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Assessing the Opportunity Offered by Electric Vehicles in Performing Service Trips to End Consumers

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Abstract: This paper proposes the assessment of the impacts of using electric vehicles for urban service trips. In particular, the focus is on trips performed for delivering and installing products, as well as for reverse logistics. Such components of commercial traffic in urban areas have not received the level of attention it deserves. In fact, recent research on commercial traffic mainly deals with shop restocking, service visits to establishments and e-commerce deliveries, and limited attention has been paid to the service sector (e.g., installation, maintenance, repairs) which can have a high impact on city sustainability in terms of pollution emissions, congestion as well as land use for parking. Furthermore, pushed by the current trend towards the promotion of electric vehicles, an assessment is developed comparing potential service patterns using real data from the inner area of Rome (Italy) when the electric fleet replaces the traditional one. Results show the opportunity to decouple the delivery operation from the installation one, and to integrate service with reverse logistics. These significant results could address the adoption of suitable integrated urban policies to make the most of the opportunities arising from the use of electric vehicles.

Keywords: city logistics; green logistics; service trips; electric vehicles; cargo bike; reverse logistics

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1. Introduction

Cities are the main engines of a nation's economy, generating more than 80% of the GDP in Europe. Regular business dealings also result in a significant volume of traffic, which exacerbates the community's un-livability problems such as traffic jams, pollution, and safety hazards. It is hard to stop this surge in commercial vehicle traffic since the economy depends on the daily delivery of goods and services to consumers and businesses. The extent of the issue must be recognized by city agencies and transportation planners in order to put appropriate policies into place that will enhance both the financial stability of businesses and the welfare of citizens [1–4]. Therefore, both cities and urban freight operators are faced with significant issues. In fact, local authorities have to ensure a good quality of life while providing citizens with easy access to services and goods [4,5], while companies are committed to making their processes more efficient in order to increase profits and respect increasingly stringent environmental constraints [6]. In this context, international communities promoted the Sustainable Development Goals (SDGs; [5]) and the SDG 11 is properly devoted to cities. Besides, the European Commission developed the Guidelines for Sustainable Urban Plans and for Sustainable Urban Logistics Plans ([7,8]) for supporting the transition towards more sustainable cities.

Among the different actions to implement for improving the sustainability of cities, and, in particular, for improving environmental ones, significant attention is paid to the electrification of both passenger and freight fleets. Manufacturing and service companies in various sectors are trying to make their supply chains green in two ways: by optimizing processes and using green technologies such as electric vehicles [9]. In this context, previous research that focuses on the electrification of freight vehicles pointed out restocking and e-commerce delivery trips, although other commercial trips, such as those related to service activities in urban areas, have a significant impact [10,11]. Commercial trips include the vehicle traffic generated by freight pick-ups and deliveries and service visits to establishments, as well as those for installation, maintenance, repair and reverse logistics.

The relevance of such a little-investigated mobility sector becomes more relevant in recent years also due to the proliferations of numerous small operators and the exponential growth of home services. This growth of home delivery has contributed to making the delivery of products that require home installation services even more fragmented, which, in most cases, is managed by the carrier that took care of the transport. The first consequence is a considerable increase in vehicle parking time which, in the best-case scenario, produces inefficiency in the use of transport and logistic features (i.e., those of the vehicles and drivers). In a considerable percentage of cases, vehicles are also parked illegally and in areas where parking is not permitted and the time required for installation directly impacts the occupation of public land, contributing to increase the city congestion. Furthermore, the packaging of these products (mainly household appliances such as washing machines, refrigerators) is not always managed by the courier who takes care of the delivery, and the waste supply chain is not always easy to monitor [12,13]. The Environment Commission, the ENVI, of the European Parliament, on 24 October 2023, approved its report on the proposal for a regulation on packaging and packaging waste, presented by the European Commission last year. The text provides, among other things, new obligations to make packaging more easily recyclable [14]. Therefore, it is increasingly important to encourage all those processes, linked to last-mile logistics, which guarantee traceability and the correct management of packaging. The use of electric vehicles (EVs), as an isolated measure, cannot address all the challenges related to the urban transportation of goods in urban areas today. The complexity of the topic makes a multidisciplinary approach necessary and can only be addressed by referring to different initiatives which, through technological evolution, can now be integrated into a common scenario. A possible organizational scheme should be based on the different perspectives involving the local authorities responsible for territorial planning (policies), the organization of logistical processes by commercial operators (logistics) and the implementation of technological solutions connected to use of EVs (technical factors).

Therefore, this work aims to propose an assessment of the impact of EVs on home deliveries for foreseen installations (service trips) with references to the joint use of the above three factors, i.e., policies, logistics and technical factors. This paper, through a case study developed in the inner area of Rome, evaluates the impacts of a delivery service using light commercial vehicles (LCVs) for installation service. The effects of three different solutions are compared which, starting from a freight distribution carried out by conventional vehicles, subsequently see the use of EVs and also cargo e-bikes for the collection of packaging materials.

The rest of the paper is organized as follows. Section 2 presents the background, pointing out the current main research on service trips and on fleet electrification. Section 3 introduces the case study methodology used, while Section 4 presents and discusses the results obtained. Finally, conclusions and the road ahead are drawn in Section 5.

2. The Background

According to the need to contribute to the investigation of service trips and the opportunity offered by electrification for improving the sustainability of urban areas, below the current literature is reviewed in terms of service trips and fleet electrification.

2.1. The Service Trips

The freight movements related to deliveries and pick-ups, including those of e-commerce, have drawn the greatest attention out of these two types of commercial activities (freight and service). This phenomenon is the cause of the current explosion in urban freight publishing, both for shopping (e.g., [15,16]) and for delivery travels (e.g., [17,18]). Among these, there are studies focused on emerging technologies [19,20] or on the use of eco-friendly vehicles [21–23]. Studies that concentrate on service traffic, however, are less common, and can rely on trip generation [24], trip attraction [25], and parking [26]. Because there is a far smaller percentage of traffic linked to services than there is to freight, these studies are not as common. However, it is a big issue when service traffic is ignored in an urban traffic environment since, despite being less common, it takes up a lot of curbside space due to the longer parking durations needed. According to other studies on the appeal of service trips (e.g., [26]), "service vehicles generate between 22.7% and 78.4% of the total parking requirements, because of the effects of the duration times, while they only represent 6.32–24.84% of the total commercial traffic".

As previously stated, service trips are not limited to delivering or collecting freight, their primary purpose is performing servicing activities. Service trips can be grouped into four main categories [24,25]: quotations, installations, planned services, and unplanned/emergency services. However, a further classification can be done according to the type of the service receiver: industry sectors or an end consumer. In fact, among the classes of service trips, it is possible to identify the trips generated by commercial entities associated with service-intensive sectors (SISs), or industry sectors where service activity is the main activity at the commercial establishment [27], and those related to delivering, installing, or maintaining/repairing products for end consumers (both those in private and those in business sectors). In both types of the identified service trips, servicers must travel to the end consumers' locations to perform the service, and those are considered to be commercial trips.

Although, within certain limits, current studies point out the service trips occurring due to industry sectors, while very few of the works are on service trips to end consumers. Therefore, this paper wants to contribute to such a topic.

As mentioned, despite the unique issues that service trips present, they receive little attention. Although not all of these visits are recurring, some of them can be arranged. Furthermore, they are typically supplied in areas that are both residential and commercial, which presents a number of challenges with regard to parking zone availability [28]. The cause of this parking challenge is the differences in time that correspond to various services (the durations of the services). Moreover, the need for commercial vehicles to park in areas not intended for such operations—such as visitor parking spaces or areas intended for loading and unloading—contributes to the parking issues related to servicing excursions.

In actuality, these approaches might not result in solutions for curbside management and the evaluation of parking needs, among the other problems that are impacted by service trip activity, since service trips have not been well described.

Additionally, it is becoming increasingly typical for service trips to include the transportation of items, and some excursions involving commodities also entail service activities. It is now more challenging to discern between freight and service trips, as a result.

Creating effective parking management solutions requires an understanding of the distinctions between cargo (freight) trips and service trips. Understanding these variations can also help with understanding the other facets of the transport network that are impacted by service trips.

Even though both are commercial in character and are provided by business enterprises, the definitions and specifics of freight and service trips show that the parking requirements for cargo are not the same as those for service trips. These journeys may not always require parking near their destinations because "the amount of cargo or equipment that needs to be carried may be minimal". In contrast, in the case of service trips to serve end consumers (i.e., deliveries and installations, as well as collecting packaging), the parking space has to be close to the final destination, and when missing a double lane, illegal parking is usually performed. Longer service trips typically necessitate longer curb space usage, which restricts access for freight vehicles to perform loading and unloading operations [29]. That is to say, among other things, service and freight trips—especially last-mile trips—must compete for parking spaces, schedules and street space [30].

2.2. Fleet Electrification

In recent years, there has also been a profound change in the vision of society about the issues of environmental sustainability and the correlation that our habits have with air pollution and its consequences [5,31,32].

Among the various initiatives to pursue sustainable development, there is the use of ecological vehicles, which is certainly in the foreground [4,22,23]. A comparative environmental assessment of electric and traditional light-duty vehicles has been performed in [33], in which three light commercial vehicles produced by the same manufacturer with three different powertrains (diesel, compressed natural gas and electric) have been compared showing that the electric motor presents advantages in urban environments because of the numerous stops and regenerative braking that are typical for urban deliveries. Essential observations about the recent trends of EVs in urban freight transport services and analyses of technical specifications as well as operational issues for routing and scheduling procedures have been shown in [34], while in [35], the authors have analyzed LCVs' energy and purchase costs with respect to conventional diesel trucks in USA market values. The study proposed in [36] explores drivers of and barriers to existing EV adoption, which are categorized as internal, external and governmental. The implications are evaluated from a theoretical, managerial and political point of view, recognizing that an evaluation of the real advantages in the adoption of EVs for the urban distribution of goods can only be carried out from a systemic perspective. In [37,38], the authors evaluate, from a technical point of view, both the development phases of an electric LCV and the infrastructural possibilities for the sustainable production of fuel for zero-emission vehicles (electricity, hydrogen).

Policies implemented to achieve "sustainable" objectives can sometimes be conflicting and the estimate of the related impacts in social, economic, and environmental terms is not simple to assess. For example, end consumers want to take advantage of home deliveries, but residents of congested areas need more organized delivery services, planners want to meet climate-altering emission reduction targets, while producers and transporters hope to operate at the lowest cost and in the shortest possible amount of time.

Electric powertrains not only allow the use of vehicles without direct emissions of CO_2 and air pollutants, but also have fewer design constraints than conventional vehicles. Although traction batteries still offer an energy density much lower than that of petrol, electric motors can generally express a higher torque and power and allow for flexible integration into vehicle chassis [22,23,39,40]. Today, the electrification of the fleets of vehicles of logistics companies is one of the main initiatives aimed at improving the sustainability of transport operations. The potential benefits of using electric vehicles for last-mile distribution have been studied from different perspectives. In [41], a reduction of up to 25% in external costs is calculated with the introduction of electric vehicles in urban logistics activities, as well as a 73% reduction in CO_2 emissions. The optimization of vehicle routing and scheduling specificities remains limited due to the importance of operational cost savings for freight EVs [34,35]. Even if, from a technical point of view, Battery Blectric Vehicles (BEVs) are suitable as delivery vehicles thanks to their performance being comparable to that of vehicles with Internal Combustion Engines (ICEs), and to their autonomy generally being sufficient for urban missions of use (in this case, this does not represent a critical factor) and silence, there are currently few models of battery electric LCVs available on the market and their prices are even higher than those of ICE vehicles. In addition to costs, the availability of charging infrastructure, the size of the city and the main logistics operators operating there and their location, the indications deriving from any Sustainable Urban Logistics Plan (SULP), are all factors with which fleet managers find themselves having to deal with the electrification process of the fleet. A necessary evaluation of the use of EVs is also the connection to their so-called environmental sustainability. It is certain that EVs do not pollute the air compared to ICE vehicles, but it is necessary to consider that their simple use does not completely solve the problem, although they contribute significantly to locally improving environmental sustainability. Firstly, non-exhaust emissions are still significant. Then, it is necessary to look at the production phases of the vehicle, and the result of the comparison is less favorable for EVs if we consider the current impacts of their production on ecosystems and the toxicity of the materials involved. Finally, whether it is certain that a full EV does not pollute locally, the overall share of emissions depends on the method of producing the electrical energy used for its propulsion. For this reason, calculating the amount of energy used is relevant for the purposes of an environmental sustainability analysis.

Energy consumption is clearly variable and depends on a series of external factors such as traffic, road topology and driving style [42]. The energy consumption values proposed by manufacturers are often distant from those of the real consumption amounts, and in this paper, it was preferred to develop a model which, based on the mechanical data and the characteristics of the battery pack of a vehicle present on the market in both ICE and BEV versions, allowed for their calculation.

However, the use of EVs has limited effects if policy measures and regulations are not developed and implemented to reduce the negative effect of city logistics [43,44]. Recent experiences show that cargo bikes, which are increasingly widespread in urban centers, offer an innovative solution for the sustainable transport of goods packaging, thus reducing the environmental impact of urban deliveries and introducing elements of flexibility in urban planning [41,45]. There are numerous studies that concern the integration of cargo bikes into the supply chain, specifically for last-mile transportation tasks. The anticipated benefits indicate their sustainability for a significant portion of freight movements [46–48]. Their limited carrying capacity, traffic safety, and infrastructure challenges have, in the past, posed barriers to their widespread adoption, but their agility and easy access allow them to move easily through the busy streets of urban centers, reducing the risk of congestion and improving delivery efficiency. Furthermore, a latest-generation cargo bike can carry loads of up to 500–700 kg and almost half of urban freight transport in the EU does not exceed 10 km [49] The size of the cargo bike market exceeded 900 million in 2022 and is projected to grow at a 9% CAGR until 2032 [49].

The combination of the use of LCVs and cargo bikes opens new scenarios. In [46], the authors compared three different circumstances: a basic model with vans, the possibility of autonomous collection by the customer and distribution with cargo bikes and delivery points. A combination of cargo bikes with drop-off points is therefore suggested for self-service pickup to improve the quality of life as the use of cargo bikes improved external costs such as emissions, noise, and congestion, but did not necessarily improve internal costs.

In [50], two scenarios were examined, one with only trucks and the other with trucks including the use of hubs, with different demand and dwell times. In the alternative scenario, consolidated loads were transported by truck to the hub and a predefined fleet of bicycles performed last-mile delivery. This showed that the bicycle's capacities and dwell times were the most influential factors on travel times and distance.

In this context, the paper merges the need to point out service trips directed to end consumers and to renovate commercial fleets towards the transition to being electric. Then, the assessment of the impact of electric vehicles on urban service trips to serve end consumers is proposed. Two possible scenarios, including the current one, are assessed using the inner area of Rome as a case study.

3. Materials and Methods

To evaluate the potential benefits of an integrated approach for service trips to serve end consumers, the first step was to analyze a typical distribution carried out by an LCV with conventional propulsion, which is present on the market, on four representative routes in the inner area of Rome (Italy). In such an area (see Section 3.1, where the characteristics of the area and the technical specifications of the vehicles are discussed), a set of depots and end consumers are identified and the problems associated with the three scenarios reported in Section 2 are solved. In particular, these problems are formulated (see Section 3.2) as a vehicle-routing problem with the aim to minimize the travel time under a set of constraints (among these being a constraint on the electric vehicle's range). The solution procedure is heuristic (an adaptive large neighborhood search [51]), implemented in an open access solver [52]. The results are the base for the assessment of the scenarios, allowing for the estimation of the pollutant emissions of the energy consumption.

3.1. The Case Study

The proposed assessment has been developed through a case study in Rome. It has been assumed that, as described in the next section, Section 4, a set of depots have to serve 75 end consumers in the urban area using traditional and electric LCVs. The delivery of purchased items and their installation is required by each customer. Then, the benefits in terms of pollutant and greenhouse gas emissions and the availability of parking spaces, i.e., two of the main issues in inners areas of the city [50,53,54], are assessed.

In particular, according to the two main trends in city logistics, as shown in Section 2, three scenarios have been defined and assessed (Figure 1):

- The status quo (*Service pattern 1*), i.e., the delivery and installation services are performed by LCVs with Internal Combustion Engines (ICEs); then, the environmental impacts and the request for parking is calculated;
- Electrification (*Service pattern 2*), i.e., pushed to the needs to reduce the environmental impacts of commercial vehicles, delivery and installation services are performed by LCVs with electric engines; then, referring to service pattern 1, the distribution tour, the same vehicle with electric propulsion is used; in this case, the energy consumption has been also calculated;
- Electrification and parking space optimization (*Service pattern 3*), i.e., pushed by the need to optimize the use of LCVs (which should remain stopped during installation) and the space occupied by their parking, delivery and installation are assumed to be de-coupled; delivery is performed by an LCV and after this, an operator via a cargo e-bike reaches the place and proceeds with the installation. The further evolution of such a service could consider the opportunity to collect the packaging and operate the reverse logistics with significant benefits for recycling and waste collection.

The energy consumption calculation has significant relevance because it opens the road for the optimization of energy use. In fact, it allows us to correctly size the vehicle (oversizing in terms of the propulsion system would make the choice inefficient) and, above all, allows us to allocate the assessment of the real environmental benefits through subsequent analyses if, for example, that energy was produced, in whole or in part, from fossil and non-renewable sources.

LCVs could transport large cargo, making them a versatile choice for urban logistics. In this work, an LCV was selected from the market, offering two types of propulsion systems, both a conventional one with an ICE and one with an electric motor (BEV). Among the manufacturer's vehicle configurations and according to the type of vehicle currently used in the city of Rome [18], a large load space version was selected, suitable for transporting household appliances that require installation services. A cargo e-bike with a large cargo compartment was also chosen. The mechanical characteristics of the LCV such as its size, weight, type of wheels and loading volume are shown in Table 1. Mechanical data will be used to calculate the traction effort based on the mechanical forces, such us the aerodynamic drag, rolling resistance and road grade, to formulate a model for estimating energy consumption. Table 1 also shows the technical specifications of the ICE version of the vehicle and those of the BEV version. In the latter case, the battery is lithium-based with nickel–manganese–cobalt chemistry (NMC). For the selected electric LVC, the total energy was also obtained. Therefore, for subsequent analyses, based on the chemistry declared by the manufacturer, it was assumed that the battery pack consists of 85 cells in series. The main characteristics of the cargo e-bike are then shown in Table 2.

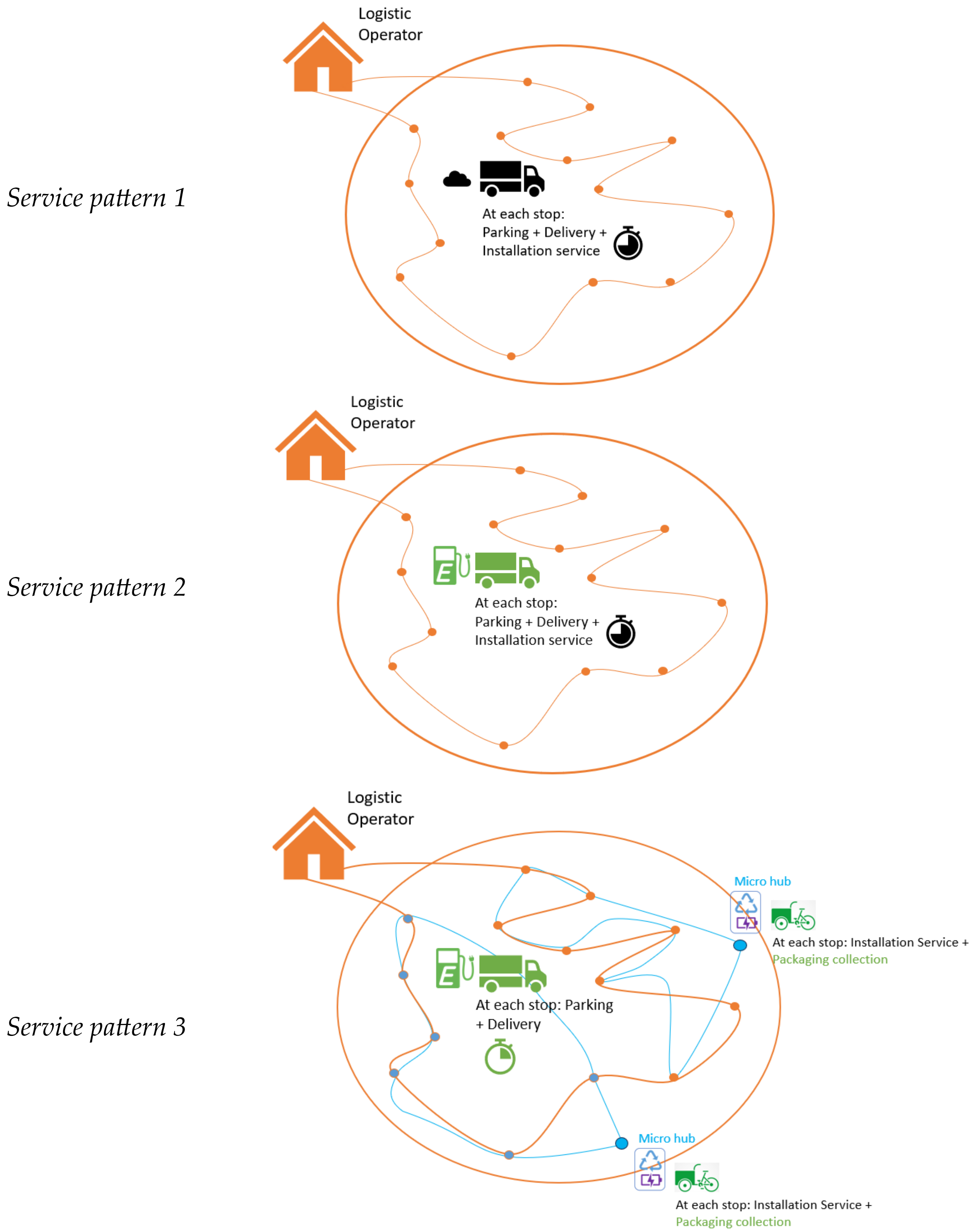

Figure 1. The three patterns of urban freight distribution. Above: an ICE LCV. In the middle: an electric LCV. Below: an electric LCV and cargo e-bikes for services. Orange: LCV routes; Light blue: cargo-ebike routes.

Table 1. The LCVs' technical specifications.

Mechanical	
Length	4.1 m
Width	2.15 m
Height	2.2 m
Cargo Volume	19.6 m^3
Curb weight	2114 kg
Frontal Area	4.26 m^2
Drag coefficient	0.3
Rolling friction coefficient	0.013
Tire type	225/65R16
ICE	
Engine Power	81 kW
Engine Torque	330 Nm
Fuel consumption	9.8 L/100 km
CO_2 emissions	256 g/km
Electric propulsion systems	
Motor type	SSM—Magnet-less
Motor Power	57 kW
Motor Torque	225 Nm
Battery type	NMC
Battery Energy	52 kWh
Cell Type	***Lithium-Ion***
Chemistry Cathode	NMC
Chemistry Anode	Graphite
Capacity	63 Ah
Nominal Voltage	3.75 V
Operating voltage	2.7–4.12 V
Battery temperature range	−40–65 °C

Table 2. Cargo e-bike technical specifications.

Mechanical/Electric Propulsion Systems	
Motor type	Electric
Weight	49 kg
Consumption	0.009 kWh/km
Cargo volume	2 m^3
Length	1 m
Width	2.5 m

3.2. Routing and Scheduling

The problems described by *service patterns 1–3* can be formulated as a vehicle-routing problem (VRP), taking into account the availability of multiple depots and time window constraints. The list of the symbols used in this section is as follows:

- i, j are the indexes for end consumers;
- v is the index for LCVs;
- b is the index for cargo e-bikes;
- d is the index for depots;
- C is the set of end consumers;
- D_1 is the set of depots for *service patterns 1* and *2*;
- D_2 is set of depots for *service pattern 3*;
- U_1 is the union between set C and set D_1 ($U_1 = C \cup D_1$);
- U_2 is the union between set C and set D_2 ($U_2 = C \cup D_2$);
- V is the set of vehicles;
- B is the set of cargo e-bikes;

- B_d is the subset of cargo e-bikes belonging to depot d;
- c_{ijv} is the cost to move from i to j by vehicle v ($c_{ijv} = TT_{ijv} + ST_{jv}$);
- TT_{ijv} is the travel time to move from i to j by vehicle v;
- ST_{jv} is the service time at node j of vehicle v;
- g_{ijb} is the cost to move from i to j via vehicle b ($g_{ijb} = TT_{ijb} + ST_{jb}$);
- TT_{ijb} is the travel time to move from i to j via cargo e-bike b;
- ST_{jb} is the service time at node j of vehicle b;
- q_j is the quantity to be delivered to customer j;
- p_j is the quantity to be picked up from customer j;
- w_v is the LCV v's capacity;
- w_{b} is the cargo e-bike b's capacity;
- t_{lim} is the threshold value for route duration;
- ℓ_v is the vehicle v's range;
- ℓ_b is the vehicle b's range;
- t_i is the arrival time at customer i;
- $[a_i, b_i]$ is the time window at customer i;
- x_{ijv}, y_{ijv} are the problem variables.

The problem formulation collapses into a single depot VRP [55,56] for *service patterns 1* and *2* and, for these service types, the formulation is essentially the same. In fact, the only difference is in the type of vehicle engines. The formulation is as follows:

$$\text{Minimize } Z_1 = \sum_{i\in U_1}\sum_{j\in U_1}\sum_{v\in V} c_{ijv}\cdot x_{ijv} = \sum_{i\in U_1}\sum_{j\in U_1}\sum_{v\in V}\left(TT_{ijv} + ST_{jv}\right)\cdot x_{ijv} \quad (1)$$

s.t.:

$$\sum_{v\in V}\sum_{j\in U_1} x_{ijv} = 1 \;\; \forall i \in U,\, i \neq j,\, i \neq d;\; j \neq d \quad (2)$$

$$\sum_{v\in V}\sum_{j\in U_1} x_{djv} = |V| \;\; j \neq d \quad (3)$$

$$\sum_{v\in V}\sum_{j\in U_1} x_{jdv} = |V| \;\; j \neq d \quad (4)$$

$$\sum_{i\in U_1}\sum_{j\in U_1} q_j \cdot x_{ijv} \leq w_v \;\; \forall\, v \in V \quad (5)$$

$$\sum_{i\in U_1}\sum_{j\in U_1} c_{ij} \cdot x_{ijv} \leq t_{\mathrm{lim}} \;\; \forall\, v \in V \quad (6)$$

$$\sum_{i\in U_1}\sum_{j\in U_1} l_{ij} \cdot x_{ijv} \leq \updownarrow_v \;\; \forall\, v \in V \quad (7)$$

$$x_{ijv} \in [0, 1] \quad (8)$$

The objective function (1) is on the minimization of the cost c_{ijv}, expressed as the sum of the travel time (TT_{ijv}) to move from i to j using the LCV v and the service time (ST_{jv}) at the client j; x_{ijv} is a binary variable equal to 1 if the LCV v moves from the user i to the user j, and is *0* otherwise.

From the definition of the VRP, an end consumer can be reached only once by a single vehicle; constraint (2) ensures this aspect of the problem. In the VRP, the vehicles used for service must leave from the depot (constraint (3)) and go back to it (constraint (4)). The maximum load of the vehicle is expressed by constraint (5), where the vehicle load is correlated with the vehicle capacity (w_v). In real-world problems, the duration of a driver's work cannot exceed a certain threshold (t_{lim}), as imposed by constraint (6). Another constraint is that on the vehicle's maximum range (ℓ_v), as reported in constraint (7). Finally, constraint (8) restricts the variable x_{ijv} to be a binary variable.

For *service pattern 3*, the scenario changes: in this case, the LCVs are used for the delivery, while the cargo e-bikes are used for installation and pick-up. Thus, two optimization problems to be solved in series are defined: the first one is related to the LCVs (Equtaion (9)) and the second one takes into account the use of cargo e-bikes for installation operations and package pick-up (Equtaion (10)).

The first problem is similar to problem (1), with a change in the service time, as follows:

$$\text{Minimize } Z_2 = \sum_{i \in U_1} \sum_{j \in U_1} \sum_{v \in V} c_{ijv} \cdot x_{ijv} = \sum_{i \in U_1} \sum_{j \in U_1} \sum_{v \in V} \left(TT_{ijv} + ST_{jv} \right) \cdot x_{ijv} \quad (9)$$

s.t.:

constraints (2)–(8).

For the second problem, the cargo e-bikes are homogeneous and leave from multiple depots [57]. In this problem, a constraint on time windows [58] is defined to consider that the service can be provided only after the LCV's delivery. The formulation is as follows:

$$\text{Minimize } Z_3 = \sum_{i \in U_2} \sum_{j \in U_2} \sum_{b \in B} g_{ijb} \cdot y_{ijb} = \sum_{i \in U_2} \sum_{j \in U_2} \sum_{b \in B} \left(TT_{ijb} + ST_{jb} \right) \cdot y_{ijb} \quad (10)$$

s.t.:

$$\sum_{b \in B} \sum_{j \in U_2} y_{ijb} = 1 \;\; \forall i \in U_2,\; i \neq j \quad (11)$$

$$\sum_{b \in B_d} \sum_{j \in U_2} y_{djb} = |B_d| \;\; \forall\, d;\; j \neq d \quad (12)$$

$$\sum_{b \in B_d} \sum_{j \in U_2} y_{jdb} = |V_d| \;\; \forall\, d;\; j \neq d \quad (13)$$

$$\sum_{i \in U_2} \sum_{j \in U_2} g_{ij} \cdot y_{ijb} \leq t_{\lim} \;\; \forall\, b \in B \quad (14)$$

$$\sum_{i \in U_2} \sum_{j \in U_2} l_{ij} \cdot y_{ijb} \leq \updownarrow_b \;\; \forall\, b \;\in B \quad (15)$$

$$t_i \in [a_i, b_i] \quad (16)$$

$$\sum_{i \in C} y_{idb} = 0 \;\; \forall d, \forall b \notin B_d \quad (17)$$

$$y_{ijb} \in [0, 1] \quad (18)$$

Constraints (11)–(15) have the same meaning as constraints (2)–(7), while constraint (16) is on time windows. Constraint (17) establishes that a vehicle leaving from a depot returns to the same depot. Constraint (18) restricts the variable y_{ijb} to being a binary variable.

It should be considered that in both optimization process, there is no need to foresee the recharging phase of the battery given that the delivery tours are within the means of autonomy.

3.3. The Estimation of Pollutant Emissions and Energy Consumption

In Europe, the path to reducing greenhouse gases and decarbonizing the economy has received a decisive boost with the 2020 strategy of the European Commission, through the Green Deal with the aim of achieving climate neutrality in the EU by 2050. In the implementation of the Green Deal, the European Climate Law was approved, which aims to ensure that all economic sectors and sectors of society contribute to the goal of net-zero emissions by 2050, and outlines a framework for evaluating the progress made in this direction. It also proposes a new EU target of a net emissions reduction of at least 55% by 2030 compared to 1990 levels. In 2019, the European Union approved the regulation of

(EU) 2019/1242, which established the CO_2 emission standards for heavy-duty vehicles until 2030, and in 2023, the Commission proposed a revision of the same regulation [59,60]. These CO_2 standards are a fundamental part of a broader objective, which is to contribute to the target of cutting transport emissions by 90% by 2050, as set out in the European Green Deal, while allowing the EU single market to continue growing [61,62]. COPERT Street Level software (version 2.4) has been used in the proposed case study to estimate the pollutant emissions produced for the selected route by an ICE LCV [63–65]. Emissions have been calculated using 2023 as the base year. A file has been created with the vehicle's route data between delivery points, indicating the route length, average speed, and coordinates of the delivery points. The simulation has been carried out for a vehicle with a diesel-powered Euro 6 engine. The pollutant emissions estimated are the carbon oxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), particulate matter (PM) and volatile organic compounds (VOC).

The calculation of energy consumption is, as mentioned, of extreme importance to be able to analyze, ex post, the real environmental impact of the vehicle, not limiting itself to the evaluation of the emissions at the tailpipe. Another particularly important aspect is linked to an analysis of real consumption which often differs from the values declared by the manufacturers [66]. In this case, an electric powertrain model [67], developed in a Matlab-Simulink environment, has been used to evaluate the electric consumption of the electric LCV based on the information reported in Table 1. It consists of four main subsystems, the vehicle mechanical model, the AC motor model, the converter model, and the battery model. The first block determines the traction effort based on the mechanical force; the AC motor model calculates the electrical power that the inverter has the task of providing. The battery model evaluates the power required by the inverter and, following the charging and discharging dynamics of the battery pack, calculates the voltage, current and SOC response. The entire model therefore determines the energy consumption of the vehicle in relation to the characteristics of both the vehicle and the route. To calculate the model output data, it is necessary to identify a driving cycle in terms of speed and time as well as the weight of the freight transported and the delivery routes. The driving cycle chosen for the application is the World harmonized Light vehicles Test Procedure (WLTP). For the urban distribution application under analysis, only the first part of the driving cycle has been selected [67].

3.4. Scenario Assessment

Given the definition of the delivery and installation service and its potential benefits in environmental and energy terms, a preliminary assessment of its contribution to city sustainability can be done. In such a study, the pollutant and greenhouse gas emissions, as well as the parking space availability, have been pointed out. However, further analyses that include economic and financial appraisals have to be investigated, aiming at assessing the benefits and costs of the introduction of the new service, as well as defining fares.

Even though the urban logistics interventions produce benefits in terms of reductions in pollution and traffic congestion, they do not always result in becoming economically self-sustainable in a stable manner. For example, the introduction of a further operator for installation in the service cycle could lead to an increase in costs (in the structure management, stocking and handling, etc.) that are not always economically balanced by logistical benefits (the optimization of the use of human and vehicular resources, with, for example, a greater utilization of a vehicle's capacity, and so on). These extra costs should be supported by the local authorities in order to support the benefits of external cost reductions (road safety and security, environmental impacts, and so on).

Therefore, such a study scenario will be evaluated with respect to indicators of efficiency (e.g., energy consumption), social sustainability (indicators related to the use of parking spaces which can be considered a proxy of impact on congestion and safety), and environmental sustainability. The values obtained for the indicators are compared with some reference values (targets). The indicators chosen for this stage of the ex ante assessment could be monitored in the ex post assessment to track their real evolution over time. These indicators could be developed considering the set of variables promoted by the European Environment Agency (TERM, the Transport and Environment Reporting Mechanism). In fact, the TERM indicator list covers the most important aspects of the transport and environment system (driving forces, pressures, the state of the environment, impacts and societal responses). It represents a long-term vision of the indicators that are ideally needed to monitor the progress and effectiveness of transport and environmental integration strategies.

In general, some other types of impacts could be considered as such the financial impacts by reducing costs to carriers and shippers.

4. Results

As previously stated, a test application was developed in a real-word area to assess the three *service patterns* reported in Figure 1. In particular, as introduced earlier, the study area was the city of Rome, where a set C of 75 users has to be reached starting from a set of depots. In particular, in *service pattern 3*, the cargo e-bikes leave from five depots (micro-hubs) scattered throughout the study area. Each user is associated with a quantity of freight to be delivered, a time for operations (parking and delivery, [10]) and, eventually, a time window.

Problems (1) and (2) are solved considering the three cases:

- a service is performed by ICE LCVs,
- a service is performed by electric LCVs,
- a service is performed by combining the use of electric LCVs and cargo e-bikes.

The solution procedure used is the adaptive large neighborhood search proposed by [52]. Using the API from Bing and VRP_Spreadsheet_Solver [52], the travel time on the real road network has been collected for several working days. After defining the end consumers and the types of freights and services, using the average travel times, the best customer sequence can be calculated. Table 3 reports a solution for the problem formulated by Equtaions (1)–(8) for the test case, while Figure 2 shows the routes found. In particular, in this test, the service is performed by four vehicles, travelling (in total) about 255 km in nine travel hours with a total service time (sum of the travel time and the operation time) of about 30 h.

Table 3. The VRP solutions for *service patterns 1*, *2* and *3*.

Service Pattern	Number of Routes	Distance Travelled [km]	Driving Time [h]	Total Service Time [h]
1, 2	4	255.64	9.07	33.87
3	12	461.84	20.74	45.54
3 LCVs	*4*	*245.34*	*8.58*	*15.53*
3 Cargo e-bikes	*8*	*216.50*	*12.16*	*30.01*

Taking into account *service pattern 3*, the problems to solve are expressed by Equtaions (9) and (10). In this test, the solution for problem (9) is composed of four trips (see Table 3 and Figure 3) for a total of 245.34 km travelled in 8.58 h, with a total service time of 15.53 h. This solution defines, in addition to the routes, the time windows that will serve as constraints for the service offered by the cargo e-bikes. In relation to the e-bike service (see Table 3 and Figure 4), eight tours are needed, for a total of 461.84 km travelled in 20.74 h with a total service time of 45.54 h.

As stated, the methodology presented in the earlier section, Section 3, was specified for the evaluation of the impacts reported in Table 4. The effects of the implementation of each scenario have been evaluated in differential terms, i.e., as variations and differences of the variables representing them, between service patterns 2 or 3 and 1 (the status quo).

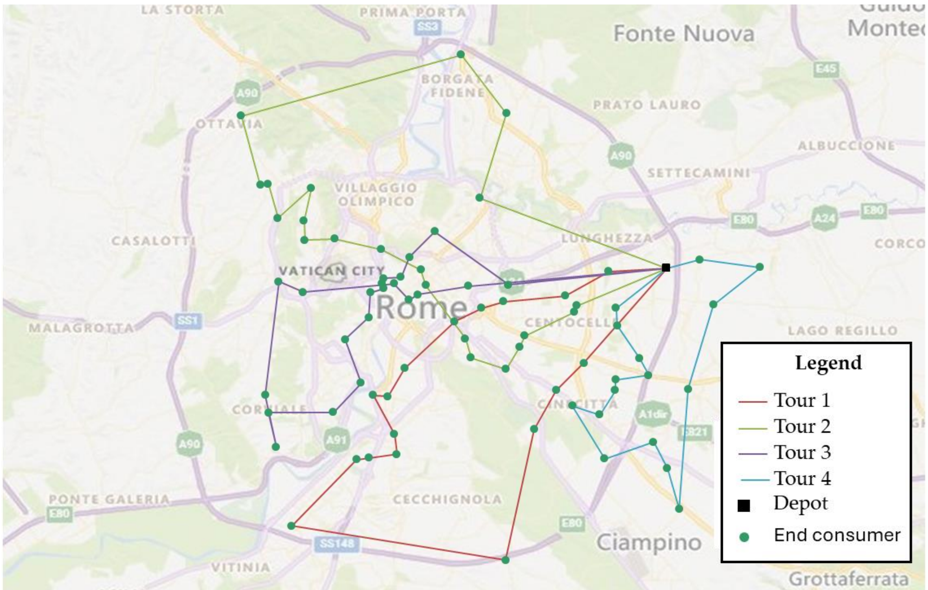

Figure 2. The services performed by ICE or electric LCVs for *Service patterns 1* and *2*.

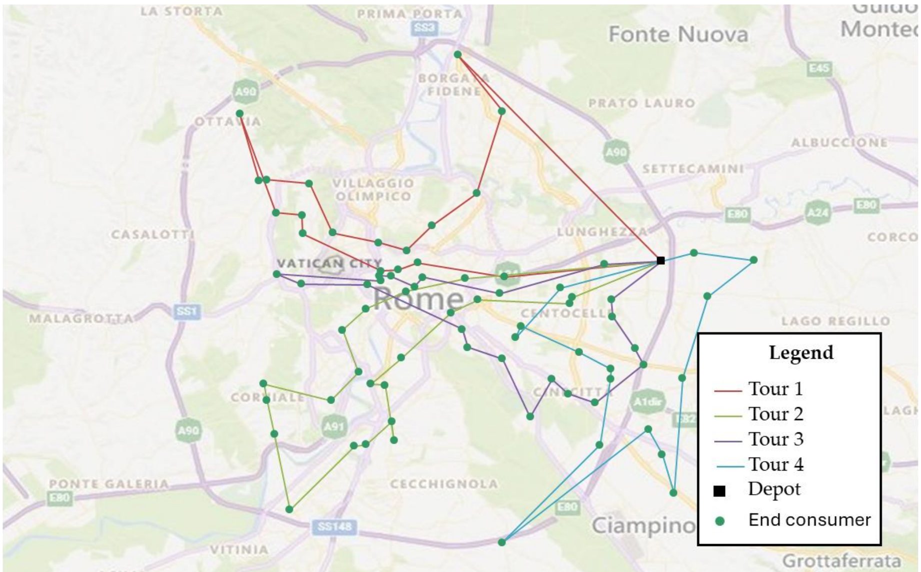

Figure 3. The services performed by an electric LCV for *Service pattern 3*.

Based on the analysis of the state of charge and energy consumption needed for the various delivery routes, several key observations emerge. The final states of charge for the routes span from 66.9% to 50.37% for service pattern 2 and from 64.29% to 53.98% for service pattern 3, indicating an appropriate sizing of the routes with respect to the autonomy of the vehicles used. The corresponding energy consumptions, ranging from 17.21 to 25.81 kWh for *service pattern 2* and from 18.57 to 23.93 kWh for *service pattern 3*, with variations across the different routes, highlight the capacity of the vehicles in dealing with working hours without any need for charging. Despite these differences, the remaining energy reserve seems ample for accommodating additional delivery rounds in urban areas without encountering significant challenges [69]. Furthermore, the observed energy consumption levels for the missions undertaken appear to align reasonably well with anticipated requirements, suggesting an efficient utilization of resources. These findings underscore the feasibility and effectiveness of the delivery vehicles used, affirming their suitability for urban delivery operations.

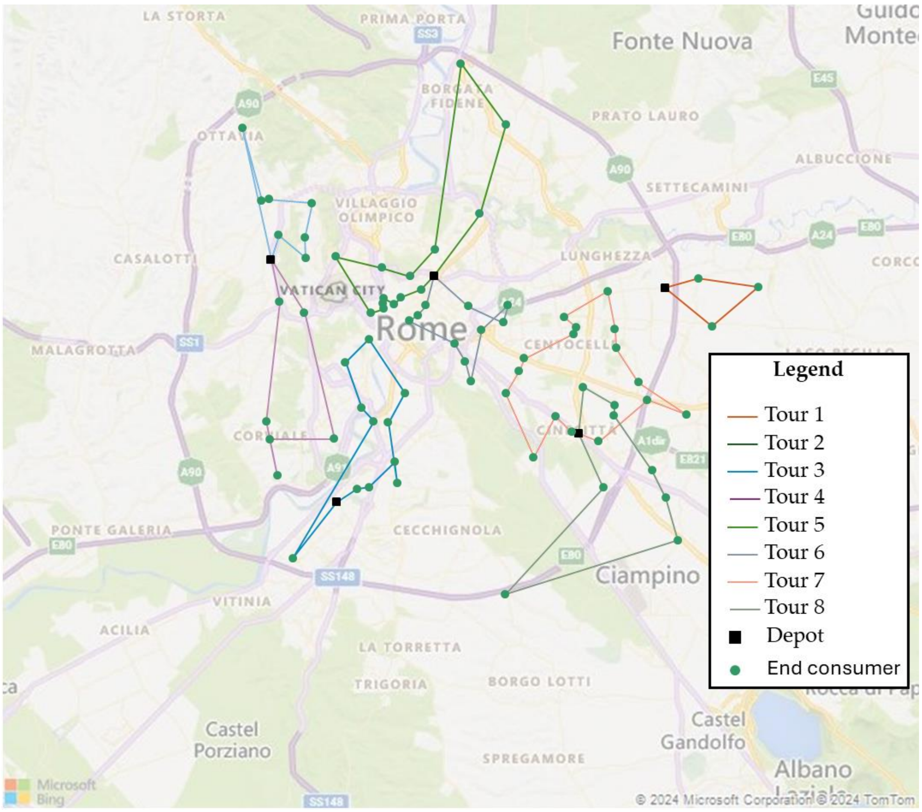

Figure 4. The services performed by cargo e-bikes for *Service pattern 3*.

Table 4. The result indicators of test application.

		Service Pattern 1 ICE LCV	Service Pattern 2 Electric LCV	Service Pattern 3 Electric LCV + Cargo e-Bike
Tailpipe Emissions [g]	CO	0.155	-	-
	CO_2	64,285.00		
	NOx	57.760		
	PM	0.394		
	VOC	8.590		
Energy consumption [kWh]		-	91.77	89.37 *
Emissions from electricity production [g]		-	CO_2 28,357.00 ***	CO_2 27,615.00 ***
Requested time for parking [equivalent parking hours]		49.60	49.60	31.75 **

*—2.61% compared to *service pattern 2*. Energy consumption [kWh]: 87.42 (electric LCV) 1.95 (cargo e-bike). **—25% compared to *service pattern 1* and 2. ***—The calculation was carried out considering the Italian energy mix. 1 kWh = 0.309 kg of CO_2 [68].

Further analysis pointed out the request for parking spaces considering that in urban areas, there are high amounts of competition between private cars and commercial vehicles. The car parking space occupancy has been used as a reference. According to the characteristics of the LCVs and cargo e-bikes used, and that usually the studied service is performed in areas where the supply of loading and unloading on street bays is not so high, it is assumed that an LCV needs two units of car parking space while one is needed for a cargo e-bike.

Therefore, referring to the driving and service time, which is one of the main headings of costs supported by city users in terms of parking space availability, the suggested *service* *pattern 3* could allow for a significant reduction, estimated in the case study to be about 25% compared to the status quo. Additionally, the use of electric vehicles allows for significant benefits to be obtained in terms of pollutant emissions (*environmental* sustainability) with a contained use of energy. In addition to this, through the inclusion of further ancillary services performed by cargo e-bikes (e.g., the collecting of packing materials), the benefits for a city raise further.

5. Conclusions

This paper has proposed an assessment of the impact of electric vehicles on urban delivery services, focusing on commercial trips that include product installation.

Three different patterns for service have been analyzed: the first two consider a traditional delivery service with light commercial vehicles (ICE vehicles or electric vehicles), while the latter is a new approach where the delivery service is performed by a light commercial vehicle and the installation is performed by cargo e-bikes. The problem has been formulated as a VRP with a single depot for patterns 1 and 2, while, for pattern 3, a multi-depot VRP has been proposed: in this case, the LCVs leave from a single depot and the cargo e-bikes leave from multiple depots. Although this requires a higher number of vehicles, it allowed for a reduction in the service time of LCVs that has a higher impact on urban traffic.

From such preliminary results, the future developments derived mainly refer to an in-depth analysis of the service time, aimed at separating the parking time from the delivery service (which includes the time spent searching for an available parking space close to the end consumers in relation to the size of delivery), and the time for installation, taking into account the type of product to be installed. To achieve this goal, an investigation with the carriers is planned.

Further development could also include advancement in the optimization of the service tours (i.e., the VRP) in order to include the opportunity for exploiting the full energy load of the battery and, eventually, the option to recharge, as well as use the travel/driving time estimated taking into account the real-time data from the network. By proposing shorter paths according to the real-time configuration of the network, trucks drive on roads with low amounts of congestion, with significant benefits in terms of the pollutant emissions (environmental sustainability) and interferences with other road users (social sustainability). In fact, as shown in other studies, travelling on less-congested roads can lead to an increase in average travel speed with lower emissions of pollutants. Furthermore, if the driver chooses the shortest route only in terms of the travelled distance, then they might reach their destination faster if no congestion occurs. Due to the fact that they usually move in highly congested, daytime periods (e.g., 8–10 a.m.), there may be a significant increase in service costs.

All these things considered, further analyses are ongoing for improving the assessment phase for supporting decision making. This consists of the development of a methodology based on the logistics sustainability index (LSI), a multi-criteria decision analysis (MCDA) tool [70]. With the use of this index, an MCDA tool can be changed into a multi-stakeholder tool that incorporates the various viewpoints of the stakeholders during the review process. The Logistics System Index (LSI) is a comprehensive assessment instrument that may measure a logistics system's overall performance based on many factors and viewpoints. According to [18,70], it is elaborated using a bottom-up methodology that begins with the valuation of fundamental performance indicators. These indicators are then combined into weighted composite indicators for each impact area, including economy and energy, environment, transport and mobility, society, policy and measure maturity, social acceptance, and user uptake. In addition, given the definition of the new delivery and installation services, the economic and financial appraisal should be investigated. It aims at assessing the benefits and costs of the introduction of the new service, as well as defining fares. Then, a cost–benefit analysis could be developed for such a service, aiming to supply useful tools to clarify the direct and indirect costs connected to the new operative solution, and assign stakeholders and possible extra-costs.

Even though urban logistics interventions produce benefits in terms of the reductions in pollution and traffic congestion, they do not always result in becoming economically self-sustainable in a stable manner. For example, the introduction of further services could lead to an increase in costs (for structure management, stocking and handling, etc.) that are not always economically balanced by logistics benefits (the optimization of final distribution with, for example, a greater utilization of a vehicle's capacity, and so on). These extra costs should be supported by local authorities in order to support the benefits of the external cost reductions (those to road safety and security, environmental impacts, and so on).

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