Exploring the Factors that Encourage the Spread of EV-DRT into the Sustainable Urban Mobility Plans

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Abstract. The development of sustainable mobility is linked to technological developments and different forms of vehicle power supply. Despite all the difficulties brought by the COVID-19 pandemic, therefore, it is necessary to provide road users with an adequate network of public recharging infrastructures and to facilitate the setting-up of private recharging stations through shared and participatory development plans between the stakeholders and all the institutions involved. The present work introduces an analysis of some of the European Sustainable Urban Mobility Plans (SUMPs) and the transport supply connected to several cities. After an evaluation of the macro areas of intervention, factors and criteria for the deployment of the electric vehicle linked to the demand responsive transport choice (EV-DRTs) have been defined in terms of user classification and environmental factors, but also considering the services and infrastructures for electric charging. The identification of these factors and criteria allows an exemplification in the development and adaptation of the planning and design concept.

Keywords: Electric vehicle · SUMPs · Demand Responsive Transport (DRT) · Shared mobility

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1 Introduction

One of the main objectives of the European Union is to achieve climate neutrality by 2050. One of the main sources of emissions and greenhouse gases (GHG) is transport. By 2030, it is expected that there will be about 10% less travel by private car. In addition, the rise of the sharing economy, multi-modality and autonomous vehicles, as well as the global ageing of the population, will drastically reduce the need to own a car. This decrease will be offset by compensated by a progressive increase in the use of public transport [1], bicycles and walking [2–4], as well as by a transition to more sustainable and ecological transport systems [5]. New mobility habits related to increased cycling and walking for short distances (<2 km) and the use of public or shared mobility for medium and long distances (>2 km) are supported by many projects such as the extension of cycle paths, the implementation of sharing systems, pedestrianization projects and the improvement of public transport [6, 7].

Investing in the use of technologies for urban mobility will be decisive in facilitating the transition towards more agile and sustainable solutions in the next 10 years [8, 9].About 40% of people globally are inclined to the idea of using more innovative transport solutions. But not all cities are prepared for a radical transformation of mobility [8, 9]. Among the technologies and mobility solutions with the greatest potential to meet the needs of tomorrow's commuters there are:

- Mobility as a Service (MaaS) This model integrates different transport modes, including buses, trams, bicycles and car sharing, and combines them in a single ticket or in a single app. In this way, the multimodal travel experience can be optimized into a unique user experience that has the same convenience as a trip in your own car [10];
- Mobility hubs: located in the peripheral areas of cities, these stations allow commuters to switch from their polluting cars to vehicles with zero emissions, such as electric buses, e-bikes and scooters, so as to contribute to the reduction of pollution and decongestion urban area [12];
- Autonomous parcel delivery vehicles: vehicles with automatic parcel delivery such as mobile stations, where the customer can activate the delivery via an app, in order to direct the vehicle to a predetermined place and autonomously retrieve the package from it. This system helps to limit trips with unsuccessful delivery, significantly reducing traffic and ensuring greater effectiveness [13].

Within this framework, the main aim of this paper is to define factors and criteria for the deployment of EV-DRTs, in terms of user classification and environmental factors, but also considering the services and infrastructures for electric charging. The determination of these factors and criteria allows an exemplification in the development and adaptation of the planning and design concept. The work focused on the research steps defined by Figure 1:

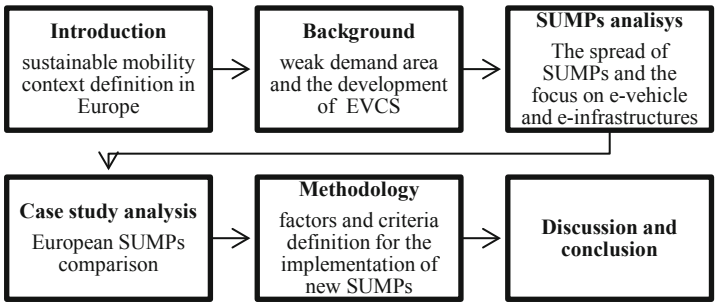

Fig. 1. Steps of research

2 Background

Low demand areas are located in urban or interurban contexts and are generally characterised by low or medium-low transport demand. These areas are notable for their spatial and temporal dispersion.

The "weak demand" attribute is directly related to the number of travels but can also refer to the degree of fragmentation of the demand for which small groups of users generate low levels of demand for mobility. The identification of these areas must be carried out considering the presence within the municipal area of a large number of villages or scattered houses that require to be connected to the main urban center of the Municipality (where, e.g. commercial businesses, offices, transport hubs are located). These types of settlements should not be served by conventional public transport systems, which would be expensive and inefficient for the level of mobility of the area. Indeed, it may be necessary to combine different routes with many stops, long distances to be covered with low load factors, reinforcing the need to adopt more flexible forms of local public transport [14, 15].

In this context, the Demand Responsive Transport (DRT) represents an innovative solving solution. It consists in using a fleet of small-sized public transport (e.g. minivans) capable of making personalized trips based on user requests (with origin and destination chosen each time), bringing a certain number of users and managing the concatenation of paths with a good level of flexibility to satisfy all requests [16, 17].

The DRT must be able to plan the route of each vehicle used based on the requests received. The models used to manage these systems are also adaptable to the transport of goods, albeit with a slightly higher level of rigidity [18]. In general, the implementation of DRT tries to satisfy two opposing needs:

- Minimization of operating costs (which can increase in the case of maximum flexibility);
- Maximization of the level of service offered to the user (which decreases if waiting or travel times become longer).

Therefore, in the absence of a local public transport service, the innovations brought about by both new technologies and the new shared mobility paradigm can help to bridge the gap by redefining the concept of public transport.

The new mobility paradigm provides for an on-demand transport service, which allows users distributed in an area to book and make a trip and allows to transport operators to perform the service reducing the waiting time for users, the number of vehicles and the travelled kilometres, thanks to the sharing of the ride with the same vehicle among multiple users. However, to the concept of weak demand areas, which have low demand for mobility only at certain hours of the day or periods of the year, is evolving in the light of the pandemic caused by COVID-19, which has made it essential to strengthen the service in lines with higher demand.

Thus, it is possible to consider a different perspective regarding the temporal dimension. This means that a DRT system can also be useful in cities with a high demand for transport, also characterized by possible daily peaks. In this case, the DRT can act as an integration to public transport, in order to increase the capacity of the service, maintaining lower seat-load factor and answering to the requests for social distancing [19, 20].

The significant increase in electric vehicles in Europe should be related to the charging infrastructure which should adapt to these innovative forms of mobility. The evolution of these services and the increasing demand for their use must be the subject of planning tools for optimizing the benefits for the user and the surrounding environment. Therefore, European planning instruments at local, regional and national scales must consider these developments.

3 SUMPs Analysis

In Europe, two main planning tools have been defined to develop local strategies integrating electric mobility, namely Sustainable Energy Action Plans (SEAPs) and Sustainable Urban Mobility Plans (SUMPs).

A SEAP is a document related to cooperation between cities (called Pact of Mayors) in which activities and measures are defined to reduce CO2 emissions by 2020 according to certain targets. Since 2005, EU projects have considered SUMPs and they are now an essential part of European policy [21, 22]. Unfortunately, the deployment of electric vehicles in Europe has so far a minimal impact on the strategic objectives of a SUMP. This is related to the duration of the SUMP (5–10 years) and thus the time correlation with a full adoption of e-mobility. In addition, some of the operational e-mobility objectives, such as capacity and local network use, are still difficult to link to SUMP objectives. Nevertheless, a state-of-the-art SUMP that, together with other measures, considers the introduction of e-mobility as an objective to achieve improved air quality, energy efficiency and reduced greenhouse gas emissions.

Several research studies deal with the topic of e-mobility and emissions by comparing scenarios and mitigating possible effects [23] and by analysing citizens' opinions on private use [24] or renting or sharing [25]. Therefore, this section analyses and compares on the one hand the diffusion of SUMP urban mobility plans and forms of electric mobility in some European contexts with reference to shared mobility [26] and DRT [17, 27, 28]. Secondly, it defines the factors and evaluation criteria that can be used to draw up a SUMP with a future and increasing focus on electric mobility.

3.1 Evolving Urban and Electric Mobility Planning Tools in Europe

Urban mobility planning is complex and focuses on new concepts that not only cover transport, but also integrate many related areas (land use, environment, economic development, social policy, health, safety, energy, etc.).

A sustainable urban mobility plan is a strategic plan designed to meet the mobility needs of people and businesses in and around cities for a better quality of life. It builds on existing planning and considers integration, participation and evaluation principles. The objectives focus on both traffic congestion and space consumption but also address safety, dependence on certain resources and local and global emissions. Promoting a sustainable [29], resilient [30] and smart city [31].The evolution of the latter is closely related to the diffusion of alternative mobility and in shared and on-demand mobility with electric or hybrid type engines [32]. Unfortunately, the EU does not have an overall strategic road map for e-mobility, the availability of publicly accessible charging stations varies considerably from country to country, payment systems are not harmonised, and no information is available.

Rechargeable electric and hybrid vehicles are growing but charging networks are not developing at the same pace Indeed they can act as first and last mile solutions for passengers and freight, especially when combined with electric infrastructure, as electric vehicles are suitable for short distances (see also use cases of transport networks for electric vehicles and electric charging infrastructure).

Furthermore, the charging time depends mainly on the type of vehicle battery and the capacity of the charging point, also on the battery capacity and other variables described in Table 1.

Table 1. Different charging stations details (Source: [33])

Charger speed and type	Power rating	Approximate time to charge
Slow (single-phase AC)	3–7 kW	7–16 h
Normal (three-phase AC)	11–22 kW	2–4 h
Fast (DC)	50–100 kW	30–40 min
Ultra-fast (DC)	> 100 kW	< 20 min

The definition of the SUMP [34] must therefore consider the development of the Mobility on Demand (MoD) [35] for combustion and electric fuels and the MaaS digital platforms [36], underlining the benefits and weaknesses according to the infrastructure (charging stations and parking areas) and the type of vehicle:

- Private (car, bike, micro-mobility)
- Public (bus)
- Shared mobility (car, bike, micro-mobility)
- DRT

DRT can replace low-frequency and low-frequency services, shuttling users between them and the wider public transport network.

To better plan both the infrastructure of charging stations and the inclusion of shared electric mobility (in relation to other forms of alternative electric mobility) in the SUMP, this work has defined a preliminary comparison between urban mobility planning tools and the presence of electric mobility, considering the definition showed in Table 2.

Table 2. Distribution of SUMPs in different European cities (Our elaboration. Data source from [37, 38])

City	Country	SUMP period	Local rules	EVCS (2020)	ECS	EBS	DRT
Athens	GR	n.d	SUMP	5	yes	yes	no
Barcelona	ES	2013–2018	PMUS	45 (fast)	yes	yes	partial
Berlin	DE	2025	UTDP	728	yes	yes	yes
			STEP				
Bremen	DE	2025	VEP	> 100	yes	yes	yes
Budapest	HU	2014–2030	BMT	262	yes	yes	no
Copenaghen	DK	2016–2020	SUMP	600	yes	yes	no
:eneva	SW	n.d	SUMP	57	yes	yes	no
Hamburg	DE	2013–2015	VEP	600	yes	yes	yes
			SMP 2.0				
Helsinki	FI	2015	HLJ	110	yes	yes	yes
Ljubljana	SL	2015	SUMP	80	yes	yes	no
Madrid	ES	2014	PMUS	148	yes	yes	yes
		2025	PEMSCAM				
Malmö	SE	2001–2032	SUMP	150	yes	yes	no
			TRAST				
			TROMP				
Milan	IT	2013–2018	PUMS	156	yes	yes	yes
			PUT				
Oslo	NO	2020	SUMP	400	yes	yes	yes
			SUT				

Furthermore, in the digital age, there are numerous ways to improve the efficiency of DRT systems through software and hardware solutions such as intelligent sensors, big-data or artificial intelligence. Indeed, using easy-to-use apps and their mutual connectivity with superior platforms of transport providers, the customer experience can be enhanced while maintaining or increasing the efficiency of DRT systems at the same time. An important aspect to watch out for is the introduction and use of autonomous vehicles. This technology has the potential to change the public transport landscape, especially in rural areas [39].

Therefore, the following are some European case studies defining good practices related to e-mobility deployment and sustainability and urban resilience strategies.

3.2 The Evolution of European Best Practices on e-Mobility

In the last years, European countries encourage electric mobility. However, there are not a single approach and the same policies adopted and different measures were implemented by different cities to achieve the objectives of the related SUMP. Germany has significantly implemented the number of public charging points for electric vehicles in recent years and Munich is the German city with the largest number, equal to 1,185. It has set itself the goal of optimally coordinating services such as public transport and car sharing and connecting them to an efficient electricity network. Already in 2018, to better integrate the new Domagkpark district, mainly residential and suburban, with the center, to discourage the use of private vehicles, flexible and sustainable alternative mobility[1] have been tested, such as car sharing, electric scooters and electric bicycle rental. At the same time, a charging infrastructure was implemented to support electromobility (Fig. 2). In particular it is consisting of charging points and mobility stations (in which different charging points for bicycles, electric scooters and cars are located) that combine and provide integrated services shared mobility with access to public transport services, such as trams and buses. The innovative concept introduced in Munich is the design of mobility stations as an integral part of traffic planning and urban mobility. Another objective pursued in Munich is the optimal coordination of services such as public transport and with new shared mobility services different forms of shared mobility and the respective connection to an intelligent electricity network. In this context, a best practice is the Mobility Station Freiheit Munchen[2], that integrates public transport (subway, bus, tram,) with taxi services, car sharing e bicycle rental. Also in this case, the electric charging infrastructure was planned as an integral part to support the services offered. In fact, there are both electric charging areas and parking spaces dedicated to vehicles of e-car sharing and bicycle parking facilities.

In 2019, Oslo was the first Green Capital of Europe and was among the first cities in Europe to promote electric mobility, having set itself the goal of drastically reducing carbon gas emissions by 95% by 2030 (compared to 1990). Therefore, it has combined several local and national measures. According to Norway's goal of eliminating sales of petrol or diesel-powered vehicles by 2025, the City has launched a program of electrification of road mobility, including buses and taxi. Locally it has banned the traffic of cars powered by fossil fuels in the central areas. Free parking areas have been created that offer the possibility of connecting vehicles to the electricity grid and recharging the

[1] They are implemented as part of the project ECCENTRIC by CIVITAS, also financed from the European Union's Horizon 2020 research and innovation programme, tried new sustainable mobility solutions.

[2] The result of a joint project of the City of Munich in collaboration with Münchner Verkehrsgesellschaft (MVG), a municipally owned company responsible for operating public transport in Munich, which operates buses, the tramway and the U-Bahn, and Stadtwerke München GmbH (SWM), a company owned by the city of Munich which offers public services for the city and the region of Munich.



Fig. 2. Domagkpark charging point (Source: [40])

batteries for free. An innovative element is the creation in the parking areas reserved for taxis of a recharging network using induction plates. Furthermore, to reduce urban traffic congestion, electric car sharing services have been implemented and have been created the "Green Mobility Houses", areas that offer e-car sharing services, charging points, bicycle parking, e-scooters. A common action undertaken is the installation of charging infrastructures in public areas that exploit clean energy by renewable energy source (Fig. 3).



Fig. 3. Oslo charge & drive stations (Source: [41])

Barcelona in recent years has been promoting the use of cleaner, cheaper and more sustainable modes of transport and alternative energies, improving public transport systems and encouraging electric mobility and the mobility sharing services to improve environmental quality. According to the Strategy for electric mobility, the Catalan city aims to have 80% of the municipal fleet, buses and taxis, electric by 2024. The municipality has an efficient bike sharing service. As part of the Green Charge[3] project, actions have been implemented that aim to encourage intermodality and easily accessible forms

[3] The project Green Charge by CIVITAS (https://www.greencharge2020.eu/), also financed from the European Union's Horizon 2020 research and innovation programme, aims to create an electricity-based transport system and has started pilot projects in Oslo, Barcelona and Bremen.

of individual mobility and reduce externalities such as the use of public space by private vehicles. One goal pursued is the replacement of fossil fuel-powered scooters with light electric vehicles (LEVs), such as e-bike and e-scooters.

Therefore, they were installed charging location in office and public areas: over 500 charging points distributed in numerous stations and car parks in all districts, currently (February 2021) there are 555 electric charging points located in the city, 25 of which are fast charging points.

4 Methodology

This paragraph focuses on the definition of macro-areas of action. By identifying the factors and criteria, this paragraph allows the assessment of the evolution of electric infrastructures and EV-DRT in order to foster greater sustainability in transport planning and promote decarbonisation strategies.

4.1 Setting Criteria for Planning and Designing Electric Mobility

The European Commission has adopted a wide-ranging strategy which, in its rich articulation of actions, pursues the objective of reducing Europe's dependence on oil imports and reducing carbon dioxide emissions in transport by 60% by 2050. To achieve this result, a makeover of the current European transport system will be necessary. To allow adequate development of electric mobility, consistent with the objectives set by the European Union for 2030, planning tools with a 2030 time-horizon will have to define possible scenarios defining private vehicle fleets, public fleets, company fleets and sharing services, respectively. In general, electric mobility brings energy, environmental and economic advantages, which are summarised in Table 3.

Table 3. Macro-areas definition and relative benefits (Our elaboration)

Energy	Environmental	Economy
Greater efficiency compared to a vehicle with a combustion engine	Decreasing environmental emissions or particulate matter (PM10, NOx, CO, CO2)	Increasing the development of smart energy networks
Reduced dependence on oil-based energy		Promotion of an innovative industrial sector
Integration of renewable energies in mobility	Decreasing acoustic emissions	Territorial rebalancing
Increased distributed generation and self-sufficiency		Promotion of connectivity and interaction with ICTs

About the DRT, it is observed that it can:

- Replace low-frequency routes with a dynamic service that responds to demand, which can reduce the overall costs of providing the service;

- Reduce road deterioration and maintenance costs by increasing the number of economic vehicles on the road instead of heavier, low-frequency vehicles;
- Reduce the need for additional capital investment as the use of existing road infrastructure can be optimised;
- Increase economic, social and environmental values;
- Reduce emissions by replacing inefficient fixed services with flexible and adaptable services that optimise service use;
- Encourage modal shift from private car use with convenient shared mobility options that are tailored to the specific needs of the user.

The implementation of electric mobility with DRT is closely linked to the planning of charging areas. In general, DRT operations based on electric vehicles present a more complex environment in terms of mathematical modelling and decision analysis, because battery autonomy and charging constraints need to be addressed.

It is possible to define some criteria related to both service and infrastructure to identify which criteria need to be analysed to easily plan and implement an EV-DRT service. According to [42], four aspects are necessary for the implementation of a Demand Responsive Transport system, namely the definition of the area and the potential demand preferably between 3000 and 5000 users [43], the users (e.g. elderly, young people, families and their children, etc.) and the reason for the trip, that would determinethe type of vehicle to bechosen. Furthermore, for the optimisation of an electric service, it is necessary to consider the driving style, the environmental and morphological characteristics of the area (such as slopes), the urban evolution and activities and the location of the charging stations [44] In order to implement an EV-DRT service.

The main critical issues to be analysed are related to:

- How to efficiently design and manage the integrated EV-DRT system, aiming at energy efficiency and considering the challenges of stochastic demand and charging operations;
- How DRT can best augment/replace mass transport by improving adaptation to spatial and temporal variations in demand, ensuring high quality of service and limiting operational costs;
- Define the expected benefits of an integrated EV-DRT system in terms of ridership, reduced emissions and operational costs.

Strategic planning must therefore be undertaken to decide on the provision of projects that address infrastructure gaps and future development needs (changing the use of parking, stops, stations, network; monetising the use of public infrastructure for private providers). Results-based regulation of DRT provision must also be implemented to serve the policy of integration and development/optimisation of mass transport infrastructure.

Governments need strategic network planning, commercial and project management capabilities to understand and address infrastructure gaps (physical, electrical and digital) to integrate such solutions with existing transport and energy service provision and develop the commercial framework to support the transition to results-based provision [45]. Therefore, to proceed to the infrastructure phase, it is essential to first carry out analyses at a territorial level, to identify potential users, define usage scenarios and

the corresponding recharging requirements. In this case, a New York architecture firm carried out important research on its territory, where it analysed the correlation between infrastructure locations, geographical and demographic data, and current policies to highlight the main trends in location, define recommendations for maximising the use of facilities and indicate further areas for study [46].

4.2 Development of Aspects and Criteria for Planning and Designing Electric Mobility

The analysis of mobility demand and supply (infrastructures) is constantly being developed [47] and requires the identification of actions to be implemented in the short, medium and long term. This makes it possible to make the sector's regulatory process effective, to identify what actions need to be taken to improve and disseminate technical data, and finally to implement a series of actions and incentives to raise awareness among the population of the use of electric mobility. Table 4 below highlights the main action points for improving infrastructure and increasing the propensity to use electric mobility.

Table 4. Definition of actions for the improvement of SUMP in regulatory, technical and socio-cultural terms (Our elaboration)

Area	Definition	
Legal Aspects	SUMP update	Greater uniformity between European regulations on charging infrastructure
	Increasing car sharing with electric vehicles and reducing pollutant emissions and congestion	
Technical Aspects	Site selection	Public land use permits
	Connection to the electricity grid	Capacity of connection to the local network
	Type of charging station	Spatial configuration of car parks
	Parking regulations and signage	Urban design
	Type configurations for different areas	Accelerating the development of a publicly accessible charging network
	Expanding charging possibilities in residential and business premises	
Socio-cultural Aspects	Incentives to use shared or dial-a-ride mobility	Awareness campaigns
	Participatory planning	Stimulate the introduction of electric vehicles in the most effective and practicable mobility segments

The actions also make it possible to define criteria for describing electric vehicle DRT (EV_DRT) mobility. Therefore, a series of criteria have been identified in Table 5 to be used to characterise and thus improve the connection between the infrastructures and services relating to the supply of electric demand-responsive transport, as well as the environment and the users that make up demand.

Table 5. Criteria for the definition of the electric DRT service (Our elaboration)

Criteria	Definition	
Infrastructure	Infrastructure quality index	Number of recharging stations at local and regional level
	Type of charging station	Presence of maps and geo-localization tools
	Presence of parking spaces reserved for electric mobility	Presence and implementation of green mobility development plans
	Presence and implementation of maintenance plans for electrical infrastructure	
Service	Incentives for customers to Use electric mobility	Availability of electric vehicles (n. of e-vehicle/fleet)
	Multimodality	Presence of digital MaaS platforms
	Partnerships with other companies	Monitoring through survey campaigns
	Definition of performance and service quality indicators	Possible integration with PT
	Sustainable pricing	
User	Estimation of resident and commuter population	Socio-demographic characterization
	Income	Driving license possession
	Car/van ownership	Bicycle/micromobility ownership
	Democratic participation in planning	Presence of psycho-social barriers limiting the use of e-mobility (handicap, religion…)
	Educational and awareness campaigns	
Environment	Monitoring of acoustic and environmental parameters (pollutants)	Presence of green energy sources
	Presence of aquifers or lakes	Presence of green areas
	Presence of steep areas (slope)	

5 Conclusions

Sustainable mobility planning strategies are generally linked to a set of planning and design tools that dictate their characteristics, critical aspects or encourage their use. SUMPs include among their objectives the progressive replacement of the public transport fleet with electrically powered vehicles, the dissemination of incentive measures for private transport and the dissemination of measures in support of shared and on-demand mobility with a time horizon of 2030 and/or 2050. The diffusion of DRT makes

it possible to address several critical issues that have recently been affecting public transport. The implementation of electric DRT services makes it possible to reach areas of weak demand and to discourage the use of private vehicles.. The evolution of these vehicles and thus the possibility of disseminating EV-DRT services depends not only on the present infrastructure (charging stations) but also on the propensity of users to use electric mobility.

This research work aims to introduce an exploratory and comparative survey on the evolution of SUMP in different European cities and the correlation of the evolution of planning tools with the diffusion of charging infrastructure and the spread of shared transport services (bike and car) and DRT.

After an introduction on the current development of the electric car market in Europe, the analysis of the transport offer was examined considering the spread of electric charging stations and the spread of alternative forms of mobility. The comparison of several case studies and the relative facts made it possible to outline the macro areas of investigation to be taken into consideration when discussing the variables that determine the benefits and criticalities of the spread of electric mobility and in particular of EV-DRTs. It emerges that it is necessary to entrust the managers of collective and shared transport services and the managers of recharging services with the task of progressively and constantly investigating the process of planning and monitoring electric mobility, with the aim of guaranteeing the capillarity of electric columns in the city context, as well as ensuring the adaptation to evolutionary standards in terms of sockets and installed power.

To encourage the above-mentioned spread of the infrastructure, a series of national and other measures and strategies will have to be disseminated to obtain the national and European funds necessary to improve the quality and quantity of the recharging systems present in the territory. The dissemination of service conferences for the extension of the infrastructure of charging points should be promoted by participatory planning and by mapping them. This is aimed at making the infrastructural progress public to citizens and operators, in line with the objectives of the Urban Plan for Sustainable Mobility (PUMS) and the Guidelines for the location of infrastructures for the recharging of electrically powered vehicles on public land for public use and subsequent amendments/integrations. In the final part the criteria linked respectively the infrastructure, the transport service, the user and the context have been defined in order to be able to analyse in the next research steps the weights to be attributed to each factor and therefore to be able to study through a multi-criteria analysis the diffusion of EV-DRTs.

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