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Review

The Adoption of Green Vehicles in Last Mile Logistics: A Systematic Review

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Abstract: Widespread adoption of green vehicles in urban logistics may contribute to the alleviation of problems such as environmental pollution, global warming, and oil dependency. However, the current adoption of green vehicles in the last mile logistics is relatively low despite many actions taken by public authorities to overcome the negative externalities of distributing goods in cities. This paper presents a comprehensive literature review on studies investigating the adoption of green vehicles in urban freight transportation, paying specific attention to e-commerce. To shed light on the adoption of green vehicles in city logistics, the paper conducts a systematic review of the empirical literature on the topic. The 159 articles reviewed were classified into the following: (a) Optimization and scheduling (67 papers); (b) policy (55 papers); (c) sustainability (37 papers). Among the 159 articles, a further selection of 17 papers dealing with e-commerce, i.e., studies that highlight the most relevant aspects related to the integration of green vehicles in e-commerce urban logistics, was performed. Our findings indicate that green vehicles are competitive in urban deliveries characterized by frequent stop-and-go movements and low consolidation levels while incentives are still necessary for their adoption. The use of autonomous vehicles results the most promising and challenging solution for last-mile logistics.

Keywords: last mile logistics; green logistics; urban freight; e-commerce; green vehicles; drones; autonomous vehicles

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1. Introduction

The demand for urban freight transportation has increased considerably owing to urbanization and demographic growth, along with the increased diffusion of e-commerce, new management principles (e.g., just-in-time), and the introduction of new pervasive technologies [1].

The ever-increasing trade volumes of e-commerce, which still showed a worldwide growth rate of 23.3% in 2018 and have drastically increased during the COVID-19 pandemic, have led to huge parcel volumes that need to be delivered each day especially in large urban areas. More and more delivery vehicles are required to bridge the last mile towards the customers [2].

Due to the increasing number of goods vehicle movements in urban areas, modern cities are facing congestion, lack of public space, air pollution, noise, etc., which are reducing life quality. In fact, as mentioned by Janjevic et al. [3], urban logistics operations have a considerable impact on three different aspects of sustainability: Economic (e.g., efficiency and costs of deliveries), environmental (e.g., CO_2 emissions), and social (e.g., congestion).

To cope with this situation, city municipal administrations are implementing several sustainability initiatives such as urban consolidation centers, intelligent fleet management systems, use of green vehicles, and putting in place various freight regulations such as vehicle sizing, access timing restrictions, and congestion pricing [4–6]. The efforts made by public authorities are also in line with the goals that the EU is pursuing with respect to this sector as indicated in the white paper 2011 on transport [7] where it is stated that a reduction of at least 60% of GHGs by 2050 with respect to 1990 is required from the transport sector. Moreover, in the second point of the white paper 2011 it is affirmed that, in order to reach the energy and environmental target set, technological innovations able to raise vehicle energy efficiency are required along with the implementation of new technologies and engines for clean road transport. Among these concepts, this paper focuses on green vehicles adoption due to its relevance in a context where the increase in the e-commerce market and the rise of on-demand logistics imply poor efficiency and might cause additional negative environmental consequences.

The innovations introduced have been disruptive, especially with respect to new engine technologies and driverless vehicles [8,9]. The European Commission considers green vehicles (a 'green' vehicle is defined as one with emissions intensity that does not exceed 120 g of CO_2 emissions per km [10]) relevant for decarbonizing transport, reducing air pollution, and increasing system efficiency. Green vehicles such as electric vehicles (EVs), autonomous vehicles (AVs), and drones will be evaluated in terms of their current integration in city logistics.

The paper aims at providing a literature review concerning the introduction of green vehicles in the last mile distribution to identify the main issues and challenges. Moreover, this study proposes some research directions and approaches for the advancement of sustainable freight transportation in urban logistics.

As observed by Hu et al. [11], achieving green logistics goals relies on two dominant strategies: (1) To promote the introduction of green vehicles; (2) to develop and implement policy measures and regulations to reduce the negative effect of city logistics. The research presented in this paper attempts to perform a systematic review on the first of these aspects, distinguishing from previous similar works for this specific focus. The state of the art and trends of the growing research on the integration of green vehicles in urban freight distribution are explored.

A recent review reporting a comprehensive analysis from a broad perspective of the research on green logistics has been proposed by Ren et al. [12]. They found that the number of papers published in this field has been rapidly growing in the past two years as well as the multitudinous research directions.

An integrated view of the literature published on the research area of last mile logistics, has been also proposed by Olsson et al. (2019) [13]. They report four previous systematic reviews focusing on specific elements within the area of last mile logistics [14–17]. Among these studies, only the review proposed by de Oliveira et al. [17] focused on vehicles alternatives for last mile distribution in urban freight.

In this light, the purpose of this study is to update and consolidate the current understanding with respect to the adoption of EVs, AVs, and drones in urban logistics, shedding light on the e-commerce sector.

The reminder of the paper is organized as follows. Section 2 outlines the methodology used to perform the literature review, with results presented in Section 3. Section 4 provides an overview of the most relevant aspects related to the integration of green vehicles in e-commerce urban logistics. Section 5 concludes, summarizes the paper, and provides some suggested future research paths.

2. Methodology

The literature selection procedure is shown in Figure 1. The keywords selected in the initial thematic search were: 'autonomous vehicles', 'electric vehicles', 'green vehicles', 'last mile logistics', 'urban logistics', 'city logistics', and 'urban freight'. The query string used for database searches was: ((«autonomous vehicles» OR «electric vehicles» OR «green vehicles» OR «drones») AND («last mile logistics» OR «urban logistics» OR «city logistics» OR «urban freight»)).

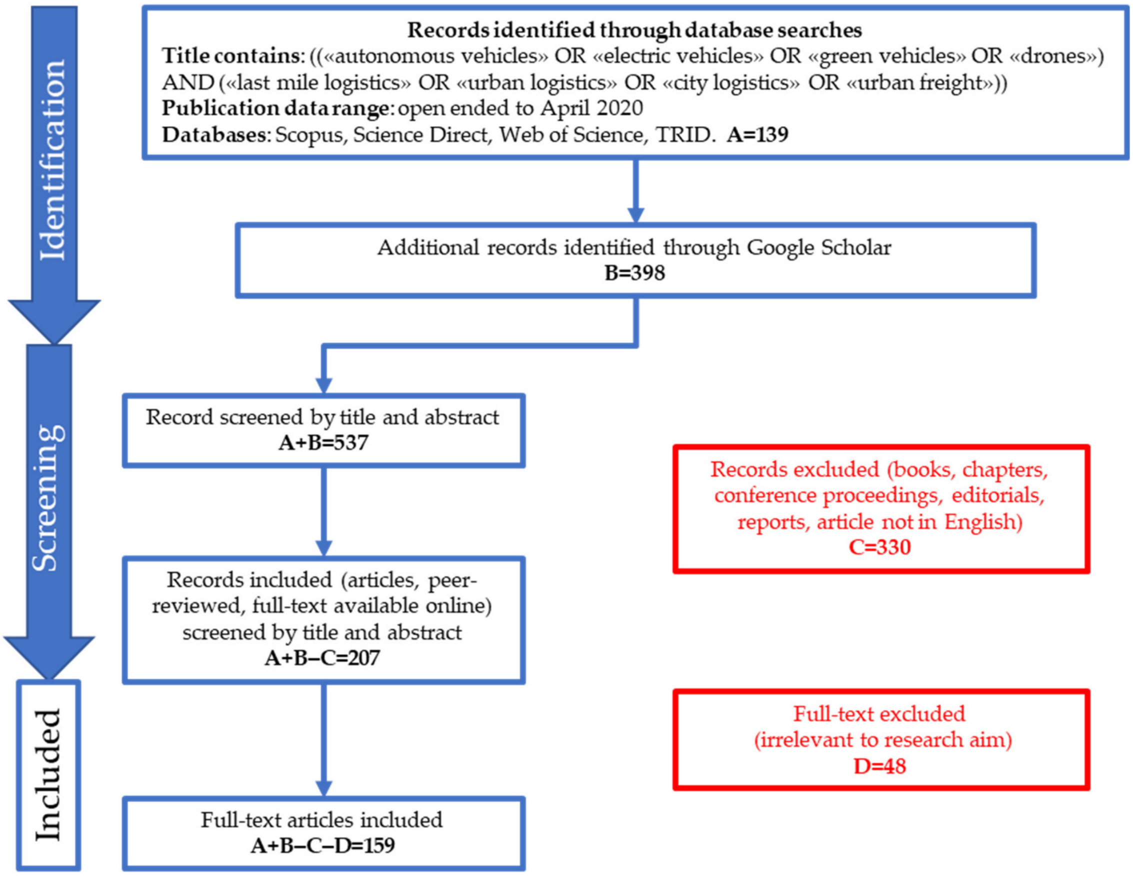

Figure 1. Procedure for literature selection.

To ensure homogeneous quality levels of the contribution investigated, we have only included papers published in peer-reviewed journals in English. Consequently, the literature review excludes sources falling outside the perimeter of peer-reviewed articles available online (e.g., conference proceedings, book chapters, and white papers) or not written in English, since this represents the dominant language in last mile logistics research (box C in Figure 1). Although some papers were selected since they matched the keywords used in the search process, after reading the abstracts we excluded 48 since the key topic was not aligned with the research focus of our paper (box D in Figure 1). As mentioned in the Introduction, the paper aims at improving the understanding of the underlying motivations with respect to green vehicles adoption in last mile logistics.

A final selection of 159 papers was included in this review. Among these articles, a further selection of 17 papers which provide significant insights into the introduction of green vehicles in urban freight distribution, are discussed in Section 4.

3. Results

Urban logistics is a research area that encompasses different fields ranging from engineering to transportation policy and human studies. This work proposes a systematic literature review of articles belonging to different research areas. A classification of the papers reviewed is introduced to better evaluate and discuss their added value and their potential integration in the future research directions about the diffusion of green vehicles in e-commerce and urban logistics. Three main categories were identified: Optimization and scheduling (O), policy (P), and sustainability (S). A similar categorization was also found in other literature review papers [18,19]. The following criteria were employed for the classification of the papers.

- Optimization and scheduling: The works investigating operation research problems were included in this category. The methodologies that are generally applied are based on mixed integer mathematical problems formulated to study vehicle routing problems and solved using algorithms aiming at minimizing delivery time, total costs of the activities, or the generated emissions. Neural networks, mathematical optimization techniques, and stochastic modeling are further characteristic applications regarding this category.
- Policy: The works classified in this category focus on governance, planning, regulations, and incentives for innovative technologies. The topics are centered on:
  - Evaluation of policy interventions effectiveness/acceptability before and/or after their deployment.
  - Innovative incentivization schemes in order to facilitate the spread of 'green vehicles'.
  - Coordination among stakeholders having contrasting interests.
  - Recommendations for policy or decision makers, both public and private, aiming at improving urban logistics.

The methods that are commonly applied are based on econometric or statistical analyses of empirical data acquired via questionnaires or stakeholders' interviews.

- Sustainability: Environmental, economic, and social sustainability considerations characterize this group. The papers included usually evaluate some logistics configurations or future scenarios comparing their economic and environmental performances. Social sustainability focuses on quality of life and conflicts concerning the use of space in urban cities. The methodologies that are often applied in this section make use of life cycle analysis, energy/fuel consumption modeling, economic analysis, or performance indicators.

Some review articles [18–21], employing a multidisciplinary approach, investigated aspects belonging to different categories (e.g., policy and sustainability). In these few cases the papers were classified following the topic that was considered characteristic and prevailing. Finally, the works about e-commerce were simply retrieved verifying that the topic was adequately dealt with in the text.

Tables A1–A3 in the Appendix A summarize the classification of the main contributions of the relevant papers included in this review sorted by the number of citations; a similar approach has been already proposed by Hilmola [22]. Figure 2 plots the publication year of the works selected. It can be noted that most of the works are quite recent and belong to the 2010–2020 decade. Figure 3 shows the distribution of the works per category: 42% belongs to the optimization and scheduling group (O), 34% is related to policy (P), and 24% is sustainability centered (S). The total percentage of papers containing references to e-commerce is 11% with 5.7% belonging to the policy group (see Figure 3). Figure 4 shows a word map colored for the number of authors per country: As can be expected, the most of them are affiliated with research institutions settled in developed countries (e.g., Europe and North America). Table 1 shows the most active authors with more than three papers in the sample analyzed.

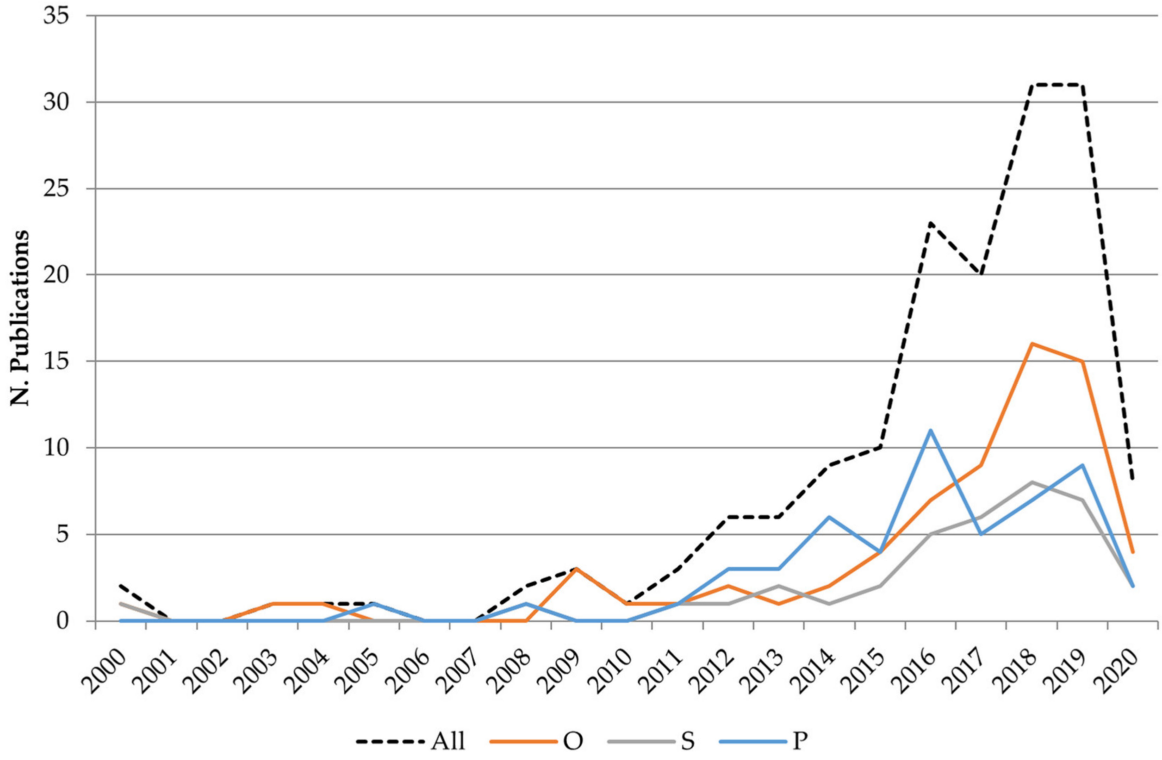

Figure 2. Number of papers considered per category and year of publication.

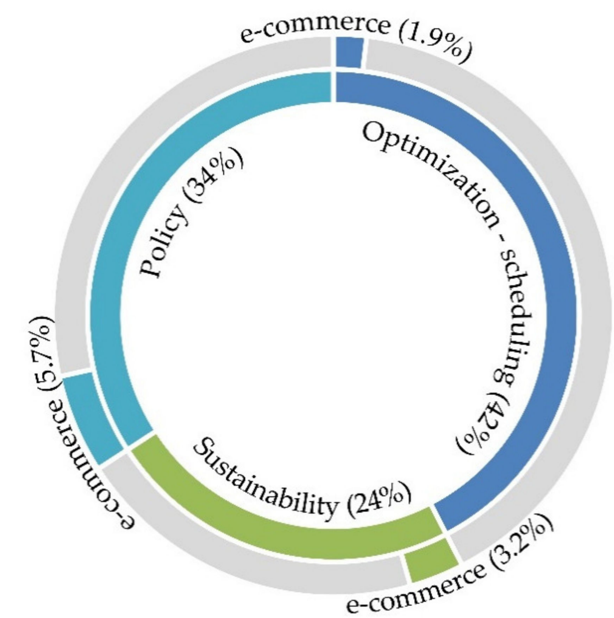

Figure 3. Representativeness of every category and of e-commerce related works.

Figure 4. Colored map—number of authors per country.

Table 1. Most active authors (more than three papers) sorted by number of citations.

Author	Institution	Number of Papers	Number of Citations
Teodor Gabriel Crainic	CIRRELT, Montréal	3	1081
Maria Lindholm	Chalmers University of Technology of Göteborg	3	521
Fraser McLeod	University of Southampton	4	336
Tom Cherrett	University of Southampton	4	336
Julian Allen	University of Westminster of London	3	286
Antonio Comi	Tor Vergata University of Rome	3	198
Cathy Macharis	Vrije Universiteit Brussel	7	156
Javier Faulin	Public University of Navarre	4	154
Gilbert Laporte	HEC, CIRRELT Montréal	4	141
Joeri Van Mierlo	Vrije Universiteit Brussel	5	135
Philippe Lebeau	Vrije Universiteit Brussel	5	135
Ola Jabali	Polytechnic University of Milan	3	125
Samuel Pelletier	HEC, CIRRELT Montréal	3	125
Dirk Christian Mattfeld	University of Braunschweig	3	75
Tessa T. Taefi	Reutlingen University	3	71
Nils Boysen	Friedrich-Schiller-Universität of Jena	3	68
Stefan Schwerdfeger	Friedrich-Schiller-Universität Jena	3	68

3.1. Optimization and Scheduling Group

As reported in Figure 2, the academic interests in urban freight distribution from the operation research point of view is significantly increased through time. Most of the literature focus on green vehicles routing and scheduling problem (GVRSP). This aims to minimize green-house gas (GHG) emissions in logistics systems through better planning of deliveries/pickups made by a mixed fleet of vehicles (green and traditional). The optimization techniques can be applied to several aspects capable of reducing externalities in smart logistics [14]. Cattaruzza et al. [23] provide a general overview of the most relevant studies of the GVRSP for city logistics.

In the mathematical formulations of the GVRSP the charging time is considered a downtime and the insufficiency of charging infrastructure as well as the battery limitations are considered a barrier for the integration of green vehicles in urban logistics.

Many studies propose models and applications for the optimal location of charging stations for electric freight vehicles [24–26]. A recent article by Cortés-Murcia et al. [27] propose a novel variant of the electric vehicle routing problem (EVRP) where the customer visits are allowed by an alternative means of transport while the EV is at a recharging station.

Recent studies have proposed models for the GVRSP considering a mixed fleet of traditional manually operated vehicles and autonomous vehicles (AVs). This represents a substantial technological advance in the field of transportation [28] and is expected to play an important role in supporting the last mile logistics within intelligent transportation systems [29]. Bucsky [30] highlights that autonomous vehicles can navigate less efficiently than human driven trucks and special drop-off places should be created since parking for a longer period and lack of human communication with other drivers could generate traffic congestion in mixed fleet scenarios.

To reduce excessive road traffic from last mile deliveries, Boysen et al. [31] propose the use of unmanned aerial vehicles (also known as drones) launched from trucks. The authors provided an optimization model where the truck serves both as a mobile depot for the goods and as a mobile launching platform for one or multiple drones based on the top of the truck. The en-route launch of the drone, i.e., the drone is launched from the truck and later re-joins the truck, and its relative optimization model has been also proposed by [32–34].

Since the standard GVRSP does not allow multiple trips to the depot, Dorling et al. [35] suggests solving drone delivery problems with a multitrip vehicle routing problem to overcome the difficulties caused by the short operating ranges of drones. Other studies [36,37] are aimed at finding the best spatial distribution of facilities of launch and recharge stations for a drone delivery system.

It is worth mentioning that recent and comprehensive review on GVRSP from various perspectives can be found in Moghdani et al. [38] and Ferreira et al. [39].

3.2. Policy

One of the main issues regarding policy applied to urban freight logistics is to develop methods to support decision makers for the ex-ante evaluation of possible alternative solutions taking into account the interests and preferences of all different stakeholders involved [40,41]. The integration and coordination of the different stakeholders (public and private) is a valuable solution to improve urban freight logistics reducing costs and negative environmental externalities [42,43]. The creation of urban consolidation centers (UCCs), for example, can result in a great commitment for the stakeholders involved and the interplay among them is often characterized by conflicting objectives [44]. As observed by Cleophas et al. [45], the key challenge to developing sustainable urban logistics is collaboration between businesses, logistics service providers, citizens, and the public sector.

The horizontal and vertical collaboration among courier companies in load consolidation can provide consistent benefits for all the subjects involved [46,47] also reducing urban congestion and pollution problems. Subcontracting and partnership should be preferred over creating new on-demand dedicated services [48] that would imply a huge investment on warehouse facilities and large delivery fleets. The use of sub-contractors is particularly desirable in urban contexts with strong regulatory constraints, high flexibility, and seasonal variations of flows. The spread of cross borders parcel distribution is boosting the cooperation of different distribution actors in the use of a common information technology platform and in the establishment of cross border settlements. The awareness of political authorities about the potential of e-commerce is growing and new regulations are developing aiming at improving the convenience of the service for customers [48].

The usage of small electric vehicles for urban deliveries is incentivized by public authorities because of their capacity for local pollution reduction [49]. For this reason, electric vehicles are often free from restrictions of access to inner city centers [5]; moreover, their ease of movement through the narrow streets of historic centers facilitates the delivery processes.

3.3. Sustainability

The claim for the reduction of negative externalities deriving from urban freight logistics is growing and the attention is focused on economic and environmental sustainability. This is strongly linked to the reduction of greenhouse gas emissions and other air pollutants in urban areas. The strategies that are often considered in order to improve the logistics system from both the environmental and costs perspectives are the reduction of the vehicles size and their electrification [14,17,50], conversion of a homogeneous fleet to a mixed one [1,51], creation of UCCs that work in combination with a mixed fleet for deliveries [14,52–54].

A recent solution refers to the use of crowdshipping especially for last-mile deliveries, however, its impacts mostly depend on the mode employed, length of detour, parking behavior, and daily traffic variations [55]. Gatta et al. [56] investigate a green-type of crowdshipping based on public transportation, estimating its environmental and economic impacts.

The use of light electric vehicles, drones, unmanned aerial vehicles, or cargo bikes constitute a solution that can reduce the operational energy requirements in most of the cases analyzed [52,57] even if the mileage toured is higher than that characterizing traditional vans. The capacity of new delivery vehicle types is lower, and a higher number of tours are necessary to serve the same number of customers. The spread of renewable electricity production is able to further reduce operational well-to-wheel energy consumption increasing the sustainability level of the electrification of the fleets employed for last mile deliveries [58]. The reduction of the operational energy is always coupled with a reduction of some environmental impacts, such as the amount of greenhouse gas emissions.

Life cycle assessment (LCA) applications are performed by different authors [59–61] to evaluate the overall benefits when the reduction of the operational energy consumption of urban freight vehicles is followed by an increase of the use of energy storage technologies or the necessity of new urban facilities. The importance of a life cycle approach is also underlined by Taefi et al. and Patella et al. [62,63]. This article, analyzing the economic sustainability of the application of electric vehicles in urban logistics, stresses the importance of long mileages and long battery warranties as the precondition for their real competitiveness in substitution with traditional internal combustion engines. Moreover, the high cost of the battery is still a strong limit for the diffusion of electric vehicles and incentives are fundamental to guarantee their economic competitiveness [37,64]. Furthermore, some literature works [65–67] showed a negative correlation between the reduction of greenhouse gas emissions and the life cycle costs of the delivery system: only in some specific cases it is possible to obtain a win-win scenario.

The presence of battery charging restrictions and reduced vehicle speed cause the design of shorter routes, the increase of the total daily mileage of tours, and the multiplication of urban facility requirements (e.g., UCC, satellites, micro-consolidation centers, charging stations). Melo et al. [68] provided an example showing that cargo bikes, which have a strong potential in emission and environmental impacts reduction, need to establish an urban facility in city centers to operate adequately. The reduction of the operational energy use and of the related environmental impacts linked to the delivery vehicles causes an increase in the embodied components characterizing the supporting logistics facilities. Moreover, the increase in the number of warehouses causes an increment of the energy required for their operation. Stalaroff et al. [61] show that, in some cases, the proliferation of new urban depots and facilities can result in an increase of the overall life cycle environmental burdens so that their implementation should be carefully evaluated. The application of LCA is strongly recommended since the methodology can evaluate the right compromise between environmental impacts belonging to different life cycle phases avoiding burden shifting. Moreover, the localization of depots in the inner parts of the cities is becoming complicated and scarcely affordable because of increasing land use values [69]. The sprawl of freight facilities in the suburbs or in the external parts of the cities, where the price of land is lower, contributes to increasing the length distances of the journeys. The high competition for land use in the core of the cities also involves the reallocation of space for social activities, green mobility, public transport, and pedestrians. The increasing congestion on the streets is, in fact, reducing the space required for socialization due to the deterioration of the quality of livable areas. Furthermore, the absence of bike lanes and pedestrian safe paths hinders sustainable mobility and provokes road accidents [70]. Dedicated infrastructure for walking, cycling, and recreational activities are necessary in modern sustainable cities and sustainable lifestyles are demanding a reduction of the amount of space for traffic [71].

4. The Adoption of Green Vehicles on E-Commerce City Logistics

Different studies [61,72,73] showed that e-commerce is more sustainable than retail pick-up or traditional shopping. In a life cycle perspective, Weber et al. [74] showed that e-commerce delivery systems are characterized by 30% lower primary energy consumption and CO_2 emissions when considering the warehouses energy demand, energy used in retail stores and headquarters, electricity used for home computer shopping activities and data centers, fuel necessary for transportation (from manufacturer to wholesale warehouse, from the wholesale warehouse to the retail stores or distribution centers, for last mile deliveries), and packaging. The last mile delivery represents, on average, the most important contribution with respect to total CO_2 emissions associated with e-commerce (32%). The wholesale warehousing energy use represents the second contribution (31%) of the total emissions linked to the e-commerce delivery system, but a similar share is registered also for traditional retail (26%). The main difference between the two systems is linked to the increase of the packaging impacts in e-commerce and to the reduction of the energy necessary for customers' transport to retail stores that, in traditional retail shopping, plays a preponderant role. The significant role played by last mile delivery in the definition of the global impacts linked to e-commerce activities explains why the topic attracts such attention by the scientific literature.

One of the main characteristics of e-commerce deliveries is their small size and light weight. The former property makes the consolidation of traditional diesel vans very difficult [75] and pushes towards the reduction of the size of the vehicles used for last mile activities in response to smaller, fragmented, and more frequent deliveries. Boosted by the spread of e-commerce, the number of light goods vehicles circulating in the inner city areas is increasing more than the number of heavy goods vehicles or cars [69]. The reduction of the capacity of fleet vehicles is, however, necessary for deliveries in historic centers characterized by narrow streets. Electrification is pursued since the efficiency of electric engines at low driving speeds (about 50 km/h [67]) is higher than that of fossil fuel-propelled engines due to regenerative braking. The diffusion of renewable energy generation can furthermore boost the competitiveness of green vehicles in last mile logistics both from an economic and environmental perspective. The drawback of the use of light weight green vehicles is the increase of the travelled distance as shown by different authors [47,49,76]. The higher mileages travelled by green vehicles can increase traffic congestion and its negative externalities; off-peak deliveries are suggested by different authors [49] to avoid worsening scenarios.

The possibility of choosing different delivery options is often given by online retailers with time windows that can be lower than 24 h (same-day delivery) [19]. Customers are demanding easy and fast deliveries and companies are experiencing a high pressure on delivery costs. The on-demand market is characterized by several independent players aiming at increasing the sales of their products and gaining market shares from their competitors also accepting to operate without covering the cost of last mile delivery operations. In order to increase online sales and meet customers' expectations, retailers guarantee 'free' delivery or offer different delivery options with a wide range of time windows. The guaranty of narrow time windows as a delivery option can furthermore stress the system reducing the possibility of demand aggregation and lowering the consolidation level of freight vehicles. The lower aggregation of demand produces an increase of the number of vehicles in circulation, of the distance travelled and, consequently, of the operational energy requirement and related environmental burdens [69,76]. In these cases, green vehicle or drone deliveries, replacing vans that are poorly consolidated, can play an important role in optimizing the system from both an environmental and economic perspective. However, even in case of drone usage, Dorling et al. [35] showed an inverse exponential relationship between the time limit and the total cost of the deliveries.

5. Conclusions

This systematic literature review showed that academic interest in the adoption of green vehicles in urban logistics has significantly increased as documented by the increasing number of publications on this topic in recent years.

This study confirmed that city logistics is intertwined with many aspects belonging to different fields related to urban planning, especially when considering sustainability. Three main categories were identified with respect to the various perspectives of the papers dealing with urban logistics: Optimization and scheduling (O), policy (P), and sustainability (S).

Green vehicles routing problems (GVRP), which represent the most relevant contribution of operations research to green logistics, are included in the “optimization and scheduling” category. Our analysis confirmed findings from Moghdani et al. [38], showing that the number of research studies interested in GVRP has grown rapidly.

Policy actions aiming at increasing the sustainability level of the system and the collaboration between stakeholders are discussed in the second category. The collaboration has been identified by many authors (e.g., Gatta et al. [40], Cleophas et al. [45]) as the key factor to increase urban freight sustainability.

The third category includes studies about environmental (employing LCA methodologies), economic, and social sustainability. The category subdivision resumes three different approaches developed by the literature analyzed in the study of the adoption of green vehicles in last mile logistics.

The issues connected to the rise of e-commerce are addressed by papers classified in each category identified. E-commerce is more sustainable than traditional retail shopping [61,72–74]: last mile delivery and warehouse management represent the trickiest phases but an important reduction of the environmental impacts linked to customers travelling to retail stores, that in traditional shopping are the highest, can be reached. However, the effort in market shares acquisition by independent online sellers, the guaranty of narrow delivery time windows options, and the small size of the largest part of delivered items challenge the consolidation level of traditional diesel vehicles stressing the system and increasing its negative externalities [19,76]: The higher resulting number of vehicles in circulation and the higher distance travelled increase the energy use and the connected environmental burdens related to the delivery phase. In order to respond to this challenge, the adoption of green vehicles (lightweight electric vehicles, cargo bikes, unmanned aerial vehicles (UAVs), etc.) are being evaluated because of their potential to reduce the environmental burdens connected to last mile delivery, particularly in urban environments [52,57,58,68]. Their adoption is also incentivized by administration authorities to control local pollution [5]. The life cycle economic and environmental sustainability of the process is however still debated since the high impacts of batteries [62] and the necessity of new depots and facilities characterized by not negligible energy requirements [61,68,77] contribute to worsen this scenario.

The development of vehicle technologies such as electric vehicles, connected and automated vehicles, and drones, as well as the introduction of new business models for freight transportation, requires new strategies to control the urban transportation system (freight and travelers) effectively and globally. There is a need for a system-based vision, and therefore researchers are encouraged to chart new territory in the literature by exploring ways in which overall urban transport sustainability can be enhanced. Even more important, whenever innovative solutions or disruptive changes, such as those related to the introduction of green vehicles, are tested and implemented, accurate behavioral analyses based on stated preference methods are needed to investigate stakeholders' acceptability and reactions.

As to the limitations of the research presented in this paper, this review is subject to the potential omission of relevant studies which have not been covered by the keywords. Moreover, the search excludes records which may potentially be relevant such as books, chapters, conference proceedings, editorials, reports, and articles not in English.

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Nomenclature

EVs	Electric vehicles
LCA	Life cycle analysis
UCC	Urban freight consolidation center
UDC	Urban distribution center
UAV	Unmanned aerial vehicle
GVRSP	Green vehicles routing and scheduling problem

Appendix A

Table A1. Papers included in "optimization and scheduling" category by the proposed review (sorted by citations as of June 2020).

Reference	Pub. Year	Citations	Category	Main Topic and Findings
Crainic et al. [78]	2009	556	O	Two-echelon, synchronized, scheduled, multi-depot, multi-tour heterogeneous vehicle routing problem with time window: mathematical formulation.
Crainic et al. [79]	2004	483	O	Model for the optimization of freight transport in congested urban areas (e.g., Rome).
Murray and Chu [80]	2015	360	O	Vehicle routing problem with a UAV working in parallel with a truck.
Ropke and Cordeau [81]	2009	351	O	Pick-up and delivery problem with time window: mathematical formulation and solution methodology.
Dorling et al. [35]	2017	292	O	Vehicle routing problem considering drones delivery.
Taniguchi and Van Der Heijden [82]	2000	258	O	Vehicle routing and scheduling problem with time windows combined with a dynamic traffic simulation model to assess the performance of city logistics initiatives.
Boyer et al. [83]	2009	216	O	Optimization of the last mile delivery: effects of density and time-windows.
Cattaruzza et al. [23]	2017	148	O	Review about "Vehicle Routing Problem".
Ha et al. [32]	2018	133	O	Travelling salesman problem with drones minimizing costs and delivery times.
Ćirović et al. [84]	2014	109	O	Vehicle routing problem of a mixed fleet of green and traditional vehicles. The optimization is performed from an environmental and economic perspective.
Motraghi and Marinov [85]	2012	89	O	Logistics optimization of freight train networks: a case study in Newcastle.
Ehmke et al. [86]	2012	69	O	Floating car data to optimize tour times.
Juan et al. [87]	2016	68	O	Vehicle routing problem considering electric vehicle autonomy.
Fatnassi et al. [88]	2015	61	O	Transportation problem of a dynamic personal rapid transit and freight rapid transit solution.
Devari et al. [89]	2017	59	O	Benefits of crowdsourcing in last mile delivery.
Gentile and Vigo [90]	2013	56	O	New models to describe generation and distribution of freight movements in urban areas.
Zhou et al. [91]	2018	53	O	Multi-depot two-echelon vehicle routing problem with delivery options (e.g., intermediate pickup facilities).

Table A1. *Cont.*

Reference	Pub. Year	Citations	Category	Main Topic and Findings
Shavarani et al. [36]	2018	50	O	Hierarchical facility location problem for a drone delivery system: the model proposed finds the optimal number and location of launch and recharge stations with the objective of minimizing the total costs of the system (cost of the facilities and of the operation and maintenance of drones).
McLeod and Cherrett [92]	2011	50	O	Loading bay: advance booking and control system.
Ham [93]	2018	49	O	Parallel drone scheduling travelling salesman problem.
Muñoz-Villamizar et al. [66]	2017	47	O	Horizontal collaboration between carriers and use of electric vehicles in urban freight transport: Vehicle routing problem optimizing delivery and environmental costs. A relationship between delivery and environmental costs is drawn.
Lebeau et al. [51]	2015	46	O	Vehicle routing problem with time window: sizing of a mixed vehicle fleet minimizing costs.
Deutsch and Golany [94]	2018	44	O	Last mile delivery problem considering lockers.
Awasthi et al. [4]	2016	42	O	Selection of collaborative partners: mathematical modeling.
Park et al. [95]	2016	42	O	Vehicle routing problem considering collaborative logistics in last mile delivery.
Boysen et al. [96]	2018	38	O	Truck-based robot delivery scheduling problem: formulation and solution.
Tavana et al. [97]	2017	38	O	Optimization of the logistics operations in cross-docks considering the use of drones or of traditional vehicles.
Schiffer and Walthera [98]	2018	36	O	Location routing problem with intra-route facilities solved using an adaptive large neighborhood search algorithm.
Yu and Lam [99]	2018	31	O	Optimization of routes and charging schedules of autonomous vehicles to maximize the use of renewable energy.
Boysen et al. [31]	2018	30	O	Vehicle routing problem with drones minimizing the delivery duration.
Pamučar et al. [100]	2016	30	O	Green-vehicles routing model implemented in a GIS platform that aims at optimizing the parameters of the environment (e.g., CO, NOx; noise, SO_2, PM), health, use of space and logistics operating costs.
Wang and Sheu [34]	2019	29	O	Capacitated vehicle routing problem considering drones.
Jie et al. [101]	2019	26	O	Two-echelon capacitated vehicle routing problem with battery swapping stations.
Behiri et al. [102]	2018	25	O	Freight-rail-transport-scheduling-problem: a tool for the evaluation of the feasibility in Paris.

Table A1. *Cont.*

Reference	Pub. Year	Citations	Category	Main Topic and Findings
Marinelli et al. [33]	2018	23	O	Travelling salesman problem with drones: the truck can deliver and pick a drone up not only at a node but also along a route arc.
Chiang et al. [103]	2019	21	O	Mixed integer routing problem with unmanned aerial vehicles (UAV).
Pelletier et al. [104]	2018	21	O	Comprehensive mathematical model for the cost optimization of a fleet of electric freight vehicles (EVs).
Battini et al. [105]	2014	21	O	Optimization problem of the last mile delivery in Haiti.
Behnke and Kirschstein [106]	2017	20	O	Emission minimizing routing problem.
Ahani et al. [107]	2016	20	O	Optimization procedure for vehicles fleets used in last-mile delivery.
Mbiadou Saleu et al. [108]	2018	19	O	Parallel drone scheduling travelling salesman problem.
Baldi et al. [109]	2019	16	O	New packing problem with bin-dependent items profits.
Kin et al. [110]	2018	16	O	Cost optimization of alternative systems for last mile delivery.
Franceschetti et al. [111]	2017	16	O	Model for the optimization of the total cost of a vehicles freight fleet considering restrictions in the access of the city.
Deflorio and Castello [25]	2017	15	O	Traffic and energy modelling of dynamic charging-while-driving systems for freight delivery services using electric vehicles.
Sopha et al. [112]	2016	13	O	Dynamic vehicle routing problem.
F. Wang et al. [113]	2019	12	O	Intelligent freight vehicles scheduling and management system based on crowd intelligence and ride-sharing.
Firdausiyah et al. [114]	2019	12	O	Modelling the behavior of freight carriers and of an urban consolidation center (UCC) operation.
Karak and Abdelghany [115]	2019	11	O	Hybrid drone-vehicle routing problem.
Pelletier et al. [116]	2019	9	O	Electric vehicle routing problem with energy consumption uncertainty.
Troudi et al. [117]	2018	9	O	Capacitated vehicle routing problem with time window for the sizing of a drone fleet.
Muñoz-Villamizar et al. [65]	2019	7	O	Horizontal collaboration between carriers and use of electric vehicles in urban freight transport: Vehicle routing problem optimizing delivery and environmental costs in short and medium term. A relationship between delivery and environmental costs is deployed.

Table A1. *Cont.*

Reference	Pub. Year	Citations	Category	Main Topic and Findings
Rezgui et al. [118]	2019	6	O	Electric vehicles routing problem with time window considering modular electric freight vehicles.
Scherr et al. [119]	2019	6	O	Service network design problem for a mixed fleet of motor and autonomous vehicles: the model proposed aims at optimizing the size and mix of the fleet as well as the routing of vehicles.
Shavarani et al. [37]	2019	6	O	Mathematical formulation of a facility location problem aiming at minimizing the total costs of a drone-based delivery system concerned with refuel stations, warehouses, drone procurement, and transportation.
Bergqvist and Monios [120]	2016	6	O	Intermodal high capacity transport.
Y. Li et al. [121]	2020	4	O	Vehicle routing problem that minimizes the cost of an urban distribution system.
Moeini and Salewski [122]	2020	2	O	Solution of the truck-drone-autonomous vehicles routing problem.
Cortés-Murcia et al. [27]	2019	2	O	Electric vehicles routing problem with time window considering the possibility of costumers' self-collection during the charging process.
H. Li et al. [123]	2020	-	O	The two-echelon city logistics system with on-street satellites: mathematical formulation and solution.
Schwerdfeger and Boysen [2]	2020	-	O	Mobile parcel lockers for last mile distribution: an optimization model minimizing the locker fleet when satisfying all customers is proposed.
Pinto et al. [26]	2019	-	O	Optimization model addressing the design problem of a network of charging stations to support a meal delivery service using drones.
Yu [29]	2019	-	O	Optimization in the routing and charging schedules for an autonomous vehicles logistics system using distributed renewable energy generation.
Fikar et al. [124]	2018	-	O	Model optimizing the interaction between a traditional logistics operator and a group of freelancers using cargo bikes.
Chen [125]	2017	-	O	Model for the site selection of logistics center in an e-commerce network environment.
Cavadas et al. [24]	2015	-	O	Mathematical model to locate charging stations for electric freight vehicles.
Ehmke and Mattfeld [126]	2010	-	O	Time dependent optimization: management of big data about traffic.
Dekker et al. [127]	2012	734	S	Operational research emphasis on environmental problems.
Browne et al. [52]	2011	205	S	Evaluation of the impacts (travelled distances, emissions, costs) of the creation of a UCC in central London that employs cargo bikes and electric vehicles for the deliveries.

Table A2. Papers included in "sustainability" category by the proposed review (sorted by citations as of June 2020).

Reference	Pub. Year	Citations	Category	Main Topic and Findings
Behrends et al. [128]	2008	178	S	Definition of a new indicator able to describe the level of sustainability in urban freight transport (SUFT).
Boerkamps et al. [54]	2000	143	S	Model for the evaluation of the logical and environmental performances of three types of urban distribution systems: the traditional system and two concepts using urban distribution centers (one using vans, the other using automated underground vehicles).
Goodchild and Toy [77]	2018	96	S	Comparison of the emissions reduction potential of two delivery modes: one using UAV and the other using trucks.
Stolaroff et al. [61]	2018	82	S	LCA of an urban logistics system employing UAV: drones consume less energy per package-km than delivery trucks but the additional energy for warehouse requirements and the longer distances per package travelled greatly increase the life-cycle impacts. Small drones are more environmentally friendly.
Arvidsson [129]	2013	69	S	Sustainability paradox: access restrictions in city centers might increase social sustainability aspects while decreasing economic sustainability. The use of multiple key performance indicators in urban freight distribution is recommended.
Brown and Guiffrida [73]	2014	68	S	Comparison of the environmental impacts of traditional shopping and e-commerce activities.
Ranieri et al. [14]	2018	66	S	Evaluation about how some negative externalities of urban freight transport can increase a cost function and how some last mile logistics innovations can reduce it.
Russo and Comi [130]	2016	63	S	Regressive model for the evaluation of the reduction potential of the environmental impacts (CO, NO_x, SO_x, PM) resulting from the implementation of some sustainable measures in urban logistics.
Melo and Baptista [68]	2017	47	S	The use of electric cargo bikes is a sustainable option for last mile delivery: when replacing all the conventional vans, the well-to-wheel CO_2 emission saving is 73%.
Aditjandra et al. [131]	2016	38	S	Environmental impacts (CO_2, PM, and NO_x) of heavy and light freight vehicles operating in urban areas.
Lebeau et al. [132]	2015	36	S	Total cost of ownership analysis of electric light vehicles for city logistics.
Schöder et al. [49]	2016	33	S	Impact of e-commerce on urban logistics sustainability.
de Oliveira et al. [17]	2017	32	S	Review about literature on sustainable vehicles for last mile delivery. A trend supporting smaller and lighter electric vehicles for last mile deliveries in urban areas is discovered.

Table A2. *Cont.*

Reference	Pub. Year	Citations	Category	Main Topic and Findings
Faccio and Gamberi [53]	2015	32	S	Evaluation, based on field data, of the economic and environmental sustainability deriving from the creation of a centralised platform using electric vehicles to cover the last 50 miles of distribution.
Figliozzi [59]	2017	32	S	LCA of a drone.
Duarte et al. [57]	2016	29	S	Data analysis about the energy consumptions and environmental impacts of electric vehicles used for last mile logistics in Lisbon.
Giordano et al. [58]	2018	21	S	Comparison of diesel and battery electric delivery vans using emission and costs LCA. If electricity is clean and diesel vans are old, high savings can be reached in both fields from their substitution with electric ones (e.g., −93/98% of GHGs).
Park et al. [133]	2018	19	S	Comparison of the LCA impacts of a motorcycle delivery and of a drone delivery in urban and rural areas.
J. Wang et al. [67]	2019	18	S	A negative correlation between the cost and carbon emissions under the shortest distribution routes is found. The optimized solution that minimizes the emissions of greenhouse gases and the overall operational cost is searched.
Durand et al. [134]	2013	17	S	Comparison of the environmental and cost performances of three scenarios for delivering to urban online shoppers.
Taefi et al. [62]	2017	14	S	A high mileage increases the cost-effectiveness of medium-duty electric vehicles. However, expensive battery replacements or quick charging can reduce the benefits significantly.
Aurambout et al. [135]	2019	12	S	Market potential and economic sustainability of using drones in last mile delivery within EU-28 countries.
de Mello Bandeira et al. [50]	2019	10	S	Sustainability assessment of electric light vehicles in the last mile of transportation and of postal deliveries in Rio de Janeiro.
Teoh et al. [136]	2018	10	S	The opportunity charging can significantly reduce the life cycle cost and emission of EVs used for urban freight transport operations.
Taefi [63]	2016	8	S	Potential of double-shift usage in reducing the total costs of ownership of electric vehicles: EVs are competitive for high daily mileages.
Koiwanit [72]	2018	7	S	LCA of drone delivery on an online shopping system.
Semanjski and Gautama [137]	2019	6	S	Multi-criteria decision-making approach to achieve consensus among stakeholders on the best routing option from a sustainability perspective.
Digiesi et al. [138]	2017	5	S	Review work about the strategies for the reduction of externalities in last mile logistics.

Table A2. *Cont.*

Reference	Pub. Year	Citations	Category	Main Topic and Findings
Figliozzi et al. [60]	2020	5	S	Life cycle carbon emissions of an urban distribution centers.
Nenni et al. [20]	2019	5	S	Sustainability-based review of urban freight models: impacts related to economic (freight transport, infrastructure, employment), social (safety, security, noise) and environmental (land use, energy and emissions) fields are considered.
Bucsky [30]	2018	2	S	Review of data about the economic and environmental sustainability concerning the use of autonomous vehicles for urban freight delivery.
Lebeau et al. [139]	2019	1	S	Total cost of ownership of electric freight vehicles.
Marmiroli et al. [140]	2020	1	S	Comparative life cycle assessment of electric, compressed natural gas and diesel light-duty vehicles. Electric motors are more efficient in urban environments and the role of the batteries in embodied impacts is dominant.
Cárdenas et al. [141]	2017	-	S	Analysis about the spatial distribution of e-commerce deliveries in Belgium and definition of an external cost index per parcel delivered that considers the costs of congestion, accidents, noise, air pollution and climate change. Average costs per parcel are higher for deliveries in rural areas.
Moore [142]	2019	-	S	Innovative scenarios for intra-city freight delivery are considered and compared with a baseline scenario (diesel based) from an energy consumption perspective.

Table A3. Papers included in "policy" category by the proposed review (sorted by citations as of June 2020).

Reference	Pub. Year	Citations	Category	Main Topic and Findings
Fagnant and Kockelman [143]	2015	1451	P	Autonomous vehicle in the USA: advantages barriers and policy recommendations.
Muñuzuri et al. [5]	2005	373	P	Evaluation of the solutions or initiatives that can be implemented by local administrations in order to improve freight deliveries in urban environments and expected effects.
Savelsbergh and Van Woensel [47]	2016	265	P	Challenges and opportunities in city logistics.
Cherrett et al. [144]	2012	196	P	Review article about data and information on urban freight transports. A central coordination of some activities, such as service provision, can reduce environmental impacts.
Lindholm and Behrends [145]	2012	191	P	Integration between public and private actors to face the sustainability challenges raised by urban freight transport in Baltic countries.

Table A3. *Cont.*

Reference	Pub. Year	Citations	Category	Main Topic and Findings
Tadić et al. [146]	2014	170	P	A multi-criteria decision-making model is proposed for the selection of the city logistics concept which would be most appropriate for different participants, stakeholders, and attributes of the surroundings.
Schliwa et al. [147]	2015	158	P	The local authorities play a key role in creating the conditions that incentivize large logistics companies to integrate cargo cycles into their supply chains.
Marcucci and Danielis [148]	2008	153	P	Stated-preference study about the potential use of an urban freight consolidation center in Fano (Italy).
Ballantyne et al. [149]	2013	152	P	The work aims at demonstrating that urban freight transport planning can be improved only by involving a wider range of stakeholders.
Guerra [150]	2016	150	P	Policy recommendations for planning the diffusion of autonomous vehicles in urban environments.
Muñuzuri et al. [151]	2012	144	P	Typical regulation schemes in Spain and reason of their obsolescence and lack of enforcement. Possible efforts towards improvement are discussed.
Lagorio et al. [18]	2016	104	P	Systematic literature review that addresses urban logistics from a logistics and management perspective. The focus is recently moving to stakeholder involvement in the decision-making process.
Gruber et al. [152]	2014	102	P	Electric cargo bikes: potential market, organization of the current market, how they are perceived by bike and car messengers, and what factors drive their willingness to use them.
Pelletier at al. [21]	2016	95	P	Review article about goods distribution with electric vehicles: the technological and market background are addressed.
Russo and Comi [153]	2011	89	P	Model that aims at supporting the ex-ante assessment of city logistics measures simulating the choices of each decision-maker involved in response to policy measures.
Ducret [48]	2014	86	P	Analysis of the changes in European courier, express and parcel sector: the rise of cross-border e-commerce.
Morganti and Gonzalez-Feliu [154]	2015	79	P	The case study of the urban distribution center of Parma (Food Hub): the role of public actors in defining adequate policy measures.
Taniguchi et al. [76]	2003	74	P	Mathematical computer-based models for the planning of city logistics schemes and predicting their effects.

Table A3. *Cont.*

Reference	Pub. Year	Citations	Category	Main Topic and Findings
Allen et al. [69]	2018	66	P	Challenges of e-commerce delivery and initiatives that retailers, parcel carriers, and city authorities, can implement to reduce the costs associated with last mile logistics.
Ajanovic and Haas [155]	2016	66	P	Identify the major impact factors for a broader dissemination of EVs in urban areas. The incentives should depend on the decarbonization potential of electricity generation.
Lenz and Riehle [156]	2013	61	P	European experiences of cargo bike usage for delivery in cities. The spread is possible only if public authorities play an important role in the promotion (incentives, provision of space for depots in city centers, dedicated infrastructures).
Roumboutsos et al. [157]	2014	59	P	Definition of a methodology based on the Systems of Innovation approach to examine the process by which EVs may be introduced in city logistics.
Taefi et al. [158]	2016	49	P	Multi-criteria analysis of policy measures in Germany that support the adoption of electric vehicles in urban road freight transport.
Anand et al. [159]	2014	48	P	An ontology model of city logistics is proposed which includes independent city logistics entities and the relationships between them in a structured form.
Nuzzolo et al. [160]	2016	46	P	Comparison of the characteristics of urban freight transport and of the logistics measures being implemented in Rome, Barcelona, and Santander.
Bjerkan et al. [161]	2014	43	P	Collaborative approach in urban freight transport: stakeholder evaluations about the implementation of a mobile depot and night and evening deliveries.
Yuen et al. [162]	2018	41	P	Analysis on the customers' intention to use self-collection as a last mile delivery method and how to increase it.
Lebeau et al. [163]	2016	41	P	Vehicle choice behavior of transport companies and expectations: authorities should encourage the use of battery electric vehicles.
Harrington et al. [164]	2016	37	P	Multi-stakeholder conceptual framework: socio-economic common interests, trade-offs, and interdependences.
Jaller et al. [165]	2015	31	P	Logistics initiatives to alleviate the externalities of the freight traffic produced and attracted by large freight traffic generators.
Morganti and Browne [166]	2018	30	P	Technical and operational obstacles to the adoption of electric vans in France and the UK. Some financial and non-financial incentives to foster the adoption of electric vans.
Perboli and Rosano [1]	2019	26	P	Harmonization of the business and operational models of traditional and green logistics (mainly cycled) actors.
Mirhedayatian and Yan [167]	2018	26	P	Framework to evaluate policy options supporting EVs in urban freight transport.

Table A3. *Cont.*

Reference	Pub. Year	Citations	Category	Main Topic and Findings
Allen et al. [46]	2017	24	P	A "freight traffic controller" is proposed to manage the repartition of work between parcel carriers collaborating horizontally to reduce urban congestion.
Kane and Whitehead [168]	2017	23	P	Policy actions to manage the on-going transport disruptions avoiding non-optimal outcomes.
Musolino et al. [169]	2019	22	P	Methodology for the evaluation of an urban distribution center location in order to pursue sustainability goals.
Ville et al. [44]	2013	22	P	The case study of the UCC of Vicenza: limits of the public policy intervention in restricting vehicle access to the city center.
Dolati Neghabadi et al. [19]	2019	20	P	Systematic literature review about policy, innovative solutions, stakeholders, and sustainability aspects in city logistics.
Arvidsson et al. [170]	2016	15	P	The integration of passenger and freight transport in urban areas is a promising approach to ease the last mile problem.
De Marco et al. [75]	2018	14	P	Empirical analysis of a dataset about implemented city logistics measures: pollution, diffusion of e-commerce and gross domestic product are important drivers of city logistics deployment.
Hopkins and McCarthy [171]	2016	14	P	Significant trends in urban freight delivery and policy implications: online shopping, new technologies, and changing expectations.
Hoffmann and Prause [172]	2018	13	P	Necessity of a clear regulatory framework for the usage of autonomous vehicles in last mile delivery.
Cagliano et al. [173]	2017	13	P	Public intervention is necessary to speed the diffusion of EVs: definition of an incentive scheme and evaluation of their effects.
Lebeau et al. [174]	2018	11	P	Multi-criteria analysis to support administrations in choosing, involving stakeholders, the priority policy to be implemented in order to improve the sustainability of city logistics.
Christensen et al. [175]	2017	10	P	Commercial sectors suitable for a shift to electric mobility: construction, human health, and other service sectors.
Kellermann et al. [176]	2020	6	P	Review about the use of drones for parcel and passenger transportation: technical and regulatory problems and barriers.
Buldeo Rai et al. [177]	2019	5	P	Local authorities can facilitate the adoption of emerging measures to optimize the activities of logistics by cooperating with the private sector and by developing a harmonized, long-term vision on freight transport policy across cities and regions.

Table A3. *Cont.*

Reference	Pub. Year	Citations	Category	Main Topic and Findings
Hu et al. [178]	2020	4	P	Integration of freight logistics into urban passengers' rail transit network: stakeholders' characterization, variables affecting the system operations and external impacts.
Matusiewicz [179]	2019	3	P	Identify the conditions for the implementation of deliveries in the limited accessibility zone in Gdansk and the guidelines for the implementation of a new sustainable transport policy.
Skiver [180]	2017	3	P	Competition between brick-and-mortar retailers and e-commerce in guaranteeing the same-day home deliveries.
Arroyo et al. [181]	2019	2	P	The effectiveness of carbon pricing policies for promoting urban freight electrification in Madrid is low in the short term.
Monios and Bergqvist [182]	2019	2	P	Description of the transport geography of electric and autonomous vehicles for road freight transport and identification of the many unresolved issues about to emerge.
Ehrler et al. [183]	2019	-	P	Perspectives, prerequisites, and challenges for a shift to electric vehicles in the last mile logistics of grocery e-commerce.
Ørving et al. [184]	2019	-	P	Public-private partnership to facilitate the development of commercial cargo bike use in Oslo.
Cheng and Liu [185]	2016	-	P	Government policies aiming at the diffusion of EVs.

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