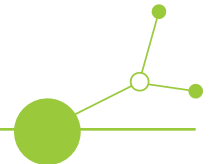


D.1.2.3 Joint strategy and action plan



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A. Introduction

This document is part of Deliverable 1.2.3 of the Interreg CENTRAL EUROPE 2021-2027 CE0200590 - Green LaMiS Project. The document is developed within the Activity 1.1 - *Development and adoption of the common strategy and Action Plan* of the WP1 - *Assessment and monitoring of services' environmental impact for a Joint Action Plan*.

This document reviews relevant literature and best practices for making HDSS more sustainable. Based on these findings, it develops a general framework for categorizing HDSS and identifies key actions to enhance their sustainability. The focus is on selecting suitable vehicle types for different purposes and optimizing trip planning and scheduling tools. These methodologies will lead to a set of general recommendations that can be adapted to meet the specific needs of various service providers.

The second part of the document presents an action plan for municipalities, derived from the general recommendations and further refined to provide a structured implementation strategy. The scope of the recommendations is the project's lifetime and derived from the scientific literature focusing on CO₂ emission reduction. During the project's lifetime the impact of the recommendations can be monitored and guaranteed. However, the final decision on implementation is made by the municipality that can consider other factors, not discussed in this document.



B. Literature review, best practices

Although sustainable mobility is very relevant and intensively researched topic, in the domain of home delivered social services, the literature is incomplete. Organizations recognize the importance of sustainability and attempt to change their processes to adopt more environmentally friendly solutions. In Corporate Social Responsibility programs, mobility plans are more and more important as processes involving travel can have significant environmental impact [1]. On municipality level, the EU also proposed guidelines on implementing sustainable urban mobility plans, giving recommendations and listing best practices in doing so [2]. Both types of mobility plans include strategies related to promoting alternative transport modes, parking and the sustainable use of company vehicles, work schedules and telecommuting, and designating transport coordinators [3]. Gorges and Holz-Rau [4] provide a semi-systematic literature review and bibliographic analysis of corporate mobility management, focusing on reducing carbon footprints and improving sustainability. They emphasize leveraging technology and a systemic transition toward zero-emission goals using electric and shared mobility. Additionally, an alignment of enterprises and urban transport planning (e.g., parking rules) is needed.

Most of HDSS related works deal with improving the quality and coverage of service or try to tackle social services as an operations research problem (e.g., [5], [6]). The literature review paper by Cissé et. al. [7] summarizes relevant routing and scheduling optimization problems related to home delivered services. On the other hand, as pointed out by [8], issues like resource dimensioning, home care modelling and districting problems are less treated.

Liu et. al. [9] deals with assigning social services to patients in need. The algorithm operates in three steps: i) sort patients by priority, ii) sort services by cost, iii) match patients to the most suitable, low-cost, and available service. The proposed tool works with multiple services and focuses on reducing costs.

Bräysy et. al. [10] explore optimization techniques for home-delivered meal services. The study models the delivery problem as a multiple Travelling Salesman Problem with time windows (m-TSPTW) and aims to minimize costs by reducing total travel distance and the number of vehicles used. They conclude that utilizing routing optimization software significantly reduces costs and resource consumption compared to manual planning. Additionally cold meal deliveries can further streamline operations while meeting customer needs. They underline the need for flexible delivery time windows that can be extended for the sake of energy efficiency and centralized loading facilities. They demonstrate their findings through a pilot in Finland.

The high cost of inefficient transportation of clients for social care services and methods to reorganize transport in a region in the Netherlands are addressed in [11]. Two strategies are proposed by the author to reduce both the number of vehicles required and the total kilometres travelled: i) horizontal cooperation strategy, in which clients remain with their current care provider, but the transportation is coordinated from a central vehicle depot. ii) Client allocation strategy, where, in addition to the central vehicle depot, clients can also be allocated to other care providers if this is beneficial for the transportation routes.

A decision support framework for optimizing transportation and staff scheduling in home health care is presented in [12]. It uses an optimization framework to address challenges of simultaneous scheduling of services and home delivery tasks. For case study, it uses synthetic data from Hong Kong. The main finding of the paper is that synchronized scheduling and multi-vehicle routing algorithms improve efficiency.

Cappanera et. al. [13] extended scheduling optimization by balancing the operator workload and users served considering caregivers with different skill levels.

An innovative approach to improving community health programs in resource-limited settings is presented in [14]. The case study took place in rural Madagascar and used OpenStreetMap data and Vehicle Routing Problem with Time Windows (VRPTW) algorithms. It focuses on two types of interventions: mass distribution



campaigns and proactive community case management. The study revealed significant variability in the resources required to serve users in different areas highly influenced by the geographic layout and population density. The researchers integrated the optimization results into an e-health platform, enabling program managers to visualize resource needs and design tailored interventions.

Since most HDSS operate in an on-demand way or on a fixed schedule, visiting the users at fixed times and for the convenience of the users, always the same caregiver visiting them, there isn't much flexibility in how these organizations serve users. On the other hand, there are some ways in reducing their carbon footprint of their mobility. Based on the above literature review, the key intervention points are:

1. Electrification of their vehicle fleet.
2. Promoting mode shift to greener modes of transport (e.g., smaller vehicles, using public transport (if available) or micromobility for short distances and if the weather permits it).
3. Purchasing energy from greener sources.
4. Optimizing routing and scheduling by trying to avoid congestion, planning daily activity chains and prioritizing routes with the least fuel consumption.

The following sections will elaborate on the above actions and propose some suggestions and best practices for HDSS.



C. General framework

Based on the literature, this general framework defines key dimensions for categorizing HDSS mobility. It also provides a list of vehicle options, outlining their advantages and disadvantages for HDSS. Additionally, the document introduces trip planning and routing strategies, supplemented with practical examples specific to HDSS.

1. Key dimensions for categorizing HDSS mobility

1.1. Service delivered

- A caregiver visits the users at their homes to provide some service
- Items (e.g., meals, groceries, medicine, bills) delivered from/to the user (assuming the item is not oversized or overweight)
- Personal transport service for the users

1.2. Distance

- Within the city (short, <10km trips)
- Municipality level (>10 km trips)

The frequency of the service and number of users served is rather related to the size of the service provider. Scaling the service is only briefly considered in the recommendations. However,

- road topology,
- traffic characteristics and public transport availability,
- weather,
- charging infrastructure,
- and organizing how users are serviced (i.e., activity chains)

play important roles in emissions and may rule out some transport modes.

Based on the above classification, a set of measures and recommended transport modes that are universal can be formulated. For specific service providers, it can be tailored further.



Table 1 Recommended transport modes for service types

Distance \ Service del.	Short (<10 km trips)	Long (>10 km trips)
Caregiver visit	Micro-mobility (e.g., bicycles, e-bikes, e-scooters), public transport, walking	Electric cars, electric motorcycles, public transport
Item delivered	Cargo bikes, e-cargo bikes, e-scooters, public transport, walking	Electric cars, electric vans, public transport
Personal transport	Electric cars, electric vans	Electric cars, electric vans

1.3. Road topology

- Hilly terrain might rule out active modes, such as bicycles or excessive walking.
- Narrow roads and limited parking availability might rule out cars or vans.
- Unsafe paths for cycling (e.g., cobblestone roads, mixed traffic, etc) might rule out micro-mobility.

When planning the routes, road quality and topology must be taken into account for a given mode. If choosing safer routes results in much longer journey times, a mode shift might not worth it. Even if the transport mode is carbon neutral, longer trips will reduce the productivity of the service.

1.4. Traffic characteristics

- In heavy traffic, micro-mobility might be more efficient compared to cars or vans.
- If there is no public transport available, or the coverage is not sufficient (both temporally and spatially), using public transport significantly affects the reliability and efficiency of the service.

When planning the routes, real-time traffic information can help determining not only which routers to take but also which modes to use if it is possible to choose alternatives.

1.5. Weather

- If the weather is bad (cold/hot temperature, strong wind, rain, snow), modes where the employees are in the open (e.g., bikes, scooters), could degrade the wellbeing of the employees, consequently making the service quality worse.

A general recommendation considering weather, is to organize the work considering weather too: if the weather is good, encourage green modes.

1.6. Charging infrastructure

- When considering electric mobility, the availability of charging infrastructure and charging costs must be considered.
- In case of longer trips and no time for recharging (continuous utilization of the vehicle), electric vehicles may not be optimal for the service.



If the service provider considers use of electric vehicles, they shall also consider setting up proper charging infrastructure and charging strategies. The charging of electric vehicles (EVs) can be done with different strategies, significantly impacting both trip planning and costs.

Regarding the charging infrastructure, there are three options [15]:

- Using public charging infrastructure: this approach has zero investment cost (if the EVs are already available). On the other hand, this has the highest running cost. Additionally, even though the municipality may have proper charging infrastructure, its availability cannot be guaranteed. Failure to find free chargers or two long waiting times for charging can risk being able to provide the service due to the unavailability of the vehicle.
- Charging the vehicles at the employees' homes: this places the responsibility of charging the vehicles to the employees. This approach could help reducing overall trip length if the employee can directly travel to the user. This is only true if no items are to be picked up at the headquarters of the service provider. In such cases proper reimbursement policies are needed to cover the charging costs. Additionally, employees cannot be enforced to charge company vehicles at home, because employees may live in areas where they could only park the vehicle on the street incurring additional costs or plugging in the vehicle isn't feasible (e.g., living in a flat or the electrical wiring is insufficient). Home charging can only be done with proper contractual agreement between the employee and the employer. If the employee can self-produce electricity (e.g., has solar panels on their rooftop), charging company vehicles could yield a green solution and contribute to a smart-grid approach.
- Charging the vehicles at the service provider's headquarters: if vehicles are parked at the service provider's headquarters, overnight charging is logical. Depending on the number of electric vehicles, the electrical wiring and the charging infrastructure might need to be upgraded to cope with the extra load and cover the energy needs of mobility. Improving the headquarters with renewable energy generation (e.g., solar panels) can reduce running costs and result in greener outcomes. Costly fast charging infrastructure is only necessary if the vehicles are heavily utilized. Preliminary calculations for improving the infrastructure are necessary, considering the price of purchased electricity and investment costs.

2. Types of vehicles for HDSS and their key features

2.1. Small vehicles for HDSS - Microbomility

Lightweight, often electric-powered vehicles designed for short distances, typically within urban areas [16].

2.1.1. E-scooters

E-scooters are versatile, affordable, and have a 15-60 km range with a top speed of 25-40 km/h. They're easy to park, portable, and can be folded for transport. However, heavier models can be harder to carry, and they're not ideal for use in rain, snow, or extreme temperatures. Has limited carrying capacity. Batteries can take up to 4-8 hours to fully charge (depending on size).



2.1.2. E-bikes (Electric Bicycles)

Electric bikes have higher initial and maintenance cost compared to traditional bikes. Depending on battery size they have 40-120 km range with one charge and can go as fast as 25-40 km/h. Can easily handle inclines with motor assistance and have regenerative braking feature. It has low (well to wheel) emissions. Has limited carrying capacity.

2.1.3. E-mopeds

E-mopeds are cheaper to run than fuel-powered mopeds and have lower maintenance costs and have significantly lower environmental impact. Good for short to medium-distance travel (typically 40-100 km range per charge) with speeds up to 25-50 km/h, suitable for urban use. They are easy to ride, with no manual transmission or clutch. Batteries can take up to 4-8 hours to fully charge, limiting their availability. Heavier than bicycles or e-scooters, making them harder to move manually. Requires driving license, registration and insurance in some countries. Performance may decline in rain, snow, or extreme temperatures. There are specialized builds (e.g., covered, three-wheeled, etc.) that are developed for specific tasks, e.g., item delivery.

2.1.4. E-cargo bikes

Electric cargo bikes are similar to regular cargo bikes but have an electric drive, assisting pedalling or throttling, reducing strain, even on hills. They have 40-100 km range with 4-8 hours of charging time. Their capacity is similar (100-250 kg) to regular cargo bikes. Ideal for heavy loads, hilly terrain. Susceptible to bad weather.

2.1.5. Conventional Bicycles

Bicycles are affordable and have low maintenance. Since they have no external power source, its range and speed depend on the user. They are easy to park and lift. It has zero emissions, have limited carrying capacity and limited use in bad weather.

2.1.6. Cargo bikes

Cargo bikes are heavier and slower than conventional bicycles but have freight capacity up to 250 kg making it suitable for item delivery in urban areas. They come in various designs (e.g., front-loading, longtail, or trikes) to suit different cargo needs. They have no emissions and much cheaper to operate compared to cars or vans. Can use bike lanes and park anywhere. On the other hand, they are heavier than regular bikes, making them harder to store, transport, or manoeuvre in tight spaces. Can be challenging to ride without e-assist, especially when fully loaded and takes time to learn using them properly.

2.1.7. Microcars

Microcars (e.g., Renault Twizy) are smaller than regular cars, can only transport one (or maximum two) passenger(s). They are easier to navigate in urban areas and have low environmental impact. They exist in small cargo version too. In some countries, microcars are classified as quadricycles, requiring less stringent licensing or registration. Lower speeds (typically 45-90 km/h) make them unsuitable for highways or long-distance travel and lack many safety features a regular car has. Electric microcars have limited ranges (50-



150 km), making them unsuitable for long trips. In contrast to most other micromobility options, they are less sensitive to weather.

2.2. Passenger cars and vans

Passenger cars and vans are the most versatile mode of transport. For passenger transport cars and vans are the most appropriate. Vans have larger carrying capacity (up to 3,5 t gross vehicle weight) and can be rebuilt to support the transport of people with disabilities (e.g., wheelchair access). They are comfortable and insensitive to weather. On the other hand, congestion and limited parking infrastructure can reduce their efficiency.

2.2.1. Internal combustion engine vehicles

Currently, the Internal combustion engine vehicles are the most widespread types of cars. The infrastructure for them (refuelling, maintenance) is well-established. They are generally less expensive upfront compared to hybrids or electric vehicles, provide longer range and quick refuelling times, making them ideal for long distance trips, have high availability and are insensitive to weather. On the other hand, they are causing significant air pollution relying on fossil fuels. Their operating costs is much higher compared to micromobility and there are several associated costs to their operation (insurance, taxes, maintenance, etc.).

2.2.2. Hybrid vehicles

Hybrids combine an ICE with an electric motor, offering improved fuel efficiency and reduced emissions compared to traditional ICE vehicles. Hybrids don't require external charging, as they use regenerative braking and the ICE to recharge the battery, making them convenient for users without access to charging infrastructure. Hybrids are generally more expensive than ICE vehicles due to their dual drivetrain systems. There are multiple types of hybrids based on drivetrain configuration [17]:

- Full Hybrids (FHEV): Operate using the internal combustion engine (ICE), electric motor, or both, with short electric-only driving capability (e.g., Toyota Prius); no charging is required, range is typically 500-800 km, and prices are moderate.
- Mild Hybrids (MHEV): Use a small electric motor to assist the ICE for better efficiency but cannot run on electricity alone; they have similar range (500-800 km) to ICE vehicles, no charging needed, and slightly higher prices than traditional cars.
- Plug-In Hybrids (PHEV): Have larger batteries that can be charged externally, offering 30-100 km of electric-only range before switching to the ICE (e.g., Toyota Prius Prime); charging takes 2-4 hours, and they are more expensive than FHEVs but cheaper than EVs.
- Series Hybrids (Range-Extended EVs): The electric motor powers the wheels, while the ICE functions as a generator to recharge the battery (e.g., BMW i3 REx); range depends on the battery and fuel tank size (typically 200-400 km), charging takes 4-8 hours, and prices are relatively high.
- Parallel Hybrids: Both the ICE and electric motor are connected to the drivetrain and can power the vehicle simultaneously (e.g., Honda Accord Hybrid); range is comparable to FHEVs at 500-800 km, no charging is required, and prices are moderate.



2.2.3. Electric vehicles

EVs produce zero tailpipe emissions, making them the most environmentally friendly option. They have lower operating and maintenance costs due to fewer moving parts and the absence of an ICE. With government incentives and expanding charging infrastructure, EV ownership is becoming more accessible. EVs have a higher upfront cost than ICE and hybrid vehicles, although prices are gradually declining. Their driving ranges vary from 200-600 km per charge, charging takes 30 minutes (fast) to 8 hours (home).

Fuel cell vehicles

FCVs use hydrogen fuel cells to produce electricity, emitting only water vapor, making them an eco-friendly choice [18]. They offer a driving range comparable to ICE vehicles, typically 300-500 km per tank, and refuelling takes only a few minutes. Hydrogen infrastructure is severely limited and investing in one is very costly. Hydrogen production is energy-intensive, and most hydrogen is currently derived from natural gas, which reduces its environmental benefits. FCVs are more expensive to produce than other vehicles, and their maintenance requires specialized expertise. This technology is still in its early stages of adoption, meaning limited model availability and higher costs for consumers.

3. Alternative energy sources

3.1. Biofuels

Biofuels are most suitable as transitional energy sources, supporting decarbonization in transportation [19]. They are compatible with conventional internal combustion engines. Biofuels are renewable energy sources derived from organic materials like plants, agricultural residues, and waste. Common types include ethanol, produced from crops like corn and sugarcane, and biodiesel, made from vegetable oils, animal fats, or recycled cooking oils. They have reduced greenhouse gas emissions compared to fossil fuels. Biofuels are renewable and are often locally sourced. Their main disadvantage is they are competing with the food industry for land use and are hard to scale. The European Union (EU) has implemented regulations to ensure that biofuels contribute to greenhouse gas (GHG) reduction making them a green energy source.

3.2. Buying electricity from greener sources - The market-based approach

The market-based method considers the organization's specific electricity purchasing choices, considering: Direct contracts with renewable energy providers, Purchase of renewable energy certificates (GO, REC, etc.), Power Purchase Agreements (PPA), Energy mix declared by the chosen supplier. The certified share of electricity produced by renewable sources results in zero emissions. The residual amount results in emissions, to be estimated using a residual mix emission factor. The electricity residual mix of a country represents the share of electricity supply for which the energy source is not proven through cancellation of Guarantees of Origin or other Reliable Tracking Mechanisms. The residual mix emission factor is generally higher than the average grid factor (location-based) because it excludes renewable energy that has already been claimed through contractual instruments. A suitable reference at European level is represented by the AIB - European Residual Mixes 2023 Report, subject to yearly updates 0.

Accordingly, HDSS should thrive for sourcing electricity from greener sources when possible.



4. Trip planning apps for HDSS

There are multiple trip planning tools that can assist HDSS to plan their daily activities in a more efficient way. Many of them can plan with multiple transport modes, have real time traffic information integrated and carbon footprint too. On the other hand, most widespread tools cannot plan routes with multiple stops (i.e., solving the travelling salesman problem or its variants). Advanced route planning features are mainly available in commercial software developed for logistics companies. In this section, some of the most relevant ones are listed for HDSS. Additionally, at the end of this section, *Table 2* summarizes the main features of the listed applications.

Google maps [21]

The most widespread trip planning application. It is very user friendly and free to use. Gives accurate estimated time of arrival and a turn-by-turn itinerary. Features real-time traffic data, can plan with multiple modes, local public transit feeds are fed into the application. It can also compute CO2 emissions, however not in a transparent way. It can plan with multiple stops but cannot optimize the order of visits and the wait times between destinations. The map used is very up to date, containing many points of interest, opening hours and busyness of locations. For HDSS, it is suitable if caregivers do not have to visit multiple users in one go. It is also recommended to use even if the routes are known to check for real time traffic updates and road closures. The Street View functionality provides visual help for caregivers to find their destinations.

MapQuest [22]

MapQuest is also free and user-friendly. It has real-time traffic information and returns turn-by-turn directions. The application supports multiple destinations and a basic optimization among them up to 26 destinations per route (optimizing for shortest path or shortest time). It shows estimated fuel costs for each trip. The main limitation of the application is that it can only plan with driving and walking. Using such an application is highly recommended for HDSS where one caregiver must fulfil a chain of tasks per workday.

MyRouteOnline [23]

MyRouteOnline is a route planning application designed for solving complex multi-stop routing problems. Designed for solving routing problems for deliveries, service visits, or personal activity chains. Allows users to input multiple destinations via manual entry or by importing a list (e.g., from Excel). Generates optimized routes to minimize travel time or distance. Provides options to prioritize stops or set constraints, such as time windows. Primarily focused on road-based transport, such as cars, vans, and delivery vehicles. It does not currently support planning for modes like cycling, walking, or public transit. The application is not free. It offers a trial for limited time. It has a subscription or pay-as-you go pricing model. It is recommended for HDSS that use several vehicles and serve lots of users.

Routific [24]

Routific is route optimization software that's built for small to medium-sized local delivery businesses. It includes dispatcher-friendly features like:

- Drag and drop to re-order stops and edit routes
- One-click dispatch to drivers
- Automated customer notifications
- A timeline view to track progress through the day
- Scheduling drivers/vehicles
- 0-24 Customer support



Routes are optimized for shortest distance and driver acceptability (e.g., considering route quality). Pricing starts at \$49 per vehicle per month, or \$59 per vehicle per month for GPS tracking and proof of delivery features. It is recommended for HDSS that use several vehicles and serve lots of users and want to build a more optimized caregiver dispatching system.

Table 2 Summary of trip planning apps

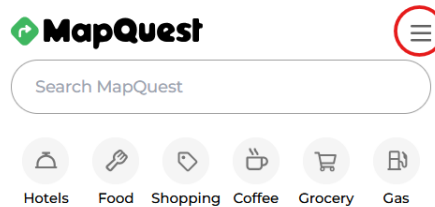
	Google maps	Map Quest	MyRouteOnline	Routific
Pricing	Free (some advanced features like API calls require subscription)	Free (some advanced features like API calls require subscription)	Free trial, subscription or pay as you go	Free trial, subscription-based
Supported transport modes	Driving, walking, public transport, biking	Driving, walking	Driving	Driving
Real time traffic information	Yes	Yes	No	Yes
Additional features	CO2 emissions, fuel consumption (in app, requires setting vehicle type), toll cost, points of interest, Street View	fuel cost	fuel cost	fuel cost
Optimized routes	No	Yes	Yes	Yes
Multiple vehicles	No	No	Yes	Yes
Platform	Web, mobile app	Web, mobile app	Web	Web, mobile app
Target audience	Individual drivers	Small businesses	Small to medium businesses	Small to medium businesses
Recommendation for HDSS	Use for real-time traffic information for single trips. Use Street View to better find destinations	Use when the caregiver has to visit multiple users per day	It is recommended for HDSS that use several vehicles and serve lots of users.	It is recommended for HDSS that use several vehicles and serve lots of users and want to build an optimized caregiver dispatching system

4.1. MapQuest usage example:

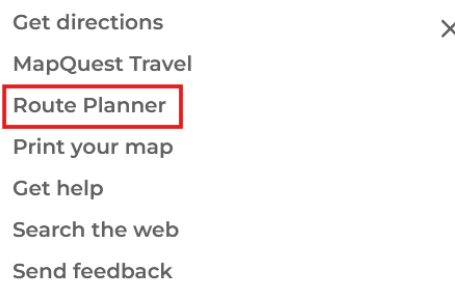
It can plan the trip similar to GoogleMaps for multiple destinations. It can also be set to reorder the destinations so that the distance travelled is the shortest. The program solves the Travelling Salesman Problem (TSP).



1. Enter <https://www.mapquest.com/>
2. On the left sidebar click on the sandwich menu:



3. Click on route planner



4. There are three options to input the destinations.
 - a. Manually, destination-by-destination, similar to google maps.
 - b. With the copy/paste option addresses can be pasted, with each line being one destination.
 - c. Import: upload an excel file with the specified structure.

Line by Line Copy/Paste Import

One address per line (26 max)

A 123 Main Street, City, State, Zip

B 123 Main Street, City, State, Zip

+ Add another stop

Stops Optimize for

☐ Let us re-order stops ☒ Shortest time

☐ Round trip ☐ Shortest distance

More route settings ▾

View route directions



There are some additional settings. The trip can be optimized for shortest time or shortest distance. In the “More route settings”, options such as avoiding toll roads can be set. This is not relevant for this service provider.

The program only works for cars.

Round trip specifies that the trip must end where it started.

The most important feature is setting “Let us re-order stops”. By doing so, the TSP is solved, and the optimal order of locations is returned.

5. With copy/paste, some locations are inserted. Note that the first and the last element are the same, indicating a round trip (so that does not have to be ticked when configuring the optimization).

Line by Line Copy/Paste Import

One address per line (26 max) ✕ Clear all

Baturine 4, Nisko, Croatia
Hrvatskih velikana 113, Klis
Baturine 17, Nisko, Croatia
Čerine-Torlaci 11, Klis
Baturine 4, Nisko, Croatia

5/26

View route directions

6. Clicking on “View route directions” returns the trip unoptimized. Clicking on “View route directions” again on this page will give detailed directions as well as the total length of the trip.

Line by Line Copy/Paste Import

One address per line (26 max)

4 Baturine, Klis, 21204, HR
107 Hrvatskih velikana, Klis, 2...
17 Baturine, Klis, 21204, HR
11 Čerine-Torlaci, Klis, 21204, ...
4 Baturine, Klis, 21204, HR

+ Add another stop

Stops Optimize for

☐ Let us re-order stops ☒ Shortest time

☐ Round trip ☐ Shortest distance

More route settings ▼

View route directions

300 m

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7. Setting “Let us re-order stops”, the order is updated. Clicking on “View route directions” again will give detailed directions (and distance) for the optimized trip.



One address per line (26 max)

A

4 Baturine, Klis, 21204, HR

B

17 Baturine, Klis, 21204, HR

C

107 Hrvatskih velikana, Klis, 2...

D

11 Čerine-Torlaci, Klis, 21204, ...

E

4 Baturine, Klis, 21204, HR

[+ Add another stop](#)

Stops **Optimize for**

☒ Let us re-order stops

☐ Round trip

☒ Shortest time

☐ Shortest distance

[More route settings](#) ▾

[View route directions](#)

4.2. Vehicle routing

A more advanced approach to trip planning involves optimizing routes for multiple vehicles simultaneously, a problem known as the **Vehicle Routing Problem (VRP)** [25]. When an HDSS operates multiple vehicles to serve users daily, VRP can be used to determine the optimal assignment of users to each employee and the most efficient order of visits. VRP is a well-researched topic in operations research, not only due to its many variations and applications but also because solving it for large-scale problems (e.g., thousands of destinations) is computationally challenging. However, for the typical scale of an HDSS, VRP-based solutions can be effectively applied.

In practice, HDSS providers often face additional constraints, such as employee specialization—where certain employees can only serve specific types of users. These constraints can make a direct application of standard VRP infeasible. However, VRP remains a useful tool for estimating potential efficiency gains when reassigning employees or integrating new users into the system. Additionally, VRP can be adapted to include various constraints that reflect a service provider's operational preferences. However, incorporating these constraints results in more complex optimization problems, which may exceed the scope of this project and the computational capacity of a typical service provider.

Free, ready-to-use online tools for solving VRP are generally unavailable, while commercial software can be expensive and tailored for different types of routing problems. Nevertheless, custom VRP solvers can be implemented relatively easily using various programming languages, making them a feasible option for HDSS providers with access to basic programming resources.

4.3. Vehicle routing example

In this example the data provided by Bergamo CDD is used. They use 4 9-person vans (with 1 driver and one caregiver each). They serve 33 addresses (based on the data provided.). Since $4 \times (9-2) = 28 < 33$, the problem is solved for only 28 locations selected randomly. Without any further constraints, the optimization procedure is run to find the optimal routes for the four vehicles for the 28 destinations.



In Figure 1, the result of the planning is shown. The headquarters are indicated by the blue dot, the destinations are the red ones. The route for each vehicle is denoted by a different color. The route statistics are summarized in Table 3. Theoretically, this layout results in the shortest total distance traveled.

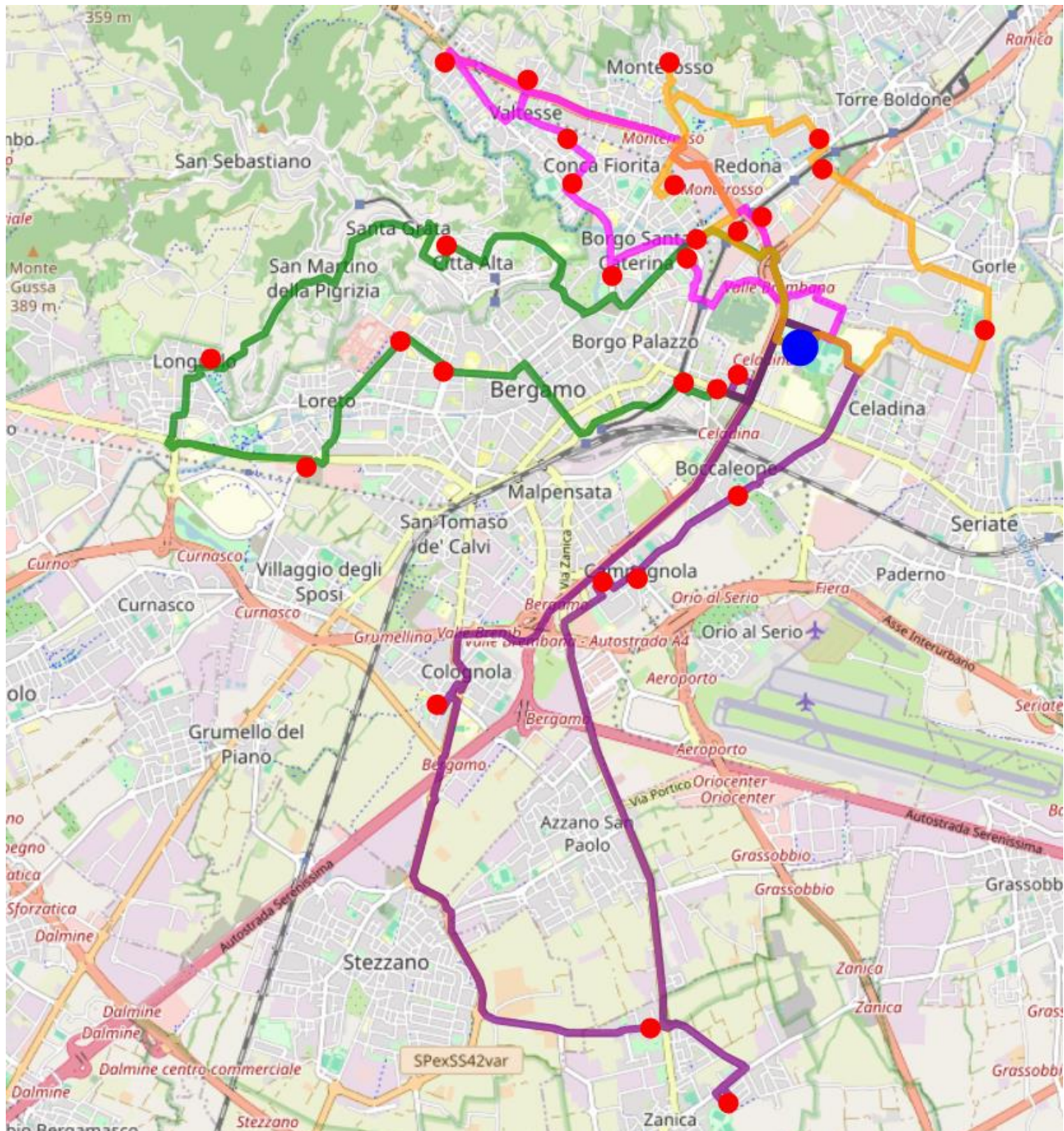


Figure 1 Result of the VRP for CDD



Table 3 Result of the VRP for CDD

	Distance (m)	Visit order
Vehicle #1	12086	0 -> 15 -> 16 -> 28 -> 27 -> 8 -> 21 -> 12 -> 0
Vehicle #2	17397	0 -> 9 -> 14 -> 18 -> 7 -> 6 -> 11 -> 25 -> 0
Vehicle #3	21691	0 -> 4 -> 17 -> 5 -> 2 -> 26 -> 3 -> 24 -> 0
Vehicle #4	12335	0 -> 13 -> 10 -> 20 -> 23 -> 22 -> 1 -> 19 -> 0

To solve the above routing problem the following tools were used:

- A local instance of OpenTripPlanner v2.6 [26] built with the map of Northwest Italy using OpenStreetMap [27].
- A Python script using ORtools [28] for optimization and folium [29] for visualization. The code can be found in the appendix of this document.



D. Joint strategy

5. Transnational methodology

Building on the literature review and proposed categorization, this section outlines key actions for making HDSS more sustainable. These actions are summarized below, along with a flowchart designed to assist service providers in decision-making for greener mobility.

In the previous section, three main categories of action were identified:

- **Switching to greener vehicles and promoting mode shift**
- **Implementing mobility management strategies**
- **Utilizing sustainable fuel and electricity sources**

Each of these actions is feasible only under specific conditions, as outlined in the General Framework. In this section, those considerations are presented in a structured format to guide implementation.

5.1. Vehicle selection

For greener vehicles, a decision support table is provided in Table 4, considering the service types and different influencing conditions. Columns are derived from 1.1-1.6, rows from 1.7-1.8. Green tick means that the mode is not excluded by the condition and is generally a good choice, red X means that a certain condition excludes the mode, and yellow line means that the mode is not ideal or additional considerations must be taken into account.



Green LaMiS

Table 4 Recommended vehicle type choice table based on service type and external conditions. (✓ good choice for given condition, --- ok choice for given condition, ✗ bad choice for given condition)

Mode	Condition											
	Service type				Long distance covered by an employee per day	Road and traffic conditions					Bad weather	Charging infrastructure unavailable
	Person transport		Item delivery	Caregiver visit		Hilly terrain	Roads in poor condition (or unpaved)	Heavy traffic	Hard to park near users	Public transport unavailable or insufficient		
	Need wheelchair access	Doesn't need...										
E-scooter	X	X	X	✓	X	✓	X	✓	✓	✓	X	✓
Electric Bicycle	X	X	X	✓	X	✓	✓	✓	✓	✓	X	✓
E-moped	X	X	X	✓	X	✓	---	✓	✓	✓	X	✓
E-cargo-bike	X	X	✓	✓	X	✓	✓	✓	✓	✓	X	✓
Bicycle	X	X	X	✓	X	X	✓	✓	✓	✓	X	✓
Cargo bike	X	X	✓	✓	X	X	✓	✓	✓	✓	X	✓
Microcar	X	X	---	✓	---	✓	---	---	---	✓	✓	---
Electric car	X	✓	✓	✓	✓	✓	✓	---	---	✓	✓	---
Electric Van	✓	✓	✓	✓	✓	✓	✓	---	---	✓	✓	---
Public transport	X	X	---	✓	---	✓	✓	---	✓	X	---	✓



In addition to the above limitations, the greenest suitable vehicle should be selected for the task. For example, although an electric van is versatile and can support various services, it consumes significantly more electricity than an electric bike. Therefore, when deciding which vehicle to purchase or assign to a task, precisely defining the vehicle's intended use is crucial.

Service providers currently using gasoline or diesel cars and vans should consider transitioning to electric vehicles. Electric vehicles' driving characteristics make them particularly efficient for HDSS operations, especially in urban areas where trips are typically short. However, reliable charging infrastructure is critical to ensuring seamless service. In cases where trips are longer and recharging time is limited due to continuous vehicle utilization; electric vehicles may not be the most practical option. In the table, the unavailability of the charging infrastructure is marked as non-critical, not ruling out any of the vehicle types. This is because smaller electric vehicles can be charged from the wall socket, and larger electric cars can be charged from e.g., public charging stations, which is an acceptable but not ideal solution.

In addition to the type of vehicle, its financing is also important. Since municipalities have limited budgets for vehicles, they can choose to buy new or used vehicles or to rent or lease vehicles. Buying has a higher upfront cost, allowing for fewer vehicles. However, they can be used for a longer period of time, extending beyond the lifetime of this project. Leasing allows for the acquisition of more vehicles, which has a more significant impact on CO2 savings during the project's duration. Ultimately, when selecting a vehicle, multiple factors must be considered that may constrain the optimal decision from the project's KPIs point of view (see Deliverable D2.2.1).

5.2. Trip planning

For mobility management, recommendations are based on the number of vehicles, users served, and demand types.

In terms of trip planning, the following actions should be considered:

1. **Monitor vehicle utilization** - The first step is proper monitoring, which includes keeping logs of when and which users are visited by each vehicle. This enables better decision-making regarding vehicle suitability for tasks and helps detect delays due to congestion. A mobility expert should be appointed, and monitoring should be integrated into operational processes.
2. **Plan fixed-route trips in advance** - If trips follow a fixed route, the mobility expert should plan them ahead of time. Trip planning should also include scheduling adjustments to avoid congestion by factoring in real-time traffic information and weather conditions.
3. **Re-plan demand-driven trips dynamically** - If the service is demand-driven, trips should be (re)planned after each new request. On-demand services often have lower vehicle utilization and typically operate point-to-point. In such cases, electric vehicles can be conveniently charged at the service provider's base, eliminating the need for complex activity chain planning.
4. **Optimize single-vehicle, multi-stop trips** - If planning involves a single vehicle visiting multiple locations (e.g., a caregiver visiting multiple users or transporting multiple passengers), trip optimization should be done using the **Traveling Salesman Problem (TSP)** (see Section 1.11). Even for static services, routes should be re-optimized when changes occur, such as serving a new user. For highly dynamic and complex trips, advanced trip planners are strongly recommended.
5. **Use VRP for multi-vehicle services** - If the service operates multiple vehicles, solving the **Vehicle Routing Problem (VRP)** (see Section 1.13) is recommended. However, if each caregiver consistently visits the same set of users, solving the TSP separately for each vehicle is sufficient.
6. **Leverage multimodal transport for clustered users** - If service users are geographically clustered, a multimodal approach can be beneficial. For example, an employee can travel to a general location



(e.g., a village) using long-range transport such as a car or public transit, then switch to walking or micromobility to reach individual users.

7. **Minimize unnecessary vehicle returns to the depot** - Whenever possible, avoid returning vehicles to the depot between trips. This reduces unnecessary commuting for employees and can lead to fewer kilometers traveled overall.

In general, using advanced trip planners with real-time traffic information and emissions tracking is highly recommended. As trip complexity increases, these tools provide increasingly superior results compared to ad hoc planning. Additionally, **bundling trips**—waiting for multiple requests before dispatching a vehicle—can help reduce “empty trips” by chaining activities efficiently [7].

5.3. Green energy

There are two key cases to consider:

1. **The service provider uses petrol or diesel vehicles** - If purchasing or leasing electric vehicles is not feasible, the existing fleet can run on biofuels to reduce its carbon footprint (see Section 1.9).
2. **The service provider has electric vehicles** - To further minimize the carbon footprint, electricity can be sourced from greener energy providers (see Section 1.10).

When adopting electric mobility, factors such as charging infrastructure availability and charging costs must also be taken into account (see Section 1.6).

The following sections will elaborate on each of these aspects, providing a strategic framework that service providers can follow and adapt to their specific needs.



E. Action plan and specific recommendations to involved service providers in GreenLaMiS

This section is organized as follows: each service provider is addressed in a separate subsection going through the following steps.

1. First, a general description is provided, outlining the service provider's operations and mobility patterns to establish a baseline.
2. Next, preliminary measures are proposed based on the general framework and transnational methodology.
3. These measures are then refined, with certain options ruled out based on feedback, preferences, and operational constraints identified through direct communication with the service providers.
4. Finally, the refined measures are translated into a tailored action plan for each service provider.

6. Bergamo

To get a deeper understanding on how the selected social services operate in Bergamo, on top of the provided Social Services Descriptions (Deliverable 1.2.1), an online interview was organized. Interview questions were tailored to find out whether the set of possible actions outlined in the first part of this document is applicable. Although, it is called interview, these meetings were intended to be interactive discussions to think together and support the service providers in deciding which actions to take in this project. The Municipality of Bergamo sent the preliminary answers of the service providers to the interview questions in a document prior to the interview, which was scheduled to 2025.01.27.

The interview questions were the following:

1. *Describe a typical trip including*
 - a. *With which vehicle*
 - b. *Trip characteristics*
 - c. *Departure scheduling*
2. *Explain how do you plan a typical trip, what tools do you use for trip planning?*
3. *How could you integrate electric vehicles into your fleet? How do you imagine charging?*
4. *Do you plan to scale the service (i.e., more users served, more caregivers, more vehicles)?*
5. *Do you think that your employees are willing to make modal shift or multimodal trips?*
6. *Is there a possibility to source electricity from greener sources, i.e., realize the market-based approach?*



6.1. Social Transport for People with Disabilities

6.1.1. Service description

The service includes accompanying people with disabilities from their residences to various services within the Municipality of Bergamo. Service during normal working hours, serving approximately 100 persons. Services use 18 vehicles, (some equipped with lifts for wheelchair). Vehicles used for transporting disabled persons have 9 seats each. There are both paid operators and volunteers working in the service. There is both daily and consistent service and on-demand service. The operators use passenger cars for other services and some of those are already electric.

The service cannot be shifted to another mode of transport (e.g., micromobility, cycling, public transport) as the safety and comfort of the transported people are predominant.

6.1.2. Preliminary recommendations

Based on the best practices and general framework in the previous section, the following items seem appropriate for this service provider.

- **Vehicle selection:**

Based on Table 4, the feasible vehicle types are identified. In Table 5, columns are marked with white color where the conditions apply. Then, vehicle types are ruled out that do not meet the criteria.



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Table 5 Feasible vehicle types

Mode	Condition											
	Service type				Long distance covered by an employee per day	Road and traffic conditions					Bad weather	Charging infrastructure unavailable
	Person transport		Item delivery	Caregiver visit		Hilly terrain	Roads in poor condition (or unpaved)	Heavy traffic	Hard to park near users	Public transport unavailable or insufficient		
	Need wheelchair access	Doesn't need...										
E-scooter	X	X	X	✓	X	✓	X	✓	✓	✓	X	✓
Electric Bicycle	X	X	X	✓	X	✓	✓	✓	✓	✓	X	✓
E-moped	X	X	X	✓	X	✓	---	✓	✓	✓	X	✓
E-cargo-bike	X	X	✓	✓	X	✓	✓	✓	✓	✓	X	✓
Bicycle	X	X	X	✓	X	X	✓	✓	✓	✓	X	✓
Cargo bike	X	X	✓	✓	X	X	✓	✓	✓	✓	X	✓
Microcar	X	X	---	✓	---	✓	---	---	---	✓	✓	---
Electric car	X	✓	✓	✓	✓	✓	✓	---	---	✓	✓	---
Electric Van	✓	✓	✓	✓	✓	✓	✓	---	---	✓	✓	---
Public transport	X	X	---	✓	---	✓	✓	---	✓	X	---	✓



Since the service involves transporting individuals with disabilities, the only viable option is an electric van with wheelchair access. The primary challenge for electric vans is heavy traffic and congestion. Given that no alternative vehicle type is unaffected by congestion, the solution lies in effective trip planning to alleviate these issues.

The availability of charging infrastructure is crucial to ensuring a reliable service. The most suitable charging strategy appears to be utilizing the infrastructure at the service provider's headquarters, as this would help reduce the CO2 emissions associated with transportation.

■ Trip planning

Trip planning could help in the following ways:

- **Monitor vehicle utilization and appoint a mobility expert:** This will help improve the vehicle utilization ratio and enable better scheduling to avoid congestion. Effective scheduling can also reduce the number of trips during peak hours by coordinating destinations and making appointments in advance (e.g., at hospitals). During peak hours, not only are travel times extended, but passenger comfort also diminishes due to stop-and-go traffic.
- **Apply TSP and VRP for planning:** Given the combination of fixed and on-demand trips and the use of multiple vehicles, the mobility expert can apply both the Traveling Salesman Problem (TSP) and Vehicle Routing Problem (VRP) to optimize service. By using advanced routing algorithms, trips can be planned on routes with the least emissions, taking into account real-time data such as traffic congestion and weather conditions.

■ Green energy

The service provider has both electric and diesel vehicles. Therefore, both biofuels and the market-based approach should be considered.

6.1.3. Action plan

After further discussions with the providers, the following actions were deemed feasible:

■ Electric vehicles

The service provider could rent electric vehicles suitable for transporting individuals with disabilities. The number of vehicles that can be rented will depend on the project's budget. Currently, the service operates one electric van equipped with the necessary features for disabled passengers. The vehicle is charged overnight at a designated private charging point in the neighborhood.

Given that the vehicle travels an average of 50-60 kilometers per day (with high variance), overnight charging is not always necessary. Therefore, adding an additional electric vehicle with a sufficient range (200 km+) will not create a bottleneck at the charging station.

The electric vehicle to be leased should be a 9-seater and capable of being equipped with wheelchair access. Some models that meet these criteria include:

Ford e-transit (longer version with 9 seats): <https://www.sunsetvans.com/e-transit-commercial-electric-wheelchair-van/>)



- the Citroen e-SpaceTourer <https://www.citroen.co.uk/models/new-e-Spacetourer.html>
- Toyota Proace Verso EV: https://www.toyota.co.uk/new-cars/proace-verso?srsId=AfmBOoqCcV1qOrU_xmjeKSNN1GgCnCgQlgMOMKRxs_4K71nrYN9zTUZA

Some other electric model vans exist that either have less seat capacity or needs further modifications for wheelchair access, e.g.,

- VW ID Buzz (only available with 7 seats max): <https://www.volkswagen-vans.co.uk/en/electric-and-hybrid/electric-models/id-buzz/e-mobility.html>
- Peugeot e-traveller (only available with 8 seats max): <https://www.media.stellantis.com/en/peugeot/press/new-peugeot-e-traveller-allure-made-for-transport-professionals>

For all models, the range is sufficient for the travel needs.

Increasing the share of electric vehicles and adopting the market-based approach, would be effective to reduce direct and indirect CO2 emissions.

■ Smaller vehicles

If some transport tasks can be performed with smaller vehicles (less than 9-passenger capacity), these vehicles are typically lighter and more energy-efficient. Smaller vans with better energy efficiency and a higher seating position may still meet the comfort needs of those being serviced, without compromising quality. By switching part of the fleet to smaller vehicles, the service could reduce energy consumption and lower CO2 emissions. For instance, 7-seater electric vehicles could be rented as an alternative to the 9-seater vehicles.

■ Trip planning

Organize trips better by using e.g., trip planning applications. For example, a mobility manager could be appointed that helps optimizing routes to save time and fuel. In the morning the goal is to rationalize, reduce the trip times. There are ad-hoc trips during the day with which it is hard to plan.

■ Buying electricity from greener sources

Purchasing electricity from greener sources is not possible from the charging station provider, so that action is ruled out. The electricity in that charging station is not coming from renewables. Still, biofuels could be used.

The steps to implement the above actions are the following.

1. Based on the requirements and budget, decide what type of vehicle to lease and start the procurement process as soon as possible.
2. Appoint a mobility expert.
3. When refueling the diesel vans, buy biofuels
4. Continuously monitor and optimize vehicle routing during the pilot. This is the task of the mobility expert. The results should be reported to the project leaders.



6.1.4. Summary of recommendations for Bergamo - Social transport for people with disabilities

We recommend renting electric vehicles, particularly 9-seater wheelchair-accessible vans with a range of 200 km+, to complement the existing electric van. Based on budget, smaller electric vehicles (e.g., 7-seaters) may also be viable for tasks that don't require larger capacity. Improved trip planning using route optimization tools will help cut travel time and fuel use, which will be the task of the appointed mobility expert.

6.2. Day Centre for people with disabilities (C.D.D.)

6.2.1. Service description

The Day Centre for people with disabilities (C.D.D.) of the City of Bergamo is a service for severely disabled people who need continuous and specific assistance. They provide service from 9 am to 4 pm, from Monday to Friday. Transport service is provided to the users is the daily transport service from 7.45am to 9.00am Home/ C.D.D. and from 4pm to 5.15pm C.D.D. / Home, after the ordinary frequency at the C.D.D. from 9.00 to 4pm. The transport service is used by 33 users (the capacity of the day center) and provided by 8 caregivers (4 drivers and 4 assistants). They have 4 vans with 9-person capacity with wheelchair access.

6.2.2. Preliminary recommendations

Based on the best practices and general framework in the previous section, the following items seem appropriate for this service provider.

- **Vehicle selection:**

Based on Table 4, the feasible vehicle types are identified. In Table 6, columns are marked with white color where the conditions apply. Then, vehicle types are ruled out that do not meet the criteria.



Green LaMiS

Table 6. Feasible vehicle types

Mode	Condition											
	Service type				Long distance covered by an employee per day	Road and traffic conditions					Bad weather	Charging infrastructure unavailable
	Person transport		Item delivery	Caregiver visit		Hilly terrain	Roads in poor condition (or unpaved)	Heavy traffic	Hard to park near users	Public transport unavailable or insufficient		
	Need wheelchair access	Doesn't need...										
E-scooter	X	X	X	✓	X	✓	X	✓	✓	✓	X	✓
Electric Bicycle	X	X	X	✓	X	✓	✓	✓	✓	✓	X	✓
E-moped	X	X	X	✓	X	✓	---	✓	✓	✓	X	✓
E-cargo-bike	X	X	✓	✓	X	✓	✓	✓	✓	✓	X	✓
Bicycle	X	X	X	✓	X	X	✓	✓	✓	✓	X	✓
Cargo bike	X	X	✓	✓	X	X	✓	✓	✓	✓	X	✓
Microcar	X	X	---	✓	---	✓	---	---	---	✓	✓	---
Electric car	X	✓	✓	✓	✓	✓	✓	---	---	✓	✓	---
Electric Van	✓	✓	✓	✓	✓	✓	✓	---	---	✓	✓	---
Public transport	X	X	---	✓	---	✓	✓	---	✓	X	---	✓



Given that the service involves transporting individuals with disabilities, the only viable option is an electric van with wheelchair access. Additionally, since the service provider transports multiple passengers, a larger vehicle—specifically, a 9-seater van—is required. The main challenge for electric vans is heavy traffic and congestion. However, since no alternative vehicle type is immune to congestion, this issue can be mitigated through effective trip planning.

The availability of charging infrastructure is crucial to ensuring reliable service. The most suitable charging strategy appears to be utilizing the infrastructure at the service provider's headquarters, as this would help reduce CO2 emissions from transportation.

■ Trip planning

The trips are the same every day, vehicles operate on a fixed route at fixed times. There is only possibility for minor improvements with trip optimization. Due to the static nature of routes, reviewing the routes is only necessary when the users change (by solving the TSP). Therefore, this action could be done with minimal effort, just by using a free trip planning tool, such as MapQuest.

■ Green energy

The service provider has both electric and diesel vehicles. Therefore, both biofuels and the market-based approach should be considered.

6.2.3. Action plan

Based on the best practices and general framework in the previous section, the following items seem appropriate for this service provider.

■ Electric vehicles

To make the transportation of users more sustainable, the service provider could lease an electric van with wheelchair access. The key requirements are similar to those for the other service provider in Bergamo.

The electric vehicle to be leased should be a 9-seater, as smaller vehicles are not suitable due to higher transport demand at fixed times. Additionally, the vehicles must be equipped with wheelchair access. Some models that meet these criteria include:

- Ford e-transit (longer version with 9 seats): <https://www.sunsetvans.com/e-transit-commercial-electric-wheelchair-van/>)
- the Citroen e-SpaceTourer <https://www.citroen.co.uk/models/new-e-Spacetourer.html>
- Toyota Proace Verso EV: https://www.toyota.co.uk/new-cars/proace-verso?srltid=AfmBOoqCcV1qOrU_xmjeKSNN1GgCnGqQlgMOMKRxs_4K71nrYN9zTUZA

The range and use characteristics for the service provided are suitable for a typical electric van. As per the municipality, charging the vehicle is feasible and resolved. Increasing the share of electric vehicles would be effective to reduce direct and indirect CO2 emissions.



■ Trip planning:

The trips are the same every day, vehicles operate on a fixed route at fixed times. There is only possibility for minor improvements with trip optimization. Due to the static-nature of routes, reviewing the routes is only necessary when the users change. Therefore, this action could be done with minimal effort, just by using a free trip planning tool, such as MapQuest. Additionally, for multiple vehicles, the organization of trips could be reorganized using the VRP (see a concrete example for this service provider in Section 4.3).

■ Buying electricity from greener sources

Implementing the market-based approach depends on the operator of the charging station. Could be possible in the future. Using biofuels is also feasible for the diesel vans.

The steps to implement the above actions are the following.

1. Based on the requirements and budget, decide what type of vehicle to lease and start the procurement process as soon as possible.
2. Appoint a mobility expert.
3. When refueling the diesel vans, buy biofuels
4. Continuously monitor and optimize vehicle routing during the pilot. This is the task of the mobility expert. The results should be reported to the project leaders.

6.2.4. Summary of recommendations for Bergamo - Day centre for people with disabilities

The service provider can improve sustainability by leasing a 9-seater electric van with wheelchair access. Smaller vehicles are not suitable for this type of transport. Charging infrastructure is already available. While route optimization opportunities are limited because trips are static, minor adjustments can be made using free tools like MapQuest or VRP for multi-vehicle coordination. Key steps include selecting and procuring the appropriate vehicle, appointing a mobility expert, and continuously monitoring and optimizing routes during the pilot.

7. Klis

7.1. Household assistance and meal delivery services

7.1.1. Service description

The municipality provides household assistance services and meal delivery services for socially disadvantaged residents. The service provider serves approximately 60 users with 9 caregivers. Every caregiver provides on average 6 users. The service is during normal working hours, but the exact time is agreed upon - not the same time every day. The main challenge regarding mobility is that the terrain is hilly, and some locations are distant.



7.1.2. Preliminary recommendations

Based on the best practices and general framework in the previous section, the following items seem appropriate for this service provider.

- **Vehicle selection**

Based on Table 4, the feasible vehicle types are identified. In Table 7, the table columns are marked with white color where the conditions apply. Then, vehicle types are ruled out that do not meet the criteria.



Table 7. Feasible vehicle types

Mode	Condition											
	Service type				Long distance covered by an employee per day	Road and traffic conditions					Bad weather	Charging infrastructure unavailable
	Person transport		Item delivery	Caregiver visit		Hilly terrain	Roads in poor condition (or unpaved)	Heavy traffic	Hard to park near users	Public transport unavailable or insufficient		
	Need wheelchair access	Doesn't need...										
E-scooter	X	X	X	✓	X	✓	X	✓	✓	✓	X	✓
Electric Bicycle	X	X	X	✓	X	✓	✓	✓	✓	✓	X	✓
E-moped	X	X	X	✓	X	✓	---	✓	✓	✓	X	✓
E-cargo-bike	X	X	✓	✓	X	✓	✓	✓	✓	✓	X	✓
Bicycle	X	X	X	✓	X	X	✓	✓	✓	✓	X	✓
Cargo bike	X	X	✓	✓	X	X	✓	✓	✓	✓	X	✓
Microcar	X	X	---	✓	---	✓	---	---	---	✓	✓	---
Electric car	X	✓	✓	✓	✓	✓	✓	---	---	✓	✓	---
Electric Van	✓	✓	✓	✓	✓	✓	✓	---	---	✓	✓	---
Public transport	X	X	---	✓	---	✓	✓	---	✓	X	---	✓



Based on the table above, some trips are longer than usual, and the need for item (food) delivery eliminates most transport modes, leaving an electric car as the most versatile option. Although, microcars and public transport are feasible, they come with limitations. Electric vans, although meet the criteria are not recommended because the bigger size is not justified. Switching to electric vehicles is a logical choice, as their driving characteristics make them efficient for trips that are not very long but could be exhausting with active modes of transport.

The availability of charging infrastructure is essential to ensure a reliable service. The most appropriate charging strategy appears to be relying on the infrastructure at the service provider's headquarters or, if acceptable, at the homes of the employees.

Some trips could potentially be served on foot or by bike, depending on the caregiver's willingness. An operator serving several users in close proximity could do so multimodally—e.g., if several users live in a remote village, the operator could travel there by car, then switch to a bicycle or micromobility for visiting users. Additionally, if weather conditions and operator preferences allow, motorcycles or scooters could serve as more environmentally friendly alternatives.

Since meal deliveries often involve small delays, public transport may not be feasible at all times. Therefore, it is crucial to select the right vehicle based on the daily tasks at hand.

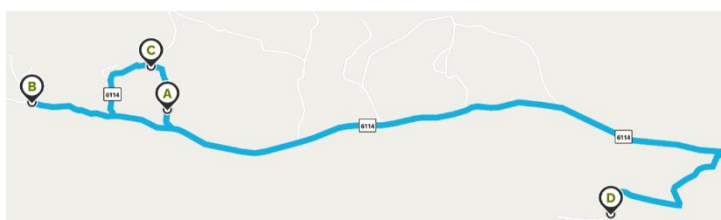
■ Trip planning

The trips are not planned in advance, the caregivers make trips based on experience and convenience. When looking at the daily trips, it seems that the caregivers visit 2-4 addresses. Some trips are rather short. If there are two addresses visited, there is no possibility for optimizing routing. In case of more addresses, the trips are either very short, done by walking, or their order cannot be optimized further. In all, only very minor improvements can be achieved by trip planning. For that, the users, caregivers visit should be reorganized. This might not be possible in the short term.

E.g., for Vehicle 2 on date 01/10/2024 (from Klis addresses of users.xlsx):

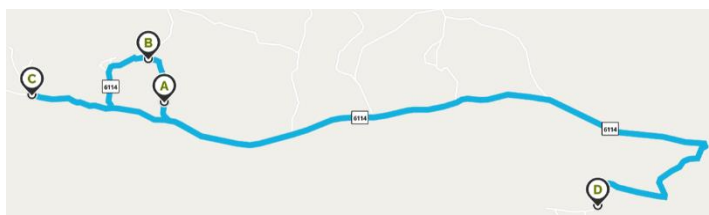
The reported route was (9.9 km):

- A. Baturine 4, Nisko, Croatia
- B. Hrvatskih velikana 113, Klis
- C. Baturine 17, Nisko, Croatia
- D. Čerine-Torlaci 11, Klis
- E. Baturine 4, Nisko, Croatia



The optimized route (using MapQuest) is (9.7 km)

- A. Baturine 4, Nisko, Croatia
- C. Baturine 17, Nisko, Croatia
- B. Hrvatskih velikana 113, Klis
- D. Čerine-Torlaci 11, Klis
- E. Baturine 4, Nisko, Croatia





Based on the provided example routes, some trips could be done with less car usage, reducing the kilometers travelled by car, reducing the total CO2 emission. Where possible, serve users who live close to each other, reducing the total distance travelled. Use trip planning, routing or activity chain planning algorithms to optimise the order in which users are served from a CO2 emissions perspective.

Since the same caregiver always visits the same set of users, using the VRP to plan trips is not feasible. On the other hand, it could help to optimize trips in the future when new caregivers or users are served.

For household assistance service, reduce the number of trips during peak hours by rescheduling visits could be feasible.

■ Green energy

The service provider has both electric and diesel vehicles. Therefore, both biofuels and the market-based approach should be considered. To charge the electric vehicle(s), the infrastructure is available. It is not decided yet whether the market-based approach is possible.

7.1.3. Action plan

A dedicated interview with the Municipality of Klis was conducted on January 27, 2025, to gain a deeper understanding of how their service operates and to identify potential areas for improvement.

Currently, they use personal vehicles and public transport to serve users, with the same six users being served consistently. These users may be geographically distant from each other. However, by reorganizing the service, users who live closer to each other could be served more efficiently, reducing the kilometers traveled. The typical trip length is shorter than the range of an electric vehicle (EV), and most trips share similar characteristics.

Due to the hilly terrain (which makes active modes of transport impractical) and the willingness of the caregivers, mode shift is not an option.

The vehicles are either used exclusively by the caregiver or driven by a relative of the caregiver. The vehicles are owned by the caregivers themselves.

During the meetings, a critical question arose regarding purchasing one or renting multiple vehicles for the project's duration. Below is a simple decision support calculation based on the emission data from the Baseline Analysis document. We have considered two scenarios (assuming approximately 20k€ budget) a) buying a small electric car and b) renting 3 electric vehicles for the project's duration (3 years). In each case, simply the vehicles that pollute the most are replaced by electric vehicles (sharing the vehicle among caregivers is not considered here).



Table 8. Electric vehicle scenarios for Klis

Baseline 2023		Buying 1 electric vehicle		Renting 3 electric vehicles	
	CO2 emission per year		CO2 emission per year		CO2 emission per year
vehicle_1	402.38	vehicle_1	402.38	vehicle_1	402.38
vehicle_2	327.96	vehicle_2	327.96	vehicle_2	327.96
vehicle_3	1717.26	vehicle_3	0	vehicle_3	0
vehicle_4	662.12	vehicle_4	662.12	vehicle_4	0
vehicle_5	288.29	vehicle_5	288.29	vehicle_5	288.29
vehicle_6	675.64	vehicle_6	675.64	vehicle_6	0
vehicle_7	170.04	vehicle_7	170.04	vehicle_7	170.04
vehicle_8	267.53	vehicle_8	267.53	vehicle_8	267.53
vehicle_9	108.89	vehicle_9	108.89	vehicle_9	108.89
Total	4620.1	Total	2902.85	Total	1565.09

It is evident that compared to the baseline, using more electric vehicles results in more CO2 emission reduction, (37% reduction when buying one, 66% when renting three). This means more contribution to the project's KPIs. On the long run the results may be different, but that is out of scope of this project (Table 9).

Table 9. Yearly total CO2 emissions in each scenario (green: project duration)

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
Baseline 2023	4620	4620	4620	4620	4620	4620	4620	4620	4620	4620
Buying 1 electric vehicle	2903	2903	2903	2903	2903	2903	2903	2903	2903	2903
Renting 3 electric vehs.	1565	1565	1565	4620	4620	4620	4620	4620	4620	4620

Table 10 Cumulated CO2 emissions in each scenario (green: project duration)

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
Baseline 2023	4620	9240	13860	18480	23101	27721	32341	36961	41581	46201
Buying 1 electric vehicle	2903	5806	8709	11611	14514	17417	20320	23223	26126	29029
Renting 3 electric vehs.	1565	3130	4695	9315	13935	18556	23176	27796	32416	37036

When assessing CO2 savings on the long run (e.g., 10 years), the total CO2 savings can be higher when buying (Table 10). For the project's duration, renting is foreseen to reduce CO2 emissions by 66% (13860-4695=9165 kg CO2) and buying result in the reduction of 37% (13860-8709=5151 kg CO2). However, after 6 years, buying becomes the greener option. After 10 years, renting results in only 19% CO2 reduction (46201-37036=9165 kg CO2), while buying still results in 37% CO2 reduction (46201-29029=17173 kg CO2).

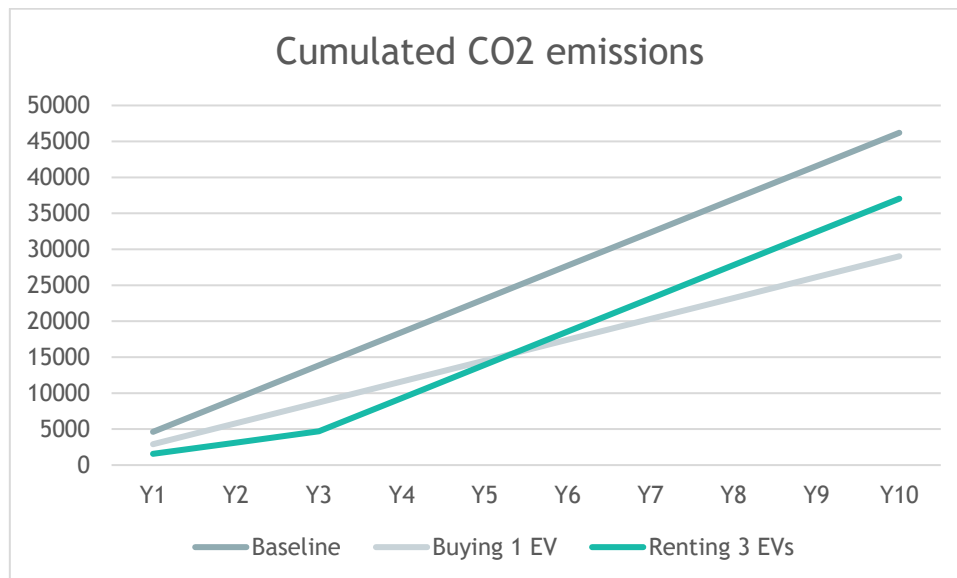


Figure 2. Cumulated CO2 emissions

The analysis just presented includes some considerations regarding the reduction of CO2 emissions; although this KPI is a priority, it cannot be the only factor to take into account. The specific needs of home delivery services are also important to ensure that the proposed solutions are accepted and enable a first step toward the adoption of sustainable mobility.

Based on the identified constraints and preferences of the service provider, the following actions appear to be the most appropriate:

■ Electric vehicles

Based on the requirements and budget, decide what type of vehicle to purchase or rent. There are three possible paths to take based on the budget:

- Purchase a small electric car - This is a sustainable option, as the electric vehicle can continue to serve beyond the project's duration. Additionally, a car is versatile and can handle the diverse tasks and mobility requirements of the service. Since the service also relies on the caregivers' personal vehicles, integrating one car into the fleet is more practical than multiple vehicles. A potential drawback of purchasing a single car is that its operating costs would need to be covered by the service provider, and it would be available for use by only one person at a time.
- Lease multiple electric vehicles - The budget could allow for the rental of multiple smaller electric vehicles that are more suited to the transport needs. This would enable more employees to use electric vehicles, leading to larger potential CO2 emissions savings during the project duration. However, leasing vehicles long-term might be less cost-effective compared to purchasing one vehicle if the amortization period of a vehicle exceeds the cost of leasing multiple vehicles over the project's timeline. Additionally, leasing multiple vehicles could present long-term risks, such as potential conflicts with caregivers when the project ends, and they are required to return to using their own vehicles.
- Purchase multiple smaller, micromobility vehicles - These could be used for a subset of trips. While the lower cost allows for the acquisition of multiple vehicles, there are constraints such as the type of trip, weather, and other factors that limit their usability.



All three actions would lead to the sustainability impact of the project. For the project's lifetime, leasing as many electric vehicles as possible would result in the most CO₂ savings for the project. On the other hand, the economic feasibility of that option must be checked. The decision should be made with consideration of the recommendations in this document as well as other economic factors (see Deliverable 2.2.1).

Charging the vehicle is solved, the service provider already has an EV with a designated charging station. Since the trips are short, charging the vehicles every day is not necessary considering the kilometers travelled.

When considering buying or renting car(s), the chosen vehicle(s) should be a smaller electric vehicle due to road characteristics and since there is no need to transport large cargo or persons. Possible vehicles are e.g. Dacia Spring, Opel Mokka, or Peugeot 2008, costing around 22-25k Euros fitting into the project's budget.

The final decision can be made by the mayor, since the service provider can only make requests and support in the decision making.

■ Trip planning

Based on the preliminary analysis, there is some potential in trip planning. It could be done in three levels:

1. With the current set of caregivers and users, the order in which employees are served could be re-planned. This could result in some fuel savings. For this, using a simple routing algorithm to solve the TSP is sufficient.
2. Gradually, when new users or caregivers are involved in the service, the service should be planned with the shortest and greenest option in mind. For example, when a new user is added, they should be assigned to the caregiver who lives closest to them or whose daily route is near the user's location. When a new caregiver starts working, they should be assigned to users that can be served with the least amount of travel. This planning should be done using the TSP. Of course, there may be additional factors to consider when planning trips, not just the travel distance (e.g., the grocery store should be visited before delivering groceries to the serviced user). Nevertheless, trip planning can be beneficial for this service provider.
3. Not only the routes but also the modes could be optimized. Some trips could be served on foot or by bike, depending on the caregiver's willingness. An operator serving several users in close proximity could do so in a multimodal way. For example, if several users live in a remote village, the operator could travel there by car, then switch to a bicycle or micromobility and visit the users. Additionally, if the weather or the caregivers' willingness allows, switching to motorcycles or scooters could be a more environmentally friendly alternative. Since meal deliveries typically involve small delays, public transport might not always be feasible. Based on the daily tasks, it is important to select the right vehicle.

■ Buying electricity from greener sources

Implementing the market-based approach is not possible. Could be possible in the future. Using biofuels is also feasible for the petrol and diesel vehicles.

The steps to implement the above actions are the following:

1. Decide which vehicle type and renting or buying is the most appropriate
2. Start the procurement process as soon as possible



3. Appoint a mobility expert responsible for
 - a. Re-organizing the order of trips for each caregiver (wherever possible)
 - b. Re-organize which caregiver serves which set of users (when there is a change in the human resources or the served users)
 - c. Review trips and check whether any of them can be shifted to a greener mode

7.1.4. Summary of recommendations for Klis

This service provider should focus on replacing their most polluting vehicle(s). Considering three paths within a €20k budget: purchasing one small electric car for long-term use, leasing multiple EVs for greater short-term CO₂ reduction, or buying smaller micromobility vehicles for limited trips. Charging infrastructure is already in place. Trip planning improvements can optimize routes through simple TSP algorithms, assign new users and caregivers based on proximity. Key steps include deciding on the vehicle strategy, starting procurement, and appointing a mobility expert to manage route optimization, caregiver-user assignments, and potential mode shifts.

8. Szombathely

With the Municipality of Szombathely, multiple meetings were carried out focusing on two topics:

1. Selecting which service from Pálos to include in the project: home care delivery or daycare. The decision had to be made based on which service have the most potential to be improved.
2. Support with the vehicle selection for FÉHE that will be purchased from the project's budget and how it can be managed with the ongoing vehicle purchases that are financed outside this project.

With Szombathely, three meetings dedicated for this topic were organized: 2025. 01. 08, 2025. 01. 22., and 2025.01.29.

Additionally, the meetings provided an opportunity to better understand how services are organized at Pálos and FÉHE, the organizing principles when providing the service, and how work is structured. There were some promising discussions about jointly organizing certain person transport services between the two organizations (i.e., FÉHE's vehicle also transporting some people to Pálos daycare if there is available capacity). However, this was discarded due to the potential overhead in coordination, the unreliable availability of FÉHE's vehicle for Pálos (as peak transport demand occurs at similar times for both), and the unclear reimbursement of such a service (the kilometers traveled by the Ford Transit are only reimbursed if it transports a disabled person).

During the meetings, the action plan for this pilot site was also determined. In the following sections, these actions and recommendations are outlined in line with the general framework described above and the KPIs defined in WP2.2.1.

8.1. FÉHE

8.1.1. Service description

FÉHE provides support services for people with disabilities, partly home service (helping with everyday tasks at home, doing shopping etc.), partly transportation (driving the disabled to school, work or to health service). Serving on average 60-65 persons per year during normal working hours.



Although the distance they travel varies, they need a specialized vehicle (with ramp or lift for wheelchair access). For that reason, there is no flexibility in the vehicle type they use. Also, due to transporting disabled people, mode shift is ruled out. Currently, the service provider has two vehicles. A Ford Transit with a lift and a Renault Kangoo, both with diesel drivetrain. From another project, they intend to purchase a newer Ford Transit.

8.1.2. Preliminary recommendations

Based on the best practices and general framework in the previous section, the following items seem appropriate for this service provider.

- **Vehicle selection**

Based on Table 4, the feasible vehicle types are identified. In Table 11, columns are marked with white color where the conditions apply. Then, vehicle types are ruled out that do not meet the criteria.



Table 11. Feasible vehicle types

Mode	Condition											
	Service type				Long distance covered by an employee per day	Road and traffic conditions					Bad weather	Charging infrastructure unavailable
	Person transport		Item delivery	Caregiver visit		Hilly terrain	Roads in poor condition (or unpaved)	Heavy traffic	Hard to park near users	Public transport unavailable or insufficient		
	Need wheelchair access	Doesn't need...										
E-scooter	X	X	X	✓	X	✓	X	✓	✓	✓	X	✓
Electric Bicycle	X	X	X	✓	X	✓	✓	✓	✓	✓	X	✓
E-moped	X	X	X	✓	X	✓	---	✓	✓	✓	X	✓
E-cargo-bike	X	X	✓	✓	X	✓	✓	✓	✓	✓	X	✓
Bicycle	X	X	X	✓	X	X	✓	✓	✓	✓	X	✓
Cargo bike	X	X	✓	✓	X	X	✓	✓	✓	✓	X	✓
Microcar	X	X	---	✓	---	✓	---	---	---	✓	✓	---
Electric car	X	✓	✓	✓	✓	✓	✓	---	---	✓	✓	---
Electric Van	✓	✓	✓	✓	✓	✓	✓	---	---	✓	✓	---
Public transport	X	X	---	✓	---	✓	✓	---	✓	X	---	✓



The service provider has two diesel vehicles for two separate tasks. Electrification of either of them is a logical step.

For transporting disabled persons, the only feasible option is an electric van with wheelchair access. Since the Ford Transit is being replaced by another project, the only remaining option is to purchase an electric car to replace the Renault Kangoo. Given that there are also longer trips involved, and the service already uses bicycles for shorter trips, micromobility is ruled out. Public transport is also inadequate for reliably carrying out the service.

Trip characteristics such as short to medium length trips and urban environments allows for efficient use of electric vehicles. The availability of charging infrastructure is essential to provide a reliable service. The most appropriate charging strategy appears to be relying on the infrastructure at the service provider's headquarters.

■ Trip planning

The number of trips during peak hours could be reduced by coordinating with destinations and making appointments in advance (e.g., at the hospital). During peak hours, not only are travel times longer, but passenger comfort is also reduced due to stop-and-go traffic.

Where possible, serve users who live close to each other, reducing the total distance traveled. Use trip planning, routing, or activity chain planning algorithms (TSP) to optimize routes. Optimize routing by not returning the vehicle to the depot (if possible). This reduces additional commuting by employees and could potentially lead to fewer kilometers traveled. It can reduce CO2 emissions as well as the distance traveled. The feasibility of this depends on how work is organized at the service provider.

8.1.3. Action plan

■ Electric vehicles

The municipality of Szombathely provided a concrete list of requirements for the vehicle needed. They would prefer purchasing a used electric vehicle to replace the Renault Kangoo. Based on previous discussions, this is a good choice, as it would not only make the service greener but also increase their capabilities by upgrading the vehicle with wheelchair access. Given the project's budget, only a used vehicle or leasing a new electric vehicle is feasible. For the project's lifetime and KPIs, both options are equally viable. Buying would mean higher maintenance cost but potentially longer usability beyond the project's scope. The following requirements are defined for the vehicle:

- Have at least 5 seats, optimally 7.
- A minivan type vehicle is preferred (similar category as the Renault Kangoo)
- Has an electronic on-ramp for wheelchair access
- Has a sliding slide door
- Can be charged from the household network grid
- Have at least 100 km range.
- Have at least 90 km/h top speed (for rural use)

Based on the requirements, the Renault Kangoo could be replaced by a vehicle with a more modern drivetrain, such as an electric small van or car. Since the Kangoo is not used for passengers with wheelchairs, a passenger car could also be appropriate. In this project, purchasing a vehicle seems more appropriate than leasing, since the service provider does not use many vehicles, and the project budget potentially allows for the purchase of one, enabling a longer-lasting impact. The most impactful decision



for this service provider is shifting towards greener vehicles of the same type they currently have. Charging the electric vehicle can be done overnight using a wall socket. Although this is convenient, it rules out the possibility of buying electricity from a greener source. The vehicle would park on the premises of the service provider. Increasing the share of electric vehicles would be effective in reducing both direct and indirect CO2 emissions.

■ Trip planning

Improving routing is challenging because the vehicle is utilized almost the entire day (starting from 6:30 AM). There is less demand around noon, but occasional on-demand trips (e.g., visiting the doctor) still occur. Organizing a chain of activities for a demand-driven service is not feasible. This would require a mobility manager who can respond to the upcoming needs and reschedule the vehicles accordingly. Additionally, there is limited room for optimizing the route the vehicle takes to avoid congestion and save fuel.

■ Green fuel

The market-based approach is not feasible for this service provider.

The steps to implement the above actions are the following:

1. Based on the provided requirements, select the most appropriate vehicle on the used vehicle market (also considering imports)
2. Start the procurement process as soon as possible

8.1.4. Summary of recommendations for Szombathely - FÉHE

This service provider should replace its Renault Kangoo with a greener option, preferably by purchasing a used electric minivan that meets specific requirements: 5-7 seats, wheelchair access with an electronic ramp, sliding door, household charging capability, at least 100 km range, and 90 km/h top speed. Buying is favoured over leasing due to long-term benefits and budget feasibility. Charging can be done overnight, though green electricity sourcing is not possible. Trip planning improvements are limited because the vehicle operates almost all day with occasional on-demand trips.

8.2. Pálos Károly home care

8.2.1. Service description

Based on the provided data, the social service can be categorized as caregiver visit plus item delivery. The caregivers typically use their own vehicles and when possible, use bikes. Driving is only permitted if there is a reason for that. The typical trip length for one caregiver is between 10 and 30 km with bicycles but there are some destinations in nearby villages that cannot be served with bikes.

8.2.2. Preliminary recommendations

Based on the best practices and general framework in the previous section, the following items seem appropriate for this service provider.



■ Vehicle selection

Based on Table 4, the feasible vehicle types are identified. In Table 12, columns are marked with white color where the conditions apply. Then, vehicle types are ruled out that do not meet the criteria.



Table 12. Feasible vehicle types **Green LaMiS**

Mode	Condition											
	Service type				Long distance covered by an employee per day	Road and traffic conditions					Bad weather	Charging infrastructure unavailable
	Person transport		Item delivery	Caregiver visit		Hilly terrain	Roads in poor condition (or unpaved)	Heavy traffic	Hard to park near users	Public transport unavailable or insufficient		
	Need wheelchair access	Doesn't need...										
E-scooter	X	X	X	✓	X	✓	X	✓	✓	✓	X	✓
Electric Bicycle	X	X	X	✓	X	✓	✓	✓	✓	✓	X	✓
E-moped	X	X	X	✓	X	✓	---	✓	✓	✓	X	✓
E-cargo-bike	X	X	✓	✓	X	✓	✓	✓	✓	✓	X	✓
Bicycle	X	X	X	✓	X	X	✓	✓	✓	✓	X	✓
Cargo bike	X	X	✓	✓	X	X	✓	✓	✓	✓	X	✓
Microcar	X	X	---	✓	---	✓	---	---	---	✓	✓	---
Electric car	X	✓	✓	✓	✓	✓	✓	---	---	✓	✓	---
Electric Van	✓	✓	✓	✓	✓	✓	✓	---	---	✓	✓	---
Public transport	X	X	---	✓	---	✓	✓	---	✓	X	---	✓



Based on the data provided, some trips are to nearby villages that are longer, and there is also item (food) delivery. This rules out most modes. For longer trips, only passenger cars or maybe microcars are feasible. Switching to electric vehicles is a logical choice. The driving characteristics of electric vehicles allow them to be used efficiently, as trips are not very long but long enough to be exhausting with active modes. For local trips, bikes, cargo bikes, or their electrified versions are also suitable. Since most shorter trips are already served by bicycles, purchasing electric bicycles would worsen the total carbon footprint. Therefore, buying or leasing an electric vehicle seems like the best option. Additionally, some trips could be served with microcars or electric scooters instead of cars. In summary, three options could be considered:

- a) In terms of sustainability, buying an electric vehicle seems like a good option, as the electric vehicle can serve well beyond the duration of the project. Additionally, a car is the most versatile option, which is beneficial because the tasks and mobility requirements are diverse. Since the service also relies on the vehicles of the caregivers, integrating one vehicle into the fleet seems easier than multiple vehicles.
- b) Leasing multiple electric vehicles - During the project duration, this could have the largest impact on CO2 savings.
- c) Purchasing a microcar or electric scooter - This option is also feasible to serve some users who would otherwise be served by cars. However, this would mean some compromise, as these vehicles are slower and might be more sensitive to weather conditions. In addition, since they could only be used on a few routes, their utilization might not be high enough to justify this mode. Additionally, acceptance from the caregivers would also need to be taken into account.

■ Trip planning

Where possible, serve users who live close to each other, reducing the total distance travelled by clustering these users. Use trip planning, routing, or activity chain planning algorithms to optimize the order in which users are served from a CO2 emissions perspective. Additionally, if an operator serves several users in close proximity, this could be done in a multimodal way. For example, if several users live in a remote village, the operator could travel there by car, switch to a bicycle or micromobility, and visit the users. Based on the daily tasks, it is important to select the right vehicle.

8.2.3. Action plan

■ Electric vehicles

The municipality of Szombathely provided a concrete list of requirements towards the vehicle needed. They would prefer a very small electric car or even a microcar.

- 1 person capacity
- Small electronic engine
- Cover against bad weather conditions
- Packing capacity: min 10 kg and 100 l
- Can be charged from the household network grid
- Have at least 40 km range.
- Have at least 45 km/h top speed (in-town use)



If the project's budget permits, the service provider would prefer the purchase or leasing of a small electric vehicle (e.g., a low-speed microcar, an electric cargo bike, or a used small car such as a VW e-up) to replace one of the passenger cars. Trip characteristics permit this, as the length of a typical trip is shorter than the range of such vehicles. The willingness of employees to make the mode shift is not yet clear. Based on the interviews, the service provider would prefer a small car rather than a microcar due to its limitations, such as speed, reliability in poor weather, and cargo capacity. This action will reduce CO₂ emissions by reducing the kilometers traveled by one of the caregiver's motor vehicles. Charging the electric vehicle can be resolved overnight using a wall socket. The vehicle would park within the premises of the service provider.

■ Trip planning

When reviewing the daily schedules of the caregivers, it was found that significant improvements could be achieved by optimizing their activity chains by solving the Travelling Salesman Problem for all employees. This could be further improved if the sole focus was reducing the distance traveled by solving a variant of the Vehicle Routing Problem, i.e., when the employees are not bound to fixed users. On the other hand, how work is organized does not permit this, as the main factors are the quality of service for the users and the balancing of the caregivers' workload, i.e., they should perform diverse tasks during the day. Additionally, elderly people prefer consistency, so mixing employees could degrade the quality of service.

Previously, organizing trips was mainly done based on experience and human intuition. Therefore, during this project, the service provider will use an advanced routing algorithm, based on MapQuest. Acknowledging that this adds extra workload on the person responsible for trip planning, the Hungarian consortium partners will support Pálos in using this tool and provide consultancy on how to integrate it into their processes. Due to the dynamic nature of user demands (e.g., emergencies), it is expected that complete adherence to the optimally planned daily trips will not always be possible. However, the provider will make efforts to adhere to them as much as possible to reduce the carbon footprint.

Since the caregivers use their own vehicles, and they do not use motor vehicles in the case of bikes, the carbon footprint cannot be directly reduced. On the other hand, at an organizational level, it will bring clear benefits, as the kilometers travelled will be reduced, improving the well-being of caregivers and reducing the distance travelled.

As a side note, the municipality of Szombathely has demonstrated interest in the trip planning algorithm for other social services unrelated to this project.

■ Green fuel

The market-based approach is not feasible for this service provider.

The steps to implement the above actions are the following.

1. Based on the requirements and budget, decide what type of vehicle to buy and start the procurement process as soon as possible.
2. Appoint a mobility expert.
3. Continuously monitor and optimize vehicle routing during the pilot. This is the task of the mobility expert. The results should be reported to the project leaders.

8.2.4. Summary of recommendations for Szombathely - Pálos Károly home care

This service provider should improve sustainability by acquiring a small electric vehicle or a microcar, electric cargo bike, or small car (e.g., VW e-up)—to replace a passenger car, provided the budget allows.



The preferred should be a small car due to better speed, weather protection, and cargo capacity compared to microcars. Additionally, significant CO₂ reduction and efficiency gains are expected from optimizing caregiver routes using advanced tools like MapQuest, despite challenges posed by user consistency requirements and dynamic demands. Key steps include selecting the vehicle type, appointing a mobility expert, and continuously monitoring and improving routing during the pilot.



F. Appendix

Python code for solving the VRP

main.py

```
import polyline
import shapefile
import requests
import json
import urllib
import folium

from ortools.constraint_solver import routing_enums_pb2
from ortools.constraint_solver import pywrapcp
from pyproj import Transformer, CRS

otp_url = 'http://localhost:8080/otp/routers/default/plan'
cdd_start = shapefile.Reader("../Shapefile_ToSend/BG_StartingPoint_CDD.shp")
cdd_user_address = shapefile.Reader("../Shapefile_ToSend/BG_UserAddress_CDD.shp")
projection_path = "../Shapefile_ToSend/BG_StartingPoint_CDD.prj"

with open(projection_path, "r") as f:
    wkt = f.read()
crs = CRS.from_wkt(wkt)
epsg = crs.to_epsg()
transformer = Transformer.from_crs(epsg, 4326, always_xy=True)

def get_shp_addresses(shp_file):
    coordinates = []
    for shape in shp_file.shapes():
        coordinates.append(transformer.transform(shape.points[0][0], shape.points[0][1]))
    return coordinates
```



```
def call_otp(start_lat, start_lon, end_lat, end_lon):
    otp_url = 'http://localhost:8080/otp/routers/default/plan'

    # Set the request parameters
    params = {
        'fromPlace': f'{start_lat},{start_lon}',
        'toPlace': f'{end_lat},{end_lon}',
        'mode': 'CAR',
        'numItineraries': 1, # Number of itineraries to retrieve
        'walkReluctance': 10,
        'showIntermediateStops': False,
    }

    # Send the GET request to OpenTripPlanner
    response = requests.get(otp_url, params=params)
    result = json.loads(response.text)
    try:
        return result['plan']['itineraries'][0]['walkDistance'],
        result['plan']['itineraries'][0]['legs'][0]['legGeometry']['points']
    except:
        return None

def create_distance_matrix(coordinates):
    matrix = []
    route_matrix = []
    for i in range(len(coordinates)):
        row = []
        route_row = []
        for j in range(len(coordinates)):
            if i == j:
                row.append(0)
                route_row.append(None)
```



```

else:
    distance, route = call_otp(coordinates[i][1], coordinates[i][0], coordinates[j][1],
coordinates[j][0])
    row.append(int(distance))
    route_row.append(route)
matrix.append(row)
route_matrix.append(route_row)
return matrix, route_matrix


def create_data_model(distance_matrix):
    data = {}
    data['distance_matrix'] = distance_matrix
    data['num_vehicles'] = 4
    data['depot'] = 0 # Start node
    data["demands"] = [0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1]
    data['vehicle_capacities'] = [7,7,7,7] #
    return data


def calculate_route(data):
    manager = pywrapcp.RoutingIndexManager(
        len(data["distance_matrix"]), data["num_vehicles"], data["depot"]
    )

    # Create Routing Model.
    routing = pywrapcp.RoutingModel(manager)

    # Create Routing Model.
    routing = pywrapcp.RoutingModel(manager)

    # Create and register a transit callback.
    def distance_callback(from_index, to_index):
        """Returns the distance between the two nodes."""

```



```
# Convert from routing variable Index to distance matrix NodeIndex.
from_node = manager.IndexToNode(from_index)
to_node = manager.IndexToNode(to_index)
return data["distance_matrix"][from_node][to_node]

transit_callback_index = routing.RegisterTransitCallback(distance_callback)

# Define cost of each arc.
routing.SetArcCostEvaluatorOfAllVehicles(transit_callback_index)

# Add Capacity constraint.
def demand_callback(from_index):
    """Returns the demand of the node."""
    # Convert from routing variable Index to demands NodeIndex.
    from_node = manager.IndexToNode(from_index)
    return data["demands"][from_node]

demand_callback_index = routing.RegisterUnaryTransitCallback(demand_callback)
routing.AddDimensionWithVehicleCapacity(
    demand_callback_index,
    0, # null capacity slack
    data["vehicle_capacities"], # vehicle maximum capacities
    True, # start cumul to zero
    "Capacity",
)

# Setting first solution heuristic.
search_parameters = pywrapcp.DefaultRoutingSearchParameters()
search_parameters.first_solution_strategy = (
    routing_enums_pb2.FirstSolutionStrategy.PATH_CHEAPEST_ARC
)
search_parameters.local_search_metaheuristic = (
    routing_enums_pb2.LocalSearchMetaheuristic.GUIDED_LOCAL_SEARCH
)
search_parameters.time_limit.FromSeconds(1)
```



```
# Solve the problem.
solution = routing.SolveWithParameters(search_parameters)

# Print solution on console.
if solution:
    print_solution(data, manager, routing, solution)

    routes = []
    for vehicle_id in range(data['num_vehicles']):
        index = routing.Start(vehicle_id)
        route = []
        while not routing.IsEnd(index):
            route.append(manager.IndexToNode(index))
            index = solution.Value(routing.NextVar(index))
        route.append(manager.IndexToNode(index)) # Add depot at end
        routes.append(route)

    return routes, solution
else:
    print("No solution found !")

def plot_routes_on_map(routes, route_polyline, coordinates):
    """Plots VRP routes on a Folium map."""
    coordinates = [[y, x] for x, y in coordinates]
    map_center = coordinates[0] # Center map on the depot
    folium_map = folium.Map(location=map_center, zoom_start=13)

    # Colors for different vehicle routes
    colors = ['magenta', 'green', 'purple', 'orange']

    for i, route in enumerate(routes):
        route_road = []
```



```
for j in range(len(route)-1):
    route_road.extend(polyline.decode(route_polyline[route[j]][route[j+1]]))
# subroute = [coordinates[i] for i in route]
folium.PolyLine(route_road, color=colors[i], weight=5, opacity=0.7).add_to(folium_map)

# Add markers for all locations
i = 0
for coord in coordinates:
    folium.CircleMarker(
        location=coord,
        radius=10 if i == 0 else 5, # Size of the dot
        color="blue" if i == 0 else "red", # Outline color
        fill=True,
        fill_color="blue" if i == 0 else "red", # Fill color
        fill_opacity=1.0,
        popup=f"Node {i}"
    ).add_to(folium_map)
    i += 1

folium_map.save("vrp_solution_map.html") # Save as HTML
print("Map saved as vrp_solution_map.html. Open this file to view the routes.")

def print_solution(data, manager, routing, solution):
    """Prints solution on console."""
    print(f"Objective: {solution.ObjectiveValue()}")
    max_route_distance = 0
    for vehicle_id in range(data["num_vehicles"]):
        if not routing.IsVehicleUsed(solution, vehicle_id):
            continue
        index = routing.Start(vehicle_id)
        plan_output = f"Route for vehicle {vehicle_id}:\n"
        route_distance = 0
        while not routing.IsEnd(index):
            plan_output += f" {manager.IndexToNode(index)} -> "
```




```
previous_index = index
index = solution.Value(routing.NextVar(index))
route_distance += routing.GetArcCostForVehicle(
    previous_index, index, vehicle_id
)
plan_output += f"{manager.IndexToNode(index)}\n"
plan_output += f"Distance of the route: {route_distance}m\n"
print(plan_output)
max_route_distance = max(route_distance, max_route_distance)
print(f"Maximum of the route distances: {max_route_distance}m")
```

```
def main():
```

```
    center_coord = get_shp_addresses(cdd_start)
    addresses_coord = get_shp_addresses(cdd_user_address)
    coordinates = center_coord + addresses_coord[0:28]
    distance_matrix, route_matrix = create_distance_matrix(coordinates)
    data = create_data_model(distance_matrix)
    routes, solution = calculate_route(data)
    plot_routes_on_map(routes, route_matrix, coordinates)
```

```
if __name__ == '__main__':
    main()
```



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