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ORIGINAL PAPER

Evaluating the impacts of using cargo cycles on urban logistics: integrating traffic, environmental and operational boundaries

Sandra Melo[1] · **Patrícia Baptista**[2]

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Abstract
Introduction European Commission has promoted actions and policies with the aim of reducing the negative impacts on traffic and environment caused by city logistics. One increasingly popular measure is the use of cargo bikes in city logistics due to their improved energy efficiency, lower emissions and lower traffic disturbance. The paper assess the impacts of electric cargo bikes, from a public policy perspective and, simultaneously, taking into account variables that cover the urban logistics operators' interests. Under a public policy perspective, the considered variables evaluate mobility, environmental impacts and indirectly, the quality of life. In terms of private interests, the studied variables cover costs levels (operation and driving) and efficiency. This evaluation aims at clarifying if electric cargo bikes can indeed represent a sustainable mobility policy under specific boundaries, by leading to better environmental and social impacts and not hindering the operational efficiency of urban logistics activities.
Methods For that purpose, the measurement of the traffic key performance indicators, as well as of Well-to-Wheel energy and CO_2 emission savings is performed allowing to quantify mobility, reliability and operational efficiency indicators. Several scenarios related with the introduction of electric cargo bikes replacing conventional vans were assessed and evaluated in order to compare the effects of different market shares in the mobility of the studied area located in Porto (Portugal). Acknowledging the short distance range of cargo bikes, the simulation is carried out and an estimation of the total transportation cost is performed, which includes transport and emission cost when the vehicle is driving, emission cost while idling and labor cost.
Results The main conclusion is that cargo bikes can replace up to 10% of the conventional vans in areas with maximum linear distances of about 2 km, without changing the overall network efficiency. Additionally, urban logistics WTW CO_2 emission impacts can be reduced by up to 73%, which represents 746 kg of CO_2 avoided emissions. Furthermore, the introduction of electric cargo bikes in urban logistics activities has positive effects for all the vehicle categories and all the scenarios, reaching up to 25% of reductions in external costs.
Conclusions As a result, cargo bikes implemented at the appropriate spatial scale within the city can be a sustainable solution for urban logistics, depending on a prior delimitation of the conditions and adequate implementation strategy, to guarantee that it actually leads to improvements in terms of mobility, environment, energy, running costs and externalities.

Keywords City logistics · Sustainable mobility · Cycle logistics · Electric cargo bikes

This article is part of Topical Collection on The role of planning towards sustainable urban mobility

✉ Sandra Melo
sandra.melo@tecnico.ulisboa.pt

[1] LAETA, IDMEC, Instituto Superior Técnico, Universidade de Lisboa, IDMEC-IST, Av. Rovisco Pais, 1-1049-001 Lisbon, Portugal

[2] IN+, Center for Innovation, Technology and Policy Research - Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal

1 Introduction

The increasing urbanization, population growth and changes in the goods' demand patterns favoring just in time solutions, combined with the reduced stock in stores, has led to increasing freight movements within cities. As a result, urban goods distribution has been associated with negative impacts mainly related with traffic congestion of commercial vehicles, as well as of the road capacity reduction caused by frequent stops for loading or unloading operations, which results in lower energy efficiency and higher emissions profiles [1–3].

Under such unsustainable context, society is demanding public administrators' to promote the sustainability of cities, to guarantee mobility and quality of life, while ensuring an efficient urban goods distribution system [4–6]. While pursuing effective policies to achieve these goals, various measures and initiatives have been recently promoted and tested, namely the introduction of light electric vehicles for urban logistics purposes [5, 6]. The fact that more than 80% of freight movements in European urban areas are of distances below 80 km [7], added to the target of emission free city logistics by 2030 [8], has put light electric vehicles in the public agenda as a possible alternative that can help in this direction.

Light electric vehicles are defined as battery, fuel cell, or hybrid-powered 2-or-3-wheel vehicles generally weighing less than 200 lb (100 kg). Examples of light electric vehicles are small electric vehicles (SEV), electric cargo bikes and electric cargo tricycles. These vehicles rely on a more efficient propulsion technology and result in lower local emissions and reduced noise compared to conventional vehicles. In what refers to its operational costs, light electric vehicles are associated with benefits over larger conventional diesel vans and trucks on taxes, insurance, storage and depreciation costs. Additionally, light electric vehicles are also easier to park than vans or trucks and are viewed as less intimidating and safer by the public. Furthermore, they allow the reduction of the total curbside space occupied by vehicles making on-street deliveries, further reducing the impact of unloading operations on traffic congestion [3]. The use of smaller vehicles also results in fewer conflicts with other road users as is easier to overcome those [5].

Nonetheless, these vehicles are still struggling to be widely accepted by the urban logistics' industry. There is a valid argument that downsizing vehicles typology can lead to "penalty costs" of unsatisfied demand due to the weight, volume limitations as well as distance range of these vehicles [9]. The strong resistance from operators towards this solution, as well as the disproportionate enthusiasm by public administrators and politics, are not supported by the scientific literature on the real impacts, potential market share and geographical scope of light electric commercial vehicles.

The use of light electric vehicles for urban logistics purposes, namely small electric four wheel vehicles, has already been approached by the authors in previous works [3, 10, 11]. Along that research, it was demonstrated that light commercial vehicles are appropriate as a niche of market complimentary to conventional vans. It was identified a limit of up to 5% of conventional vans that could be replaced by those vehicles at the city level, without causing relevant traffic disturbances and operational restrictions. The geographical coverage where light electric commercial vehicles could perform in order to be economically competitive and lead to a sustainable mobility was set to a limit of 12 to 30 blocks corresponding to a maximum linear distance of 2 km (1.2 miles), with a replacement rate of 1 SEV: 1 van. Within this pre-defined spatial limit, light electric commercial vehicles, SEV, could replace up to 30% of the conventional vans operating within that distance range.

Along this paper, the authors assess the impacts of light electric commercial vehicles, namely of electric cargo bikes, from a public policy perspective and, simultaneously, taking into account variables that cover the urban logistics operators' interests. Under a public policy perspective, the considered variables evaluate mobility, environmental impacts and indirectly, the quality of life. In terms of private interests, the studied variables cover costs levels (operation and driving), service levels and efficiency. This evaluation aims at clarifying if electric cargo bikes can indeed represent a sustainable mobility policy under specific boundaries, by leading to better environmental and social impacts and not hindering the operational efficiency of urban logistics activities.

2 State of the art

Cycle logistics have risen as an attractive concept for urban areas, with high potential of reducing energy and environmental impacts [12]. Cycle logistics refers to professional logistics like delivery services, waste collection or small trade services using cargo bicycles (2, 3 or 4 wheelers either electric or conventional) and bicycle trailers. The specific use of electric cargo bikes in cycle logistics presents advantages within urban logistics operations, such as less driver fatigue and higher payload due to the electric assistance help in moving the vehicle. They are particularly suited for urban goods distribution, for last mile deliveries associated to short distances or incorporated in innovative logistics systems, such as micro-consolidation centers (demonstrated in London [13]) or mobile depots (e.g. in Brussels [14]). A good example of the use of cargo bikes is implemented in Paris, with an increasing number of cargo bikes for last mile deliveries [15], which has led to a strong growth of this niche market [16]. 60 freight related EV demonstration projects in the Baltic states have been identified [17], with cargo bikes being used as "accompanying modules" (for example, in retail deliveries in Hasselt, Belgium, and postal deliveries in Brussels, Belgium). In spite of the growing examples of the use of electric cargo bikes in the literature, the correct number of electric cargo bikes in use is uncertain [18]. The same goes to its unclear economic operational feasibility [19], since the higher purchase cost and respective recharging requirements may not overturn the lower operating costs per kilometers when comparing similar electric and conventional vehicles.

Research has assessed the use of electric bicycles mainly applied to private transport users rather than for urban logistics purposes. Gruber [18] studied the typical profile and potential to reject new vehicle technologies of individuals and decision makers concluding that factors such as electric range, purchase price and availability of information are essential to enable the adoption of this alternative. These factors are commonly used to justify the urban logistic operators' resistance to change to electric vehicles revealed in other studies [3, 11]. Borgaray [20] modeled the quality perceived by users from public bicycle systems through the use of Probit models, concluding that safety and information have the greatest impact on public bike users' perceived quality. Safety is also one of the most important concerns with the use of bicycles in city logistics, since cyclist constitute a vulnerable road user because they have problems being seen and have increased difficulties in undertaking avoidance maneuvers and understanding the movements of other vehicles [21]. Additionally, the cyclist's safety as well as the weather conditions in which they must drive without damaging their cargo, can also be determinant factors that justify urban logistics operators' resistance towards the adoption of cargo bikes.

Besides the studies on users' acceptance, scientific literature has also approached the topic focused on the system supply characteristics and its optimization. Anderluh [22] evaluated a two-echelon city distribution scheme with temporal and spatial synchronization between cargo bikes and vans based on a greedy randomized adaptative search procedure with path relinking. Authors concluded that costs and emissions can be saved by the combined usage of cargo bikes and vans instead of vans alone. Dell'Olio [23] estimated the potential demand of a public bicycle system and the optimization of pick-up and drop-off point's locations. Lin and Yang (2010) also proposed a methodology for estimating the location and number of docking stations needed for a given system. The translation of these analysis into urban logistics would lead to the estimation of the location and the number of proximity delivery consolidation centers from and to which electric cargo bikes would run. Melo [3] defined the limit to maximum linear distance of 2 km (1.2 miles), when considering the use of small electric vehicles for urban logistics purposes. Further studies should be performed to define the distance range within the city where electric cargo bikes can perform in conditions to lead to a sustainable mobility. Additionally, the network can only accommodate a limited number of electric cargo bikes due to its intrinsic physical characteristics in order to guarantee the same supply reliability and traffic performance within the area. Melo [10] identified a limit of up to 5% of conventional vans that could be replaced by SEV's at the city level, without causing relevant traffic disturbances and operational restrictions. Policy makers must be aware of these boundaries in order to promote effective sustainable mobility policies in a realistic and successful way. Along the case study presented on the following section, the authors estimate the effects of downsizing urban logistics vehicles without penalty costs of unsatisfied demand in a specific area within the city. The effect of replacing vans by cargo bikes is analyzed, considering public and private stakeholders' interests, in a case study carried out in the city of Porto (Portugal). Changes on the distance travelled, energy consumption and CO_2 emissions as well as on running costs are also discussed.

3 Data and methods

The use of light electric commercial vehicles, namely electric cargo bikes, is likely to become a reality in the coming future. The usability and the effectiveness of light electric vehicles greatly depends on their ability to satisfy the local logistics demand and reduce traffic disturbance and its impacts. Taking into consideration the lack of studies that quantify the overall effect of such systems, this paper addresses the following questions:

- Do light electric vehicles, such as cargo bikes, lead to better environmental and social goals, while assuring the same level of operational and traffic efficiency on urban logistics?
- How relevant is the impact of the use of electric cargo bikes to local administrators to achieve the concept of sustainable mobility?
- In what conditions, when, with whom and how municipalities should implement it?

3.1 Methods

This assessment was carried out by developing a microscopic traffic simulation model for the city of Porto (Portugal). A highly-detailed traffic model was built in AIMSUN 8.1.2 model (Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks) for this case study to replicate and estimate traffic conditions and its related environmental and operational effects. AIMSUN is a microscopic traffic simulation model that can simulate the individual behavior of a vehicle on the network over time and in accordance to the various theories of vehicle behavior, namely the Gipps car-following [24], lane-changing [25] and gap acceptance models [26]. This model was developed to be a tool to support traffic engineers so that they can analyze and design traffic models. AIMSUN has proven to be useful in testing new traffic control systems and management policies based on traditional technologies, as well as in the implementation of Intelligent Transport Systems [27]. AIMSUN simulations can be classified as hybrid processes, combining an event approach with activity scanning. This microscopic traffic simulator considers the changes in travel time along the day, as a result of variations in traveling speeds due to variation in traffic density. As a consequence, the model identifies traffic congestion problems and allows to explore potential policies to deal with it. Moreover, it allows the assessment of transportation energy efficiency, in variables such as fuel consumption and emissions, since the measurement of fuel consumption and emissions is closely associated with the time-varying real-time speed in urban areas. AIMSUN also allows calculating fuel consumption levels at a second by second basis, which makes it possible to avoid the simplification of average values per kilometer. Additionally, it allows to simulate overtaking maneuvers to deal with illegal double lane parking, which is a significant activity when analyzing urban logistics operations. Further technical details about the AIMSUN and its capabilities can be found in Barceló [28] and Casas [26].

Taking advantage of the AIMSUN potentialities, several studies on urban logistics have been recently developed using this simulation tool [3, 4, 29–32]. Considering the described context and the intention of using a spatial reference and the possibility to define different road-user behavior parameters and sub-models for different vehicle types and traffic controls as car following and lane change that would hardly be captured by other models, the use of the commercial software AIMSUN allows the development of a highly detailed, dynamic traffic simulation model to estimate traffic conditions in a selected area located in Porto.

The input data for AIMSUN was information on the physical characteristics of the infrastructure, vehicle dynamics, traffic volumes (taking into account flows from surveys) and traffic signals timing and incidents. This data was firstly used for building a baseline scenario, which was used for validating the developed model.

Different vehicle demand composition (e.g. passenger vehicles, light goods vehicles and heavy goods, cargo bikes) and vehicles' propulsion technologies (e.g. gasoline, diesel, LPG) were considered for each link category within the network, as a result of local surveys. In more detail, specific vehicle parameter adaptations from the literature [33] for vehicle dimensions, speed and acceleration profiles were performed to include electric cargo-bikes within the default vehicle typologies, based on real world measurements of these vehicle types performing urban logistics activities.

After that, several scenarios related with the introduction of electric cargo bikes replacing conventional vans were assessed and evaluated in order to compare the effects of different market shares in the mobility of the studied area. The last step was to estimate the total transportation cost, which includes transport and emission cost when the vehicle is driving, emission cost while idling and labor cost. The emission cost when driving between nodes was calculated by carbon cost and carbon emission factor per liter of fuel consumed by the vehicle. Labor cost was calculated by multiplying the labor cost per hour with the total time of travelling and idling. Emissions from driving and idling of vehicles were transferred to a cost factor that was added to the total cost. The costs considered in the model, therefore, consisted of transportation cost (resulting from fuel use), labor average cost and emission cost. Driver wage was assumed to be the Portuguese national average wage with values from Eurostat [34]. The fuel costs considered were the average gasoline and diesel price of DGEG [35]. Considering the specific scope of the paper, costs related to purchasing, depreciation, insurance and maintenance of vehicles were not included in the analysis. As the analysis covers a limited area with a maximum linear distance of 2 km, possible consolidation and satellite depots where the transfer would take place are not covered, neither are its costs.

In the following section, the study domain is presented, as well as the traffic and the emission variables. Then the process of calibration and validation used to evaluate the baseline scenario is displayed and, finally, a description of several scenarios is presented.

3.2 Study domain and data collection

This research work was conducted in Porto (Portugal), a European medium-sized city with 237,000 inhabitants. Previous research carried out by authors in this topic has addressed the impact of using small electric commercial vehicles [3, 10, 11]. These studies have defined that light electric vehicles (SEV) could replace up to 5% of the vans within the overall city area and its best geographical coverage was limited to a unit with 12 to 30 blocks, which corresponds to a maximum linear distance of about 2000 m. Authors also analyzed how varying replacement rates could assure the same delivery capacity within that limited area and concluded that small electric commercial vehicles were economically competitive (not considering purchasing and battery issues) with conventional vans with a replacement rate of 1:1. A 1:1 replacement rate is justified by the fact that the study covers a limited area of a maximum linear distance of about 200 m and the guarantee that the same delivery capacity within that limited area is assured.

In this paper, the limit of 12 to 30 blocks and the replacement rate of 1:1 are also adopted. The area includes 321 sections, 158 nodes and a total extension of the road network (that is the sum of sections extension) of 26 km, as presented in Fig. 1.

To assess the baseline scenario, the input demand of the model both for private and freight transport was defined by the real data provided and obtained from traffic counting from other ongoing research project [36]. The simulation of incidents causing congestion, such as illegal parking in double lane, was also incorporated in this microscopic traffic simulation. The number and duration of incidents was defined based on delivery patterns collected through wind shield survey [36].

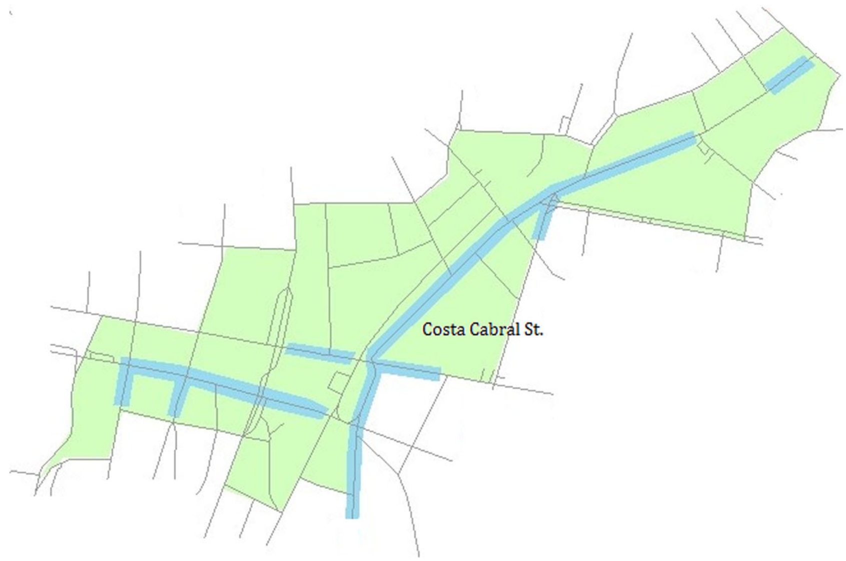


Fig. 1 Layout of the test network in the city of Porto (Portugal)

The vehicles dynamics was adjusted through the collection of second-by-second vehicles dynamics using GPS data application. Data was then uploaded with GPX Viewer to the traffic simulator and used to calibrate and validate the traffic model. AIMSUN 8.1.2 model was applied to simulate individual vehicle movements.

3.3 Calibration and validation

The model development was made in two steps: calibration and validation. The first step focused on the driver behavior parameters and the second step addressed traffic volumes, travel time, speed profiles. The calibration was based on the simulation results from a preliminary number of runs, where the average sample and variance are used to obtain the Confidence Interval (CI) based on the t-distribution. 20 initial random seeds runs were previously considered. For the calibration of driver behavior parameters, the strategy recommended by Dowling [37] was adopted. Firstly, driver behavior parameters, such as car-following (e.g. average standstill distance, additive and multiple part of safety distance) and lane-change (e.g. maximum acceleration for merging and trailing vehicles) were tested in order to assess their effect on travel times, speed and traffic flows. To evaluate the goodness of fit, the percent Root Mean Square Error (RMSE) between observed and estimated data was applied for 184 points. Slight variations (less than 5%) were observed in travel times, speed and traffic flows values in the overall network. Therefore, the driver behavior parameters values remained unchanged in this study.

In the validation step, the estimated traffic volumes, travel times and speed profiles were compared with the observed data from 36 trips within the unit performed using a passenger car during the morning peak hour. To compare means and overall "goodness of fit" of those measures the GEH Statistic test [37] was used, obtaining a final value lower than 10. This result indicates a good accuracy for the developed model.

3.4 Base conditions and scenarios

For the purpose of designing the network, 158 intersections and 321 sections were defined, by including their respective geometry and movements, which were later confirmed in more detail in loco. The performed simulation covers the daily peak of deliveries (8 h30-9 h30). The traffic model assumes that the traffic demand for public, passenger and freight transport remains the same as of the baseline scenario. Since trucks are targeted for different demands as the ones of electric cargo bikes (namely on the geographical coverage, location of receivers on peri-urban areas, type and size of packages), trucks demand matrix remains the same along the simulated scenarios. Electric cargo bikes replace diesel vans moving goods and within a pre-defined limited area with a maximum linear distance of 2 km. At this spatial coverage, it is not included – neither is it considered to be within the scope of the paper – an analysis on the infrastructure where the transfer of goods take place. Therefore, the sum of both O/D traffic matrices (vans and electric cargo bikes) for each of the scenarios corresponds to the values of the O/D vans traffic matrix of the baseline scenario calibrated with the respective replacement share between vans and electric cargo bikes to assure there is no unsatisfied demand.

The case study covers a pre-defined limited area with a maximum linear distance of 2 km, which is not large enough to capture novel e-bike models based on satellite depots. At this short scale, the "origin" is the entrance (street) that the vehicle choses to access the limited area and the "destination" is the exit point (street), with possible intermediate stops to deliver inside the area. If the study would approach a case study with a supermarket, indeed the cargo bike ODs would be different from the ones for vans based on a different urban delivery model and respective urban distribution centres. Since a limited study area was considered, it was assumed that the two types of vehicles would have the same routes (see Fig. 2), but novel delivery models based on vans and bikes working together should be addressed in future studies.

The analysis of the stakeholders' effects was carried out through the quantification of indicators by type of vehicle: electric cargo bikes, vans, trucks (transporters/suppliers), passenger vehicles (citizens and city users), buses and taxis (public transport operators) and on the total system (sum of all users of the road system).

In terms of vehicle parameters, electric cargo bikes were considered to have external dimensions of 2 m long and 1 m wide, a maximum speed of 40 km/h, and a load space of 1 m. The electric cargo bike has an average speed of 20 km/h in free flow conditions, and requires a 4 to 8 h charging period. The vans have average external dimensions of 5 m long and 2 m wide.

The morning peak hour considered covers the period from 8 h30 to 9 h30 and the data collection was performed under dry weather conditions. The delivery patterns adopted on the exercise are the ones obtained during delivery windshield surveys in the area [36]. Roughly 90% of the stores of the area receive a single parcel. At some stops, the driver makes deliveries to more than one store due to their close proximity to one another. The range of parcel sizes and weights makes it viable for all parcels to be delivered by electric cargo bikes and, therefore, it is possible to assume a replacement rate of 1:1, within the pre-limited area as described in 3.2. The flow unit is vehicles, not passengers or cargo.

The outputs of the simulation refer to the hourly average of the daily peak period of deliveries. The following indicators were quantified: mobility (distance travelled, average speed excluding stops to make deliveries, travel time, delay time, density of traffic, flow), environment (fuel consumption and global CO_2 in a fuel life-cycle approach Well-to-Wheel), operating costs and external costs. Operating costs includes the direct vehicle fuel related cost and the time cost for persons in vehicles [38]. The total vehicle energy related costs to travel a particular distance is the sum of the cost of electricity needed to charge the battery and the cost of the diesel/gasoline used. The fuel/electricity consumption estimations are converted to direct vehicle running costs, based on an electricity charging cost of 0.20 EUR/KWh, retail diesel price of 1.209 EUR/L (Portuguese average values for 2015).

Regarding energy consumption and CO_2 emissions, a Well-to-Wheel (WTW) approach was considered. The combination of the Tank-to-Wheel (TTW) and the Well-to-Tank (WTT) stages accounts for the WTW. While TTW accounts for the emissions and fuel consumption that result from moving the vehicle through its drive cycle, the WTT impacts results from the expended energy and emissions from bringing an energy vector from its source until its utilization stages. Reference factors were used for each of the different energy pathways considered (gasoline and diesel production and electricity production mix of Portugal for 2015) [39, 40].

The baseline scenario corresponds to the output from the validated model without cargo bikes in urban logistics activities. The average travel time within the study area is of 128–161 s/km, which corresponds to average speed range of 22–28 km/h. Incidents occur with a frequency of 50 per hour taking 4 min each, along Costa Cabral street.

The tested scenarios consider the replacement of vans by electric cargo bikes for different market penetration rates of the latter: 0, 3, 5, 10, 20, 50, 100%. This range allows to understand if there is a saturation of the network from the traffic performance point of view. After this analysis, an environmental quantification and the calculation of operational and external costs of each scenario was possible. The overall

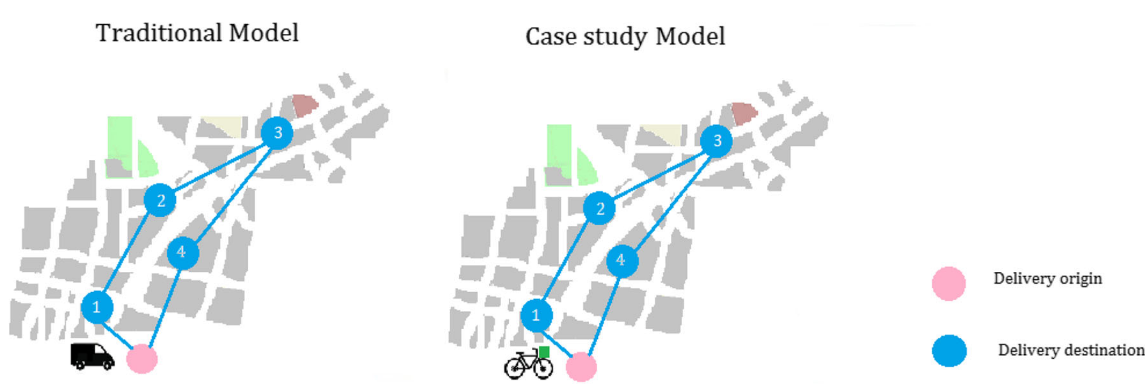


Fig. 2 Delivery models considered

effect allows to perform an accurate overview on the potential of electric cargo bikes as a sustainable mobility solution.

4 Results and discussion

When analyzing the overall traffic performance indicators, it becomes clear that the replacement of conventional vans by electric cargo bikes should only be promoted to a certain extent. In Fig. 3, it is visible that replacing 3, 5 or even 10% of freight movements by electric cargo bikes in the study area can lead to a better traffic performance. The speed slightly increases in relative terms, although its absolute variance is not significant (<1 km/h). Additionally, there is a decrease in delays of up to −4%, correspondent to a minor difference of 3 s per km.

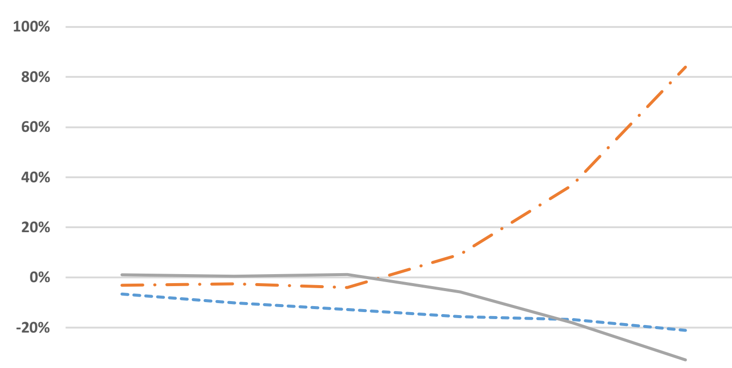
To explain these results, it is necessary to highlight that electric cargo bikes are easier to overcome in traffic due to its dimensions (either circulating or parked for unloading activities), but simultaneously impose a lower speed compared to vans. What happens in the three scenarios with up to 10% of the share of light freight movements is that the positive effect of using electric cargo bikes is more relevant than the speed restriction. That is particularly relevant in the case of buses, the vehicle typology that registers the higher relative reductions of delays in the overall area for those scenarios and due to its intrinsic characteristics can easier overcome cargo bikes than vans (as presented in Fig. 4).

Traffic simulation results show that if the mobility criterion to be used is the ease of movement, then electric cargo bikes are limited to a niche of market up to 10%. Such boundary is also conditioned by the geographical range of movements, already defined in previous research for this area as a maximum of 2 km of linear distance [10]. The fact that electric cargo bikes can replace up to 10% of conventional vans movements within delimited areas in the city suggest that tailor-made solutions for urban logistics can be promoted by specific mobility policies.

Complimentary to the traffic performance analysis, an environmental quantification was performed for the different replacement rates. Figure 5 shows that variation both for all the stakeholders (Fig. 5a)) and for the urban logistics operators running on commercial vehicles (Fig. 5b)) of WTW energy consumption and CO_2 emissions. For urban logistics operators which includes vans, trucks and electric cargo bikes, up to 73% of CO_2 emissions can be avoided, which represents 129 to 746 kg of CO_2 avoided emissions from Scenario 3% to Scenario 100%. When observing the fuel and environmental effects, the results in WTW energy consumption and CO_2 emissions are also positive for all the simulated replacement shares (Fig. 4a) and for the urban logistics operators (Fig. 4b). For urban logistics operators (which includes vans, trucks and electric cargo bikes) up to 73% of CO_2 emissions can be avoided, which represents 129 to 746 kg of CO_2 avoided emissions from Scenario 3% to Scenario 100%.

It is necessary to state that the Scenarios of 20, 30 and 100% penetration of electric cargo bikes lead to worse traffic conditions and, therefore, register longer queues for all type of vehicles, longer delays (up to 84%, corresponding to differences of more than 1 min per km) and longer idling times compared with the baseline scenario. Such conditions have negative effects in terms of environment, but the benefits that occur because of the replacement of vehicles are much higher and, therefore, even for the scenarios with worst traffic performance there are fuel savings and lower CO_2 emissions. The higher share of the electric cargo bikes is directly associated with the decrease of the share of conventional vans, which unavoidably means that there are fewer vehicles polluting.

The conversion of fuel savings into monetary costs results in reductions that vary from 50 to 266€ for the



	Sc 3%	Sc 5%	Sc 10%	Sc 20%	Sc50%	Sc 100%
Flow	-7%	-10%	-13%	-16%	-17%	-21%
Delay time	-3%	-3%	-4%	9%	37%	84%
Speed	1%	1%	1%	-6%	-18%	-33%

Fig. 3 Traffic flow, delay time and average speed for the tested scenarios of introduction of cargo bikes

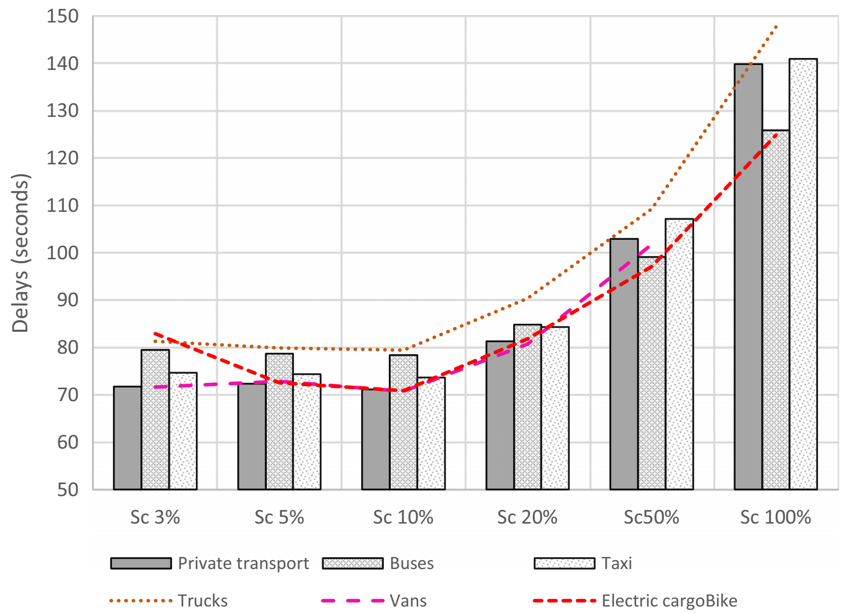


Fig. 4 Delay times according with vehicles typology for different electric cargo bikes market penetration rates

sum of the urban logistics operators running in the area (per hour) and from 284 to 747€ for all the traffic system users (including passenger, public and freight transport), as presented in Fig. 6. These values refer to the morning peak hour and provide evidences that the replacement of conventional vans by electric cargo bikes have a positive effect in the environment and on fuel savings. The impact in terms of driving costs is negative due to the additional driving time, registering additional costs of up to 0.13 € per hour for urban logistics operators. When comparing this penalty with the fuel savings, the running cost is still significantly positive for their operation.

When looking to the public stakeholders' perspectives, under an analysis of the external costs, the introduction of electric cargo bikes for urban logistics activities has positive effects for all the vehicle categories and all the scenarios reaching up to 25% of reductions in external costs. In the overall network, the effects in the external costs correspond to average monetary reductions of 0.06 € per vehicle per hour.

5 Conclusions

The use of cargo bicycle for urban logistics appears as one promising solution for congested and polluted urban centers. Despite the increasing promotion of cargo bikes in urban logistics by public stakeholders, there are still some reservations from urban logistics operators to its adoption. Operational issues are supporting these reservations. One of the main issues is that cargo bikes can only cope with parcels and not pallets and, consequently, can only cover specific types of business. The size and weight of parcels or mail are rather small and the travel distance must be short. Moreover, it implies the existence and availability of a consolidation centre – can be a post

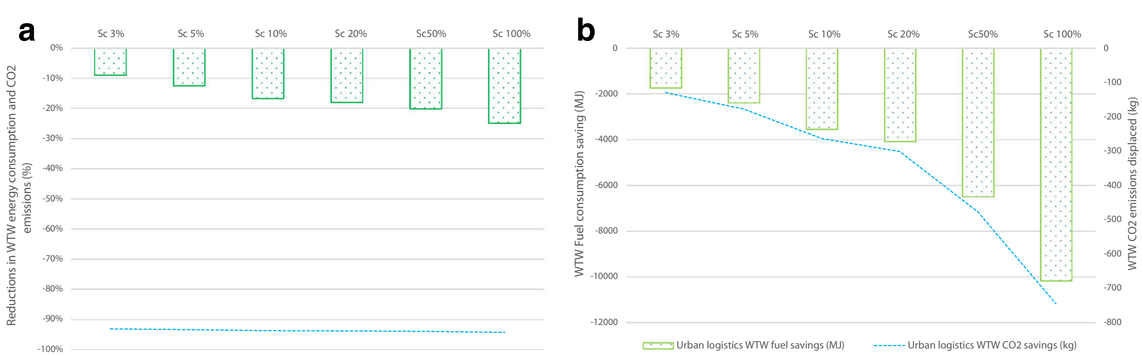


Fig. 5 WTW energy consumption (MJ) and CO2 emissions (kg) impacts: **a** overall network; **b** urban logistics vehicles. *Green bars* refer to WTW energy consumption result, while *blue line* refers to WTW CO2 emissions

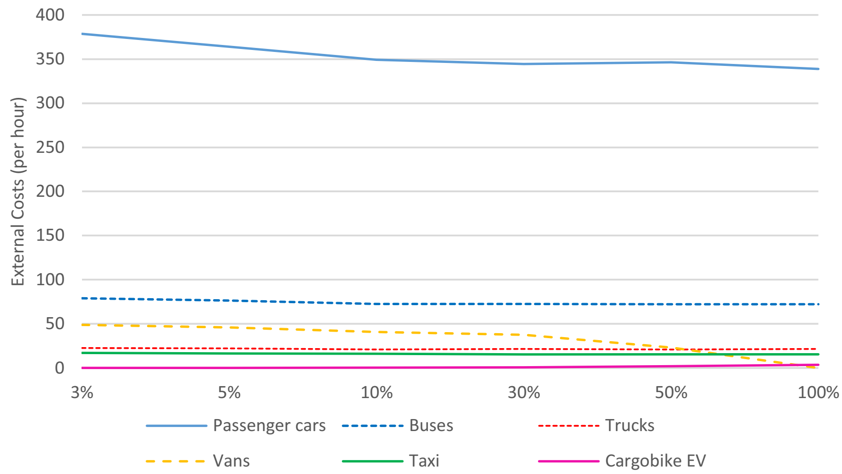


Fig. 6 External Costs of introducing electric cargobikes in the study area

office station – from where the cargo bikes depart. Added to these operational limitations, there are also considerable issues of the still difficult maintenance, a small second-hand market, and an insufficient number of recharging public facilities. Nonetheless, accurate quantifications and ex-ante assessment of its potential impacts need to be performed to better design policies that fit in cargo bikes intrinsic characteristics and simultaneously allow overcoming the mentioned obstacles. For that purpose, a case study in the city of Porto, Portugal, was developed to estimate the effects of replacing vans by cargo bikes to deliver parcels at a pre-defined limited spatial coverage.

This research follows previous works from authors [3, 10, 11], that had already identified that the geographical scope of the implementation of light electric commercial vehicles is not the city level, but rather specific areas within the city with maximum linear distances close to 2 km. Starting from that assumption and because at that spatial level of analysis and the observed delivery patterns allowed it to be carried out using cargo bikes, with a replacement rate of 1:1, this paper tried to understand if the current focus and investment that is being promoted by public policies in this type of vehicles can actually promote the public good interests and private stakeholders' efficiency and in what conditions can it be implemented. The results of this paper show that electric cargo bikes can leads to better environmental and social goals, while assuring the same level of operational and traffic performance on urban logistics. Results from simulation show that the conditions in which cargo bikes can help to achieve the concept of sustainable mobility are limited to what can be considered a niche of market. There is a mobility limitation that establishes as a boundary the 10% of electric cargo bikes in freight movements for the studied area within the city of Porto. Such boundary should be explored and clearly defined by public stakeholders prior to the implementation of exclusive areas for these vehicles in city centers. Adding to the results of this paper, cargo cycles are not a costly solution and have the potential to be easily integrated with local last mile solutions, such as the ones generated by e-commerce. Additionally, the fact that drivers do not need a driver's license are factors to influence operators' perception on cargo bike requirements in a positive perspective.

Ultimately, the use of electric cargo bikes can play a relevant role to local administrators to achieve the concept of sustainable mobility in specific delimited areas of a city. The success of its implementation will depend of an integrated strategy with private operators for the promotion of this solution and the prior delimitation of the conditions in which it actually leads to improvements in terms of mobility, environment, energy, running costs and externalities.

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