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An Evaluation and Prioritization Framework for Pilot First- and Last-Mile Ridesharing Services

Lambros Mitropoulos [1,*], Annie Kortsari [1], Aikaterini Maria Fotiou [1], Georgia Ayfantopoulou [1] and David Golightly [2]

[1] Hellenic Institute of Transport, Centre for Research and Technology Hellas, 57001 Thessaloniki, Greece; akorts@certh.gr (A.K.); cfotiou@certh.gr (A.M.F.); gea@certh.gr (G.A.)
[2] School of Engineering, Newcastle University, Newcastle upon Tyne NE1 7RU, UK; david.golightly@newcastle.ac.uk
* Correspondence: lmit@certh.gr

Abstract: Ridesharing is part of the innovative shared transport regime which aims to maximize the utilization of mobility resources. Gaining knowledge of ridesharing's impacts and how to assess them can significantly improve such services and thus contribute to their adoption among broader groups of travelers and to travel behavior change. This paper presents the framework deployed for assessing the impacts of a first-/last-mile ridesharing pilot in Athens, Greece, and capturing stakeholders' (i.e., a researcher organization, a public authority and an infrastructure provider) point of view about planning objectives. Four impact areas are defined in total, and Key Performance Indicators (KPIs) are used. In parallel, in order to understand the stakeholder priorities when designing ridesharing services, the Analytical Hierarchical Process is implemented to estimate weights for each impact area. Increasing rail ridership is considered the top priority for all stakeholders during the planning phase for a first-/last-mile ridesharing service, which may have various implications for future initiatives. In total, 28 participants used the ridesharing service as drivers and passengers during the demonstration period. Results show that although a ridesharing service is expected to be an asset in daily transport for city travelers, the technological constraints currently burden its usage. However, as supported by demo results and travelers' experience, there is great potential of ridesharing to contribute to a sustainable transport system and serve as a first- and last-mile solution to public transport.

Keywords: ridesharing; carpooling; ridesharing demonstration; demo outcomes; impact assessment

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1. Introduction

Population growth in the world's cities has led to an increase in the number of road vehicles; an increase in traffic congestion, fuel consumption and exhaust emissions; and a deterioration in the quality of life of citizens [1]. To make matters worse, most people commute alone, which leads to low vehicle utilization [1]. Road transport is the largest contributor to transport-related emissions in the EU and was responsible for 76% of all transport-related greenhouse gas emissions (including domestic transport and international bunkers) in 2021 [2]. Preliminary estimates of emissions from transport in 2022 indicate a further increase of 2.7% in 2022 [2]. The share of passenger cars in the EU ranged from 82.0% to 83.1% between 2010 and 2019 [3]. This share increased to 87.2% in 2020, reflecting the impact of the COVID-19 pandemic, which alienated citizens from public transport (PT). The share of coaches, buses and trolleybuses ranged from 9.5% to 10.4% over the same period and fell to 7.4% in 2020. For trains, the share increased from 7.1% in 2010 to 8.0% in 2019 before decreasing to 5.4% in 2020.

To reverse the negative effects of COVID-19 and increase public transport ridership, the EU works with cities and regions to develop a sustainable urban mobility policy [4]. Ridesharing is one of the mobility measures being promoted in response to the need to promote sustainability and multimodality. Ridesharing has been stated to be the most efficient means of reducing energy consumption, second only to banning driving altogether [5]. The term "ridesharing" is used by the international literature in reference to all types of transport where the trip is shared by the driver with other passengers [6,7]. Nowadays, advanced technologies contribute to the development of advanced ridesharing services. For example, machine learning is being utilized to accurately predict traffic spatiotemporal dynamics or calculate the estimated time of arrival, thus resulting in improved user satisfaction and likely in higher positive impacts [8]. Past studies have focused on dynamic ridesharing services that tend to match up drivers and riders on very short notice, or even en route [9], and motivating factors and barriers for the adoption of ridesharing services [10–13]. The most recent literature review on this subject [10] identified three main categories of factors that influence the uptake of ridesharing: (a) demographic characteristics [14], (b) psychological factors [14] and (c) situational factors which refer to external objective factors (e.g., policies, COVID-19).

The review of ridesharing literature shows that ridesharing has the potential to be part of the solution, in a broader context of sustainable mobility initiatives, and to serve as the first/last mile of a trip. A non-exhaustive list of ridesharing's benefits to society include: (a) reduction in energy consumption and emissions, (b) congestion mitigation and (c) reduced parking infrastructure demand. Individually, ridesharing may benefit citizens by: (a) shared travel costs, (b) travel time savings, (c) reduced commute stress and (d) often preferential parking and other incentives [15].

Several studies have focused on ridesharing's impacts (e.g., [15–18]); however, little information is provided regarding their methodological assessment. Consistency in the deployed frameworks to evaluate the impacts of ridesharing would facilitate the identification of good practices and transferability of results. Toward this end, this research aspires to contribute to the literature by introducing a framework for assessing impacts and prioritizing actions within a city that implements first-/last-mile ridesharing services as a pilot case. In this study, pilot cities or areas are defined as geographic entities where field experiments or demonstrations occur with the sole objective of testing new technologies, initiatives, policies or projects before they are implemented on a larger scale. The boundaries of a pilot area are selected in a way that serve the project's goals to evaluate the feasibility, effectiveness and potential challenges of these innovations in a controlled and real-world environment.

Specifically, this study presents the impact assessment and prioritization framework and outlines the results of a pilot ridesharing demonstration in Athens, Greece. It should be noted that ridesharing in this study has the meaning of carpooling; thus, it refers to a mode of transport in which individual travelers (i.e., driver and passengers) share a vehicle for a trip and split travel costs (no profit is foreseen), such as gas, tolls and parking fees, with others that have similar itineraries and time schedules [13,19].

In the remainder of this paper, Section 2 reviews literature related to ridesharing impacts and relative assessment frameworks. Section 3 introduces the evaluation and prioritization framework deployed in the pilot case in Athens, Greece. The key points of the demonstration are presented in Section 4. The results of the impact assessment and prioritization are described in Section 5. Finally, Section 6 concludes with a discussion of findings and recommendations for performing an impact evaluation for first- and last-mile ridesharing services. Other topics, such as factors affecting ridesharing use from the perspective of users [13,19] and the operator [20], are not covered herein.

2. Background

Ridesharing is associated with social, environmental and behavioral impacts [15,16,21,22]. A common framework for assessing ridesharing impacts typically defines categories in which impacts are expected (e.g., economic, social, etc.) and measures specific indicators which are grouped within those categories [18,21,23]. Studies that do not use empirical ridesharing data to estimate impacts tend to use statistical and survey data to model environmental and transport impacts [16,17,24]. The remainder of this section presents ridesharing impacts by focusing both on pilot projects and modeling results.

2.1. Impact Assessment of Ridesharing Pilots

The CIVITAS "Alternative Car Use" initiative showcased significant advancements in sustainable car use by establishing or enhancing existing ridesharing services within the European Union [18]. For assessing the impacts, three different impact categories were considered: (a) Economy, Energy, Environment; (b) Transport; and (c) Society [18]. The majority of pilots in this CIVITAS initiative monitored changes in energy and emission for a period of two years (2005–2007). The implementation of ridesharing services at the Krakow University of Technology (Poland) resulted in a reduction of 27% in operating costs and of 32% in fuel consumption between 2007 and 2008. In addition, it was claimed that the average car occupancy during workdays and ridesharing trips increased by 7% and 18%, respectively. Regarding societal impacts, awareness of ridesharing raised from 34% to 66%.

A ridesharing scheme was established in Norwich, England, and members of business and educational organizations were recruited. Between September 2005 and May 2008, collective fuel and car cost savings of EUR 99,369 were reported. In addition, around 304 tons of CO_2 and 993,690 vehicle miles were saved, and 1646 car trips were avoided during peak time [18]. Similar impacts were recorded between 2005 and 2007 in Toulouse, France, where total cost savings of EUR 321,880 and a CO_2 reduction of 0.338 kg of per km were reported for a medium-sized car [18].

Similarly, for the evaluation of ridesharing service for students in Debrecen (Hungary) [23], three different impact categories were defined: (a) transport system, (b) quality of service and (c) acceptance. Interviews conducted with participants and data (e.g., daily users) were utilized as a means of measuring impacts.

The EU-funded "Changing Habits for Urban Mobility Solutions" project (CHUMS) developed and deployed a methodology to assess the impact of the project; a set of indicators was defined and evaluated. These indicators were divided into three main groups: (a) contextual information, (b) target group information and (c) effects on mobility and the environment [21]. Based on before/after assessment, the attitude toward ridesharing for most target groups changed in a positive way. As far as the impact on travel behavior is concerned, the number of registrations increased by 2397 new users. It was estimated that 55,000 new ridesharing trips were generated, resulting in more than 640,000 extra ridesharing kilometers. The CHUMS measured a ridesharing share of 1.45% (between 0.01% and 36.17% for different user groups). Concerning the environmental impact:

- In Norwich (England), 57,192 Vehicle Kilometers Travelled (VKT) were saved (i.e., savings of 0.1% in CO_2 emissions).
- In Toulouse (France) 127,037 VKT were saved (i.e., savings of 0.09% in CO_2 emissions).
- In Perugia (Italy), 998 VKT were saved (i.e., savings of 0.01% in CO_2 emissions).

Two different methodologies were adopted in the EU SocialCar project to assess the impact of ridesharing: a citywide impact assessment modelling and a real-life testing of the RideMyRoute app [25]. The citywide impact assessment estimated the share of citizens who were willing to utilize the RideMyRoute app and studied the variation in mobility patterns among societal groups. Different scenarios were built, and the (%) change in car and PT share was calculated. The second method measured the RideMyRoute app impacts in four pilots. The impact assessment involved the evaluation of the smart app through [26]:

- Data collected by the app SocialCar;
- user acceptance surveys with formal testers, before and after testing;
- focus groups to capture more qualitative feedback and explore attitudes toward use in the future.

Finally, the INDIMO project focused on broadening the advantages of digitally interconnected transport systems to individuals who currently encounter obstacles in utilizing or reaching such solutions. One of its pilots included on-demand ridesharing services (door2door service) in Berlin. The general evaluation framework of INDIMO project was structured around five pillars: (1) user acceptance, (2) inclusivity and accessibility, (3) cybersecurity and personal data aspects, (4) process evaluation of the INDIMO Inclusive Digital Mobility Toolbox and (5) applicability and transferability assessment [27].

Regarding future ridesharing, electric vehicles (EVs) and autonomous driving are gaining momentum. MOIA, which is a subsidiary of the Volkswagen Group, is currently offering ridesharing service using Evs in Hanover and Hamburg. Its first ridesharing pilot project was carried out in Hanover in October 2017, and by July 2018, it became a public operation. MOIA's ridesharing scheme was also implemented in Hamburg in 2019. During these four years, approximately 1,000,000 registrations have been made, and 8,385,000 passengers have traveled in Hamburg, while the application has been exceptionally ranked (4.9/5). Since January 2023, MOIA has operated as a scheduled on-demand service within the public transport system in Hamburg. In this context, MOIA is considered to be partner of cities and public transport companies [28]. The ALIKE project aims to evaluate autonomous shuttles that can be conveniently reserved through a mobile app. These shuttles are designed to pick up passengers and transport them to their specified destinations. The operating phase is expected to start in 2025 [29].

2.2. Impact Assessment of Ridesharing through Modeling

In addition to pilot demonstrations, several studies have investigated the assessment of ridesharing impacts using statistical and modeling data. For example, Nechita et al. [30] simulated the fuel consumption and CO_2 emissions of commuters during a working day in Bacau (Romania). Results showed that during the morning peak time of 06:00–10.00 a.m., the total fuel consumption and CO_2 emissions from solo-driving commuters was 28.25 L and 64,561 g, respectively. Adding one passenger per vehicle results in a total fuel consumption of 13.11 L and CO_2 emissions of 20,174 g, which corresponds to over 50% savings in fuels and CO_2 emissions.

The Jojob is a carpooling application that assessed impacts related to: (a) CO_2 emitted by cars, (b) the number of vehicles on the road and (c) economic savings for commuters [31]. Application data (e.g., number of shared trips) were used to estimate a reduction of 275 tons of CO_2 in 2020, 66,702 journeys shifted from private means of transport, and EUR 462,550 saved by individual users who shared rides.

A stated preference survey was conducted in the Tehran Metropolitan Area (Iran) to estimate ridesharing impacts in energy efficiency and fuel savings [16]. IT was found that: (a) 44% of the participants would share a ride regardless of knowing someone to ride with, (b) 14% expressed a willingness to share a ride only if they could share it with someone they knew and (c) 26% were willing to share a ride (regardless if they knew someone to share with) to reduce their travel time. The annual fuel savings were calculated and are summarized in Table 1.

Table 1. Estimation of annual fuel saving for different scenarios in Tehran (Source: [16]).

Participants Willing to Share Ride (%)	Daily Trip Reduction (Morning Peak Hour)	Daily Fuel Saving (Liters)	Annual Fuel Saving for Working Days (Million Liters)
44	773,748	1,294,325	336.5
14	225,088	376,517	97.9
26	680,185	1,137,813	295.8

The effect of ridesharing depends on the vehicle ridership and the number of vehicles they reduce. Adding one additional passenger per 100 vehicles, if no additional trips are required, could result to potential fuel savings of 0.80–0.82 billion gallons of gasoline per year [24], whereas the same research indicated that if one additional passenger was added to every 10 vehicles, it could result in annual fuel savings of 7.54–7.74 billion gallons in the U.S. Ridesharing can significantly reduce greenhouse gas emissions by lowering fuel consumption. According to the same study, if one more passenger joined every 100 vehicles, it could result in an annual reduction of 7.2 million tons of greenhouse gas emissions in the U.S. Furthermore, if one passenger was added to every 10 vehicles, it could lead to an annual reduction of 68.0 million tons of greenhouse gas emissions [15].

Yin et al. (2018) [17] built four different ridesharing scenarios to appraise ridesharing benefits in the Paris region (France). The initial scenario (2015) defined the baseline situation, while the other three (for year 2030) differed regarding the vehicle occupancy and the cost parameters. The second scenario considered a uniform growth of vehicle occupancy by 50% for all trips. The third scenario assumed that ridesharing was more likely to develop over long-distance trips, and thus the vehicle occupancy varied. The results for three indicators are presented in Table 2.

Table 2. Change (%) of KPI values for different ridesharing scenarios in the Paris region compared to 2015 (Source: [17]).

	Ridesharing Scenarios		
	1	**2**	**3**
Traffic volume	MRH: +1.3%	MRH: −22.7%	MRH: −29.4%
	ERH: +1.0%	ERH: −21.3%	ERH: −28.5%
Road network congestion ratio	MRH: −1.5%	MRH: −10.9%	MRH: −19.9%
	ERH: −1.4%	ERH: −4.6%	ERH: −14.8%
CO_2 emissions	MRH: −1.5%	MRH: −18.4%	MRH: −35.6%
	ERH: −2.3%	ERH: −11.0%	ERH: −28.9%

MRH: morning rush hour, ERH: evening rush hour.

Synthesizing the literature data, it was concluded that ridesharing impacts may be grouped in three impact areas (Table 3).

Table 3. Categorization of ridesharing's impacts and description of measuring methods.

Impact Area	Goal	Measuring Methods and Tools
Socio-economic	Reduction of travel costs due to shared travel costs Reduction of commute stress Awareness raising toward ridesharing/sustainable mobility	Questionnaires/surveys combined with statistical analysis, focus groups before and/or after the pilot Recruitment and engagement of formal testers Data recording through ridesharing application
Environmental	Fuel saving/reduction of CO_2 emissions Reduction of vehicles on the road	Simulation combined with survey and other data Modelling combined with survey and other data
Transport	Congestion mitigation Decrease of single occupancy car trips Decrease in car mode share/increase in PT mode share Reduction of parking infrastructure demand	Direct air pollution measurements Simulation combined with survey and other data Modelling combined with survey and other data

The literature indicates a lack of a structured framework to provide guidelines for evaluating ridesharing services. Moreover, the examined ridesharing services concentrate on citywide travel and neglect the aspect of first- and last-mile trips. Impact assessment at the pilot level incorporates data collected through dedicated ridesharing applications to quantify KPIs related to environment, as well as participants' feedback to assess qualitatively the ridesharing service. This study aims to contribute to the ridesharing field by outlining the methodological framework that was used in a pilot city case and presenting empirical data and constraints to support forthcoming ridesharing demonstrations.

3. Evaluation and Prioritization Framework

The present study builds on a methodological framework (Figure 1) to systematically assess, prioritize and implement actions within a pilot city that are aligned with community objectives, stakeholder priorities and measurable indicators of success.

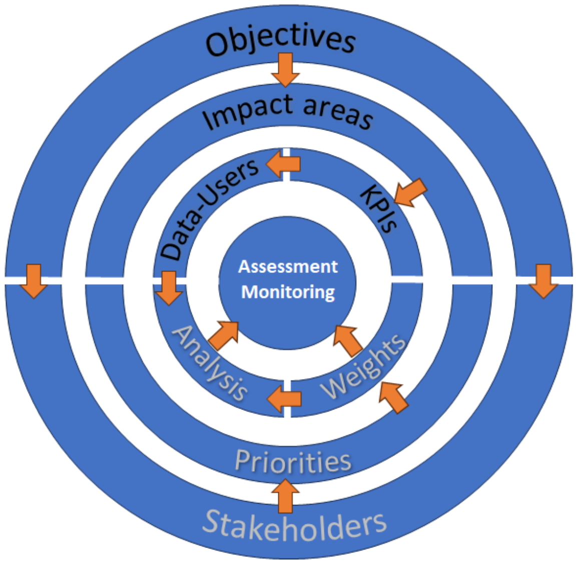

Figure 1. Methodological framework.

The layers of the methodological framework represent the order that each step is taken (first steps are located on the outer side of the circle), and the arrows between them show the input that is provided from one to another layer to complete the process. For example, while identifying the community objectives (i.e., layer objectives). The stakeholder groups related to ridesharing service (i.e., layer stakeholders) may also be identified. The objectives are used as input to stakeholders to initiate a discussion about their prioritization.

Step 1—Define community objectives: Identify and define the overarching goals and objectives of the pilot city. These objectives should reflect the community's vision for improvement to encompass various aspects like sustainability, quality of life, economic development, etc.

Step 2—Identify impact areas: Identify the key impact areas that align with the community objectives. These could include areas like transport, environment, education, healthcare, infrastructure and more.

Step 3—Define KPIs: Establish specific and measurable KPIs for each impact area. These KPIs should be quantifiable and provide data that can be used to assess the progress and success of the actions. For example, if the impact area is transport performance, KPIs could include reduction in traffic congestion, increase in public transport ridership, etc.

Step 4—Community stakeholders: Identify and involve a diverse group of stakeholders who represent different sectors of the community. This could include residents, businesses, non-profit organizations, local government, academic institutions and more.

Step 5—Determine stakeholder priorities: Engage with the identified stakeholders to understand their priorities relative to each impact area. Use surveys, workshops, meetings and other methods to gather their input and preferences. This step helps ensure that the actions chosen align with the needs and aspirations of the community.

Step 6—Prioritize actions (estimate weights): Using the insights gained from stakeholder input and the defined KPIs. Assign weights to different impact areas and KPIs based on their importance to the community objectives.

Step 7—Analyze user and stakeholder data: This synthesis phase helps in understanding which impact areas and actions are of higher importance to the majority of stakeholders and how users behave in a pilot demonstration.

Step 8—Assessment and monitoring: Assess the ridesharing services while monitoring progress over time to ensure that it produces the expected results. If adjustments are needed, make them based on the collected data and users' feedback.

The following sections describe the application of the steps to the ridesharing pilot demonstration in Athens, Greece. The ridesharing demo was supported by a mobile application, which is presented in Section 4.2.

3.1. Goals and Impact Areas

The first-/last-mile ridesharing pilot was implemented in the framework of Ride2Rail project, which was funded by the Shift2Rail (S2R) Joint Undertaking under Innovation Programme 4 (IP4) "IT Solutions for Attractive Railway Services".

Two impact areas are defined directly from the S2R objectives. The Shift2Rail initiative seeks to increase the capacity for a given infrastructure by increasing the number of trains (control command) and the number of seats per train (rolling stock) and reducing the life cycle cost (of the rolling stock and infrastructure). It is essential, however, to increase the number of passengers (occupied seats) by providing better reliability and quality of service—seamless travel and better integration of the rail into the overall mobility ecosystem [32]. Ridesharing as the first/last mile has the potential to increase the rail ridership.

Shift2Rail also aims to transform travel interactions into a fully integrated and customized experience, rendering the entire European transport system. However, enabling rail as the core mode of mobility can be challenging in a rural environment where there may be poorer provision of public transit.

The influence in the environment and the user satisfaction are added as core impact areas to complete the list. User satisfaction is related to traveler satisfaction and quality of services in the list above and it is one of the core impacts in planning of public transport systems [33].

According to the aforementioned, the four key impact areas (IA) and the respective objectives are:

1. Public transport ridership (IA1)—increase the number of passengers using public transport;
2. Rail connectivity (IA2)—improve rail connectivity with rural areas;
3. Environment (IA3)—minimize environmental pollution while traveling;
4. User satisfaction (IA4)—improve user satisfaction.

3.2. Key Performance Indicators (KPIs)

The definition and measurement of KPIs that fall under the specified impact areas are a core part of the demo performance evaluation. The SMART approach [34] was used to define the KPIs, and finally, KPIs applying to the demo site were set (Table 4). The KPIs are related directly or indirectly to each defined impact area.

For the calculation of rural trips (KPI #6), a boundary between urban and rural areas needed to be defined. Defining the urban area by geographic coordinates made it possible to calculate the number of trips in the countryside, which were considered as trips originating or ending outside this area. For Athens, it was decided that the best definition of the urban area, from a transport point of view, is the one that covers exactly the administrative area of the province of Athens.

The reduction In CO_2 emissions refers to the reduction in trips made by solo drivers and thus to a reduction in vehicle kilometers travelled. Solo drivers are expected to leave their cars and join other solo drivers, thus creating trips with two or more passengers.

Table 4. Key Performance Indicators (KPIs) and their relation to impact areas.

KPIs	Definition	Relation to Impact Areas
KPI#1 Number of app users	Demo site users who download the app and request at least one trip.	It is assumed that the number of downloads increases as the user satisfaction increases (IA4).
KPI#2 Number of completed app trips	A completed trip made by a demo site app user.	Given a well-designed application for ridesharing, the number of users is expected to increase, which will be the outcome of satisfied users. R2R has specifically addressed this by developing an app that addresses users' preferences and providing the opportunity to customize trip conditions (IA4).
KPI#3 Number of completed multi-occupancy vehicle trips with the app	A completed trip made by a demo site app user that involves rideshare.	Given a well-designed ridesharing service, the number of users is expected to increase, which will be the outcome of satisfied users. In this way more, multi-occupancy trips will be planned and completed (IA4).
KPI#4 Number of completed trips involving public transit/rail with the app	A completed multimodal trip.	Particularly, the demo aims to connect ridesharing to rail focus on first/last mile trips to public transport. R2R through the personalized services is expected to contribute significantly to the number of passengers using public transport (IA1).
KPI#5 Number of completed commuter trips with the app	A completed trip is a regular journey (work or education) conducted 4 or more times a week (incl. outward or return).	The R2R app gives the opportunity to plan shared trips in advance, so commuters that travel regularly may pre-plan their trips. Commuters will be able to plan trips with other commuters and set up a travel schedule, thus contributing to the number of passengers using public transport (IA1).
KPI#6 Number of completed rural trips with the app	A rural trip is when one or both origin and destination is from a rural (or suburban) location.	The demo uses a driver (DC) and passenger (PC) app to plan ridesharing trips. It is expected in rural areas, where people use more often their private vehicles to be able to increase availability of shared vehicles (increase supply through the DC app) and increase rail connectivity with rural areas (IA2).
KPI#7 Number of app downloads	Number of times app has been downloaded by unique users.	The personalized app, which has been built in research on users' motives, constraints and reasons for ridesharing, is expected to contribute significantly satisfied users (IA4).
KPI#8 Usability rate	Refers to user satisfaction	Refers to user satisfaction and is estimated based on survey results (IA4).
KPI#9 CO_2 emissions	CO_2 change before and after demo implementation	Ridesharing aims to reduce passenger vehicles by increasing occupancy and improving the environment (IA3).

3.3. Data Collection

Two different data collection methods were used to quantify KPIs; primarily, information was collected through a survey, and when available, data were collected by the application (R2R ecosystem) as an additional validation. The survey was emailed to demo participants after the pilot was conducted (the survey is described in Section 3.4). Once data collection terminated, the resulted data were cross-checked and harmonized. Table 5 presents KPIs and the corresponding data collection methods.

Table 5. KPIs and data collection methods.

KPIs	Data Collection Method
KPI#1 Number of R2R app users	Captured in the R2R ecosystem—users who reside in and around demo site area who have downloaded or registered to the service.
KPI#2 Number of completed R2R app trips	Captured in the R2R ecosystem—a journey request for a trip where geospatial data confirms the arrival at the destination; captured in survey—user indicates a completed trip.
KPI#3 Number of completed multi-occupancy vehicle trips with R2R app	Captured in the R2R ecosystem—a trip that has involved driver/passenger matching and confirmed by the arrival at the destination through geospatial data.
KPI#4 Number of completed trips involving public transit/rail with R2R app	Captured in the R2R ecosystem—a trip with origin or destination at a PT hub; captured in survey—user indicates multimodal trip.
KPI#5 Number of completed commuter trips with R2R app	Captured in the R2R ecosystem—analysis at end of the demo period identifies repeated trips for a user profile; captured in daily diary—identify commuter trips.
KPI#6 Number of completed rural trips with R2R app	Captured in the R2R ecosystem—the origin/ destination for a trip in designated rural/peri-urban area.
KPI#7 Number of R2R app downloads	Captured in R2R the ecosystem—the registration in the app.
KPI#8 Usability rate	Captured by a survey—the users' opinion for the application.
KPI#9 CO_2 reduction	Estimated using the travel behavior data of users and the survey responses.

3.4. Usability Rate

The usability of rideshare schemes is vital to adoption. Usability covers the ease of use, and usefulness, of any service. Usability extends beyond the functionality of ordering a trip. The mobile app is overwhelmingly the most common way to register and pay for shared travel services, and this is an aspect of the service that is often overlooked [35]. Janashani et al. (2019) [36] and Fishman et al. (2015) [37] found usability factors for a shared bike scheme included specific concerns around the ease of registration. A lack of clarity around features such as smart routing, registration or peer-to-peer coordination have proved to be significant barriers to shared travel app adoption [38] and comprise part of the overall 'friction' of using a service which may impede uptake [39]. However, it may be possible to encourage sustainable mobility by presenting information that can encourage a sustainable trip choice, such as identifying routes that are safe or more comfortable for cyclists [40]. This is important given that purely rational motivations (i.e., cost and time) have limited impact on moving people out of private cars and into alternative sustainable modes, and demonstrating the affective and aspirational benefits of modal alternatives is seen to be critical to mode shift [41,42].

There are a number of ways that usability can be assessed, including interviews, observations and surveys. Given that interviews and observations are time intensive and typically qualitative in terms of outputs, a survey-based approach was used to generate quantification of usability in a way that was highly convenient to participants and would therefore encourage compliance [43]. Furthermore, a number of pre-existing usability and user experience surveys exist, which would support the use of a scale that is standardized and potentially benchmarked. Typical scales involve the System Usability Scale [44], Technology Acceptance Model [45] and SUMI questionnaire [46].

The choice of scale was driven by factors such as whether the scale had previously been used and therefore validated in the ridesharing context, and having a scale that would be short enough to encourage a good response rate from participants. The System Usability Scale was chosen. The System Usability Scale (SUS) is a common usability measure [44,47]. The tool comprises a 10 item, five-point Likert scale (Table 6). Items are weighted in terms of both negative and positive responses and an overall percentage score of usability can be calculated through the following formula [48]:

$$(([i1 + i3 + i5 + i7 + i9] - 5) + (25 - [i2 + i4 + i6 + i8 + i10])) \times 2.5 = SUS\% \quad (1)$$

Table 6. The System Usability Scale for the Athens ridesharing demonstration.

	Strongly Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Strongly Agree
I think that I would like to use the Ride2Rail service frequently.	x	x	x	x	x
I found the Ride2Rail service unnecessarily complex.	x	x	x	x	x
I thought the Ride2Rail service was easy to use.	x	x	x	x	x
I think I would need the support of a technical person to be able to use the Ride2Rail service.	x	x	x	x	x
I found the various functions in the Ride2Rail service were well integrated.	x	x	x	x	x
I thought there was too much inconsistency in the Ride2Rail service.	x	x	x	x	x
I would imagine that most people would learn to use the Ride2Rail service very quickly.	x	x	x	x	x
I found the Ride2Rail service very cumbersome to use.	x	x	x	x	x
I felt very confident using the Ride2Rail service.	x	x	x	x	x
I needed to learn a lot of things before I could get going with this the Ride2Rail service.	x	x	x	x	x

Note: 'x' symbol is used to show that only one respond is accepted per question.

The scale is widely used and has been adapted multiple times to fit multiple contexts. Furthermore, the SUS has been benchmarked, with an overall SUS score of 50% or above being an indicator of acceptable usability [49]. Finally, SUS has been used on multiple occasions in the analysis of mobility solutions (e.g., [50]), including ridesharing (e.g., [51]), such as in its application for the assessment of SocialCar [26].

The SUS for Athens was translated into Greek and delivered to participants in an online format using Online surveys—a GDPR-compliant online survey delivery tool. Additionally, there were two free form questions: "What is the best thing about the ridesharing service? What did you like about it?" and "What problems did you face with the rides-haring service? What did you dislike about it?" The survey was branched, with participants selecting as a first question whether they had used the travel companion only, the driver companion only or both. The option selected took the participant through almost identical questions, and in this way, it was possible to determine the functionality that participants were giving their feedback on. When selecting both, participants were asked to complete questions first for the travel companion and then again for the driver companion.

3.5. Stakeholders and Priorities

In addition to the KPI analysis, direct investigation was conducted with demo stakeholders to contribute toward understanding priorities that should be set when planning such services.

Toward this objective, the Analytical Hierarchy Process (AHP) method was used as it is considered the most widely used method for multi-criteria analysis into the transport and urban logistics fields [52]. The AHP method is one of the most popular multi-criteria analysis methods in urban transport due to its ability to handle the complexity of decision-making while incorporating subjective inputs in a structured manner, facilitating clearer and more comprehensive decision processes. It helps break down complex decisions into hierarchies, thus making it easier to manage and evaluate multiple criteria. Additionally, it includes consistency checks to ensure that decision-makers' pairwise comparisons align logically.

Stakeholders who facilitated the demonstration were asked to evaluate the four principal goals when planning a ridesharing service with public transport. These goals are related to the four identified impact areas:

- Increase the number of passengers using public transport;
- improve rail connectivity with rural areas;
- minimize environmental pollution while traveling;
- improve user satisfaction for public transport.

The stakeholders were asked to indicate the importance (or preference) of goal 1 compared to goal 2 by rating it on a scale from 1 to 5. When the goal 1 is less important than goal 2, then the respective reciprocal value is attributed (e.g., 1/5). An online questionnaire was created to facilitate the prioritization of impact areas.

The given rating by the user fills a column-stochastic matrix (comparison or reciprocal matrix) sized by the number of the compared goals (priority vectors). The cells over the diagonal unitary cells are filled with the user's rating input value, while the ones below them are equal with the reciprocal value of the input value.

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} & a_{1n} \\ a_{21} & 1 & a_{23} & a_{2n} \\ a_{31} & a_{32} & 1 & a_{3n} \\ a_{n1} & a_{n2} & a_{n3} & 1 \end{bmatrix}$$

where:

$$a_{ij} = \frac{1}{a_{ji}},\ a_{ji} \neq 0 \tag{2}$$

The Normalized Principal Eigen vector, which represents the weight w_i of the element in row i, is calculated based on Equation (3). Consistency is examined by the Principal Eigen Value (λ_{max}) when summing up the product of each Eigen vector and the sum of the column of the reciprocal matrix and estimating consistency index (CI) through Equation (4) and consistency ratio (CR) (5).

$$w_i = \frac{\sum_j \frac{a_{ij}}{\sum_i a_{ij}}}{n} \tag{3}$$

$$CI = \frac{\lambda_{max} - n}{n} - 1 \tag{4}$$

$$CR = \frac{CI}{RI} \tag{5}$$

The Random Consistency Index (RI) depends on the number of elements n to be compared, as follows:

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

4. Demo Description

This section presents the demonstration carried out in Athens by focusing on the description of the area and the use case, the user engagement strategy and the application. This section aims to give readers an overview of the pilot to interpret the impacts assessment which is presented in Section 5.

4.1. Demonstration Area

Athens is the capital and largest city of Greece, and it is located in the Attica Region. It is the seventh-largest city in the European Union. While Athens is divided administratively into 113 municipalities due to its size, the Region of Attica has an area of 3808 km^2, a population of around 3,923,000 people and is subdivided into seven districts [53,54].

The public transport system in Attica consists of five main modes: metro, suburban train, tramway line, buses and trolleybuses, all of which are operated by various organizations [55]. Around 1,400,000 passengers per day are transported on the three lines and 67 stations that make up the Athens Metro network, which has a total length of 85.3 km [56].

The demo area in Athens consists of the 20 km rail corridor stretching from Athens Airport to Doukissis Plakentias rail station, along Attiki Odos toll road, which includes three intermediate stations in Eastern Attica: Pallini, Kantza and Koropi, all accessible via metro and suburban rail [55,57]. The suburban railway, which commenced its operation in 2004, is 20.7 km long and connects the Athens International Airport with the city center of Athens and the port of Piraeus. This area comprises territories of five municipalities with low population densities compared to the core center of the Athens municipality (Figure 2). The specific area was selected because it is connected through rail with central Athens, the population densities are lower compared to other regions of the prefecture of Athens, the frequency for public transport is low and bus stops more disperse. Therefore, the selected area serves the goals of the project, to test ridesharing as a solution for improving first-/last-mile mobility.

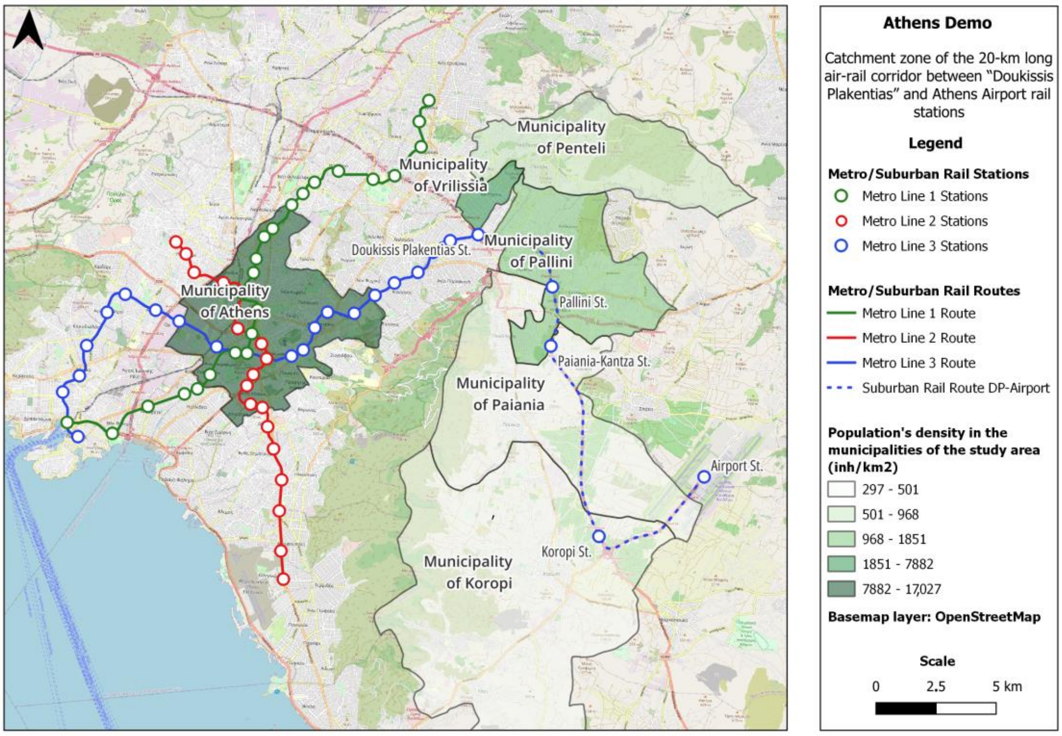

Figure 2. Map of the Athens demo area.

More specifically, two test sites were foreseen in the Athens demonstration:

1. Paid Park and Ride (P&R) with 500 parking spaces (PS) at D. Plakentias—located about 12 km from Athens' city center (i.e., Syntagma square).
2. Free municipal P&R with 300 PS at the Koropi station—located 13 km south of D. Plakentias station.

P&R amenities are available at both stations, promoting ridesharing for multimodal travelers. The key characteristics of the parking lots at both locations are displayed in Table 7. Due to parking fees, D. Plapentias P&R station utilization is about average. The P&R operator leases the property from the metro's owner near the D. Plakentia hub. An estimate of the typical parking time is from 6 to 8 h. In the morning rush on weekdays, the parking lot at Koropi station is full. Additionally, an average of 300 passenger automobiles spills over into the parking lot each day.

Table 7. P&R facilities' features in the selected intermodal hubs (Source: [58]).

Metro/Suburban Rail Station	Area (m^2)	Capacity	Fees per Hour
Doukissis Plakentias (DP)	15,200-paved	630 spaces	0.5€ (up to 12 h per day)
Koropi (KR)	6100-unpaved	300 spaces	Free

4.2. Ridesharing Application

The ridesharing demonstration was facilitated by the Travel Companion (TC) application (Figure 3). In more detail, it provides journey planning considering public transport and ridesharing services. The TC also enables the characterization of the options appearing in the user's search so the system can classify the different options according to their preferences.

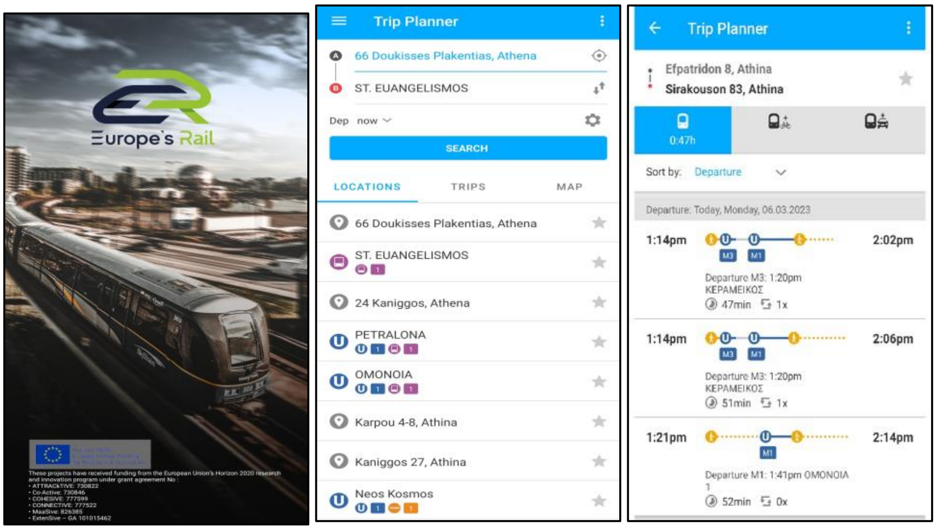

Figure 3. Travel Companion (TC) application (Source: [58]).

A stand-alone component named Driver Companion (DC) was also demonstrated (Figure 4). The DC enables drivers to create a ride and publish the planned journey so that TC makes it available to other users. DC provides valuable information during the journey by showing the origin of each traveler as well as their destination.

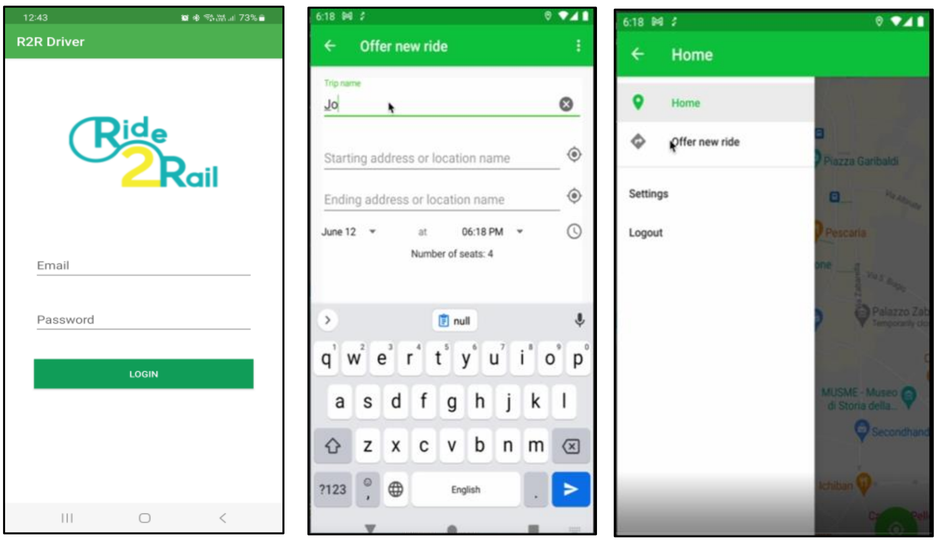

Figure 4. Driver Companion (DC) application (Source: [58]).

4.3. Use Case Scenario and User Engagement

The objectives of the demo are to: (a) explore and provide feedback on smart multimodal solutions that integrated ridesharing to increase car occupancy and rail ridership; (b) establish demand-responsive ridesharing connections with rural parts of Attica; (c) integrate ridesharing routes with the urban rail network, in combination with a network of peripheral urban rail hubs; and (d) evaluate innovative concepts of multimodality. The use case scenario can be summarized in the following storytelling:

- Marietta is an employee living in Koropi (suburban Athens).
- She commutes daily from Koropi to Zografou (central Athens without metro access).
- She needs to go shopping after work.
- On her return trip to home, she looks for a bus ride to reach the Evangelismos metro station (central Athens).
- After shopping in the vicinity, she rides on the metro to Doukissis Plakentias rail/metro station in the late evening when bus service level is low.
- Thanks to the Travel Companion, she uses a ridesharing driver to reach home.

The user engagement strategy included extensive dissemination through social media and websites, and then the final recruitment was supported by a Stated Preference (SP) survey. The primary goal was to determine whether commuters who utilized the metro/suburban rail system in the Attica Region to travel to and from Athens from eastern regions would be inclined to use a ridesharing service for their first/last mile of the trip, either as drivers or passengers.

In addition to the dissemination strategy and the SP survey, incentives were also provided to urge participation in the demonstration. Drivers who participated were awarded a EUR 50 voucher for gasoline, while riders were awarded a EUR 30 voucher for the supermarket.

5. Results

It should be noted that travel protection measures against COVID-19 were active during the demo period, which posed major limitations to recruit travelers (i.e., convince travelers to participate to the trials and conduct trips and especially to persuade drivers to share their private vehicles with strangers). These conditions contributed further to reduced participation in terms of commuters. Although restrictions have been relaxed, travelers were still afraid of using PT; concerns about shared transport and social distancing prompted a preference for personal vehicles over public transit, rideshares and other communal modes of transport [58]. Participation in Athens pilot may be summarized as follows:

- Number of registered passengers: 19.
- Number of registered drivers: 9.
- Number of surveys sent out to participants: 28.
- Number of users that completed the survey for estimating the SUS%: 17.

The demo in Athens lasted one work week, from 18 to 22 July 2022.

5.1. KPIs Results

The KPIs relate exclusively to the services offered by the R2R project. Thus, comparison with any pre-existing or contingent situation is not applicable and, consequently, it is not feasible to establish a baseline value. Table 8 presents the actual values per KPI compared to target values.

Table 8. Athens quantified KPIs.

Id	KPIs	Impact Area	Target	Actual
KPI#1	Number of app users	IA4	50	17
KPI#2	Number of completed app trips	IA4	500	26
KPI#3	Number of completed multi-occupancy vehicle trips with the app	IA4	10	15
KPI#4	Number of completed trips involving public transit/rail with the app	IA1	2	30
KPI#5	Number of completed commuter trips with the app	IA1	187	39
KPI#6	Number of completed rural trips with the app	IA2	500	13
KPI#7	Number of Ride2Rail app downloads	IA4	125	39
KPI#8	Usability rate	IA4	50%	64% TC 58% DC
KPI#9	CO_2 reduction	IA3	10%	18%

5.1.1. Public Transport Ridership

The KPI#4 and KPI#5 relate to the IA1-public transport ridership. The KPI#4 change demonstrates the potential of ridesharing to be used as a first-/last-mile mode to public transport to contribute toward increasing PT ridership. It should be noted that the demonstration took place in a rural/interurban area, from which travelers are willing to travel to the closest sub-urban rail station to reach central areas of Athens (and vice versa). On the other hand, completed commuter trips through the app (KPI#5) did not reach the target. The limited period of the demonstrations did not provide the opportunity to regular commuters to plan and trust an innovative mobility solution to complete their trips. This is aligned with most studies that have shown that it is quite challenging to persuade solo car drivers to carpool. Wang and Chen (2012) [59] investigated the transition from single-occupancy vehicle (SOV) to carpooling and concluded that despite the modest number of switchers, there are few factors that significantly affect the demand for moving from SOV to carpool. These factors include the commute length (a structural component) and respondents' affective bias in favor of carpooling (a psychosocial factor).

5.1.2. Rail Connectivity

Regarding rail connectivity (IA2), the KPI#6 remained too low compared to the target value. A possible reason for the low rate is attributed to the fact that travelers from rural areas in Athens, willing to join a ridesharing service with PT, are commuters. Consequently, since commuting trips were significantly reduced due to COVID restrictions, rural trips that would use rideshare with public transport were affected negatively. Additional considerations in order to justify the reduced number include the spread of teleworking/shifted mobility peaks, not the ideal time of the year for a demo execution because of the proximity of summer holidays and a heatwave in the city affecting people's choice to move in urban and rural areas.

5.1.3. Environmental Impact Assessment

Travel behavioral data of users who participated in the survey were exploited to estimate the reduction of CO_2 emissions at demo level (IA3). In this direction, several assumptions were made regarding the vehicle occupancy, fuel type and emission types. In this context, the average trip distance by passenger car in Athens was estimated to be 11.3 km. The average emissions per passenger car for petrol vehicles was 122.4 g/km, while it was estimated that 100% of passenger cars in the demo area were petrol cars [60]. Based on demo survey results, trips completed by ridesharing participants as drivers and as passengers were 7 and 11, respectively. According to Athens demo data, the overall ridesharing occupancy of passengers per vehicle was estimated to be 2.33, while 1.29 trips per person were conducted.

Three different scenarios concerning the modal share of travelers prior joining a ridesharing service were built in order to calculate the percentage change of CO_2 emissions.

Regarding the number of trips before and after joining ridesharing it was assumed that they will remain the same.

Case A: It was assumed that all trips for travelers prior to joining ridesharing were SOV trips. After joining the ridesharing demo, it was assumed that only those that participated as drivers (seven in total) maintained the role of a driver and shared their vehicles to the ridesharing program, whereas all others (participated as passengers—eight in total) were shared among previous SOV.

Case B: It was assumed that all trips for those who participated as drivers in the demonstration prior to joining ridesharing were SOV trips. For travelers that participated as ridesharing passengers, it was assumed that 50% of them were SOV and 50% were public transport users prior joining ridesharing. After joining the ridesharing demo, it was assumed that only those that participated as drivers (seven in total) maintained the role of a driver and shared their vehicles to the ridesharing demo, whereas 50% of PT users continued to use public transport.

Case C: It was assumed that all trips for those that participated as drivers to the ridesharing demo prior to joining ridesharing were SOV trips. For travelers that participated as ridesharing passengers, it was assumed that 15% of them were SOV and 85% were public transport users prior to joining ridesharing. After joining the ridesharing demo, it was assumed that only those that participated as drivers (six in total) maintained the role of a driver and shared their vehicles to the ridesharing demo, whereas 15% of PT users continued to use public transport.

It should be noted that PT users do not impact the environment since an additional PT service is not considered in the after case (i.e., PT operation does not depend on ridership). Therefore, the before-after cases in terms of CO_2 are equal for PT (no side effect). Since available passenger cars in the network are sufficient to accommodate previously PT users, an impact is not introduced. If a sufficient number of PT travelers decide to share a new passenger car or cars, then the impact of the new introduction in the network should be considered. However, such a case was not examined in this study since the number of passengers was low and the number of drivers was sufficient in the ridesharing demo. Table 9 presents the percentage change in CO_2 emissions for the three scenarios.

Table 9. Changes in CO_2 emissions according to the three scenarios.

	SOV	**PT Users**	**CO_2**
Scenario	Before	Before	Change (%)
Case A	100% (n = 18)	0%	−61.1%
Case B	100% of participants as drivers (n = 7) 50% of participants as passengers (n = 6)	50% of participants as passengers (n = 5)	−44.0%
Case C	100% of participants as drivers (n = 7) 15% of participants as passengers (n = 2)	85% of participants as passengers (n = 9)	−19.1%

The estimation of emissions is usually based on models, which have been advanced significantly due to different vehicle characteristics, road and environmental conditions, the diversity of pollutants and fuel types [61]. For example, ignoring the effect of acceleration and deceleration of the vehicles could pose challenges to the precision of outcomes, particularly in urban traffic zones featuring signalized intersections [62]. Except for vehicle-related characteristics (e.g., age, type, acceleration etc.) [63], a significant parameter is the scale at which emissions are calculated, which determines the required data. Emission models are divided according to their precision scale into macro (regional, national area), meso (local area) and micro (areas of a dedicated part of a city, intersection road sections) [61]. For instance, the COPERT and MOVES [61] models calculate emissions at the macro scale using the vehicle class, number of vehicles, weather conditions, load, average speed, distance travelled and so on. On the other hand, MODEM and EMPA [61], which are microscopic models, use the speed and the acceleration profiles of vehicles as input. Several studies have focused on different factors of traffic emissions [64], such as land use [65], socio-economic parameters [66], urbanization [67] and transportation structure [68].

Although the literature has shown that the estimation of on-road emissions depends on multiple and different factors, in this research, the effect of ridesharing depends on vehicle ridership and the number of vehicles they replace. The three cases presented here are considered to provide a range of impact values given maximum and minimum values. The greatest potential for ridesharing is estimated when single drivers join ridesharing services; thus, this finding should also reflect the ridesharing potential and constitute a policy direction for regions with high shares of SOVs.

Estimating emissions reductions from ridesharing programs faces multifaceted challenges. Variation and different functional units to report findings related to CO_2 emissions in the literature incommodes interpretation and comparison of results and highlights the need to follow a methodology that is flexible enough to generate results in different units. Primarily, securing comprehensive data on individual pre-ridesharing driving behaviors proves challenging, relying often on self-reported or limited information. Dynamic human behavior and changing travel patterns introduce variability, impacting the reliability of estimations. Variations in routes, traffic conditions and mixed transport modes further complicate calculations, while assumptions in emissions factors and technology limitations add to the complexity.

5.1.4. User Satisfaction

Concerning the improvement of user satisfaction (IA4), five different KPIs were measured (Table 8). User satisfaction was assessed through both quantitative and qualitative means. As presented in Table 8, two target values were reached while the values of the remaining three KPIs were below the initial target. In more detail, the number of completed multi-occupancy vehicle trips with the app (KPI#3) and the usability rate (KPI#8) exceeded the target, showcasing the great potential of ridesharing as a concept and, at the same time, the acceptance of the ridesharing application. On the other hand, the number of app users (KPI#1), number of completed Ride2Rail app trips (KPI#2) and number of downloads (KPI#7) did not reach the target.

The usability rates for drivers and passengers were estimated to be 58% and 64%, respectively, showing that passengers were more satisfied than drivers. The KPI#8 values showed that room for improvement existed for both TC and DC and especially for the latter. Both scores were therefore above the target threshold of 50%, with the travel companion showing a good usability response, given that this was a pilot (and therefore first trial of the application). Also, these scores are similar to SUS scores recorded by SocialCar (Wright et al., 2020) that ranged between 49% and 67% for four trail sites and thus indicate a good initial usability performance.

In terms of qualitative comments, positive comments about the Driver Companion included the design of the app, finding other travelers to share a ride and having one app to cover all modes. Dislikes included finding the app complicated, particularly with how roads were displayed. For the travel companion, positive comments were more orientated toward its functionality in terms of cost reduction, the display of available rides and it being a useful app. Dislikes included app complexity and issues with bugs.

5.2. Stakeholders' Prioritizations

For a stakeholder group to be included in the process of estimating priorities, at least five participants per organization should have filled in the questionnaire, which was considered adequate since they hold knowledge and practical experience with the matter [69]. Stakeholders from Athens included representatives from the research community, public authorities and an infrastructure provider (Table 10).

Table 10. Athens' stakeholders.

Stakeholder	Research Academia	Public Authority	Other
Stakeholder 1	Transport research organization		
Stakeholder 2			Critical Infrastructure Provider
Stakeholder 3		Municipality	

The research sector (Figure 5) prioritized the four impact areas equally with values ranging between 20% and 30%. Specifically, when planning for ridesharing services, the top priority was considered to be the increase of PT ridership (29%), while improving the environment was ranked last (22%). Similarly, the municipality ranked the increase of PT ridership (30%) first, while improving the user satisfaction was ranked last (16%). The critical infrastructure provider considered the increase of PT ridership (39%) more important when planning for ridesharing services. The lowest priority was given to the improvement of the environment (18%).

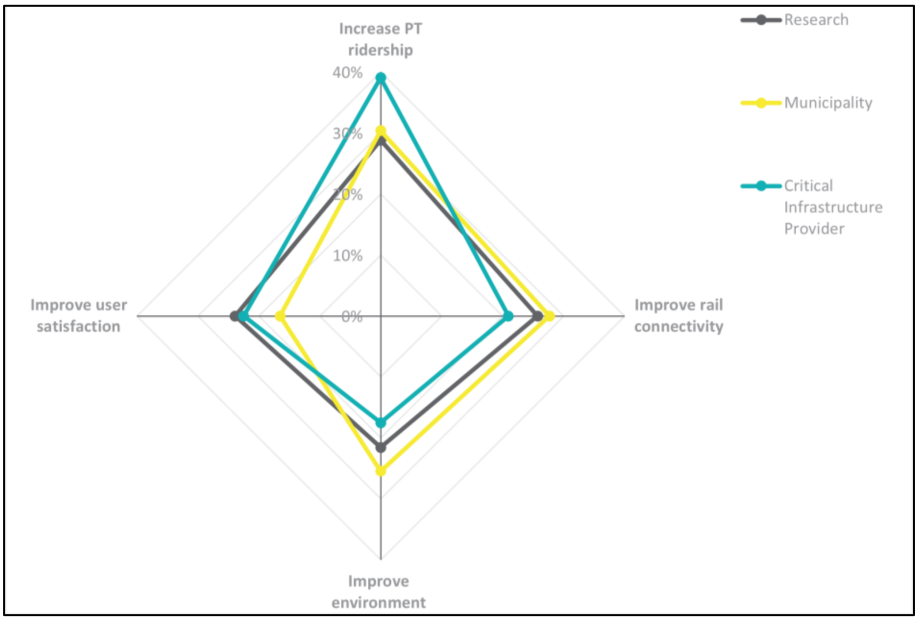

Figure 5. Athens' stakeholders' impact priorities.

The top priority, according to all Athens' stakeholders, was the "PT ridership" (33%), which was followed by the "rail connectivity to rural areas" (25%). The third place was attributed to both "user satisfaction" and the "environment" with 21% each.

6. Discussion

This study focuses on assessing the impacts and evaluating a first- and last-mile ridesharing pilot in Athens, Greece. It introduces a framework for assessing impacts across four defined areas and employs KPIs while considering stakeholder perspectives. While other demonstration studies have been presented in Section 2, there are several discrepancies that could be shared. The CIVITAS "Alternative Car Use" [18] initiative presents broader outcomes of the CIVITAS initiative, emphasizing reductions in costs, fuel consumption and societal awareness, while the EU SocialCar project [25] explores variations in mobility patterns. The CHUMS project [21] assesses impacts more broadly, covering changes in attitudes, registrations, trips and environmental aspects without focusing on specific stakeholder perspectives or detailed impact areas. On the contrary, in the Athens demonstration, the lack of data did not allow for fuel or VKT savings, which resulted in a limitation regarding quantified impacts. All previous studies involved citywide impact assessments, while our study focused specifically on first- and last-mile trips, resulting in different KPIs.

Data recorded through the survey and/or the ridesharing application indicate that KPIs' targets have not been fully achieved. Nevertheless, participation was sufficient to permit and collect necessary data to build evaluations on the demonstrated services. Discussion will focus on the evaluation of the users' satisfaction, the ridesharing potential, as well as the challenges that were encountered and led to the partial success of the demonstration.

6.1. User Feedback

The user feedback seems to highlight several issues and shortcomings in the context of the objective of Shift2Rail Strategic Master Plan and Multi-Annual Action Plan (MAAP) to develop a one-stop-shop solution for multimodal shopping and ticketing with integrated door-to-door, multimodal itineraries:

- App usability: To achieve a one-stop-shop solution, it is crucial to ensure a user-friendly and intuitive interface. The comments suggest that the app may be overly complex and challenging to use, which can deter users from utilizing the integrated multimodal services.
- Lack of communication and information: Seamless communication and information sharing between users (both passengers and drivers) are essential for multimodal travel. If users cannot easily connect or communicate, it hinders the integrated door-to-door experience.
- App stability: App stability is crucial for any travel application. Frequent crashes can lead to a poor user experience and erode trust in the one-stop-shop solution.
- Integration and functionality: The comments highlight several key areas where the app falls short of providing a comprehensive one-stop-shop solution. It lacks critical features such as real-time information, communication tools and the integration of ridesharing functionalities, all of which are vital for creating a seamless multimodal travel experience.

In summary, these comments reveal critical issues with both the Travel and the Driver Companion. To address these issues and align with the stated objective, the project team should prioritize simplifying the user interface, improving app stability, enhancing communication features and expanding the range of functionalities to provide a holistic and integrated travel experience. This would involve integrating ridesharing services, improving real-time tracking and communication, and adding safety and convenience features to meet the needs of travelers seeking multimodal solutions.

6.2. Stakeholder Priorities

The priorities are all important aspects of the IP4 (Innovation Programme 4) Shift2Rail Master Plan, which focuses on the three research and innovation areas: technical framework, customer experience applications and multimodal travel services. These priorities can have various implications for the Master Plan.

Increasing public transport ridership suggests a strong emphasis on encouraging more people to use public transport. Implications for the Master Plan could include developing features and technologies within the technical framework that enhance the attractiveness and convenience of rail travel. Customer experience applications should focus on making public transport more user-friendly and accessible. Additionally, multimodal travel services can integrate public transport options effectively into travelers' itineraries.

Improving rail connectivity is essential for creating a seamless and efficient transport network. Within the technical framework, this priority could lead to the development of technologies that enhance rail infrastructure, connectivity between different rail networks and interoperability. Customer experience applications should facilitate easy transitions between different rail services, while multimodal travel services should integrate rail options with other modes of transport.

The environment is a key concern in modern transportation. This priority likely means a focus on reducing the environmental impact of rail travel. Within the technical framework, this could involve developing eco-friendly technologies, such as cleaner propulsion systems or energy-efficient rail infrastructure. Customer experience applications may promote sustainable travel choices, and multimodal travel services could emphasize environmentally friendly options when planning routes.

User satisfaction is crucial for the success of any transport system. Prioritizing this aspect means focusing on creating a positive experience for travelers. In the technical framework, this could involve improving the reliability, safety, and comfort of rail travel. Customer experience applications should be designed to enhance the overall journey experience, and multimodal travel services should prioritize options that lead to higher user satisfaction.

6.3. Ridesharing's Potential

Ridesharing has demonstrated in the literature a significant potential to reduce road-based CO_2 emissions. The estimated impact depends on the transport mode that travelers preferred to use before joining the ridesharing program. According to a stated preference survey (n = 493) conducted in the framework of the Athens demo, almost 62% of the first-mile trips were made with a private vehicle, of which 45% were made as a SOV and 16% as a driver with passengers. The bus was used by 29.3% of the respondents, and 9.1% of them used a taxi for the first mile. Regarding the last mile, almost 47% of the sample commuted as a SOV, 11.8% used their car with at least one passenger and 20.1% travelled by bus. The average trip distance was 13.8 km.

In total, 57% of respondents would be willing to join a ridesharing program either as a driver (29%) or a passenger (28%). Table 11 provides CO_2 emissions reduction estimations when the share of travelers that are willing to join a ridesharing program ranges between 10% and 57% and the vehicle occupancy ranges between two and three passengers. As a result, in terms of environmental impact, there is great potential of CO_2 reduction ranging between 5.0% and 38.3% (Table 11).

Table 11. CO_2 emissions reduction for different ridesharing penetrations and vehicle occupancies for Athens.

	Ridesharing Penetration					
	10%	**20%**	**30%**	**40%**	**50%**	**57%**
Rideshare pass. ×2	5.0%	10.0%	15.0%	20.0%	25.0%	28.8%
Rideshare pass. ×3	6.7%	13.3%	20.0%	26.7%	33.3%	38.3%

It is important to acknowledge that emissions are directly proportional to the number of vehicles, assuming all passenger vehicles use gasoline as fuel. Consequently, reduced traffic congestion is expected due to a decrease in the number of vehicles on the road. Additionally, while improvements in vehicle fuel efficiency are not considered in this evaluation, given the limited adoption of electric vehicles in Athens, it can be argued that when electric vehicles increase, the reduction in CO_2 emissions will surpass the estimates provided in Table 11. For example, with a maximum ridesharing participation of 57% and electric vehicle utilization of 50%, the decrease in CO_2 emissions could reach 43%. Therefore, a thoughtfully designed ridesharing service, supported by a technologically advanced application, has the potential to enhance traffic conditions and the environment.

The conclusions drawn from the participants' feedback show that although a ridesharing service is expected to be an asset in daily transport for city travelers, the technological constraints currently burden its usage. Regarding the advantages of the Driver Companion (DC), most of the users applauded the concept of the app and mentioned that it helps reducing travel costs; however, they also reported cons including the complexity of the interface and unresponsiveness on some occasions. Similarly, users of the Travel Companion (TC) agreed that the application was very useful, and it helped reduce travel costs. In addition, a lot of participants found the user interface quite simple and easy to use and considered practical the ability to pay through the app. The integration of PT with ridesharing and other shared mobility modes was also considered as an asset.

6.4. Challenges

The inability to achieve all the targets set prior to the demonstration is related to several challenges arisen during the implementation of the demonstration. Citizens, in addition to the COVID-19 restrictions, were generally reluctant to use public transport and changed their mobility behaviors. Another important consideration linked to COVID-19 is the reluctancy to share vehicles with strangers.

The limited period of the demonstrations did not provide the opportunity to regular commuters to plan and trust an innovative mobility solution to complete their trips. This is aligned with most studies that show that it is quite challenging to persuade solo car drivers to share rides. In their study of students and staff at the University of Milan, Bruglieri et al. (2011) [70] discovered that when the following conditions are met, students are interested in ridesharing: allocated parking spaces, riding with known students, always traveling with the same crew and a reliable compatibility of departure and arrival times. The need for riding with known students and traveling always with the same crew implies that it is not easy for commuters to change their habits in the short term and commute with strangers [71]. One of the main attributes that influences the consideration of ridesharing in the traveler's choice of commuting mode is the frequency of carpooling within the last months [72]. This further demonstrates the difficulty of commuters to switch to other modes of transport in a short period of time.

For rail to become a more attractive transport option, it must achieve interoperability with other transport modes and mobility services, with regions, cities and people engaged in social and economic activities. The implementation of innovative mobility schemes such as ridesharing requires a well-structured and transparent impact assessment methodology to gain useful insights of what is effective, what is not and the corresponding reasons [73]. Such methodological frameworks most commonly include the definition of categories in which the impacts and relevant indicators will be evaluated. An integral part of the evaluation approach is the measurement of the 'baseline' or 'before' situation. Baseline surveys and measurements are necessary to assess subsequent changes resulting from mobility schemes and are carried out prior to their implementation [73].

7. Conclusions

The planned ridesharing service enabled seamless integration of various transport options, both public and private, through the development of matching algorithms, applications and a demonstration pilot; integration addressed the critical first- and last-mile challenge, allowing passengers to easily access and depart from rail services. This comprehensive approach to mobility not only improves accessibility but also enhances the efficiency and convenience of rail travel.

It should be mentioned that there were several challenges in implementing the demos as the COVID-19 pandemic broke out and travel restrictions were in place. This was particularly true after the first two big "waves" of the pandemic. As confirmed by the literature, the limited period of the demonstrations does not always provide the opportunity to regular commuters to plan and trust an innovative mobility solution to complete their trips. This is particularly true in a post-COVID environment with the above-mentioned new mobility patterns widespread in Europe and beyond.

Having in mind all challenges described above, through the evaluation of the demo's impacts, it came out that there is great potential to adopt ridesharing and increase PT ridership. Despite the shorter duration of the demo, targets of several KPIs were exceeded, such as KPI#3 (completed multi-occupancy vehicle trips with R2R app), KPI#4 (completed trips involving public transit/rail with R2R app) and KPI#5 (completed commuter trips with R2R app). The overall usability rate of TC and DC was around 59%, exceeding the target of 50%, and indicating that participants applaud the ridesharing concept, even at low TRL.

The estimated stakeholder priorities when designing a ridesharing service represented the research community, public authorities and critical infrastructure providers. The aggregated results showed that the top priority was the increase of public transport ridership, which was followed by the improvement of rail connectivity. Following the COVID-19 pandemic, a lot of effort was placed at the EU level to recover and even increase PT ridership, and this was also reflected by the estimated priorities overall.

Furthermore, pointing out limitations related to the estimation of CO_2 emissions, the authors have considered single-passenger trips that would be avoided when ridesharing was used instead (based on responses). This assumption relies on respondents reporting their intentions to use ridesharing services; however, people may overstate their willingness to use such services in surveys due to social desirability bias or other motivations which may lead to an overestimation of the potential reduction in single-passenger trips. Combining multiple methods can provide a more comprehensive estimation of emissions reduction resulting from carpooling efforts. Tailoring the approach based on available data and resources will enhance the accuracy of the estimation. Collection of data by deploying before/after surveys and using robust data collection methods, technological advancements and continuous monitoring will enhance the precision of estimating emission reductions attributable to ridesharing initiatives.

Secondly, the respondents stated intentions may not align with their actual behavior due to specific ridesharing conditions such as cost and availability of service. Additionally, changes that may affect travelers' choices, such as changes in urban planning, public transport or the availability of alternative transport options, are not considered in the used method. Finally, the number of participants in demonstrations is not representative of the entire population, leading to potential biases in the estimates.

Impact assessment and ridesharing services may be enhanced by the integration of machine learning. In essence, machine learning empowers ridesharing services by optimizing matching algorithms, predicting demand, analyzing environmental impacts and continuously improving the overall user experience. This technology may play a significant role in making ridesharing more efficient, accessible and environmentally friendly. Furthermore, the disaggregation of emissions per different pollutants would provide a more comprehensive evaluation of ridesharing services. Emerging technologies like machine learning and data mining may contribute significantly toward transforming carpooling planning. They may enable platforms to enhance the matching process between drivers and passengers, creating more efficient and satisfying rides. By analyzing extensive user data, these technologies can refine algorithms, ensuring better matches based on individual preferences and behavior patterns. Additionally, new language models (LM) have the potential to optimize ridesharing like they have been proposed to optimize delivery routes [74]. The LM may enable platforms to understand user behavior, preferences and historical data to create more sophisticated algorithms for matching drivers and passengers in a ridesharing service. By analyzing past routes and navigation decisions, these models may optimize routes dynamically, considering factors like traffic congestion and preferred routes, ensuring time-saving trips for both drivers and passengers. Moreover, language models facilitate natural language interactions, allowing users to communicate preferences, request rides and receive updates seamlessly through voice or text. Finally, such technologies may also support the identification of passenger and driver personality types based on their Tweets and feedback and group them in the same car with similar personalities, which will enhance user experiences, as the platform can tailor rides based on individual preferences [75].

Ridesharing has demonstrated a great potential for feeding PT and increasing its ridership, yet the technological barriers and provision of incentives should be well integrated to gain new customers that trust and feel confident to use this innovative mobility solution.

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