Traffic & Transportation

Assessing the Effect of Shared Mobility on Transport Energy in a University Campus – Focusing on Young College Students in Ningbo, China

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Original Scientific Paper
Submitted: 10 Apr 2024
Accepted: 28 Aug 2024

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Publisher:
Faculty of Transport and Traffic Sciences, University of Zagreb

ABSTRACT
This study focuses on understanding the effects of shared mobility on travel behaviours and transport energy in the university campus. Using survey data collected from college students in Ningbo, China, a substitution model was developed to identify changes in travel modes with the introduction of shared mobility on college campuses and to quantify its impact on net energy saving. Considering the average time travelled and the life cycle energy unit of the trip, the before-and-after analysis was conducted to determine the travel behaviours and related transport energy of college students in 2016 and 2019. Compared with the data of 2016 when no shared mobility was introduced, 2019 data revealed three changes in travel behaviours. First, although the total number of trips per person decreased slightly, the trip distance increased in 2019. Second, the energy for trips by each student increased by 25% from 19,809 KJ in 2016 to 24,897 KJ in 2019. Third, the overall energy efficiency of the trips decreased. In conclusion, the effect of shared mobility introduced in the university campus on reducing the transport energy of college students has not been satisfactory.

KEYWORDS
shared car; college campus; student; energy consumption; travel behaviour.

1. INTRODUCTION

Economic development and improved living standards have contributed to an increasing demand for automobile transport in China. The number of automobiles has doubled in just two years, and it was 412 million in 2022 [1]. A great growing scope continues to exist for the automobile transport sector in China because the number of passenger cars per thousand people is low. Compared with 552 cars per thousand people in developed countries such as Germany, car ownership in China is only 118 per thousand people [2]. The growing demand for automobile transport has contributed to more traffic jams in cities, thereby causing a huge loss, including loss of time value, increased fuel consumption, negative impact on the ecological environment and economic losses. The traffic congestion-induced annual losses in Beijing reach up to 70 billion yuan (8.9 billion EUR), including time loss, fuel loss and environmental costs [3]. The annual cost of traffic jams in Beijing reached 8,717 RMB yuan (estimated at 1,109 EUR) per citizen in 2016.

Many policies and technologies have been developed to solve the traffic jam problem. The basic reason for traffic jams is the very high number of vehicles on the roads. Therefore, policies aimed at reducing the number of vehicles can be an effective solution to this problem. Many cities have implemented policies to reduce the number of private vehicles. For example, in Shanghai, the auction policy for the licence plates of private vehicles was implemented in 1994. The higher the bidding price, the higher the possibility of winning licence plates. The average bidding price per licence plate reaches 89,637 RMB yuan (11,426 EUR). Although this policy is effective in controlling the number of private vehicles, the demand for travel and the need for higher living standards remain unfulfilled. Is there any method that could satisfy the travel demand and reduce the number of vehicles simultaneously?

Shared mobility is expected to be one of the solutions to the traffic problem. Shared mobility is defined as the sharing of transportation services and resources among users. It includes sharing of public transport; taxis and limos; bikes; cars; ride-sharing, ride-sourcing or ride-hailing, and ride splitting; and scooter sharing [4]. Unlike ride-sharing and ownership sharing, shared mobility in China focuses on the sharing of usage. Companies provide vehicles and users themselves provide services by renting vehicles from different platforms. China encourages shared mobility and has invested considerably in the market. In 2019, the shared travel market in China reached 270 billion RMB yuan (34.4 billion EUR), with a year-on-year increase of 8.91%. Shared mobility has eventually become the trip choice for residents, especially young people. According to a report from China Auto Rent, young adults (aged 20–39 years) comprised a major percentage of shared car consumers (86.8%) [5], with college students constituting the most promising group. This is because youngsters exhibit high acceptability of new transportation modes and have a limited income. Given that a university campus is the site with the highest number of shared bike users, a college student-dominated high education zone (HEZ) is expected to be one of the main points for the use of shared mobility in China [6, 7]. However, fewer studies have investigated the shared mobility behaviours of college students in a HEZ. To promote the use of shared mobility, such a study must be conducted to clarify the travel behaviours of college students in China.

Shared mobility, especially shared cars, is effective in reducing the vehicle–miles–travelled on trips. It also contributes to fewer parking spaces and traffic jams and decreases energy use and emissions [8-10]. Shared cars contribute to less emissions and congestion because they involve energy-efficient vehicles and reduce car usage [11-14]. A significantly modest reduction in the annual total mobility-related lifecycle greenhouse gas (GHG) emissions caused by car-sharing participation was estimated in the Netherlands, San Francisco and Calgary [12]. Some researchers have also argued that shared mobility is attributable to increased direct energy consumption and CO_2 emissions [15, 16]. In the city of Ann Arbor, Michigan, the use of autonomous taxis decreased commuting costs by 38%, but energy consumption and GHG emissions were 16% and 25%, respectively, higher than those with conventional solo commuting [15]. Evidence for the environmental impact of shared mobility is fragmented and scattered. After reviewing many related papers on the topic, Vélez refuted unconditional claims that shared mobility offers environmental benefits. Many factors influence the environmental impact of shared mobility, including travel behaviour, the design of shared mobility modes, how schemes are implemented and the local context [5].

What is the effect of shared mobility on travel behaviours? Does it offer environmental benefits such as energy reduction as expected? How the development of shared mobility should be promoted? More empirical studies are warranted to answer these questions in the local context of China. The research gap needs to be filled to provide credible proof to exhibit the change in travel energy consumption before and after introducing shared mobility. Considering that young people are major users of shared mobility, the present study attempted to answer the aforementioned questions in the case of Ningbo, China. Through a case study, the paper focuses on the effect of shared mobility on travel behaviours and transport energy consumption of college students on the university campus.

The remainder of this paper is organised as follows. Section 2 provides a literature review of relevant studies. Section 3 introduces the assumptions, structure and math expression of the method model. Section 4 presents a case study of Ningbo. In Section 5, the discussion is presented. The conclusion is presented in Section 6.

2. LITERATURE REVIEW

The effect of shared mobility on energy consumption and related emissions has attracted considerable research attention. Literature on this topic can be classified into two groups. One group focuses on the effect of shared mobility on energy consumption and emission by analysing survey data or other data. For example, shared mobility has been proven to be effective in reducing the negative effects of traffic and the environment in big cities. In 2016, shared mobility was estimated to save 45 million litres of gasoline and reduce 540,000 tons of nitrogen emissions in Beijing [6]. Using Beijing's vehicle trajectory data of 12,083 taxis, the environmental benefits of ride-sharing were quantified. Shared taxis saved 28.3 million gallons of gasoline and reduced the production of 186 tons of volatile organic compounds [7]. Through a scenario simulation, shared car users who abandoned private car ownership decreased their carbon footprint of transport by approximately 40% [17]. These studies have crucial implications for formulating policies related to shared mobility development. However, obtaining related data is difficult because they are not open-access. Moreover, studies often ignore the influence of socioeconomic features of individuals.

The second group of studies focused on developing models for estimating the potential effect of shared mobility on trip behaviours and the corresponding environmental outcomes. One of the widely applied models is the agent-based model. After developing an agent-based model, Fagnant and Kockelman applied it to estimate the effect of shared autonomous vehicles on the transport mode and environment. Each shared autonomous vehicle was estimated to replace 11 traditional vehicles and reduce overall emissions [18]. In another study, an agent-based model was used to simulate the influence of commutes using autonomous taxis (aTaxis) in a road network. Compared with solo tradition commuting, energy consumption and GHG emissions increased by 16% and 25%, respectively, with aTaxis commuting [19]. An integrated simulation of car-sharing, bike-sharing and ride-hailing was conducted in Zurich. Shared mobility increased energy efficiency by 7% and reduced energy consumption by 25% in the transport sector [20]. These studies have unveiled the environmental outcome of shared mobility usage through simulation travel behaviours for both present and future scenarios. These findings offer critical implications for policy-making. However, the models and parameter settings determine the accuracy of the estimation results.

Current studies have focused on the usage of shared mobility and its environmental effects at the region or city level. The effects have been found to vary across diverse cases. Some results are even conflicting because of the differences in social and economic stages of the studied cases, as reflected through the income level and consumption. To ensure that the findings are more credible by limiting the influence of social and economic factors on energy consumption, more case studies must be conducted. Moreover, limited studies have quantified the effect of shared mobility on transport energy consumption for a group of individuals with similar social and economic features, such as college students, and studies comparing the travel energy efficiency during two time periods for the group have also been limited. Identifying the change in individual travel behaviours before and after the introduction of shared mobility and its related environmental effects is crucial for devising effective policies for shared mobility development.

3. METHOD AND MATERIALS

This study evaluated the effect of shared mobility on the environment by comparing energy consumption before and after the introduction of shared mobility. The energy efficiency index was calculated to replicate the relative energy consumption for each trip, while excluding the influence of the total number of trips on energy consumption. First, considering the actual substitution relationships among trips, a three-stage constant elasticity of substitution (CES) function was applied to present personal mobility and relationships among different types of trips. Second, the number of trips was estimated because it is a key factor affecting energy consumption. Third, the energy consumption of each type of trip was estimated. Lastly, the energy efficiency value was calculated.

3.1 Expression of personal mobility

Personal mobility is determined by green and fuel trips based on active or motorised modes (*Figure 1*). Green trips are trips executed through active modes, such as walking and bicycling. Fuel trips are trips executed through motorised modes, that is, by consuming energy from other sources except the human body, such as fossil fuel and electricity. Overall, personal mobility is determined on the basis of the number of green and fuel trips. Fuel trips include trips executed using the bus, subway, taxi, private car and shared car. In total, seven types of trips were considered for each person in this study.

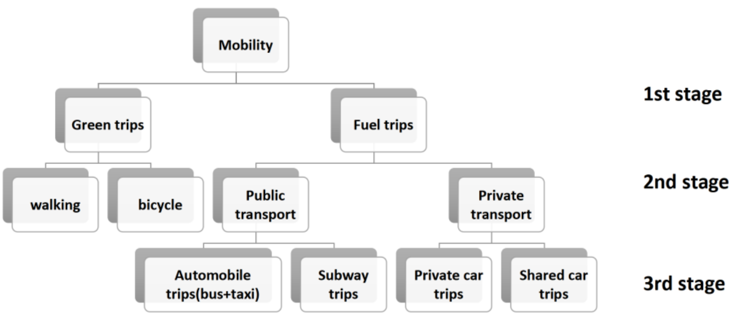

Figure 1 – Structure of mobility model

In the first stage, mobility was determined on the basis of green and fuel trips. The mobility of the person *i* indicated as u_i was determined by green and fuel trips. The substitution relationship between the demand for green trips and that for fuel trips is expressed as *Equation 1*. x_{Gi} is the demand for green trips, which reflects a composite trip of walking and bicycle trips. x_{Fi} is the demand for fuel trips, which indicates a composite trip of public and private transport trips. σ_1 is the elasticity of the substitution between green and fuel trips in the first stage. α_G and α_F represent the expenditure shares of green and fuel trips in the total transport budget, respectively.

$$u_i(x_{Gi}, x_{Fi}) = \left\{\alpha_G x_{Gi}^{(\sigma_1-1)/\sigma_1} + \alpha_F x_{Fi}^{(\sigma_1-1)/\sigma_1}\right\}^{\sigma_1/(\sigma_1-1)} \quad (1)$$

In the second stage, green and fuel trips were divided into many types of trips based on vehicle types. Substitution relationships between walking and bicycle trips and between public and private transport trips are represented as *Equations 2* and *3*, respectively. x_{GWi} and x_{GBi} represent the demands for walking and bicycle trips, respectively. x_{FPUi} is the demand for public transport trips, which indicates a composite trip of bus, taxi and subway trips. x_{FPRi} is the demand for private transport trips, which reflects a composite trip of private and shared car trips. σ_{21} is the elasticity of the substitution between walking and bicycle trips. σ_{22} is the elasticity of the substitution between public and private transport trips. α_{GW} and α_{GB} represent the expenditure shares of walking and bicycle trips in the total expenditure of green trips, respectively. α_{FPU} and α_{FPR} represent the expenditure shares of public and private transport trips in the total expenditure of fuel trips, respectively.

$$x_{Gi}(x_{GWi}, x_{GBi}) = \left\{\alpha_{GW} x_{GWi}^{(\sigma_{21}-1)/\sigma_{21}} + \alpha_{GB} x_{GBi}^{(\sigma_{21}-1)/\sigma_{21}}\right\}^{\sigma_{21}/(\sigma_{21}-1)} \quad (2)$$

$$x_{Fi}(x_{FPUi}, x_{FPRi}) = \left\{\alpha_{FPU} x_{FPUi}^{(\sigma_{22}-1)/\sigma_{22}} + \alpha_{FPR} x_{FPRi}^{(\sigma_{22}-1)/\sigma_{22}}\right\}^{\sigma_{22}/(\sigma_{22}-1)} \quad (3)$$

In the third stage, public and private transport trips are divided into many types based on the features of the vehicles. Public transport trips include trips executed by public automobile (taxi and bus) and subway. Substitution relationships between automobile and subway trips and between private and shared car trips are expressed as *Equations 4* and *5*, respectively. x_{FPUAi} and x_{FPUSi} are the demands for public automobile trips (bus and taxi) and subway trips, respectively. x_{FPRPi} and x_{FPRSi} represent the demands for private car trips and shared car trips, respectively. σ_{31} indicates the elasticity of the substitution between automobile and subway trips. σ_{32} is the elasticity of the substitution between private and shared car trips. α_{FPUA} and α_{FPUS} are the expenditure shares of automobile and subway trips in the total expenditure of public transport trips, respectively. α_{FPRP} and α_{FPRS} indicate the expenditure shares of private and shared car trips in the total expenditure of private transport trips, respectively.

$$x_{FPUi}(x_{FPUAi}, x_{FPUSi}) = \left\{\alpha_{FPUA} x_{FPUAi}^{(\sigma_{31}-1)/\sigma_{31}} + \alpha_{FPUS} x_{FPUSi}^{(\sigma_{31}-1)/\sigma_{31}}\right\}^{\sigma_{31}/(\sigma_{31}-1)} \quad (4)$$

$$x_{FPRi}(x_{FPRPi}, x_{FPRSi}) = \left\{\alpha_{FPRP} x_{FPRPi}^{(\sigma_{32}-1)/\sigma_{32}} + \alpha_{FPRS} x_{FPRSi}^{(\sigma_{32}-1)/\sigma_{32}}\right\}^{\sigma_{32}/(\sigma_{32}-1)} \quad (5)$$

3.2 Estimation of the number of trips

Individuals are assumed to maximise their utility under the transport budget constraint. Personal travel behaviours are determined in the choice process of optimising the utility under the transport budget constraint. The actual travel behaviours of individuals can be simulated by the results of utility maximisation based on the price of the trips. In this case, five maximisation problems should be solved at three stages to forecast the demand for trips at maximum utility (*Equations 6, 7, 8, 9* and *10*). In the third stage, the demands for automobile and subway trips were determined by solving the maximisation problem of public transport trips under the transport budget constraint for such trips B_{31i} (*Equation 6*). The demands for private and shared car trips were determined by solving the maximisation problem of private transport trips under the transport budget constraint for such trips B_{32i} (*Equation 7*). p_{FPUA} and p_{FPUS} represent the prices of automobile and subway trips, respectively. p_{FPRP} and p_{FPRS} indicate the prices of private and shared car trips, respectively.

$$\max_{x_{FPUAi},\, x_{FPUSi},} \quad x_{FPUi} = \left\{ \alpha_{FPUA} x_{FPUAi}^{(\sigma_{31}-1)/\sigma_{31}} + \alpha_{FPUS} x_{FPUSi}^{(\sigma_{31}-1)/\sigma_{31}} \right\}^{\sigma_{31}/(\sigma_{31}-1)} \tag{6}$$

$$s.t.\, p_{FPUAi} x_{FPUAi} + p_{FPUSi} x_{FPUSi} \le B_{31i}$$

$$\max_{x_{FPRPi},\, x_{FPRSi},} \quad x_{FPRi} = \left\{ \alpha_{FPRP} x_{FPRPi}^{(\sigma_{32}-1)/\sigma_{32}} + \alpha_{FPRS} x_{FPRSi}^{(\sigma_{32}-1)/\sigma_{32}} \right\}^{\sigma_{32}/(\sigma_{32}-1)}$$

$$s.t.\, p_{FPRPi} x_{FPRPi} + p_{FPRSi} x_{FPRSi} \le B_{32i} \tag{7}$$

In the second stage, the demands for walking and bicycle trips were determined by solving the maximisation problem of green trips under the transport budget constraint for such trips B_{21i} (*Equation 8*). The demands for public and private transport trips were determined by solving the maximisation problem of fuel trips under the transport budget constraint for such trips B_{22i} (*Equation 9*). p_{GW} and p_{GB} reflect the prices of green and bicycle trips, respectively. p_{FPU} and p_{FPR} indicate the prices of public and private transport trips, respectively.

$$\max_{x_{GWi},\, x_{GBi},} \quad x_{Gi} = \left\{ \alpha_{GW} x_{GWi}^{(\sigma_{21}-1)/\sigma_{21}} + \alpha_{GB} x_{GBi}^{(\sigma_{21}-1)/\sigma_{21}} \right\}^{\sigma_{21}/(\sigma_{21}-1)} \tag{8}$$

$$s.t.\, p_{GWi} x_{GWi} + p_{GBi} x_{GBi} \le B_{21i}$$

$$\max_{x_{FPUi},\, x_{FPRi},} \quad x_{Fi} = \left\{ \alpha_{FPU} x_{FPUi}^{(\sigma_{22}-1)/\sigma_{22}} + \alpha_{FPR} x_{FPRi}^{(\sigma_{22}-1)/\sigma_{22}} \right\}^{\sigma_{22}/(\sigma_{22}-1)}$$

$$s.t.\, p_{FPUi} x_{FPUi} + p_{FPRi} x_{FPRi} \le B_{22i} \tag{9}$$

In the first stage, the demands for green and fuel trips were determined by solving the maximisation problem of mobility under the transport budget constraint B_1 (*Equation 10*). p_G and p_F reflect the prices of green and fuel trips, respectively.

$$\max_{x_{Gi},\, x_{Fi},} \quad u_i = \left\{ \alpha_G x_{Gi}^{(\sigma_1-1)/\sigma_1} + \alpha_F x_{Fi}^{(\sigma_1-1)/\sigma_1} \right\}^{\sigma_1/(\sigma_1-1)} \tag{10}$$

$$s.t.\, p_{Gi} x_{Gi} + p_{Fi} x_{Fi} \le B_{1i}$$

Using the Lagrangian method, the solutions for the maximisation problems (*Equation 10*) are presented as the optimum demands for green and fuel trips (*Equations 11* and *12*, respectively). Thus, the maximum mobility was defined as *Equation 13.*

$$x^*_{Gi} = \left(\frac{\alpha_G}{p_{Gi}} \right)^{\sigma_1} \frac{B_{1i}}{\left\{ \alpha_G^{\sigma_1} p_{Gi}^{1-\sigma_1} + \alpha_F^{\sigma_1} p_{Fi}^{1-\sigma_1} \right\}} \tag{11}$$

$$x^*_{Fi} = \left(\frac{\alpha_F}{p_{Fi}} \right)^{\sigma_1} \frac{B_{1i}}{\left\{ \alpha_G^{\sigma_1} p_{Gi}^{1-\sigma_1} + \alpha_F^{\sigma_1} p_{Fi}^{1-\sigma_1} \right\}} \tag{12}$$

$$u_i^* = \left\{ \alpha_G^{\sigma_1} p_{Gi}^{1-\sigma_1} + \alpha_F^{\sigma_1} p_{Fi}^{1-\sigma_1} \right\}^{1/(\sigma_1-1)} \times B_{1i} \tag{13}$$

Using the Lagrangian method, the prices of these composite trips are expressed by the prices of real trips. *Equations 14, 15, 16* and *17* represent the prices of public and private transport trips, and green and fuel trips, respectively.

$$p_{FPUi} = \left\{ \alpha_{FPUA} p_{FPUAi}^{1-\sigma_{31}} + \alpha_{FPUS} p_{FPUSi}^{1-\sigma_{31}} \right\}^{1/(1-\sigma_{31})} \tag{14}$$

$$p_{FPRi} = \left\{ \alpha_{FPRP} \, p_{FPRPi}^{1-\sigma_{32}} + \alpha_{FPRS} \, p_{FPRSi}^{1-\sigma_{32}} \right\}^{1/(1-\sigma_{32})} \tag{15}$$

$$p_{Gi} = \left\{ \alpha_{GW} \, p_{GWi}^{1-\sigma_{21}} + \alpha_{GB} \, p_{GBi}^{1-\sigma_{21}} \right\}^{1/(1-\sigma_{21})} \tag{16}$$

$$p_{Fi} = \left\{ \alpha_{FPU} \, p_{FPUi}^{1-\sigma_{22}} + \alpha_{FPR} \, p_{FPRi}^{1-\sigma_{22}} \right\}^{1/(1-\sigma_{22})} \tag{17}$$

The maximum mobility u_i^* was calculated based on the actual prices of walking, bicycle, bus, subway, taxi, private car and shared car trips (*Equation 18*).

$$u_i^* = \left\{ \begin{array}{l} \alpha_G^{\sigma_1} \left(\alpha_{GW} \, p_{GWi}^{1-\sigma_{21}} + \alpha_{GB} \, p_{GBi}^{1-\sigma_{21}} \right)^{(1-\sigma_1)/(1-\sigma_{21})} + \alpha_F^{\sigma_1} \times \\ \left[\begin{array}{l} \alpha_{FPU} \left(\alpha_{FPUA} \, p_{FPUAi}^{1-\sigma_{31}} + \alpha_{FPUS} \, p_{FPUSi}^{1-\sigma_{31}} \right)^{(1-\sigma_{22})/(1-\sigma_{31})} + \\ \alpha_{FPR} \left(\alpha_{FPRP} \, p_{FPRPi}^{1-\sigma_{32}} + \alpha_{FPRS} \, p_{FPRSi}^{1-\sigma_{32}} \right)^{(1-\sigma_{22})/(1-\sigma_{32})} \end{array} \right]^{(1-\sigma_1)} \end{array} \right\}^{1/(\sigma_1-1)} \times B_{1i} \tag{18}$$

3.3 Estimation of energy consumption of trips

The energy consumption of trips by an average person *i* is referred to as E_i, which was estimated based on the demand for trips and the corresponding energy units. Energy units reflect the energy required for each unit of trip time by one person. The energy usage for seven types of trips was calculated using *Equation 1*. x_{si}, x_{bi}, x_{ti}, x_{pci}, x_{sci}, x_{wi} and x_{bi} are the demands for subway, bus, taxi, private car, shared car, walking and bicycle trips (includes both bicycle and electric bike trips) by person *i*, respectively. e_1, e_2, e_3, e_4, e_5, e_6 and e_7 denote the energy units consumed by one person in subway, bus, taxi, private car, shared car, walking and bicycle trips, respectively. Considering the influence of speed on energy consumption, trip times were included in *Equation 19*, which are represented as t_{si}, t_{bi}, t_{ti}, t_{pci}, t_{sci}, t_{wi} and t_{ci}.

Energy unit of trip = [energy unit of trip distance (KJ/vehicle per km) × average speed (km/min)]/trips per vehicle (trip) (20)

The energy unit of the trip (KJ/trip·min) was calculated using *Equation 20*. Electricity consumption for one subway train in operation was 1.37 kwh/km, which is 4,932 KJ/vehicle/km [21]. In Ningbo, subway trains were operated 209,600 times to complete 102,000,000 trips in 2017 [22]. The average number of trips per train was 486. When the average speed was 34.3 km/h [23], the energy unit of the subway (e_1) was 5.8 KJ/trip/min.

The energy unit of trip distance is 195 KJ/vehicle per km for an electric car and 366 KJ/vehicle per km for a gasoline-consumed vehicle [24]. In Ningbo, 57% of buses are powered by electricity and 43% by gasoline [25]. According to this ratio, the energy unit of trip distance was 268 KJ/vehicle/km for a bus. The average speed of a bus was 20 km/h, and the average number of passengers in a bus was 8. The energy unit of a bus trip e_2 was, therefore, 11.2 KJ/trip/min.

The average speed of cars was 42.06 km/h. The average number of passengers in a taxi and private and shared cars was 2.2 and 1.5, respectively [26]. The energy unit of a taxi (e_3) and a private car (e_4) was 116.6 and 171 KJ/trip/min. The ratio of electric and gasoline shared cars was 3:2, and the energy unit of a shared car (e_5) was 122.9 KJ/trip/min.

Walking and cycling require energy from human muscle power, which originates from foods. Considering the energy use and emission for food production and accessibility, the energy unit of walking and cycling trips and other fuel trips is determined. Both genders were expected to consume 0.75 Kcal/kg/km at a higher mean speed of 5.5 km/h [27]. Because students are young and walk fast for the class, a high walking speed of 5.5 km/h was applied. The average weight of male and female students was 65 and 55 kg, respectively. Thus, the energy unit of the walking trip (e_6) was 18.8 KJ/min. The average speed of a bicycle on the campus was 15 km/h. The energy consumed in a bicycle trip (e_7) was 7 KJ/min [28]. *Table 1* presents the result of energy units of each type of trip.

Table 1 – Energy unit of modes

Energy unit (KJ/trip·min)	e_1	e_2	e_3	e_4	e_5	e_6	e_7
	5.8	11.2	116.6	171	122.9	18.8	7

3.4 Energy efficiency

Energy efficiency is used to indicate the amount of energy required for unit production and services. High energy efficiency gains significantly affect the reduction in global energy demand and the energy expenses of consumers [29]. In the transportation sector, energy efficiency reflects the energy used for each travel activity. Economists employ a utility to express the satisfaction of consuming different types of goods. In the present study, utility was employed to express the satisfaction of travel behaviours, which are reflected by the demand for trips. Here, energy efficiency is defined as the ratio of the utility level determined by trips to energy consumption (*Equation 21*). The energy efficiency ef_i indicates the efficiency of a composite trip, which is a unified trip. A high ef_i value indicates a high energy efficiency of the trips.

$$ef_i = {}^{u_i}/_{e_i} \tag{21}$$

4. CASE STUDY

4.1 Study area

The study was conducted in Ningbo, a port city in eastern China. In Ningbo, the college campus includes facilities for study, such as teaching buildings and a library, and for living, such as dormitory, gyms, restaurants and other business shops. Because two or three colleges are located in the same area, some living facilities are shared among these colleges. This type of area and campus together is called a HEZ. The north HEZ (NHEZ) is among the two primary HEZs of Ningbo (*Figure 2*). This zone has three universities, namely Ningbo University, Ningbo University of Technology and Zhejiang Fashion Institute of Technology. NHEZ covers an area of 5.63 km^2 and has a student population of 32,000. More than 40 shared cars and 33 service nodes were present in the NHEZ in 2019. Gofun, EvCard, Liandongyun and Didi are the four key car-sharing companies in Ningbo.

Figure 2 – North High Education Zone in Ningbo

4.2 Survey conduction

Two surveys involving face-to-face interviews were conducted in this area. In 2016, 210 lower-grade college students were randomly selected from the service nodes in the main activity centre, such as a commercial centre or public parking lot in the zone. In 2019, both direct face-to-face interviews and online surveys were conducted among 256 respondents, including 105 respondents who were selected from the last survey. Only samples of the same respondents were analysed for the two time periods to compare changes. The questionnaire consisted of three parts: (1) basic demographic and socioeconomic information, such as gender, age, education level, income and occupation; (2) trip characteristics, such as trip type, trip duration, trip distance and transport fee; and (3) experience of using sharing mobility.

4.3 Basic travel data

Travel attributes were investigated from the perspectives of demand, distance, time and cost (*Table 2*). College students had a similar number of commuting trips (i.e. 45 and 44) in both years, and most of them resided in campus dormitories. Therefore, they returned to the dormitory after the class and went to the class again if they had classes in the afternoon. The number of commuting trips of the college students depended on the schedule of classes. In both surveys, the distance of commutes was short, and so, the trip time was also less. The students had fewer recreation trips than commuting trips. Only 3 and 2.5 recreation trips were conducted in 2016 and 2019, respectively. Only trips with a distance of >2 km were considered in this study. Most students resided inside the campus where recreational activities were also conducted. Meanwhile, the availability of mobile internet also restricted the need to go outside the campus for entertainment. The distance covered in the recreation trips of the students in the first and second surveys was 14.3 and 15.9 km, respectively. The duration of the recreation trips was longer because of the distance. Compared with 54 min in the first survey, the duration of the recreation trips was 49 min in the second survey. Regarding the expenditure, the students spent 126 RMB yuan (16 EUR) and 148 RMB yuan (19 EUR) for travelling each month in 2016 and 2019, respectively.

Table 2 – Travel attributes of respondents in the first and second survey

Variable	Commuting trips		Recreation trips	
Trip number (times/month)	First survey	45	First survey	3
	Second survey	44	Second survey	2.5
Trip distance (km)	First survey	2.5	First survey	14.3
	Second survey	3.7	Second survey	15.9
Trip time (minutes)	First survey	20	First survey	54
	Second survey	21	Second survey	49
Transport cost (RMB yuan/month)	First survey		126	
	Second survey		148	

4.4 Price of trips

The price of trips was calculated on the basis of the running fee unit and average travel distance (*Equation 22*). Time was not considered a type of cost here because the transport budget only referred to money. Accordingly, the price of walking trips was zero. A bicycle trip costs 1.5 RMB yuan (0.2 EUR) for the first half an hour and 3 RMB yuan (0.4 EUR) for each hour. The average speed of a bicycle on the campus is approximately 15 km/h. Therefore, the running fee unit of the bicycle trip is 0.2 RMB yuan/km (0.03 EUR yuan/km). In Ningbo, a bus trip costs 2 RMB yuan (0.25 EUR) within 7 km and 1 RMB yuan (0.12 EUR) more for each extra 2 km. Taxi trips cost 11 RMB yuan (1.4 EUR) for the first 3 km and 2.4 RMB yuan (0.3 EUR) more for each extra km. Subway trips cost 2 RMB yuan (0.25 EUR) for the first 4 km. For the distance ranging between 4 and 8 km, 1 RMB yuan (0.12 EUR) is charged more for each extra 4 km. If the distance is between 8 and 13 km, 1 RMB yuan (0.12 EUR) is charged more for each extra 5 km. If the distance is between 13 and 20 km, 1 RMB yuan (0.12 EUR) is charged more for each extra 7 km. If the distance is more than 20 km, 1 RMB yuan (0.12 EUR) is charged more for each extra 9 km. The maximum price for one subway trip is 8 RMB yuan (1 EUR). On investigating car drivers in Beijing, we found that the direct operation cost of private car trips is 0.9 RMB yuan/km (0.11 EUR). The standard fare for a shared car trip is 0.3–0.5 RMB yuan (0.04–0.06 EUR) per minute. We used the median value of 0.4 RMB yuan/min (0.05 EUR/min). The average speed of a private car, taxi and shared car in Ningbo is 42.06 km/h. Therefore, the price of a shared car trip is 0.57 RMB yuan/km (0.07 EUR/km). Each time, 3 RMB yuan (0.38 EUR) is paid toward the insurance fee.

$$p_i \text{ (RMB yuan/trip)=running fee unit (RMB yuan/km)} \times \text{distance (km/trip)} \quad (22)$$

5. RESULTS AND DISCUSSION

5.1 Changes in energy consumption

Energy consumed during trips taken by each respondent per month was estimated using *Equation 1* and energy units (*Table 3*).

Table 3 – Energy consumption of trips in 2016 and 2019

	2016		2019	
Energy consumption (KJ/person·month)	**Commuting trips**	**Recreation trips**	**Commuting trips**	**Recreation trips**
All trips (KJ)	15,567	4,242	20,417	4,480
Trips by bus (KJ)	2339(15.0%)	704(16.6%)	1708(8.4%)	328(7.3%)
Trips by subway (KJ)	1034(6.6%)	230(5.4%)	877(4.3%)	239(5.3%)
Trips by taxi (KJ)	3043(19.5%)	1794(42.3%)	3424(16.8%)	1473(32.9%)
Trips by private car (KJ)	1847(11.9%)	1053(24.8%)	8350(40.9%)	1959(43.7%)
Trips by shared car (KJ)	0(0%)	0(0%)	953(4.7%)	329(7.3%)
Trips by walking (KJ)	6328(40.7%)	311(7.3%)	3920(19.2%)	115(2.6%)
Trips by bicycle (KJ)	977(6.3%)	150(3.5%)	1184(5.8%)	37(0.8%)

Note: number in ( ) indicates the energy share

A student required 19,809 and 24,897 KJ energy to support 48 and 46.5 trips per month in 2016 and 2019, respectively. The total energy consumption of trips increased by 5,088 KJ, and the average energy consumption per trip increased from 413 KJ in 2016 to 535 KJ in 2019. Thus, energy consumption per trip increased by 29.5% in three years. In 2016, 78.5% and 21.5% of the total energy was used for commuting and recreation trips, respectively. In 2019, the energy share of commuting trips increased to 82%, which was 20,417 KJ, whereas that of recreation trips decreased to 18%, which was 4,480 KJ. Compared with 2016, energy consumption increased for both commuting and recreation trips in 2019.

The energy for different transportation modes also changed. In 2016, the energy usage of the green mode group, which was 47%, constituted the largest share of commuting trips. The energy used for bicycle trips increased from 977 KJ to 1,184 KJ for commuting trips in 2019. However, the energy used for walking trips decreased from 6,328 KJ to 3,920 KJ in 2019, which was 38% lower than that in 2016. In addition, more walking trips for commutes were substituted by bicycle trips. In general, the energy usage of the automobile group constituted the largest share in 2019, which was 62.4%. This percentage was higher for recreation trips, which reached 83.9%. The energy usage of the automobile group increased by 64.4% in 2019 for commuting trips. With increased demand for private vehicles and the promotion of shared cars, the energy share of automobiles is expected to keep growing in the future. Overall, the energy usage of the mass transit group decreased for both commuting and recreation trips in 2019.

5.2 Changes in energy efficiency

The energy efficiency was estimated based on energy consumption for maximum utility and composite trips (*Table 4*). Compared with the 60 utilities in 2016, higher utilities were observed in 2019. A total energy of 19,809 KJ was required for 71 utilities in 2019, which means 350 KJ energy was required to support each utility. In 2016, total energy of 19,809 KJ was required for 60 utilities, which means 330 KJ of energy was required to support each utility. Compared with 2016, the energy efficiency of utility exhibited a decreasing trend after three years. The energy efficiency of green and public transport trips was higher, whereas that of private transport trips was the lowest.

Compared with the results in 2016, interesting trends were noted in 2019. First, the energy efficiency of green trips improved remarkably from 0.00095 in 2016 to 0.00195 in 2019. The amazing improvement is attributable to the increase in bicycle trips. With shared bicycle usage becoming popular in the high education area, bicycle trips have increased in the three studied years. Bicycle trips are considerably more energy efficient than walking trips. Preferring more bicycle trips over walking trips would be more energy beneficial. Second, the energy efficiency of public transport trips decreased slightly in 2019. As the number of shared taxi trips increased, the energy efficiency reduced. However, the energy efficiency of private transport trips improved slightly because of the growth in shared car trips.

Table 4 – Energy efficiency of travel behaviours in 2016 and 2019

	2016 (per student one month)	2019 (per student one month)
Maximum utility	60	71
Energy for all trips (KJ)	19,809	24,897
Energy efficiency of mobility	0.00302	0.00285
Energy efficiency of green trips	0.00095	0.00195
Energy efficiency of public transport trips	0.00078	0.00072
Energy efficiency of private transport trips	0.00011	0.00012

As a whole, energy efficiency decreased after the introduction of shared mobility. The effect of transport sharing on the energy efficiency of the utility was complex. On one hand, introducing shared bicycles contributed to an increase in bicycle trips, which led to the high energy efficiency of green trips, representing a positive effect on energy efficiency. On the other hand, the effect of shared cars on energy efficiency was so small that it was difficult to detect. With automobiles becoming popular in society, the improvement in energy efficiency depended on the promotion of energy-efficient modes. Therefore, increasing the use of shared car trips, rather than private car trips, would be the point of policy-making in the future.

6. CONCLUSIONS

Does shared mobility result in less energy consumption for travel trips? This question has attracted considerable attention worldwide in the background of the booming shared economy. Numerous studies have investigated the environmental effect of shared mobility from a macro viewpoint, focusing on the whole social population. By contrast, only a few studies have analysed the effect based on the survey data of private persons, let alone college students. Because young college students are the generation driving the future, their behaviours of shared mobility usage can considerably influence private vehicle usage and thus the reduction of transportation-associated carbon emissions. Studies must be conducted to explore the influence of shared mobility on the travel behaviour of college students and estimate the effect on energy consumed in transportation.

To examine changes in the travel behaviours of college students following the introduction of shared mobility on the college campus, the present study conducted a before-and-after analysis of the travel behaviours through two surveys in 2016 and 2019 in the NHEZ of Ningbo. In total, 107 undergraduate students were included in the survey. Based on the data, we compared the change in travel behaviours and calculated the energy consumption at two-time windows. The energy efficiency index was introduced to reflect the energy required for a unit composite trip, which was mobility. Mobility has been estimated using the three-stage CES utility model.

Based on the results obtained, three findings were deduced regarding the changes in trips before and after shared mobility was introduced in the area. First, the trend of both commuting and recreation trips decreased overall. Travel distance increased, whereas travel time decreased. However, the total travel cost increased. Second, the energy consumption of all trips exhibited an increasing trend. The energy requirement for private vehicles and shared cars increased the most. Third, the energy efficiency decreased from 0.00302 in 2016 to 0.00285 in 2019. These findings collectively suggest that shared mobility has limited positive effects on energy efficiency.

The study findings provide additional evidence on policy-making for transport development on the college campus. First, the influence of technology on the demand for trips must be considered when formulating a traffic policy. The decrease in the demand for trips after three years in the zone reflects the fact that advanced information and communications technology influence travel behaviours. The boom of online communication and e-commerce has reduced the necessity to travel for goods. This tendency is especially obvious among young college students who spend more than 4 h on online activities. Parts of recreational activities and interactions are completed through the internet without any long-distance physical movement of the body. This definitely has a negative effect on the demand for trips. Second, shared car trips should be promoted as an alternative to private car trips in the background of increasing automobile trips. As observed through the result of the energy efficiency of private transport trips, shared car trips positively affect energy efficiency. The mode share of shared car trips is so small that the positive effect is limited. The basic policy point is to transform the potential driving demand of young students into the demand for shared vehicles. The energy structure of shared vehicles can be easily changed by marketing and promoting energy-efficient vehicles in the shared car market.

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大学校园共享出行对交通能源消耗的影响评估：以中国宁波年轻大学生为例

摘要：
本文重点研究大学校园内共享出行对学生交通行为和交通能源消耗的影响。基于中国宁波地区大学生的出行数据，本文开发了一个出行方式替代模型，量化模拟大学校园引入共享出行后学生出行方式的变化，并评估预测其对交通节能的影响程度。基于平均出行时间及交通方式生命周期出行能量单位，分别计算 2016 年、2019 年大学生出行行为的交通能源消耗量。与 2016 年未引入共享出行相比，2019 年在引入共享出行后学生出行行为有三个主要变化。首先，人均总出行次数略有下降，但出行距离有所增加。其次，人均出行交通能耗从 2016 年的 19809 千焦增加到 2019 年的 24897 千焦，增加了 25%。第三，出行整体能耗效率下降。根据以上数据总结，大学校园引入共享出行带来的交通能耗作用有限，并不如期待的那么高。

关键词：
共享汽车，大学校园，学生，能源消耗，出行行为