


## Article

# Impact of Car-Sharing and Ridesourcing on Public Transport Use: Attitudes, Preferences, and Future Intentions Regarding Sustainable Urban Mobility in the Post-Soviet City

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**Abstract:** The impacts of ICT-based mobility services vary in different cities, depending on socioeconomic, urban form, and cultural parameters. The impacts of car-sharing and ridesourcing on public transport have not been investigated appropriately in post-Soviet Union cities. This study presents exploratory evidence on how ridesourcing and car-sharing affect public transport usage in Moscow. Additionally, it studies how demographics, spatial parameters, attitudes, and travel preferences influence the frequency of use of ridesourcing and car-sharing in Moscow. An online mobility survey was conducted at the beginning of 2020 among respondents (sample size is 777) in the Moscow agglomeration. Overall, 66% of ridesourcing users shifted from public transport to these mobility services, which shows the substitutional impact of ridesourcing on public transport. Additionally, the logit model indicates that the regular use of ridesourcing negatively correlates with the regular use of buses/trams/trolleybuses in Moscow. The impact of car-sharing on public transport seems less substitutional and more complementary than the impact of ridesourcing. Overall, 40% of car-sharing users would replace their last car-sharing trip with public transport if car-sharing was unavailable. Moreover, the logit model indicates a positive association between the regular use of car-sharing and the use of buses/trams/trolleybuses. Moreover, the modal split analysis shows a bigger share of public transport use and walking than car use among citizens' urban journeys in Moscow.

**Keywords:** on-demand mobility services; transportation network companies (TNCs); ridesourcing; car-sharing; ordinal logistic regression; mode choice; travel behavior; attitudes; future intention



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## 1. Introduction

The recent app-based on-demand mobility services, such as car-sharing, bikesharing, e-scooter sharing, and transportation network companies (TNCs, also called ridesourcing and ridesharing), are significant instruments of transport politics in urban areas. They have transformed citizens' travel behavior and triggered the trend of rejecting private car usage in Moscow last year [1]. At the same time, the recently emerged COVID-19 pandemic and strict lockdown measures in Moscow from April 2020 might have had an impact on citizens' travel behavior, as the share of trips made by private vehicles and taxis increased by 33% and 8%, respectively [2]. This could become an additional barrier to sustainable mobility transition in Moscow.

Many studies showed how information and communications technology (ICT) has changed trip generation, costs, and travel purposes by modifying the principles of forming routes and making related changes in people's lifestyles [3–6]. ICT has shaped new types of mobility modes, such as ridesourcing (which has given rise to TNCs), car-sharing, bikesharing, and scooter sharing, connecting the main parts of the transport system to-

gether (transport infrastructure, vehicles, travelers) regularly via apps (online platforms) to contribute optimal real-time mobility services.

Some studies indicate that the effect of ridesourcing on modal shift and travel behavior has an interrelation with the shapes of urban areas, socioeconomic factors, and quality of service available in cities, which vary in different cities [7–10]. Other studies researched the effect of car-sharing and ridesourcing on public transport and non-motorized travel in cities in the USA [11,12]. It is thought that car-sharing and ridesourcing complement the public transport system, and people increase their overall public transport and non-motorized modal use.

Consequently, it is important to analyze the impact of on-demand mobility services on travel behavior in the context of each region by considering the related demographic and urban parameters. However, the impacts of on-demand services in Moscow are unclear. On the one hand, the Moscow metro system is overcrowded at peak hours and has a growing trend of usage by citizens. For instance, the share of people using public transport increased from 62% to 70% from 2010 to 2019 [13]. On the other hand, the Russian capital is the leader in car-sharing services globally [14]. At the same time, the use of ridesourcing services (Yandex.Taxi, Gett taxi, Uber, etc.) has been increasing steadily for the last ten years [15]. The station-based bike-sharing service Velobike has been expanding for the previous seven years.

Furthermore, e-scooter sharing services, which emerged over the last two years, are also popular in the city center as a means of transport. Are these new kinds of transport sustainable in Moscow? Or, are they just a way to avoid using public transport for residents?

There are a lot of studies about how people use various services in Moscow [16–19], mostly for marketing purposes. An overall picture of how on-demand service affects using public transport and non-motorized transport does not exist or is not openly available. However, it is significant for forming urban transport policy. According to this gap, this study focuses on two research questions: (1) how does an on-demand mobility service impact the use of public transport? (2) How do personal attitudes, preferences, and future intentions toward sustainable urban mobility influence the range of transport decisions made by users of TNC and car-sharing services in Moscow?

An online opinion poll was conducted among Moscow agglomeration residents older than 18 to investigate these questions. The survey consisted of 68 questions, and 777 people participated. In order to analyze the data collected, this study will use the following methods: descriptive statistics and ordinal logistic regression models (OLR) of frequency of usage of TNC and car-sharing. OLR models are often used to understand mobility behavior changes in many studies [20–22].

This paper is organized as follows: Section 1 includes a brief review of the literature, focusing on the impact of shared mobility services and the overview of the modal split in Moscow in the last ten years; Section 2 provides the materials and methods; Section 3 describes the results of the survey; Section 4 presents the discussion about the study.

### *1.1. Impact of Transportation Network Companies*

Transportation network companies (TNC), also known as ride-hailing or ridesourcing, accelerate and simplify the connection between drivers and passengers via smartphone apps and provide passengers with the best real-time mobility service. The technology of real-time matching of the locations of travelers and drivers through online platforms and GPS makes this service available. In addition, ridesourcing provides travelers with more services, such as e-payment, reviewing drivers, and selecting a car class.

The advantages of TNCs are increasing the financial and practical effectiveness of car travel in cities compared to traditional taxis and private cars. At the same time, ridesourcing raises the availability and affordability of car usage for citizens. As a result, it increases the vehicle-kilometers travelled (VKTs) in the city, as it shifts some citizens from using public transport to TNC or provides more mobility for non-mobile users [23,24]. This, consequently, changes the more sustainable modes to less sustainable ones. There is

a concern that ridesourcing raises the Jevons paradox, which means that its functional productiveness may boost rather than reduce overall VKTs and car usage in cities [25]. The rebound effect, caused by the Jevons paradox, counteracts the expected benefits of emerging efficient technologies [26,27]. For example, Rayle et al. argued that 8% of Uber and Lyft users would not have taken a journey if TNCs had not provided services in San Francisco [12]. At the same time, the study of seven large metros (Boston, Chicago, Los Angeles, New York, San Francisco, Seattle, and Washington DC areas) showed that 22% of respondents would not have made TNC trips if this service had not been available [24].

The impact of ridesourcing on public transport usage in cities is controversial as researchers show that TNC has substitutionary and complementary effects on public transport usage in American cities [28,29]. Furthermore, Ilavarasan et al. (2018) indicated that TNC might help with first/last mile problems of public transport, because 66% of survey respondents in New Delhi said that an important reason to choose ride-hailing is the access to public transport stations [30]. Moreover, the results of the American Public Transportation Association indicate that ridesourcing was more popular among citizens at weekends and late at night when public transport offers a reduced service [31].

However, regarding substitutionary effects, ridesourcing could cause a shift in travel behavior from public transport to car usage, particularly in big cities. For example, 33% of the ridesourcing users in San Francisco would have taken public transport if Uber and Lyft were not available [12]. Later, Henao (2017) found almost the same result (22.2% of users of the TNC) for Denver [23]. Additionally, Clewlow and Mishra (2017) found that ridesourcing lures citizens from public buses and light rail [24]. The research in Boston in 2018 indicated that 42% of respondents would have replaced their current ridesourcing trip on public transport had the ridesourcing service not been available [32].

Later, Schaller concluded that TNCs in big American cities are primarily supplanting modes such as buses, the subway, biking, and walking, instead of “replacing the personal auto” [33].

At the same time, Tiranchini (2020) investigated 27 empirical ride-hailing studies in cities in the Global North and Global South [34]. He concluded that there are not enough data to determine whether the complementary effect is bigger than the substitution, but there is enough evidence to claim that multi-modal travelers are more likely to adopt ride-hailing than public transport, especially for occasional trips. However, at the same time, observing studies with updated data, he found the tendency that the substitute impact is stronger than complementary in several cities [34].

The recent research in China investigated the factors which determine the nature of ridesourcing impact on public transport usage. For example, the study in Chengdu found that the substitute effect of ridesourcing on public transport is more common for short trips (<15 min) in areas with high-density land-use and with good transit access, especially for the areas featuring a large number of business and much more real estate [35]. Another study in Chengdu showed that ridesourcing as a substitute for public transport is more evident in the city center and the areas covered by the subway, whereas the complementary effect is more evident in suburban areas with poor public transport coverage [36]. In addition, the fleet size and fares of ridesourcing greatly affect the complementary and substitutive relationship between ridesourcing and public transport [37].

Some studies in American cities also show that ridesourcing is more associated with downtown core neighborhoods and areas with good public transport access, rising rents, and whiter and more educated residents [38,39].

Simultaneously, ridesourcing might affect the urban environment by changing the level of car ownership in cities and, consequently, have an impact on the emissions of urban transport [40–43].

These different studies indicate that ridesourcing might have an effect on car usage; as an alternative mode for regular commuting, ridesourcing creates a new form of car dependence with a smaller tendency toward public transport usage. The understanding

of the association between ridesourcing, public transport, and car dependence could give essential input for policymaking and on-demand mobility management at a city level.

### *1.2. Impact of Car-Sharing*

On the whole, the research in the last few years can give a comprehensive understanding of car-sharing benefits and impacts on different social, urban and economic conditions [44,45].

There is enough evidence that car-sharing services reduce car ownership of citizens and transfer car-oriented users to more sustainable travel behavior in the cities of the Global North [46–50]. For example, Becker et al. (2018) showed that 6% of users of free-floating car-sharing reduced their private car ownership in Basel [51]. An early study in Germany showed that 6% of DriveNow users (a free-floating service) and 15% of Flinkster users (a station-based service) decided against using a private car due to car-sharing [52].

The updated case study of Dublin shows that the main motivation for users of car-sharing is the reduction in travel costs compared to car ownership [53]. At the same time, the investigation of the adoption of car-sharing in Norway demonstrated that most users who choose car-sharing are not motivated by a reduction in travel costs [54].

At first, urban planners and city managers expected that car-sharing would increase the affordability of car usage for low-income social groups such as students and seniors [55]. However, an updated systematic literature review on car-sharing by Nansubuga and Kowalkowski (2021) showed that in Europe and North America, car-sharing is mainly used by highly educated people, while in developing economies, the same group of people prefers car ownership [45].

The shedding of private cars resulted in car-sharing motivating people to make more multi-modal choices depending on their travel purpose. As a result, people are motivated to have more environmentally friendly travel behaviors [11,52,56,57]. In addition, Coll et al. (2014) concluded that urban sprawl and a good public transport system are important driving forces for the car-sharing business [58]. Additionally, Gordon-Harris (2016) claimed that car-sharing and public transport systems have a complementary nature, so the success of car-sharing in a particular city depends on the presence of a good public transport system [59].

However, the impact of car-sharing on public transport in the Global North is controversial. Some recent European studies proved a substitutional association between public transport and car-sharing in Copenhagen [60], Basel [61], and Madrid [62]. For example, Caulfield and Kehoe (2021) found that car-sharing is replacing public transport for longer-distance trips in Dublin [53]. At the same time, Martin and Shaheen (2011a) investigated the shift of modes among 6281 users of North American car-sharing organizations and found that only 1% of car-sharing customers reduced their public transport usage [11]. After all kinds of modal shifts were investigated, they concluded that car-sharing mitigates congestion and encourages sustainable transport.

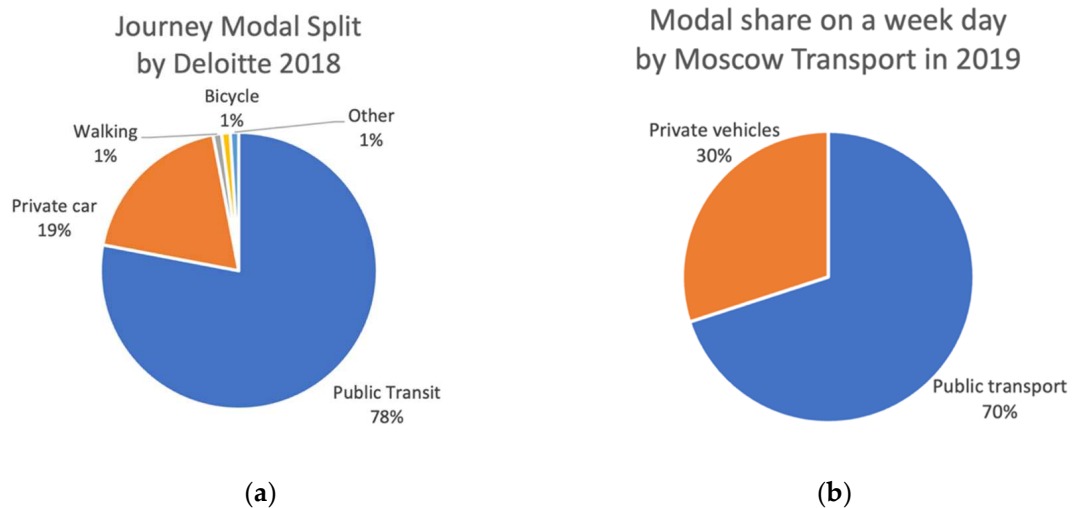
In parallel, Moscow has the most developed car-sharing system in Europe, performing 6–8 trips per vehicle within the Moscow Car-Sharing Project [63], and it is on top among European cities regarding passenger flow on public transport [13]. However, there is no understanding of the impact of car-sharing on public transport in the city. Nevertheless, this understanding can provide essential insights to the city's government and the international scientific community. This is because Moscow has a mixture of urban structures with elements of European and Asian cities, such as the preserved historical structure of the city center with low-rise buildings and new high-density residence areas.

### *1.3. Modal Split in Moscow*

The metropolitan region of Moscow has a growing population of around 12.678 million people [64]. The urban mobility system of the city has a public transport-oriented structure, with a modal share of 70% on a weekday in 2019 [2]. Unfortunately, there is no single

comprehensive annual data collection system on modal split in Moscow as compared to Germany or the USA.

At the same time, a rough generated modal split in Moscow in 2019 is available from two resources (Figure 1): Deloitte City Mobility Index [65] and Moscow Transport data [2]. Both assert the dominant role of public transport in the urban mobility system but ignore on-demand mobility services.



**Figure 1.** Modal split in Moscow: (a) Journey Modal Split by Deloitte 2018 [65]; (b) modal share on a weekday by Moscow Transport in 2019 [2].

The data provided by Moscow Transport [13] in Table 1 are more comprehensive statistical data, and thus serve this study's aims better. Although there are data about on-demand mobility and public transport usage in Moscow in 2010 and 2019, these data do not present information about the daily passenger traffic of private vehicles. These data were collected via big data infrastructure and the transport model of the Moscow government and reflected the status-quo of the usage of the complex of Moscow transport in 2019.

**Table 1.** Daily passenger traffic in Moscow in 2019 [13].

Million trips per weekend	2010	2019
Moscow Metro, including the MCC <sup>1</sup>	8.0	9.2
Surface transport	7.2	7.4
Suburban railways, including the MCD <sup>2</sup>	1.5	2.1
Taxi	0.03	1.01
Car-sharing	0.04	0.23
Bike-sharing	-	0.03
Total	16.7	20

Note: <sup>1</sup> MCC—The Moscow Central Circle (Railway); <sup>2</sup> MCD—Moscow Central Diameters (Railway).

According to the data, on-demand mobility services show robust growth in the share of daily passenger traffic over the previous ten years. However, the amount of taxi traffic was around 5% of all daily passenger traffic (Moscow Metro, surface transport, suburban railways) in public transport, and car-sharing was around 1.2% of that in 2019.

### 1.3.1. TNC in Moscow

The widespread ridesourcing technology pushed the development of the market of transportation network companies in Moscow at the beginning of the 2010s, and it is still growing, especially through the COVID-19 pandemic. Because of this, there was almost a 20-fold growth in the number of passengers in taxis [15], from 45,000 to 890,000 passengers

per day, from 2010 to 2019. During the same time period, the taxi fleet increased by 6.5 times, from 7500 to 48,000 cars in Moscow [15]. Moreover, 58% of the ridesourcing fleet was renewed by a Moscow government subsidy from 2010 to 2019. As a result, there are still several players in the TNC market in Moscow, such as Yandex-taxi, Uber, Gett, Citimobil, Vezet, inDriver, Maxim, and Taxovichkoff, which are step by step being merged with the largest player—Yandex-taxi.

Regarding the urban mobility system, there seems to be a high risk of a rebound effect [26] of car usage in Moscow because of ridesourcing. What if users choose ridesourcing instead of other modes, including public transport? Consequently, it changes the travel behavior of users from more to less sustainable modes and produces more traffic congestion. However, this is unlikely to apply to Moscow because there was a population growth of 9.2% from 2010 to 2019 [64], and the share of people using public transport also increased by 6–10% over the same period [2]. Filling this gap in understanding of the influence of TNCs on public transport is one of the aims of this study.

### 1.3.2. Car-Sharing in Moscow

The Moscow agglomeration is the most developed market of car-sharing in Russia and has a high degree of monopolization [66]. It consists of eight B2C car-sharing companies and has more than 31 thousand cars [62]. Consequently, Moscow's fleet of car-sharing was the largest in the world in 2019 [14].

According to the information provided by Moscow Transport data, the number of car-sharing users reached more than one million in February 2020 [62]. In addition, 69% of car-sharing users have their own car, but they reduced the number of trips in their own cars by two to three times because of car-sharing. At the same time, each car-sharing vehicle makes seven to eight trips per day [62]. The reason for the success of car-sharing in Moscow is due to the support of the Moscow government, which includes preferential parking permits and subsidies for the purchase of vehicles for car-sharing companies [67]. Despite preferential parking for car-sharing, the City Hall of Moscow obligates car-sharing services to consider requirements, such as the ecological classification of the cars (which should be Euro-4 or higher), special insurance, and vehicle size limitation [68]. The Moscow City Hall is attempting to use a car-sharing service to solve the congestion problem in the city.

At the same time, Moscow rarely performs P2P car-sharing initiatives. The study by Arthur D. Little [69] showed that Russians do not trust car owners to share their cars with strangers.

One of the leaders of the Moscow car-sharing market is Yandex.Drive, launched on 21 February 2018 in Moscow, and it has the largest fleet in Moscow, totaling more than eleven thousand cars at the beginning of 2021 [19]. This study [19] showed that the age of customers became older from 2018 to 2021. Consequently, the global trend of young, highly educated people mostly using car-sharing [54,61,70,71] is gradually changing. However, the age structure of car-sharing users is significantly younger than private car drivers in Moscow, which highlights a higher level of adaptation of new technology and flexibility of transportation modes by younger people than older.

The Yandex.Drive [19] data demonstrate that users who are in the 35–44 age category often use car-sharing for their daily commute (home to work). However, the younger the users are, the rarer they use car-sharing for the peak hour commute, and they prefer to take car-sharing in the evening.

When Yandex surveyed the trip purposes of Yandex drive users (Table 2), they found that airport/railway station trips and alcohol drinking-related trips are dominant among customers. At the same time, almost the same number of users use car-sharing to travel to the next Metro station (26%) and to/from work or studies (23%). Consequently, in terms of the purpose of the trip, car-sharing seems to be more of a compliment for public transport rather than a substitute in Moscow, but this study should check this assumption.

**Table 2.** The trip purpose of Yandex.Drive users <sup>1</sup>.

Trip Purpose	Share of Users
To/from a railway station or airport	44%
In bars, restaurants and other places, where the user drinks alcohol	38%
To the next Metro station	26%
Carrying of staff	23%
To/from work and studies	23%
Full day renting a car, when it is needed to travel a lot	17%
Shopping	16%
Out of the city, to a summer house	12%
Just for driving	11%

Note: <sup>1</sup> According to an opinion poll of Yandex.Drive users.

## 2. Materials and Methods

### 2.1. Survey Objectives and Sample Design

The main aim of this study is to enhance an in-depth understanding of the impact of TNC and car-sharing on public transport usage in Moscow, and try to find interrelations between mode choice, attitudes, and preferences. The potential output of this research can assess the opportunity for travel behavior change and determine more targeted policy instruments. It focuses not only on travel revealed preference (RP), but also on mobility attitudes and stated preference in the context of the effect of on-demand mobility services (such as TNC, car-sharing) on public transport usage.

The survey, conducted in 2020 before the lockdown due to the COVID-19 pandemic, based on the platform <http://anketolog.ru> (accessed on 1 March 2022), collected more than 1000 answers. This platform provides diverse instruments for conducting a survey, including mapping as an option for answering certain questions (e.g., Please indicate on the map the closest street intersection to your home) and for providing geographical variables for research (distance between home and city center, etc.). The questions on the survey were targeted, on the one hand, at understanding shift modes presented by car-sharing and TNC, and on the other hand at understanding the future intentions, attitudes and preferences among responders in sustainable urban mobility.

The study methodology explored the impact of car-sharing and TNC on public transport usage based on two approaches. The first of these was using counterfactual questions to understand the modal shift from public transport to car-sharing and TNC. These questions generally asked “Which mobility mode would you have used if TNC (or car-sharing) had not been available for your last trip on this mode?”. This approach of using think-backward questions, when respondents have to be reminded of a hypothetical past situation to respond, is widely used in several studies of modal impact [7,12,23,24,32,72]. The second approach investigates associations between on-demand mobility services (TNC and car-sharing) and other modes (including surface public transport modes) using an ordinal logistic regression model [20–22].

The second research question is investigated by asking about personal attitudes, preferences, and future intentions toward sustainable urban mobility. Thereafter, the responses were analyzed by descriptive statistic methods, and some of them were used as independent variables in ORL models of ridesourcing and car-sharing.

A 68-question survey was designed and administered, including queries about:

- socio-demographic variables;
- travel preference;
- mode shift questions in the context of on-demand mobility service (for example: “What mode(s) of transportation would you have taken if car-sharing was not available for your last trip of car-sharing?”);
- future intentions (stated preference) about on-demand mobility service and ideas towards more sustainable mobility;
- attitudes and preference effect on mode choice.

This study used a variety of sampling approaches, including inspiring posts about air pollution in Moscow and research, helping to solve this problem on social media (in private and public pages such as facebook.com/InterestingMoscow). Nevertheless, a disproportion among old people was observed at the end of the survey. To correct this disproportion, responders of the missing social groups got paid via an online panel at <https://anketolog.ru/> (accessed on 1 March 2022) to fill out the survey. The sample aimed to collect a sufficient number of active users of on-demand mobility services for calculating significant regressions. Unfortunately, the time limitation prevented the collection of enough responses by active bike and scooter sharing users. However, this was caused by the common-mode split in Moscow—1% for bicycles in journey modal split [65]. The final data sample comprised 777 responders. All responses with potential mistakes, such as out-of-region respondents, frivolous or incoherent answers, and severely incomplete answers on key variables, were filtered out.

## 2.2. Ordinal Logistic Regression

Ordinal dependent variables are analyzed by ordinal logistic regression (or ordered logit model). This was used to forecast the ordinal level of dependent variables with a group of independent variables with a level of significance of 0.05. There were two dependent variables in this study. The first dependent variable was the frequency of TNC usage in the Likert scale from 1 to 5 for “never or almost never” to “daily or almost daily”, respectively. The second one was the frequency of using car-sharing on the same Likert scale from 1 to 4 for “never or almost never” to “one to three days per week and often”, respectively. At the same time, each dependent variable had its own ordinal regression model with the same set of independent variables, as presented in Table 3.

**Table 3.** Independent variables chosen for ordinal logistic regression.

Variables	Survey Question	Responses	Values
Age	What is your age?	input by hand	18, 19, . . . more than 70
Gender	What is your gender?	male/female	0, 1
Time from home to city centre by car	Could you provide the nearest crossing to your home?	Calculated in Yandex map from home to Garden Ring road in minute by car on Tuesday 25th of May 2020 at 17:00–18:00	0, 1, 2, . . . 180
Frequency of driving (private car)	How often do you usually drive your car in Moscow?	Never or almost never Less than monthly One to three days per month One to three days per week Daily or almost daily	1, 2, 3, 4, 5
Frequency of bus/tram/trolley use	How often do you use buses, trams, and trolleys in Moscow?	Never or almost never Less than monthly One to three days per month One to three days per week Daily or almost daily	1, 2, 3, 4, 5
Frequency of walking	How often do you walk a distance longer than 500 m?	Never or almost never Less than monthly One to three days per month One to three days per week Daily or almost daily	1, 2, 3, 4, 5



Table 3. Cont.

Variables	Survey Question	Responses	Values
Intention to manage CO <sub>2</sub> emission while traveling	Do you agree with the statement: If I knew how much CO <sub>2</sub> emission was produced during my trips in Moscow, I would choose the mode of transport I use more consciously.	Strongly disagree Disagree Neutral Agree Strongly agree	1, 2, 3, 4, 5
Importance of walking and moving during trips	How often are the factors below important for you during a trip? The desire to walk and move	Never Occasionally Sometimes Often Always	1, 2, 3, 4, 5

The ordinal logistic regression (OLR) is a kind of a binary logit model, which allows more than two ordered independent variables to be used. The advantage of OLR is that the variables which have the largest influence can be isolated; this helps to control the impact of other variables.

The ordinal logit model allowed us to evaluate the odds ratios as the exponential of the coefficient, which indicated the increase in the odds of using car-sharing (or ridesourcing) more often for one unit increase in the independent variable. If the odds ratio was more than 1, the probability of more frequent car-sharing (ridesourcing) and the value of independent variables increased together. However, an odds ratio below 1 showed a decline in this probability with the growth of the value of an independent variable. In the case of an odds ratio of 1, the change in the value of the independent variable did not cause a change in the probability of more frequent car-sharing (ridesourcing).

To best evaluate the quality of the OLR model - applied to the data, the test of parallel lines was used. This concept verified that the independent variables equally influenced the odds of all thresholds of the dependent variable. Consequently, all ordinal levels of the dependent variable had the same estimated coefficients [73]. The parallel test was used to compare the coefficients of the estimators by the OLR model for all ordinal levels of the dependent variable with the estimated coefficients for each of them. If the *p*-value of the chi-square test in the test of parallel lines was significant (less than 0.05), then the hypothesis of proportional odds was dismissed. Additionally, conversely, if the chi-square test showed a *p*-value of more than 0.05, then the hypothesis of proportional odds was not rejected.

Additionally, it was essential to check whether the data fitted well for the chosen model. This was performed through the comparison of  $-2 \log$ -likelihood by the chi-square test, which assessed whether the calculated model enhanced the predictability of the baseline model. A *p*-value of less than 0.05 indicated that the model essentially enhanced the baseline model.

Moreover, to check the goodness-of-fit of the model, the Pearson's chi-square test and Deviance chi-square test were conducted. These tests estimated whether the assessment of the model was coherent with the observed data. If the *p*-value was more than 0.05, then the null hypothesis—which was that the model's fit was good—was not rejected. Therefore, there was no significant difference between the predictions of the model and the data. In cases where the *p*-value was less than 0.05, then the model and the observed data did not fit each other well [74,75].

Additionally, checking R-square was important for model verification. However, for ordinal logistic regression, it was impossible to calculate the same R-square as for the linear regressions, and instead of this, Nagelkerke R-square was applied [76–79].

### 3. Results

#### 3.1. Explanatory Variables

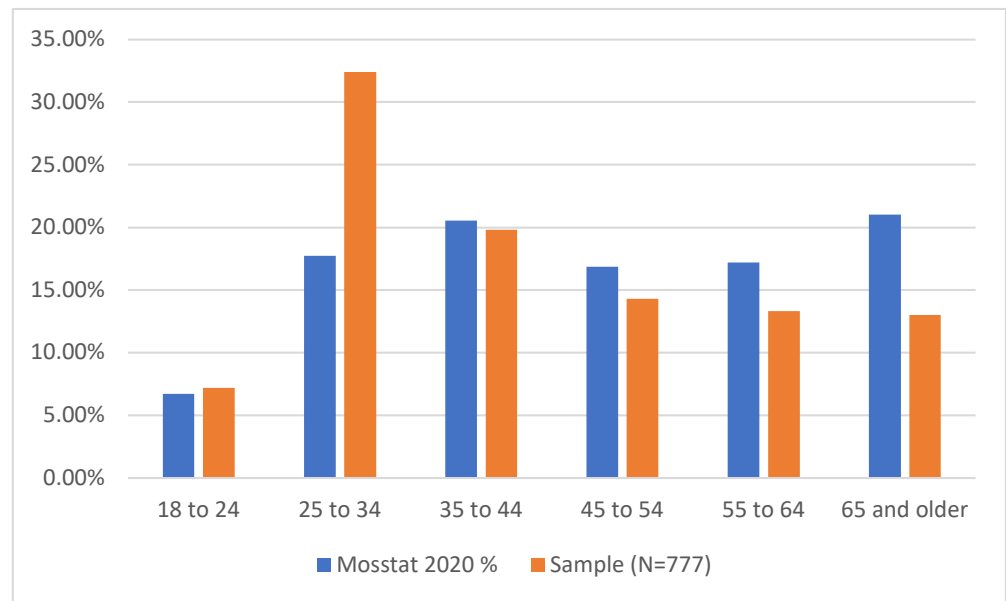
##### 3.1.1. Demographic and Spatial Variables

Due to the sampling strategy, the sample descriptive (Table 4) can differ greatly from that of the general population. In particular, the sample considerably underrepresents old users because they use on-demand mobility services less often, and this trend was explored in a couple of other studies as well [17–19]. A comparison between this sample and the Moscow population in 2020, according to Federal Service Office state statistics in Moscow and the Moscow region [64], is summed up in Figure 2. The difference between the shares of males and females in this sample and that of Mosstat is around 1% (Figure 3), which indicates that the received data are acceptable.

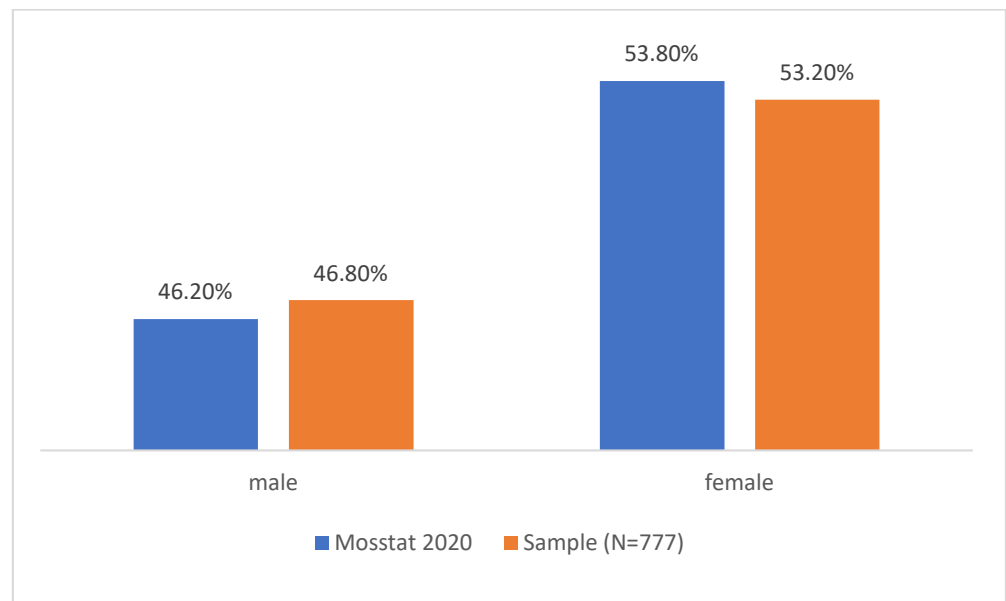
**Table 4.** Selected socio-demographic characteristics of the sample.

Characteristic (Sample Size = 777)	N (%)	Characteristic (Sample Size = 777)	N (%)
<i>Region</i>		<i>Income</i>	
Moscow	664 (85.5)	less than 15 K rubles per month	36 (4.6)
Moscow region	86 (11.1)	16–55 K rubles per month	260 (33.5)
New Moscow	27 (3.5)	56–115 K rubles per month	257 (33.1)
<i>Gender</i>		116–250 K rubles per month	127 (16.3)
Female	413 (53.2)	251–500 K rubles per month	40 (5.1)
Male	364 (46.8)	more than 501 K rubles per month	5 (0.6)
<i>Age</i>		Denie	52 (6.7)
18 to 24	56 (7.20)	<i>Education</i>	
25 to 34	252 (32.4)	Secondary general education and below	19 (2.4)
35 to 44	154 (19.7)	Secondary special education	97 (12.5)
45 to 54	111 (14.4)	Incomplete higher education, etc. <sup>1</sup> ,	661 (85.1)
55 to 64	103 (13.1)	<i>Frequency of traveling by plane</i>	
65 and more	101 (13.1)	At least monthly	93 (12.0)
<i>Occupation</i>		Every one to three months	224 (28.8)
Work full time	508 (65.4)	Every half of year	205 (26.4)
Work part-time	42 (5.4)	Rarely	176 (22.7)
Freelancer	77 (9.9)	Never or almost never	79 (10.2)
Study	15 (1.9)	<i>Do you rent housing?</i>	
Retired	104 (13.4)	Yes, I rent an apartment/whole house	138 (17.7)
On maternity or care leave	11 (1.4)	Yes, I rent a room in the apartment	37 (4.8)
Housewife / householder	8 (1.0)	No, I live in my own or with relatives	600 (77.2)
Unemployed	12 (1.6)	Denie	2 (0.3)
<i>Driver's license ownership</i>		<i>Smartphone ownership</i>	
Yes	499 (64.2)	Yes	748 (96.3)
No	278 (35.8)	No	29 (3.7)
<i>Household car ownership</i>		<i>How often do you do sports?</i>	
Yes, have more than one car	129 (16.6)	Daily or almost daily	70 (9.0)
Yes, have one car	363 (46.7)	one to three days per week	231 (29.7)
No	258 (36.7)	one to three days per month	34 (4.4)
<i>Bike or scooter for personal use</i>		Less than monthly	9 (1.2)
bike	266 (34.2)	Never or almost never	388 (49.9)
e-bike	7 (0.9)	Ca not answer	45 (5.8)
Scooter	90 (11.5)		
E-scooter	25 (3.2)		
None of the above	458 (58.9)		

Note: <sup>1</sup> Higher education, incomplete higher education, MBA, PHD.

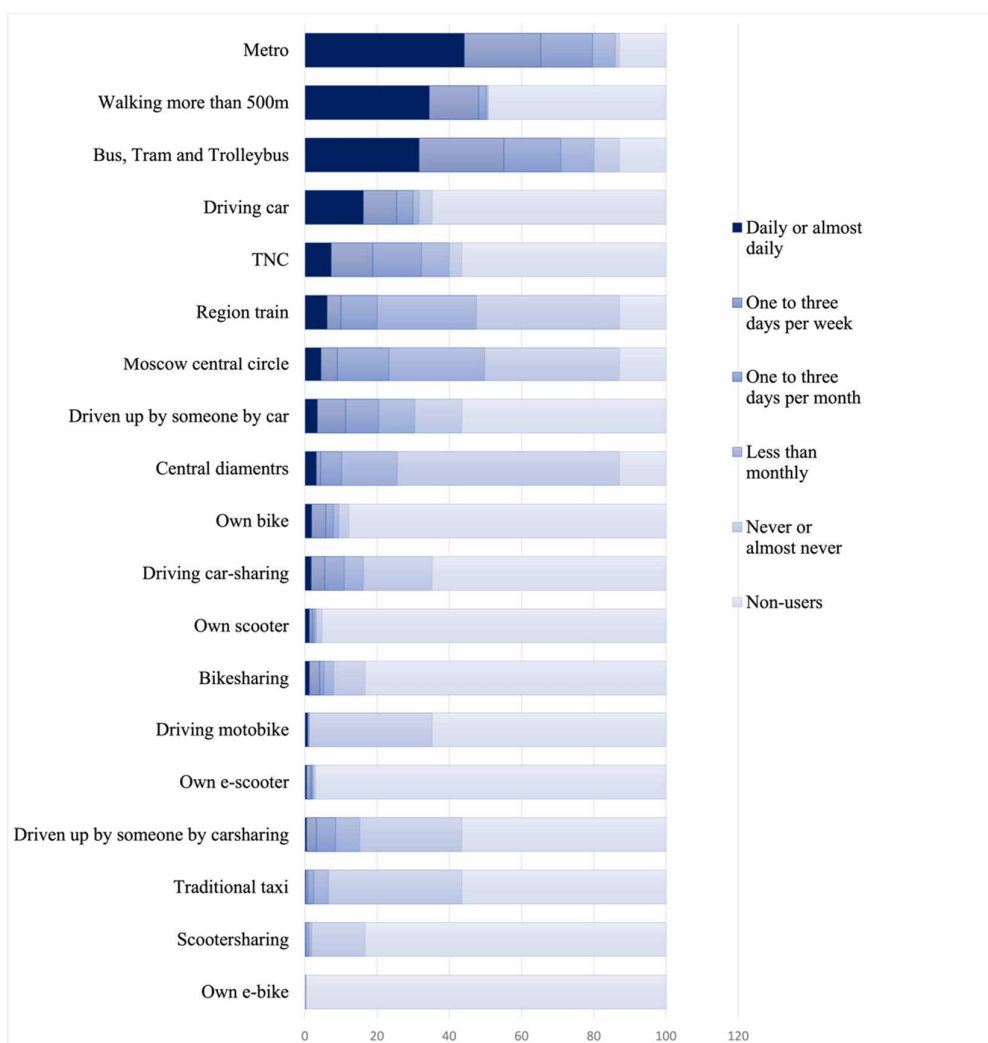


**Figure 2.** Age distribution of adults (18+) for the Moscow population vs. the sample (N = 777).



**Figure 3.** Comparison of gender structure between Moscow population and the sample (N = 777).

The number of households without car ownership has been changing in Moscow in recent years. In particular, it was 37% in 2014 in Moscow [80], but all-Russian polls in 2018 and 2019 determined that the share of no-car owners among householders in Moscow and St. Petersburg was 34% and 30%, respectively [81,82]. This share in the sample is 35%, which corresponds to the focus of this study of on-demand mobility users in which private car dependency is lower. The ownership of micro-mobility of the respondents in the sample (Figure 4) correlates with the previous survey [16], which was conducted in 2014 and used a representative telephone survey of the population aged 18 and over in Moscow.



**Figure 4.** Frequency of usage of different means of transport in Moscow (N = 777).

The share of smartphone ownership in this sample is 96.7%. However, the share of smartphone users in Russia in 2020 was 72.79% [83]. The aim of this survey was not to achieve a sample that was totally representative of the Moscow population of interest, but rather to collect a sample with “enough” (more than one hundred) users of each mode of on-demand mobility service to produce significant statistical results. To achieve this goal, the sample has a bigger share of smartphone users than the whole Moscow population because on-demand mobility services emerged as vehicles and smartphones started being used inter-connectedly.

### 3.1.2. Travel Preference Variables

Travel preferences of responders were collected by asking the key question of, “What types of transport do you usually use in Moscow?” with the opportunity to choose several answers. This question was formed to get a deep understanding of travel behavior and collect comprehensive data to calculate regression models. The results are presented in Table 5. Based on their response to this question, the participants were asked about the frequency of usage of each mode of transport included in the chosen group. For example, if a responder chose “Car as a passenger”, then he or she had to answer the questions “How often do you use “TNC” / “traditional taxi” / “driven by someone by car” / “driven by someone by car-sharing” in Moscow usually?”. To sum up the exploration of travel preferences, all answers about revealed travel preferences are combined in Figure 4.

**Table 5.** Travel preference of sample's responders (N = 777).

Travel Mode	N(%)
Public Transport	677 (87.1)
Walking more than 500 m	395 (50.8)
Car or/and motorcycle as a driver	274 (35.2)
Car as a passenger	338 (43.5)
Bike or/and Scooter	130 (16.7)

The responses received (Table 5) are correlated with data from Moscow Transport [2], where the modal share of public transport usage is 70% on a weekday in 2019, but the rest of the modal split—30%—is occupied by private vehicles (Figure 1). Unfortunately, the data collection and performance of Moscow Transport are not clear enough and focused only on general usage of public transport, not taking into account on-demand mobility services and private micromobility, so this dataset contributes only roughly to the comparison of this sample and general situation. However, the Deloitte City Mobility Index of 2018 [65] demonstrated that the share of public transport in Moscow was 78% in 2019, which proves the dominant role of public transport in the city. The Deloitte data [65] also include walking and cycling in the modal split (Figure 1). However, the share of walking is considerably smaller than in the sample, which might indicate, on the one hand, the different approaches to data collection and, on the other hand, the complexity of determining walking commutes. Nevertheless, the aim of the sample is not to calculate the modal split in Moscow but to obtain a deep understanding of the interrelation between on-demand mobility, public transport usage, social-demographic parameters, attitudes, and preference of the users.

The order of popularity of different kinds of transport in Moscow is represented in Figure 4. It reflects the unexpected popularity of walking more than 500 m in Moscow, which is even more popular than driving a car. Of course, in the modal split [65], walking has a lower share because the average distance of walking compared to driving is significantly less.

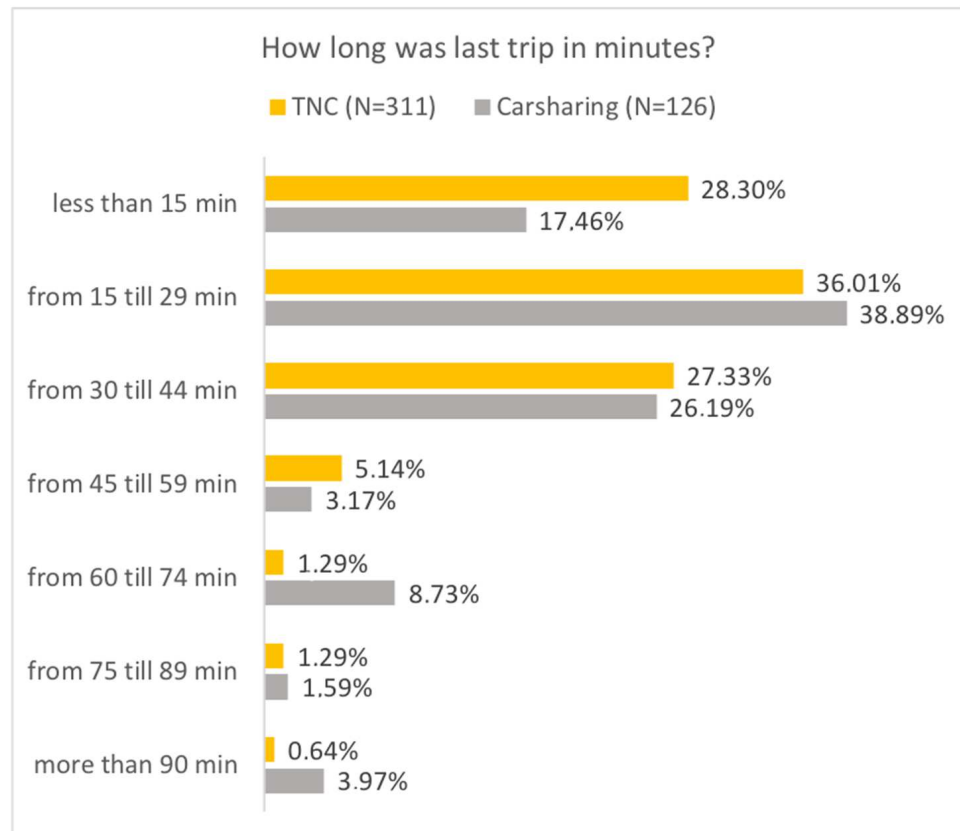
The popularity of walking as a means of transport could be the result of Moscow's last 6 years spent updating the walking infrastructure in the city center and prioritizing walkers over drivers. Public transport ranking indicates that new types of public transport, such as the Moscow Central Circle and Central Diameters complement well-established Metro, bus, tram and regional train systems. However, they cannot be the comprehensive substitutes for them.

Those driving a car (private car) daily or almost daily comprise 16.5% of this sample, which positively correlates with Deloitte and Moscow Transport data [2,65] where the share of private cars/vehicles is 19% and 30%, respectively. However, these two datasets do not distinguish between the exact kind of usage of private cars/vehicles, i.e., car-sharing, taxi, etc. Thus, the mode "private car" or "private vehicles" in both studies include more types of transportation than just "driving a private car".

### 3.1.3. Mode-Shift Variables

To understand the impact of TNC and car-sharing on public transport usage in Moscow is important to investigate the modal shift tendency of its users, as in many studies before [7,12,23,24,32,72]. First of all, responders who use TNC (N = 311) and car-sharing (N = 126) "less than monthly" and more were asked "Please, recall your last trip by TNC (or car-sharing)". After that, they were asked, "How long was your trip in minutes?".

The results are summarized in Figure 5. According to the data, the distribution of the duration of the last trip in car-sharing and TNC looks similar among responders, with the most common duration of the trips by TNC (36.01%) and car-sharing (38.89%) being "from 15 to 29 min".



**Figure 5.** Duration of the last trip of car-sharing and TNC of respondents.

However, there are some differences, such as that for trips “less than 15 min”, it is 10% more popular to use ridesourcing (or TNC) than car-sharing. Similarly, for trips with a duration “from 60 to 74 min”, it is seven times more popular to use car-sharing than TNC. Consequently, car-sharing trips have a tendency to last for longer durations than TNC trips.

Afterward, the categorical variable of the modal shift was derived by the question: “What mode of transportation would you have taken if . . . (kind of transport: car-sharing or TNC) was not available for this trip?”. This question is a think-backward question in which respondents have to imagine a manipulated situation in the past when they used ridesourcing and answer which mobility modes were the alternative to ridesourcing services. The mobility mode as the answer to this question is interpreted as the modal shift from this mode to ridesourcing. The same approach was used for analyzing car-sharing modal shift. The results are shown in Tables 6 and 7.

**Table 6.** Survey responses to “What mode(s) of transportation would you have taken if TNC was not available for this trip?” (N = 311, % of all TNC users).

Travel Mode	%
Public Transport	66.24%
Traditional taxi	10.93%
Car or moto-bike	6.75%
Walking as commute mode	6.43%
Car-sharing	5.79%
I would not have done this trip	3.22%
Bike	0.32%
Bike-sharing	0.32%

**Table 7.** Survey responses to “What mode(s) of transportation would you have taken if car-sharing was not available for this trip?” (N = 126, % of all car-sharing users).

Travel Mode	%
Public Transport	40.48%
Taxi	31.75%
Car or moto-bike	18.25%
Walking as commute mode	5.56%
I would not have done this trip	3.17%
Scooter	0.32%

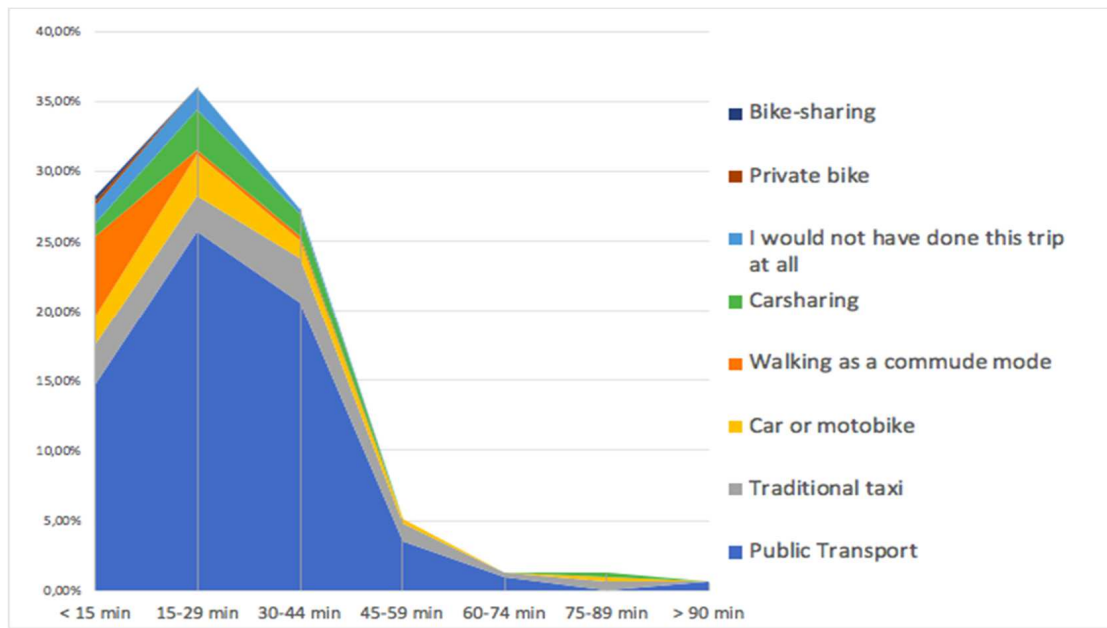
The mode-shift caused by ridesourcing shows that more than 66% of all users would have replaced their last TNC trip with public transport in Moscow (Table 6). That is almost two times more than in California (33%) in 2015 [84], San Francisco (33%) in 2016 [12], Santiago de Chile (37.6%) in 2019 [85] and Madrid (33%) in 2020 [72]. However, it is close to New York city (50%) in 2018 [86]. Surprisingly, only 10.93% of respondents in Moscow chose traditional taxis as an alternative mode for their last TNC trip, in stark contrast with other cities, such as New York (50%) [86], Madrid (50.6%) [72], Santiago de Chile (39.2%) [85], and San Francisco (39%) [12]. This confirms that, on the one hand, Moscow has a more public transport-oriented structure in the modal split than other cities. On the other hand, TNCs are the main mode for avoiding trips by public transport in Moscow.

Notably, users of car-sharing have a similar structure of responses regarding alternative modes to users of TNC, but with a lower share of public transport (only 40.8%) and a greater share of taxis (31%) (Figure 9). This significant share of “taxi”, as an alternative mode, can be explained by the fact that citizens of Moscow do not see the difference between a traditional taxi and ridesourcing (Yandex.taxi, Uber, Gett, etc.), and perceive these two under the same concept of “taxi”. The similar structure of responses between car-sharing and TNC users confirms the strong substitutional nature between public transport and TNC services in Moscow again.

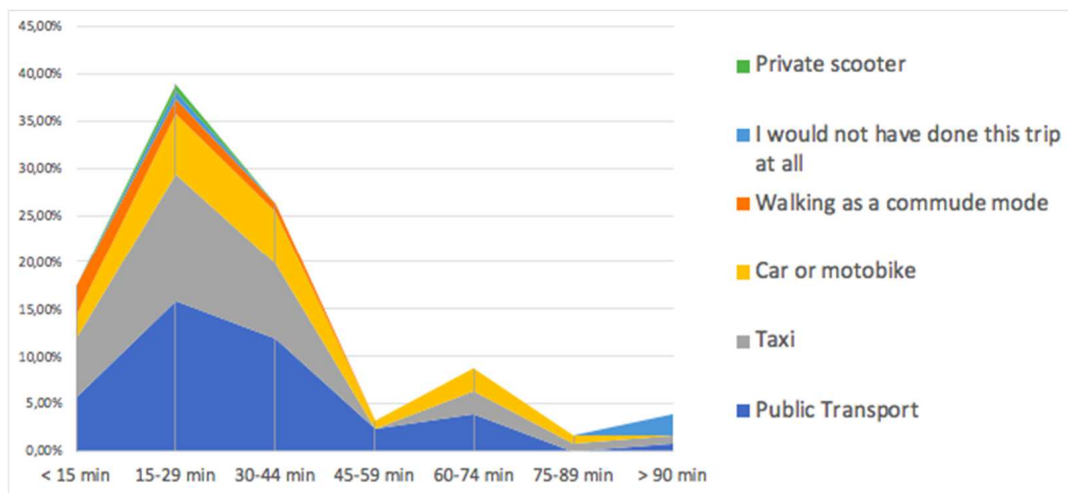
Notably, 18.25% of car-sharing trips would have been taken by a private car or a motorbike, which confirms that car-sharing motivates people to shed their cars in Moscow, almost three times more than for TNC trips. However, Figure 9 shows that shifting from public transport to car-sharing (40.48%) is two times more than shedding private vehicles (18.25%). Additionally, Yandex’s (2021) study of Yandex.Drive users claimed that 26% of customers use car-sharing to reach the next Metro station [19]. Therefore, car-sharing possibly has a more complementary impact on public transport usage in Moscow than substitutional.

The comparison of the distribution of the duration of the last ridesourcing trip and alternative modes is shown in Figure 6. It illustrates the dominant role of public transport as an alternative mode in almost all durations of the trip, except 75–90 min, where car-sharing, cars, and traditional taxis are the main alternative modes. Logically, walking, bike-sharing, and private bikes are popular as alternative modes for short trips (less than 15 min). Besides that, it seems interesting that the alternative mode “I would not have taken this trip at all” is popular among short trips not longer than 29 min.

The same distribution for car-sharing (Figure 7) has an essential difference from TNC. First of all, there is a smaller share of short trips (less than 15 min) and, consequently, a smaller share of walking and micro-mobility (private scooter) as alternative modes. Secondly, the share of public transport for all durations of trips as an alternative mode is smaller than the sum of the rest of the alternatives. This indicates that car-sharing is used less as a substitute for public transport than TNC.



**Figure 6.** The last TNC trip: frequency of duration and alternative modes (N = 311, % of all TNC users).



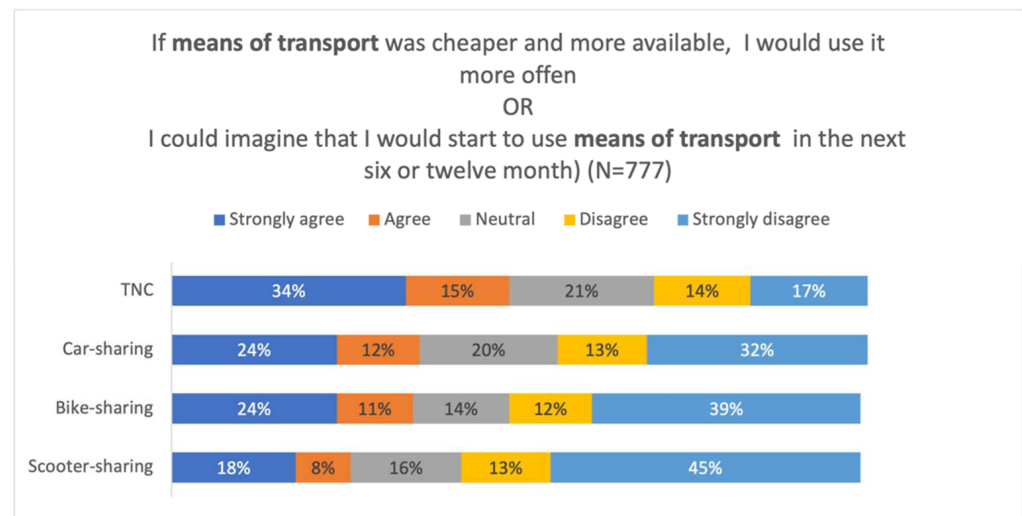
**Figure 7.** The last car-sharing trip: frequency of duration and alternative modes (N = 126, % of all car-sharing users). In the figure, “Taxi” includes traditional taxis and TNC.

### 3.1.4. Future Intention Variables

To understand what is behind the mode choice of Moscow citizens and, consequently, to understand trends of on-demand mobility services in the city, it seems important to survey future intentions, attitudes, and preferences of respondents based on the idea of the theory of planned behavior [87].

All respondents—both users and non-users—were asked about their future intentions (stated preference) to use on-demand mobility services (TNC, car-sharing, bike-sharing, scooter-sharing). The questions about future intentions were adapted depending on the kind of on-demand mobility services and user (non-user status) of the respondent. The generalized results of responses are presented in Figure 8.





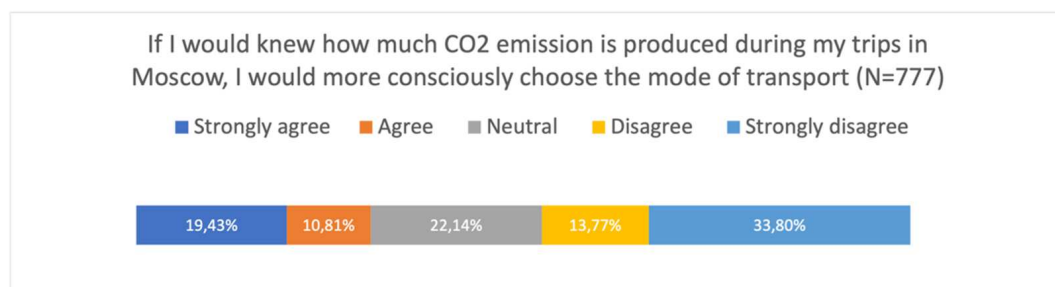
**Figure 8.** Future intention to use on-demand mobility services in Moscow (N = 777).

The data summarize the responses of users and non-users to specialized questions on different means of transport. Examples for users include: (1) if car-sharing was cheaper and more available in Moscow, I would use it more often; (2) if bike-sharing and biking infrastructure covered all areas of Moscow, I would use it more often. Examples for non-users include: (1) if I had a driving license, I could imagine that I would start to use car-sharing in the next six or twelve months; (2) if scooter sharing and biking infrastructure covered all areas of Moscow, I could imagine that I would start to use e-scooter sharing in the next six or twelve months.

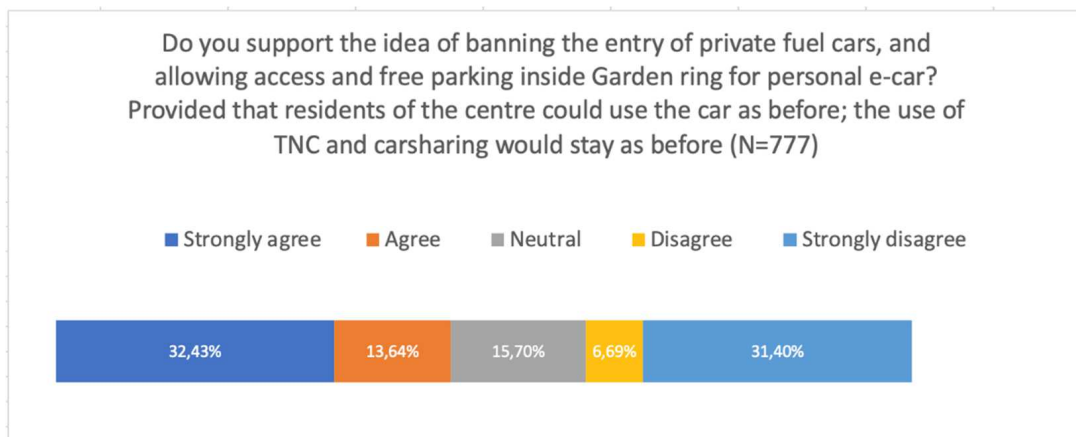
The study found that TNC has the highest usage intention among all on-demand mobility services, with almost 50% of respondents choosing either “agree” or “strongly agree”. Interestingly, it seems that car-sharing and bike-sharing have almost the same level of future intention to use (around 35%), but the attention of local authorities is more concentrated on supporting car-sharing services rather than bike-sharing ones. The development of bike-sharing is limited, on the one hand, by the lack of cycling infrastructure and, on the other hand, by the monopolization of Velobike station-based services in this market. Obviously, bike-sharing has big potential in Moscow, especially if the Moscow Hall invests more in infrastructure and gives more freedom to this market.

Investigation of the environmental behavior of Moscow citizens can also bring insights into transport policymaking in Moscow. This pattern was researched by asking different questions about future intentions (Figures 9 and 10), preferences, and attitudes (see Section 3.1.5).

Figure 9 shows that more than 31% of respondents “agree” and “strongly agree” on the question “If I knew how much CO<sub>2</sub> emission was produced during my trips in Moscow, I would more consciously choose the mode of transport”.



**Figure 9.** Future intention of respondents to manage their CO<sub>2</sub> emission by their trips (N = 777).

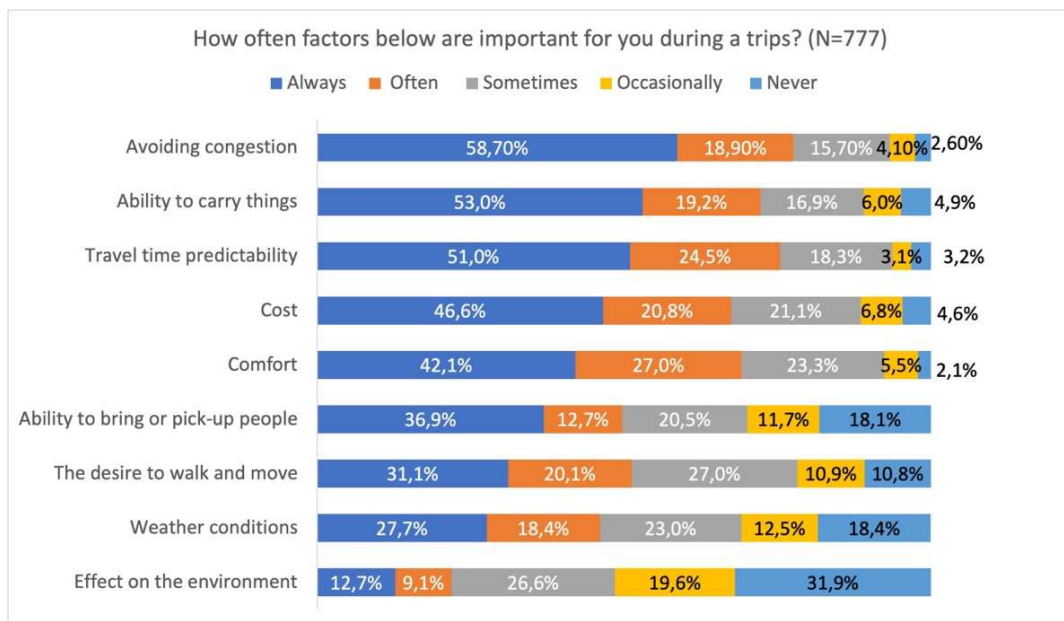


**Figure 10.** Future intention of respondents to banning area inside Garden Ring (city centre) for private internal combustion engine vehicles (N = 777).

At the same time, more than 46% of respondents “strongly agree” and “agree” with banning private internal combustion engine vehicles from city centers, while saving free access for private e-vehicles. As a result, the environmental agenda in Moscow is important for more than a third of respondents, and as such it should be taken into account for mobility policymaking.

### 3.1.5. Attitude and Preference Variables

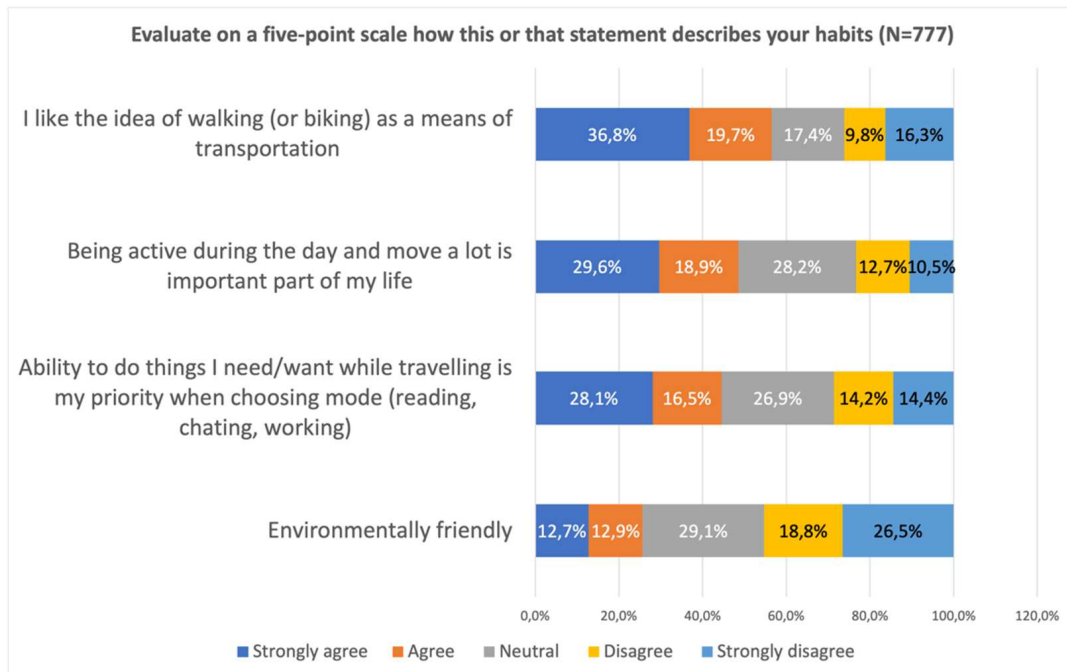
Attitude and preference were investigated for understanding the mobility problems of the citizens and evaluating the potential of citizens’ openness to environmental behavior. Figure 11 illustrates the summarized results of revealed preferences (RP) which influence the travel behavior of respondents, filtered from more significant to less, thus giving an understanding of the hierarchy of mobility problems among Moscow citizens.



**Figure 11.** Preferences of respondents (N = 777).

Predictably, avoiding congestion and travel time are the most popular preferences among Moscow citizens. Consequently, cost and comfort are less important than time. The effect on the environment has the least importance among respondents in terms of preference.

Questions about attitudes were formulated based on the ideas of environmentally friendly behavior and multitasking during the trips. The results (Figure 12) indicate that 56.5% of the respondents liked the idea of walking and biking as a means of transportation. Meanwhile, 48.5% of respondents consider that being active and moving a lot is an important part of their life. Thus, Moscow citizens have a significant demand for physically active modes of traveling in the city. This is also confirmed in Figure 5, where walking is the second most popular mode of choice among respondents. Multitasking during the trips is more important than being environmentally friendly and less so than being active and walking/biking.



**Figure 12.** Attitudes of respondents (N = 777).

### 3.2. OLR Model

The association of socioeconomic parameters, attitudes, preference and mobility behaviors with the frequency of ridesourcing and car-sharing usage was investigated by two ordinal logistic regression models. Both of them contain the same set of independent variables for each kind of on-demand mobility service. OLR is effective if the test of parallel lines is not significant, and, consequently, the proportional odds assumption is not dismissed.

Table 8 shows that the  $p$ -values of the chi-square of the parallel lines test for ridesourcing and car-sharing models are 0.184 and 0.999, respectively. Therefore, we does not dismiss the hypothesis of proportional odds. At the same time, the significance of the Omnibus test for both models is less than 0.001, which indicates that the models with the independent variables are better than the baseline regressions without them.

In addition, the goodness of fit between these data and the models were checked with Deviance and Pearson chi-square tests. Both of the models (ridesourcing and car-sharing) provided non-significant results ( $p$ -values are more than 0.05) for both tests, which indicates that the models and data fit each other well. The results of Deviance and Pearson chi-square tests for both models are shown in Table 6.

**Table 8.** The Omnibus tests, the goodness of fit, parallel lines test, and Nagelkerke R2 for the ordinal logistic regression models.

Model Coefficients	TNC Model	Car-Sharing Model
<b>Omnibus Tests</b>		
Chi-square	166.632	211.216
<i>p</i> -value	<0.001	<0.001
−2 Log likelihood	1721.003	754,379
<b>Pearson Test</b>		
Chi-square	2977.948	2165.326
<i>p</i> -value	0.921	0.987
<b>Deviance Test</b>		
Chi-square	1721.003	754.379
	1.000	1.000
<b>Test of Parallel Lines</b>		
Chi-square	30.029	3.677
<i>p</i> -value	0.184	0.999
<b>Nagelkerke R Square</b>	0.212	0.335

The estimated coefficients of ridesourcing and car-sharing ordinal regression models are shown in Tables 9 and 10, respectively.

The estimations of the ordinal logistic regression model indicate that six independent variables are significant (*p*-value < 0.01), which are:

- age,
- time from home to city center by car,
- frequency of driving,
- frequency of bus/tram/trolleybus,
- frequency of walking,
- importance of walking and moving during trips.

At the same time, the estimations of the car-sharing ordinal logistic regression model show that five independent variables have significant coefficients at the 0.05 level:

- age,
- gender,
- frequency of driving,
- frequency of bus/tram/trolley use,
- intention to manage CO<sub>2</sub> emission while traveling.

**Table 9.** Ordinal regression model for the frequency of TNC use.

		Estimate	Std. Error	Wald	<i>p</i> -Value	Exp (B)
Age	Years	−0.025	0.005	21.582	0.000 *	0.976
Gender	Femal = 1 Male = 0	0.166	0.154	1.153	0.283	1.180
Time from home to city centre by car	Minutes	−0.042	0.007	35.328	0.000 *	0.959
Frequency of driving (private car)	Ordinal 1–5 level	−0.267	0.055	23.716	0.000 *	0.766
Frequency of bus/tram/trolley use	Ordinal 1–5 level	−0.146	0.053	7.533	0.006 *	0.864
Frequency of walking	Ordinal 1–5 level	0.288	0.044	43.666	0.000 *	1.333
Intention to manage CO <sub>2</sub> emission while traveling	Ordinal 1–5 level	−0.020	0.054	0.137	0.712	0.980
Importance of walking and moving during trips	Ordinal 1–5 level	−0.290	0.061	22.287	0.000 *	0.748

Note: \* significant independent variables (*p*-value < 0.01).

**Table 10.** Ordinal regression model for the frequency of car-sharing use.

		Estimate	Std. Error	Wald	p-Value	Exp (B)
Age	Years	−0.073	0.011	45.307	0.000 *	0.930
Gender	Femal = 1 Male = 0	−0.747	0.239	9.799	0.002 *	0.474
Time from home to city centre by car	Minutes	−0.013	0.009	2.221	0.136	0.987
Frequency of driving (private car)	Ordinal 1–5 level	0.864	0.085	104.043	0.000 *	2.372
Frequency of bus/tram/trolley use	Ordinal 1–5 level	0.252	0.085	8.705	0.003 *	1.287
Frequency of walking	Ordinal 1–5 level	0.060	0.067	0.787	0.375	1.062
Intention to manage CO <sub>2</sub> emission while traveling	Ordinal 1–5 level	0.186	0.086	4.733	0.030 *	1.205
Importance of walking and moving during trips	Ordinal 1–5 level	−0.012	0.096	0.015	0.902	0.988

Note: \* Significant independent variables ( $p$ -value < 0.01).

The exponentiated coefficient Exp (B) for each independent variable shows the odds ratio of more frequent ridesourcing use (higher value of an ordinal variable) for each change (category or unit) in the estimator by keeping other estimators constant.

### 3.2.1. Effects of Demographic and Socioeconomic Variables

The age of the respondents has a significant negative impact on the frequency of ridesourcing and car-sharing usage. The odds ratio of age in the ridesourcing model is 0.976, which shows that the odds of frequent use of TNC decrease by 2.4% for each year of increase in age. The same estimator in the car-sharing model is 0.930, which indicates that the odds of frequent use of car-sharing decrease by 7% for each year of increase in age. Therefore, age has almost three times more negative effects on the frequent use of car-sharing than on the frequent use of ridesourcing. In other words, car-sharing is more popular among young respondents.

Moreover, the odds ratio of the travel time from home to the city center by car is 0.959, which indicates that the odds of frequent use of ridesourcing decrease by 4% for each minute increase in the time between home and the city center by car. In other words, the further the respondents live from the city center, the less frequently they use ridesourcing, and vice versa. However, the association between the frequent use of car-sharing and the travel time from home to the city center by car is not significant in the model ( $p$ -value > 0.05).

Nevertheless, the odds ratio of gender in the car-sharing model is 0.474, which indicates that the odds of the frequent use of car-sharing decrease by 52% if the user is female. Therefore, men use car-sharing almost two times more often than women. At the same time, the interrelation between the frequent use of ridesourcing and gender is not significant ( $p$ -value > 0.05) in the model.

As a result, the models indicate that younger respondents who live close to the city center have a tendency to use ridesourcing frequently. At the same time, young males have a tendency to frequently use car-sharing.

### 3.2.2. Effects of Travel Preference Variables

Frequent rides on private cars have an opposite impact on the frequent use of ridesourcing and car-sharing in Moscow. The odds ratio of the frequency of driving indicates that the odds of using ridesourcing in a higher category of frequency decrease by 23% for each higher level of the frequency of driving. Therefore, a person who drives a lot will use TNCs less. Simultaneously, the odds ratio of the frequency of driving in the car-sharing model is 2.372, which indicates that the odds of the frequent use of car-sharing (higher category of variable) is growing by a factor of 2.372 for each higher category of frequency

of driving private cars. Thus, the more the respondents drive private cars, the more often they use car-sharing.

Furthermore, the frequency of bus/tram/trolley use has significant but opposing associations in the models. The odds ratio of this is 0.864 and 1.287 in ridesourcing and car-sharing models, respectively. Therefore, the ridesourcing model indicates that each unit increase in the frequency of using bus/tram/trolley reduces the odds of frequent use of TNC by 13%. In other words, the more the respondents use ridesourcing, the less they use buses/trams/trolleys. However, the opposite relationship can be found between the frequent use of car-sharing and buses/trams/trolleys, where each unit increase in the frequency of bus/tram/trolley use increases the odds of more frequent use of car-sharing by 29%.

As a result, the models prove the strong complementary relationship between car-sharing and bus/tram/trolley use and the substitutional nature between ridesourcing and bus/tram/trolley use in Moscow.

At the same time, ridesourcing shows a significant positive interrelation with “walking more than 500 m”, but car-sharing does not. Furthermore, each unit increase in the frequency of walking raises the odds of more frequent use of ridesourcing by 33%. Consequently, the more often the respondents “walk more than 500 m”, the more often they tend to use ridesourcing. Additionally, walking as a mode has a substitute association with ridesourcing for trips of less than 15 min (Figure 10).

### 3.2.3. Effects of Attitude and Preference Variables

Simultaneously, the importance of walking and moving during trips for respondents has a negative correlation with the frequency of using ridesourcing. The odds ratio of this independent variable shows that the probability of using TNC in a higher category of frequency usage decreases by 25% ( $\text{Exp}(B) = 0.748$ ) for each higher level of importance of walking and moving during trips. Therefore, respondents who use ridesourcing more often think less about walking and moving during the trips but perform these activities more often than people who use TNC rarely.

However, there is no significant interrelationship between the frequent use of ridesourcing and the intention to manage CO<sub>2</sub> emissions while traveling, although frequent use of car-sharing has this association. Table 8 shows that the odds ratio of intention to manage CO<sub>2</sub> emissions while traveling is 1.205 for car-sharing. Therefore, each unit of increase in the intention to manage CO<sub>2</sub> emissions while traveling raises the odds of more frequent use of car-sharing by 20%. Consequently, when respondents use car-sharing frequently, they have a high intention to reduce their CO<sub>2</sub> emissions during traveling. Therefore, regular users of car-sharing in Moscow have a greater tendency toward environmentally friendly behavior.

## 4. Discussion

This paper investigated the impact of on-demand mobility services (ridesourcing and car-sharing) on public transport, using an online survey on stated and revealed preferences of the citizens of Moscow. These findings are useful for policymaking toward a more sustainable mobility system in Moscow. Based on a survey conducted among 777 Moscow citizens, we calculated descriptive statistics, which helped us to understand the association between the frequency of using different modes, attitudes, preferences, and future intentions of people from the perspective of environmentally friendly behavior. Additionally, we built two OLR models with the same set of independent variables to predict the likelihood of frequency of using TNC and car-sharing. The models contribute to understanding this frequency's dependence on demographics, resident locations, individual attitudes, preferences, and current mobility behaviors. In order to analyze survey data, we estimated OLR models in the SPSS statistical software, which discovered eight significant independent variables in the TNC and car-sharing choices.

The impact of ridesourcing on public transport has a strong substitutional nature. Overall, 66% of TNC users would replace their last TNC trip with public transport if ridesourcing was not available. Additionally, the OLR model indicated that the more the respondents use TNC, the less they use buses/trams/trolleys and the more they use walking as a mode of transportation. In addition, the OLR model contributes to understanding the profile of people who frequently use TNC companies in Moscow. They are usually young or middle-aged people living in or next to the city center, rarely driving a private car and walking for more than 500 m during the day. At the same time, making time to walk or do other physical activities during the day is likely to be of little importance to them because they are active enough and do not care about it as much as other respondents do. Due to the survey results, public transport is the most replaced mode by ridesourcing in Moscow. Besides that, the usage of ridesourcing as a substitute for public transport is two times greater in Moscow than in San Francisco [12], California [84], Santiago de Chile [85], and Madrid [72]. This once again confirms the highly public transport-oriented mobility system of Moscow.

The impact of car-sharing on public transport seems more complimentary compared to that of ridesourcing in Moscow. First of all, only 40.48% of car-sharing users would have replaced their last car-sharing trip with public transport if car-sharing had not been available. The OLR model indicated that the respondents that use car-sharing more frequently are more likely to use buses/trams/trolleybuses, which means that car-sharing complements public transport usage. Simultaneously, the OLR model for car-sharing describes the typical frequent car-sharing user as a young man with a high tendency to drive private cars and a high intention to manage his CO<sub>2</sub> emissions.

At the same time, 18.25% of car-sharing users in the sample would have replaced their last car-sharing trip with a private car had car-sharing not been available for this trip. Meanwhile, only 6.75% of ridesourcing users in the sample would have done so. Consequently, car-sharing motivates people to shed their cars in Moscow almost three times more than TNCs. Despite this, the description statistics (Figures 6 and 7) show that car-sharing trips have a tendency to last for a longer duration than TNC trips.

An investigation of the future intention of the respondents to use on-demand mobility services (Figure 8) shows that car-sharing and bike-sharing have almost the same level (around 35%). At the same time, the COVID-19 pandemic and the fast development of the free market of e-scooters sharing in Moscow caused the growth of e-scooter sharing services (e-kick sharing) by five times in Moscow in 2020 compared to 2019 [2]. However, the attention and budget of Moscow Hall are more concentrated on the development of car-sharing rather than on that micro-mobility infrastructure. The understanding of this imbalance can bring more sustainable and efficient development to the policymaking of the urban mobility system in Moscow. This can satisfy the potential mobility demand and growing public concern regarding environmentally friendly behavior and reduction in CO<sub>2</sub> emissions.

The descriptive statistical analysis shows the hierarchy of frequency of usage of different means of transport in Moscow (Figure 4). It shows the unexpected popularity of “walking more than 500 m” in Moscow, which is even more popular than driving a car. Additionally, public transport plays a dominant role in the hierarchy (87.1% of respondents use it). Simultaneously, “walking more than 500 m” is the second most popular mode of transportation: 50.8% of all respondents practice it, and 34.5% of all respondents do it daily or almost daily (Figure 4). Similarly, walking is the second most popular means of transport as an alternative mode for ridesourcing for short trips (less than 15 min, see Figure 10), which confirms the high potential of walking as a mode of transportation in Moscow. Nevertheless, walking as a mode is only 1% of the modal split of Moscow in 2018 [65], and is not even calculated in the Moscow Transport modal split estimation [2]. The Deloitte city mobility index showed that urban mobility demand in Moscow is more concentrated in public transport than that in other European cities [65]. Despite that, the survey shows that the future intentions of the environmental agenda (control of CO<sub>2</sub> emissions during

the trip and banning private cars with internal combustion engines in the city center) are important to more than a third of respondents (Figures 8 and 9).

All these facts give a new perspective on walking as a means of transport for policymakers and highlight the importance of improving the pedestrian infrastructure and developing an environmentally friendly agenda among Moscow's citizens.

At the same time, Moscow City Hall tries to expand the urban mobility system mostly through building new metro lines (37.5% of Moscow's transport budget in 2020) and road networks (44.9% of Moscow's transport budget in 2020). Simultaneously, 9.63% of Moscow's urban mobility budget in 2020 was spent on bus/tram/trolleybus development and was subsidized for ridesourcing and car-sharing companies overall. However, the investments in bike and walking infrastructures comprise only 0.04% and 3.78% of all investments in Moscow's urban mobility systems in 2020. Obviously, the Moscow City Hall has great potential for the more effective management of investments in the urban mobility system and therefore satisfying the preferences of its citizens. It is important to deeply investigate different kinds of travel behavior patterns and attitudes of Moscow citizens towards mobility. The collected data in this study give the opportunity to conduct the comprehensive segmentation of citizens according to their attitudes, intentions towards environmental agenda, and travel behaviors.

The study of the segmented travel behavior of citizens can contribute to a better understanding of the association between different modes of public transport, consequently giving insights into better travel demand management in the public transport sector. Additionally, it can contribute to the understanding of key solutions for the rapid development of walking and micro-mobility modes. Moreover, this study will provide initial data for raising the effectiveness of information campaigns in order to stimulate the shift to more sustainable modes among citizens.

## 5. Conclusions

This paper studied the impact of ICT-based mobility services, including ridesourcing and car-sharing, on the mode choice of public transport in Moscow. An online survey was conducted in Moscow with a sample size of 777. The results of descriptive statistics and logit models indicate a contradictory association between car-sharing and ridesourcing with public transport in Moscow. Ridesourcing users shifted from public transport more than car-sharing users. Moreover, the OLR model indicated that the citizens who use ridesourcing more frequently use buses/trams/trolleys less frequently. However, the citizens who use car-sharing more frequently use more public transport. Therefore, the results indicate that ridesourcing has a more substitutive impact on public transport, in contrast to car-sharing, which has a more complementary effect.

The findings suggest that ridesourcing is more likely to be used in the future than other ICT-based mobility services. The respondents have almost the same level of future intention to use car-sharing and bike-sharing. However, the attention of local authorities is more concentrated on supporting car-sharing services rather than shared micro-mobility such as bike-sharing.

Moreover, the findings of the modal split analysis show a higher frequency of use of public transport and walking rather than car travel among citizens in Moscow. Therefore, these findings show how the shares of sustainable mobility modes have the potential to be increased in the urban mobility split by improving pedestrian and public infrastructure.

The segmentation of the citizens according to attitudinal profiles and behavioral characteristics contributes to urban mobility management, which makes investments and policy interventions more efficient and sustainable. The understanding of the main traveling scenarios by Moscow's citizens can become a foundation for stimulating the rapid growth of environmentally friendly travel behavior in Moscow.

For further research, it is suggested to recreate this mobility survey after the COVID-19 period. The collected data, before and after COVID-19, will give insights into the impact of



the pandemic on the travel behaviors, attitudes and preferences of Moscow citizens toward different ICT-based mobility services.

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