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The Relationship between the Evaluation of Public Transport Services and Travel-Based CO_2 Emissions from Private Transport Modes in Regional and Metropolitan Areas in Japan

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Abstract: Promoting public transport use is expected to contribute to reducing CO_2 emissions in the transport sector. Using Okayama City and Central Tokyo as representative case studies of regional and metropolitan areas in Japan, this study examines the impact of the evaluation of the 'hard' and 'soft' attributes of rail and bus services on the overall evaluation. This study then explores the relationship between the overall evaluation and usage frequency of rail and bus services, as well as the relationship between the usage frequency and travel-based CO_2 emissions from private transport modes. Furthermore, this study investigates whether the emissions cause differences in the evaluation of the 'hard' and 'soft' attributes of public transport services. The findings suggest prioritising an improvement in 'hard' rather than 'soft' attributes in order to reduce emissions through the use of public transport in regional areas. However, in metropolitan areas, no relationship was found between the evaluation of public transport services and emissions, presumably because of the lower ownership rate of private cars that residents can use freely and the markedly higher level of rail and bus services. This study provides a methodological reference for analysing the potential to reduce travel-based emissions from private transport modes by enhancing public transport service contents.

Keywords: CO_2 emissions; public transport; evaluation; 'hard' and 'soft' attributes; usage frequency; private transport modes

Citation: Pradhan, S.; Ujihara, T.; Hashimoto, S. The Relationship between the Evaluation of Public Transport Services and Travel-Based CO_2 Emissions from Private Transport Modes in Regional and Metropolitan Areas in Japan. *Sustainability* **2023**, *15*, 13296. https://doi.org/10.3390/su151813296

Academic Editor: Elżbieta Macioszek

Received: 13 July 2023
Revised: 18 August 2023
Accepted: 24 August 2023
Published: 5 September 2023

1. Introduction

Since the Paris Agreement of 2016, effectively superseding the Kyoto Protocol, global efforts to reduce greenhouse gases considerably, and thereby curb global warming, have been made [1]. Japan has set a reduction target of 46% in greenhouse gas emissions by 2030 compared to its 2013 levels, with the goal of reaching net-zero emissions by 2050. All sectors must make progress in their decarbonisation efforts in order to achieve these aims [2]. In 2020, the transport sector accounted for 17.7% of Japan's carbon dioxide (CO_2) emissions, of which 45.7% are attributed to private passenger cars [3]. These data suggest that achieving the decarbonisation of daily travel requires a reduction in emissions from private transport modes such as private cars. With the need for implementing more convenient transport modes [4], one strategy of the Japanese government is promoting the use of public transport [2].

In terms of research on the potential to boost public transport use, recent studies have focused on transit-oriented development (TOD). TOD is widely acknowledged as a strategy to reduce car travel and, in turn, increase the use of sustainable transport modes, including public transport [5,6]. On the other hand, other past studies on the potential to reduce emissions induced by lessened car use have been mainly conducted from the perspective of urban form, which is used to describe the physical characteristics of cities.

One element of urban form, population density [7], is what these studies have used as a basis. A study of the relationship between population density and petrol consumption per person in 32 cities worldwide indicated that less car use is likely to occur in places with higher population densities [8]. A similar study of Japan also showed that denser cities tend to have less car use [9]. In general, higher urban densities might engender higher levels of public transport and a lower degree of car use, resulting in less travel-based emissions from private transport modes. It can therefore be inferred that the potential for low-carbon travel brought about by the promotion of public transport use depends on the urban form of the region. Consequently, in order to consider the directions for reducing travel-based CO_2 emissions from private transport modes, it might be necessary to examine them from the perspectives of regional and metropolitan areas.

However, public transport issues might discourage people from using them, which is why it is important to set directions for reducing emissions based on the current usage and an evaluation of services. Studies on the effects of public transport attributes on CO_2 emissions from private transport modes are inadequate. By particularly addressing the level of satisfaction with the contents of the services, it is likely that the potential to improve their evaluation, increase their usage, and thereby achieve a reduction in emissions can be considered. Since public transport service contents comprise 'hard' (e.g., number of services, locations of rail stations and bus stops) and 'soft' (e.g., information and guide of services, fares) attributes, the possibility of reducing emissions must be analysed by improving the evaluations of both aspects. Furthermore, it is noteworthy that pilot programmes of Mobility as a Service (MaaS), which originated in Finland in 2014 [10], have been conducted throughout Japan in recent years, thereby emphasising the promotion of public transport use by increasing its convenience [2].

In light of this background, this study takes a novel approach to investigate the influence of public transport service evaluation on travel-based CO_2 emissions from private transport modes. The relationship between the evaluation of rail and bus services and emissions is analysed particularly in the representative regional and metropolitan areas of Japan. In addition, evaluations of the 'hard' and 'soft' attributes of public transport are taken into account, thereby leading to the consideration of improvements in existing services and the spread of new transport services that utilise information and communications technology (ICT), including MaaS. This study provides a method for examining the potential for reducing emissions by improving the evaluation of public transport services. Therefore, the following research questions are addressed:

1. Would an improved evaluation of the service contents of public transport boost its use and lead to a reduction in travel-based CO_2 emissions from private transport modes in both regional and metropolitan areas?

To answer this question, we postulate that, as the evaluation of the 'hard' and 'soft' attributes of rail and bus services increases, the overall evaluation of both services also improves. Building on this assumption, we further hypothesise that a higher overall evaluation of these services corresponds to a higher usage frequency of rail and bus, thus leading to reduced emissions due to a lessened use of private transport modes.

2. Is there a direct relationship between the evaluation of the attributes of public transport services and travel-based CO_2 emissions from private transport modes?

For this question, we presume that a higher evaluation of the 'hard' and 'soft' attributes of rail and bus services is associated with lower emissions from private transport modes.

The remainder of the paper is organised as explained as follows. Following a review of earlier research, Section 2 presents a description of the study features. Section 3 provides an overview of the case study areas and the questionnaire survey conducted for this study. Section 4 gives an explanation of the data used for the analysis, the method of estimating travel-based CO_2 emissions from private transport modes, and the analytical method. Section 5 presents the results of the analysis. Section 6 discusses the analysis results and addresses future tasks for additional research. Section 7 gives a summary of the study findings and concludes the paper.

2. Literature Review

Regarding studies of travel-based CO_2 emissions and car use, Reckien et al. [11] applied regression analysis to ascertain the factors that influence emissions from road traffic in the 23 former urban districts of Berlin, Germany, in accordance with the settlement structure, transport structure, and with income. The authors then created a comprehensive model incorporating the significant variables and identified the most important factors. Specifically examining five cities with different urban forms in the USA for case studies, Zhang et al. [12] investigated the directions for lowering vehicle miles travelled (VMT) from the perspectives of residential density, employment density, land use mix, average block size, and distance from the city centre. Song et al. [13] analysed the effects of socio-demographic characteristics and the built environment on individual-level CO_2 emissions via type choice and the usage of vehicles in Greater Boston, USA. Liu et al. [14] similarly examined the CO_2 emissions reduction effects at the individual level by examining the effects of neighbourhood-scale urban form on residents' travel behaviour (i.e., number of trips, total distance travelled, probability of selecting low-carbon transport modes) in 10 neighbourhoods of Beijing, China. Cao and Yang [15] investigated the factors affecting commuting trips and the resulting CO_2 emissions based on socio-demographic characteristics, the built environment (e.g., distance to the city centre, land use mix, residential density), and residential self-selection, using Guangzhou, China as the site for the case study. Hong [16] assessed the non-linear relationship between primarily density-related factors and road-based CO_2 emissions calculated using data from the Puget Sound Regional Council (PSRC) Household Activity Survey, the Motor Vehicle Emission Simulator (MOVES) data for Pierce County, Washington, and GIS network data. Regarding studies based on Japanese data, Taniguchi et al. [9] identified the relationship between annual per-capita petrol consumption and the urban forms of 67 cities. They found that a higher potential to use public transport is associated with a lower likelihood of car use. Makido et al. [17] investigated the relationship between CO_2 emissions and urban form among six sectors of 50 cities. The authors discovered that cities with a compact urban form tend to emit less CO_2 from passenger transport than sprawled cities. Using Kagawa Prefecture and the Tokyo Metropolitan Area, respectively, as case studies for regional and metropolitan areas, Kii [18] forecasted scenarios for reducing CO_2 emissions from passenger cars by 2050 from the perspectives of three factors: population, urban form, and automobile technology. Although these studies have analysed the potential for emissions reduction by primarily focusing on urban form, none have considered the evaluation of transport modes or services as a possible factor.

Concentrating on the evaluation of public transport, Eboli and Mazzulla [19] investigated the relationship between the satisfaction of rail users and rail service quality. They specifically determined the main factors influencing the latter in Milan, Italy. Using the city of Guangzhou in China as the subject of a case study, Cao and Cao [20] investigated the service attributes which were crucially important for the satisfaction of bus, bus rapid transit (BRT), and metro transit users through an importance-performance analysis and three-factor theory. Zhen et al. [21] applied multiple regression and importance-performance analysis to identify service attributes to improve user satisfaction with the Shanghai-Nanjing High Speed Rail in China. Through a literature review, van Lierop et al. [22] inspected the factors affecting satisfaction and loyalty in public transport. Soza-Parra et al. [23] examined the effects of crowding and the number of denied boardings on the relationship between headway irregularity and user satisfaction among bus and metro passengers in Santiago de Chile. Lunke [24] investigated the factors influencing commuters' satisfaction with public transport by conducting analyses of all users and the number of users per transport mode in Oslo, Norway. Sukhov et al. [25] investigated the effects of the combinations of various bus service quality attributes on travel satisfaction before and after an intervention intended to improve public transport, specifically investigating Karlstad, Sweden as the subject of a case study. Using data collected from a national survey of all 50 states in the USA, Mattson et al. [26] determined residents' satisfaction with community transport systems in metro and non-metro areas based on six variables and assessed the influence of these variables on ease of travel within areas. While these studies have explored factors that could conceivably improve the evaluation of public transport, there is a lack of insight into whether this improvement may result in generating environmental benefits, such as lower CO_2 emissions, through its use.

To summarise, past studies have verified the factors affecting travel-based CO_2 emissions from the perspective of urban form using various methods such as regression and structural analysis. In addition, studies of public transport satisfaction have explored directions for its improvement. Nevertheless, studies investigating the relationship between the evaluation of public transport services and travel-based CO_2 emissions from private transport modes remain insufficient. Therefore, this study was conducted to establish how the difference in the assessment of rail and bus services affect travel-based CO_2 emissions from private transport modes in regional and metropolitan areas, which have contrasting urban forms. Furthermore, this study produces insights into reducing emissions from the perspective of the evaluation of the attributes of rail and bus services in these areas.

3. Overview of Case Study Areas and Survey

3.1. Case Study Areas

Generally, it can be assumed that metropolitan areas have high urban densities and that they offer highly convenient public transport. However, regional areas are regarded as having contrasts in urban forms between the city centre and the suburbs. Based on this assumption, Okayama City and Central Tokyo were chosen, respectively, as regional and metropolitan case study areas. The relationship between the evaluation of public transport services and travel-based CO_2 emissions from private transport modes was investigated for these two locales. Figure 1 displays the locations of the case study areas of this study.

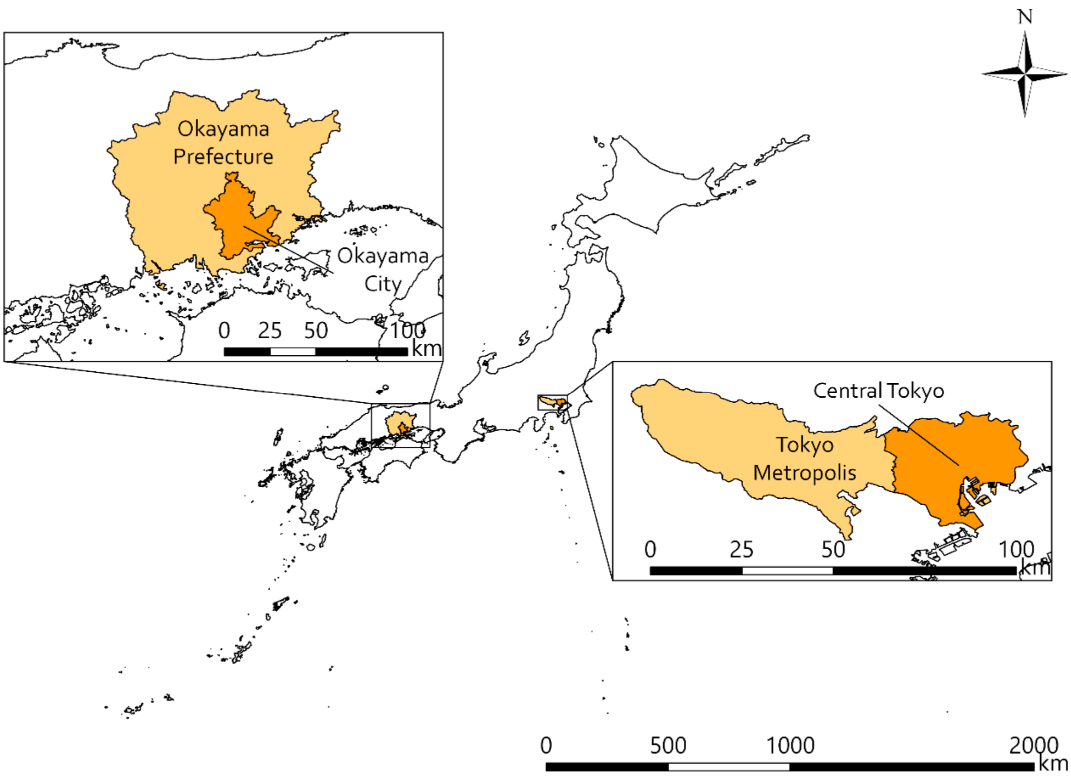

Figure 1. Locations of the case study areas.

3.1.1. Regional Area: Okayama City

Located in the southern part of Okayama Prefecture, Okayama City has a population of 724,691 [27], an area of 789.95 km^2 [28], and a population density of 917.4 people/km^2. From 1971 to 2012, the share of cars as a main transport mode increased from 26.8% to 59.5%. By contrast, the share of public transport decreased from 14.2% to 6.5%, indicating a strong dependence on automobiles [29]. Six rail lines operated by the West Japan Railway Company (JR West) run to the city [30], and a station density of 0.06 per square kilometre was calculated using GIS for this study. Although the total number of rail passengers rose 1.22 times from 1991 to 2018, three of the rail lines have seen a dip, with the Tsuyama Line experiencing the most drastic decline of 40% [30]. Bus lines that spread from the city centre to the suburbs have also undergone a reduction in terms of the number of services and the abolishment of certain routes. Between 1994 and 2016, bus routes in the city decreased by 24%. Regarding trams that run through the city centre, the number of passengers decreased during a period extending from the early 1990s, although they have been increasing slightly since 2010. Finally, approximately 28% of the total population reside in areas with poor accessibility to rail stations and bus stops. Roughly 30% take over half an hour by public transport to reach Okayama Station, the main terminal, or other hubs. As a result, providing transport services that are appropriate to areas and which improve the quality of existing public transport services are key issues related to transport in the city [29,30].

3.1.2. Metropolitan Area: Central Tokyo

In this study, Central Tokyo refers to the 23 "special wards" located in the eastern part of the Tokyo Metropolis. The region has a population of 9,733,276, an area of 627.53 km^2, and a population density of 15,510.5 people/km^2 [31]. As of 2018, rail accounted for 50.3% of the share of main transport modes, whereas the figure for cars was 7.9% [32]. The area boasts one of the world's most accurate and safest rail networks [33], with a station density of 0.86 per square kilometre, as calculated for this study using GIS. In addition to the 11 rail lines operated by the East Japan Railway Company (JR East), Central Tokyo has 11 privately run rail and monorail lines, a tram line, an automated guideway transit (AGT) owned by the metropolitan government, and 13 underground lines [34]. However, because of the poor accessibility between rail stations and bus stops when transferring between trains and buses, and because of the extremely high density of the public transport network, users face difficulties in selecting a suitable route. Therefore, while acknowledging the high quality of current public transport services, further improvement is necessary to ensure comfortable travel for users [33]. Furthermore, compared to other regional areas, private car ownership can be challenging in Central Tokyo because of the high maintenance costs of vehicles and limited parking availability. However, because the quality of the public transport services is of high level, residents can travel rather conveniently without private cars.

3.2. Survey

An online survey of residents aged 20 and older was conducted in Okayama City and Central Tokyo for this study. The target demographic was chosen because the majority of owners of private transport modes generally fall within this age group and is therefore appropriate for the aim of this study. Table 1 presents an overview of the survey. It is noteworthy that the survey was conducted during the global COVID-19 pandemic. Consequently, the travel behaviour of certain respondents might presumably be different from before the pre-pandemic period. For instance, a study on regional and metropolitan areas in Japan revealed that the decline in the use of public transport among residents during the pandemic was statistically significant. The study also found a rise in the percentage of residents working or attending school online as opposed to commuting [35]. Such circumstances must be considered when interpreting the analysis results. Furthermore, while answering the survey, respondents were instructed to reflect on their daily life before the rise in petrol prices in October 2021.

Table 1. Overview of the survey.

Target	Residents aged 20 and older in Okayama City and Central Tokyo
Method	Online survey
Company	Rakuten Insight, Inc.
Period	9 December 2021–13 December 2021
No. samples collected	• Okayama City: 1381 • Central Tokyo: 1308
Items	(1) Socio-economic characteristics (2) Daily travel patterns (3) Public transport use (4) Evaluation of public transport services

The survey was conducted among males and females, with an approximately even distribution across the following five age groups: 20s, 30s, 40s, 50s, and 60s or older. While this design does not represent the population structure of Japan, it was implemented to avoid selection bias during data collection. In addition, the survey included questions related to socio-economic demographics such as gender, education, profession, and employment status. It also covered questions about travel satisfaction, travel constraints, ease of travel, and more. This study, however, used data pertaining to daily travel patterns, public transport use, and the respondents' evaluation of its services.

The survey items for daily travel patterns were created for four travel purposes: "commuting", "shopping", "dining/socialising/leisure", and "other purposes" (e.g., hospital visits, lessons). Respondents were asked to select all transport modes they would use for a single trip to their most frequently visited location for each purpose. Respondents who chose "private car", "car sharing", "motorbike", "scooter", or "others" were asked to provide the one-way travel distance, vehicle type, and energy consumption rate for each purpose. These respondents were given eight options for the vehicle type and were instructed to enter the value of the fuel or electrical mileage depending on the vehicle type per transport mode. In addition, all respondents were directed to provide the travel frequency for each purpose.

The survey also included questions about public transport use, such as the frequency of residents' use of rail and bus services in the case study areas. Regarding the evaluation of public transport services, respondents were asked to rate their satisfaction level using a five-point Likert scale ("dissatisfied", "somewhat dissatisfied", "neutral", "somewhat satisfied", and "satisfied") for the 'hard' and 'soft' attributes of rail and bus services, as well as overall satisfaction with both transport modes. Specifically, respondents were asked to assess five 'hard' (number of services, locations of rail stations/bus stops, comfort of rail stations/bus stops, ease of transfer, and comfort of trains/buses) and four 'soft' (ease of understanding information and guide of services, ease of searching information and guide of services, fares, and payment methods) attributes.

4. Methods

4.1. Estimation Conditions for Travel-Based CO_2 Emissions from Private Transport Modes and Samples Used

For this study, the following transport modes described in the survey were classified as private transport modes: "private car", "car sharing", "motorbike", "scooter", and "others" (if applicable). Annual travel-based CO_2 emissions from these transport modes were estimated for each respondent. Data used for this process from the survey include the one-way travel distance, vehicle type, and energy consumption rate associated with each travel purpose. Since respondents provided the values themselves, some data might likely be erroneous because of input errors or misunderstandings. Therefore, the following five conditions were applied to formulate the samples for the analysis:

1. Respondents are not included approximately in the top 10% of the average response time per question. For this study, the criterion for the average response time is more than 8 s.
2. The addresses of respondents are in the case study area.
3. The one-way travel distance of private transport modes per travel purpose is less than 100 km.
4. The fuel mileage of “private car”, “car sharing”, or “others” (if the transport mode is a car) is between 4 km/L and 40 km/L, depending on whether the transport mode is a petrol, diesel, or hybrid (petrol/electric or diesel/electric) vehicle.
5. The fuel mileage of “motorbike”, “scooter”, or “others” (if the transport mode is a two-wheeler) is between 4 km/L and 70 km/L, depending on whether the transport mode is a petrol, diesel, or hybrid (petrol/electric or diesel/electric) vehicle.

For Condition 1, as a rough measure to account for overly rapid response times, respondents in approximately the top 10% percentile were excluded because they were deemed likely to include inaccurate data. For this study, respondents with an average response time of 8 s or less per question were removed, constituting 10.5% and 11.2% of the total responses collected in Okayama City and Central Tokyo, respectively. For Condition 2, responses that did not include the respondent’s postcode in the address data or which were outside the case study areas were removed. Condition 3 was set as the daily travel range within the respondents’ prefecture or metropolis of residence. Condition 4 was established after ascertaining the maximum and minimum fuel mileages in WLTC mode for petrol and diesel passenger cars in the lists of mileage data for motor vehicles provided by Japan’s Ministry of Land, Infrastructure, Transport, and Tourism. The range was set based on the consumption rates in urban, rural, and expressway modes for the car models corresponding to each value of fuel mileage [36–39]. Similarly, Condition 5 was determined after verifying the models with the highest fuel consumption in WMTC mode among those sold by four motorbike manufacturers in Japan: Honda Motor, Kawasaki Motors, Suzuki Motor, and Yamaha Motor [40–43]. It is important to note that, although the survey included plug-in hybrid (petrol/electric or diesel/electric) and electric vehicles as vehicle type options, respondents who selected these were excluded because the number was extremely small.

Ultimately, approximately 17.3% of the samples collected in the survey in both Okayama City and Central Tokyo were removed for the analysis. The final sample sizes were, respectively, 1142 and 1082 for Okayama City and Central Tokyo. Table 2 displays a cross-tabulation of gender and age groups within the samples used for this study.

Table 2. Cross-tabulation of gender and age group.

Age Group	Okayama City			Central Tokyo		
	Male (n = 547)	**Female (n = 595)**	**Total (n = 1142)**	**Male (n = 537)**	**Female (n = 545)**	**Total (n = 1082)**
20s	7.3%	17.8%	12.8%	19.6%	19.6%	19.6%
30s	21.9%	21.7%	21.8%	20.5%	19.4%	20.0%
40s	22.7%	22.0%	22.3%	20.5%	19.8%	20.1%
50s	24.3%	22.4%	23.3%	18.6%	20.4%	19.5%
60s or older	23.8%	16.1%	19.8%	20.9%	20.7%	20.8%

4.2. Estimation Method for Travel-Based CO_2 Emissions from Private Transport Modes

The CO_2 emissions estimated for this study are attributed directly to travel by the private transport modes used by respondents. Since the emissions are estimated based on the amount of energy consumed during travel, a well-to-wheel analysis for this process was performed for this study, which encompasses the stages of the extraction and shipping of raw materials, fuel refining, and vehicle journey. Figure 2 depicts the procedure used for estimating the travel-based emissions of respondents. First, the amount of fuel consumed by the respondents for each trip per travel purpose was calculated by dividing the round-trip travel distance by the energy consumption rate. Since some survey respondents reported that they did not know the fuel mileage of the transport modes they used, the emissions from the trips of these respondents were estimated using the average values of the fuel mileage data for each private transport mode per travel purpose, accordingly. Next, the amount of fuel consumed was multiplied by the CO_2 emission factors of each private transport mode per travel purpose under the well-to-tank and tank-to-wheel stages. The well-to-tank stage specifically reflects the extraction and shipping of raw materials, fuel refining, and the supply of fuel to vehicles. On the other hand, the tank-to-wheel stage incorporates the vehicle journey after the fuel supply. The well-to-tank emission factors used in this study were values calculated by the Japan Automobile Research Institute using a method established by the organisation [44]. These factors were multiplied by the gross calorific values corresponding to the fuel type to convert the unit. The data of the gross calorific values are provided by the Agency of Natural Resources and Energy of Japan [45]. The emission factors that directly account for the actual usage of fuel were calculated by the Ministry of Environment of Japan. These factors were used as the tank-to-wheel values in this study [46]. Then, by adding the emissions of these two types for all four travel purposes together, the amount of CO_2 released annually from the private transport modes of each respondent was estimated. It is noteworthy that, in the case of respondents who selected "rail/underground/monorail/tram", "route bus/community bus", "taxi", "ride-sharing", "bicycle", "bicycle sharing", or "walking", emissions from these modes are regarded as zero in this study because they do not contribute directly to the CO_2 released from private transport modes. Similarly, respondents who use no private transport mode for any travel purpose were assigned a zero emissions value.

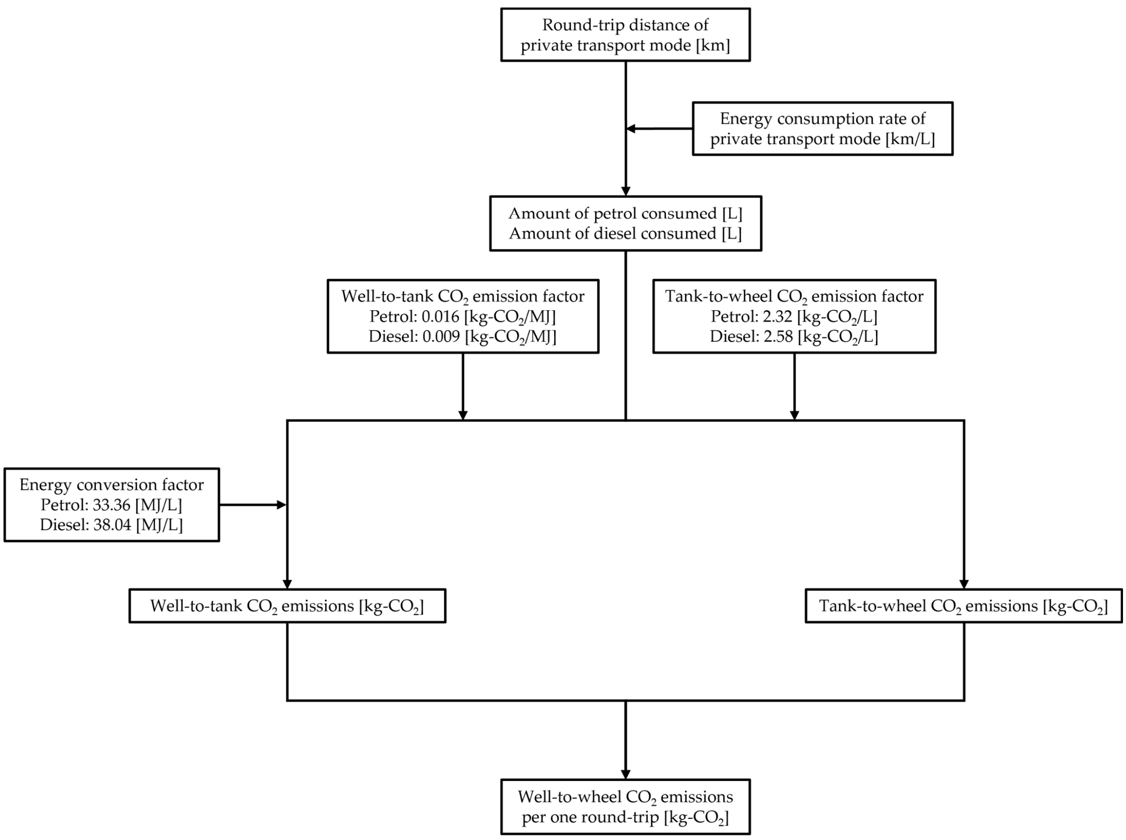

Figure 2. Method of estimating travel-based well-to-wheel CO_2 emissions from private transport modes per one round-trip [44–46].

Based on the estimation conditions described in the preceding paragraph, the annual travel frequency of the respondents for each travel purpose was calculated using the answers collected from the survey. The following was set as the corresponding values for the travel frequency options provided in the survey:

- "about once a year" = "1 time a year"
- "about once in six months" = "2 times a year"
- "about once in two or three months" = "4 times a year"
- "about once a month" = "12 times a year"
- "about once in two weeks" = "24 times a year"
- "about once a week" = "48 times a year"
- "about two or three times a week" = "144 times a year"
- "almost every day" = "240 times a year"

Using these corresponding values, the annual travel-based CO_2 emissions from private transport modes per respondent were estimated using Equation (1).

$$E = \sum_{k}\left(\sum_{n}\left(e_{kn} \cdot \frac{x_n}{f_k} \cdot \varphi_{\text{year}_n}\right)\right) \tag{1}$$

In this equation, E represents the annual travel-based CO_2 emissions from private transport modes per respondent [kg-CO_2/(person·year)], e stands for the well-to-wheel CO_2 emission factor [kg-CO_2/L], x denotes the travel distance per one round-trip [km/trip], f expresses the energy consumption rate of the corresponding private transport mode [km/L], φ_{year} signifies the annual travel frequency of the corresponding travel purpose [trips/year], k stands for the arbitrary private transport mode, and n represents the arbitrary travel purpose. Furthermore, the well-to-wheel CO_2 emission factor was calculated using Equation (2).

$$e_k = \alpha_{\text{WtT}k} \cdot \beta_{\text{WtT}k} + \alpha_{\text{TtW}k} \tag{2}$$

In this equation, e represents the well-to-wheel CO_2 emission factor [kg-CO_2/L], α_{WtT} denotes the well-to-tank CO_2 emission factor [kg-CO_2/MJ], α_{TtW} stands for the tank-to-wheel CO_2 emission factor [kg-CO_2/L], β_{WtT} expresses the well-to-tank CO_2 energy conversion factor [MJ/L], and k denotes the arbitrary private transport mode.

4.3. Method for Analysing the Relationship between the Evaluation of Public Transport Services and Travel-Based CO_2 Emissions from Private Transport Modes

This study clarifies whether an improvement in the evaluation of public transport services would encourage its use and thereby engender a reduction in travel-based CO_2 emissions from private transport modes in regional and metropolitan areas. In other words, this study is designed to indicate whether the relationship between the evaluation and usage frequency of public transport services is related to travel-based CO_2 emissions from private transport modes in the case study areas of Okayama City and Central Tokyo. Specifically, we assume that, with a higher evaluation of the 'hard' and 'soft' attributes of rail and bus services, the overall evaluation of both services increases. Based on this premise, we then hypothesise that the higher the overall evaluation of these services, the more frequently the respondents use rail and bus, hence the higher the potential to reduce CO_2 emissions because of the less frequent use of private transport modes.

In addition, this study investigates whether there is a direct relationship between the evaluation of the 'hard' and 'soft' attributes of public transport services and travel-based CO_2 emissions from private transport modes. For this analysis, we assume that the higher the average satisfaction, the less CO_2 is emitted.

In summary, this study examines the correlation among the following four items in turn: the evaluation of the 'hard' and 'soft' attributes of public transport services, the overall satisfaction with public transport services, the usage frequency of public transport services, and travel-based CO_2 emissions from private transport modes. This study also directly examines the correlation between the evaluation of the 'hard' and 'soft' attributes of public transport services and travel-based CO_2 emissions from private transport modes.

Table 3 presents a list of the variables used for the analysis, which were organised based on data collected from the survey. The hypotheses of this study are depicted in Figure 3.

Table 3. List of variables used for the analysis.

Variables	Details
Annual travel-based CO_2 emissions from private transport modes [kg-CO_2/(person·year)]	Annual travel-based CO_2 emissions from daily travel per respondents
Evaluation of rail and bus services: 'hard' attributes	• Dissatisfied: 1 • Somewhat dissatisfied: 2 • Neutral: 3 • Somewhat satisfied: 4 • Satisfied: 5
Number of services	
Location of rail stations/bus stops	
Comfort of rail stations/bus stops	
Ease of transfer	
Comfort of trains/buses	
Evaluation of rail and bus services: 'soft' attributes	
Number of services	
Ease of understanding information and guide of services	
Ease of searching information and guide of services	
Fares	
Payment methods	
Overall evaluation of rail and bus services	
Usage frequency of rail and bus services	• Never • About once a year–once in six months • About once in two or three months–once a month • About once in two weeks–two or three times a week • Almost every day

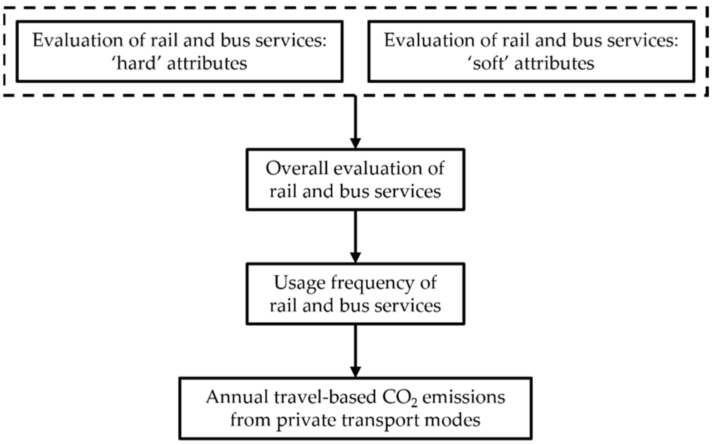

Figure 3. Conceptual diagram of the relationship between the evaluation of public transport services and travel-based CO_2 emissions from private transport modes.

For this study, we first performed an ordinal logistic regression to analyse the effects of the evaluation of the 'hard' and 'soft' attributes of public transport services on the overall evaluation. In creating the separate models for rail and bus services, the overall evaluation was set as the dependent variable, whereas the independent variables were the evaluation of the 'hard' and 'soft' attributes. The overall evaluation was re-coded as "1" and "2" of the five-point Likert scale into low-performance variables, and "4" and "5" into high-performance variables. Regarding the evaluation of the 'hard' and 'soft' attributes, the satisfaction levels rated as "dissatisfied", "somewhat dissatisfied", and "neutral" were re-coded as "0", and "somewhat satisfied" and "satisfied" as "1". Next, this study used the chi-square test of independence to clarify the relationship between the overall evaluation and the usage frequency of rail and bus services. A residual analysis was also conducted to determine the significant differences among the categories of the overall evaluation and usage frequency. Following this analysis, this study investigated the relationship between the usage frequency of public transport services and annual travel-based CO_2 emissions from private transport modes per respondent. Since the data related to CO_2 emissions were not normally distributed among all categories, we used the Kruskal-Wallis test and performed a pairwise comparison using the Steel-Dwass method. The Kruskal-Wallis test is a nonparametric statistical method used to determine if there are differences among three or more mutually independent groups of samples [47]. The Steel-Dwass method is a nonparametric pairwise comparison test used to identify significant differences between all combinations of pairs of groups [48]. Finally, this study analysed the differences in the average satisfaction with the 'hard' and 'soft' attributes of rail and bus services among the respondents, classified into groups according to the amount of travel-based CO_2 emitted from private transport modes. For this analysis, the evaluation level was re-coded as "1" and "2" of the five-point scale into low-performance variables, and "4" and "5" into high-performance variables. The respondents were divided into four groups: non-emitters (0 kg-CO_2/(person·year)), low emitters (<500 kg-CO_2/(person·year)), medium emitters (<1500 kg-CO_2/(person·year)), and high emitters ($\geq$1500 kg-CO_2/(person·year)). We used the Kruskal-Wallis test and performed a pairwise comparison using the Steel-Dwass method for this analysis as well, because the data related to the evaluation level of the 'hard' and 'soft' attributes of both rail and bus services were not distributed normally.

5. Results

5.1. Descriptive Statistics of Travel-Based CO_2 Emissions from Private Transport Modes and the Share of CO_2 Emitter Groups and Private Car Ownership

The average annual travel-based CO_2 emissions from private transport modes per respondent were 825 kg-CO_2/(person·year) and 186 kg-CO_2/(person·year), respectively, in Okayama City and Central Tokyo. Regarding the share of CO_2 emitter groups, non-emitters constituted 14.5% of the respondents in Okayama City, whereas, in Central Tokyo, they accounted for 72.8% (Figure 4). Furthermore, 82.7% of the respondents in Okayama City reported owning private cars that they can use freely, whereas, in Central Tokyo, this figure was 29.6% (Figure 5).

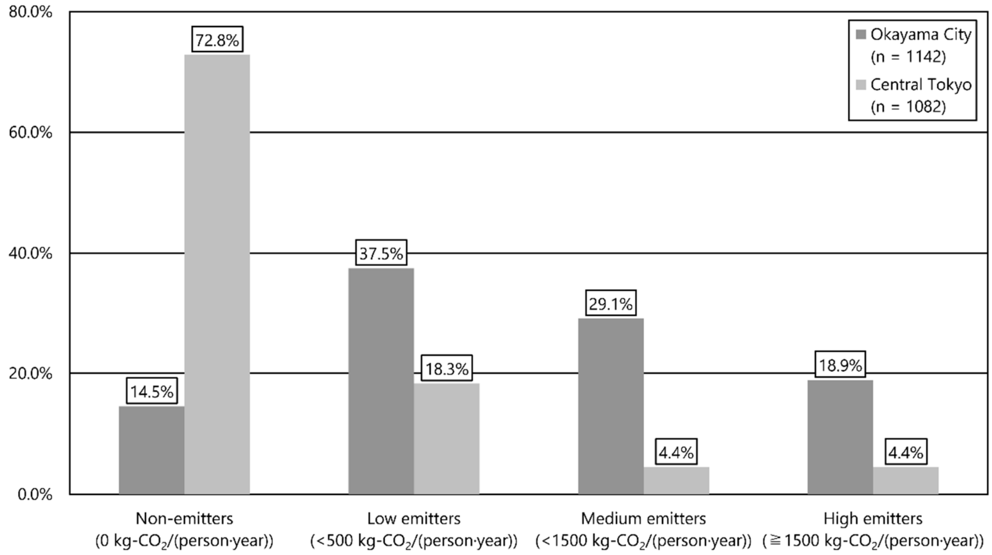

Figure 4. Share of CO_2 emitter groups among survey respondents.

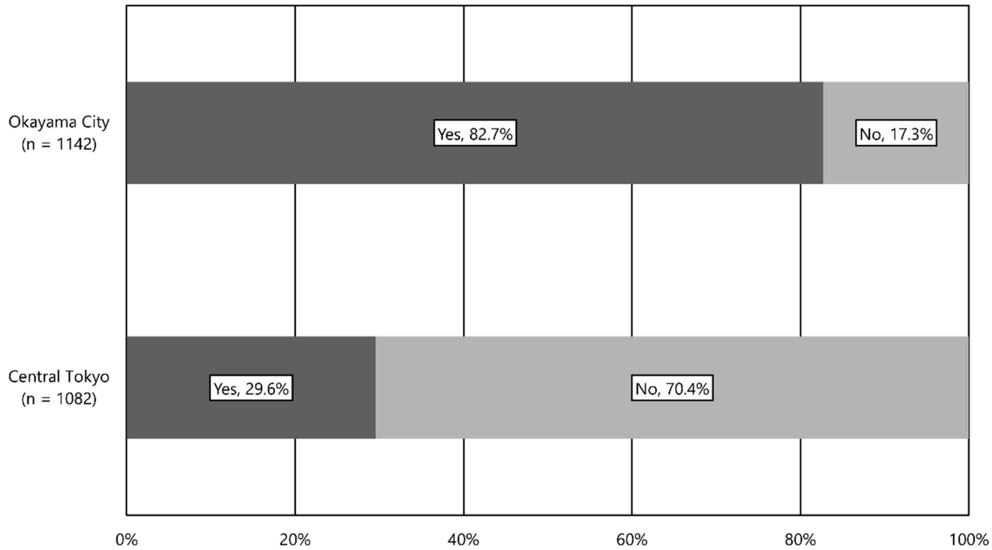

Figure 5. Share of private car ownership among survey respondents.

5.2. Effects on the Overall Evaluation of Public Transport Services

Table 4 presents the results of the ordinal logistic regression analysis examining the effects on the overall evaluation of rail and bus services in regional and metropolitan areas. The three pseudo-R^2 coefficients indicate the goodness-of-fit of the models, although there is no general agreement upon which value to refer to. The values of these coefficients fall between 0 and 1, with higher values indicating a better model fit. The McFadden R^2 is commonly used but has the disadvantage of not reaching 1. The Cox and Snell R^2 is designed to address this issue but is also smaller than 1 in all cases. The Nagelkerke R^2 makes further adjustments and yields larger values [49].

Table 4. Results of the ordinal logistic regression for the overall evaluation of public transport services.

	Public Transport Services	**Rail**			**Bus**		
	Variables	**Coeff.**	**SE**	***p* Value**	**Coeff.**	**SE**	***p* Value**
Regional area (Okayama City)	Evaluation of public transport services: 'hard' attributes						
	Number of services	1.344	0.222	0.000 **	1.694	0.264	0.000 **
	Location of rail stations/bus stops	1.109	0.231	0.000 **	0.708	0.207	0.001 **
	Comfort of rail stations/bus stops	0.272	0.258	0.291	1.142	0.332	0.001 **
	Ease of transfer	0.521	0.246	0.035 *	0.660	0.292	0.024 *
	Comfort of trains/buses	0.586	0.235	0.013 *	0.143	0.280	0.609
	Evaluation of public transport services: 'soft' attributes						
	Ease of understanding information and guide of services	0.508	0.296	0.086	0.148	0.339	0.662
	Ease of searching information and guide of services	0.202	0.289	0.483	0.866	0.327	0.008 **
	Fares	1.086	0.246	0.000 **	1.818	0.287	0.000 **
	Payment methods	1.227	0.228	0.000 **	0.464	0.259	0.073
	Intercepts (Thresholds)						
	Overall evaluation: Dissatisfied	−2.473	0.139	0.000 **	−1.951	0.105	0.000 **
	Overall evaluation: Somewhat dissatisfied	−1.051	0.084	0.000 **	−0.528	0.071	0.000 **
	Overall evaluation: Neutral	3.330	0.160	0.000 **	3.631	0.175	0.000 **
	Overall evaluation: Somewhat satisfied	6.541	0.307	0.000 **	7.323	0.407	0.000 **
	Model fit (*p* value)		0.000			0.000	
	McFadden R^2		0.269			0.220	
	Cox and Snell R^2		0.463			0.413	
	Nagelkerke R^2		0.514			0.453	
	% of correct classifications		69.6%			62.3%	
	Sample size		1142			1142	

Table 4. *Cont.*

	Public Transport Services	**Rail**			**Bus**		
	Variables	**Coeff.**	**SE**	***p* Value**	**Coeff.**	**SE**	***p* Value**
Metropolitan area (Central Tokyo)	Evaluation of public transport services: 'hard' attributes						
	Number of services	1.624	0.215	0.000 **	1.103	0.236	0.000 **
	Location of rail stations/bus stops	0.363	0.211	0.085	0.788	0.240	0.001 **
	Comfort of rail stations/bus stops	0.299	0.193	0.122	0.508	0.287	0.077
	Ease of transfer	0.755	0.189	0.000 **	1.284	0.285	0.000 **
	Comfort of trains/buses	1.230	0.197	0.000 **	0.935	0.265	0.000 **
	Evaluation of public transport services: 'soft' attributes						
	Ease of understanding information and guide of services	0.143	0.256	0.577	0.525	0.315	0.096
	Ease of searching information and guide of services	0.472	0.254	0.064	0.302	0.322	0.348
	Fares	0.975	0.189	0.000 **	0.734	0.244	0.003 **
	Payment methods	1.751	0.195	0.000 **	0.765	0.225	0.001 **
	Intercepts (Thresholds)						
	Overall evaluation: Dissatisfied	−3.253	0.318	0.000 **	−3.024	0.186	0.000 **
	Overall evaluation: Somewhat dissatisfied	−1.347	0.147	0.000 **	−1.201	0.092	0.000 **
	Overall evaluation: Neutral	3.188	0.194	0.000 **	3.368	0.171	0.000 **
	Overall evaluation: Somewhat satisfied	6.820	0.306	0.000 **	6.363	0.314	0.000 **
	Model fit (*p* value)		0.000			0.000	
	McFadden R^2		0.398			0.319	
	Cox and Snell R^2		0.631			0.521	
	Nagelkerke R^2		0.687			0.578	
	% of correct classifications		71.9%			73.8%	
	Sample size		1082			1082	

* $p < 5\%$, ** $p < 1\%$.

Among the 'hard' attributes of the rail services in Okayama City, the number of services, location of rail stations, ease of transfer, and comfort of trains were associated significantly with the overall evaluation. Regarding the 'soft' attributes, fares and payment methods were found to be significant. For bus services, the 'hard' attributes which significantly influence the overall evaluation include the number of services, location of bus stops, comfort of bus stops, and ease of transfer. The 'soft' attributes of ease of searching information and guide of services and fares were also significant. The results demonstrated that all significant variables were related positively to the overall evaluation of rail and bus services, which indicates that a higher evaluation of these 'hard' and 'soft' attributes is associated with a higher overall evaluation of the two public transport services. Furthermore, the absolute values of coefficients for number of services and location of rail stations/bus stops were higher than those of ease of transfer for both rail and buses.

For the results obtained for Central Tokyo, the analysis revealed that, among the 'hard' attributes of rail services, the number of services, ease of transfer, and comfort of trains were significantly associated with the overall evaluation. In terms of bus services, the 'hard' attributes which were found to be significant included the number of services, location of bus stops, ease of transfer, and comfort of buses. The 'soft' attributes which significantly influence the overall evaluation for both rail and bus were fares and payment methods. Similarly to the results obtained for Okayama City, all significant variables exhibited a positive relationship with the overall evaluation of rail and bus services. Furthermore, when comparing the absolute values of the coefficients of significant variables, it was observed that, for rail services, payment methods, numbers of services, and comfort of trains were higher than those of others. On the other hand, for bus services, the ease of transfer and number of services showed higher values.

5.3. Relationships: Overall Evaluation, Usage Frequency of Public Transport, and Travel-Based CO_2 Emissions from Private Transport Modes

Table 5 presents the results of the chi-square test of independence and residual analysis that analysed the relationship between the overall evaluation and usage frequency of rail and bus services in regional and metropolitan areas. The findings obtained for Okayama City indicate a significant relationship between the overall evaluation and usage frequency of both rail and bus services, with higher evaluation ratings positively corresponding to higher usage frequency. For Central Tokyo, a significant relationship was found between the overall evaluation and usage frequency of rail services. Nevertheless, no clear trend was apparent in displaying how changes in usage frequency were influenced by differences in the evaluation. In the case of bus services, a dependent relationship was found between the overall evaluation and usage frequency, suggesting that a higher evaluation is associated with a higher usage frequency. However, it is noteworthy that respondents who reported using the bus "almost every day" tended to be slightly dissatisfied with the overall service.

Table 5. Results of the chi-square test of independence and residual analysis between the overall evaluation and usage frequency of public transport modes.

		Usage Frequency of Rail					
	Overall Evaluation of Rail Service	**Never**	**About Once a Year–Once in Six Months**	**About Once in Two or Three Months–Once a Month**	**About Once in Two Weeks–Two or Three Times a Week**	**Almost Every Day**	**Total**
Regional area (Okayama City)	Dissatisfied	36 (64.3%) ++	8 (14.3%) ++	5 (8.9%) +	4 (7.1%)	3 (5.4%)	56
	Somewhat dissatisfied	51 (37.2%)	50 (36.5%)	19 (13.9%)	9 (6.6%)	8 (5.8%)	137
	Neutral	330 (46.7%) ++	202 (28.6%)	118 (16.7%) +	35 (5.0%) +	21 (3.0%) +	706
	Somewhat satisfied	31 (17.6%) ++	57 (32.4%)	62 (35.2%) ++	14 (8.0%)	12 (6.8%) +	176
	Satisfied	16 (23.9%) ++	24 (35.8%)	13 (19.4%)	11 (16.4%) ++	3 (4.5%)	67
	Chi-square test of independence: $p = 0.000$ **						
		Usage Frequency of Bus					
	Overall Evaluation of Bus Service	**Never**	**About Once a Year–Once in Six Months**	**About Once in Two or Three Months–Once a Month**	**About Once in Two Weeks–Two or Three Times a Week**	**Almost Every Day**	**Total**
	Dissatisfied	68 (64.8%) ++	19 (18.1%) +	9 (8.6%) +	7 (6.7%)	2 (1.9%)	105
	Somewhat dissatisfied	102 (47.0%)	69 (31.8%)	31 (14.3%)	10 (4.6%)	5 (2.3%)	217
	Neutral	357 (54.5%) ++	174 (26.6%)	83 (12.7%) ++	29 (4.4%)	12 (1.8%)	655
	Somewhat satisfied	24 (19.2%) ++	35 (28.0%)	52 (41.6%) ++	11 (8.8%)	3 (2.4%)	125
	Satisfied	12 (30.0%) +	11 (27.5%)	12 (30.0%) +	4 (10.0%)	1 (2.5%)	40
	Chi-square test of independence: $p = 0.000$ **						
		Usage Frequency of Rail					
	Overall Evaluation of Rail Service	**Never**	**About Once a Year–Once in Six Months**	**About Once in Two or Three Months–Once a Month**	**About Once in Two Weeks–Two or Three Times a Week**	**Almost Every Day**	**Total**
Metropolitan area (Central Tokyo)	Dissatisfied	2 (20.0%) +	0 (0.0%)	3 (30.0%)	3 (30.0%)	2 (20.0%)	10
	Somewhat dissatisfied	4 (8.0%)	3 (6.0%)	8 (16.0%)	19 (38.0%)	16 (32.0%)	50
	Neutral	28 (6.6%) ++	29 (6.8%)	87 (20.5%)	148 (34.8%) +	133 (31.3%)	425
	Somewhat satisfied	4 (1.1%) ++	22 (6.2%)	67 (19.0%)	145 (41.1%)	115 (32.6%)	353
	Satisfied	6 (2.5%)	14 (5.7%)	38 (15.6%)	103 (42.2%)	83 (34.0%)	244
	Chi-square test of independence: $p = 0.011$ *						

Table 5. *Cont.*

	Overall Evaluation of Bus Service	Usage Frequency of Bus					Total
		Never	About Once a Year–Once in Six Months	About Once in Two or Three Months–Once a Month	About Once in Two Weeks–Two or Three Times a Week	Almost Every Day	
Metropolitan area (Central Tokyo)	Dissatisfied	13 (43.3%)	7 (23.3%)	5 (16.7%)	3 (10.0%)	2 (6.7%)	30
	Somewhat dissatisfied	26 (20.5%) ++	31 (24.4%)	39 (30.7%)	22 (17.3%)	9 (7.1%) +	127
	Neutral	259 (38.9%) ++	124 (18.6%)	165 (24.8%)	99 (14.9%) ++	18 (2.7%) +	665
	Somewhat satisfied	16 (10.3%) ++	36 (23.1%)	44 (28.2%)	54 (34.6%) ++	6 (3.8%)	156
	Satisfied	18 (17.3%) ++	13 (12.5%)	35 (33.7%)	31 (29.8%) ++	7 (6.7%)	104
	Chi-square test of independence: $p = 0.000$ **						

* $p < 5\%$, ** $p < 1\%$ for chi-square test of independence. + $p < 5\%$, ++ $p < 1\%$ for residual analysis.

Table 6 presents a summary of the results of the Kruskal-Wallis test and the Steel-Dwass pairwise comparison examining the relationship between the usage frequency of public transport services and annual travel-based CO_2 emissions from private transport modes per respondent. The findings obtained for Okayama City suggest that the usage frequency of both rail and bus services is related to CO_2 emissions, with higher usage frequency exhibiting lower emissions among the significant categories. For rail services, the "about once a year—once in six months" group had the highest average of travel-based CO_2 emissions from private transport modes at 923 kg-CO_2/(person·year) among the five categories. In contrast, the "about once in two weeks—two or three times a week" group had the lowest average at 566 kg-CO_2/(person·year). The average emissions in the former category were approximately 1.63 times higher than in the latter. Regarding bus services, the "never" group had the highest average of travel-based CO_2 emissions from private transport modes at 899 kg-CO_2/(person·year). However, among the significant categories, the "about once in two weeks—two or three times a week" group had the lowest average at 547 kg-CO_2/(person·year). The average emissions were approximately 1.64 times higher in the former category than in the latter. In addition, although no significant difference was found between the two categories, the average emissions in the "never" group were roughly 1.78 times higher than in the "almost every day" group. In Central Tokyo, however, the relationships between the usage frequency of both rail and bus services and travel-based CO_2 emissions from private transport modes per respondent were not significant.

5.4. The Direct Relationship between the Evaluation of the 'Hard' and 'Soft' Attributes of Public Transport Services and Travel-Based CO_2 Emissions from Private Transport Modes

Tables 7 and 8 outline the results obtained from the Kruskal-Wallis test and the Steel-Dwass pairwise comparison examining the relationship between the evaluation of the 'hard' and 'soft' attributes of rail services and travel-based CO_2 emissions from private transport modes in regional and metropolitan areas, respectively. In Okayama City, significant differences in average satisfaction were found only among the 'hard' attributes: the number of services, location of rail stations, comfort of rail stations, and comfort of trains. Among these significant attributes, comfort of rail stations had the lowest p value, indicating the largest differences in average satisfaction. Furthermore, lower CO_2 emitter groups tended to have higher average satisfaction among the significant categories. However, in Central Tokyo, no significant differences were found among any of the 'hard' and 'soft' attributes.

Table 6. Results of the Kruskal-Wallis test for travel-based CO_2 emissions from private transport modes.

	Usage Frequency of Rail (p = 0.000 **)	***n***	**Mean**	**Std. Dev.**	***p* Value between Categories (<0.05)**		
Regional area (Okayama City)	Never	464	862	1026	Never	About once in two or three months–once a month	p = 0.022
	About once a year–once in six months	341	923	1025	Never	About once in two weeks–two or three times a week	p = 0.001
	About once in two or three months–once a month	217	715	954	About once a year–once in six months	About once in two or three months–once a month	p = 0.001
	About once in two weeks–two or three times a week	73	566	965	About once a year–once in six months	About once in two weeks–two or three times a week	p = 0.000
	Almost every day	47	657	1060	About once a year–once in six months	Almost every day	p = 0.016
	Usage Frequency of Bus (p = 0.000 **)	***n***	**Mean**	**Std. Dev.**	***p* Value between Categories (<0.05)**		
	Never	563	899	1004	Never	About once in two or three months–once a month	p = 0.001
	About once a year–once in six months	308	824	953	Never	About once in two weeks–two or three times a week	p = 0.001
	About once in two or three months–once a month	187	734	1154	About once a year–once in six months	About once in two or three months–once a month	p = 0.018
	About once in two weeks–two or three times a week	61	547	963	About once a year–once in six months	About once in two weeks–two or three times a week	p = 0.005
	Almost every day	23	505	733			
Metropolitan area (Central Tokyo)	**Usage Frequency of Rail (p = 0.662)**	***n***	**Mean**	**Std. Dev.**	***p* Value between Categories (<0.05)**		
	Never	44	215	494			
	About once a year–once in six months	68	231	591			
	About once in two or three months–once a month	203	215	804			
	About once in two weeks–two or three times a week	418	157	502			
	Almost every day	349	192	651			
	Usage Frequency of Bus (p = 0.341)	***n***	**Mean**	**Std. Dev.**	***p* Value between Categories (<0.05)**		
	Never	332	150	566			
	About once a year–once in six months	211	258	838			
	About once in two or three months–once a month	288	188	611			
	About once in two weeks–two or three times a week	209	180	500			
	Almost every day	42	124	276			

** p < 1%.

Table 7. Results of the Kruskal-Wallis test for the evaluation of rail services in Okayama City.

	Number of Services (p = 0.001 **)	n	Mean	Std. Dev.	p Value between Categories (<0.05)		
Evaluation of rail service: 'hard' attributes	NE	166	3.08	1.11	NE	HE	p = 0.013
	LE	428	3.06	0.99	LE	HE	p = 0.001
	ME	332	2.94	1.05			
	HE	216	2.72	1.08			
	Location of Rail Stations (p = 0.041 *)	***n***	**Mean**	**Std. Dev.**	**p Value between Categories (<0.05)**		
	NE	166	3.16	1.06	NE	HE	p = 0.026
	LE	428	3.04	0.99			
	ME	332	3.02	0.96			
	HE	216	2.88	1.05			
	Comfort of Rail Stations (p = 0.000 **)	***n***	**Mean**	**Std. Dev.**	**p Value between Categories (<0.05)**		
	NE	166	3.04	0.96	NE	HE	p = 0.001
	LE	428	2.93	0.83	LE	HE	p = 0.001
	ME	332	2.90	0.79	ME	HE	p = 0.022
	HE	216	2.69	0.86			
	Ease of Transfer (p = 0.075)	***n***	**Mean**	**Std. Dev.**	**p Value between Categories (<0.05)**		
	NE	166	3.00	1.02			
	LE	428	3.02	0.86			
	ME	332	3.02	0.89			
	HE	216	2.83	0.91			
	Comfort of Trains (p = 0.008 **)	***n***	**Mean**	**Std. Dev.**	**p Value between Categories (<0.05)**		
	NE	166	3.14	0.90	LE	HE	p = 0.018
	LE	428	3.10	0.74			
	ME	332	3.02	0.82			
	HE	216	2.90	0.86			
Evaluation of rail service: 'soft' attributes	**Ease of Understanding Information and Guide of Services (p = 0.061)**	***n***	**Mean**	**Std. Dev.**	**p Value between Categories (<0.05)**		
	NE	166	3.23	0.96			
	LE	428	3.22	0.80			
	ME	332	3.14	0.91			
	HE	216	3.02	0.90			
	Ease of Searching Information and Guide of Services (p = 0.231)	***n***	**Mean**	**Std. Dev.**	**p Value between Categories (<0.05)**		
	NE	166	3.23	0.96			
	LE	428	3.22	0.84			
	ME	332	3.17	0.93			
	HE	216	3.07	0.86			
	Fares (p = 0.141)	***n***	**Mean**	**Std. Dev.**	**p Value between Categories (<0.05)**		
	NE	166	2.85	0.96			
	LE	428	3.01	0.75			
	ME	332	2.93	0.81			
	HE	216	2.97	0.87			
	Payment Methods (p = 0.394)	***n***	**Mean**	**Std. Dev.**	**p Value between Categories (<0.05)**		
	NE	166	3.20	0.92			
	LE	428	3.16	0.78			
	ME	332	3.10	0.77			
	HE	216	3.09	0.86			

* $p < 5\%$, ** $p < 1\%$. NE: Non-emitters (0 kg-CO_2/(person·year)), LE: Low emitters (<500 kg-CO_2/(person·year)), ME: Medium emitters (<1500 kg-CO_2/(person·year)), HE: High emitters (≥1500 kg-CO_2/(person·year)).

Table 8. Results of the Kruskal-Wallis test for the evaluation of rail services in Central Tokyo.

	Number of Services (p = 0.585)	***n***	**Mean**	**Std. Dev.**
Evaluation of rail service: 'hard' attributes	NE	788	3.99	1.00
	LE	198	4.06	0.90
	ME	48	3.88	1.06
	HE	48	4.17	0.83
	Location of Rail Stations (p = 0.717)	***n***	**Mean**	**Std. Dev.**
	NE	788	3.79	1.01
	LE	198	3.80	0.97
	ME	48	3.75	0.86
	HE	48	3.96	0.97
	Comfort of Rail Stations (p = 0.146)	***n***	**Mean**	**Std. Dev.**
	NE	788	3.46	1.01
	LE	198	3.58	0.96
	ME	48	3.27	0.89
	HE	48	3.56	1.11
	Ease of Transfer (p = 0.083)	***n***	**Mean**	**Std. Dev.**
	NE	788	3.55	1.04
	LE	198	3.73	0.92
	ME	48	3.46	0.90
	HE	48	3.71	1.13
	Comfort of Trains (p = 0.111)	***n***	**Mean**	**Std. Dev.**
	NE	788	3.46	1.01
	LE	198	3.62	0.97
	ME	48	3.46	0.92
	HE	48	3.69	1.13
Evaluation of rail service: 'soft' attributes	**Ease of Understanding Information and Guide of Services (p = 0.415)**	***n***	**Mean**	**Std. Dev.**
	NE	788	3.87	0.99
	LE	198	3.98	0.92
	ME	48	3.79	0.82
	HE	48	3.96	0.99
	Ease of Searching Information and Guide of Services (p = 0.263)	***n***	**Mean**	**Std. Dev.**
	NE	788	3.87	0.98
	LE	198	3.97	0.93
	ME	48	3.85	0.87
	HE	48	4.10	0.97
	Fares (p = 0.592)	***n***	**Mean**	**Std. Dev.**
	NE	788	3.29	1.01
	LE	198	3.36	0.92
	ME	48	3.21	0.90
	HE	48	3.40	1.20
	Payment Methods (p = 0.126)	***n***	**Mean**	**Std. Dev.**
	NE	788	3.71	0.97
	LE	198	3.80	0.92
	ME	48	3.60	0.89
	HE	48	3.94	1.14

NE: Non-emitters (0 kg-CO_2/(person·year)), LE: Low emitters (<500 kg-CO_2/(person·year)), ME: Medium emitters (<1500 kg-CO_2/(person·year)), HE: High emitters (≥1500 kg-CO_2/(person·year)).

Regarding bus services, the results obtained for Okayama City show that significant differences were found among all the 'hard' attributes and payment methods for the 'soft' attributes. Among these significant attributes, the comfort of buses had the lowest p value, indicating the greatest differences in average satisfaction. Similarly to rail services, the lower CO_2 emitter groups were inclined to have a higher average satisfaction among the significant categories. However, in terms of payment methods, although the Kruskal-Wallis test yielded a significant result, no difference was identified from the pairwise comparison (Table 9). In Central Tokyo, however, no significant difference was found among any 'hard' or 'soft' attributes, as presented in Table 10.

Table 9. Results of the Kruskal-Wallis test for the evaluation of bus services in Okayama City.

Evaluation of bus service: 'hard' attributes	**Number of Services (p = 0.010 *)**	**n**	**Mean**	**Std. Dev.**	**p Value between Categories (<0.05)**		
	NE	166	2.73	1.03	LE	HE	p = 0.010
	LE	428	2.78	1.02			
	ME	332	2.64	1.00			
	HE	216	2.50	1.10			
	Location of Bus Stops (p = 0.001 **)	**n**	**Mean**	**Std. Dev.**	**p Value between Categories (<0.05)**		
	NE	166	2.96	0.97	LE	HE	p = 0.001
	LE	428	3.08	0.97			
	ME	332	2.93	0.90			
	HE	216	2.77	1.02			
	Comfort of Bus Stops (p = 0.004 **)	**n**	**Mean**	**Std. Dev.**	**p Value between Categories (<0.05)**		
	NE	166	2.73	0.92	LE	HE	p = 0.003
	LE	428	2.75	0.85			
	ME	332	2.66	0.79			
	HE	216	2.51	0.94			
	Ease of Transfer (p = 0.028 *)	**n**	**Mean**	**Std. Dev.**	**p Value between Categories (<0.05)**		
	NE	166	2.78	1.00	LE	HE	p = 0.024
	LE	428	2.79	0.86			
	ME	332	2.75	0.82			
	HE	216	2.57	0.97			
	Comfort of Buses (p = 0.001 **)	**n**	**Mean**	**Std. Dev.**	**p Value between Categories (<0.05)**		
	NE	166	2.99	0.87	NE	HE	p = 0.011
	LE	428	2.98	0.72	LE	HE	p = 0.002
	ME	332	2.87	0.78			
	HE	216	2.73	0.91			
Evaluation of bus service: 'soft' attributes	**Ease of Understanding Information and Guide of Services (p = 0.203)**	**n**	**Mean**	**Std. Dev.**	**p Value between Categories (<0.05)**		
	NE	166	2.81	1.00			
	LE	428	2.82	0.87			
	ME	332	2.76	0.81			
	HE	216	2.65	0.98			
	Ease of Searching Information and Guide of Services (p = 0.162)	**n**	**Mean**	**Std. Dev.**	**p Value between Categories (<0.05)**		
	NE	166	2.81	1.00			
	LE	428	2.82	0.88			
	ME	332	2.73	0.84			
	HE	216	2.66	1.00			
	Fares (p = 0.217)	**n**	**Mean**	**Std. Dev.**	**p Value between Categories (<0.05)**		
	NE	166	2.86	0.97			
	LE	428	2.83	0.87			
	ME	332	2.78	0.84			
	HE	216	2.67	0.93			

Table 9. *Cont.*

	Payment Methods (p = 0.043 *)	n	Mean	Std. Dev.	p Value between Categories (<0.05)
Evaluation of bus service: 'soft' attributes	NE	166	3.02	0.96	
	LE	428	3.02	0.80	
	ME	332	2.93	0.75	
	HE	216	2.82	0.93	

* p < 5%, ** p < 1%. NE: Non-emitters (0 kg-CO_2/(person·year)), LE: Low emitters (<500 kg-CO_2/(person·year)), ME: Medium emitters (<1500 kg-CO_2/(person·year)), HE: High emitters (≥1500 kg-CO_2/(person·year)).

Table 10. Results of the Kruskal-Wallis test for the evaluation of bus services in Central Tokyo.

	Number of Services (p = 0.293)	n	Mean	Std. Dev.
Evaluation of bus service: 'hard' attributes	NE	788	3.07	0.98
	LE	198	3.16	0.97
	ME	48	3.21	0.80
	HE	48	3.31	1.15
	Location of Bus Stops (p = 0.161)	***n***	**Mean**	**Std. Dev.**
	NE	788	3.21	0.97
	LE	198	3.33	0.96
	ME	48	3.15	0.82
	HE	48	3.48	1.17
	Comfort of Bus Stops (p = 0.367)	***n***	**Mean**	**Std. Dev.**
	NE	788	2.99	0.96
	LE	198	3.07	0.89
	ME	48	2.90	0.88
	HE	48	3.08	1.07
	Ease of Transfer (p = 0.257)	***n***	**Mean**	**Std. Dev.**
	NE	788	2.97	0.92
	LE	198	3.10	0.83
	ME	48	3.08	0.82
	HE	48	3.04	0.99
	Comfort of Buses (p = 0.303)	***n***	**Mean**	**Std. Dev.**
	NE	788	3.10	0.90
	LE	198	3.21	0.76
	ME	48	3.08	0.77
	HE	48	3.25	1.02
Evaluation of bus service: 'soft' attributes	**Ease of Understanding Information and Guide of Services (p = 0.427)**	***n***	**Mean**	**Std. Dev.**
	NE	788	3.05	0.99
	LE	198	3.17	0.87
	ME	48	2.98	0.81
	HE	48	3.19	1.14
	Ease of Searching Information and Guide of Services (p = 0.474)	***n***	**Mean**	**Std. Dev.**
	NE	788	3.03	0.99
	LE	198	3.14	0.87
	ME	48	3.00	0.90
	HE	48	3.13	1.18
	Fares (p = 0.065)	***n***	**Mean**	**Std. Dev.**
	NE	788	3.10	0.91
	LE	198	3.20	0.82
	ME	48	3.29	0.82
	HE	48	3.31	1.11

Table 10. *Cont.*

	Payment Methods (p = 0.399)	n	Mean	Std. Dev.
Evaluation of bus service: 'soft' attributes	NE	788	3.34	0.91
	LE	198	3.38	0.87
	ME	48	3.46	0.82
	HE	48	3.54	1.03

NE: Non-emitters (0 kg-CO_2/(person·year)), LE: Low emitters (<500 kg-CO_2/(person·year)), ME: Medium emitters (<1500 kg-CO_2/(person·year)), HE: High emitters ($\geq$1500 kg-CO_2/(person·year)).

6. Discussion

The findings of this study indicate that a higher evaluation of the number of services and the location of rail stations and bus stops among the 'hard' attributes, as well as the 'soft' attributes such as fares, can increase the overall evaluation of rail and bus services. This higher evaluation may, in turn, increase the usage frequency of rail and bus services and therefore reduce travel-based CO_2 emissions from private transport modes in regional areas.

Furthermore, a direct relationship was found between the 'hard' attributes of both rail and bus services and travel-based CO_2 emissions from private transport modes in regional areas. Considering the high ownership rate of private cars that residents can freely use in these areas, reducing travel-based CO_2 emissions from private transport modes may be achieved by prioritising the maintenance of and improvements in 'hard' rather than 'soft' attributes. Specifically, the focus must be placed on enhancing existing service attributes such as the number of services and the location of rail stations and bus stops, before addressing aspects including information and fares, which tend to be emphasised in newer transport services that use ICT, such as MaaS.

On the other hand, in metropolitan areas, the low ownership rate of private cars that residents can use freely, combined with the significantly higher level of rail and bus services compared to regional areas, might explain the absence of a relationship between the evaluation of public transport services and travel-based CO_2 emissions from private transport modes. Therefore, to reduce travel-based CO_2 emissions from private transport modes in these areas, priority should be assigned to improving the use of such modes, including private cars, rather than the service contents of rail and buses. This assignment of priority can involve measures such as increasing fuel efficiency and promoting reduced usage.

While this study analysed the correlation between the evaluation of public transport services and travel-based CO_2 emissions from private transport modes, additional research should specifically examine the establishment of a cause-and-effect relationship. In addition, since this study uses two specific locales representing regional and metropolitan areas in Japan, further research is required to investigate the application of the findings to other regions and countries. Nevertheless, this study can serve as a reference for analysing the potential to reduce travel-based emissions from private transport modes by improving the service contents of public transport in different areas. Specifically, the methodology outlined in this study may be extended to areas with highly convenient public transport services, as well as areas that offer varying levels of public transport service quality. There is also scope for a more thorough analysis considering other possible factors that influence mode choice and emissions, such as urban planning, infrastructure, economic conditions, and individual travel behaviour and preferences, which have been overlooked in this study. Finally, it is crucially important to investigate the relationship between the evaluation of public transport services and the actual indicators of the service contents. This might lead to the identification of differences in the evaluation resulting from varying service levels.

7. Conclusions

This study investigated the effects of public transport services on travel-based CO_2 emissions from private transport modes in regional and metropolitan areas, using Okayama City and Central Tokyo as case studies. Specifically, we examined the relationship between the evaluation of service contents and the usage frequency of rail and bus services, and whether this frequency is related to emissions. In addition, following the series of analyses concerning the evaluation of public transport services, usage frequency, and travel-based CO_2 emissions from private transport modes, this study examined whether a direct association exists between the evaluation of the 'hard' and 'soft' attributes of rail and bus services and emissions. The method established in this study can be utilised to analyse the potential to reduce travel-based emissions from private transport modes through an improvement in public transport service contents.

The results of this study revealed that, in both Okayama City and Central Tokyo, more 'hard' than 'soft' attributes influenced the overall evaluation of rail and bus services. Specifically, the findings in Okayama City revealed a positive relationship between the overall evaluation and the usage frequency of both rail and bus services. Furthermore, a higher usage frequency of public transport services was associated with lower travel-based CO_2 emissions from private transport modes. In addition, the results of this study demonstrated that, in Okayama City, lower travel-based CO_2 emissions from private transport modes are associated with higher average satisfaction of the 'hard' attributes of rail and bus services (excluding ease of transfer for rail). However, in Central Tokyo, although a dependent relationship was found between the overall evaluation and usage frequency of public transport services, no relationship was found between this frequency and travel-based CO_2 emissions from private transport modes.

Author Contributions: Conceptualisation, S.P. and T.U.; methodology, S.P. and T.U.; software, S.P.; validation, S.P.; formal analysis, S.P.; investigation, S.P.; resources, S.P. and T.U.; data curation, S.P.; writing—original draft preparation, S.P.; writing—review and editing, S.P., T.U. and S.H.; visualisation, S.P.; supervision, T.U. and S.H.; project administration, T.U.; funding acquisition, T.U. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Environment Research and Technology Development Fund (JPMEERF20201G01) of the Environmental Restoration and Conservation Agency provided by the Ministry of the Environment of Japan.

Institutional Review Board Statement: At the time of this study, our institution did not require an ethical review, and all participants were assured anonymity. They received an explanation of the survey before agreeing to take part.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available in order to safeguard the information of the survey respondents.

Acknowledgments: The authors gratefully acknowledge the financial support received from the Environmental Restoration and Conservation Agency of the Ministry of the Environment of Japan, which enabled this study.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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