure on objective safety remains unclear, but that subjective levels of safety are higher when dedicated bicycle facilities are "present".

It was found that the existence of a larger number of bicycle paths resulted in a higher percentage of bicycle use [8]. Construction of bike paths has increased the share of bicycles in some locations by 1-2%, compared to a small increase in other places. According to Dill and Voros [11], people tend to say that they ride a bike more often if they have bike paths, and when they are easily accessible and well connected to important destinations. Dickinson et. al. [6] conclude that providing bike paths would be popular among employees. However, Moudon et. al. [31] state that the presence of a higher percentage of cycling infrastructure does not have a significant impact on the level of cycling. Wilkinson [59] believes that most people will not try to ride a bicycle if they are not provided with bicycle lanes or paths separate from motor traffic. Providing and adequately maintaining cycling infrastructure that will not have obstacles can reduce the percentage of traffic accidents involving e-bikes [53]. Stop signs, traffic lights and other traffic control systems are necessary to regulate traffic, but can also cause irritation due to delays. Stopping and accelerating cyclists is a disproportionate amount of effort [5]. Therefore, we can expect cyclists to avoid traffic lights and stop signs [50]. Rietveld and Daniel [43] conclude that fewer people ride bicycles in cities that have a large number of stops.

2.1.12. E-bikes in Terms of Distances, Roads and Infrastructure

When researching an individual's choice among cycling or other modes of transport, the distance or travel between locations is almost always taken into account [42]. Increasing the travel distance leads

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to an increase in the time and effort required to travel. Therefore, we would expect a decrease in the share of cycling in suburban travel and the frequency of commuting by bicycle [22].

Efforts to promote cycling have been reflected in the construction of bike paths and lanes. Pucher [37] states that all cycling facilities must be supplemented in comprehensive ways, so that all roads are subject to cycling, through physical adaptation, as well as, allowing the cyclists to use the roads for traveling.

After the implementation of separate bicycle paths, the number of cyclists increased by 15 to 20%, while the feeling of traffic safety among cyclists, due to separate bicycle paths, increased by 20 to 100% [36].

In countries with a high number of bicycles and e-bikes, such as most northern European countries, all barriers related to traffic safety and infrastructure have been overcome, thus enabling the maximum benefits of the use of e-bikes [35].

Heinen et. al. [22] considered that distance can be a frightening factor for cyclists and has a negative impact on individuals' decision to ride a bicycle. Little is known about the effect of distance on cycling frequency. Factors that contribute to shorter road distances, such as denser network layout, higher density and mixed land use, have a positive impact on cycling.

2.1.13. E-bikes Observed According to the Terrain Configuration and the Quality of the Surfaces

Little research has been conducted on the effect of surface quality on e-bike use. Existing literature suggests that older people, women, and experienced cyclists attach more importance to a smooth surface [48].

A large number of studies have examined the relationship between the environment and behavior during travel. This behavior changed during the COVID-19 virus period [60, 61]. Although we know a lot about the effects of the environment on cycling, certain aspects related to the landscape, such as hilly terrain, which seems to be particularly important for cycling, have been insufficiently researched in studies of mode choices [46].

Plazier et. al. [34] consider that slopes have a negative impact on bicycle use. For example, a city with slopes greater than 3% to only 5% of the area has a cycling share of 13.1% [22]. Bradford city has a cycling share of 0.8% [31], however the slopes do not have a significant impact on the share of bicycles for all trips [22]. Moudon et. al. [31] indicate the fact that the personal factors included in the study play a greater role than the environmental factors. Most cyclists in the study were recreational cyclists, who might have preferred to ride a bike on hilly terrain. Heinen et. al. [22] state that slopes have a negative impact on cycling. In one study, experienced cyclists showed an unexpected propensity for hilly environments over flat and mountainous terrain. It is not clear whether experience is an explanatory variable, or other related factors are involved. Heinen et. al. [22] found that the topography of the area can be interpreted differently, depending on the experience of the cyclist.

2.1.14. E-bikes Observed Through Income or Education of Users

In most studies, regardless of origin, people with higher incomes and/or education are overrepresented among e-bike users [36].

The relationship between cycling and income is even less clear. High incomes would be expected to have a negative impact on cycling, because overall, high incomes lead to less bicycle use [38]. However, Parkin et. al. [34] conclude that in England and Wales there is a link between lower incomes and lower participation of bicycles in order to travel to work. Dill and Voros [11] found a positive link between income and cycling. However, Guo et. al. [19] cite a negative relationship between cycling and income. Cauwenberg et. al. [53] stated that in their research, the higher educational level of users was associated with lower chances of being e-bikes users.

2.1.15. E-bikes Viewed Through Political Support for Promotion Purposes

Local authorities and communities benefit from the increased participation of cycling thanks to the relatively low investment costs for cycling infrastructure compared to other modes of transport [2].

However, it is astonishing that, despite the growing interest in politics and the academia in cycling, little attention is paid to cycling compared to other modes of transport. Klobucar and Fricker [25] believe that the key to increasing cycling may be a policy that forces drivers to respect non-motorized road users.

In the United States, the low cost of cars is crucial in discouraging almost all other modes, even walking. Low taxes on gasoline, several tolls, and ubiquitous free parking make car use almost irresistible in the United States. With a slight marginal cost to users, using a car becomes a habit even for short trips that can be crossed by walking or cycling [37].

As they noticed [56] to date, there has been insufficient political support for the adoption and implementation of "policies" related to the development of cycling. It could be argued that the decisions of the Chinese government on banning or restricting motor scooters with internal combustion engines [10] launched demand and stimulated the spread of e-bikes in the world market [44].

German, Dutch and Danish cities give priority to cyclists on certain streets and intersections and routinely use "advanced" green lights and "quiet street" roads. Some one-way streets are made two-way for cyclists, and cyclists are exempt from many restrictions that apply to motor vehicles. Some European cities have converted parking spaces into bike paths, not only to allow cycling, but also to discourage the use of cars. The adoption of such measures has led to concerted political pressure, even in cities where 20% of the population regularly rides a bicycle. Such self-restrictive initiatives still do not seem politically feasible in America [37].

Although local cycling policies are not the only factor in successfully increasing bicycle use, they play a key role in the process of increasing bicycle use in cities. Both the improvement of cycling

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infrastructure and the campaigns, initiated, supported and implemented by local authorities, are key factors in increasing the use of bicycles in cities [26].

Therefore, many national and local authorities today promote cycling in order to achieve a more sustainable transport system by reducing the negative impact of transport on the environment (among other things, greenhouse gas emissions to mitigate climate change) and by increasing the quality of life and health in cities. Some examples of related policies are well documented in the literature, with cities investing in cycling infrastructure, implementing cycling strategies, launching marketing campaigns or building new bicycle rental systems [40].

3. CONCLUSION

In the last few years, cycling has experienced a great expansion of use, so in many European cities on the "agenda" is the planned and continuous development of cycling, and viewed through two aspects: the development of cycling in the function of passenger transport and from an environmental point of view.

Based on research conducted in the project "Cycle logistics", it is estimated that 51% of all trips made by motor vehicles in European cities, which involve the transport of goods, can be replaced by bicycles or cargo bicycles [47]. According to the conducted research, it can be concluded that 99% of cycling takes place mainly within the inner-city zone. Analyzing the transport of shipments by bicycle and car, it can be concluded that the delivery by bicycles is most represented at a distance of 3 km, while the delivery of shipments by car is most represented at a distance of 6 km [18]. Between 19% and 48% of the kilometers traveled, in order to deliver goods, which are currently performed by motor vehicles can be replaced by cargo e-bikes. Shipments at "short" and "medium" distances (below 15 km), within the inner-city zone, are especially unpopular for carriers who transport by motor vehicles, due to the high risk of congestion, which can lead to losses [18]. However, although the most advanced traffic control systems are being deployed worldwide in the past few decades, they still lack proper integration of non-motorized (i.e., bicyclists) users [62]. In the future, with fully automated vehicles, the integration of non-motorized users in urban traffic control procedures will be viable [63].

Ergonomic aspects of e-bicycle usage in traffic and transportation have been considered in this paper. Several ergonomic aspects were analyzed: e-bikes use with respect of geographical position of countries and cities, culture of countries and cities, purpose of travel, the length of travel, climatic factors and weather conditions, income or education of users; age, users psychological characteristics: attitudes, social norms and habits, socio - economic factors of users, Safety of e-bicycles in traffic and transport, Cycling and road infrastructure, travel distances, terrain configuration and quality of areas for movement. This framework could serve for preliminary engineering analyses, planning ergonomics interventions, as well as, for gaining political support for the purpose of promotion of e-bikes usage.

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