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Exploring Sustainable Urban Transportation: Insights from Shared Mobility Services and Their Environmental Impact

Ada Garus [1,*], Andromachi Mourtzouchou [2], Jaime Suarez [1], Georgios Fontaras [1] and Biagio Ciuffo [1]

[1] European Commission–Joint Research Centre, Via E. Fermi, 274921027 Ispra, Italy; jaime.suarez-corujo@ec.europa.eu (J.S.); georgios.fontaras@ec.europa.eu (G.F.); biagio.ciuffo@ec.europa.eu (B.C.)

[2] Department of Transportation and Projects and Processes Technology, University of Cantabria, Av. de los Castros s/n, 39005 Santander, Spain; andromachi.mourtzouchou@alumnos.unican.es

* Correspondence: ada.garus@ec.europa.eu

Abstract: The transportation landscape is witnessing profound changes due to technological advancements, necessitating proactive policy responses to harness innovation and avert urban mobility disruption. The sharing economy has already transformed ridesharing, bicycle-sharing, and electric scooters, with shared autonomous vehicles (SAVs) poised to reshape car ownership. This study pursues two objectives: firstly, to establish a market segmentation for shared ride services and secondly, to evaluate the environmental impact of ridesharing in different contexts. To mitigate potential biases linked to stated preference data, we analysed the navette service, utilized by a research institute in Europe, closely resembling future SAVs. The market segmentation relied on hierarchical cluster analysis using employee survey responses, while the environmental analysis was grounded in the 2019 navette service data. Our analysis revealed four unique employee clusters: Cluster 1, emphasizing active transportation and environmental awareness; Cluster 2, showing openness towards SAVs given reliable alternatives are available; Cluster 3, the largest segment, highlighting a demand for policy support and superior service quality; and Cluster 4, which places a premium on time, suggesting a potential need for strategies to make the service more efficient and, consequently, discourage private car use. These findings highlight a general willingness to adopt shared transport modes, signalling a promising transition to shared vehicle ownership with significant environmental benefits achievable through service design and policy measures.

Keywords: shared autonomous vehicles (SAVs); ridesharing; urban mobility; transportation policy; environmental impact

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1. Introduction

1.1. Context

Transportation for the majority of the second half of the 20th century has been rather stable, with growing infrastructure and known services handling a foreseeable demand. Nevertheless, in the recent years, the field has moved into a revolution period, in which technological advancements enable innovative and often disrupting new mobility services [1,2]. Therefore, it is crucial, especially for policy makers, to react in a precautionary manner, making sure that the local, national, and international regulation is capable of leveraging technological advancements rather than allowing the technology to chaotically take over the cities.

One of the potential opportunities that comes with the technological advancement in transportation is the sharing economy [3,4]. Nowadays, numerous mobile-based services allow users to share a ride, bicycle, electric scooter, or a car, diminishing the need for car ownership. Nevertheless, the technology that might truly revolutionise car ownership is still ahead—shared autonomous vehicles (SAVs) [5–7]. In the evolving landscape of

SAVs, there are several types designed to cater to varying transportation needs. Some of these vehicles offer private rides, while others are intended for shared use among passengers with similar destinations [8]. These vehicles can vary in occupancy, ranging from small two-seater vehicles designed for individual journeys to four-passenger vehicles that closely resemble today's typical cars [9–11]. Additionally, larger shuttles with a capacity of 12 to 20 people function as on-demand public transport, providing a flexible and efficient alternative to traditional buses [10,12,13]. This study focused on understanding the impact and potential of these larger shuttles, as they align with the goal of exploring sustainable and inclusive urban mobility solutions.

The transport sector is already preparing for the arrival of SAVs, as the notoriously used ridesharing services such as Uber and Lyft can depend on constant support the investors despite failing to make a profit since their introduction [14]. As the cost of labour is roughly 50 per cent of the operational cost of a ride [15,16], both companies are heavily investing in the R&D of autonomous vehicles [17,18]. Apart from the costs, SAV-based services are expected to be similar to today's dynamic ridesharing services; however, SAVs are expected to be more flexible, convenient [15], and cheap. Specifically, SAV services will be more accessible and convenient, as they can reposition themselves to balance vehicle supply demand and pick up waiting customers at desired locations [7,15]. In addition to the current dynamic ridesharing operators, the automotive sector is not lagging far behind when it comes to the potential development of SAVs, with BMW and Daimler already offering ridesharing and carsharing services [19] and with BMW, Mercedes, and Volkswagen, among other manufactures, investing heavily in driverless technology [20].

It is still unclear what observable and unobservable factors will drive public interest in AVs, which may differ between regions, social groups, and trip purposes [21,22]. However, building an understanding of the potential future uptake of SAVs should already be considered by urban and transport planners, as the rate of sharing is a key factor in determining the sustainability of future autonomous on-demand mobility services [23–25]. Sheppard et al. in fact proved that the electrification of the vehicle fleet could reduce the GHG emissions by 46%, while the introduction of the electric SAVs could push this reduction to 70% as compared to a gasoline baseline [26]. In view of the above, it is necessary to prepare for the development and uptake of autonomous mobility. In particular, it is crucial to understand the possible demand for SAV services, the potential decrease in car ownership rates, and the preferences towards privately owning an autonomous vehicle. Thereafter, these projections should fit with the sustainable visions of the future urban areas drafted by today's urban planners and policymakers.

In recent years, urban mobility has faced significant challenges, fuelled by rapid urbanization, escalating environmental concerns, and transformative advancements in transportation technology. This study is set against the backdrop of these issues, with a particular focus on shared mobility solutions, such as ridesharing and autonomous vehicle services, which have emerged as pivotal elements in the quest for sustainable urban transportation. Our research aimed to fill critical gaps in understanding how these shared mobility options can be integrated effectively into urban systems to reduce environmental impact, alleviate congestion, and enhance accessibility. The significance of this work lies in its potential to inform and influence urban transportation policies, guiding city planners and policymakers in adopting strategies that leverage technological innovations for sustainable development. By providing empirical insights into the adoption and impact of shared mobility services, this paper contributes valuable perspectives to the ongoing discourse on urban mobility solutions, underscoring its importance for stakeholders involved in shaping the future of urban transportation.

1.2. Objective and Approach

The objective of this study was twofold: first, to create a market segmentation for shared ride services and second, to report the environmental impact that ridesharing has in various configurations. Nevertheless, to possibly avoid the potential bias linked to stated preference data collection, the authors decided to use data from a service already available today that adequately mimics the future SAV services—the navette service. The navette service is used by the employees of a research institute in Europe for the first and last legs of work-related travels. While the navette service is not an SAV in its entirety, there are key resemblances that validate its use as a proxy for studying potential SAV operations:

1. On-demand ordering: The navette service operates on an on-demand basis, where users can request a ride via a web application. What is important to note is that this on-demand feature allows users to specify not only when they need the ride but also where they want to be picked up and dropped off, including the ability to set specific time windows. This level of customization closely mirrors the expected operation of future SAVs, where passengers will have the convenience of naming the pick-up and drop-off zones as well as the desired timings when ordering a ride.
2. Cost-effectiveness: We assumed that the navette service is an option cheaper than taking one's own car or public transportation. This assumption aligns with the general expectation that SAVs, as shared and autonomous vehicles, would offer cost-effective transportation. The absence of a driver in SAVs and their shared nature are factors that contribute to cost savings, making them a feasible and economical choice for users.
3. Shared Mobility: The navette service is shared (if possible) by up to six passengers, and there is a fleet provider responsible for managing requests and arranging trip chains. This concept of shared mobility managed by a centralized provider is a core characteristic of future SAV systems. SAVs are envisioned to be part of shared mobility services, allowing multiple passengers to share a vehicle for more efficient and sustainable transportation.

The navette service is used by the employees to reach nearby airports and train stations. If there is a possibility of conveniently allocating two or more passengers (up to six) for the same ride, the service operator would do so. Moreover, the usage of the service is encouraged by the employer. The authors believe that this setting mimics adequately the future policy measures, according to which individuals would be encouraged to share rides rather than use one's private vehicle and therefore represents well the SAV-based service with the technology available today.

The market segmentation of those willing and unwilling to use the service was made using hierarchical cluster analysis. The data input for clustering were responses to a survey dispatched among the employees inquiring about their usage of the navette service, whereas the environmental analysis was made based on real data on demand and cost of the service for the year 2019 provided by the navette service operator. The year 2019 was chosen because during the years 2020–2022, work-related travel was minimised due to the COVID-19 pandemic. This study is divided into five sections. First, the previous literature on the topic is presented, and then the data collection and analysis section lay out the implemented methodologies, with Results and Conclusion sections following.

While the existing literature offers insights into carsharing and ridesharing behaviours in academic settings, it often lacks a detailed exploration of the environmental impacts of these practices and their integration into daily university life. Studies such as those by Zheng et al. [27] and Akar et al. [28] provide valuable information on general trends such as the influence of car ownership and demographic factors on ridesharing preferences. However, these studies typically do not delve into the environmental outcomes of implementing ridesharing programs or address the specific operational challenges and user acceptance issues within a university community.

This study sought to fill in the following research gaps:

- The study focused on real-world application, providing a comprehensive understanding of how ridesharing services can be environmentally sustainable and tailored to meet the unique demands of a community. By utilizing real-world data rather than relying solely on stated preferences, a more accurate portrayal of user preferences and behaviours was achieved. This approach enabled actionable insights into the environmental sustainability of ridesharing services, thus facilitating informed decision-making for stakeholders aiming to implement or optimize such programs within academic settings.

- This study conducted an in-depth analysis of the implementation and environmental implications of the navette service, a ridesharing program in an academic but not university setting. We offer a critical examination of how the navette service is adapted to the unique dynamics of the research centre environment, assessing factors influencing its adoption, such as operational feasibility, user comfort, and preferences.

This holistic approach allowed us to offer practical recommendations for universities and academic settings aiming to implement or optimize ridesharing services, bridging the gap between theoretical potential and practical, environmentally conscious execution.

2. Literature Review

This subsequent Literature Review Section investigates various facets of sustainable urban transportation, encompassing not only academic environments but also broader urban contexts. In Section 2.1, an analysis of travel behaviour patterns within universities and research centres reveals the influential factors, including distance, cost, and individual preferences, shaping transportation choices. Section 2.2 outlines an exploration of the dynamic landscape of ridesharing, carpooling, and shared mobility services, encompassing both academic institutions and urban settings, elucidating the complexities and opportunities inherent in these transport modes. Lastly, Section 2.3 offers insights into preferences regarding shared and private AVs, featuring speculation on adoption trends and an examination of potential determinants influencing their forthcoming role within urban transportation systems.

2.1. Mobility Patterns in Academic Settings

Universities, typically situated in urban areas with diverse transport options, show distinct travel behaviour patterns, particularly among students who favour public transport and active modes due to factors such as age, proximity to campuses, and lower car ownership [29,30]. Travel choices are influenced by a combination of distance, time, public transport accessibility, cost, and individual preferences [30]. For instance, studies indicate that shorter distances encourage walking and cycling, while longer distances increase the likelihood of using motorized transport [31–33]. Inefficiencies in public transport, such as low frequency and long commuting times, often lead to increased car usage [34–36].

Cost considerations, including parking fees and public transport fares, significantly affect travel mode decisions, with lower costs encouraging active modes and subsidized fares increasing public transport use [32,37,38]. Adequate, safe infrastructure for walking and cycling is crucial for promoting these modes, while concerns such as safety and weather conditions act as deterrents [39,40]. Demographic factors, such as gender, income, and age, also play significant roles in shaping travel choices [31,33,38].

A study on the mobility preferences of employees of academic institutions, which are more likely to resemble those of population of a research institute than those of students, showed lower carsharing rates, with these rates being higher among those who used alternative modes of transport, had lower incomes, or were female [41]. Previous studies suggest that this difference may be caused by the home location of most university staff being often far from campus. This could hamper the possibility of finding a partner [42]. Moreover, university staff are more likely to own cars and have familial obligations, which decreases the convenience of ridesharing [42].

In the context of our navette study, these findings underscore the potential for ridesharing as a viable option in university settings. By addressing barriers such as travel time and cost and capitalizing on the population's openness to alternative modes of transport, ridesharing can offer a practical, eco-friendly solution that aligns with the travel preferences and needs of university communities. This approach not only aids in reducing individual carbon footprints but also contributes to the broader goal of creating more sustainable and efficient transport systems within academic environments. This overview of mobility patterns in university settings, particularly emphasizing the roles of distance, cost, and individual factors in travel mode choices, provides a crucial backdrop as we now transition to examining the preferences and potential for ridesharing.

2.2. Sharing Preferences

Current technological advancements contribute to a sharing economy, in which the consumers are more open to sharing goods or services among the community. Sharing economy companies in the transport sector are capitalising on numerous transport needs of citizens, allowing them to share rides within the city, carpool for long distances, and rent bicycles or e-scooters by the minute. The introduction of such services has fuelled the need for further research on such technologies, and attitudinal changes can be harnessed at the macro level by transport planners [43,44].

Nevertheless, there is still a long way ahead before the full potential of sharing rides can be achieved, as previous studies have revealed persisting difficulties in motivating new mobility practices, i.e., switching from private car to bus, cycling, walking, or shared mobility services [45–49]. Moreover, the assumption that positive opinion about ridesharing will result in its usage was reported to be mistaken [50]. Based on the research conducted by Ciari [51], it can be observed that even though 78% of respondents expressed a positive opinion about ridesharing, only half of them were actually willing to share their rides. This, however, is not entirely unsurprising, as driving on one's own entails full privacy and flexibility, while carpooling calls for sacrifices in these areas [52]. In fact, Cass and Faulconbridge [46] showed that commuting involves getting to/from home or work as part of a sequence that includes other daily practices, such as shopping, exercise, recreation, leisure, and perhaps most impactfully, parenting by taking the children to school or extra-curricular activities.

Numerous studies have been dedicated to understanding the travel behaviour linked with the preference for sharing a ride. These studies predominantly used stated preference surveys combined with the neoclassical econometric models to understand the preference for using ride-hailing services in general, as well as investigating the factors that contribute to riders opting for a shared ride-hail trip [50,53–56]. The results reported in these studies suggest that employed and educated men living in high-density areas are more likely to share rides. The research also suggests that major barriers for sharing the ride are the increase in travel times and a feeling of discomfort among strangers [50,54–56].

Studies in various academic institutes have revealed intriguing insights into carsharing and ridesharing behaviours. For instance, Zheng et al. [27] found that students and foreign residents were more inclined towards carsharing compared to faculty members, with increased car ownership decreasing the likelihood of participation. Similarly, Akar et al. [28] saw a substantial interest in carpooling programs among its university members, with factors such as distance, fuel costs, and flexible pick-up/drop-off times enhancing this likelihood. Zhou and Kockelman [57] also noted that higher car ownership and part-time status reduced carsharing participation.

In the context of our navette study, these findings emphasize the potential for ridesharing to be a viable transportation option in academic settings. The navette service, by offering convenient and cost-effective travel, aligns well with the preferences of university community members who are less likely to own cars and are sensitive to travel costs and convenience. This is particularly relevant given that factors such as familiarity with ridesharing programs, flexible schedules, and cost-saving opportunities have been identified as key drivers for ridesharing adoption [43,58,59]. Interventions such as discounted parking for car-poolers, premium parking locations, and prize drawings have been shown to significantly increase carpooling in academic institutions, as demonstrated by a program at the University of California, Davis, which boosted carpooling rates among faculty and staff [60].

These insights into carsharing and ridesharing tendencies within university settings highlight the potential for ridesharing services such as the navette to meet the unique mobility needs of academic communities, contributing to reduced traffic congestion and lower GHG emissions and promoting a more sustainable commuting culture.

As it pertains to revealed preference and empirical studies, the literature is not as rich, although numerous studies have investigated the city of Chicago [25,61–63] due to its high rate in ridesharing (3%) [64,65]. The authors of these studies leveraged big datasets and used machine learning predictive algorithms to investigate the willingness to share of various citizens. The evidence suggests that socioeconomic factors could indeed be successfully used in the predictive algorithms as well as the socioeconomic characteristics of the origin and destination of the trips, with airport-based trips yielding significant results.

Revealed preference studies focusing on other regions include an analysis of Brown, who found that Los Angeles-based riders living in low-income, dense areas make a higher proportion of shared trips [66]. Also, in Toronto, higher demand and longer trip distances significantly improve matching propensity for shared trips [67]. Tu et al. found that in Chengdu, distance to city centre, land use diversity, and road density are the key influencing factors of sharing behaviour [68]. Regarding studies focusing on European citizens, Vega Gonzalo et al. [69] recently considered preferences between private taxis and ride-hailing services. Moreover, Sopjani et al. [49] investigated how day-to-day mobility patterns change when private car commuting is replaced by a shared peer-to-peer alternative. Their approach was living lab based, and the service was prototyped and tested with 16 users.

The results from the stated preference studies and first revealed preference studies were gathered in a meta-analysis performed by Neoh et al. [70], who proposed a classification of factors influencing carpooling. The classification considers internal, external, judgmental, and situational factors. Internal factors occur at the individual level for each commuter, including demographic (i.e., individual characteristics) and judgmental factors (i.e., commuter's reason to carpool). External factors take place at the environment level of the commuter, including third-party interventions (i.e., policy measures to facilitate carpooling) and situational factors (i.e., location-based factors).

2.3. The Future of On-Demand Services—SAVs

The literature focusing on the possible reasons for preferences of shared versus private AVs nowadays could, of course, be only speculative, as these vehicles are not fully available. However, the first approaches to assess the societal preferences for AV adoption have already been made and are summarized in the following review articles [6,11,12]. Nazari et al., Nair et al. [71], and Lavieri et al. [72] used data from a stated preference survey conducted in the state of Washington. The survey examined public interest in privately owned AVs and multiple SAV configurations based on trip purpose. The studied SAV services included carsharing, ride-hailing, ridesharing, and access/egress mode. Other studies that investigated the preference for SAV-based services also adopted the stated preference or hypothetical approach [73–78].

As for the modelling approach, researchers have opted for a traditional model used to identify transport preferences—the discrete choice model. Nazari et al. [7] and Bansal et al. [73] used multivariate ordered probit models, while Krueger et al. [76] and Yap and al. [78] decided on a mixed logit model with latent variables. Other used methodologies included the generalized heterogeneous data model [72] and the logit kernel model [74].

Nazari et al. [7] found that safety concern hinders public acceptance of (S)AVs, whereas green travel pattern and previous experience with mobility on demand promote one's interest in (S)AVs, as expected. However, results suggest that marginal effects of safety concern are greater than those of green travel pattern and previous experience with mobility on demand. Confirming results were yielded by Lavieri et al. [72], who used the same dataset and also found the positive associations between the environmentalism, internal innovativeness, and interest in SAV. As per the socioeconomic factors, it has been identified that young men who are accustomed to private car use [72,74,76] and live in multi-member households and in suburbia are likely interested in private AVs [7]. Studies focusing on SAVs pointed towards individuals with longer commute times [7] who would feel comfortably assigned to a ride with a specific group of people [79]. In terms of individuals' willingness to share trips with strangers on AVs, Lavieri and Bhat [23] find that "the travel time added to the trip to serve other passengers may be a greater barrier to the use of shared services compared to the presence of a stranger".

To summarize, most academic research on the demand for shared AV services has found that currently, a considerable share of the population is reluctant to use these services. Nevertheless, once the infrastructure is developed and the customers familiarise themselves with SAV technology, these views might change [16].

3. Methodology

This Section briefly describes the methodological approach taken in the study. Section 3.1 outlines the main principles and reasoning for usage of the hierarchical clustering algorithm used for market segmentation. Section 3.2 presents the methodology adopted for environmental analysis.

Hierarchical clustering analysis was utilised to identify market segments within the urban transportation data. This method works by grouping data points based on their similarity across various indicators such as demographics, travel patterns, and preferences for mobility services. The clustering was conducted in a hierarchical manner, starting with each data point in its own group and progressively merging the closest pairs until optimal clusters emerged. We chose hierarchical cluster analysis for market segmentation due to its capability to efficiently manage and interpret the diverse and complex data gathered through our survey. This method is adept at identifying unique market segments, which is essential for tailoring urban mobility strategies effectively.

For the environmental impact assessment of the navette service, we relied on emissions data calculation in COPERT (version 5.6.1) from vehicle use and passenger travel patterns, comparing this against the baseline impact of private vehicles. Key indicators included average trip distance, fuel consumption, and emissions per kilometre. This approach was selected for its accuracy in calculating emissions based on actual usage patterns, providing a trustworthy evaluation of the environmental benefits associated with shared mobility solutions. Together, these methodologies offered a rigorous framework that enhanced both the granularity of the market segmentation and the validity of our environmental impact assessments.

3.1. Hierarchical Clustering

Quantitative market segmentation can be done using various methods of data analysis, with clustering or classification used prominently if a large volume of data is available [80]. Clustering was chosen for this study as per the variety of the data collected through the survey which in turn resulted in the potential distinction of subsets within the data.

The hierarchical clustering method was chosen as per its suitability for datasets with an arbitrary attribute type [81], which is often present in transport surveys. Specifically, an ascending hierarchical cluster analysis was chosen (HCA). HCA is "an iterative classification method whose principle consists in producing sequences of nested partitions of increasing heterogeneities between the partition in N classes where each object is isolated, and the partition in 1 class which groups all the objects" [80].

As with any other clustering method, HCA uses a notion of distance, either in space of individuals or in space of variables. However, while determining the distance between two objects is rather trivial, the distance between two classes constitutes the criterion of dissimilarity in classification [80]. HCA uses Ward's method as the dissimilarity criterion, which allows for the minimisation of variance through usage of squared Euclidean distance [82].

The HCA algorithm works in an iterative manner, by first establishing the classes as objects, then calculating the distance between the objects, and merging the two closest to each other. Thereafter, the procedure is repeated until all objects are contained within a class [83].

The HCA was also chosen, as it allowed us to determine the optimal number of classes and does not impose the number of classes in starting unlike other clustering methods such as k-means. Instead, the analyst can determine the optimal number of clusters by plotting the dendrogram [84]. A dendrogram is the successive groupings resulting in the formulation of a classification tree. Moreover, the dendrogram does not need to be exhaustive, but the user can define the number of partitions, which would be represented in a hierarchy.

In addition to these aspects, our methodology involved pre-processing steps to handle the dataset's characteristics. We employed one-hot encoding to convert nominal categorical variables into a binary format, enabling us to work with a numerical representation of the data. Furthermore, principal component analysis (PCA) was applied to reduce the dimensionality of the dataset while preserving variance, ultimately enhancing the effectiveness of our clustering analysis.

To identify the variables that were over- or under-represented within different clusters, a two-step methodology was employed. First, the proportion of each variable in each cluster was calculated and compared to the general population to gauge potential disparities. This initial observation was followed by applying the chi-square test, allowing for a statistical assessment of the observed distribution. The chi-square test confirmed whether any significant deviation existed between the distribution within each cluster and the expected distribution across the overall population. This dual approach ensured rigorous identification of the variables that significantly differed among the clusters.

3.2. Methodology of the Environmental Analysis

To better understand the environmental impact of transport services, an analysis of NO_X, PM10, PM2.5, and GHG emissions was needed. Such data could be obtained using the demand for the transport services along with a supply model that allowed us to estimate the emissivity of the system. The methodological approach adopted for this study focused on recreating the current demand for transport services via expert interviews with the people responsible for the transport services. The emissivity was calculated using two tools developed and used at the European Commission (EC): the Green Driving Tool [85] and COPERT.

The Green Driving Tool is designed to assess how driving behaviour and vehicle efficiency can influence emission reductions. This tool takes a behaviour-centric approach, focusing on the impact of eco-driving and efficient vehicle operation on fuel consumption and emissions. Inputs for the Green Driving Tool include vehicle-specific data such as engine size, fuel type, and vehicle class. Additionally, it requires inputs on driving behaviour patterns, which encompass acceleration profiles, average speed, and idling times. By incorporating these variables, the Green Driving Tool simulates real-world driving conditions to estimate the potential for emission savings under different driving scenarios. The results assist policymakers and transport planners in understanding the benefits of promoting eco-driving practices and can be used to develop targeted interventions aimed at reducing road transport emissions [85].

Moreover, to obtain detailed information about the emissions, the trips and the type of vehicles were inputs into the COPERT model (Computer Programme to Calculate Emissions from Road Transport) [86]. COPERT is an emissions modelling software developed by EMISIA and recommended by the European Environment Agency for the estimation of greenhouse gases and air pollutants from the road transport sector. The model is widely used for its comprehensive coverage of various vehicle categories, including passenger cars, light commercial vehicles, heavy-duty vehicles, buses, and motorcycles [87]. COPERT calculates emissions based on a series of input parameters that reflect the fleet composition, activity data, and environmental conditions. These inputs include specific vehicle characteristics such as technology type, age, and weight class; operational parameters such as fuel type, annual mileage, and driving patterns; and environmental factors such as ambient temperature and road gradient. COPERT utilizes a series of emission factors and correction functions to account for cold starts, evaporation, and the influence of speed. The model's outputs provide detailed estimations of emissions, including CO_2, NOx, PM10, and volatile organic compounds, allowing for a thorough analysis of environmental impacts across different transport scenarios [88].

In our methodology, we carefully considered the operational costs associated with both the navette service and private vehicle use. This included a comprehensive analysis of direct expenses such as fuel, maintenance, and driver salaries for the navette service and fuel consumption, tolls, and parking costs for private vehicles. By quantifying these costs, we aimed to provide a thorough understanding of the financial implications of each travel mode, contributing valuable insights into their economic feasibility in the context of our study.

4. Case Study

The study was conducted at one of Europe's leading research campuses. With over 2000 employees, the institute hosts numerous laboratories and unique research infrastructures. It specialises in research across a range of crucial fields including sustainable resources and transport, space exploration, security, migration, health and consumer protection, energy efficiency and climate change, and growth and innovation. These diverse research focuses reflect the institute's mission to advance scientific understanding and develop innovative solutions for global challenges.

The following Section of the paper further describes the type of data used in the study and presents the sample composition of the survey conducted among the employees. Thereafter, the Section includes the explanation of how the environmental analysis of the navette services was performed.

4.1. Data Collection

The data supporting this study were collected using an online survey platform between October and November 2020. Given the pandemic context, with respondents not commuting or travelling for work, the survey explicitly referred to pre-pandemic choices. To satisfy all the objectives, the survey was divided in the following six parts (The reader can access the survey through the following link: https://ec.europa.eu/eusurvey/runner/Legacy-Mobility-Survey-2020 accessed on 16 March 2024):

1. Questions regarding the mobility habits and preferences of respondents prior to the COVID-19 pandemic.
2. Questions about commuting preferences and habits prior to the pandemic and expected commute and working pattern preferences once the population was allowed to both work from home and from office.
3. Questions about the intention to purchase an electric vehicle as well as preferred onsite locations of chargers and potential data sharing of charging patterns with the research institute.
4. Questions about the onsite mobility (the size of the research institute is 167 ha) and potential usage of mobility living lab solutions (such as droid delivery or autonomous shuttle).
5. Questions about the mobility preferences while traveling for work. As previously mentioned, the employees are encouraged to use a shared shuttle bus provided by the institute to reach the airport or train station. Questions asked in this section were used to understand personal preferences for traveling in a shared or private environment.
6. Socioeconomic and sociodemographic questions to gain insight into characteristics of the respondent, such as gender, age, employment, highest obtained education level, and household composition and size.

4.2. Sample Composition

The sample of the survey comprised more than 600 individuals, amounting to 23% of the total population. For data analysis, a weighted sample was generated based on the overall population margins with age and gender being used as the key weighting criteria. Nevertheless, the reader should note the specifics of the research institute population, which (unsurprisingly so for a research institute) is highly educated (with almost 40% of employees with PhD diplomas) as well as highly motorised due to its rural setting, with almost 90% of the households owning at least one vehicle.

The population of the research institution, while distinct in its high educational level and environmental awareness, displays a behaviour that may well be reflective of wider societal trends. This observation is pertinent considering the prevalence of vehicle ownership in rural settings, akin to our study context. Such a backdrop provided a robust test case for the adoption of shared mobility systems. The embrace of navette services by this demographic suggests that similar initiatives could find traction in broader populations, especially when aligned with targeted policy incentives and environmental goals.

4.3. Case Study Assumptions of the Environmental Analysis

To better understand the environmental impact of the institutional navette service an analysis of NO_X, PM10, PM2.5, and GHG emissions for the year 2019 was conducted. To obtain these values, the navette service needed to be recreated based on total annual data provided by the service management. The data included the total number of trips, the distribution by number of passengers, and the type of vehicles used. Moreover, the navette service can pick up or drop off the employee either at home or at work depending on if the trip is made during working hours. Therefore, the distribution by the pick-up/drop-off location was also used. The minor distance between the navette's storage location and the research institute was excluded from our calculations, as it was not expected to materially affect the findings.

To recreate the annual operation of the service, the total number of trips was generated randomly (6500 trips) using the distribution of the number of passengers and the origin/destination of the trip. For the home-based trips, the distribution of employees per postal zone was also used in the random generation.

Additionally, the results of the survey indicated that 15% of the respondents used a private vehicle for the trip to the airport, of whom 31% requested a compensation of cost borne.

The randomly generated trips and vehicle types were input to the Green Driving Tool [85], which allowed us to optimise the passenger pick up per each trip generated. Moreover, to obtain detailed information about the emissions, the trips and the type of vehicles were further input into the COPERT model mentioned before in Section 3.2.

In conducting our environmental analysis for the navette service, we meticulously selected input parameters to accurately reflect the vehicle profiles in use. The navette shuttles were represented in the Green Driving Tool and COPERT model as light commercial vehicles (LCVs) of the N1-1 category, specifically diesel engines produced between 2017 and 2019, adhering to Euro 6 emission standards. This classification ensured a precise match with the shuttles' emission characteristics. For the broader fleet analysis, data were procured from the site management, which provided comprehensive details on all vehicles registered on the site. Based on these data, we constructed a representative fleet mix composed of 20% Euro 6 Diesel SUVs from 2017 to 2019, 50% small petrol cars that met the Euro 6 standards and were newer than the year 2020, and 30% medium-sized diesel vehicles from 2017 to 2019 with Euro 6 classification. These categories were specifically chosen to provide a realistic depiction of the vehicle distribution within the fleet, allowing for an accurate assessment of the potential environmental impact under different operational scenarios.

In our study, the operational costs of the navette service are represented as the cost of leasing the service from an external provider given to us by the site management responsible for the upkeep of the service. This comprehensive cost per kilometre includes various components essential for the operation and maintenance of the service. Specifically, these components are vehicle maintenance and servicing, fuel costs, driver salaries, insurance fees, administrative costs, vehicle depreciation, and parking and toll expenses.

The operational cost of private vehicles was estimated with a detailed approach, with several key factors being considered. These costs included fuel consumption, calculated based on model-specific data and average fuel prices for 2019, highway toll charges, and the cost of airport parking for an average duration of two days, reflecting the typical length of work-related trips.

To further understand the environmental impact of the service, the following scenarios were considered:

S1: Current services: Currently, the navette service uses minibuses for all trips, except for VIP trips for which a passenger car is used. Additionally, 15% of trips are made using the private vehicles owned by the employees, as per the data obtained from the survey. The operational costs for the institution are calculated based on the survey responses. This scenario serves to estimate the current environmental impact of the service.

S2: Minibuses: All of the trips are made with the minibuses offered by the navette services.

S3: Minibuses and passenger cars: The trips with not more than two passengers are made with a passenger car offered by the navette services, while the minibus is used for trips of greater capacity.

S4: Private vehicles: All the trips are made using the private vehicles of the employees. Additionally, to calculate the total operational cost of the scenario, all costs borne by the employees are considered (fuel, parking costs and highway tolls).

These scenarios were constructed to assess the potential environmental impact comprehensively and were informed by interviews with site management and the personnel responsible for the navette service. These stakeholders suggested the scenarios as reflective of the available options, ensuring the analysis was grounded in practical operational considerations. This systematic approach to scenario creation provided a multi-faceted view of the navette service's environmental footprint, allowing for informed analysis and interpretation of results.

5. Results

In the following subsections, the results of the market segmentation and the environmental analysis are presented.

5.1. Hierarchical Clustering

The HCA was applied for up to 15 clusters. The choice of the optimal number of clusters was based on the dendrogram analysis and the Calinski–Hrabasz criterion [89], which resulted in the choice of four clusters. The dendrogram of the HCA clustering is presented in Figure 1. Next, Figure 2 depicts the principal component map with various colours standing for the four clusters.

In the presented PCA scatter plot, instances of distinct clustering categories occupying proximate positions in the two-dimensional space were observed. This phenomenon can be attributed to the intrinsic limitations of PCA as a dimensionality reduction technique. Although PCA facilitates the visualisation of complex, multi-dimensional datasets, it primarily focuses on preserving the variance rather than the original clustering structure. Consequently, data points that are well-separated in the high-dimensional space may project closely in the reduced space, particularly if the variance they embody aligns with the principal components. Moreover, the clustering algorithms define clusters based on multi-dimensional proximity, which may not always be apparent after dimensionality reduction. Hence, clusters that appear to overlap in the PCA plot may, in reality, be distinct when considering the full dimensionality of the data.

The four clusters exhibit distinctive profile characteristics. The first two profiles represent individuals who are inclined towards ridesharing in the navette service. In contrast, the third profile leans more towards choosing private cars than does the general population, distinguishing it from the first two profiles. The fourth profile stands out with the lowest inclination towards ridesharing. The hierarchical clustering analysis provided an insightful breakdown of employee preferences towards SAVs within an academic environment, identifying four distinct clusters with unique transportation proclivities. Adapting strategies to the preferences identified in each cluster enhances the understanding of potential SAV implementation. The hierarchical clustering could inform strategic approaches to addressing adoption challenges in shared mobility, which is crucial for the effective promotion of future SAV concepts.

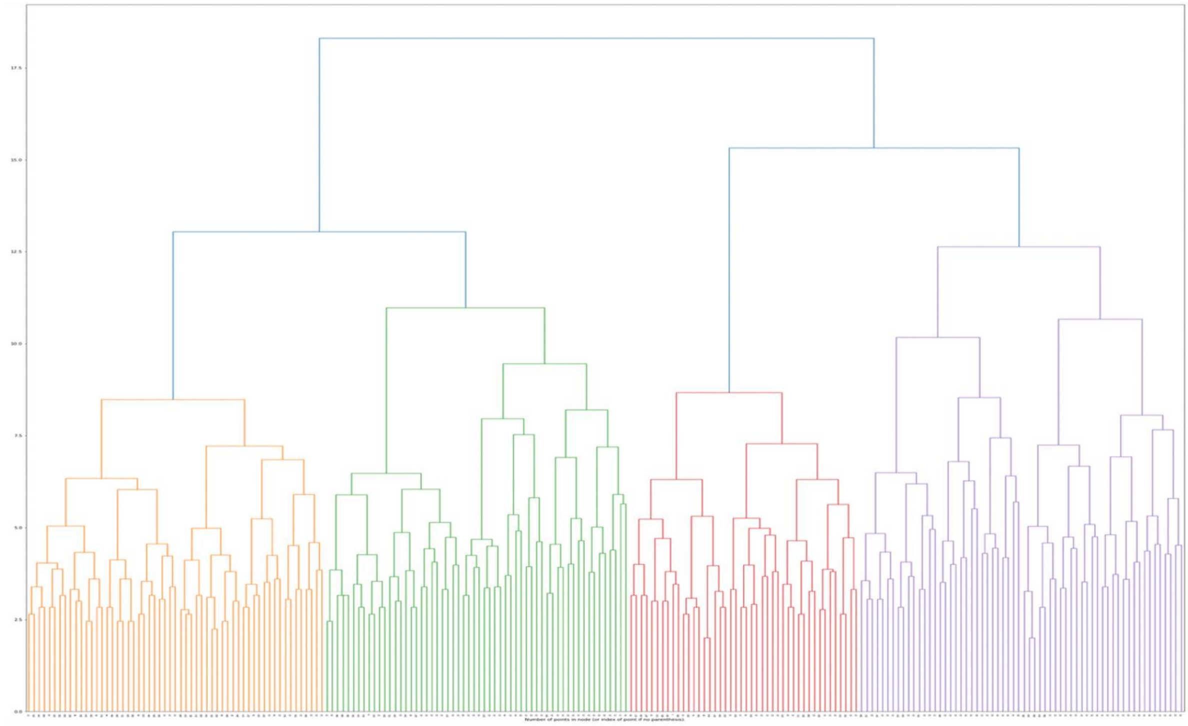

Figure 1. The dendrogram of the HCA.

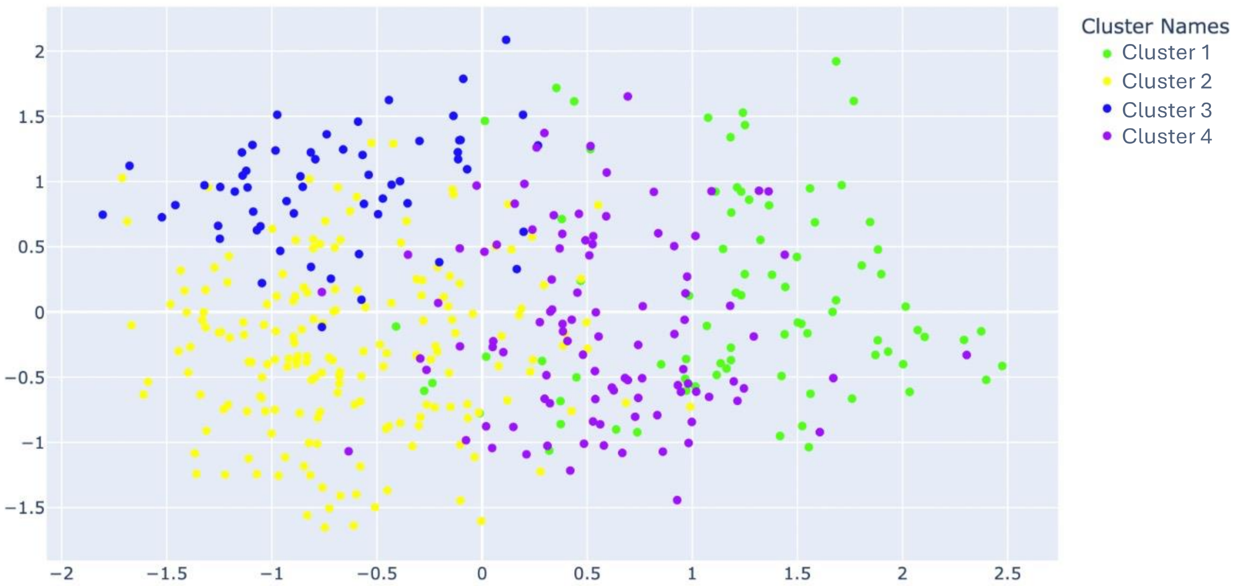

Figure 2. Individual principal component map.

Cluster 1 (19%): Cluster 1 is characterised by a strong inclination towards eco-friendly transportation ($\chi^2 = 99.17$, $p < 0.001$) and environmental conscientiousness ($\chi^2 = 156.78$, $p < 0.001$). Members of this cluster typically have fewer years of experience at their institution and are often in non-managerial roles. They tend to be younger, with a significant proportion in the 18-to-35-year age bracket, and are more likely to be single. Their transportation choices are aligned with their environmental ethos, favouring active and sustainable modes such as cycling or walking. Their transportation preferences reflect their commitment to sustainability, with 71% opting for eco-friendly and active modes such as cycling or walking as their primary means of transport (χ^2 = 168.89, $p < 0.001$). Environmental considerations (72%) and the sheer pleasure (χ^2 = 77.65, $p < 0.001$) of such trips (67%) are key factors influencing their mode choices. Additionally, this group exhibits a heightened sensitivity to travel costs (χ^2 = 44.69, $p < 0.001$), with 25% more likely to consider these expenses compared to just 7% of the general population, underscoring their practical approach to eco-conscious transportation. While almost all cluster members possess a driving license, they tend to own fewer cars per household compared to other groups (χ^2 = 43.08, $p < 0.001$). This is often due to their smaller household sizes. When it comes to short trips on site, they prefer walking or biking (81%) (χ^2 = 21.82, $p < 0.001$), citing environmental reasons as their motivation (62%) (χ^2 = 76.23, $p < 0.001$). They also appreciate the well-being associated with short walks during work hours (69%) (χ^2 = 47.63, $p < 0.001$). In the context of work-related travel, the group shows a strong preference for the institutional navette service (99%) (χ^2 = 71.59, $p < 0.001$). This choice is significantly influenced by the recommendation of their employer (56%) (χ^2 = 18.47, $p < 0.001$).

The first cluster embodies a demographic profile of younger, highly educated individuals with a keen sense of environmental responsibility. Their transportation choices align with their values, with a preference for sustainable modes. For Cluster 1, the appeal of SAVs lies in their potential to reduce carbon footprints, traffic congestion, and travel costs. Highlighting the environmental benefits and the communal aspect of SAVs can effectively resonate with this group's strong eco-conscious ethos. Incorporating elements such as shared rides and using eco-friendly vehicles can further enhance the appeal.

Cluster 2 (24%): Cluster 2 demonstrates a balanced gender composition with a marginally higher proportion of women. The age profile is predominantly within the 35-to-54-year age range. The cluster members typically have work experience at the institution, ranging from 3 to less than 10 years. In terms of transportation preferences, Cluster 2 exhibit a clear preference for private cars as their primary mode of daily commuting (82%) (χ^2 = 123.76, $p < 0.001$). This choice often arises from a perceived lack of viable alternatives (47%) (χ^2 = 23.63, $p < 0.001$) and a preference for the reliability of this mode (53%) (χ^2 = 55.03, $p < 0.001$). Importantly, a significant percentage of this cluster (54%) expresses interest in exploring more environmentally friendly alternatives, such as electric vehicles (EVs) (χ^2 = 7.03, $p < 0.05$). For short trips within the research centre, members of this group tend to opt for walking or biking (84%) (χ^2 = 21.82, $p < 0.001$), and their choices are motivated by the well-being it offers (80%) (χ^2 = 47.63, $p < 0.001$) and environmental considerations (62%) (χ^2 = 76.23, $p < 0.001$). In the context of work-related travel, the group exhibits a strong preference for the institutional navette service (96%) (χ^2 = 71.59, $p < 0.001$). This choice is significantly influenced by the lower environmental impact of the service (19%) (χ^2 = 7.64, $p < 0.05$) and their regard for the institutional recommendation (49%) (χ^2 = 18.47, $p < 0.001$). Notably, the preference for private cars for the members of Cluster 2 arises from the perception that they lack viable alternatives that would provide as much value. They are dissatisfied with their current transportation choice and contemplate switching to a more environmentally friendly option. This group exhibits a higher level of dissatisfaction with their car choice compared to the general population.

The members of Cluster 2, currently constrained by limited transport choices and an overreliance on private cars, represent a segment ready for change. SAVs can be positioned as an innovative, practical alternative to their current routines, offering the convenience of car travel without the associated costs and environmental impact. Informative campaigns that showcase the technological advancements and practical benefits of SAVs could be particularly persuasive for this group.

Cluster 3 (43%): Members of Cluster 3 tend to be middle-aged, with a significant majority falling within the 35-to-54-year age range. They bring substantial work experience to the table, with the majority having 7–20 years of service at the institution. In terms of transportation habits, Cluster 3 members exhibit a clear preference for private cars as their primary mode of daily commuting (92%) (χ^2 = 123.76, $p < 0.001$). This choice is predominantly driven by their appreciation for the comfort and flexibility that car travel offers (73%) (χ^2 = 39.88, $p < 0.001$) and their trust in its reliability (72%) (χ^2 = 55.03, $p < 0.001$). Members of this group are less inclined to evaluate the costs of traveling (3%) (χ^2 = 44.69, $p < 0.001$) and the environmental impact of their choices (7%) (χ^2 = 156.78, $p < 0.001$) compared to other clusters. Within the research centre, members of this group commonly use private cars for short trips between buildings (87%) (χ^2 = 190.03, $p < 0.001$), prioritizing comfort as the main reason behind this choice (75%) (χ^2 = 92.68, $p < 0.001$). For work-related travel, Cluster 3 members are more inclined to choose a private car over the institutional navette service (23% vs. 18% of the general population) (χ^2 = 71.58, $p < 0.001$).

Cluster 3, which prioritize the convenience and comfort of their transportation, might initially be sceptical of SAVs. To attract this cluster, SAVs could be designed with comfort and privacy in mind, such as offering individual compartments that allow passengers to work or enjoy their leisure time during the ride with additional amenities such as Wi-Fi and charging ports. This would create an experience that rivals the comfort of private car travel.

Cluster 4 (14%): Cluster 4 is characterized by a distinct composition primarily of senior male members, a majority of whom are over 55 years old. Their professional background is notable for extensive experience at the institution, with most members having more than 20 years of service. This experience often translates into managerial positions, distinguishing them from the general survey population (χ^2 = 9.34, $p < 0.05$). Their significant professional roles within the institution are evident. For daily commuting, private cars are the overwhelmingly preferred mode of transport within Cluster 4 (χ^2 = 123.76, $p < 0.001$), with reliability (67%) (χ^2 = 55.03, $p < 0.001$) and comfort (62%) (χ^2 = 39.88, $p < 0.001$) being a key factor in this choice. This preference also extends to short intra-campus trips with reliability (59%) (χ^2 = 64.38, $p < 0.001$) and well-being (45%) (χ^2 = 47.63, $p < 0.001$) as the main reasoning behind this choice, underscoring the importance of personal convenience and efficiency for short trips between buildings at the research institute. In the context of work-related travel, Cluster 4's use of private cars (48%) (χ^2 = 71.58, $p < 0.001$) markedly exceeds the general population's 18%, highlighting a significant divergence in transportation preferences. This choice is driven by the critical importance of travel time (52%) (χ^2 = 22.47, $p < 0.001$). The substantial reliance on private vehicles reflects a strategic consideration for time efficiency, both personally and for the institution, suggesting that the elevated use of cars for work-related purposes is seen as beneficial for meeting the professional demands of their roles.

The members of Cluster 4, who value reliability and personal efficiency, might be more inclined towards SAV services that offer a premium, private experience. Although this would come at a higher cost, providing a service that guarantees on-time travel, with the flexibility and privacy of a personal vehicle, could be a compelling proposition for this group.

For a better understanding, Table 1 present a summary of the prevalent profiles presented according to their mobility habits and attitudes, as well as modal choice for work-related travel.

Table 1. Summary of the prevalent profiles.

Variable	Category	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Total
Main mode for daily commuting	Car	11%	82%	92%	95%	75%
	Carpooling	5%	3%	6%	5%	5%
	Walking	12%	7%	1%	0%	4%
	Bus	11%	3%	1%	0%	3%
	Bike	59%	5%	1%	0%	13%
Reason of choice of main mode	Comfort	33%	50%	73%	62%	58%
	Privacy and pleasure	67%	20%	16%	22%	28%
	Reliability	23%	53%	72%	67%	57%
	Cost	25%	5%	3%	2%	7%
	Environment	72%	16%	7%	5%	21%
	No alternative	6%	47%	29%	28%	29%

Table 1. *Cont.*

Variable	Category	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Total
Intra-campus mode	Walking or biking	81%	84%	13%	26%	45%
	Car	19%	16%	87%	74%	55%
Reason of choice of intra-campus mode	Comfort	41%	17%	75%	45%	50%
	Environment	62%	62%	18%	31%	39%
	Well-being	69%	80%	41%	45%	56%
	Reliability	46%	23%	72%	59%	53%
Mission mode	Car	1%	4%	23%	48%	18%
	Navette	99%	96%	77%	52%	82%
Reason of choice of mission mode	Time	22%	18%	30%	52%	29%
	Recommendation	56%	49%	42%	21%	43%
	Reliability	37%	37%	40%	38%	38%
	Environment	10%	19%	10%	17%	13%
	Cost	19%	11%	24%	17%	19%

In examining the alignment of our study's results with existing literature, several interesting parallels and divergences emerge. Consistent with findings from studies at academic institutions [27,28,90], our research indicates a significant inclination towards ridesharing among students and younger community members. Studies outside of academic settings also align with the results obtained showing that older adults are less inclined towards acceptance of new mobility solutions [91,92]. This aligns with the observed trend that younger, less car-dependent demographics are more receptive to alternative modes of transport, including carsharing and ridesharing. However, our study extends these findings by demonstrating the effectiveness of a structured ridesharing program—the navette service—in not only appealing to these demographics but also in achieving tangible environmental benefits. This aspect of practical application and environmental impact analysis provides a novel contribution to the field, which has traditionally focused more on theoretical potential and preference assessments. Furthermore, our research offers a unique perspective on the operational challenges and successes of implementing a ridesharing program within a university setting. While previous studies have acknowledged barriers such as travel time, convenience, and individual preferences [31,32], our study delves deeper into how these barriers can be effectively overcome through strategic planning operational efficiency.

5.2. Results of the Environmental Analysis

In this Section, the outcomes of each navette service scenario are presented. The scenarios considered are the following: S1, current services (minibuses on demand and occasional use of private vehicles); S2, minibuses (exclusive use of minibuses for all work-related travel); S3: minibuses and passenger cars (combination of minibuses for larger groups and passenger cars for up to two passengers both offered by the employer); and S4, private vehicles (utilisation of only private vehicles by employees). For a comprehensive overview of these scenarios, including their specific operational configurations, please refer to Section 4.3. The results of the environmental analysis included GHG emissions in regards to their importance for the climate crisis as well as nitrogen oxides (NO_X) and particulate matters emissions (PM 10 and PM 2.5) because of their contribution to air quality. Moreover, to ensure that any of the analysed solutions is viable financially from the point of view of the institution, the approximate annual operational costs were estimated. The results of the analysis are presented in the Table 2 hereunder.

The results of the environmental and financial analysis show that the current scenario, in which passengers could choose to drive their own vehicle or be driven by the minibus, is not the optimal one. The emissions caused by an NO_X intensive minibus combined with private trips are higher than those of any other scenario. The particulate matter and CO_2

emissions could as well be lowered due to inefficient use of resources caused by usage of private vehicles. Moreover, the costs associated with the scenario are also a sum of operational costs for the navette service and the reimbursement for the usage of the private vehicles.

Table 2. Results of the environmental analysis of the navette service.

	Unit	S1: Current Services	S2: Minibus	S3: Minibus and Passenger Car	S4: Private Vehicles
NOx emissions	kg	252	235	231	170
PM 10 emissions	kg	24	19	12	35
PM 2.5 emissions	kg	14	11	10	21
CO_2 emissions	kg	180,359	142,337	139,046	253,985
Total distance driven	km	Minibus: 275,852 Private vehicles: 142,911	297,612	Minibus: 188,174 Passenger car: 109,438	746,716
Operational costs	EUR	329,841	320,437	320,437	288,776

In turn, if the employees are always driven to the airport by a minibus, the NO_X emissions and the particulate matter emissions decrease, as the majority of the trips previously taken by private vehicles could be shared in the navette. Moreover, the rides that were previously coming back empty would also secure passengers. In fact, the total distance driven could be decreased by almost 30% and, as a consequence, greenhouse gas emissions would also be substantially reduced (by over 20%). Further environmental benefits can be seen if a passenger car is used for trips with a maximum of 2 passengers. In fact, this scenario is the most environmentally beneficial one among the three, with an almost 10% decrease in NO_X, a 50% decrease in PM a 10, 30% decrease in PM 2.5, and a 23% decrease in CO_2 emissions. This is a result of using a more efficient vehicle for trips with a lower number of passengers. The operational costs for the two scenarios are equal, as the navette service fee was provided by the external company in a form of a quota per km driven with a passenger on board. Nevertheless, implementation of those scenarios leads to a cost improvement, with a possible further decrease, as 30% of the total distance is carried out by a cheaper in operation passenger car.

The scenario in which the navette services are removed and the private cars are used could be more cost-efficient as compared to having minibuses and drivers available 24/7 leading to 13% in cost reduction. However, this cost estimate might be speculative, given that currently only about 30% of individuals who use their private car for work-related travel seek reimbursement. Should this policy be enforced across the entire organization, it is likely that a greater number of employees would opt to claim reimbursement. This scenario also results in the least NO_X emissions because of the high emissivity of an LCV type vehicle as compared to the passenger cars. Nevertheless, because of high distance driven (126% increase as compared to the business-as-usual scenario), the remaining emissions significantly increase, with CO_2 emissions increasing by 40%. Therefore, considering the ambitious Green Deal objectives, the scenario should not be considered as being environmentally beneficial. Moreover, such a scenario would lead to exclusion of employees without a driver's license or a car and could not be considered sustainable.

Our study's exploration of the environmental impact of shared mobility services in an academic context offers a nuanced understanding of their potential benefits. This is in contrast to Henao and Marshall's [93] findings, where ride-hailing services in an urban environment led to a significant increase in vehicle miles travelled (VMT) and consequent emissions. The study by Khavarian-Garmsir et al. presents a more varied picture, suggesting that ridesharing services can have both positive and negative environmental impacts in urban settings, including increases in VMT and emissions in certain scenarios [94]. Similarly, the 2021 research of Tirachini on ridesharing observed that these services often contribute to increased VMT and emissions in urban areas [95].

In rural contexts, studies such as those by Thao et al. [96] and Lygnerud and Nilsson [97] demonstrated that ridesharing can integrate effectively with public transport, reducing reliance on personal vehicles and leading to environmental benefits. This suggests that shared mobility services, as indicated by our findings, could be effectively utilized in rural areas as well, where high user interest and optimized service usage could lead to environmental benefits. However, the contrasting results from urban contexts, as highlighted by previous research, imply that the effectiveness and environmental benefits of these services are highly context dependent. Urban areas, with their unique transportation dynamics, may not experience the same positive impacts as seen in academic or rural settings. This comparative analysis underscores the importance of considering the specific characteristics of each area when implementing shared mobility services, ensuring that their deployment aligns with the goal of reducing environmental impacts.

6. Policy Recommendations and Conclusions

Our study explored the use of a navette service within a research institute to understand preferences for shared mobility and to assess the environmental impacts of different transport scenarios. The environmental and financial analyses have provided critical insights into the potential for improving the efficiency of shared transport modes. The most notable finding is that transitioning to a model where passengers primarily use navette services, complemented by passenger cars for smaller groups, could lead to significant reductions in CO_2, PM10, and NOX emissions, aligning with the ambitious Green Deal objectives. However, it is clear that removing navette services in favour of private cars, despite potential cost savings, would not serve the environmental goals and would exclude those without a car or driver's license, highlighting the need for inclusive transport policies.

Policy environments play a critical role in the generalizability of shared mobility models. Across Europe, policy shifts towards sustainability are increasingly influencing public transportation choices. Our study's findings are thus significant in their implication that even in highly motorised rural communities, policies promoting shared mobility can lead to substantial environmental gains. These insights have the potential to inform policymaking that encourages shared mobility adoption more broadly, with the aim of replicating the environmental benefits observed in our study.

The technological framework of the navette service, designed to be user-friendly and efficient, is another key factor in its potential for acceptability. The navette service, central to our study, embodies a technology that is not exclusive to the research institute's setting, symbolizing widely implemented, shared mobility platforms. The technology underpinning navette services is representative of the shared mobility solutions increasingly prevalent in urban and rural settings alike, underscoring its potential applicability across various contexts.

The hierarchical clustering analysis within an academic environment highlights the diversity of employee transportation preferences and their potential openness to shared autonomous vehicles (SAVs). From the eco-conscious and younger Cluster 1, eager for sustainable commuting options, to the experienced and efficiency-valuing Cluster 4, each group presents unique opportunities for SAV integration. Clusters 1 and 2 show a readiness to embrace innovative, environmentally friendly transport solutions, indicating that emphasizing SAVs' ecological benefits and technological advancements could significantly appeal to their preferences. On the other hand, Clusters 3 and 4, with a current preference for private cars due to the comfort, reliability, and efficiency they offer, might be swayed by SAVs designed to offer comparable or superior experiences in these areas. Overall, understanding these distinct clusters and their transportation inclinations is crucial for developing targeted strategies that could facilitate the adoption of SAVs, potentially revolutionizing commuting within academic settings by aligning with varied user needs and environmental goals.

The widespread vehicle ownership in rural areas, akin to our study's setting, suggests that shared mobility services such as the navette could be successfully introduced in similar regions. The readiness of such populations to adopt shared mobility solutions indicates a potential for these services to complement, rather than replace, existing transportation habits, offering a sustainable alternative that resonates with current environmental policies and public sentiment.

The limitations of our study include its context-specific nature and the evolving landscape of vehicle technology in shared mobility services. The sample population from a single public administration body, while insightful, may not fully encapsulate the broader European context due to its unique characteristics, such as higher education and environmental awareness levels. Additionally, our environmental impact assumptions, based on current vehicle types and technologies, may not accurately represent future scenarios, as vehicle technology rapidly advances towards more environmentally friendly models. Moreover, while the 2019 navette service data predate the significant technological advancements in transportation and the disruptions caused by COVID-19, the resurgence in pre-pandemic levels of work-related travel provides a context in which these findings still offer valuable insights. These limitations underscore the importance of continuous research to update and refine our understanding, ensuring that the environmental implications of shared mobility services remain relevant and accurate.

Future research should further investigate the generalizability of our findings across different demographic and geographic contexts to validate the transferability of shared mobility services. Comparative studies could illuminate how various factors influence the adoption of such services and the role that typical shared mobility technologies could play in different settings. Additionally, longitudinal studies could assess how changes in policy and technology adoption affect the sustainability and efficiency of shared mobility over time.

In conclusion, our research confirms a general willingness among the studied population to adopt shared transport modes and identifies significant environmental benefits of such practices. These findings underscore the potential shift from vehicle ownership to sharing models, offering valuable insights for transport planning, policy development, and the future of mobility services.

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Informed Consent Statement: The processing of personal data was carried out pursuant to Article 5(1)(a) of Regulation (EU) 2018/1725, the Treaty of the European Union, specifically its Articles 1 and 11, and Article 298 of the Treaty on the Functioning of the European Union, in conjunction with Recital 22 of Regulation (EU) 2018/1725, regulation (EU) No. 1291/2013, and the commission implementing decision of 18 March 2019.

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