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Cargo Bikes and Van Deliveries in Rome: A Comparative Analysis

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Abstract

The rapid growth of e-commerce and the pandemic-driven surge in deliveries have intensified the challenges last-mile logistics poses to urban areas. Road transport, the predominant delivery mode, is a major contributor to greenhouse gas emissions. Despite a downward trend since 2008, emissions rose in 2022, reflecting an increased mobility demand. Light commercial vehicles and trucks impact air and noise pollution due to their high emissions and noise levels. Innovative solutions, such as cargo bikes (CBs), have emerged as sustainable alternatives to mitigate these effects. This paper reports a brief literature review on CBs and evaluates their environmental, economic, and social benefits by comparing real-life data from a shipping company operating with CBs in central Rome to simulated data for motorized delivery vehicles. By analyzing their potential to reduce emissions, improve urban livability, and lower operational costs, this study seeks to raise awareness on CBs' sustainability as a viable alternative for last-mile logistics. Highlighting these advantages can support policymakers, businesses, and urban planners in fostering a transition to more sustainable urban mobility solutions.

Keywords: cargo bikes; last mile logistics; delivery impact; city logistics; urban freight; urban freight distribution; vehicle routing andimpact assessment

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1. Introduction

In recent years, home delivery has grown significantly, driven by the rise of e-commerce and the impact of the pandemic. This has produced significant challenges in last-mile logistics—the final segment of the distribution chain—with implications for urban planners, policymakers, businesses, and citizens. The main concerns are environmental. In fact, road transport is the most common mode for deliveries and heavily contributes to greenhouse gas (GHG) emissions. Light commercial vehicles and trucks generate significant amounts of CO_2.

According to the 2024 ISPRA report on emissions in Italy [1], GHG emissions from road transport in 2022 accounted for approximately 91.5% of the transport sector's total emissions. Although emissions from this sector have been decreasing since 2008, there was an increase in 2022 due to the recovery in mobility demand following the pandemic, with a 6.7% rise compared to 2021 and a 7.4% increase compared to 1990. The ISPRA database on air pollution indicators for road transport in Italy provides specific data on light commercial vehicles, which emitted approximately 242 t of carbon dioxide in 2022, while heavy trucks emitted around 668 t. The vehicles commonly used for deliveries are often heavy and bulky, exacerbating air and noise pollution as well as congestion in urban areas.

To mitigate these effects, innovative solutions are being tested [2,3], such as using CBs, sustainable vehicles that reduce emissions and improve urban livability by decreasing traffic congestion and creating a safer environment, which is well-aligned with the aims of the Sustainable Urban Mobility Plan (SUMP) of Rome [4]. A critical aspect for CBs' simple deployment is the need to adapt some city features to these characteristics. These vehicles, being wider and heavier than traditional bicycles, require larger and safer bike lanes. In many urban contexts, existing bike lanes are not designed to accommodate vehicles of this size, making it urgent to rethink the cycling network. Moreover, in areas where such paths are completely absent, it is essential to plan and build new infrastructures that allow for smooth and safe CB mobility [5]. This entails dedicated investments in financial resources, time, and collaboration between the public and private sectors.

As urban areas continue to grow and traffic congestion worsens, the need for sustainable and efficient city logistics solutions has become more urgent than ever. CBs have emerged as a game-changer in urban freight transport, offering a practical, eco-friendly, and cost-effective alternative to traditional delivery vehicles. Their role in city logistics is essential for reducing emissions, alleviating congestion, and improving last-mile delivery efficiency.

In fact, CBs can contribute to reducing emissions and improving air quality. They produce zero emissions, making them an ideal solution for reducing urban air pollution. Unlike conventional delivery vans, which contribute to carbon emissions and poor air quality, CBs help cities meet sustainability goals by lowering GHG emissions and improving overall public health [6]. CBs can also alleviate traffic congestion. Traditional delivery trucks and vans contribute significantly to traffic congestion, particularly in dense city centers. CBs, on the other hand, take up less space and can navigate through narrow streets and pedestrian zones with ease, which both characterize downtown Rome since it was built more than 2000 years ago, when chariots were the standard. This allows for more flexible and efficient deliveries, reducing the overall road congestion and improving traffic flows. Furthermore, CBs can increase last-mile delivery efficiency. This is particularly important since the last mile of the delivery process is often the most expensive and time-consuming part of the supply chain. CBs provide a more agile and efficient solution, allowing couriers to perform deliveries faster by avoiding traffic jams and accessing areas where larger vehicles cannot enter. This efficiency reduces costs for businesses and enhances customer satisfaction by ensuring timely deliveries. This last feature characterizing CBs also improves cost-effectiveness and increase business results since operating CBs is significantly cheaper than maintaining a fleet of delivery vans. They require less maintenance, eliminate fuel costs, and avoid expensive parking fees and congestion charges. Many businesses, from large logistics providers to small local retailers, are increasingly integrating CBs into their supply chains to cut costs while enhancing service quality. The authors of this study personally conversed with representatives from Amazon and Poste Italiane, who confirmed that they are testing CBs as a viable operational option for specific city areas.

CBs also support sustainable and livable cities contributing to the creation of healthier and more livable urban environments. By reducing noise pollution, emissions, and traffic congestion, they support cities in their transition toward more sustainable mobility, which the Green Deal aims to achieve [7]. Additionally, they complement other green transport initiatives such as pedestrianized zones and low-emission areas. Finally, one also has to acknowledge their versatility, which represents a valuable feature in current urban freight transport-related problems. Modern CBs are designed to handle various delivery needs, from small parcels to larger shipments. With different configurations, including electric-assisted models, they can efficiently transport goods for e-commerce, grocery deliveries, postal services, and even construction materials. To conclude this introduction, it is important to recall that CBs represent not just a niche solution but a fundamental component of the future of city logistics. Their ability to reduce the environmental impact, improve delivery efficiency, and support urban sustainability makes them an invaluable asset for modern cities. As more businesses and municipalities recognize their potential, CBs will continue to revolutionize urban freight, paving the way for cleaner, greener, and more efficient city logistics. Notwithstanding the CB-related research performed, there is still a need for experiments and pilots to test the comparative advantages of CBs with reference to vans. This paper contributes to filling this research gap by comparatively testing the economic, environmental, and social benefits CBs can generate compared to van delivery in the city of Rome. In fact, this paper reports real-life data provided by the CB company Corro Corrieri Roma (CCR) with respect to a small yet representative sample of actual CB deliveries and through a reliable simulation, it compares these results with the performance a van delivery would have had in the same real-life context.

In order to prove the statements above, this paper will, after a brief literature review (Section 2) setting the scene, illustrate the methodological approach used (Section 3), evaluate the benefits of CBs by comparing them to the van, the most frequently used means of transportation to deliver goods in cities (Section 4). This study assesses the potential of cargo bikes as a sustainable alternative for last-mile delivery in urban areas, using the city of Rome as a representative case study. Finally, this paper provides some concluding remarks (Section 5) on the pilot study deployed in Rome.

2. Literature Review

Urban freight transport is a critical component of city logistics, ensuring the efficient movement of goods within increasingly congested urban environments. However, it is also a major contributor to congestion, air pollution, and carbon emissions in city centers. As cities strive to reduce these negative externalities and decrease the reliance on fossil fuel-powered vehicles, CBs have gained traction as a sustainable alternative for last-mile deliveries [8]. With increasing regulatory pressure on emissions and growing sustainability concerns, CBs have emerged as a potential substitute for conventional vans in urban freight systems. This succinct literature review examines the role of CBs in city logistics and their benefits, challenges, and integration in urban freight distribution systems. It synthesizes academic studies comparing CBs and vans, focusing on three key dimensions: economic feasibility, environmental impact, and social implications. Furthermore, it explores the role of regulatory policies and infrastructure in shaping the effectiveness of CB logistics.

The main benefits deriving from CBs relate to the environment and sustainability, efficiency improvements in last-mile delivery services, and economic and operational advantages. In more detail, CBs contribute significantly to reducing GHG emissions, air pollution, and noise levels in urban areas [9]. Studies have shown that CBs emit 90% fewer CO_2 emissions than conventional delivery vans, making them a crucial component of sustainable urban mobility [10]. Compared to vans, CBs require significantly less energy. Research by Schliwa et al. [8] shows that electric-assisted CBs consume 90% less energy per kilometer than electric vans, making them particularly attractive in cities with strict environmental targets and the increasing electrification of urban logistics. Additionally, Guimarães et al. [11] argue that CB adoption can lead to a significant reduction in fuel dependency, particularly in urban regions with limited access to charging infrastructure for electric vans.

The last-mile delivery is one of the most challenging and expensive segments of city logistics. Research indicates that CBs can outperform vans in urban environments by navigating congested streets more efficiently and accessing pedestrianized or restricted zones where motorized vehicles are not permitted [12]. They also enable shorter delivery times by avoiding traffic bottlenecks and utilizing cycle lanes [13]. Efficiency in urban delivery is a key factor influencing economic feasibility. Melo & Baptista [14] indicate that CBs can be 30–50% faster than vans in congested urban areas due to their ability to bypass traffic and utilize bike lanes. However, Cherrett et al. [15] caution that CBs are less effective over longer distances and when delivering heavier loads, requiring hybrid solutions where vans support larger shipments to distribution hubs. Furthermore, Macioszek [16] underscores that CB efficiency is significantly influenced by the presence of micro-consolidation centers, which can streamline distribution operations by reducing trip distances. In this regard, the previously mentioned SUMP of Rome addresses this very approach.

In terms of economic feasibility, several studies highlight the economic benefits of CBs, particularly in terms of operational costs. Gruber et al. [9] found that CBs have 90% lower energy costs and 60% lower maintenance costs compared to diesel vans. Research by Conway et al. [13] also supports this point, emphasizing that CBs eliminate fuel costs, reduce parking fees, and require less road infrastructure, such as bike lanes and dedicated bicycle parking. Their minimal maintenance costs, exemption from fuel expenses, and avoidance of congestion and parking fees make them a financially attractive option for logistics providers [17]. Studies have also highlighted their potential to increase delivery efficiency in dense urban centers, reducing the overall number of trips required [18]. However, CBs have a limited payload capacity and range that can reduce overall efficiency for large-scale logistics operations [19]. Additionally, Christoforou et al. [20] highlights that the total cost of ownership for CBs remains lower than that of diesel or electric vans when factoring in subsidies, maintenance, and urban delivery efficiency.

From an environmental perspective, CBs produce zero direct CO_2 emissions, making them a cleaner alternative to diesel and even electric vans. Studies by Browne et al. [12] and Lenz & Riehle [10] show that replacing vans with CBs for short-distance deliveries can reduce urban freight CO_2 emissions by up to 50%. Additionally, CBs contribute to lower noise pollution, an often overlooked but important factor in urban quality of life. Meanwhile, recent research by Hemmelmayr et al. [21] emphasizes that the decarbonization potential of CBs is maximized when integrated with electric mobility solutions, such as electric-assisted CBs and renewable energy charging stations.

Socially, CBs can alleviate congestion by reducing the number of delivery vans in city centers, improving urban livability and reducing stress on public spaces. The research by Dalla Chiara et al. [22] found that in cities with a well-developed cycling infrastructure, the adoption of CBs could decrease freight-related congestion by 15–30%. Reduced congestion not only improves travel times but also contributes to better air quality and safer urban environments. However, road safety remains a key social concern, particularly for vulnerable users such as cyclists and pedestrians, requiring a thoughtful integration with existing transport modes. Studies by Johnson & Rose [23] suggest that while CBs reduce heavy vehicle accidents, they introduce new safety challenges for cyclists and pedestrians, necessitating specific infrastructure adaptations. Moreover, Nazari et al. [24] stresses that proper street design, dedicated CB lanes, and traffic management policies are crucial to ensuring the safe and effective operation of CB fleets in dense urban areas. The shift from van-based to CB-based deliveries also impacts employment structures in the logistics sector. Studies by Allen et al. [25] indicate that CB couriers experience lower physical strain than traditional bike couriers but face challenges such as weather dependency and limited job security. Some research also suggests that CB-based logistics may foster local employment opportunities, as they are often linked to small-scale, decentralized delivery networks [8].

Additionally, studies by Llorca et al. [26] indicate that CBs can enhance the inclusivity of urban delivery jobs by enabling employment for individuals without a driver's license, potentially expanding workforce accessibility.

Despite their advantages, one must also consider CB characteristics that hinder their widespread adoption in urban freight systems. One primary concern with CBs is their limited payload capacity compared to traditional delivery vans. Research by Melo et al. [14] suggests that CBs are most effective for small- and medium-sized deliveries rather than bulk transport. The lack of dedicated cycling infrastructure and appropriate regulatory frameworks for CBs poses a challenge for their integration into city logistics [27]. Many cities still lack policies supporting CB logistics, and existing road infrastructure may not be well-suited for large-scale implementation. CB operations can also be affected by adverse weather conditions, such as heavy rain, snow, or extreme temperatures, which impact efficiency and safety [28]. Additionally, Rome, known as the city of the seven hills, presents unique challenges for non-electric CBs due to its hilly terrain. However, advancements in e-CB technology are addressing this issue [29].

2.1. Case Studies and Real-World Implementations

Many European cities have piloted CB logistics programs. In Paris, research by Narayanan et al. [30] found that CB micro-hubs improved last-mile efficiency by 30% compared to van-only models. In London, Browne et al. [12] reported that using CBs in the Ultra Low Emission Zone (ULEZ) helped companies meet sustainability goals while maintaining competitive delivery times. Additionally, Copenhagen has been at the forefront of CB adoption, with research by Elesawy [31] highlighting that 40% of last-mile deliveries in the city center are now performed by CBs.

Several case studies highlight successful implementations of CBs in city logistics. Many European cities, including Amsterdam, Copenhagen, and Paris, have integrated CBs into their logistics networks [19]. The EU-funded CycleLogistics project demonstrated the feasibility of shifting up to 25% of urban deliveries to CBs, significantly reducing emissions and congestion [32]. The rise of electric-assisted CBs (e-CBs) has increased CBs' viability in city logistics. Research by Gruber et al. [9] suggests that e-CBs improve the delivery range, speed, and carrying capacity, making them a competitive alternative to motorized vehicles.

Rome presents unique challenges for CB logistics due to its historic infrastructure and limited cycling infrastructure. However, the research by Maltese et al. [33] suggests that integrating CBs in Rome's Limited Traffic Zone (LTZ) could lead to 20% faster deliveries, significant reductions in emissions, and a decrease in noise pollution if adequately supported by policy incentives and infrastructure improvements. Furthermore, the SUMP in Rome [4] suggests that incorporating micro-distribution centers in Rome could further enhance CB feasibility, providing logistical support to overcome distance and payload limitations.

The literature review produced both some preliminary conclusions and identified research gaps. CBs represent a promising solution for sustainable urban freight transport. The main literature gap refers to the limited and detailed real-life comparison between CB benefits over vans in urban logistics. More studies are needed to analyze their long-term economic viability, especially in large-scale logistics networks. Additionally, further research should explore how hybrid solutions combining vans and CBs can optimize urban freight efficiency. For cities like Rome, investigating the integration of CBs with existing policies such as LTZs and micro-consolidation hubs presents a promising avenue for future research. Furthermore, future studies should examine the role of advanced logistics technologies, such as AI-driven route optimization and real-time CB tracking, in improving the operational performance and integration with existing urban mobility networks.

2.2. Additional Literature on the Case of Rome

In this section, we present two recently published studies that are highly relevant to our case study. Both papers focus on the urban freight distribution in Rome and reach conclusions that are consistent with the findings of our research. Their inclusion not only strengthens the empirical basis for supporting cargo bike adoption but also confirms the environmental and operational impacts discussed in our study.

The first article presents an agent-based simulation model applied to assess the effects of introducing cargo bikes and electric vans in last-mile parcel delivery. The study highlights the potential of cargo bikes to reduce the use of motorized vehicles and emissions, although it also underlines operational limitations, such as increased delivery times and challenges with larger parcels [26].

The second article explores the implementation of a hybrid delivery system combining vans and cargo e-bikes to address the dual need for environmentally sustainable and traffic-efficient urban logistics. Focusing on Rome, this study confirms the system's effectiveness in reducing traffic impacts and improving delivery efficiency, particularly when bulky items are involved. The authors emphasize the importance of adapting delivery strategies to different urban constraints and demand profiles [34].

These studies support our argument that cargo bikes, particularly when integrated with complementary logistics systems, can play a significant role in enhancing the sustainability and flexibility of the urban freight distribution.

3. Methodology

This section illustrates the methodology this paper uses, focusing on the case study analyzed.

The process begins with data collection, where real-life operational data from Corro Corrieri Roma (CCR) were gathered through direct collaboration with the company. This included detailed courier shift records over a representative workweek in June 2024, containing objective data on deliveries, times, and package characteristics. Next, the identification of delivery points and CB routes was performed by organizing and reconstructing courier tours, using mapping tools to fill in missing route information and determine start times and distances. The same delivery addresses were then input into a Vehicle Routing Problem (VRP) solver to simulate van routes that could replicate the CB deliveries, considering vehicle load capacities and fixed stop durations. This allowed for a comparative analysis of cargo bikes and vans, focusing on environmental, economic, and social impacts.

Figure 1 illustrates the flowchart of the case study methodology, providing a summary of the process steps.

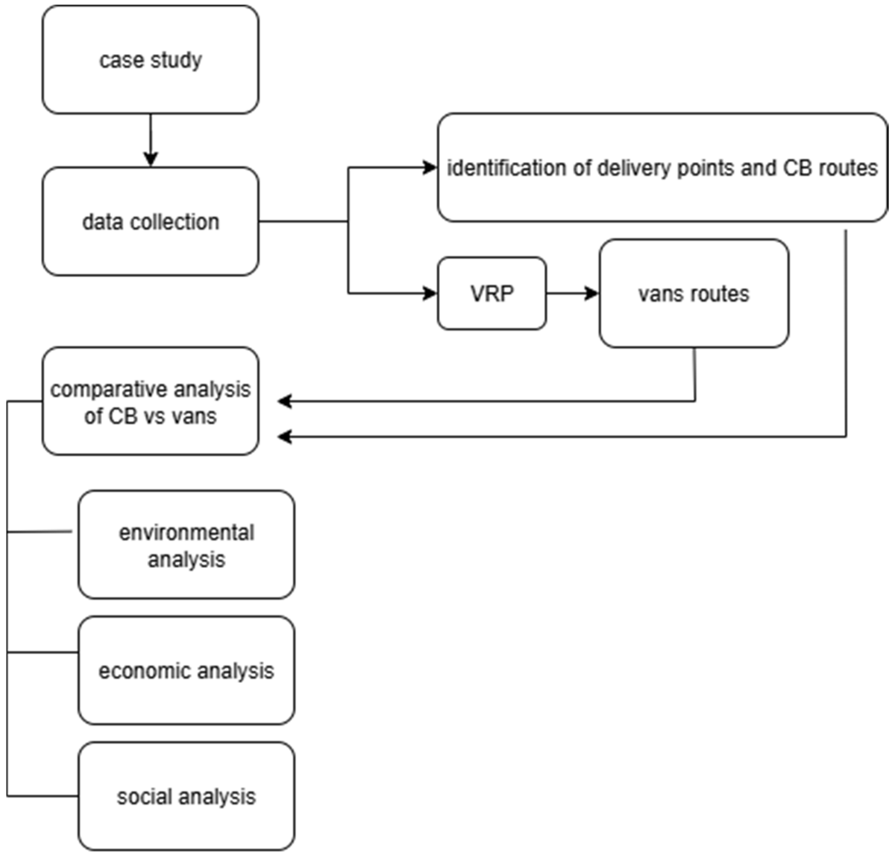

Figure 1. Flowchart of the case study methodology.

3.1. Ideal Research Approach and Operational Constraints

This research focuses on a city center characterized by high population density, significant commercial activity, and well-developed cycling infrastructure. The selected area should have documented freight transport data and a mix of traditional diesel van and CB operations. Factors such as road congestion levels, air quality, and urban logistics policies should also be considered. Additionally, historical data on delivery patterns and urban traffic regulations could be incorporated to provide a comprehensive understanding of the freight ecosystem. To ensure a robust comparison, data should be collected from multiple sources, including vehicle tracking and routing data, delivery efficiency metrics, and environmental and economic data.

In principle one should acquire vehicle tracking and routing data; then, one should define delivery efficiency metrics such as the number of stops per trip. Next, one should obtain environmental and economic data such as fuel consumption and CO_2 emissions from diesel vans. One could also administer surveys and interviews that could be conducted with logistics companies, delivery drivers, and urban planners to gather insights into operational challenges and preferences with the intent of detecting customer satisfaction data. Finally, focus group discussions could be held with business owners to understand the perceived benefits and drawbacks of each delivery method.

While this would be the ideal approach, one has to consider the time and resource constraints that have induced this research group to focus more on comparing the load capacities of CBs and vans, the distances traveled, and the time required to deliver the same number of packages. This study also analyzed the emissions saved by using CBs, based on a simulation of the emissions that would have been produced by vans under similar delivery conditions. Additionally, the operational costs and the overall delivery service costs of both methods were compared to assess their economic feasibility.

In fact, in our case the data available and used include deliveries performed with CBs over one week in the selected area, the maximum load capacity of both CBs and vans, a simulated estimate of the distance and time required for vans to complete the same routes as CBs, and the operational and service costs of both CBs and vans. While we acknowledge the limitations of our approach, at the same time, we would like to underline the high quality of the data used and their realism.

3.2. Study Area Selection

The study area selected encompasses the main districts where CCR delivers using CBs. This area includes the postal codes 00184, 00185, 00186, and 00187, comprising the busiest and most historical neighborhoods. The selection of this zone allows for a focused analysis of last-mile delivery operations in a dense urban environment, where factors such as traffic restrictions, pedestrian areas, and high delivery demand play a crucial role in shaping logistic efficiency and sustainability. Figure 2 reports the area.

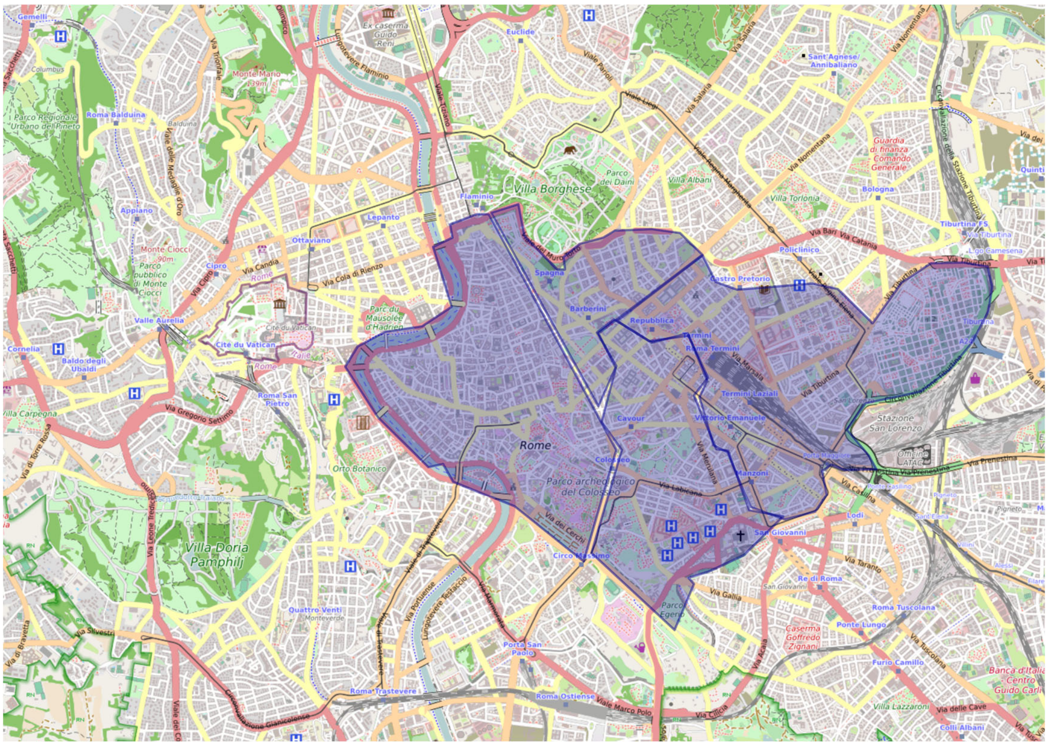

Figure 2. Map of Rome highlighting ZIP codes 00184, 00185, 00186, and 00187 (author's elaboration using uMap, data OpenStreetMap© contributors) [35].

3.3. Data Collection

This paper adopts a comparative analysis of real-life CB tours with "most likely" van alternatives needed to perform the same deliveries. The experimental analysis in Rome uses real-life data on CB deliveries. CCR provided a sample of operational data. A dedicated meeting was organized with the CEO and with the head of the supply chain of CCR. The authors of this paper actively participated in the meeting to determine a commonly accepted data structure to extract from CCR's databases to perform the actual comparison, to determine which data to include, and to establish the key performance indicators to use in this research.

The data based on CCR's internal operational records were shared with the authors directly from the head of the supply chain of CCR. No self-determined or subjective data from CCR was used in the analysis. The dataset provided by CCR included only objective operational data, such as the number of deliveries performed, the corresponding time slots, and the working hours, all recorded by the couriers during their actual work shifts. While the data contained an estimation of the CO_2 saved by the CCR deliveries, the authors calculated them independently using established emission factors and standardized assumptions regarding fuel consumption and vehicle performance.

The analysis considered data for a full workweek, from Monday, 17 June 2024 to Friday, 21 June 2024. The period was selected upon the company's suggestion as being representative of a business-as-usual delivery scenario, without unusual peaks or variations in daily operations.

The investigation refers to the deliveries of a single delivery service, chosen because it was the only service systematically including data on package dimensions (see Table 1). Additionally, courier shifts with fewer than four deliveries in a single day were excluded to avoid underestimating the total number of deliveries compared to the number of CBs used.

Table 1. Example of a simple delivery tour. Source: own calculations.

Pick Up Time	Delivery Time	Address	Weight (kg)	Volume (m^3)
11:42	12:02	00185 Roma, via Merulana 263	11.1	0.02
	12:05	00185 Roma, piazza Capo di Ferro 13	6.2	0.07
	12:09	00185 Roma, via Cavour 6	25.5	0
	12:09	00187 Roma, via di San Claudio 73	0	0
	12:16	00186 Roma, piazza Capo di Ferro 13	6.3	0.07
	12:16	00185 Roma, via Merulana 263	11	0.02
	12:36	00185 Roma, via Merulana 263	11	0.02
	Total time: 1.9 h			

CCR provided two Excel files for each workday to analyze. The first file contained all deliveries made by all couriers on that day. The second file included only deliveries from the selected services. The two files were merged to match the delivery addresses and the excess deliveries; those not belonging to the chosen service were filtered out. The deliveries were then grouped by courier and arranged in chronological order. Below is an example of the final dataset structure, with courier names anonymized for privacy protection.

To estimate the departure time from CCR's headquarters (Via Panfilo Castaldi 7, Rome) to the first delivery address, Google Maps' Directions feature was used, selecting "bicycle" as the mode of transport. Since the company's dataset did not include the headquarters, but only the first delivery, this step was necessary to reconstruct the full delivery tour. By combining this information with the timestamps provided in Corro's delivery files, it was also possible to approximate the overall duration of each courier's shift, indicating the time of the first and last deliveries.

With the obtained data, the total shift duration for each courier was estimated. This method provided a solid basis for evaluating logistical efficiency in terms of time and mileage per load.

Figure 3 shows a map of the city of Rome, reporting the deliveries performed during a single courier's shift of approximately seven hours, from those analyzed, on 19 June.

To compare CBs with commercial vehicles, the delivery addresses serviced by CBs were re-entered into Google Maps to identify the coordinates of the delivery points to input them into the VRP Spreadsheet Solver [36–38], where van routes were simulated considering the maximum load capacity of each van. This enabled the estimation of the total time required, the distance traveled, and the number of trips or vehicles needed to complete the same deliveries performed by the CBs, following the same stop sequence. A fixed stop time of 5 min per delivery was included in the simulation.

Next, the hypothetical emissions of the three most frequently used motor vehicle models were calculated for these deliveries. The vehicle models considered were the ones analyzed in the study by Temporelli et al. [39]: the Nissan e-NV200 (Nissan, Barcellona, Spain), Ford Transit Connect (Ford, Wayne-Louiseville, KY, USA), and Renault Megane plug-in hybrid (Renault, Villamuriel De Cerrato, Spain).

Figure 3. Geolocation of CCR deliveries, 19 June 2024. Source: own elaboration.

To compare the loading capacities of CBs and commercial vehicles, the loading capacity of each vehicle model was retrieved from the official website of the producers (Nissan, Ford, and Renault) to calculate how many CBs would be needed to match the capacity of the commercial vehicles.

The initial investments for CBs and the three commercial vehicle models were retrieved from official websites of the manufacturers (Nissan, Ford, Renault, and Harry vs. Larry) [40–43].

Concerning the operative costs, data on fuel consumption for motorized vehicles were obtained from the official websites of their respective manufacturers (Nissan, Ford, and Renault). Meanwhile, the average fuel prices in Rome for the selected week in June 2024 were retrieved from the Federtrasporto [44] website.

Next, we added more detailed data on fixed costs—retrieved from the Ceccato et al. [45] study, such as insurance and necessary infrastructure (e.g., the distribution center and micro-hub)—and variable costs, such as fuel, tires, maintenance, and labor for delivery and transshipment.

Regarding delivery service costs for customers, CCR's CB delivery rates were compared with the prices of other traditional motorized delivery service providers, such as GLS, Poste Italiane, and Paccofacile, retrieved from the official website of each service [46–49]. The comparison highlights that CBs help lower delivery costs, being economically more convenient than regular commercial vehicles alone [50].

Lastly, for the social impact analysis, we considered qualitative data from the literature.

These include the reduced physical strain experienced by CB couriers compared to traditional cyclists, the weather-related vulnerability associated with courier work, and the greater accessibility to delivery jobs for individuals without a driver's license, which can foster inclusivity and local employment opportunities. The literature also discusses safety-related issues, highlighting a reduction in accidents involving heavy vehicles but also the emergence of new risks for cyclists and pedestrians, which require appropriate infrastructure such as dedicated lanes. Furthermore, the adoption of CBs contributes to the company's public image, reinforcing its commitment to environmental sustainability, technological innovation, improved urban livability, and community-oriented logistics.

4. Comparative Analysis

This section evaluates the relative impacts of CBs and commercial vans from three key perspectives: environmental, economic, and social.

This comparison aims to assess to what extent the adoption of CBs reduces emissions and pollution, lowers costs, and improves social conditions in urban contexts. The analysis provides a comprehensive understanding of the potential benefits and trade-offs between CBs and vans.

The data regarding CBs were provided by CCR, while commercial vehicle data were simulated using Google Maps. The simulation considered an average speed of 21 km/h in central Rome [51].

To calculate the potential of CBs replacing commercial vehicles, the cargo capacity of the CB used by CCR, the "Bullitt" by Larry vs. Harry, (180 kg) was compared with the capacities of the commercial vehicles: Nissan e-NV200 (electric): up to 720 kg; Ford Transit Connect (diesel): up to 903 kg; and Renault Megane plug-in hybrid: up to 528 kg. Figure 4 shows an image of the CB model used by CCR.

Figure 4. CB model used by CCR. Photograph by Giuseppe Nisi. Original Bullitt by Harry vs. Larry [43].

The substitution potential of CBs was estimated to be approximately four CBs to replace one commercial vehicle. However, in the real data examined, an average daily fleet of six CBs was used to deliver around 157 packages per day. It is important to note that these 157 deliveries carried out by six CBs in one day refer to a single delivery service. In reality, each CB was also carrying additional parcels during these routes.

4.1. The CB Deliveries Data and Comparative Analysis

Table 2 reports the analysis of CCR's deliveries using CBs.

Table 2. Summary of delivery data provided by CCR and elaborated by the authors.

Days	Number of Deliveries	Number of CBs Used	Hours of Work	km Traveled	Total Weight of Packages Delivered by the Fleet [kg]
17 June 2024	183	7	33	340	309.4
18 June 2024	126	4	10	93	137.7
19 June 2024	128	5	22	90	141.4
20 June 2024	200	6	21	120	177.9
21 June 2024	137	7	26	117	140.5
Average	154.8	6	22.4	152	181.38

The actual weight transported per CB is likely higher. This is because only one delivery service was considered, and some records did not include package weight data. Errors in data entry or assigning no value to small items, like envelopes, may explain possible discrepancies.

To ensure a more accurate comparison, it was assumed that each CB operated at full capacity (180 kg). Using the VRP Spreadsheet Solver, simulations were conducted to determine the delivery routes that vans with different load capacities (specifically, Ford: 903 kg, Nissan: 720 kg, and Renault: 528 kg) would need to follow. The results of these simulations provided the distances and time required for one or more vans to complete the same number of stops and deliver the same parcels to the same addresses as the CBs (see Table 3). A five-minute stop for every delivery was assumed.

Table 3. Simulated van delivery data. Source: own calculations.

Days	Total Load (kg)	Number of Stops	Average Total Distance Traveled (km)	Average Total Working Time	Number of Trips per Vehicle		
					Ford	Nissan	Renault
17 June 2024	1239	183	81	20:57	2	2	3
18 June 2024	720	126	58.92	14:43	1	1	2
19 June 2024	1460	128	65	15:16	2	3	3
20 June 2024	1056	200	82.65	22:57	2	2	2
21 June 2024	1225	137	67.55	16:22	2	2	3
Average	1140	154.8	71	18:03	1.8	2	2.6

4.2. Environmental Analysis

As many outcome indicators related to traffic impacts [52,53], including the environmental ones [54,55], are a function of vehicle-km, in the first instance, the total distance covered by investigated vehicles has been calculated. Subsequently, the equivalent CO_2 emissions generated by each commercial vehicle model for the delivery routes are calculated as a proxy of the greenhouse gas and pollutant emissions. Emission values per kilometer were retrieved from a study adopting a Life Cycle Assessment (LCA) perspective [39]. Adopting the COPERT methodology [55] allows deriving the following estimations: around 80 g/km of CO_2 for the e-CB, 331 g/km for the diesel Ford Transit Connect, 158 g/km for the electric Nissan e-NV200, and 246 g/km for the hybrid Renault Megane. The values concerning the use phase (tailpipe emissions) are thus available only for the diesel van (Ford Transit Connect), being 234 g/km, and the hybrid van (Renault Megane), being 161 g/km.

The simulated daily average kilometers traveled by motorized vehicles (71 km) were multiplied by the tailpipe emission values, resulting in daily CO_2 emissions: 16,614 g for the Ford and 11,431 g for the Renault. The results show a significant reduction in CO_2 emissions with the use of CBs, which produce no tailpipe emissions.

4.3. Economic Analysis

To assess the economic feasibility of using CBs instead of commercial vehicles in central Rome, this study compares the life cycle costs (LCCs) of both options, following the methodology previously described (see Table 4). The initial investment for the CB used by CCR is EUR 2197, while commercial vehicles cost significantly more: EUR 17,000 for the Ford Transit Connect, EUR 33,500 for the Nissan e-NV200, and EUR 44,000 for the Renault Megane plug-in hybrid. This study considered fixed and variable costs retrieved from Zhang et al. [56], which are the same as those used in Ceccato et al. [45]. Fixed costs include expenses for insurance and infrastructure, such as distribution centers and micro-hubs. Variable costs include fuel, tire wear, vehicle maintenance, and labor costs for delivery operations and cargo handling. The fixed costs calculated in the cited papers are as follows: EUR 48.79 per day for a commercial vehicle and EUR 3.27 per day for a non-electric CB. The variable costs are EUR 0.37 per kilometer for a commercial vehicle and EUR 0.10 per kilometer for a CB. The labor cost is considered to be EUR 22.60 per hour for a commercial vehicle and EUR 12 per hour for a CB, based on CCR inputs. The average daily working hours for CBs in CCR's data are 22 h. Given the labor cost of EUR 12 per hour, the total daily labor cost for the couriers amounts to EUR 264 (22 h × 12 EUR/h). The fixed cost per CB is EUR 3.27 per day, and since the fleet consists of six CBs, the total fixed cost per day is EUR 19.62 (EUR 3.27 × 6 CBs). The variable cost is EUR 0.10 per kilometer, and with an average daily distance of 152 km covered by the fleet, the total variable cost per day is EUR 15.20 (EUR 0.10 × 152 km). Summing up the fixed and variable costs, the total operational cost of the fleet per day is EUR 34.82 (EUR 19.62 + EUR 15.20). Adding the EUR 264 labor cost, the total daily cost for operating a fleet of six cargo bikes in Rome amounts to EUR 298.82.

Table 4. Estimated costs of CBs and vans. Cost calculations performed by the authors based on input data from Zhang et al. [56].

	CB	**Van**
Fixed costs/day (per vehicle)	EUR 48.79	EUR 3.27
Variable costs (distance)/km	EUR 0.37	EUR 0.10
Variable costs (labor)/hour	EUR 22.60	EUR 12
Total operative cost:	152 km, 22 h, 6 vehicles EUR 298.82	71 km, 18 h, 2 vehicles EUR 530.65

For the commercial vehicle, the labor cost is EUR 22.60 per hour, and with an average of 18 working hours per day, the total labor cost is EUR 406.80 (EUR 22.60 × 18 h). The fixed cost per day for a commercial vehicle is EUR 48.79, and the variable cost is EUR 0.37 per kilometer. With an average daily distance of 71 km, the total variable cost is EUR 26.27 (EUR 0.37 × 71 km). Since the van operates for 18 h per day, it would require on average two separate vehicles, each driven by a different worker, to cover the full working period. This means that the fixed cost of EUR 48.79 per day, which is calculated per vehicle, should be doubled to account for the need for two vans. Therefore, the total fixed cost per day amounts to EUR 97.58 (EUR 48.79 × 2). With this adjustment, the total operational cost of the commercial vehicle per day, summing the EUR 97.58 fixed cost and the EUR 26.27 variable cost, is EUR 123.85. Including the EUR 406.80 labor cost, the total daily cost for operating commercial vehicles rises to EUR 530.65.

In the specific context of central Rome, it is important to consider the regulations for accessing the LTZs for freight vehicles. Commercial vehicles operating within the LTZ can park in designated loading and unloading areas for up to 30 min. Access times depend on the vehicle's technical characteristics (weight, fuel type, emission category) and the type of goods being transported. Restrictions vary, with some vehicles prohibited from entering during certain hours, while others, such as electric and hybrid vehicles, face fewer restrictions. The permit cost is based on the vehicle's emission class, with lower fees for less polluting vehicles. For example, Euro 4 vehicles pay EUR 2032 annually, Euro 5 vehicles pay EUR 1452, and Euro 6 vehicles pay EUR 1152, while hybrid vehicles pay EUR 392, and electric vehicles are exempt [57].

Finally, this paper compares, for similar delivery tasks, CB rates and vans rates.

CCR divides Rome into four main areas: Zone A (central), Zone B (inner suburbs), Zone C (near the GRA, the ring road surrounding the city), and Zone D (within 5 km of the GRA). The rates vary by the pickup or delivery distance and the type of service requested. Main services include the following: Espressa (max 10 kg, guaranteed in 3 h), Superveloce (max 10 kg, guaranteed in 1 h), Cargo (max 100 kg, guaranteed in 3 h), and

Multipla (10 deliveries with 1 pickup, guaranteed in 24 h). Prices, excluding VAT, start at EUR 8 for Zone A and rise to EUR 32 for Zone D, with particularly competitive rates in Zones A and B. Figure 5 represents a map of the zone division operated by CCR.

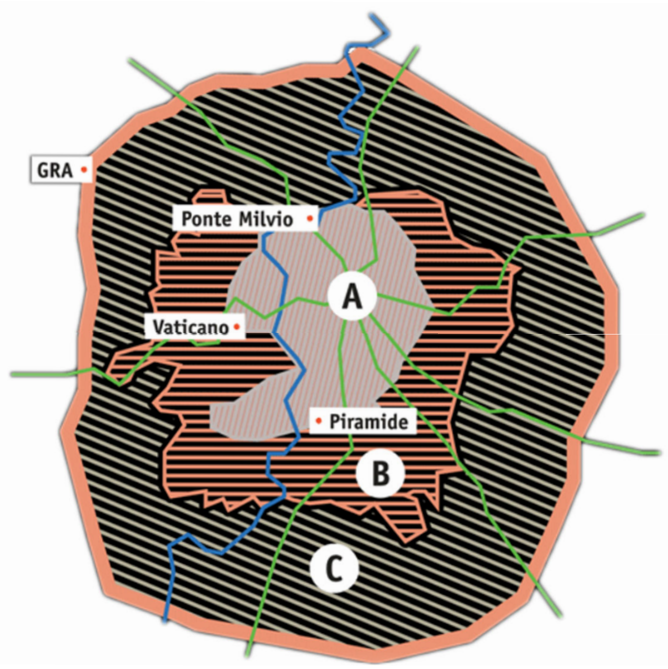

Figure 5. Price zones for CCR deliveries. Source: CCR website [46].

For national shipments using traditional vehicles, GLS charges between EUR 15 and EUR 46, depending on the package size and weight, while more affordable alternatives are Poste Italiane (starting from EUR 5.90) and Paccofacile (starting from EUR 4.17). Thus, CBs cost less than commercial vehicles for last-mile deliveries in central urban areas, but customers pay higher delivery fees for the service (see Table 5).

Table 5. CB and van operative costs and delivery prices. Source: own calculations.

<table>
<tr><th>Category</th><th colspan="5">CB</th><th colspan="5">Commercial Vehicles</th></tr>
<tr><td rowspan="2">Investment Cost [EUR]</td><td colspan="5" rowspan="2">2197 (for one CB used by CCR)</td><td colspan="2">Ford Transit Connect</td><td colspan="2">Nissan e-NV200</td><td>Renault Megane plug-in hybrid</td></tr>
<tr><td colspan="2">17,000</td><td colspan="2">35,500</td><td>44,000</td></tr>
<tr><td>Fixed Cost [EUR] per vehicle</td><td colspan="5">3.2/day</td><td colspan="5">48.79/day</td></tr>
<tr><td>Variable km Cost [EUR]</td><td colspan="5">0.10/km</td><td colspan="5">0.37/km</td></tr>
<tr><td>Hour Labor Cost [EUR]</td><td colspan="5">12.0/h</td><td colspan="5">22.6/h</td></tr>
<tr><td>Daily Labor Cost [EUR]</td><td colspan="5">264.0</td><td colspan="5">406.8</td></tr>
<tr><td>Total Daily Cost [EUR]</td><td colspan="5">298.8 (fleet of 6 CBs)</td><td colspan="5">530.6 (2 vehicles)</td></tr>
<tr><td rowspan="2">LTZ Permit Costs [EUR/year]</td><td colspan="5" rowspan="2">Not applicable</td><td>Euro 4 vehicles</td><td>Euro 5 vehicles</td><td>Euro 6 vehicles</td><td>hybrid vehicles</td><td>electric vehicles</td></tr>
<tr><td>2032 EUR/year</td><td>1452 EUR/year</td><td>1152 EUR/year</td><td>392 EUR/year</td><td>exempt</td></tr>
<tr><td rowspan="5">Delivery Rates [EUR]</td><td>CCR</td><td>E</td><td>S</td><td>C</td><td>M</td><td colspan="2">GLS</td><td colspan="2">Poste Italiane</td><td>Paccofacile</td></tr>
<tr><td>Zone A</td><td>8</td><td>16</td><td>16</td><td>8</td><td colspan="2" rowspan="4">15 ÷ 46 EUR (package size and weight)</td><td colspan="2" rowspan="4">From EUR 5.90</td><td rowspan="4">From EUR 4.17</td></tr>
<tr><td>Zone B</td><td>16</td><td>24</td><td>24</td><td>8</td></tr>
<tr><td>Zone C</td><td>24</td><td>32</td><td>32</td><td>8</td></tr>
<tr><td>Zone D</td><td>32</td><td>/</td><td>/</td><td>/</td></tr>
</table>

4.4. Social Analysis

The adoption of CBs in urban logistics offers significant social benefits. As a form of active mobility, CBs enhance couriers' physical and psychological well-being [58], reduce urban noise and air pollution, and improve road safety, particularly for vulnerable users like pedestrians. They are especially effective in congested city centers and can reach areas which are not usually served by traditional services [59].

CBs also promote social inclusion and create accessible job opportunities, requiring only basic skills like cycling and a knowledge of local streets. This makes employment in CB delivery more inclusive, particularly for young people, students, unemployed people, and those facing barriers to other types of work [60].

Additionally, the reduction in air and noise pollution improves public health and quality of life, benefiting vulnerable populations such as children, the elderly, and individuals with respiratory issues, while also lowering healthcare costs [6,61]. To maximize these benefits, cities must prioritize human-centered urban planning, expand cycling infrastructure, and foster environments that support sustainable, healthy, and inclusive mobility solutions.

4.5. Overall Evaluation

Summing up, the main results from the comparison between the performance of CBs and commercial vehicles delivering the same packages to the same addresses are as follows:

- Distance traveled—CBs traveled a greater distance than the commercial vehicles (71 km vs. 152 km).
- Working hours—CBs recorded more hours worked (22 h) compared to the commercial vehicle (18 h).
- Emissions—CCR's CBs have no electric assistance and produce zero tailpipe emissions, while commercial vehicles generate about 14 kg of CO_2 equivalents per vehicle daily.
- Cost—the company's average daily cost is lower with CBs (around EUR 298.82) compared to the commercial vehicles required to complete the same service (EUR 530.65, assuming two commercial vehicles to replace six CBs).
- Social benefits—CBs increased physical and psychological well-being, safety, social inclusion, and overall quality of life in urban contexts and decreased traffic externalities, noise, and healthcare costs.

Table 6 summarizes the environmental, economic, and social comparison between CBs and commercial vehicles.

Table 6. Environmental, economic, and social comparison. Source: own elaboration.

		CBs	**Vans**		
Environmental	Daily CO_2 emissions	/	Ford	Nissan	Renault
			16,614 g	/	11,431 g
Economic	Delivery prices	from EUR 8	from EUR 4.17		
	Average daily operative costs	EUR 298.82 for 6 CBs	EUR 530.65 for 2 vehicles		
Social		physical and psychological well-being	physical and psychological stress in urban context		
		noise reduction	noise pollution		
		air pollution reduction	air pollution		
		improved road safety	congestion and risk of accidents		
		social inclusion and accessible jobs			
		increased public health and lower healthcare costs			
		increased quality of life			

CBs proved to be more sustainable, cost-effective, and socially beneficial than commercial vehicles in terms of emissions and operational costs. However, service rates for customers are currently higher (EUR 8 for CB deliveries compared to around EUR 4 for the lowest-priced competitor), likely due to the recent adoption of this vehicle. In the long term, with increased use and infrastructure improvements, costs may decrease, encouraging a wider adoption of CBs.

5. Discussion and Conclusions

This research highlights that CBs offer a viable and sustainable alternative for last-mile deliveries, effectively reducing urban traffic congestion and pollutant emissions. Their integration into logistics networks generates significant social benefits contributing to cleaner, healthier, and safer urban environments, while also promoting the well-being of delivery workers and improving road safety for all. Indeed, the literature emphasizes some considerations for courier work, such as reduced physical strain, improved inclusivity, and the potential for local employment, which were reflected in our field observations and company feedback. Similarly, safety concerns identified in academic studies, such as the need for dedicated infrastructure and the emergence of new risks, were mirrored by the practical challenges reported by couriers operating in mixed-traffic urban environments.

From an economic perspective, CBs provide clear advantages for businesses, primarily through lower operating costs associated with maintenance, fuel, and fleet management. However, for end customers, delivery services using CBs remain relatively more expensive than those relying on motorized vehicles. This cost gap is mainly due to CBs' lower load capacity and the higher labor intensity required for their operation.

To accelerate the transition toward sustainable urban logistics, a strategic and coordinated approach is essential. Public incentives must support the widespread adoption of CBs, making them a financially competitive choice for both businesses and consumers. Strengthening collaboration between public and private stakeholders can drive the expansion of cycling infrastructure, ensuring CBs are fully integrated into existing transport systems.

Beyond infrastructure, raising awareness is key. Targeted campaigns can help businesses and the public recognize CBs as an efficient and eco-friendly alternative to traditional delivery methods. Meanwhile, continued investment in research and innovation will be crucial for optimizing logistics models, improving operational efficiency, and ensuring a seamless CB integration into urban mobility frameworks.

By tackling these challenges, CBs can become a cornerstone of modern urban logistics, significantly reducing environmental impacts while enhancing the quality of life in cities. This shift marks a decisive step toward a more sustainable, efficient, and forward-thinking approach to urban mobility.

5.1. Policy Implications

To promote the widespread use of CBs for urban deliveries, a series of interventions could be implemented. For instance, a study conducted in London highlights how current policies, primarily focused on electric vehicles and emission restrictions, are insufficient to mitigate the impact of the increasing number of vehicles [62]. An effective approach includes investments in infrastructure for cargo bikes, the creation of "Clean Air Zones", and the introduction of taxes to discourage the use of commercial vehicles. Additionally, the specific regulation of working conditions and safety for those operating CBs is needed.

The configuration of the distribution network is another aspect on which policy implementations are critical. Several models have been studied, including urban consolidation centers or micro-hubs, where goods are transferred from commercial vehicles to cargo bikes [5]. Various approaches exist, ranging from the creation of mobile transit points to the use of fixed depots or the combination of intermodal transport with trains and buses. One must consider that the fleet composition can be mixed. For instance, CBs can be dedicated to time-sensitive deliveries and other vehicles can be used for the remainder of the deliveries. With the use of specific algorithms, it is possible to optimize the use of many transport modes, reducing both costs and emissions. It must be considered, though, that synchronizing vehicles tends to be more expensive than a less complex system. Finally, the efficiency of delivery systems is also influenced by the urban configuration and motorized vehicle access policies. Parking restrictions and limits on access to city centers can promote the shift to CBs.

In Italy, interest in cycle logistics is growing, driven by incentives and new infrastructure supporting the transition to more sustainable transport models. In Rome, the SUMP has already begun incorporating measures that favor cycling, leading to tangible progress in integrating cargo bikes into the urban transport system. The SUMP aligns with the National Plan for Sustainable Mobility goals for 2030, which include the following:

- a 20% increase in bicycle trips;
- a minimum of 32 km of bike lanes per 100 km^2;
- bike lanes near schools and universities;
- bicycle parking at all public buildings and railway stations;
- at least 25% of public transport vehicles equipped with bike spaces.

These policies not only help reduce traffic congestion and emissions but also improve the efficiency of urban delivery systems.

The SUMP designs the urban transport system to: (1) to ensure that all citizens have accessible and efficient transport options to reach key destinations and services; (2) enhance safety conditions; (3) reduce air and noise pollution; (4) lower GHG emissions and energy consumption; (5) improve the efficiency and cost-effectiveness of passenger and freight transport; (6) contribute to the city's attractiveness and overall urban quality. CBs directly address these challenges, providing a sustainable solution that aligns with the SUMP's objectives, which foresees, among others, the creation of more bicycle parking spaces, financial incentives to encourage greater bicycle use, and the development of intermodality between bicycles and public transport [4]. By continuing to strengthen its commitment to cycling infrastructure, Rome can further establish itself as a leader in sustainable urban logistics, ensuring cleaner, more efficient, and more accessible transport solutions for its citizens.

5.2. Theoretical and Practical Implications

This research, being a case study, does not aim to develop a new theory; however, the authors believe it contributes to the growing literature on sustainable urban logistics by providing empirical evidence supporting the potential of CBs to replace traditional motorized delivery vehicles.

Regarding the practical implications, this research highlights how CBs can be integrated into existing logistics networks to offer more sustainable and cost-effective solutions. Businesses in the logistics and delivery sectors can apply these findings to assess the feasibility of adopting CBs in urban areas, potentially lowering their operational costs, improving environmental performance, and enhancing social outcomes for delivery workers. Considering this, the main stakeholders include companies that could adopt cargo bikes, policymakers responsible for urban transport regulations, and all road users who benefit from safer and greener urban mobility.

5.3. Limitations

It is important to highlight that the simulated routes for vans were based on the actual delivery order followed by CBs, meaning that they were not specifically optimized for motorized vehicles. Moreover, although CBs typically follow optimized routes, real-world operations often introduce deviations—for instance, the need to return to the same address due to the recipient's absence or other unforeseen events, which may affect the overall efficiency.

Another limitation concerns the dataset used: the actual CB data only includes parcels from a specific delivery service, selected because detailed information on package dimensions and weight was available. While this choice ensures the reliability of the input data, it does not fully capture the total volume of deliveries carried out by the company. To mitigate the risk of underestimating cargo capacity, the maximum load capacity of the CBs was considered. Consequently, although the number of parcels analyzed is lower than in reality, it was assumed that individual packages were heavier, thus providing a conservative estimate.

The authors believe that these gaps are not necessarily a drawback but rather a reflection of the real-world challenges couriers face every day.

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Abbreviations

The following abbreviations are used in this manuscript:

CB	Cargo Bike
e-CB	Electric Bargo Bike
CCR	Corro Corrieri Roma
GHG	Greenhouse Gas
LTZ	Limited Traffic Zone
SUMP	Sustainable Urban Mobility Plan

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