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Forward-Thinking for Sustainable Shared Mobility Solutions in Amman

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Abstract: This study presents a novel examination of shared mobility's viability and impact in Amman, Jordan, framed within the context of sustainable urban transportation. A rigorous methodological approach that integrates advanced statistical models including Probit and Decision Tree analyses was utilized to evaluate the propensity of Amman's residents to adopt shared mobility solutions. Notably, the Ordered Probit Model provided superior model prediction compared to the multinomial logit model, evidenced by a better goodness of fit measure. The results showed that public transportation users would highly use shared mobility services based on cost and reliability, with service convenience emerging as a pivotal factor. The classification tree identified the convenience of the service as the most important factor in adopting shared mobility. The survey data revealed an initial adoption rate of 25.4%, indicating a significant inclination towards shared mobility among respondents. This is pivotal in understanding the current readiness and potential growth of shared mobility in the city. This study is one of the first to quantify the readiness and potential growth of shared mobility in a Middle Eastern urban setting. Furthermore, the impact of this adoption rate on CO_2 emissions was conducted. Emission analysis is crucial for assessing the environmental benefits of transitioning towards shared mobility options and aligning with global sustainability goals. Finally, the study extrapolates strategic guidelines for advancing sustainable transportation in Amman, identifying shared mobility options with the highest potential for successful adoption and proposing strategies to foster their implementation. This research contributes a unique perspective to the discourse on urban mobility, particularly in developing urban contexts like Amman, offering valuable insights for policymakers and urban planners.

Keywords: shared mobility; urban sustainability; sustainable mobility; transportation planning; public perception; multinomial ordinal probit model; CHAID classification

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1. Introduction

The evolution of urban landscapes and the growing global population, especially in cities, has led to an urgent need for sustainable shared mobility solutions. By 2050, it is estimated that 70% of the world's population will be urban dwellers, with cities also accounting for 85% of the world's economic output [1]. This rapid urbanization is placing immense pressure on urban transport systems, with only half of the world's population currently having convenient access to public transport [1].

The rapid global trend of urbanization presents unique challenges and opportunities for cities around the world, particularly in developing regions like the Middle East [2]. Amman, the capital of Jordan, stands at the forefront of this urban transformation. As a rapidly growing metropolis, Amman faces distinct challenges in its urban transportation system, influenced by its unique topography, cultural dynamics, and infrastructural constraints. These challenges are exacerbated by the city's booming population and the increasing demand for efficient and sustainable mobility solutions. Despite these hurdles, Amman also presents unique opportunities as a city poised for innovative transportation strategies, such as shared mobility.

Urban transportation systems heavily impact a city's environmental sustainability by contributing significantly to carbon dioxide (CO_2) emissions, which are a leading cause of climate change [3]. Climate change and the need to reduce CO_2 emissions have become a global concern. This has prompted cities to reassess their urban planning strategies, particularly in the transportation sector. Amman, the expanding metropolis of Jordan, faces a variety of complex problems. For instance, Amman's urban transportation system is a vital infrastructure for its residents; it has become a significant source of challenges such as traffic congestion, environmental pollution, and unsustainable energy consumption patterns [4]. Recently, the city of Amman has increasingly focused on enhancing its transportation infrastructure to meet the demands of its rapidly expanding population and urban landscape. For example, the Greater Amman Municipality (GAM) has implemented a comprehensive Smart City strategy in collaboration with CDM Smith, utilizing digital innovation and big data to improve urban planning and transportation systems [5]. This approach aims to improve accessibility, equity, and economic vitality of the city's residents, including women, the elderly, and the handicapped, and that is to support the city's development and safety goals [5].

Shared mobility has become an essential component of sustainable urban development strategies, particularly in developing countries where cities are constantly evolving to accommodate growing populations and increasing urbanization. Regulatory and infrastructure constraints, as well as cultural perspectives, play a significant role in shaping these strategies, presenting both opportunities and obstacles [6]. In such contexts, regulatory challenges revolve around adjusting existing frameworks and creating new policies to accommodate shared mobility solutions. Countries that revise their regulatory environments to facilitate shared mobility can expedite the transition to sustainable urban transportation [7]. Infrastructure constraints are often a feature of developing urban landscapes, making it necessary to adopt innovative approaches to integrate shared mobility solutions into existing urban systems. Examples of this include optimizing existing transportation networks and implementing digitally driven, intelligent shared mobility systems that require minimal physical infrastructure [8].

Implementing sustainable shared mobility solutions can be a potential strategy to address transportation challenges while providing an eco-friendly alternative to conventional modes of transportation [9,10]. Shared mobility involves communal use of a vehicle, bicycle, or other form of transportation and offers an innovative way to reduce CO_2 emissions, leading to substantial improvements in urban sustainability. These solutions have the potential to not only reduce the city's overall carbon footprint but also enhance urban livability and accessibility for Amman's residents [11].

A previous study used exploratory factor analysis (EFA), confirmatory factor analysis (CFA), and a structural equation modeling (SEM) approach to analyze the acceptability of shared mobility in the Amman context [12]. However, important aspects such as policy landscapes, user preferences, and potential CO_2 emissions reduction were not explored, highlighting the need for further research. Additionally, investigating factors that could affect the adoption of shared mobility for parametric and data mining approaches, rather than latent factor approaches, is important.

This study employs parametric and data mining approaches due to their robustness and effectiveness in analyzing complex and multifaceted data, which is characteristic of urban mobility studies. The Multinomial Ordinal Probit Model, a parametric method, was selected for its proficiency in handling ordinal data and its ability to model the probabilities of different outcomes (such as levels of adoption of shared mobility) based on predictor variables [13]. This model is particularly suited to this study as it accurately captures the nuanced preferences and choices of Amman's residents regarding shared mobility, providing a sophisticated understanding of the factors influencing these decisions. Additionally, this study incorporated Decision/Classification Tree (DT) analysis, a data mining technique, known for its ability to simplify complex decision-making processes by breaking them down into a series of simpler choices [14]. This method is highly advantageous in revealing patterns and relationships in large datasets, which is essential in this study to understand the various factors influencing the adoption of shared mobility in the urban context of Amman. DT analysis allows us to visually and explicitly represent these factors, offering an intuitive understanding of the data. This methodological approach ensures that this study is grounded in rigorous statistical analysis while remaining practical and relevant for urban planners and policymakers looking to implement shared mobility solutions in Amman.

This study aims to address environmental concerns in Amman by investigating sustainable mobility options and providing prospective insights on how shared transportation solutions can contribute to a cleaner and sustainable Amman. The study's significance lies in its intersection with urban planning and sustainable development, aligning with the worldwide emphasis on environmental responsibility. Moreover, parametric and data mining approaches were employed to investigate the factors that significantly affect the adoption of shared mobility options. Furthermore, the study delves into potential policy barriers that might hinder the deployment of shared mobility solutions. By fostering an informed policy discourse, this research aids in shaping a resilient and sustainable urban transportation framework in Amman.

This study contributes to the existing research by focusing on a comprehensive analysis of shared mobility within the unique urban context of Amman, Jordan, employing a blend of parametric and data mining approaches. While previous studies have explored the acceptability of shared mobility using exploratory and confirmatory factor analysis, this study further delves into policy landscapes, user preferences, and the potential for CO_2 emissions reduction in depth.

This study leverages more robust and granular methodological frameworks. These innovative approaches allow for a more nuanced understanding of the factors influencing the adoption of shared mobility in Amman, offering invaluable insights for policymakers and urban planners. Furthermore, this study critically evaluates potential policy barriers and infrastructural challenges, offering strategic guidelines to facilitate the implementation of shared mobility solutions. By bridging the gap between theoretical understanding and practical application, this research marks a significant contribution to the discourse on sustainable urban transportation, aligning with global sustainability goals and paving the way for a more sustainable, efficient, and environmentally friendly transportation system in Amman.

2. Background

Transportation networks play a crucial role in the advancement of urban areas, influencing quality of life, economic growth, social cohesion, and environmental sustainability [1]. To address these challenges, several stakeholders, including governments, businesses, non-governmental organizations (NGOs), and the public sector, are advocating for sustainable urban planning.

While mass transit is seen as the most environmentally sustainable and efficient mode of urban transport, shared mobility solutions such as ride-hailing, car-sharing, and e-bike sharing offer on-demand, sustainable, efficient, safe, and affordable transportation [15].

Shared mobility has become a popular term and practice in recent years, changing the way urban residents travel within cities. According to [16], shared mobility includes car-sharing, ride-hailing, and bike-sharing services, which offer efficient, flexible, and cost-effective transportation options. These services are typically short-term and usage-based, promoting the most efficient use of transportation resources. For instance, the expanding digital infrastructure and advancement in information and communication technologies have made shared mobility services easily accessible and user-friendly [8].

Sustainable transportation is at the core of shared mobility, which aims to reduce the negative environmental impact of transportation networks, promote social equality, and ensure economic efficiency [17]. Shared mobility aligns with these principles by encouraging the efficient use of vehicles and reducing the need for private car ownership, which substantially contributes to the reduction of greenhouse gas emissions [3].

To encourage the adoption of shared mobility, it is essential to understand user behavior and preferences. According to [18], travel behavior is influenced by individual attitudes, perceptions, lifestyle decisions, and socioeconomic conditions. Therefore, shared mobility solutions must align with user requirements, preferences, and behaviors. Additionally, the regulatory landscape for shared mobility varies significantly across countries and localities, which plays a crucial role in facilitating or impeding the expansion of shared mobility services. Identifying potential regulatory obstacles and opportunities is essential for the effective incorporation of shared mobility into urban transportation systems [19].

Shared mobility's contribution to reducing CO_2 emissions is gaining recognition. By reducing reliance on privately owned vehicles, shared mobility services substantially reduce per capita CO_2 emissions, contributing to environmental sustainability [11]. However, the potential environmental benefits of shared mobility depend on several variables, including the form of shared mobility service, the adoption rate, and the existing urban transportation infrastructure. In conclusion, the study aims to contribute to the existing literature on shared mobility by focusing on the unique challenges and opportunities presented by the city of Amman context.

3. Methodology

The methodology employed in this study serves as a structured blueprint for investigating shared mobility in Amman, Jordan. This section has been crafted methodically to ensure the robustness, reliability, and validity of the research findings. It presents a comprehensive explanation of the study's design and the utilized analysis approaches. This exhaustive methodology will be utilized to analyze the various aspects of shared mobility in Amman and will yield valuable insights that can shape the future of transportation strategies in the city. The subsequent subsections provide a detailed elaboration of each component of the research methodology.

3.1. Survey Design and Data Collection

To rigorously investigate shared mobility in Amman, Jordan's capital, a structured online survey was developed in a previous study and implemented via Google Forms to capture insights from a representative segment of the city's populace. This online survey offers wide-reaching accessibility, allowing gathering of data from a diverse and extensive sample of Amman's population. This is particularly important in capturing varied perspectives on shared mobility across different demographics, including age, gender, and socio-economic backgrounds. Additionally, online surveys are more cost-effective and time-efficient means of data collection. The study aimed to understand the impact of Amman's transportation system on its residents of all ages, professions, and socioeconomic backgrounds. The survey participants were chosen based on their usage of and stake in the transportation infrastructure, with the intention of gaining insights into their perceptions, behaviors, and preferences regarding shared mobility. The inclusive approach allowed for a comprehensive view of the shared mobility landscape in Amman, taking into account the diverse experiences and needs of its urban populace. This empirical methodology is pivotal for understanding the intricacies of shared mobility, capturing user perspectives, and identifying potential improvements. The survey aimed to evaluate public travel behaviors, attitudes towards shared mobility, the likelihood of using these services, and their perceived pros and cons. This data collection strategy facilitated contributions from both users and non-users of shared mobility solutions.

The survey was meticulously crafted to cover a broad spectrum of shared mobility aspects in Amman, Jordan. It comprised 29 questions, mixing multiple-choice and Likert scale formats. The design was informed by the Driver Behavior Questionnaire (DBQ) to mitigate common survey biases. Likert scale items, offering a symmetrical agree–disagree range, were instrumental for gauging attitudes and opinions. The questionnaire was segmented into several parts: demographic information, driving behavior habits, propensity to use shared mobility under varying scenarios, perceived importance of shared mobility, barriers to adoption, and perceived benefits. This comprehensive approach aimed to gather extensive data, providing a detailed overview of Amman's shared mobility environment.

3.2. Descriptive Analysis

Table 1 presents the fundamental descriptive statistics for the 29 survey questions, encompassing mean, mode, median, and standard deviation (SD), along with the measurement scale and categories. This descriptive analysis offers preliminary insights into the responses garnered from the survey questionnaire. The total obtained sample size was 260 valid responses. Male students, an age group of 18–24, represent the majority of the responses. Usage of private cars to commute was the highest response that was selected, in which travel twice a day had the highest percentage. The finding that private cars are highly utilized in Amman holds significant implications for the potential of shared mobility in the city. This prevalent use of private vehicles suggests a well-established culture of personal car ownership and reliance, which is often linked to factors such as perceived convenience, privacy, and status. However, it also indicates potential areas of opportunity for shared mobility solutions. The challenges associated with high private car usage, such as traffic congestion, parking difficulties, and environmental pollution, can serve as catalysts for residents to consider alternative modes of transportation. By understanding the reasons behind the predominant use of private cars, stakeholders can tailor shared mobility solutions to address these specific pain points, offering a convenient, cost-effective, and environmentally friendly alternative. The average frequency of public transportation use is relatively low, suggesting that most respondents do not frequently use public transportation.

On the Likert scale of 1 to 7, the average score for willingness to switch to shared mobility for daily commuting is approximately 4.68. The results showed that the majority of respondents have used shared mobility services in the past. The study reveals a notable variation in participants' willingness to adopt shared mobility services, such as bike-sharing, car-sharing, and ride-sharing, for their daily commute. This variance is a critical factor in assessing the potential for a shift in urban transportation norms. The computed average willingness score for transitioning to shared mobility services, considering diverse influencing factors, stands at 4.68. This score suggests a comparatively elevated inclination among respondents towards embracing shared mobility solutions. This finding underscores the significance of shared mobility platforms in shaping future urban transit behaviors and preferences.

Respondents, on average, attribute the importance of shared mobility falling within the range of 4.60 to 4.85. In this regard, they perceive shared mobility as offering benefits in terms of alleviating traffic congestion, reducing transportation expenses, mitigating environmental impact, and augmenting convenience. Respondents also express reservations concerning issues related to safety, privacy, dependability, accessibility, and cost, with an average rating ranging from 4.37 to 4.44. These findings offer significant insights into the potential acceptance of shared mobility for sustainable transportation in Amman.

Figure 1 represents the respondents' engagement with shared mobility services and their prospective perception of embracing these services. A boxplot was selected to represent the four aspects that were designed to measure the public acceptability of shared mobility in Amman. Each box expresses a single level of the provided 7-point Likert scale, in which the percentage of received replies per category was combined for each aspect. The aspect of willingness to use shared mobility was measured using three questions (Q11 to Q13). Notably, the dominant response was "Never", signifying a pronounced reluctance among a substantial proportion of respondents, with an average of 30.8%. However, the relatively large variation in the "Never" selection for the three questions shows that it might not significantly represent the participants' willingness to use shared mobility.

Table 1. Designed survey questionnaire and descriptive statistics.

Q#	Description	Code: Category or Level	Mean	Mode	Median	SD
		Section 1: Demographics, Occupation, and Vehicle Ownership				
Q1	Age	1: (<18), 2: (18–24), 3: (25–34), 4: (35–44), 5: (45–54), 6: (55–64), 7: (≥65)	2.92	2.00	2.00	1.41
Q2	Gender	1: (Male) and 2: (Female)	1.39	1.00	1.00	0.49
Q3	Occupation	Student/Unemployed/Agriculture/Manufacturing/ Wholesale and Retail Trade/Information and Communication Technology/etc.	NA	NA	NA	NA
Q4	Do you own a vehicle?	0: (No) and 1: (Yes)	0.63	1.00	1.00	0.48
		Section 2: Travel Behavior for Participants				
Q5	How often do you travel a day?	0: (No daily travel), 1: (Once a day), 2: (Twice a day), 3: (Three–four times a day), 4: (Five or more times a day)	1.81	2.00	2.00	1.11
Q6	What is your primary mode of transport for daily commuting?	1: (Vulnerable Road User), 2: (Public transport), 3: (Private car) 4: (Rideshare)	2.64	3.00	3.00	0.80
Q7	How long is your average commute (in minutes)?	1: (<15 min.), 2: (15–29 min.), 3: (30–44 min.), 4: (45–59 min.), 5: (60–74 min.), 6: (≥75 min.)	2.60	2.00	2.00	1.29
Q8	How frequent do you use public transportation?	Seven-point Likert scale (Never to All the time)	2.52	1.00	2.00	1.94
Q9	In your opinion, how reliable public transportation is?	Seven-point Likert scale (Not reliable to Very reliable)	2.67	1.00	2.00	1.61
Q10	Have you used any shared mobility services in the past? (Bike sharing, car sharing, ride-sharing, etc.)	0: (No) and 1: (Yes)	0.58	1.00	1.00	0.49
		Section 3: Willingness to Use Shared Mobility				
Q11	If available, would you consider using a bike-sharing service for your daily commute?	Seven-point Likert scale (Never to All the time)	2.88	1.00	2.00	2.17
Q12	If available, would you consider using a car-sharing service for your daily commute?	Seven-point Likert scale (Never to All the time)	3.72	1.00	4.00	2.21
Q13	If available, would you consider using a ride-sharing service for your daily commute?	Seven-point Likert scale (Never to All the time)	3.70	1.00	4.00	2.18
		Section 4: Perceived Importance of Shared Mobility				
How would you rate the importance of shared mobility in:						
Q14	Reducing traffic congestion.	Seven-point Likert scale (Not important at all to Extremely important)	4.79	7.00	5.00	2.05
Q15	Reducing transportation costs.	Seven-point Likert scale (Not important at all to Extremely important)	4.82	7.00	5.00	1.98
Q16	Reducing environmental impact.	Seven-point Likert scale (Not important at all to Extremely important)	4.85	7.00	5.00	2.03
Q17	Enhancing convenience.	Seven-point Likert scale (Not important at all to Extremely important)	4.60	7.00	5.00	2.05

Table 1. *Cont.*

Q#	Description	Code: Category or Level	Mean	Mode	Median	SD
		Section 5: Perceived Barriers to use Shared Mobility				
Are you concerned about the following to be a potential barrier for using shared mobility?						
Q18	Safety.	Seven-point Likert scale (Not a concern at all to A major concern)	4.45	4.00	4.00	1.96
Q19	Privacy.	Seven-point Likert scale (Not a concern at all to A major concern)	4.41	7.00	4.00	2.01
Q20	Reliability.	Seven-point Likert scale (Not a concern at all to A major concern)	4.37	4.00	4.00	1.94
Q21	Accessibility.	Seven-point Likert scale (Not a concern at all to A major concern)	4.43	4.00	4.00	1.89
Q22	Cost.	Seven-point Likert scale (Not a concern at all to A major concern)	4.37	7.00	4.00	2.04
		Section 6: Perceived Benefits of Shared Mobility				
How would you rate the following to make you more likely to use shared mobility options for your daily commute?						
Q23	Lower cost compared to the current mode of transport.	Seven-point Likert scale (Not important at all to Extremely important)	4.50	7.00	5.00	2.09
Q24	Availability of service near my home/work.	Seven-point Likert scale (Not important at all to Extremely important)	4.63	7.00	5.00	2.05
Q25	Faster travel time compared to the current mode of transport.	Seven-point Likert scale (Not important at all to Extremely important)	4.60	7.00	5.00	2.05
Q26	More reliable service.	Seven-point Likert scale (Not important at all to Extremely important)	4.68	7.00	5.00	1.95
Q27	Better environmental sustainability.	Seven-point Likert scale (Not important at all to Extremely important)	4.67	7.00	5.00	1.97
Q28	Improved comfort and cleanliness of vehicles & better safety measures.	Seven-point Likert scale (Not important at all to Extremely important)	4.76	7.00	5.00	2.01
Q29	Convenient booking and payment options.	Seven-point Likert scale (Not important at all to Extremely important)	4.88	7.00	5.00	2.03

NA = Not Applicable.

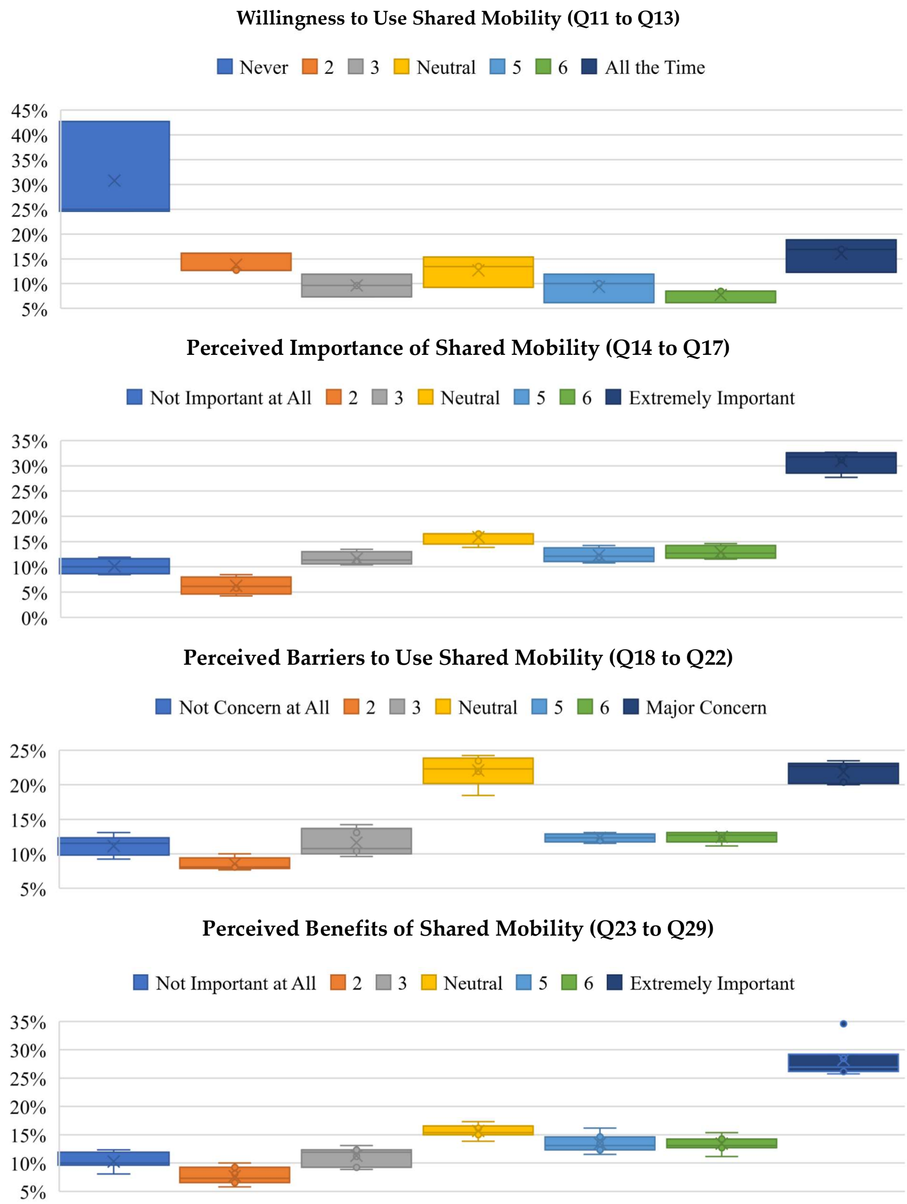

Figure 1. Boxplot for the aspects to estimate the public acceptability of shared mobility.

The aspect "Perceived Importance of Shared Mobility", measured by questions 14 to 17, had the most recurrent response as "Extremely Important". The obtained average percentage of 31% could be considered as indicative of a pervasive inclination of understanding the importance of shared mobility services. Furthermore, questions 18 to 22 were designed to measure the perceived barriers to using shared mobility. Neutral was the highest selection averaged across the five measurement questions with an average of 22.08% followed by the extremely important category with an average of 21.85%. Finally, the perceived benefits of shared mobility were measured using seven questions (Q23 to Q29). The participants clarified their understanding of the benefits of shared mobility, given the high average percentage of 28.24%.

The overall descriptive analysis suggested a generally favorable outlook for shared mobility for the participants. The majority of the responses clarified the participants' perceived benefits and importance of shared mobility services. Nevertheless, to foster greater adoption, it is imperative to address concerns associated with safety, privacy, dependability, accessibility, and cost.

3.3. Parametric and Non-Parametric Approaches

Parametric and non-parametric analysis approaches were utilized to explain the effect of socioeconomic factors on accepting shared mobility in Amman, Jordan. Given the ordinal nature of the Likert scale adopted in the survey, multinomial regression was selected as the parametric approach to model the survey responses. Logit and Probit link functions were tested with the survey data. The Probit model provided superior model prediction given the better goodness of fit measure. The Akaike Information Criteria (AIC) for the Ordered Probit model is 829.06 compared to 992.139 for the Multinomial Logit model.

The Classification Tree (CT) technique was chosen as the nonparametric data mining approach due to the ordinal nature of the response variable. The Chi-square Automatic Interaction Detection (CHAID) methodology was employed to iteratively partition the data space into two or more child nodes, starting with the entire dataset, to construct the tree.

3.4. Multinomial Ordinal Probit Model

The Multinomial Ordinal Probit (MOP) uses a latent variable to identify the underlying relationship of the developed model [20,21], as shown in Equations (1)–(4).

$$z_i = \beta X_i^T + \varepsilon_i \tag{1}$$

$$X_i = \{1, x_{i1}, \ldots, x_{ij}, \ldots, x_{im}\}^T \tag{2}$$

$$\beta = \{\beta_0, \beta_1, \ldots \beta_j, \ldots \beta_m\}^T \tag{3}$$

$$y_i = \begin{cases} 1,\ if\ \gamma_0 < z_i \leq \gamma_1 \\ k,\ if\ \gamma_{k-1} < z_i \leq \gamma_k \\ C,\ if\ \gamma_{C-1} < z_i \leq \gamma_C \end{cases} \tag{4}$$

where z_i is the latent variable; X_i is the input value for the ith participant response; x_{ij} is the jth explanatory variable for the ith participant response; β is the column vector of coefficients; ε_i is the random error term following standard normal distribution; i is the participant response identifier; j the explanatory variable identifier; y_i is an integer that represents the dependent variable for the Likert scale categories. γ represents the threshold values for the Likert scale, which is constrained by the descending or ascending order.

3.5. Decision Trees

Decision Tree (DT) is a data mining approach extensively utilized in survey analysis [22]. A DT can be used to extract Decision Rules (DR) directly, where DR is a logic conditional structure of the type "IF A THEN B". Each rule is initiated at the root node, and each variable that is significant in tree division makes an IF of the rule, which ends in leaf nodes with a value of THEN (which is associated with the state resulting from the leaf node). This results in a status of the class variable (response) that shows the highest number of cases in the leaf node analyzed. Therefore, the number of rules can be identified with the number of terminal nodes in the tree. If the class variable (response) has a discrete set of possible values, the task is called a classification; otherwise, it is called a regression. The Chi-square Automatic Interaction Detection (CHAID) decision tree technique utilizes the χ^2-test of association to construct the tree by repeatedly splitting subsets of the space into two or more child nodes beginning with the entire set [23–25]. The best split at any node is determined by merging any allowable pair of categories of the predictor variables until there is no statistically significant difference within the pair with respect to the target variable [26]. In this study, the CHAID classification is undertaken to investigate the public perception regarding shared mobility solutions in Amman.

4. Results of Applied Survey Data Analysis

4.1. Classification Tree Results

The usage of ride-sharing services for a daily commute, represented by Q13, was selected as the dependent variable for the developed classification tree. The usage of ride-sharing services has been selected as the dependent variable for this study due to several reasons. Firstly, it reflects the current trends in urban mobility, as it represents a shift from traditional transportation modes to more collaborative and technology-driven solutions. Secondly, ride-sharing services provide a direct measure of the adoption and acceptance of shared mobility concepts among residents, which helps in evaluating shared mobility potential. Thirdly, by choosing ride-sharing service usage as the dependent variable, we can explore and understand the behavioral factors influencing residents' decisions to opt for shared mobility. Finally, the findings from analyzing ride-sharing service usage can inform strategies to promote sustainable mobility solutions in Amman, as it has practical implications for urban planning and policymaking.

Figure 2 represents the Chi-square Automatic Interaction Detection CHAID model for the anticipated public usage of ride-sharing services. The obtained tree had a depth level of three with a total of 13 nodes. The model selected the variables; perceived convenience of shared mobility (Q17); lower cost as a perceived benefit (Q23); usage frequency of public transportation (Q8); and cost as a perceived barrier (Q22).

To interpret the developed decision tree, the path from the root to each terminal leaf should be considered. Each leaf within this path is a significant variable that affects the usage of shared mobility for a daily commute. The path with the highest terminal leaf percentage of 27.3% clarified that they do not use public transportation and the convivence is the most important factor affecting the usage of the ride-share services. The second highest percentage of participants of 19.2% shows that these participants sometimes use public transportation and identify the cost as a significant barrier that affects their usage of shared mobility services, however, they perceive it as convenience. A total of 13.8% of the participants clarified that the shared mobility services neither have a lower cost compared to other modes of transportation nor are considered highly convenient.

The developed classification tree provided deep insights into the factors that could affect the usage of shared mobility in Amman. However, it neither quantifies the effect of the variables on the usage of ride share nor does it define the direction of impact. To identify the effect of the variables on the acceptability of shared mobility, categorical data analysis was conducted in the form of developing a multinomial ordinal probit model.

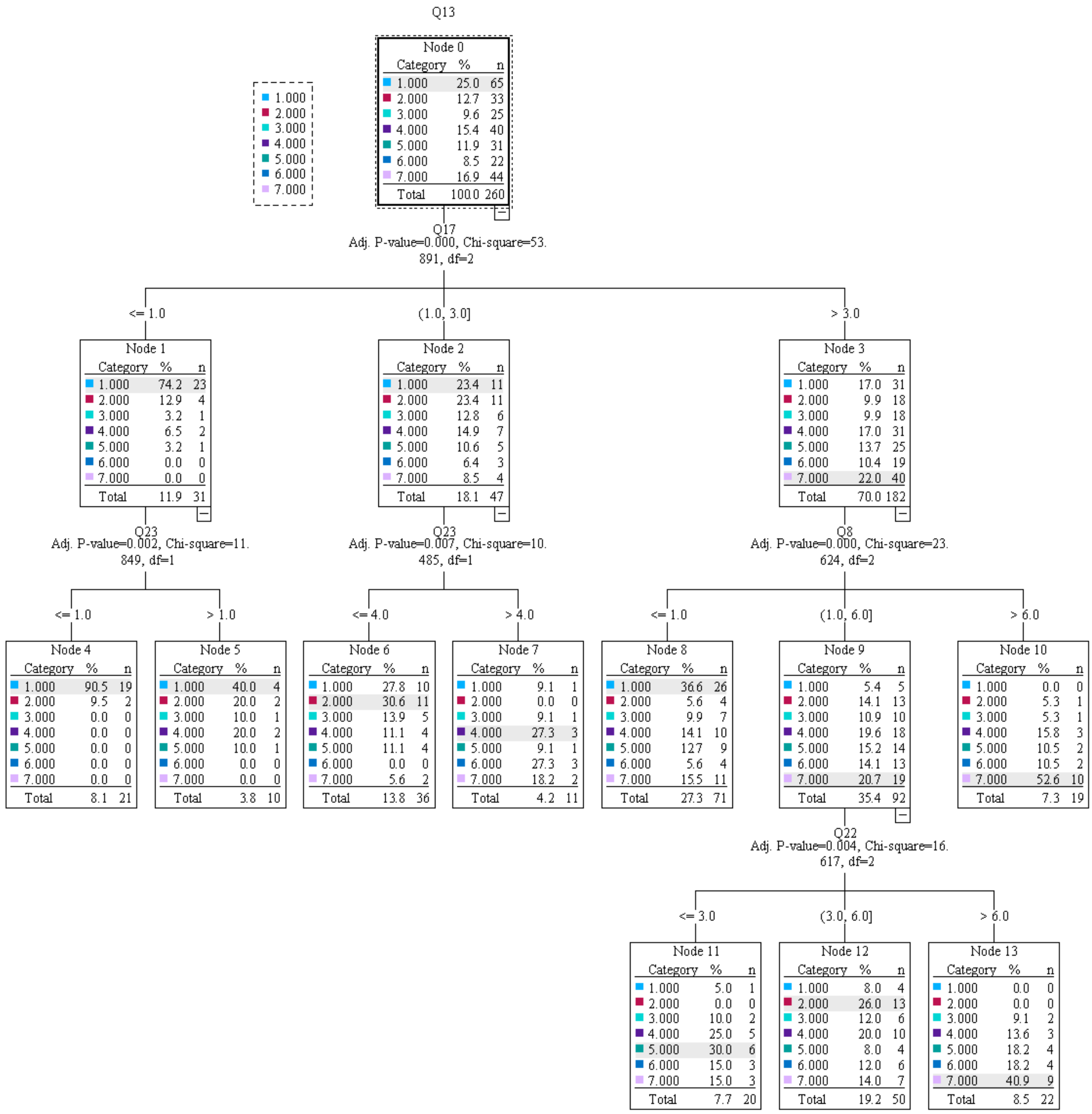

Figure 2. Classification tree for anticipated public usage of ride-sharing services.

4.2. Multinomial Ordinal Probit Model Results

Investigating the correlation between variables by developing a correlation matrix between variables was the initial step conducted for this analysis. The variables with lower significance with the response variable and high correlation with other variables, above 0.8, were removed from the modeling to avoid correlation bias [27,28]. It was found that a few variables within each survey aspect had high correlation with each other. The removed questions from this analysis due to high correlation with other variables were Q11, Q12, and Q25.

Several iterations were conducted to obtain the best-fit model using the Akaike Information Criteria (AIC). The AIC value of the final model was 957.94, which was the lowest obtained value. The results of the multinomial ordinal probit model (OPM) showed that eight variables came to be significant as factors affecting the acceptability of shared mobility services in Amman using the chi-squared test. A backward selection method was utilized to develop OPM. Table 2 shows the significant parameters, the categories of each parameter, the model estimates, standard error (SE), Wald Chi-squared value, and the p-value. The significance level considered in this study was 95% significance level.

Table 2. Parameter estimates for public acceptability of shared mobility using multinomial ordinal probit model.

Var.	Cat.	Est.	SE	Wald Chi^2	p-Value	Odds	Var.	Cat.	Est.	SE	Wald Chi^2	p-Value	Odds
Intercept 1		−4.983	0.619	64.75	<0.0001	Na	Q24	2	1.129	0.473	5.71	0.017	3.09
Intercept 2		−4.248	0.610	48.43	<0.0001	Na		*3	0.838	0.460	3.32	0.069	2.31
Intercept 3		−3.821	0.607	39.66	<0.0001	Na		4	1.122	0.456	6.05	0.014	3.07
Intercept 4		−3.548	0.605	34.43	<0.0001	Na		*5	0.930	0.483	3.70	0.054	2.53
Intercept 5		−3.154	0.602	27.45	<0.0001	Na		6	1.228	0.503	5.96	0.015	3.42
Intercept 6		−2.476	0.594	17.38	<0.0001	Na		7	1.081	0.493	4.80	0.029	2.95
Q8	2	0.431	0.202	4.57	0.033	1.54	Q26	2	1.387	0.579	5.74	0.017	4.00
	3	1.119	0.280	16.01	<0.0001	3.06		3	1.219	0.562	4.70	0.030	3.38
	4	1.210	0.286	17.88	<0.0001	3.35		4	1.252	0.628	3.97	0.046	3.50
	*5	0.545	0.315	3.00	0.083	1.72		*5	1.010	0.616	2.69	0.101	2.75
	*6	0.506	0.376	1.81	0.179	1.66		*6	1.145	0.637	3.23	0.072	3.14
	*7	0.077	0.284	0.07	0.785	1.08		*7	1.101	0.655	2.82	0.093	3.01
Q14	*2	0.862	0.462	3.48	0.062	2.37	Q27	2	−1.118	0.547	4.18	0.041	0.33
	*3	0.477	0.440	1.18	0.277	1.61		*3	−0.645	0.487	1.75	0.186	0.52
	*4	0.591	0.408	2.10	0.147	1.81		*4	−0.647	0.506	1.64	0.201	0.52
	5	0.839	0.439	3.65	0.049	2.31		*5	−0.795	0.504	2.49	0.115	0.45
	*6	0.804	0.480	2.80	0.094	2.24		*6	−0.588	0.519	1.28	0.257	0.56
	*7	0.308	0.448	0.47	0.492	1.36		7	−0.971	0.544	3.18	0.044	0.38
Q16	*2	0.501	0.520	0.93	0.335	1.65	Q28	2	0.970	0.461	4.43	0.035	2.64
	3	1.355	0.517	6.87	0.009	3.88		3	1.013	0.475	4.54	0.033	2.75
	4	0.971	0.512	3.59	0.050	2.64		4	1.155	0.442	6.82	0.009	3.17
	*5	0.482	0.521	0.85	0.355	1.62		5	0.920	0.464	3.92	0.048	2.51
	*6	0.989	0.547	3.27	0.071	2.69		*6	0.712	0.479	2.22	0.137	2.04
	*7	0.943	0.524	3.23	0.072	2.57		*7	0.775	0.499	2.41	0.120	2.17
Q22	*2	−0.571	0.408	1.96	0.161	0.56	Model Fit Indices						
	*3	−0.615	0.364	2.86	0.091	0.54	Log Likelihood			−424.972			
	4	−0.679	0.355	3.65	0.050	0.51	AIC			957.944			
	*5	−0.082	0.373	0.05	0.827	0.92	BIC			1150.221			
	*6	−0.631	0.386	2.68	0.102	0.53							
	*7	−0.542	0.334	2.63	0.105	0.58							

Na = Not appliable. Notes: * indicates an insignificant category.

The reference group for each variable was considered the first/lowest category for the Likert scale. The results of the OPM showed that the usage of public transportation affects the usage of shared mobility. With respect to the other categories, the participants who sometimes use public transportation are 3.35 times more likely to use shared mobility compared to participants who never use public transportation, which was observed to be the highest odds within this variable. This statistic indicates a strong positive correlation between the occasional use of public transport and the likelihood of adopting shared mobility solutions. Practically, this means that among our survey respondents in Amman, those who are already accustomed to using public transportation, even if not as their primary mode of transport, demonstrate a significantly higher propensity to embrace shared mobility options like car-sharing, bike-sharing, or ride-hailing services. Additionally, the willingness of occasional public transport users to adopt shared mobility may indicate a broader trend toward more sustainable and flexible urban transportation options, reflecting a shift away from reliance on private vehicles. On the other hand, participants that always use public transportation were not found to be significantly different from the same reference group.

Only one category for the participants' responses was found to be significant for their perception of shared mobility to reduce congestion. The participants that selected the fifth level are 2.31 times more to use shared mobility, with respect to other categories. The neutral category for the variable "cost as a barrier for using shared mobility" was found to be the only significant level in this variable. This category was found to be 49% less likely to use shared mobility services compared to the participants who do not perceive the cost as a barrier at all. Finally, the participants that were neutral to perceive improved comfort as one of the benefits of shared mobility are 3.17 times higher than the reference group to use shared mobility services.

5. Impact Assessment

This section intends to critically evaluate the potential effects that shared mobility options may have on Amman's urban fabric. Given the multifaceted nature of urban transportation, examining these repercussions is a challenging endeavor. Multiple aspects of a city's transportation system, such as travel patterns, traffic congestion, air quality, social equity, and the economy, can be affected by the introduction of shared mobility alternatives. This study offers policymakers, city planners, and transportation service providers valuable insights. It can guide future strategies and interventions in a manner consistent with the overarching objective of sustainable urban development.

5.1. Adoption Rate Estimation

Using the survey's data on respondents' propensity to utilize shared mobility, the potential adoption rate is estimated. This is a crucial step in determining the future rate of adoption and utilization of shared mobility services by Amman residents. This step evaluates the survey responses in order to determine the prospective number of commuters likely to switch to shared mobility options. Therefore, survey questions relevant to this evaluation would likely pertain to travel behavior, willingness to utilize shared mobility, and perceived benefits and barriers (Q11 to Q17).

The percentage of respondents who selected values "5", "6", and "7" is used to estimate the perceived adoption rate for shared mobility. Based on the survey responses, the overall estimated adoption rate is 25.4%. This rate of adoption indicates a substantial initial tendency among respondents to implement shared mobility options in Amman. This shows that approximately one in four residents surveyed are open to swapping their current mode of travel with shared mobility options. Given the nascent stage of shared mobility in Amman, this is an encouraging beginning that demonstrates promising growth potential. This highlights the need for substantial work in policy formulation, infrastructure development, and public outreach. This initial adoption rate provides a useful benchmark for assessing future progress and devising strategies to promote a broader acceptability of shared mobility as a sustainable transportation option in Amman.

5.2. Scenario & Impact Analysis

This section of the study seeks to simulate the potential effects of a 25.4% adoption rate of shared mobility services on CO_2 emissions in Amman, a crucial aspect of determining the viability of such a transition.

Recently, Jordan's carbon footprint has become a significant concern. As shown in Figure 3, in 2021, Jordan's per capita CO_2 emissions were 2.35 tons, which raises environmental and sustainability concerns, representing an average annual growth rate of 5.20 percent [29] (. As shown in Figure 3, when compared to other Asian countries, this emission rate per capita is notably high. This elevated level of CO_2 emissions per capita indicates a pressing need for policies and strategies that promote sustainability and reduce carbon emissions. Consequently, this highlights the significance and potential impact of initiatives such as the promotion of shared mobility options in cities such as Amman.

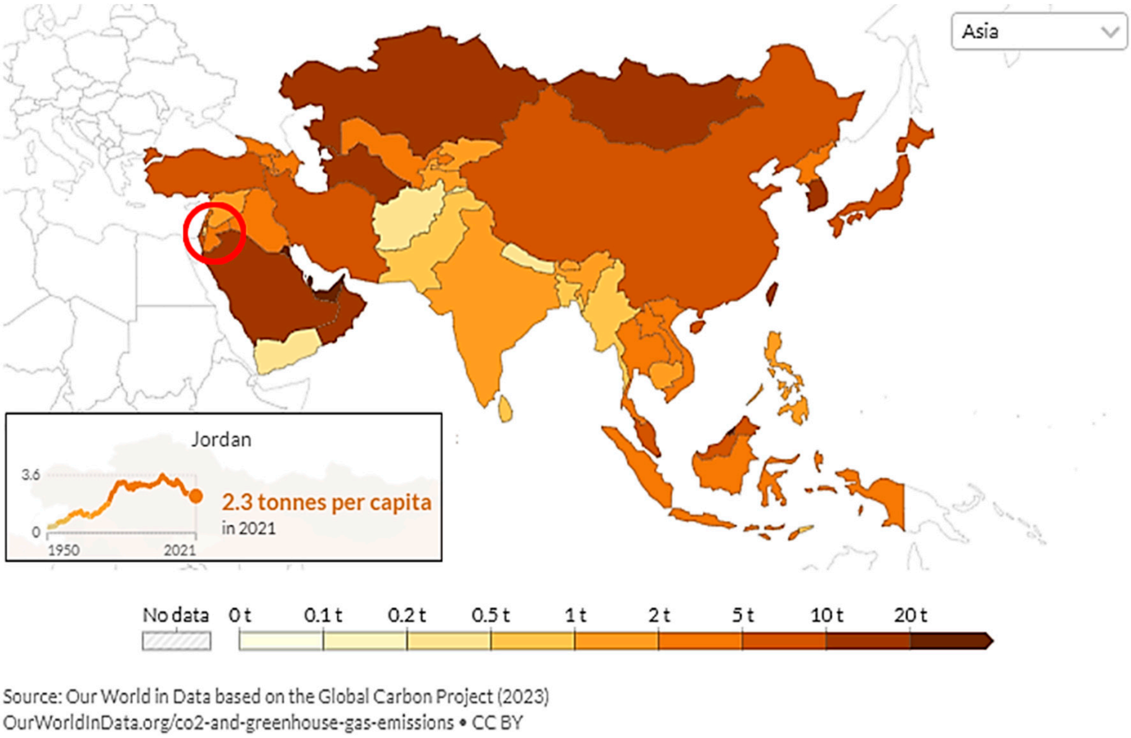

Figure 3. Per capita CO_2 emissions for Asia [29].

Assuming this growth rate continues, the expected CO_2 emissions per capita in Amman, which is home to approximately 4 million people, will reach approximately 9,888,800 metric tons in 2023. According to the Greenhouse Gas Equivalencies Calculator of the Environmental Protection Agency (EPA), the present level of CO_2 emissions is equivalent to approximately 25.35 billion miles traveled by a typical gasoline-powered passenger vehicle [30].

Adding an adoption rate of 25.4% for shared mobility services to this scenario creates a compelling potential for impact. By consolidating journeys and utilizing higher occupancy vehicles, shared mobility has the potential to substantially reduce overall vehicle mileage and, consequently, CO_2 emissions. Assuming a linear relationship between vehicle miles driven and CO_2 emissions, a 25.4% decrease in driven miles, corresponding to the adoption rate, could lead to a proportional reduction in emissions.

The calculated potential reduction in CO_2 emissions demonstrates the potential for shared mobility services in Amman to not only reduce traffic congestion but also contribute to broader sustainability and environmental objectives. Nonetheless, it is essential to recognize that these projected impacts are based on the simplification assumption of linear reduction and that the actual impacts may differ depending on a variety of factors, such as the type of shared mobility service adopted and user behavioral adaptations. In order to refine these impact projections over time, continuous surveillance and analysis would be necessary.

These findings illuminate a promising pathway for the city of Amman to transition to a more sustainable transportation future, in accordance with global carbon reduction commitments and local environmental goals.

6. Policy Recommendations

In the final section of this study, guidelines for advancing sustainable transportation in Amman, Jordan are extrapolated based on the study's results. The objective of this section is to identify the shared mobility options with the greatest potential for success and to develop adoption strategies for them. Therefore, this study influences the transportation policies of Amman toward a future that is not only more sustainable but also more efficient and equitable. In addition, potential policy obstacles that could impede the implementation of these shared mobility options are discussed. Through this informed policy dialogue, this study contributes to the development of a resilient and sustainable Amman urban transportation system.

6.1. Assess Policy Barriers

It is essential to evaluate the policy barriers associated with shared mobility in Amman in order to comprehend the barriers and constraints that may hinder the effective deployment of these services. From the analysis, a variety of challenges, including regulatory restrictions, infrastructure constraints, and cultural attitudes can be expected. From a regulatory standpoint, Jordan's legal framework for shared mobility services is in its infancy, and certain legal provisions may unintentionally impede the expansion of such services [31]. For instance, current transportation laws may not adequately recognize or provide for shared mobility, creating uncertainty for service providers and consumers [32]. Regulation-related problems could also include the lack of adequate guidelines or standards for operating shared mobility services, which could limit the ability of service providers to provide safe and dependable services.

Infrastructure-wise, Amman confronts significant challenges. Currently, the city's transport infrastructure is built for privately owned cars, which may hinder the operation of shared mobility services. There are insufficient dedicated lanes for carpooling and bike-sharing. Additionally, parking spaces for shared vehicles and services are not widely available. In addition, the digital infrastructure required for app-based services may not be completely developed, affecting their efficacy. A key factor in the successful implementation of shared mobility in Amman involves addressing existing infrastructure constraints through targeted improvements. Firstly, developing and enhancing the city's transportation network is essential. This includes expanding and maintaining roads and pathways to accommodate shared vehicles, such as dedicated lanes for car-sharing. Secondly, establishing well-designed and strategically located mobility hubs is crucial. These hubs can serve as central points for various shared mobility services, offering parking, charging stations for electric vehicles, and seamless interconnections with public transit systems. Thirdly, implementing advanced traffic management systems can significantly improve the efficiency of shared mobility. These systems should include smart traffic signaling and real-time traffic data analytics to optimize routes and reduce congestion. Lastly, investment in secure and accessible parking solutions for shared vehicles can encourage their use, especially in high-density urban areas. By focusing on these specific infrastructure improvements, Amman can create a more conducive environment for shared mobility, ultimately contributing to a more sustainable and efficient urban transportation ecosystem.

Additionally, cultural attitudes influence the adoption of shared mobility services. According to [33], vehicle ownership is regarded as a status symbol and a vital aspect of freedom of movement in Jordan. Individuals may be reluctant to abandon their personal vehicles in favor of shared mobility options due to such attitudes. In addition, safety, privacy, and hygiene concerns may discourage prospective users [33].

Consequently, it is evident that addressing these obstacles necessitates a comprehensive and targeted strategy in which policies and actions are designed to specifically address each issue and all stakeholders are involved in the process.

6.2. Forward-Thinking Policy Solutions

In order to address the identified challenges to shared mobility in Amman, innovative, comprehensive, and forward-thinking policy solutions are required. These solutions should cultivate a hospitable environment for shared mobility options, thereby encouraging their adoption.

A crucial first step on the regulatory front would be to review and amend existing transportation policies and regulations in order to facilitate and encourage shared mobility services. Law and policymakers in Jordan must develop a comprehensive legal framework that addresses shared mobility challenges and provides clear guidelines on licensing, safety standards, and operational requirements. This might minimize uncertainty for service providers and encourage more competitors to enter the market, thereby fostering competition and innovation. Additionally, regulations could be instituted to ensure that shared mobility services contribute positively to urban mobility, such as requiring service providers to share data with city authorities for transportation planning purposes.

Investing in the infrastructure of Amman could increase the accessibility of shared mobility options. This could involve the establishment of carpool lanes and bike-sharing lanes, in addition to the provision of ample parking spaces for shared vehicles. Additionally, the city's digital infrastructure could be improved to support the operation of app-based services, possibly through public–private partnerships that encourage investment in this area.

Moreover, there may be a need for public awareness campaigns to emphasize the benefits of these services and allay concerns about safety, privacy, and hygiene in order to address cultural attitudes toward shared mobility. These campaigns may be most effective if they emphasize tangible benefits, such as cost savings and congestion reduction. In addition, providers of shared mobility services could be encouraged to begin implementing measures that would solve the issues at hand, such as stringent vehicle maintenance and sanitation standards. By implementing the proposed policy solutions, Amman can overcome existing barriers and foster a more sustainable and efficient urban transportation system through the adoption of shared mobility.

Additionally, creating incentives is an effective technique for promoting the use of shared mobility in Amman. A variety of incentives could be used to make shared mobility options more appealing to prospective users and profitable for service providers. In addition, preferential regulations can aid in establishing a business-friendly environment, which motivates additional vendors to enter the market. The following list summarizes the benefits of creating incentives for three sectors (Users, Service Providers, and Regulation).

- Users of Shared Mobility Services
    - Off-Peak Discounts: Lower fares for shared mobility services during off-peak hours.
    - Loyalty Rewards: Discounts or benefits for regular users of shared mobility services.
    - Shared Trip Incentives: Rewards or benefits for users who opt for shared trips instead of solo rides.
- Shared Mobility Service Providers
    - Reduced Licensing Fees: Lower fees for obtaining necessary licenses to operate shared mobility services.
    - Infrastructure Investment Grants: Grants or subsidies for investments in necessary infrastructure.
- Regulatory Incentives
    - Eased Operational Restrictions: Easing restrictions on where and when shared mobility services can operate.
    - Priority Access: Priority access to high-demand areas or dedicated lanes in traffic for shared vehicles.

Addressing potential resistance and challenges from stakeholders is crucial for the successful implementation of shared mobility in Amman. A key strategy involves comprehensive stakeholder mapping to identify all relevant parties, including government agencies, transport operators, community leaders, and end-users. Effective communication channels must be established to facilitate open dialogue and information sharing. One approach is to organize workshops and public forums where stakeholders can express concerns, provide feedback, and contribute ideas. Highlighting the benefits of shared mobility, such as reduced traffic congestion, improved air quality, and enhanced urban mobility, can help in gaining support. Furthermore, ongoing engagement through regular updates and the inclusion of stakeholder feedback in decision-making processes is essential for building trust and consensus. Finally, partnering with local organizations and influencers can aid in garnering community support and fostering a positive public perception of shared mobility initiatives.

7. Conclusions

This study critically examines the role of shared mobility in advancing sustainable urban transportation in Amman, Jordan. Through a comprehensive analysis employing both parametric and non-parametric methods, alongside advanced models like the Multinomial Ordinal Probit Model and Decision Tree analysis, this study has established a 25.4% adoption rate for shared mobility in Amman. This reflects a significant inclination among residents towards alternative transportation modes, marking a shift in urban travel behaviors.

The study's application of the Ordered Probit model and CHAID classification has yielded insights into the complex dynamics of shared mobility adoption in an urban setting. Significantly, the study illustrates the environmental benefits of shared mobility, particularly in reducing CO_2 emissions, aligning with global sustainability objectives.

Amman's context presents unique challenges and opportunities, differing from western urban models. Here, shared mobility emerges as a foundational element of the city's evolving transport infrastructure, contrasting with cities where it complements existing systems. This distinction necessitates targeted strategies that consider local cultural attitudes and urban realities, ensuring that Amman's initiatives are both locally relevant and globally resonant.

In summary, this study offers strategic insights for implementing shared mobility in Amman, highlighting its potential to contribute to a sustainable, efficient, and eco-friendly urban transport system. This research not only aligns with global trends in sustainable urban development but also addresses the specificities of Amman's urban landscape, offering a model for similar urban settings globally.

8. Limitation

Despite the comprehensive nature of this study on sustainable shared mobility solutions in Amman, Jordan, there are several limitations that need to be acknowledged.

1. Temporal Limitations: The findings are based on current data and trends, which may change over time. As urban dynamics, technology, and public perceptions evolve, the relevance of the study's conclusions might diminish. Future studies should consider these temporal changes to maintain relevance.
2. Geographical and Cultural Specificity: The study focuses on Amman, and its findings are deeply rooted in the city's unique geographical, cultural, and socio-economic context. This specificity might limit the applicability of the results and recommendations to other urban environments with different characteristics.
3. Policy and Regulatory Environment: The study does not fully address the potential impact of changing policies and regulations on shared mobility solutions. Government actions and regulatory frameworks play a crucial role in shaping urban transportation, and shifts in these areas could significantly influence the adoption and effectiveness of shared mobility.
4. Environmental Impact Assessment Limitations: While the study examines the impact of shared mobility on CO_2 emissions, it does not fully explore other environmental factors such as noise pollution, urban congestion, and resource utilization. A more holistic environmental impact assessment could provide a more comprehensive understanding of sustainability implications.

In conclusion, while this study provides valuable insights into the viability and potential impacts of shared mobility in Amman, these limitations highlight the need for ongoing research and analysis to continually refine and update the understanding of sustainable urban transportation solutions.

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