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Effects of rural built environment on travel-related CO₂ emissions considering travel attitudes

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ABSTRACT

This study contributes to the understanding of the impacts of the rural built environment on travel-related CO₂ emissions by considering the mediating effects of household car ownership, travel frequency, travel distance, and individual travel attitudes through structural equation modeling. The travel data were collected from an activity diary survey in rural Sichuan. Geographic information system technology, combined with on-site measurement, was used to obtain data on the built environment. After controlling the socio-demographic factors, the model results corroborate that all built environment variables had significant total effects on car ownership, travel distance, travel frequency, and travel emissions. Specifically, residents living in the village with more accessible markets, higher roads, and higher building density travel a shorter distance and emit less CO₂. Meanwhile, residents living in the village with centralized living style and higher transit and destination accessibility travel less frequently but emit more CO₂. Individual travel attitudes have a limited effect on travel behavior and CO₂ emissions. This study suggests that planners and policymakers should consider shortening the distance between destination/transit and residential areas and increasing road and building densities. Moreover, promoting the construction of bicycling facilities and separate bicycle lanes to encourage rural residents to ride electric bicycles, bicycles, and motorcycles will reduce transport CO₂ emission in Chinese rural areas.

1. Introduction

Accumulated scientific evidence shows that climate change is a real and daunting threat to global human development (Stocker et al., 2013). Global climate change caused by energy consumption from human activities and related CO₂ emissions has attracted widespread attention from the international community (Ou et al., 2013; Solomon et al., 2007). Transportation is the fastest growing sector in terms of global energy consumption and CO₂ emissions (Agency, 2009; Yan and Crookes, 2009). According to the International Energy Agency (IEA), the global transportation sector produced 7001.1 Mt of CO₂ in 2011, accounting for 22.3% of all emissions and making it the second largest source of CO₂ emissions. Road traffic accounts for around three-quarters of the total CO₂ emissions from transportation (73.9%). China's transportation has a relatively low proportion of CO₂ emissions but ranks second only to the United States (Statistics, 2011). This situation means that China faces enormous challenges in reducing carbon emissions from transport (Yang et al., 2015). By the end of 2015, China's energy production and energy consumption were 2.93 and 2.61 times that

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in 2000, respectively. Meanwhile, the number of car ownership per 100 rural households in China in 2016 was 13.18 times the number in 2000. Reducing CO₂ emissions from transport is the primary way to achieve climate change mitigation goals (Ma et al., 2015), and transportation is supposed to be the most challenging sector in terms of reducing CO₂ emissions (Brand et al., 2012; Marsden and Rye, 2010). Numerous studies have investigated the relationship between transport planning and individual travel behavior (Cao et al., 2009; Cao and Yang, 2017; Ding et al., 2017b; Handy et al., 2005; Li and Zhao, 2017; Liu et al., 2016; Sun et al., 2017). Several investigations related to mobility have demonstrated the validity and importance of these relationships through empirical research (Bamberg et al., 2003; Haustein and Hunecke, 2007; Heath and Gifford, 2002; Schoenau and Müller, 2017; Thorhauge et al., 2016). Scholars have affirmed that high population density, mixed land use, and pedestrian-friendly street designs are positively related to small numbers of vehicles, short travel distances, and reduced motor vehicle travel (Ewing and Cervero, 2010; Ewing et al., 2015; Khattak and Rodriguez, 2005; Krizek, 2003).

China is in a process of rapid urbanization and new rural construction. However, all studies in relation to the relationship among the built environment, travel behavior, and travel-related CO₂ emissions focused on large cities in China, such as Beijing, Guangzhou, Shanghai, and Nanjing (Cao and Yang, 2017; Liu et al., 2016; Ma et al., 2015; Yang et al., 2015). The scale of China's rural urbanization and new rural construction is unprecedented. The interrelationship among rural space reorganization, rural resident travel attitudes, travel behavior, and travel-related CO₂ has undergone profound changes. Exploring the relationship among them is crucial for the further establishment of a new ecological and low-carbon countryside and fills the abovementioned research gap.

Therefore, this study focuses on rural areas in Sichuan, China, and explores the direct and indirect impacts of China's rural built environment on travel CO₂ emissions. The residents' psychological factors are considered in this work. The structure of this paper is as follows. Section 2 explains the methodology used in this research, data collection, and variable specification. The results and discussion of the structural equation model (SEM) are presented in Section 3. The conclusions and policy implications are summarized in Section 4.

2. Literature review

Built environment exerts a significant influence on travel behavior and transport carbon emissions (Hankey and Marshall, 2010). The built environment is measured by the D variable. With the accumulation of relevant research, the built environment measurement indicator has developed from 2D to 4D and is now widely accepted as 6D (Ewing and Cervero, 2001, 2010; Ewing and Handy, 2009; Ewing et al., 2015; Vance and Hedel, 2007). The "6Ds" of the built environment, namely, density, diversity, design, destination accessibility, distance to transit, and demand management, have been widely utilized (Ewing and Cervero, 2001, 2010; Ewing and Handy, 2009; Ewing et al., 2015; Vance and Hedel, 2007). Travel behaviors are measured in many ways, including travel mode, distance, frequency, purpose, and time (Boarnet, 2011; Ewing and Cervero, 2001, 2010; Handy et al., 2005). Overall, scholars have found that high population density, mixed land use, and pedestrian-friendly street designs are positively related to small numbers of vehicles (Brownstone and Golob, 2009; Ewing and Cervero, 2010), short distances (Ewing et al., 2015; Khattak and Rodriguez, 2005), and reduced motor vehicle travel (Krizek, 2003; Modarres, 2013) because compact and high-density urban forms promote public transport development and reduce the use of private cars (Ewing, 1997; Kenworthy and Laube, 1996). For example, Ding et al. (2014) discovered that job density in urban centers is important in reducing travel CO₂ emissions compared with the situation in household dwelling areas. Hong (2017) found a nonlinear relationship between density and transport CO₂ emissions. However, the relationship between CO₂ emission and population density is not significant to some extent. In other studies, the correlation between residential density and transport CO₂ emissions is not significant (Barla et al., 2011; Jiang et al., 2011; Xiao et al., 2011). Moreover, increasing road capacity is a viable means to increase energy efficiency in transportation and reduce related emissions. However, Shim et al. (2006) revealed an inverse relationship between transport energy consumption and road density in their study of 61 small and medium-sized cities in South Korea. Improvements in road capacity may encourage rampant driving, which may increase CO₂ emissions. Ma et al. (2015) examined commuting travel data in Beijing and found that subway accessibility is negatively correlated with CO₂ emissions. Another study in China showed that the proportion of bus travel has a significant negative impact on CO₂ in transportation (Su et al., 2011). Ribeiro and Balassiano (1997) reported that CO₂ emissions from private cars used for daily commute are nearly eight times higher than those from public transport. Yang et al.'s (2015) study indicated that a significant negative relationship exists between urban public transportation and per capita CO₂ emissions from transportation. Therefore, public transport plays a key role in reducing carbon emissions. Zahabi et al. (2012) discovered that if density, transit accessibility, and land use mix index are increased by 10% separately, travel-related greenhouse gas emissions will decrease by 0.5%, 5.8%, and 2.5%, respectively. Zhao (2010) found that the urban sprawl in Beijing's urban borders increases travel distance and car use, leading to increased emissions. Moreover, parking service as the 6th D variable (demand management) has an impact on CO₂ emissions as well. Researchers have found that low-cost parking lots are correlated with high CO₂ emission due to car ownership (Guo, 2013; Tyrinopoulos and Antoniou, 2013).

However, most of the studies above focused on the urban built environment. Only a few researchers have investigated the rural household travel behavior associated with CO₂ emission. Dargay (2002) reported that car ownership by rural households is much less sensitive to car costs than car ownership by urban households. Therefore, measures to control travel-related CO₂ emissions in rural areas through car use cost are not necessarily appropriate for rural areas. Moreover, a study showed that Chinese rural residents have a strong desire to own a car due to the lower rate of household car ownership compared with urban dwellers, and this will lead to a rapid increase in the number of cars in rural areas (Zhu et al. 2012). Christie and Fone (2003) used data from Wales and found that although car ownership is related to household income level, no evidence indicates that low-income households in rural areas own fewer cars than those in urban areas. This result indicates that car ownership is minimally correlated with household income. Once

rural residents have cars, they become increasingly dependent on their cars because of the few alternative transport modes available, which will increase travel-related CO₂ emissions in rural areas (Wang et al., 2011).

Meanwhile, a few studies have focused on travel mode analysis in rural China. As for the choice of travel mode, rural residents in different regions have slightly different choices. Rural residents in Haining, Zhejiang, prefer electric bicycles to cars and walking (Kong and Yao, 2015), whereas rural residents in northern Jiangsu prefer electric bicycles, followed by walking and motorcycles (Chen and Zhu, 2013). Children and elderly people with limited mobility needs are the major residents in rural areas because most of the young population are working outside the rural area. Therefore, rural residents have fewer trips and lower travel CO₂ emissions compared with urban residents (Yang et al., 2014). For rural households, literature has found that socio-demographic characteristics influence travel-related CO₂ emission, similar to the situation for urban households. Specifically, men, middle-aged individuals, and elderly people who live in rural areas and own bicycles have a significant but weak association with CO₂ emissions (Brand et al., 2013).

The studies above investigated the effects of the built environment on CO₂ emissions but did not consider psychological determinants, such as preference and personal attitudes. Only a few studies have considered these perspectives (Ao et al., 2019; Belgiawan et al., 2014). These studies have found that significant differences exist between developed and developing countries in terms of car purchase motivation. The expectation of others exerts substantial impacts on purchase intention in developing countries. Attitude is an essential determinant factor for driving and commuting intentions in developed countries. People view the car as a symbol of wealth, which may decide their travel mode. Environment attitudes may influence private car purchase decisions.

In summary, the studies above did not reach a consistent conclusion. This scenario indicates that the impacts vary from country to country, and this variation might be related to attitudes and preferences. Compared with Western countries, urban residents in China have particular travel-related attitudes and preferences (Wang and Lin, 2014). In addition, a massive difference in the built environment exists between urban and rural areas in China. For example, rural households cannot select residential locations according to their preferences because of the fixed homestead location, which is contrary to urban households in China. With the rapid development of new rural construction and urbanization, great changes have taken place in China's rural built environment. However, in China, all related studies on the relationship among the built environment, travel behavior, and travel CO₂ emissions were conducted in China's first-tier or second-tier cities, such as Shanghai, Nanjing, Guangzhou, and Beijing (Cao and Yang, 2017; Liu et al., 2016; Ma et al., 2015; Yang et al., 2015). Research on rural areas is lacking. The scale of China's rural urbanization and new rural construction is unprecedented. The interrelationship among rural space reorganization, rural residents' travel attitudes, travel behavior, and travel-related CO₂ emissions has undergone profound changes. Exploring the relationship among them has significant impacts on the further establishment of a new ecological and low-carbon countryside. In addition, most existing studies only considered the direct impact of the built environment on CO₂ emission from daily traveling; they ignored the indirect effects of the built environment, which may affect other variables and ultimately influence travel-related CO₂ emissions (Cao and Yang, 2017).

3. Methodology

3.1. Model specification

Two models were applied in this study. First, exploratory factor analysis (EFA) was used to reduce data to a small number of non-related comprehensive variables. EFA identified the structure of the relationship between the variables and obtained the important and common travel attitudes. Second, the EFA result was used in the structural equation model (SEM) to investigate the influence of travel attitudes on travel behavior and travel-related CO₂ emissions.

SEM is a research technique that has been used in its present form since the 1970s. This technique is widely utilized in the majority of qualitative research in psychology, sociology, biological sciences, education research, political science, and marketing (Van Acker et al., 2007). Recently, SEM was used to explore the complex effects of the built environment on travel behavior (Cao and Yang, 2017; Liu et al., 2016; Ma et al., 2015; Van Acker et al., 2007). SEM can solve endogeneity problems between variables, and it can analyze the indirect, direct, and total effects between exogenous and endogenous variables (Glaser, 2001; Jahanshahi and Jin, 2016; Jahanshahi et al., 2015; Kline and Santor, 1999). The variables used in this study were all observational. SEM without latent variables can be defined as follows:

$$y = By + \Gamma x + \xi$$

The definitions of the letters in the formula above are as follows:

y – vector of endogenous variables;

x – vector of exogenous variables;

B – matrix of coefficients representing the effects of endogenous variables on each other;

Γ – matrix of coefficients representing the effects of exogenous on endogenous variables;

ξ – vector of errors.

The conceptual framework based on SEM is shown in Fig. 1. The socio-demographic attributes and built environment affect household car ownership, travel behavior (e.g., travel frequency and distance), and CO₂ emission from daily traveling. Several existing studies used travel frequency, travel distance, and car ownership as dependent variables to explore the effects of socio-demographic attributes and the built environment. In addition, studies on travel-related CO₂ emissions typically defined travel

Fig. 1. Conceptual framework for SEM analysis.

frequency and distance, household car ownership, socio-demographic information, and built environment as exogenous variables but ignored their endogeneity. However, based on literature, we found that travel behavior and car ownership have a significant impact on CO₂ emissions from daily traveling. CO₂ emissions are affected by socio-demographic variables and the built environment as well (Van Acker and Witlox, 2010; Yang and Cao, 2018). Therefore, this study adopted travel frequency, travel distance, and car ownership as intermediary variables to explore the mediating effects of the built environment and socio-demographic characteristics on travel-related CO₂ emissions. Car ownership also affects travel frequency and travel distance (Van Acker and Witlox, 2010). People with different socio-demographic attributes choose various built environments due to residential self-selection. Many studies have considered the impact of socio-demographic attributes on the built environment (Ding et al., 2017a; Ma et al., 2015; Yang and Cao, 2018). However, Chinese rural residents have limited freedom to select their residential location because of the fixed homestead location in China. Therefore, this study did not consider the influence of socio-demographic attributes on the built environment but considered that travel attitudes directly affect travel behavior and travel emissions. Then, we assumed that different travel conditions and rural residents have unique travel preferences and attitudes in rural China. We also assumed that the built environment and socio-demographic attributes directly affect travel attitudes.

3.2. Sample selection and data collection

The data collection was implemented in Sichuan rural areas. Rural areas can be divided into three categories based on living places. The first category is scattered living places, which is the traditional way of living in Sichuan rural areas. The infrastructure has been dramatically improved in the last decades; however, the living places are still the same. The second category is new-style living spaces. The traditional residential patterns in the countryside have been changed by moving rural residents to concentrated living spaces in rural areas. They often occupy agricultural land as well. The third category is the mixture of traditional- and new-style living spaces. It is normally a transition stage from traditional living to new-style living spaces.

3.2.1. Sample selection

Based on our experiences in data collection in Sichuan rural areas and the purpose of this research, we selected sample village areas that satisfy the following criteria. (1) The area should have the necessary road infrastructure that can be used by vehicles, including buses. A road should be connected to at least one highway/freeway/motorway, which can be used by personal vehicles. (2) The residents in the rural area should support the research and are willing to cooperate for a survey or interview. We found that if a person in our research team came from the village, then obtaining support from the residents would be easy.

Based on the two criteria, we organized the sample village selection in four steps (see Fig. 2). First, we recruited volunteer students who are from Sichuan rural areas and interested in this research (1st Oct. 2017 to 31st Oct. 2017). To minimize knowledge barriers, we recruited students studying in the Environmental and Civil Engineering Department of Chengdu University of Technology. The purpose was to have at least one person in each sample village to set up communication with residents in the village. In total, 117 students submitted their applications. With the criteria mentioned above, a pre-selection was carried out, and 37 rural village areas were selected. Second, intensive training was organized for the recruited students (1st Nov. 2017 to 10th Nov. 2017). We held discussions with the students to determine if the pre-selected rural village areas are suitable for this research. After the training and examination, 14 pre-selected rural village areas were eliminated. Third, we established a connection with the village communities from the pre-selected rural village areas (10th Nov. 2017 to 120th Nov. 2017). We asked if the residents are willing to cooperate and whether the research team can approach them or not. After the discussion, only 10 pre-selected village communities provided consent. Lastly, we organized pre-interview groups for 1–2 residents living in each approved rural village area to understand the residents' willingness to cooperate (21st Nov. 2017 to 10th Dec. 2017). We found that residents were unwilling to assist and showed precaution from Helin Village (Chongren Town, Dongpo District, and Meishan City), Nanliu Community (Huangshui Town, Shuangliu District, and Chengdu City), and Shiguan Village (Sanshui Town and Guanghan City). In the end, seven rural village areas

Fig. 2. Data and sample collection flowchart.

were selected for the data collection. The seven rural village areas covered 16,953 individuals and 5888 households.

3.2.2. Data collection

Three types of data were collected in this study, and these are GIS, field measurement, and individual data. GIS and field measurement data were collected for built environment measurement. A huge difference exists between the built environment in rural and urban areas, especially traditional rural living areas. Therefore, we pre-defined a few rules to measure the built environment. For the new-style living spaces in rural areas, we measured the built environment by using the village committee office as the center point and with 1 km as the radius. For the traditional-style living areas, the village committee office was set at the center location. The built environment indicators were calculated based on the data on the natural boundary of the village. The main reason is that the scattered rural areas in Sichuan vary greatly. Using a 1 km radius to measure the area is impossible. Based on the definitions, we used Arcgis 10.2 to obtain building and road information. However, the GIS data for rural areas in China are very limited. Field measurement is necessary for collecting objective built environment information. All interviewees were equipped with the same Baidu navigation system. They used the navigation system to measure the driving distance between the center of the village and the nearest public transport stations (bus, coach, and train), main subway/freeway/motorway, open market/supermarket, school, hospital, and administration center of the city/town.

Individual information was collected via a face-to-face interview. The household survey contained a list of socio-demographic variables, including individual and household information that may help explain travel behavior decisions. We executed the data collection via a household questionnaire survey. A total of 560 questionnaires were distributed, and 413 were collected back. Owing to the missing data, 39 out of the 413 questionnaires could not be used for the analysis. In the end, 374 valid questionnaires were used from the seven rural village areas. The survey covered 1758 individuals. The survey sample distribution matched the rural population in Sichuan and China well, as shown in Table 1. The socio-demographic distribution of the sample is listed in Table 2. The data of the on-site measurement are shown in Table 3. The sample area location is shown in Fig. 3, and the GIS data are presented in Fig. 4.

3.3. Calculation of CO₂ emissions

This study used Cao and Yang's (2017) formula to calculate travel-related CO₂ emissions, as shown below.

$$CE_{ij} = Distance_{ij} \times E_factor_{ij}$$

where CE_{ij} represents CO₂ emissions from a trip using mode j for respondent i , $Distance_{ij}$ is the distance with mode j for respondent i , and E_factor_{ij} is the emission factor of travel mode j for respondent i .

The emission factor data of different transport modes are unavailable for rural areas. By referring to various studies and reports (more details can be seen in Table 4) (Entwicklungsbank, 2008; Proost et al., 2006; Yang et al., 2018; Cai and Xie, 2010; Xiao et al.,

Table 1
Sample vs. population characteristics.

	Household ^a	Village ^a	Rural Sichuan ^b	Rural China ^b
Total population	1758	16,953	419.6 2016:Billion	5897.3 2016:Billion
Total number of households	374	5888	–	–
Average household size	3.71	2.88	3.03 (2015)	3.88 (2012)
Per capita income (10 k yuan)	1.36	–	1.13 (2016)	1.24 (2016)
Average household income (10k yuan)	4.44	–	–	–

^a Data from face-to-face household survey between 16th December 2017 and 5th January 2018.

^b Source: China Statistical Yearbook (2013, 2016, and 2017).

Table 2
Distribution of socio-demographic information.

Variables	Level	Number of sample	Percent
Male	0 for female	226	60.43
	1 for male	148	39.57
Age	1 represent age 16–25	47	12.57
	2 represent age 25–40	65	17.38
	3 represent age 41–50	112	29.95
	4 represent age 51–60	80	21.39
	5 represent age 61–70	70	18.72
Driving certificate	0 for no driving certificate	279	74.60
	1 for have driving certificate	95	25.40
Ride a motorcycle	0 for cannot ride a motorcycle	229	61.23
	1 for can ride a motorcycle	145	38.77
Ride a bicycle	0 for cannot ride a bicycle	108	28.88
	1 for can ride a bicycle	266	71.12
Ride electric bicycle	0 for cannot ride an electric bicycle	137	36.63
	1 for can ride an electric bicycle	237	63.37
Income (ten thousand yuan)	1 represents 0	116	31.02
	2 represents 0–0.5	38	10.16
	3 represents 0.5–1	80	21.39
	4 represents 1–2	60	16.04
	5 represents 2–4	59	15.78
	6 represents > 4	21	5.61

Table 3
Data measured on-site.

Name of villages	Distance to the nearest bus station (KM)	Distance to the nearest train station (KM)	Distance to the nearest public transportation station (KM)	Distance to the nearest main road (KM)
Dazhuang (DZ)	18.20	19.90	2.50	2.50
Wugang (WG)	0.20	70.00	16.00	0.00
Shuangyan(SY)	16.30	13.40	0.50	0.50
Xinlong (XL)	13.40	13.40	1.20	0.80
Dongxing (DX)	3.90	16.40	3.90	0.50
Shangten g(ST)	22.40	24.80	0.69	0.69
Yanjing (YJ)	0.50	125.00	34.00	0.50
Name of villages	Distance to the nearest market (KM)	Distance to the nearest school (KM)	Distance to the nearest hospital (KM)	Distance to the nearest city centre (KM)
Dazhuang (DZ)	3.00	0.50	0.05	19.60
Wugang (WG)	3.50	2.50	0.20	16.00
Shuangyan(SY)	1.60	1.60	0.60	13.50
Xinlong (XL)	0.80	3.00	4.90	4.90
Dongxing (DX)	0.00	2.10	0.00	10.00
Shangteng (ST)	1.50	1.50	1.60	14.00
Yanjing (YJ)	1.50	0.50	1.70	35.00

Note: The map is from the National Bureau of Surveying, Mapping, and Geographic Information

Fig. 3. Map of the study area's location.

2011) and in accordance with the relative intensity of energy consumption and carbon emission for each transport mode, we used the following emission factors in this study, as shown in Table 4.

3.4. Variable specification

3.4.1. Socio-demographic variables

Travel behavior and travel-related CO₂ emissions are influenced by socio-demographic variables, as proven by literature. In this study, based on literature, eight variables were included in the final model. These variables are gender, age, income, driving license ownership, ability to drive a motorcycle, ability to drive an electric bicycle, and ability to ride a bike.

3.4.2. Travel attitude variables

To explore the effects of travel attitudes on travel behavior and travel-related CO₂ emissions, 30 statements on travel attitudes were provided in the questionnaire (Cao et al., 2007; He and Thøgersen, 2017). A Likert scale ranging from 1 to 5 was used, wherein 1 signifies “completely disagree” and 5 means “completely agree.” The respondents were asked to assess the 30 statements based on their attitudes. To identify the important broad attitudes, EFA was applied using SPSS 23.0. The Kaiser–Meyer–Olkin (KMO) measure was used to test the suitability for EFA, and Bartlett’s test was applied to examine the factorability of individual attitude variables.

Fig. 4. GIS information on road and building land.

Table 4

Emission factors of different travel modes (kg CO₂/person-km).

Walk, bike	Electric bike	Bus	motorcycle	car	Coach	references
–	–	0.026	–	0.0606	0.0203	Entwicklungsbank (2008)
0	–	0.0738	0.01136	0.01786	–	Proost et al. (2006)
0	0.008	0.035	–	0.126	–	Yang et al. (2018)
0	0.008	0.035	–	0.135	–	Xiao et al. (2011)
–	–	–	0.0472	–	–	Cai and Xie (2010)
0	0.008	0.035	0.0472	0.126	–	Selected in this research

Table 5

Travel attitude component analysis.

Statements	Component					
	pro_wb	pro_Eb	pro_Ab	less_out	use_cost	buy_cost
Cycling exercises your body	0.762					
Cycling is a low-carbon, environmentally friendly travel mode	0.767					
Bicycle parking is convenient	0.738					
The low cost of bicycle purchase and use poses no economic burden at all	0.588					
Quick and easy to walk	0.602					
Walking exercises your body	0.742					
Walking is a low-carbon and environmentally friendly travel mode	0.724					
It is quick and easy to ride electric bicycles		0.769				
It is safe and environmentally friendly to ride electric bicycles		0.828				
The low cost of electric bicycle purchase and use poses no economic burden at all		0.591				
Electric bicycle parking is convenient		0.586				
It is safe and environmentally friendly to ride motorcycles			0.523			
The low cost of motorcycle purchase and use poses no economic burden at all			0.771			
Motorcycle parking is convenient			0.696			
I often make reasonable arrangements to minimize the number of outings				0.726		
For problems that can be resolved by the telephone or the Internet, they will not be resolved on site.				0.793		
The price of gasoline affects my choice of travel mode					0.739	
Parking costs are high everywhere, and driving is not worthwhile					0.754	
There is no economic pressure to buy a car						0.811
Eigen value	5.181	1.930	1.474	1.285	1.176	1.079
Proportion of variance explained	20.311	11.500	10.185	8.623	7.274	5.922
Cumulative variance explained	20.311	31.811	41.996	50.618	57.892	63.814

Table 6
Built environment variables used in this study.

Variable	Calculation method
Road density	Total length of roads (m)/total surveyed area (hectares)
Building density	Building land area (m ²)/total surveyed area (m ²)
Transit accessibility	$\sum_k [1/(d_k + 1)]$, where $k = 1, 2, 3, 4$ and d_k represents the distance from the village center to the nearest bus station, train station, public transportation station, and main road
Destination accessibility	$\sum_k \left[\frac{1}{d_k + 1} \right]$, where $k = 1, 2, 3, 4$ and d_k represents the distance from the village center to the nearest market, school, health center (hospital), and city (county) center
Living style	Respondents living in traditional scattered areas were measured at 0, whereas those in centralized areas were measured at 1 (only two types of living style existed in the sample villages)
Number of accessible markets	The number of accessible markets was obtained from the face-to-face questionnaire survey according to actual statistical data; this variable is expressed in ordinal numbers

The final result of KMO was 0.806, and the P value of 0 confirms that high correlations exist among the attitude variables. EFA must be used to identify the main factors. The results of EFA are shown in Table 5. We eliminated the variables with a factor loading below 0.5. Finally, six travel attitude factors were identified, and they accounted for 63.814% of the variance. That is, only 36.186% loss in information was incurred by the 80.0% reduction in the number of variables. Accordingly, the obscure concepts of “travel attitude” can be interpreted and represented well.

3.4.3. Built environment variables

Six built environment variables were calculated and selected in this study according to the actual situation in rural Sichuan; these variables are road density, building density, transit accessibility, destination accessibility, living style, and number of accessible markets. Road and building density were calculated from the GIS extraction data, which are shown in Fig. 4. Transit and destination accessibility were calculated from the on-site measurement data used the Baidu navigation application, which is shown in Table 3. The calculation methods of road density, building density, transit accessibility, and destination accessibility are presented in Table 6 and can also be found in our previously published papers (Ao et al., 2018, 2019). The living style of rural residents is defined as the spatial form of different villages in this study according to the actual situation in rural Sichuan. The living style of rural residents is categorized into two types, which are scattered and centralized living styles. The shift from traditional scattered living style to centralized living style occurs gradually due to urbanization in China. It directly influences rural residents' decisions on travel behavior and travel-related CO₂ emissions. Therefore, based on the current living situation, we set the living style for the seven sample villages as 0 for the traditional scattered living style and 1 for the centralized living style. Markets are the center of transactions in rural areas. Therefore, it is important to determine if the number of accessible markets has an impact on rural travel behavior and travel-related CO₂ emissions. The number of accessible markets was obtained from the face-to-face questionnaire survey. The actual built environment of the seven villages photographed by the researchers is shown in Fig. 5.

3.4.4. Travel-related variables

All travel-related data were collected from an activity diary survey, in which respondents were asked to record two entire days of activity from 30th December 2017 to 5th January 2018. We considered three travel-related variables, namely, frequency, distance, and travel-related CO₂ emissions. Then, we obtained 1042 trips with average frequency, distance, and CO₂ emissions of 1.393 times, 6.359 km, and 0.343 kg per person per day, respectively. On the average, each household has 0.540 cars (Table 7). Compared with the average travel-related CO₂ emissions of 1.91 kg/person · day in Chinese urban areas (Liu et al., 2016), the average CO₂ emissions of rural residents was lower.

Out of the 1042 trips collected in this study, 49.81% were conducted by walking. The electric bike was the second most commonly used transport mode (17.18%). Car trips accounted for 9.88% of the total trips. Motorcycles and bicycles accounted for 8.16% and 5.85% of all trips, respectively (Table 8). The current sample is similar to that of Kong and Yao (2015), who reported that electric bikes are more preferred than cars.

4. Results and discussions

4.1. Goodness-of-fit for SEM

Amos 21.0 was used to estimate the conceptual SEM. This study adopted the Bollen–Stine bootstrap estimation method, and the number of bootstraps was set to 1000 (Yang and Cao, 2018). Links with no statistical significance ($P > 0.1$) were removed, and the model was re-estimated. The model was modified and improved according to the modification indices (MI). Table 9 presents the goodness-of-fit statistics of the final model and the corresponding reference values. The degree of freedom in the final model is 120, whereas the minimum fit function χ^2 is 167.555. All indicators suggest that the model fits the data well.

Tables 10 and 11 present the results of SEM, which indicate that all socio-demographic attributes and built environment variables significantly influenced travel behavior and travel-related CO₂ emissions. However, only three of the six travel attitude variables had

Fig. 5. Actual built environment of the seven villages.

Table 7
Information on travel behavior variables and CO₂ emission for the sample villages.

Name of villages	Mean values			
	number of trips (Number)	distance traveled (KM)	Car ownership (Number)	CO ₂ emission (kgce)
Dazhuang	1.482	6.648	0.333	0.285
Wugang	1.277	6.364	0.702	0.419
Shuangyan	0.858	7.525	0.447	0.425
Xinlong	2.148	5.577	0.328	0.106
Doxing	0.957	3.713	0.862	0.122
Shangteng	1.092	3.640	0.490	0.140
Yanjing	1.988	12.751	0.675	1.142
All samples	1.393	6.359	0.540	0.343

Table 8
Information on the 1042 trips.

	Car	Motorcycle	Electric bike	Bicycle	Walking	The others
Travel frequency	103	85	179	61	519	95
Frequency ratio	9.88%	8.16%	17.18%	5.85%	49.81%	9.12%

Table 9
Goodness-of-fit statistics of the SEM model.

Model fit indices	Values of our model	Reference value
Chi-square	167.555	
Degress of freedom (df)	120	
Probability level	0.003	< 0.05
Goodness of Fit Index (GFI)	0.962	> 0.9
Adjusted Goodness of Fit Index (AGFI)	0.92	> 0.9
Comparative Fit Index (CFI)	0.987	> 0.9
Normed Fit Index (NFI)	0.958	> 0.9
Non-Normed Fit Index (NNFI)	0.976	> 0.9
Root Mean Square Error of Approximation (RMSEA)	0.033	< 0.05

significant impacts on travel behavior and travel-related CO₂ emissions.

4.2. Effects of the rural built environment on endogenous variables

Fig. 6 indicates that destination accessibility had significantly positive and direct effects on motorcycle riding attitude (0.932), travel distance (0.349), and rural household car ownership (1.14). Furthermore, it negatively and indirectly affected travel frequency (−0.515) and travel-related CO₂ emissions (−0.059). Destination accessibility had positive and indirect impacts on travel frequency through motorcycle riding attitude (0.068) and household car ownership (0.136), which weakened the direct negative impact of destination accessibility on travel frequency. However, the total effect remained negative (−0.311). Similarly, destination accessibility had an indirectly negative effect on travel-related CO₂ emissions through “motorcycle riding attitudes → travel frequency” (−0.010) and “household car ownership → travel frequency” (−0.020). Destination accessibility also exerted an indirectly positive effect on travel-related CO₂ emissions through travel frequency (0.075), household car ownership (0.09), and travel distance (0.265). This effect ultimately weakened the directly negative effect of destination accessibility on travel CO₂ (−0.059), which made the total effect of destination accessibility on travel-related CO₂ emissions positive (0.342). The total positive effect of destination accessibility on travel distance, household car ownership, and CO₂ emission from daily traveling is in contrast to the conclusions of a previous study on Chinese urban areas (Ma et al., 2015). China is undergoing rapid rural urbanization and new rural construction. Although this unprecedented development speed has increased destination accessibility in rural areas, the distance from residential areas to the main destinations (nearest hospital, school, city or county center, and market) remains large. The improvement of rural road capacity increased rural household car ownership and driving distance, which ultimately increased travel-related CO₂ emissions. However, rural residents’ daily travel-related CO₂ emissions remain significantly lower than those of urban residents (Liu et al., 2016).

Road density had significantly direct and positive effects on motorcycle riding attitude (0.28) and household car ownership (0.223), but travel distance (0.159) had a negatively and directly impact on travel frequency (−0.269). In addition, road density indirectly and negatively affected travel-related CO₂ emissions through “motorcycle riding attitude → trip frequency” (−0.003), “household car ownership → trip frequency” (−0.004), and travel distance (−0.121). In addition, it exerted an indirect and positive effect on CO₂ emission from daily traveling through frequency (0.039) and household car ownership (0.018). Moreover, the total effect of road density on travel CO₂ emissions was negative (−0.071) (Table 10). The effects of road density on travel behavior and

Table 10
Standardized effects of exogenous variables on endogenous variables.

Variable	Effect	male	age	income	cert	R_automobile	R_ebike	R_bicycle	markets	tran	r_densi	b_densi	style	access
use_cost	Total	-	-	-	-	-0.094 ^c	-	-	-	-	-	-	-	-
	Direct	-	-	-	-	-0.094 ^c	-	-	-	-	-	-	-	-
pro_Ab	Indirect	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	-	-	0.151 ^a	-	-	-	-	-0.873 ^b	0.542 ^a	0.280 ^a	-1.050 ^a	0.514 ^b	0.932 ^a
pro_Eb	Direct	-	-	0.151 ^a	-	-	-	-	-0.873 ^b	0.542 ^a	0.280 ^a	-1.050 ^a	0.514 ^b	0.932 ^a
	Indirect	-	-	-	-	-	-	-	-	-	-	-	-	-
less_out	Total	-0.098 ^c	0.203 ^a	-	-	-	0.310 ^a	-	-	-	-	-	-	-
	Direct	-0.098 ^c	0.203 ^a	-	-	-	0.310 ^a	-	-	-	-	-	-	-
pro_wb	Indirect	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	-	-	-	-	-	0.129 ^a	-	-0.491 ^c	-	-	-0.415 ^b	0.388 ^a	0.522 ^a
car	Direct	-	-	-	-	-	0.129 ^a	-	-0.491 ^c	-	-	-0.415 ^b	0.388 ^a	0.522 ^a
	Indirect	-	-	-	-	-	-	-	-	-	-	-	-	-
Distance	Total	-	-	-	-	-	-	0.118 ^c	-0.268 ^a	-0.303 ^a	0.138 ^b	0.158 ^a	-	-
	Direct	-	-	-	-	-	-	0.118 ^c	-0.268 ^a	-0.303 ^a	0.138 ^b	0.158 ^a	-	-
Trips	Indirect	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	-0.114 ^b	0.111 ^b	0.278 ^a	0.262 ^a	-0.150 ^a	-	0.208 ^a	-1.359 ^a	0.524 ^a	0.223 ^a	0.163 ^a	0.817 ^a	1.114 ^a
CE	Direct	-0.114 ^b	0.111 ^b	0.278 ^a	0.262 ^a	-0.160 ^a	-	0.208 ^a	-1.359 ^a	0.524 ^a	0.223 ^a	0.163 ^a	0.817 ^a	1.114 ^a
	Indirect	-	-	-	-	0.011	-	-	-	-	-	-	-	-
Trips	Total	-	-0.117 ^b	0.119 ^b	0.136 ^b	-	-	-	-0.645 ^b	-	-0.159 ^a	-0.432	0.308 ^b	0.349 ^c
	Direct	-	-0.117 ^b	0.119 ^b	0.136 ^b	-	-	-	-0.645 ^b	-	-0.159 ^a	-0.432	0.308 ^b	0.349 ^c
Trips	Indirect	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	-0.028 ^a	0.044 ^a	0.045 ^a	0.140 ^b	-0.018 ^b	0.046 ^a	0.026 ^b	-0.230 ^a	-0.750 ^a	-0.222 ^a	0.215 ^c	-0.109	-0.311
CE	Direct	-	-	-	0.108 ^b	-	-	-	-	-0.854 ^a	-0.269 ^a	0.433 ^a	-0.247 ^a	-0.515 ^a
	Indirect	-0.028 ^a	0.044 ^a	0.045 ^a	0.032 ^b	-0.018 ^b	0.046 ^a	0.026 ^b	-0.230 ^a	0.104 ^a	0.048 ^a	-0.219 ^a	0.137 ^a	0.204 ^a
CE	Total	-0.005	-0.091 ^a	0.111 ^a	0.244 ^a	-0.004	-0.007 ^a	0.013 ^b	-0.566 ^b	0.157 ^a	-0.071 ^c	-0.369 ^b	0.316 ^b	0.342 ^b
	Direct	-	-	-	0.135 ^a	-	-	-	-	-	-	-	-	-0.059 ^c
CE	Indirect	-0.005	-0.091 ^a	0.111 ^a	0.109 ^a	-0.004	-0.007 ^a	0.013 ^b	-0.566 ^b	0.157 ^a	-0.071 ^c	-0.369 ^b	0.316 ^b	0.401 ^a

Note: - means there is no link in the SEM model.

“Markets” represents the number of convenient markets, “tran” represents transit accessibility, “r_densi” represents road density, “b_densi” represents building density, “style” represents living style, and “access” represents destination accessibility.

^a Refer to the significance level at 0.01, respectively.

^b Refer to the significance level at 0.05, respectively.

^c Refer to the significance level at 0.10, respectively.

Table 11
Standardized effects of endogenous variables on one another.

Variable	Effect	use_cost	pro_Ab	pro_Eb	car	Distance	Trips
Car	Total	−0.114 ^b	–	–	–	–	–
	Direct	−0.114 ^b	–	–	–	–	–
	Indirect	–	–	–	–	–	–
Distance	Total	–	–	–	–	–	–
	Direct	–	–	–	–	–	–
	Indirect	–	–	–	–	–	–
Trips	Total	−0.014 ^b	0.073 ^c	0.148 ^a	0.122 ^b	–	–
	Direct	–	0.073 ^c	0.148 ^a	0.122 ^a	–	–
	Indirect	−0.014 ^b	–	–	–	–	–
CE	Total	−0.070 ^b	−0.011 ^b	−0.022 ^a	0.063 ^c	0.795 ^a	−0.146 ^b
	Direct	−0.063 ^b	–	–	0.081 ^b	0.795 ^a	−0.146 ^a
	Indirect	−0.007 ^b	−0.011 ^b	−0.022 ^a	−0.018 ^b	–	–

Note: – means there is no link in the SEM model.

^a Refer the significance level of 0.01, respectively.

^b Refer the significance level of 0.05, respectively.

^c Refer the significance level of 0.10, respectively.

Fig. 6. Direct effects of destination accessibility and road density on endogenous variables.

travel CO₂ emissions are not completely consistent with the conclusions of similar research on Chinese cities. For instance, the higher the road density is, the better the road connectivity is, and small blocks and dense intersections can provide further alternative modes, such as biking and walking. Hence, the high level of road density reduces the probability of a household owning a car (contrary to the conclusions of this study) and the probability of traveling long distances (consistent with the conclusions of this study) (Ding et al., 2017a). Overall, increasing the road density indirectly reduced travel-related CO₂ emissions by reducing travel distance. This notion is consistent with the conclusions of research on commuting travel energy consumption (Ding et al., 2017a).

Fig. 7 shows that transit accessibility had a significantly positive and direct effect on the motorcycle riding attitude of rural residents (0.542) and household car ownership (0.524) and directly and negatively influenced travel frequency (−0.854). Transit accessibility exerted indirect and negative impacts on travel CO₂ emissions through “travel attitude → frequency of travel” (−0.0006) and “household car ownership → frequency of travel” (−0.009). In addition, CO₂ emission from daily traveling was

Fig. 7. Direct effects of transit accessibility and accessible markets on endogenous variables.

Fig. 8. Direct effects of building density and living style on endogenous variables.

indirectly and positively affected through travel frequency (0.125) and household car ownership (0.042). Transit accessibility had a completely positive effect on travel-related CO₂ emissions (0.157). Liu et al. (2016) conducted a research in Beijing which found that the distance to the subway from a residential location is positively correlated with travel CO₂ emissions. The finding is consistent with our research result. However, our intermediary variable differs.

The number of accessible markets had direct and negative effects on motorcycle riding attitude (-0.873), household car ownership (-1.359), and travel distance (-0.645). It did not directly affect travel CO₂ emissions significantly, but it indirectly and positively affected travel-related CO₂ emissions through “travel attitudes → travel frequency” (0.009) and “household car ownership → travel frequency” (0.024). Meanwhile, it exerted an indirect and negative impact on CO₂ emissions through car ownership (-0.11) and travel distance (-0.490). Finally, the number of accessible markets had a total negative effect on travel-related CO₂ emissions (-0.566). For rural areas, markets are trading centers. This means that increasing the number of accessible markets can effectively reduce travel-related CO₂ emissions, which is consistent with the conclusions of studies on Chinese cities (Ma et al., 2015; Qin and Han, 2013).

The significant direct effects of building density and living style on endogenous variables are shown in Fig. 8. Building density directly and negatively affected motorcycle riding attitude (-1.05) and travel distance (-0.432). It had direct and positive effects on travel frequency (0.433) and household car ownership (0.163). Building density did not directly affect travel-related CO₂ emissions significantly, but it indirectly and positively influenced travel-related CO₂ emissions through “travel attitude → travel frequency” (0.011) and household car ownership (0.013). Furthermore, it had an indirect and negative effect on travel-related CO₂ emissions through travel frequency (-0.063), “household car ownership → travel frequency” (-0.003), and travel distance (-0.328). Ultimately, it exerted a total negative effect (-0.369) on CO₂ emission from daily traveling, as shown in Table 10.

Centralized living style directly and positively influenced rural motorcycle riding attitude (0.514), household car ownership (0.817), and travel distance (0.308). It had a direct and negative impact on travel frequency (-0.247). Centralized living style had an indirect and negative effect on travel CO₂ emissions through travel attitude → travel frequency (-0.005) and household car ownership → travel frequency (-0.015). Furthermore, it exerted indirect and positive effects on travel CO₂ emissions through travel frequency (0.036), household car ownership (0.066), and travel distance (0.234). Finally, centralized living style had a total positive effect on travel-related CO₂ emissions (0.316), as shown in Table 10. This result confirms that a change in living style during rural urbanization and new rural construction increases travel distance and travel CO₂ emissions.

The abovementioned analysis indicates that travel distance is the main mediating variable that affects the impacts of the rural built environment on travel CO₂ emissions. Thus, effectively reducing travel distance is a key factor in controlling the travel-related

Fig. 9. Direct effects of individual travel attitudes on endogenous variables.

Fig. 10. Direct effects of basic socio-demographic variables on endogenous variables.

CO₂ emissions of rural residents.

4.3. Effects of individual travel attitudes on other endogenous variables

Fig. 9 and Table 11 provide the direct, indirect, and total effects of travel attitude on travel behavior and travel-related CO₂ emissions. Only three of the six travel attitude indicators were statistically significant on travel behavior and travel-related CO₂ emissions. In particular, the attitudes of motorcycle riding (0.073) and electric bicycle riding (0.148) had direct and positive effects on travel frequency, whereas attitudes exerted indirect (total) and negative effects on travel-related CO₂ emissions (coefficients are -0.011 and -0.022 , respectively; Table 11). This result indicates that rural residents who believe that riding motorcycles or electric bicycles is safe, convenient, and environmentally friendly with zero economic pressure emit less CO₂. Therefore, the preference for riding electric bicycles has a significant impact on travel-related CO₂ emissions. Meanwhile, car use cost had a direct and negative effect on household car ownership (-0.114) and travel-related CO₂ emissions (-0.063), but it exerted an indirect and negative impact on travel CO₂ emissions through household car ownership (-0.009). Car use cost indirectly and positively affected travel CO₂ emissions through “household car ownership $\rightarrow$ travel frequency” (0.002). However, all indirect effects were very small, and the total effect of car use cost on travel-related CO₂ emissions was negative (-0.070). Thus, expensive gas prices and parking costs can

Fig. 11. Direct effects of respondents' driving skill on endogenous variables.

significantly reduce CO₂ emission from daily traveling in Chinese rural areas.

4.4. Effects of socio-demographic attributes on endogenous variables

Figs. 10 and 11 show the significant direct effects of socio-demographic attributes on endogenous variables. The results indicate that men are unwilling to own cars and ride electric bicycles, so they emit less travel-related CO₂. This result is in complete contrast to the conclusions of existing research on Chinese cities (Cao and Yang, 2017; Ding et al., 2017a; Ma et al., 2015). This huge difference between urban and rural areas is mainly due to the fact that the rural male segment of the labor force migrates for work. Thus, women and the elderly are the mainstays of the rural population. Moreover, income had a total positive effect on travel-related CO₂ emissions, but age exerted an opposite impact. These results are consistent with those of previous studies, which indicated that income and age significantly affect travel behavior and travel-related CO₂ emissions (Ding et al., 2017a; Ma et al., 2015).

The respondents' driving skills exerted significant direct or indirect impacts on CO₂ emission from daily traveling. Holding a driver's license had the highest positive impact on CO₂ emission from daily traveling. Rural residents who rode motorcycles and electric bicycles emitted less travel CO₂ (total effect coefficients of -0.004 and -0.007 , respectively; Table 10). An interesting result is that the skill of riding bicycles had a total positive effect on travel CO₂ emissions, although bicycling is a zero-carbon travel mode. This result is mainly due to the positive correlation between bicycling skills and household car ownership (0.208 ; Fig. 11). Thus, encouraging cycling and controlling the amount of household car ownership are effective measures to reduce travel-related CO₂ emissions in Chinese rural areas.

5. Conclusions and policy implications

This study adopted Sichuan rural areas as a case study and considered the travel attitudes of rural residents. We proposed a causal model to explain the effects of built environment indicators on CO₂ emission from daily traveling. Data from the daily activity diary survey, on-site measurement, and GIS-based land use were utilized to estimate the SEM conceptual model. The following conclusions and planning implications were established. First, six elements of the built environment had significant total effects on travel-related CO₂ emissions, but only one (destination accessibility) of the six indicators had a significantly direct effect. Built environment indicators indirectly influenced CO₂ emission from daily traveling through mediating variables (travel attitude, car ownership, travel frequency, and travel distance). If only direct effects are considered, then the model would underestimate the impact of the built environment on CO₂ emission from daily traveling and thus misguide planning and policy formulation. Second, destination and transit accessibility had total positive effects on CO₂ emission from daily traveling. Therefore, shortening the distance from the residential area to the main destination and major public transport facilities is an effective measure for reducing travel-related CO₂ emissions of rural residents. Third, increasing road and building densities can effectively reduce travel-related CO₂ emissions. Although the road infrastructure in China's rural areas has greatly improved in the past decade, a large gap remains between urban and rural areas. Therefore, further strengthening rural road infrastructure investment is necessary. Moreover, the building density of centralized residential areas in new rural construction should be appropriately increased. Fourth, the number of accessible markets had a total negative effect on travel-related CO₂ emissions. Compared with the other built environment indicators, it exerted the greatest impact. Thus, the establishment of local market centers should be encouraged in rural areas to reduce travel-related CO₂ emissions. Fifth, household car ownership exerted a direct positive effect on travel-related CO₂ emissions. Rural residents should be encouraged to ride electric bicycles and motorcycles to reduce their daily travel-related CO₂ emissions. Therefore, further investing in cycling facilities and riding lanes and promoting low-carbon travel behavior are necessary. Sixth, travel attitudes had a limited impact on travel behavior and travel-related CO₂ emissions in rural areas. By contrast, the effects of the built environment were obvious and considerable. Therefore, low-carbon-oriented rural planning is particularly important for the development of ecological rural areas and affects the sustainable development of such areas.

Although the impacts of many built environment attributes on travel-related CO₂ emissions in rural Sichuan area were similar to the effects on urban areas, we have to emphasize that several calculation methods of built environment indicators in rural areas are different from the ones used in urban areas. For example, transit accessibility and destination accessibility are calculated as comprehensive indicators without considering multiple transport modes and various destinations. Although we found that transit accessibility and destination accessibility positively influence travel-related CO₂ emissions, which is different from what has been observed in urban environments, we cannot compare these results. Moreover, we found that centralized living style directly and positively influenced rural household car ownership and travel distance. The positive effects on travel-related CO₂ emissions indicated that a change in living style during rural urbanization and new rural construction increases travel-related CO₂ emissions. This finding is consistent with our expectation considering the considerable infrastructure gap between urban and rural areas in China. In the process of China's rural urbanization, the living style of rural residents gradually changed from the traditional scattered living style to the centralized living style with urban characteristics. In addition, only three of the six travel attitude indicators significantly influenced travel-related CO₂ emissions in rural China. In developed countries, such as the Netherlands (Ettema and Nieuwenhuis, 2017), residents' travel attitudes are important factors to predict travel-related CO₂ emissions. The difference indicates that in the case of limited economic development and infrastructure construction level, Sichuan rural residents' travel attitude exerts a limited impact on travel-related CO₂ emission.

This study is the first to investigate the relationship between the rural built environment and travel-related CO₂ emissions in China while considering the daily traveling behaviors of rural residents. It collected data from different rural areas in Sichuan, China, which covered both traditional living style (scattered living) and new countryside style (centralized living). The results provide

insights into the residents' travel behavior and theoretical guidance for the planning and construction of new rural areas in China.

Declaration of Competing Interest

No conflict of interest exists in the submission of this manuscript, and manuscript is approved by all authors for publication. All authors above would like to declare that the work described was original research that has not been published previously, and not under consideration for publication elsewhere, in whole or in part. All the authors listed have approved the manuscript that is enclosed.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.trd.2019.07.004>.

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