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Evaluating Cargo Bike Delivery Applications in Urban Logistics: The Case of Zagreb

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Abstract

This study examines cargo bikes as a sustainable alternative for urban deliveries in Zagreb by comparing two delivery models: a conventional van-only system and a two-stage model in which cargo bikes operate from a city micro-hub. The analysis is based on GIS-based network simulations using OpenRouteService routing algorithms, integrating spatial data on 21 GLS parcel locker locations. Emissions were calculated using standard CO_2 factors for diesel vehicles, and operational time was derived by combining travel duration and estimated stop times. Results show that the two-stage model reduces CO_2 emissions by around 40% and decreases operational time by 23.5 minutes per delivery cycle. When scaled citywide, the approach could deliver substantial annual emission savings. The findings align with European and international case studies, reinforcing cargo bikes as a practical solution for low-emission urban logistics.

Keywords: cargo bike; parcel delivery; urban delivery; sustainable transport

1. Introduction

This paper explores the role of cargo bikes as a sustainable solution for last-mile urban deliveries, focusing on their potential in Zagreb, Croatia. Robichet et al. (2022) state that, as e-commerce continues to grow, so does the demand for efficient and sustainable CEP logistics. According to the paper delivered by the European Environment Agency (2020) traditional delivery vehicles, especially diesel-powered vans, significantly contribute to urban air pollution, noise, and congestion. Recognizing these externalities, the European Green Deal aims for zero-emission transport by 2050, with all new vehicles to be zero-emission by 2035. The European's Commission (2021) Urban Mobility Framework and Croatia's National Cycling Development Plan (2023–2027) adopted by the Ministry of the Sea,

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Transport and Infrastructure (2023) further support low-emission city logistics and promote cargo bike use for urban goods transport. In their study, Lebeau et al. (2015) found out that urban freight transport is responsible for 10–15% of vehicle-kilometres but contributes to around 25% of CO_2 and 50% of particulate emissions. Ormond Jr et al. (2019) suggest that 25–51% of motorized freight trips in European cities could shift to bikes, offering reductions in emissions and traffic pressure while reclaiming public space. As reported by Eurosender (2025) the rise in parcel delivery, particularly in the express segment which expanded 91% between 2017 and 2021, further amplifies the need for efficient and sustainable solutions. Against this backdrop, the key objective of this study is to assess the economic and environmental viability of cargo bikes within the broader context of sustainable urban mobility. The article will help illuminate the operational opportunities and barriers associated with cargo bike implementation, offering practical insights for integrating them into urban logistics systems.

2. Cargo Bikes in Urban Logistics: Design, Infrastructure, and Impact

Bogdanski et al. (2021) claim that three-wheeled cargo bikes are preferred in urban logistics due to their greater static stability, especially at low speeds. Among three-wheeled options, those with the cargo box positioned behind the rider are favoured. This design ensures better weight distribution, unobstructed visibility, and improved handling. Given their urban use and payloads, cargo bikes should be battery-powered to support efficiency and reduce rider fatigue. However, wider vehicles like tricycles or quadricycles often require dedicated infrastructure adaptations, including wider cycle lanes, adjusted curb radii, and sufficient turning space, especially in historical urban cores. If the cargo space is placed in front of the rider, such as in the "Long John" variant, Kessler et al. (2023) argue that problems may arise at signalized intersections when the cyclist must roll onto the road to reach the signal button, posing a safety hazard. Safety-focused studies specifically targeting cargo bikes remain limited, while legislation varies across countries. Cycling Industries Europe (2023) report that Belgium initially restricted trailers wider than one meter, rendering popular models like the 113 cm wide BicyLift illegal until regulations were updated to allow widths up to 1.2 meters. In Germany, the Radlogistik Verband Deutschland e.V. (2023) recommends cargo bikes use road lanes rather than cycle paths or sidewalks to protect vulnerable road users. In Croatia, the Road Traffic Safety Act (2024) does not yet formally recognize cargo bikes, creating legal ambiguity. Regarding infrastructure, Liu et al. (2020) found that cargo bike operators prefer broader lanes, such as those used by public transit, for easier manoeuvrability and fewer conflicts with other users. Sarkies et al. (2022) explain that commercial bike couriers are particularly vulnerable; often younger, non-native speakers, and disproportionately involved in nighttime traffic accidents. In China, over 76% of e-bike couriers have experienced at least one crash, with speeding, lane misuse, and phone usage being common infractions. These findings by Wang et al. (2021) highlight the need for targeted safety interventions and improved data collection in hospitals to track delivery-related injuries. European Environment Agency, (2020) and Lebeau et al., (2015) identified the first, last and only mile stages as the most suitable domain for cargo bike integration, to which they refer to as “F/L/O mile stages”. These stages typically involve short distances and small package volumes. For a cargo bike to be economically viable in the CEP sector, it must complete around 100 deliveries per workday. This requires a load capacity of 200 kg and a cargo volume of 1.5 m^3, ideally using an electric-assist bike with two parallel wheels for enhanced stability (tricycle), as claimed by Bogdanski et al. (2021). Parcels are pre-sorted by destination area, further streamlining the process.

2.1. Advantages of Cargo Bikes

Incorporating cargo bikes into the F/L/O mile stages offers a range of benefits. Environmentally, they significantly reduce CO_2 and pollutant emissions and require less energy. McLeod et al. (2020) furtherly suggests that modern electric cargo bikes can transport 50 to 250 kg over a range of 80 km on a single charge, meaning that 25% to 50% of current freight traffic entering urban centres could shift from motor vehicles to cargo bikes, especially when operated from dedicated cycling terminals or micro-consolidation centres. Bogdanski et al. (2021) state the lighter bicycle construction and lower speeds contribute to reduced noise and vibration in urban areas. Additionally, their manoeuvrability and low operating costs, especially in electric variants, make cargo bikes a sustainable and practical alternative to conventional delivery vans. Compact dimensions enhance space efficiency, allowing for better use of public areas and potentially freeing up space for pedestrians European Environment Agency (2020). In terms of traffic safety, lower mass and speed reduce kinetic energy, decreasing the severity of potential accidents, states Lebeau et al. (2015).

2.2. Infrastructure Adaptations for Cargo Bike Use

To support cargo bike adoption, cities must adjust their infrastructure. Liu et al. (2020) suggests that wider lanes, like those used by public transport, are preferred for better handling. Kessler et al. (2023) suggest that adjustments to traffic signal buttons may be necessary: with long cargo bikes (e.g., "butcher's bikes"), cyclists may need to extend into the road to activate pedestrian lights, creating safety hazards. Furthermore, resizing and repurposing vehicle delivery bays can also support the transition. Reallocating excess space to sidewalks or bike parking enhances urban accessibility and supports sustainable mobility goals, state Oosten et al. (2023). A detailed infrastructure audit of Zagreb was not within the scope of this study but should be conducted in future research to assess readiness for cargo bike integration.

2.3. Reducing CO_2 emissions and improving air quality

Electric cargo bikes, when paired with micro-hubs, have demonstrated substantial environmental benefits. McLeod et al. (2020) found that, in London and Milan, such delivery setups reduced CO_2 emissions per package by 55% and 73%, respectively, compared to diesel vans. A pilot project across 20 European cities, involving 78 electric bikes operated by 40 organizations, resulted in estimated fuel savings of 8.5 million litres and CO_2 reductions of 21,000 tons, assuming a 10% market share for cargo bike couriers in the Netherlands. Ormond Jr et al. (2019) further state that, in São Paulo, the replacement of diesel trucks with electric cargo bikes or tricycles led to operational savings of up to 31% and an annual CO_2 reduction of approximately 20 tons, cutting total emissions by more than 97%.

2.4. Implementation and operational costs

Research conducted by Bogdanski et al. (2021) and Paudel and Yap (2024) shows that, despite their many advantages, cargo bikes face durability challenges that can lead to frequent breakdowns and increased operational costs, while courier injuries may further disrupt services. Robichet et al. (2022) assert that infrastructure investments, such as establishing micro-hubs, are also significant and must be justified by achieving high delivery density, especially given the high rental costs of urban micro-depots.

However, cargo bikes offer notable delivery efficiency and time savings. In a review of 30 courier services across Europe, McLeod et al. (2020) found that cargo bikes average 16 km/h, often faster than vans in congested zones like central London, where average vehicle speeds were 13 km/h in 2018 and significantly reduce parking delays. In Turin, delivery times per stop fell from 4-5 minutes with vans to 2-2.5 minutes with bikes. Similarly, in London, GPS data showed average delivery times of 3 minutes per stop for cyclists and pedestrians, compared to 5 minutes for van drivers.

2.5. Good practice examples

In Innsbruck, Austria, a two-tier logistics model using diesel vans to a city hub and cargo bikes for last-mile delivery reduced CO_2 emissions by up to 96% (70 tons annually) and cut daily distribution costs by up to €695; in Büttgen et al. (2021) research, even conservative scenarios showed €110 in daily savings. Delivering 4,000 packages required 23 cargo bikes and five electric vans, with efficiency gains from increased bike capacity and shorter restocking times. In Maastricht, Netherlands, a 2017 subsidy helped four businesses switch from vans to cargo bikes, cutting delivery distances by 20%, avoiding 5,720 km of vehicle travel, and reducing CO_2 by 1.15 tons, with two businesses retiring their vans entirely, as observed by Cairns and Sloman (2019). Hleb (2022) observed a similar shift in Zagreb, where DPD operates the city's only active micro-logistics service using electric cargo tricycles. This study builds on that example by evaluating potential delivery optimizations using spatial simulations of parcel locker coverage.

3. Methodology

This chapter describes the methodology employed to assess average CO_2 pollution quantities emitted during a typical parcel delivery to selected parcel lockers and saving that may be achieved by employing a two-stage cargo bicycle delivery. Analysis began with the assessment of parcel locker configurations, followed by cargo bike capacity evaluation, fill efficiency modelling, estimation of energy consumption, and concluding with spatial delivery route simulations within the urban context of Zagreb. As defined in the "Limitations" chapter, fill efficiency is one of the limitations of this study. Fill efficiency refers to the proportion of available space or volume that is effectively utilized in a container, vehicle, or storage unit. It is typically expressed as a percentage and represents the internal volume (or weight), up to which a container is loaded.

Common-carrier parcel lockers represent an increasingly viable solution for reducing delivery times, traffic congestion, and emissions in dense urban areas by enabling the consolidation of deliveries. These systems allow multiple couriers to drop off parcels in centralized, secure locations, reducing the need for repeated last mile stops. The modular nature of these lockers means that every unit can be customized to meet specific spatial or demographic demands, making it difficult to define a universally optimal configuration.

To address this challenge, the first step of the methodology included an analysis of a variety of locker compositions, from academic literature to official sites BoxNow (2022) and GLS (2024) and through direct field observation. Consulting academic literature, it was concluded that the most efficient layout involves a greater share of medium-sized compartments, followed by small and large compartments. This arrangement is favoured because small parcels can be placed in medium compartments, but not vice versa, providing flexibility in locker allocation. On the other hand, studies show that customers typically order more small packages, which reinforces the need for a flexible compartment configuration capable of adapting to real-world usage. Supporting this, Ranjbari et al. (2023) found that, on average, 47% of packages are small, 38% are medium, and 15% are large. According to official parcel delivery sites, most locker compartments are being sized as extra-small, small, medium, large and extra-large. Table 1 contains exact compartment measures, shown as HxWxL in cm per specific carrier, which operate in Croatia. Additionally, maximum package weights are also provided in the table.

Table 1. Locker compartment sizes per delivery service

Size	**Croatian Post**	**GLS**	**BoxNow**	**DPD**
XS	9 × 16 × 64	8,5 x 19 x 61	N/A	8 × 16 × 61
S	9 × 38 × 64	8,5 x 44 x 61	8 × 45 × 60	8 × 43 × 61
M	19 × 38 × 64	18 x 44 x 61	17 × 45 × 60	17 × 43 × 61
L	39 × 38 × 64	37 x 44 x 61	36 × 45 × 60	36 × 43 × 61
XL	N/A	75 x 44 x 61	N/A	N/A
Max. Weight	**10 kg**	**40 kg**	**20 kg**	**20 kg**

The next step in performing parcel delivery simulations is selecting the cargo bicycle as a representative vehicle. The EcoCargo XL model from MaxPRO Mobility (2024) is widely used by European courier companies. The manufacturer provided two cargo container size specifications: the GLS version, which measures 1450 × 690 × 1500 mm, and the DPD version, which measures 1250 × 690 × 1120 mm. Based on these dimensions, the corresponding internal cargo volumes are approximately 1.5 m^3 and 0.97 m^3, respectively. For modelling purposes, the larger configuration was selected as the reference value since 1.5 m^3 of cargo volume is recommended by Bogdanski et al. (2021) in academic literature, combined with a fill efficiency of 85%, since the proposed fill rate falls on the conservative end of the industry standard goals, as reported by MECALUX (2025). The cargo volume, combined with the fill rate yields an effective usable volume of 1.275 m^3. Table 2 contains average single parcel volume estimates derived from various distribution scenarios combining small, medium, and large parcel shares. For each configuration, the weighted average parcel volume was calculated using representative locker dimensions present in Table 1. For each category, the internal locker volume was computed as the product of internal height, width, and depth. Based on a usable cargo volume of 1.275 m^3, the table also estimates the maximum number of parcels that can be carried per delivery trip under each scenario, as shown in Table 2. Delivery companies, such as DPD Belgium (2021), typically cite delivery capacities between 30 and 60 parcels per bicycle, depending on parcel and cargo compartment size. For the simulation, an average of 29 parcels per trip was adopted, representing a compromise between theoretical volume-based estimates and field-reported operational capacities, as reported by as DPD Belgium (2021). This specific value was selected because, while it lies slightly below the lower bound of industry-reported ranges, it is well-supported by empirical data found in relevant studies. This discrepancy may be attributed to the use of a different cargo space fill factor than the one applied in the referenced study, which can significantly influence the estimated number of parcels per trip.

Table 2. Parcel volume average estimates

Model / Source	Small %	Medium %	Large %	Avg. Volume (m³)	Parcels per Bike Trip (1.275 m³)
Initial Estimate #1	60%	30%	10%	0.03811	33
Initial Estimate #2	50%	30%	20%	0.04576	28
Study (SAGE - parcels)	47%	38%	15%	0.04398	29
Study (SAGE - lockers)	34.5%	50.9%	14.5%	0.04686	27
Observed – Small	47.6%	33.3%	19.0%	0.04582	28
Observed – Medium	41.7%	37.5%	20.8%	0.04829	26
Observed – Large	39.0%	40.0%	21.0%	0.04908	26

As advertised by MaxPRO Mobility (2024), the EcoCargo XL electric cargo bicycle is equipped with a 1,400 Wh swappable battery and a 250W motor, offering a practical range of 40 to 100 kilometres per charge, depending on load and assist level. We can approximate the energy consumption per kilometre (1):

$$Energy\ consumption\ \left(\frac{Wh}{km}\right) = \frac{Battery\ capacity\ (Wh)}{Range\ (km)}. \qquad (1)$$

Applying this formula:

- For the worst-case scenario (2) (full load, high assist, short range of 40 km):

$$\frac{1{,}400\ (Wh)}{40\ (km)} = 35\ Wh/km. \qquad (2)$$

- For the best-case scenario (3) (light load, eco-mode, 100 km range):

$$\frac{1{,}400\ (Wh)}{100\ (km)} = 14\ Wh/km. \qquad (3)$$

Averaging the values for the worst-case and best-case scenarios, a midpoint of 25 Wh/km was selected. This level of efficiency, combined with quick battery swap capability, ensures reliable daily operation with minimal downtime and near-zero emissions.

To evaluate the efficiency and environmental benefits of cargo bicycle integration in urban delivery logistics, two primary delivery models were simulated using spatial data and routing tools in QGIS. The final step of the methodology consisted of the spatial analysis. In his work, Hleb (2022) reported an existing parcel delivery hub near Zagreb city centre, which was selected as a central routing point for bicycle delivered parcels. To define the spatial scope of the delivery simulation, a circular buffer was generated around the designated city micro-hub using GIS tools. The buffer size was incrementally adjusted until it encompassed exactly 21 GLS parcel locker locations within the Zagreb city centre, as it represented roughly 10% of all GLS parcel locks in Zagreb. A 10% sample size enables scalable extrapolation, simplifying the calculation of net savings at the network level. These lockers formed the delivery targets for both the classic van-based and the two-stage delivery scenarios. The routing simulations were conducted using the OpenRouteService (ORS) Tools plugin within QGIS. For route generation, the Travelling Salesman Problem (TSP) algorithm was applied in conjunction with the shortest path routing option to produce efficient delivery routes that minimized travel distance and time while visiting all selected locker points from a common start location. The TSP approach was chosen as it mirrors the operational goal of minimizing travel distance in parcel delivery, where drivers or couriers often aim to complete a sequence of drop-offs using the most efficient route. Although real-world routing may include additional constraints (e.g., time windows, traffic conditions, or vehicle capacities), the TSP provides a robust approximation of route efficiency in static delivery scenarios, especially for comparative analysis of vehicle types under controlled conditions. This ensures a consistent and replicable baseline for evaluating the spatial and environmental performance of alternative delivery strategies.

4. Results

This study evaluated the performance of cargo bike-based urban delivery using 21 GLS parcel locker locations in Zagreb, which represent approximately 10% of the parcel lockers operated by a single courier company, GLS, within the city. Two scenarios were compared in order to assess the impact of the deployment of a cargo bike system by the selected courier.

4.1. Scenario A: classic delivery (van-only model)

In the traditional van-only delivery scenario, the route from the GLS regional hub in Donji Stupnik to 21 locker locations across Zagreb city centre covered a total of 44.13 kilometres. Driving duration was approximately 1 hour and 37 minutes, and with a stop time of 5 minutes per delivery point, the total operational time reached 3 hours and 22 minutes. Based on an average diesel van emission factor of 180.8 g CO_2 per kilometre, the journey resulted in approximately 7.98 kg of CO_2 emissions, highlighting a significantly higher environmental footprint compared to the bicycle delivery model.

4.2. Scenario B: two-stage delivery (van + cargo bicycle model)

In the two-stage delivery model, a van travelled a round trip of 26.6 km between the GLS depot in Donji Stupnik and a city micro-hub. The second stage was performed by a cargo bicycle, which covered 20.930 km to deliver to 21 lockers. The total operational time for this model was approximately 179 minutes, combining van driving time (52 minutes) with bike delivery time and handling, 127 minutes of which an average of 2.5 minutes handling time was accounted for since this was the average handling time for cargo bicycle delivery, as suggested by McLeod et al. (2020). CO_2 emissions were limited to the van segment, amounting to 4.82 kg CO_2, while the bicycle segment was emission-free and consumed approximately 523 Wh of electric energy, which is well within one battery charge.

4.3. Scenario comparison

The results demonstrated that a two-stage delivery model, using a cargo bicycle for the last-mile segment, offered substantial time and emissions savings when compared to a traditional van-only approach.
Assuming similar delivery conditions, if the two-stage model were applied to all 212 GLS locker locations, the impact can be linearly scaled, as shown in Table 3.

Table 3. Emission saving estimates

Metric	10% Sample (21 lockers)	Full Network (212 lockers)*
Van-only CO_2 emissions	7.98 kg	≈ 80.5 kg
Two-stage CO_2 emissions	4.82 kg	≈ 48.7 kg
Estimated CO_2 Savings	3.16 kg	≈ 31.8 kg per full run

*Note: Values scale linearly assuming uniform trip distance per locker and centralized routing.

If GLS were to perform such a delivery once per day, five days per week:
Monthly CO_2 savings (20 working days) (4):

$$31.8\ kg/day\ \times 20 = 636\ kg\ CO_2/month. \tag{4}$$

Annual CO_2 savings (5):

$$636\ kg \times 12 = 7.63\ tons\ CO_2/year. \tag{5}$$

Using standardised GHG conversion factors provided by the Department for Energy Security and Net Zero (2022), it is possible to estimate that a saving of 7.63 tons of CO_2 a year can roughly equal to 2,847 litres of diesel consumption.

4.4. Discussion

This reduction is significant, especially considering it comes from just one carrier's network in one city, with one cargo bike being implemented. Wider adoption across other carriers, cities, logistics providers, and a higher number of vehicles could yield compounded environmental benefits.

The findings of this study are consistent with international evidence demonstrating the environmental and operational benefits of implementing electric cargo bikes for last-mile deliveries. In the simulated case covering 21 GLS parcel locker locations in Zagreb, the two-stage delivery model achieved a 40% reduction in CO_2 emissions and saved approximately 23.5 minutes of operational time per route compared to traditional van-only delivery. These results align with case studies from London and Milan, where similar setups reduced CO_2 emissions per package by 55% and 73%, respectively. A broader pilot across 20 European cities showed even more pronounced benefits, where 78 electric bikes deployed by 40 organizations yielded estimated annual fuel savings of 8.5 million litres and CO_2 reductions of 21,000 tons, assuming just a 10% market share.

The implications for Zagreb, with a total of over 600 locker points and growing e-commerce demand, suggest considerable upscaling potential and carbon footprint reduction. In São Paulo, replacing diesel trucks with electric bikes led to CO_2 reductions of ~20 tons per year, a 97% total cut, and 31% operational savings. While Zagreb's simulation was conducted at a smaller scale, the proportional CO_2 saving (3.16 kg per route, extrapolated to ~7.63 tons annually) illustrates similar trends under European urban conditions. The Innsbruck model, which employed a two-tier system (vans to hub, bikes for the final leg), achieved 96% CO_2 reduction and cost savings sufficient to cover urban hub expenses. Similarly, the Maastricht subsidy program led to 1.15 tons of CO_2 saved over six months and permanent operational shifts by participating businesses. These international examples, as shown in Table 4, validate the potential benefits observed in this Zagreb simulation, while also highlighting the importance of operational scale, micro-hub support infrastructure, and policy incentives to unlock full environmental and cost-efficiency gains.

Table 4. Comparison of CO_2 savings across different cities

City	Model Type	CO_2 Reduction	Cost Savings	Key Features
Zagreb	Simulation, 2-stage model	~7.63 tons/year (est.)	Not assessed	10% network coverage, modelled using TSP routing
São Paulo	Real-world deployment	20 tons/year (97%)	31% operational savings	Replacement of diesel vans with e-bikes
Innsbruck	Two-tier (van + bike) system	96% reduction	Covered cost of urban hub	Demonstrated financial viability of city hubs
Maastricht	Subsidized pilot program	1.15 tons in 6 months	Not quantified	Policy-supported shift to cargo bikes

4.5. Limitations and Future Work

To conduct the analysis, major logistics companies operating in Zagreb were contacted directly to obtain relevant data. However, even with a deeper insight, numerous assumptions were necessary due to limited data availability. Given the complexity of logistics systems and the many parameters involved, a simplified methodological approach was adopted, which may have led to omissions, approximations, or oversimplifications. For example, the scalable extrapolation used for the savings calculation assumes consistent spatial distribution and route lengths, which may vary in different city zones. Future studies could incorporate:

- Temporal dynamics (peak-hour congestion),
- Locker capacity and cargo space fill efficiency modelling,
- Fill efficiency based on weight instead of volume,
- Cost-benefit analysis including labour and equipment,
- Infrastructure readiness assessment.

5. Conclusion

This short assessment demonstrated the operational and environmental benefits of integrating cargo bikes into urban parcel delivery systems, using Zagreb as a case study. Through spatial simulation of 21 parcel locker locations, the two-stage delivery model (van to micro-hub and cargo bike to lockers) resulted in a 40% reduction in CO_2 emissions and notable time savings per delivery round. When extrapolated across the city's full locker network, the model presents a realistic and scalable path to reduce annual emissions by up to 7.5 tons of CO_2. These findings align with European best practices and affirm cargo bikes as a viable solution for sustainable last-mile delivery, especially when supported by appropriate infrastructure and policy frameworks.

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