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*Article*

# Reducing Carbon Emissions from Shopping Trips: Evidence from China

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**Abstract:** With rising income and the emergence of modern shopping centers in urban China, shopping trips by private car becomes more and more common, leading to higher carbon emissions in the transport sector. Encouraging car owners to shift transport mode from private car to public transport could achieve significant emissions reductions. This study estimate carbon emissions savings by shifting from private cars to public transport for shopping trips in urban China, using Shenyang, one of the largest cities in China, as a case study. Our results show that the average carbon emissions per shopper is 426.9 g, and the carbon emissions on weekends is 13% higher than weekdays. Moreover, shoppers travelling by private car emitted five times more carbon emission than those by public transport. We also found that car ownership gradually increased as accessibility to public transport decreased, and that more car owners chose to travel by private cars than public transport in areas with limited access. This study, thus, highlights the potential for high-quality public transport to reduce the transport sector's carbon emissions in urban China.

**Keywords:** transport; carbon emissions; travel mode; shopping; urban; China

## 1. Introduction

With an increasingly affluent middle class buying cars as soon as they can afford to, Chinese cities are becoming increasingly congested with automobiles [1]. Nationwide, private car ownership increased from 4.1 million to 88.1 million from 2002 to 2013—an annual growth rate of 32% (China Statistical Yearbook, 2014). As a result, travel on public transport has fallen, and in many large Chinese cities, private cars account for more than 60% of the mode of transport [2]. A study by the World Bank offers some clear figures: in large Chinese cities, cars contribute about 50% of the total $CO_2$ emissions; other vehicles, including public transport, motorcycles, and taxis, contribute 10%–20%; and the remaining emissions derive from factory production [3]. China is expected to have 926 million city-dwellers by 2025, and over a billion by 2030 [4]. If these residents were to drive as much as the average American, the carbon emissions produced by transportation in urban China alone would almost match that of all transportation worldwide today. Thus, there are compelling reasons for shift travelers from private motor cars to public transport in Asia's densely populated cities [5,6].

A particularly noteworthy trend in China is the increasing proportion of travel for personal business, recreational, social, and other non-work purposes, especially trips to shopping centers [7]. In many Western cities where suburbanization has progressed over several decades, the retail structure in metropolitan areas has become dominated by suburban arterial strips and shopping malls [8]. In contrast, suburbanization in Chinese cities is still at a relatively early stage, and the commercial and service sectors remain in the center of the city, creating a strong accumulation effect of traffic [9,10]. At the same time, residential suburbanization is expanding in all directions and surrounding the core city, which results in a mismatch between residential and retail areas, which in turn influences the choice of transport and affects carbon emissions [11]. With regard to the role of geography in the retail sector, consumer choice behavior reflects the important but often ignored demand side management in the economic process of shopping [12,13].

Many overseas studies have researched low-carbon transport. Some focused on reducing carbon emissions through technological measures and policies, including the development of new energy vehicles [14], improvement in energy efficiency [15], congestion charges [16,17], and the use of public transport [18]. Other studies have found that a dense urban structure can be an effective way to reduce carbon emissions [19–22]. However, the current level of understanding about the effect of urban form on carbon emissions should be strengthened, as others have found ambiguous relationships between land use and transport [23–26]. While urban structures do evolve with time, the rate of change is often slow and not always shaped by design choices [27]. One factor that is often overlooked in low-carbon transport research is personal travel behavior. Our survey of the literature found few studies on carbon emissions generated by personal travel in the context of high urban density. Thus, the main objective of our study is to calculate the carbon emissions generated by different modes of transport, especially the reduction in carbon emissions by changing to public transport from private cars for shopping trips, taking Zhongjie in Shenyang, one of the famous shopping centers as an example. Our study makes use of space-time behavior research—a unique method for understanding the complex relationships between human activities and urban environments in space and time—to describe and interpret urban spatial structures and spatial reconstructing in urban China from the perspective of individuals' behaviors [28]. By estimating travel-related carbon emissions at the individual level by using questionnaire surveys aimed directly at shoppers, this paper answers two questions. First, what are the differences in $CO_2$ emissions between shopping trips using public transport and those made by cars? Second, what are the significant factors that influence the modes of transport chosen, including both access to public transport and people's socioeconomic characteristics? The answers to the above questions will benefit fields such as urban planning and transportation design and management. The remainder of this paper is structured as follows: Section 2 describes the data collection and analysis methods; characteristics of shoppers, modes of transport, and carbon emissions are presented in Section 3; and, finally, in Section 4, the key implications of the study are addressed.

## 2. Methods

### *2.1. Zhongjie, Shenyang*

Shenyang is the capital city of Liaoning province in northeast China with a total area of 3471 $km^2$ (Figure 1). Shenyang has been an important industrial city, dominated by the equipment manufacturing industry, since the early days of the People's Republic of China. In recent years, however, successful economic transformation has seen the rapid growth of the tertiary sector, which now accounts for 48.5% of the city's GDP. Retail is booming, with retail sales of consumer goods standing at 212.7 billion RMB. Our study area is Zhongjie (Middle Street), which is one of Shengyang's busiest commercial centers, attracting over 300,000 shoppers per day from all over the city and even from surrounding cities. The main pedestrian street and its surrounding area is home to many shopping centers, megastores, department stores, hypermarkets, restaurants, and entertainment facilities (Figure 2). It has a commercial area of nearly 1 million $m^2$, which covers a floor space of 2.6 $km^2$, served by 1 subway line and 68 bus routes.

### *2.2. Data Collection*

The questionnaire surveys were delivered via face-to-face interviews with shoppers in Zhongjie in August 2013. The questionnaires included questions about shoppers' travel characteristics including the origin and routing of the shopping trip, the mode of transport, travel time, and the frequency of trips; shoppers' demographics, such as gender, age, education, residence location, employment and income; and shoppers' attitudes towards the development of public transport, their reasons for not taking public transport, and their opinions on shopping by car. Randomly selected consumers were surveyed over a period from 9:00 a.m. to 7:00 p.m. in Zhongjie, with each questionnaire taking about 8–10 min to complete. A total of 547 shoppers were surveyed: 269 weekday shoppers and 278 weekend shoppers. The data sets used in this study also comprised the road and public transport network of Shenyang.

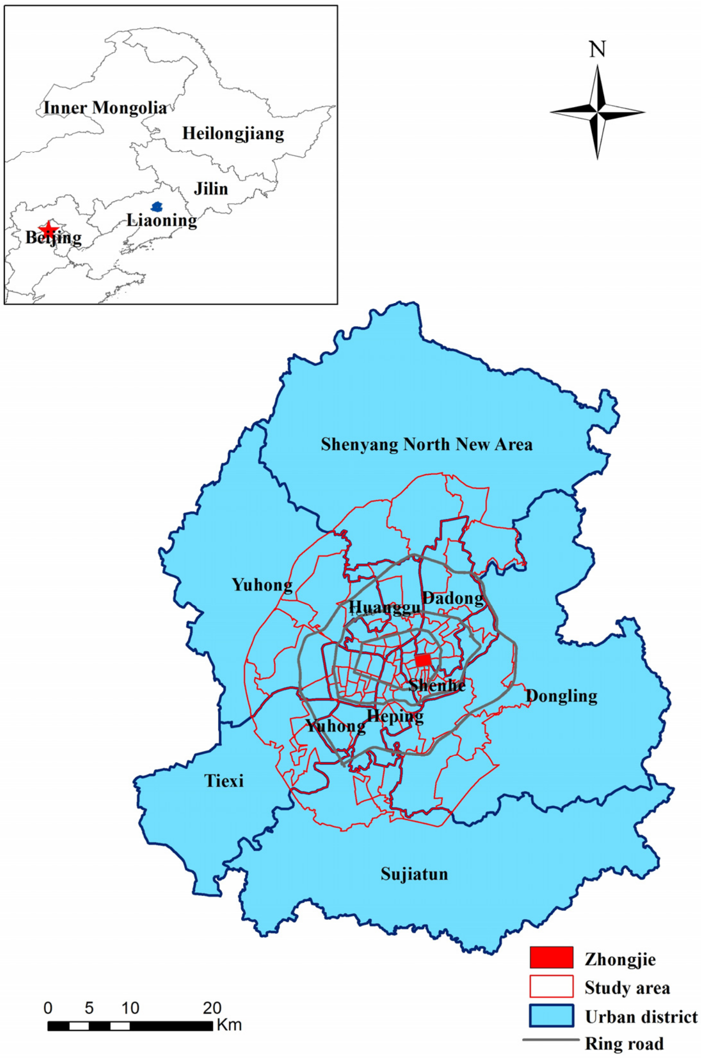



**Figure 1.** Location of Shenyang city and Zhongjie District in Liaoning Province, China.


**Figure 2.** Streetscape in Zhongjie, Shenyang.

## *2.3. Modeling*

We used optimal path analysis to model shoppers' travel distance on the basis of their origin of the trip, travel mode, travel time and routing of the trip. Carbon emissions were then calculated based on the carbon intensity of travel modes and travel distances. Furthermore, access to public transport model was introduced to reflect the location of the shopper's residence base on the public transport network data.

### 2.3.1. Optimal Path Analysis

Previous findings suggest that most shopping trips are optimal [29]. We also found that most of the observed routes are optimal, with only about 10% not following the shortest path. This implies that shopping trips can be adequately modeled by their shortest path. Therefore, we conducted an optimal path analysis using Dijkstra's algorithm to estimate each shopper's travel distance to Zhongjie.

Dijkstra's algorithm identifies the shortest paths from an initial vertex to other vertices in a graph, in which each edge has a non-negative weight (distance) [30]. For a graph $G = (V, E)$, the algorithm visits all nodes of $G$ from a predetermined source $s \in V$. The algorithm maintains a priority queue $Q$, for which the key of a node $u$ is given by the tentative distance to $s$, denoted by $d[u]$. During initialization, all tentative distances, except for $s$, are set to $\infty$, and $s$ is inserted into the priority queue with a key of 0. Then, for each iteration, the node $u$ with the minimum key is extracted from the queue, that is, the node $u$ is settled, and all edges $(u, v) \in E$ are relaxed. Relaxation of an edge is done by determining if the following inequality holds: $d[u] + len(u, v) < d[v]$, where $len(u, v)$ denotes the edge weight of $(u, v)$. If the inequality holds, the path via $u$ yields an improvement on the distance from $s$ to $v$. Thus, $v$ is either added to $Q$, or if $v \in Q$, its priority is decreased. The algorithm stops when all nodes are settled. In our case, the start node (residence) and the end node (Zhongjie) were known. Therefore, the algorithm can stop as soon as the end node is settled [31]. To calculate the shortest path from the start node to the end node, Dijkstra's algorithm was executed in the network analyst module of ArcGIS 10.0 with road and public transport network data of Shenyang City.

### 2.3.2. Estimating Transport Carbon Emissions

There are generally two ways to measure transport carbon emissions: one is to obtain the carbon emissions through fuel consumption and the fuel coefficient [32,33]; the other calculates carbon emissions directly from the carbon emission intensity of each mode of transport and travel distances using a variety of models [34–36]. The latter approach is more flexible and simple as it can directly calculate carbon emissions; hence, we adopted this approach to estimate the carbon emissions for shopping. We calculated carbon emissions per consumer by multiplying the average emissions factor for each aggregated mode of transport $i(F_i)$ (in grams $CO_2$/kilometer) by the travel distance ($D_t$) (in kilometers) as follows:

$$pCO_2 = \Sigma F_i \times D_t \quad (1)$$

The travel distance can be obtained by optimal path analysis mentioned above; emission intensity of different modes of transport was obtained from the Volkswagen Group China and the TREMOVE2.4 manual by the European Union (2006) (Table 1) [37,38].

**Table 1.** $CO_2$ emission intensity by transport modes.

| Classes | Modes | Emission intensity (g/person·km) |
|---|---|---|
| Minicar | Private car, Taxi, Official car | 135.0 |
| Motorbus | Bus, Shuttle bus, Tombus | 35.0 |
| Rail transit | Subway | 9.1 |
| Moped | Electric bike, Disability moped, Lightweight motorcycle | 8.0 |
| Others | Walk, Bicycle | 0.0 |

2.3.3. Access to Public Transport

We defined access to public transport as the total number of stations on the way to Zhongjie within a certain distance of the shopper's place of residence. Assuming people's walking speed to be 80 m/min, we calculated the total number of stations within 400 m, 800 m and 1200 m of their residence (within 5, 10 and 15 min walking distance). In order to compare the influence of different distances, the accessibility of 400 m, 800 m, and 1200 m was endowed with a weight coefficient of 1.5, 1.0, and 0.5 respectively. Finally, we derived the comprehensive accessibility as follows [39]:

$$\text{Comprehensive Accessibility} = (\text{Accessibility of 400 m} \times 1.5 + \text{Accessibility of 800 m} \times 1.0 + \text{Accessibility of 1200 m} \times 0.5)/3 \quad (2)$$

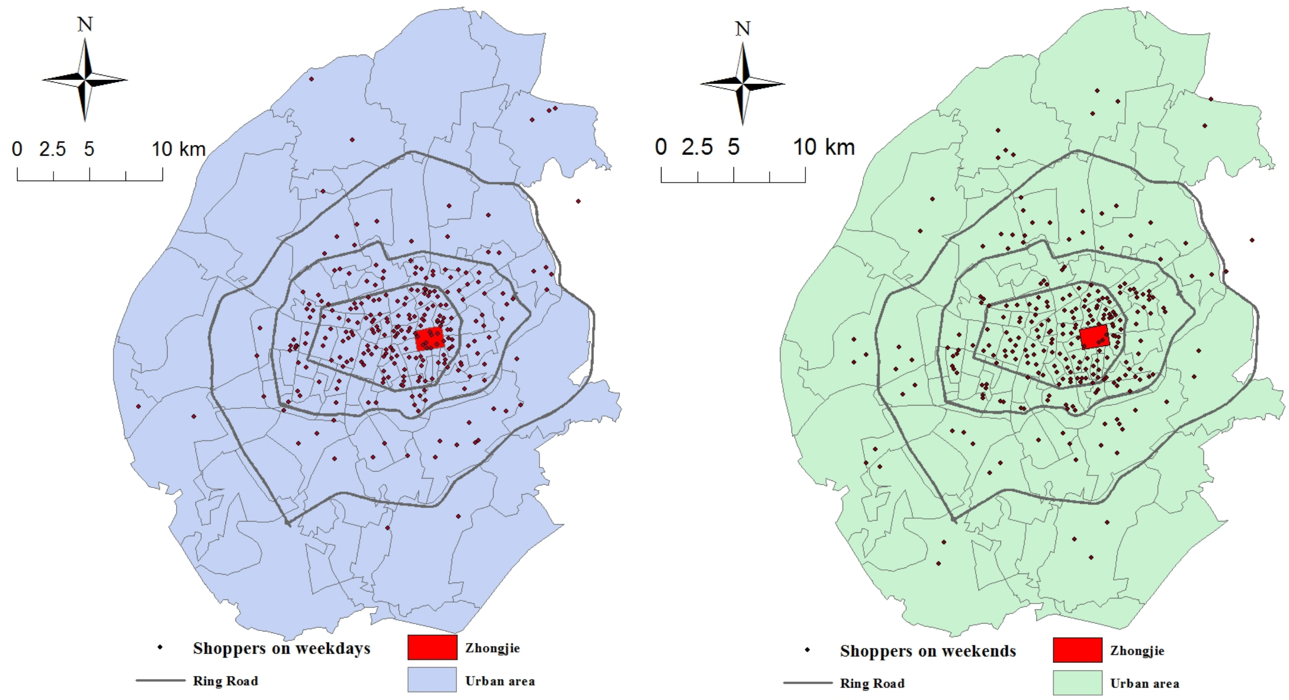
## 3. Results

### *3.1. Characteristics of Shoppers*

The results show that Zhongjie attracts shoppers from the entire city (Figure 3): 78.3% of shoppers reside within the inner city (defined as districts located within the second ring road) (82.3% and 73.6% on weekdays and weekends, respectively); 15.2% live between the second and third ring roads (13.8% and 17% on weekdays and weekends, respectively); and 6.5% come from outside the third ring road (3.9% and 9.4% on weekdays and weekends, respectively).

With regard to mode of transport, 65.8% of shoppers come to Zhongjie by bus and subway (65.4% and 65.1% on weekdays and weekends, respectively); 19.5% drive in by car (20.8% and 17.9% on weekdays and weekends, respectively); and 14.7% walk to Zhongjie (12.8% and 17% on weekdays and weekends, respectively).

Most shoppers are female (68.8%) and have received tertiary education (68.4%), while 38% are from the 18–25 and 25–35 age groups. Most shoppers work for companies, including private enterprise, state-owned enterprise, and foreign companies, with 32% earning between 2000–3000 RMB per month (The average per capita income in urban Shenyang is 2423 RMB per month according to Liaoning Statistical Yearbook 2014). The demographics of shoppers differ significantly between weekdays and weekends: the proportion of female shoppers on weekends is 10% higher than on weekdays; people in the 25–35 age group are the main shoppers on weekdays (accounting for 39.7%), whereas half of weekend shoppers are in the 18–25 age group. Furthermore, the number of shoppers from the over-50s age group on weekdays is 10% higher than on weekends. The monthly income of shoppers is higher on weekdays than on weekends. The number of shoppers earning above 5000 RMB per month on weekdays is nearly 1.7 times more than those on weekends, while the number earning less than 2000 RMB per month on weekends is about 1.6 times more than those on weekdays (Table 2).




(**a**) (**b**)

**Figure 3.** (**a**) Shoppers distribution on weekdays; (**b**) Shoppers distribution on weekends.

**Table 2.** Characteristics of Zhongjie shoppers (Total/Weekday/Weekend %).

| Gender | Age group | Education | Occupation | Per capita monthly income |
|---|---|---|---|---|
| Male (31.2/35.7/25.7); Female (68.8/64.3/74.3) | ≤18 (4.6/5.3/3.8); 18–25 (38.4/26.0/53.8); 25–35 (37.6/39.7/34.9); 35–50 (11.0/16.0/4.7); 50–65 (8.0/12.2/2.8); ≥65 (0.4/0.8/0.0) | Below HS (15.2/17.6/12.1); HS (10.5/16.0/4.7); Undergraduate (68.4/61.8/75.7); Above Master (5.9/4.6/7.5) | GAPI (6.8/6.9/6.5); SHRI (16.9/9.2/26.2); Enterprise (41.8/46.2/36.5); Self-employed (9.3/8.5/10.3); Unemployed (7.6/7.7/7.5); Retirement (17.6/21.5/13.0) | <2000 (18.5/14.7/23.8); 2000–3000 (32.4/29.5/35.2); 3000–5000 (26.9/28.7/24.8); >5000 (22.2/27.1/16.2) |

Note: HS: High School; GAPI: Government agency and Public institution; SHRI: School, Hospital and Research institutions.

### *3.2. Measuring Carbon Emissions*

In this section, we analyze the two primary modes of transport (private car and public transport) with regard to their carbon emissions. On average, shoppers travel 9.3 km and produce 426.9 g of carbon emissions. The weekend figure is 451.7 g which is 13% higher than the weekday figure. Carbon emissions per shopper are higher at the weekends because more people drive and travel longer distances (10.2 km; 21% higher than weekdays). Figure 4 shows the average carbon emissions of private cars and public transport. Private car emissions are 5 times higher than those of public transport. On weekends, carbon emissions from cars increase to 1230.5 g, which are 5.6 times higher than public transport.

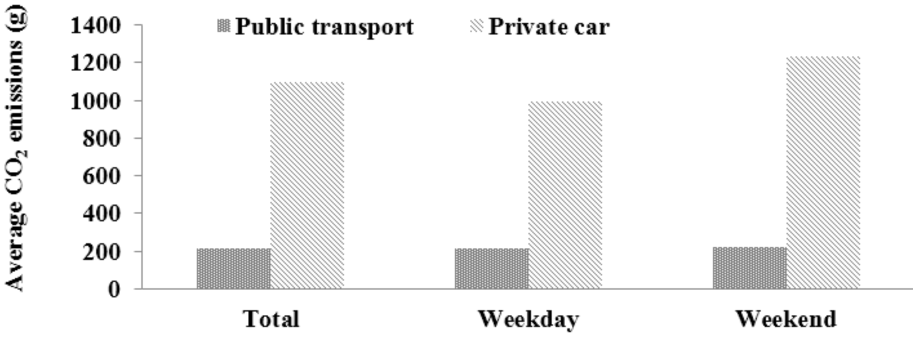



**Figure 4.** Average $CO_2$ emissions between different travel modes.

Obviously, the average carbon emissions increase with distance traveled. Private car emissions from shoppers living outside the third ring road average 2075.6 g, which is 2.2 times and 1.4 times higher than emissions from shoppers living within the second ring road and between the second and third ring roads, respectively. Moreover, average carbon emissions from private cars are 5.5 times higher than public transport both within the second ring road and between the second and third ring roads. As the average distance traveled from outside the third ring road is longer for public transport, though, carbon emissions by private cars are only 4.5 times higher.

For shoppers living within the second ring road, less than 20% travel to Zhongjie by car and more than 60% by public transport both on weekdays and on weekends. On weekdays, the distance driven by car on average is 6.5 km, which is similar to that traveled by public transport; however, the average carbon emissions from private cars are nearly 5 times higher than those from public transport. Shoppers traveled slightly further on weekends: the average distance by car and public transport was 7.9 km and 8.4 km, respectively, which produced 1066.5 g and 167.9 g of carbon emissions on average. Shoppers living between the second and third ring roads are approximately 10% more likely to drive to Zhongjie on weekends than on weekdays. The average distance traveled by car on weekends reached around 12 km and produced average carbon emissions of more than 1500 g, which is 6.5 times higher than average emissions from public transport. Those shoppers living outside the third ring road prefer to travel to Zhongjie by public transport on weekend. On weekdays, 20% of shoppers travel by car producing emissions 3.5 times higher than public transport. The maximum distance traveled by private cars and public transport reach 23.2 km and 44.1 km, and the associated maximum carbon emissions are 3132 g and 751 g, respectively (Figure 5).

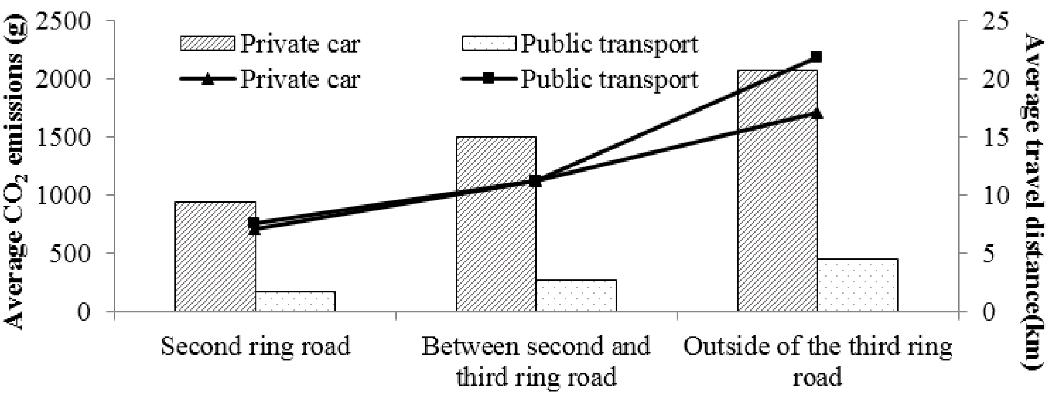
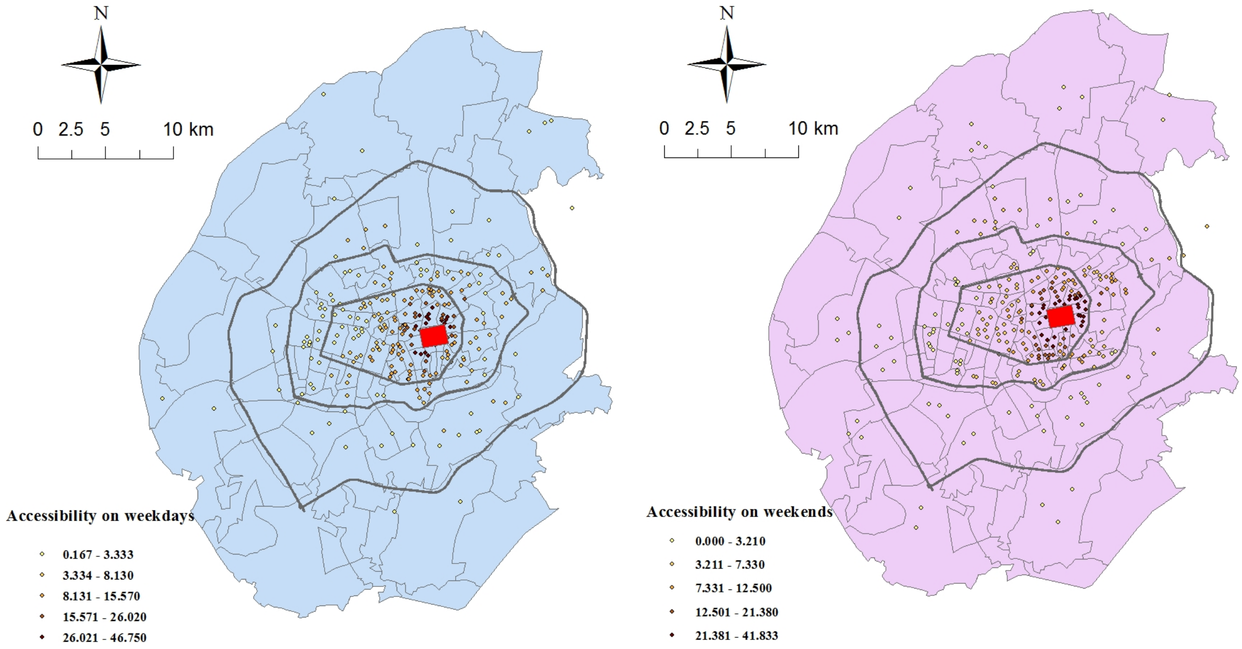



**Figure 5.** Average $CO_2$ emissions and distance traveled from different modes of transport.

*3.3. Car Owners' Transport Choice*

In this section we focus on car-owning shoppers and aim to explore the factors that influence their decisions on transport choice. We calculated access to public transport to Zhongjie based on data of public transport routes and schedules. The score was divided into five classes: very high, high, medium, low, and very low on weekdays and weekends (Figure 6).




(**a**) (**b**)

**Figure 6.** (**a**) Access to public transport to Zhongjie on weekdays; (**b**) Access to public transport to Zhongjie on weekends.

Table 3 shows the relationship between car ownership, choice of transport, and access to public transport: for both weekday and weekend shoppers, the percentage of car ownership in areas with very low access to public transport is 5 times higher than that in areas with very high access. We conducted a correlation analysis between the emission values and access to public transport. The results show that $CO_2$ emission is negatively correlated to access to public transport ($p < 0.001$).

**Table 3.** Shares of car ownership and travel mode (weekday/weekend %).

| Access to public transport | Car ownership | Travel mode | | |
|---|---|---|---|---|
| | | Private car | Public transport | Walk |
| Very high | 8.7/5.1 | 50.0/0.0 | 0.0/0.0 | 50.0/100.0 |
| High | 2.2/7.7 | 100.0/0.0 | 0.0/66.7 | 0.0/33.3 |
| Medium | 21.7/23.1 | 30.0/22.3 | 70.0/44.4 | 0.0/33.3 |
| Low | 32.6/33.3 | 60.0/53.9 | 40.0/46.1 | 0.0/0.0 |
| Very low | 34.8/30.8 | 37.5/58.3 | 62.5/41.7 | 0.0/0.0 |

Most shoppers with private cars residing in areas with very high and high access to public transport drive to Zhongjie on weekdays, but walk on weekends, while car owners living in areas with medium access are more likely to take public transport than drive both on weekdays and on weekends. In areas with low access, however, car owners are more likely to drive than to take public transport, whereas those in areas with very low access are more likely to drive on weekends and more likely to take public transport on weekdays.

We classified car owners based on their access to public transport, mode of travel, age, education, occupation, income, and gender (Tables 4 and 5). Table 4 shows the characteristics of driving cars and taking public transport according to different levels of access, on weekdays. The shoppers residing in areas with high and very high access to public transport take their cars for shopping on weekdays because they preferred to go shopping in Zhongjie near their residence and workplace; some individuals were shopping during a break from work when they were surveyed. Shoppers in areas with very high and high or medium access have similar characteristics: they are mostly 25–35 years old and have received a higher education than those taking public transport. Shoppers driving cars typically work in enterprises, government agencies, and public institutions, and their average monthly income is higher than those taking public transport. The situation for shoppers living in areas with low and very low access is slightly different: shoppers driving cars in the 35–50 age group accounted for 53.3%; shoppers also comprise some retired and unemployed people; and their educational level is slightly lower than those taking public transport. Although the income level of car drivers living in areas with low and very low access is lower than those in areas with very high, high, and medium access, it is still higher than shoppers taking public transport.

**Table 4.** Characteristics of car owners on weekdays (%).

| Access to public transport | Travel mode | Characteristics | | | | |
|---|---|---|---|---|---|---|
| | | **Age group** | **Education** | **Occupation** | **Per Capita monthly income** | **Gender** |
| High and very high | Private car | 25–35 (66.7)<br>35–50 (33.3) | Undergraduate (100.0) | GAPI (33.3)<br>Enterprise (66.7) | 3000–5000 (33.3)<br>>5000 (66.7) | Male (39.4)<br>Female (60.6) |
| | Public transport | 18–25 (50.0)<br>25–35 (50.0) | Below HS (50.0)<br>Undergraduate (50.0) | Enterprise (100.0) | 2000–3000 (50.0)<br>3000–5000 (50.0) | Male (50.0)<br>Female (50.0) |
| Medium | Private car | 18–25 (33.3)<br>25–35 (66.7) | Undergraduate (66.7)<br>Above Master (33.3) | Enterprise (66.7)<br>Unemployed (33.3) | 3000–5000 (33.3)<br>>5000 (66.7) | Male (45.2)<br>Female (54.8) |
| | Public transport | ≤18 (14.3)<br>25–35 (42.8)<br>35–50 (28.6)<br>50–65 (14.3) | HS (28.5)<br>Undergraduate (42.9)<br>Above Master (28.6) | GAPI (14.2)<br>SHRI (28.6)<br>Enterprise (28.6)<br>Unemployed (14.3)<br>Retirement (14.3) | < 2000 (14.3)<br>3000–5000 (14.3)<br>>5000 (71.4) | Male (33.3)<br>Female (66.7) |
| Low and very low | Private car | 18–25 (6.7)<br>25–35 (33.3)<br>35–50 (53.3)<br>50–65 (6.7) | Below HS (26.7)<br>HS (20.0)<br>Undergraduate (53.3) | Enterprise (60.0)<br>Self-employed (6.7)<br>Unemployed (6.7)<br>Retirement (26.6) | <2000 (6.7)<br>2000–3000 (20.0)<br>3000–5000 (20.0)<br>>5000 (53.3) | Male (60.0)<br>Female (40.0) |
| | Public transport | 18–25 (18.7)<br>25–35 (56.3)<br>35–50 (12.5)<br>50–65 (12.5) | Below HS (6.2)<br>HS (12.5)<br>Undergraduate (75.0)<br>Above Master (6.3) | GAPI (12.4)<br>SHRI (6.2)<br>Enterprise (56.3)<br>Self-employed (12.5)<br>Unemployed (6.3)<br>Retirement (6.3) | 2000–3000 (25.0)<br>3000–5000 (43.8)<br>>5000 (31.2) | Male (37.5)<br>Female (62.5) |

**Table 5.** Characteristics of car owners on weekends (%).

| Access to public transport | Travel mode | Characteristics | | | | |
|---|---|---|---|---|---|---|
| | | Age group | Education | Occupation | Per capita monthly income | Gender |
| High and very high | Public transport | ≤18 (20.0)<br>18–25 (20.0)<br>25–35 (40.0)<br>50–65 (20.0) | Below HS (20.0)<br>HS (20.0)<br>Undergraduate (40.0)<br>Above Master (20.0) | SHRI (60.0)<br>Self-employed (20.0)<br>Retirement (20.0) | 2000–3000 (20.0)<br>3000–5000 (40.0)<br>>5000 (40.0) | Male (60.0)<br>Female (40.0) |
| Medium | Private car | 25–35 (50.0)<br>50–65 (50.0) | Below HS (50.0)<br>HS (50.0) | Enterprise (100.0) | 2000–3000 (50.0)<br>3000–5000 (50.0) | Male (55.3)<br>Female (44.7) |
| | Public transport | ≤18 (11.1)<br>18–25 (61.1)<br>25–35 (16.7)<br>35–50 (11.1) | Below HS (11.1)<br>HS (5.6)<br>Undergraduate (72.2)<br>Above Master (11.1) | SHRI (44.3)<br>Enterprise (27. 8)<br>Self-employed (16. 7)<br>Unemployed (5.6)<br>Retirement (5.6) | <2000 (11.1)<br>2000–3000 (16. 7)<br>3000–5000 (50.0)<br>>5000 (22.2) | Male (22.2)<br>Female (77.8) |
| Low and very low | Private car | 18–25 (7.1)<br>25–35 (78.6)<br>35–50 (14.3) | Below HS (7.1)<br>Undergraduate (78.6)<br>Above Master (14.3) | GAPI (14.4)<br>SHRI (7.1)<br>Enterprise (57.1)<br>Self-employed (21.4) | 2000–3000 (15.3)<br>3000–5000 (38.5)<br>>5000 (46.2) | Male (64.9)<br>Female (35.1) |
| | Public transport | ≤18 (18.2)<br>18–25 (54.6)<br>25–35 (9.0)<br>35–50 (18.2) | Below HS (18.2)<br>HS (9.1)<br>Undergraduate (63.6)<br>Above Master (9.1) | SHRI (36.3)<br>Enterprise (27.3)<br>Self-employed (18.2)<br>Unemployed (9.1)<br>Retirement (9.1) | <2000 (18.2)<br>2000–3000 (18.2)<br>3000–5000 (63.6) | Male (27.3)<br>Female (72.7) |

Table 5 shows the characteristics of driving cars and taking public transport according to different levels of access, on weekends. For shoppers who own cars and live in areas with very high and high access, they all choose to walk on weekends. Average distance traveled by public transport is about 14.9 km for shoppers residing in areas with low and very low access, and car drivers mainly come from these areas. They are mainly 25–35 years old, work in enterprises, government agencies and public institutions, have received higher education, and their income level is significantly higher than shoppers taking public transport.

Female shoppers are more likely than male shoppers to use public transport, especially in areas with low and very low access. However, for shoppers who own cars, females living in areas with very high and high access are more dependent on private cars than males. Overall, male shoppers are more likely to drive cars than female shoppers on both weekdays and weekends. Female shoppers produce, on average, 22% and 40% lower emissions than male shoppers do on weekdays and weekends, respectively.

## 4. Discussion and Conclusions

This study contributes to the study of China's low-carbon transportation in two ways. First, it provides a quantitative comparison of carbon emissions between driving private cars and taking public transport for shopping both on weekdays and on weekends. As shown in this paper, shopping trips by private car produce emissions that are about five times higher than those by public transport. Furthermore, it shows that the percentage of car ownership in areas with very low access to public transport is five times higher than that in areas with very high access. The findings presented in our study are in line with Prabhu and Pai [34], who show that well-performing and high-quality urban public transport is important to emissions reduction. Cities in China should make plans to improve the coverage and quality of public transport, such as speed, frequency, reliability, comfort, and the ease of transfer, to a level that will attract car owners to use it more often; the development of subway-based mass transit systems is therefore very important. It is also necessary to expand peripheral transport service and improve public transport connecting the central city to suburban and rural areas.

There are a number of policies and forces in China that are contributing to a greater reliance on private cars and these factors must also be addressed. For instance, newly-built shopping centers make great efforts to enlarge parking supply and improve parking site design in order to attract shoppers. In Zhongjie, almost all shopping malls have their own parking lots that charge only 2–3 RMB per hour, and some malls provide free parking based on membership or spending. Furthermore, curbside parking is abundant and poorly regulated. Previous studies show that parking availability and cost have a significant effect on private car usage [40]. Therefore, a more restrictive parking policy would help reduce the number of car shopping trips.

Second, this study sheds light on choice of transportation for shoppers owning private cars and their socioeconomic characteristics. It shows that individuals with high-income, undergraduate or above education, and white-collar occupations are more likely to use private cars for shopping and therefore produce higher emissions. Furthermore, female shoppers are more likely than male shoppers to take public transport for shopping. This result echoes earlier research [41], and reflects gender inequality in household task allocation, jobs, wages, and bargaining power for car use in China. Previous studies demonstrate that emissions are increasing with income but decreasing with education [42]. Our results support the positive correlation between income and carbon emissions. As income rises, the speed and convenience of transport become more important factors than the cost of transport, making private cars a favorable mode of transport. However, in our study, most shoppers with higher education drive private cars for shopping because of the higher level of comfort than on public transport, even though they might be aware of the detrimental environmental effects from driving. Experience in Singapore and New York demonstrates that it is possible to maintain a high rate of public transport use, even among high-income earners [40]. Undoubtedly, persuading people to change from private cars to public transport is one of the most important elements in any strategy to meet the growing urban travel demand. It is therefore instrumental for the government to learn from these successful examples to develop sustainable transport initiatives, including public transit investment, traffic management, vehicle and fuel taxes, parking regulations, vehicle quota and congestion pricing, to moderate the growth of urban transport emissions in China. It is also necessarily for the government to proactively inform the public of the negative environmental effects from cars, as the effectiveness and legitimacy of low-carbon policies depends on public attitudes toward the environment.

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## Author Contributions

Jing Li, Pingyu Zhang and Mark Wang conceived and designed the basic frame. Jing Li carried out the main body of research and analyzed data with guidance from Pingyu Zhang, Mark Wang and Kevin Lo. Meng Guo contributed with expertise in optimal path analysis models. Jing Li wrote the paper; Kevin Lo reviewed the work and improved the paper continuously; Mark Wang, Pingyu Zhang and Meng Guo revised for the publication.

## Conflicts of Interest

The authors declare no conflict of interest.

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