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Sustainable e-commerce urban distribution in LEZ areas: A greening Metro-based solution (M4G: Metro For Goods)

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Abstract

A Low Emission Zone (LEZ) is a measure implemented by many European cities in their densest, most congested and most polluted areas to reduce the access of the most polluting vehicles. This limitation of access to LEZ zones collides with the growth in e-commerce delivery, which has increased sharply in recent years. This paper investigates the potential use of a metro system (M4G: Metro For Goods) to provide delivery services by leveraging its existing carrying capacity and using the metro stations as microhubs. In the last leg in the last mile, this model is complemented by cargo bikes to distribute e-commerce parcels in the LEZ in a city like Madrid. The external costs of the M4G model are compared with the current e-commerce delivery scenario (parcel delivery by road), and the results show that the proposed model can be a promising innovation to reduce the externalities in the LEZ.

Keywords: City logistics; Low emissions zone; E-commerce; Last-mile innovation; Freight intermodality; Green logistics.

1. Introduction

Cities are at the heart of human life, and they are currently undergoing an intense transformation process on several levels (urbanisation, environmental, mobility, economic, digitalisation). Thus, in general, they seek to improve the quality of life for their inhabitants through innovation. The distribution of goods within cities has emerged as one of the critical challenges for the transport and logistics sector, directly affecting the urban transformation process.

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The emergence of Covid-19 has been particularly relevant and impacted both urban mobility and electronic commerce. Business to Consumer (B2C) transactions have grown notably in recent years and accelerated further due to the pandemic, increasing Internet usage and driving consumer habits and behaviours changes.

Last-mile delivery accounts for 53% of total delivery costs and 41% of total supply chain costs (World Economic Forum, 2020). This increased number of deliveries has led all players involved in urban delivery to fear a collapse in the last mile and to consider measures to increase their delivery capacity and, in turn, reduce the environmental impact of their activity in large cities. Without stakeholder interventions, carbon emissions from urban delivery traffic are expected to increase by 32% by 2030 (World Economic Forum, 2020).

Proposals can be grouped into two distinct strands among the different solutions to the last-mile issue. On the part of Public Authorities, they try to minimise the impacts derived from urban logistics to improve the quality of life of their citizens and restrict the use of vehicles in cities (Civitas, 2015). On the other hand, the actors involved in urban distribution consider initiatives that increase their delivery productivity and minimise their costs while increasingly taking environmental impacts into account (Macharis & Kin, 2017).

Among the main alternatives proposed by Public Authorities is the creation of low-emission zones (LEZ) in cities which aim to promote cleaner vehicles and reduce the number of older, polluting vehicles circulating in city centre areas (Taniguchi et al., 2014). The inclusion of LEZ can ban all vehicle traffic or only those vehicles that do not meet a minimum environmental standard (restrictions related to engine and fuel consumption). In Europe, more than 280 cities have declared LEZ with traffic restrictions (2022), the most significant number of them in Northern Italy, Germany and the Netherlands (https://urbanaccessregulations.eu/userhome/map). These LEZs further aggravate the saturation of urban freight transport in large cities, worsened by the rise of e-commerce.

An innovative solution to minimise the impact of vehicles in the city and improve the efficiency of urban freight distribution can be the use of surplus or unused capacity of public passenger transport for freight transport. Using rail to carry out the urban distribution is defined as a consequence of trying to minimise road transport in city logistics. Concerning rail transport, there have been several studies and pilot tests in recent years to use this mode of freight transport in various cities. Many European cities have an extensive rail infrastructure to fulfil core public transport functions, either through metro, trains, or tram networks. There is increasing scope for using these systems for inner-city freight transport. Unlike the heavy rail freight industry, which would require considerable investment, freight transport via metro or tram would use existing infrastructure. There is no need to change the infrastructure of rolling stock and stations, although modifications and adaptations must be made (Dampier & Marinov, 2015).

There are confirmed cases of urban rail freight transport in Europe (Marinov et al., 2031): GüterBim (Vienna, 2004-2007), CityCargo (Amsterdam, 2007-2009), Monoprix (Paris, 2007-2017), Cargo-Tram (Zurich, 2003-current), CarGo Tram (Dresden, 2001-2021). The common denominator of these pilot tests was the urban transport of goods between companies or authorities offering a public service to citizens. They involved several areas of the city, not only LEZs. Of these projects, only the Zurich project is currently in operation. In the remaining cases, the barriers identified in both Amsterdam and Vienna were related to the initial investment required, the lack of support from public administrations, the involvement and collaboration of different stakeholders, and operational difficulties. In the case of Dresden and Paris, the reasons focused more on the definition of a new logistics model.

The remainder of this document is structured as follows: Section 2 describes the methodology used, section 3 presents the study case, and, lastly, section 4 shows the results and conclusions.

2. Methodology

This research is divided into four stages, as shown in Figure 1. The first stage defines the M4G model of e-commerce parcel delivery through metro and cargo-bike transport systems. Also, it details the technical and operational requirements for trains and stations to be used for such distribution in a large city. To this end, a series of one-on-one interviews were conducted with several operations managers of courier companies and the head of logistics operations at Madrid's Metro system. The second stage calculates the potential demand for e-commerce parcels among residents of the central district, one of the two low-emission zones (LEZ) established in Madrid. This calculation employed data from Madrid City Hall's registry of inhabitants (2022), e-commerce purchase volume data from CNMC (2021) and data on e-commerce habits and frequencies of consumption from ONTSI (2022). Once-daily e-commerce demand by LEZ residents was quantified, the station that would comprise the urban parcel distribution system was selected. Lastly, the externalities of delivering each parcel using the M4G model were quantified based on the EU's external cost manual and compared with courier vans' current costs.

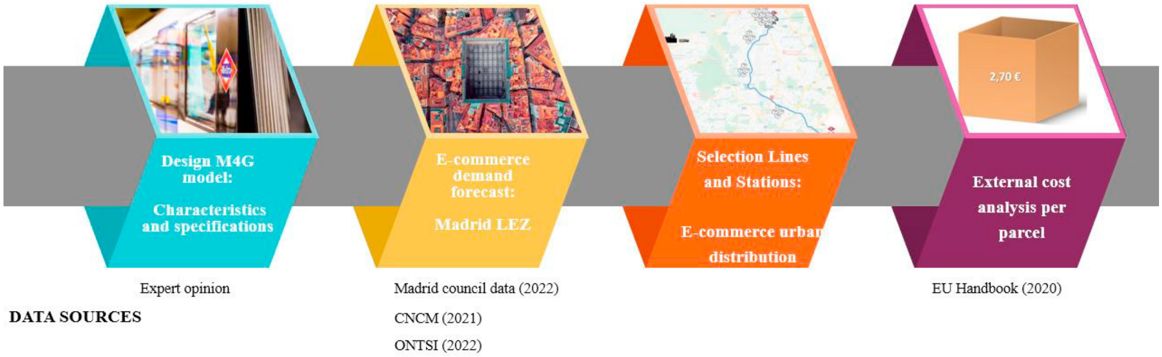

Fig. 1. Methodological Framework

3. Case Study

The objectives of this research focus on the analysis of a sustainable city logistics solution through a new mix-model of urban distribution of goods within a large city. In these large cities, the potential utilisation of existing public transport system infrastructures and the use of synergies for last-mile delivery of e-commerce goods will largely depend on two fundamental aspects: (i) their effectiveness in reducing operational costs, meeting delivery times and improving customer service for urban demand (Leung et al., 2000) and (ii) their ability to reduce the externalities that currently arise from this activity.

Therefore, the research question is: can a public transport system such as metro be considered an efficient and sustainable alternative for urban logistics in the era of e-commerce? To answer the research question, we will apply the explained methodology to the Madrid city centre district (LEZ).

3.1. Design M4G model: Requirements and specifications

The M4G (Metro For Goods) model develops the process of delivering e-commerce parcels via the Metro de Madrid network and compares the current last-mile delivery of e-commerce parcels via Light Commercial Vehicles (LCV). The parcel delivery is performed for a low-emission area of a large city like Madrid, and the activities are described below (see Fig.2):

- 1) The online order is placed online by a neighbourhood resident within the low emission zone (LEZ).
- 2) The online order is processed and prepared at the retailer's or logistics operator's logistics centre/consolidation centre. Parcels corresponding to online orders are prepared and placed in roll containers, grouping packages by each station. Rollers containers can carry loads of 500-800 kg.
- 3) Transport to the metro depot: a heavy goods vehicle (HGV) transports the parcels grouped by destination from the logistics centre to the selected metro depot.
- 4) Unloading and temporary storage at the metro depot: containers containing packages with e-commerce orders are temporarily located (cross-dock 1).
- 5) Loading parcels onto trains: before starting the journey along the entire line, the necessary carriages are loaded with the goods' containers. The distribution of parcels is carried out before users enter the Metro and take advantage of the previous movements made by the trains when they are positioned at all stations before starting service (empty trains with parcels). This implies that no additional means are used in addition to those already used by Metro daily, not to add extra operational costs in transporting parcels underground.
- 6) Transport from the metro depot to each station: the train is loaded with the rollers containers at the metro depot, and the train is used to transport the parcels orders to the stations.
- 7) The online parcels are unloaded from the trains at each station and must be transferred to a micro-hub within that station that acts as a temporary storage facility (cross-dock 2).

- 8) Delivery from the microhub at the station to the home is by "clean" transport (cargo bikes).

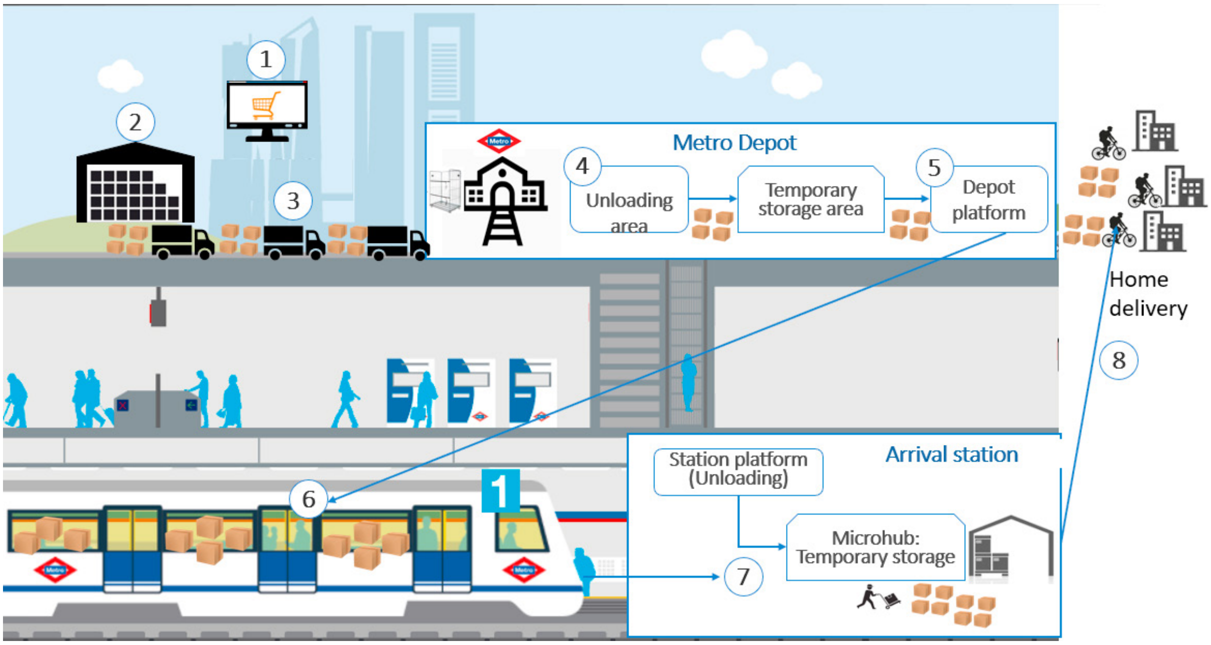

Fig. 2. M4G model

In order to define the operational feasibility of the M4G model, interviews were conducted with three operations managers of parcel delivery companies in the city of Madrid, one CEO of a last-mile cargo bike delivery company and one logistics manager of Metro de Madrid. According to their experience, for the M4G model to become a feasible reality, the following aspects must be considered:

- Concerning the transport of the goods:
  - Train type (i): each car that makes up a train has a different parcel transport capacity depending on the internal size of the train.
  - Size of roll container (ii): depending on the internal capacity of the train, the most appropriate size of roll container is selected, which in turn determines the number of parcels to be transported.
  - Incidence with passengers (iii): using trains shared with passengers (exact timetable) or specific trains (different timetable from passengers) is used to transport the parcels.
  - Access to stations with cargo bikes (iv): parcels must be loaded in stations with adequate space.
- Concerning metro stations/cargo bikes:
  - Platform characteristics (v): longer and broader platforms favour the unloading operations of rollers containers.
  - Availability of lift or hoists (vi): for efficient logistics activities, it is necessary that the station has a lift or hoist to bring the parcels to the surface.
  - Microhub characteristics and station location (vii): number of square metres are available for the temporary storage of parcels. Similarly, the station's location within the delivery area is critical to the efficiency and speed of delivery.
  - Operational activities at stations (viii): in the case of shared trains between passengers and parcels, there is a risk that logistic operations affect passengers (unloading time at stations and handling of parcels at the station).
  - Cargo bike (ix): in the centre of Madrid, a cargo bike has an average speed of 12 km/h for goods delivery and can carry up to 150 kg.

3.2. E-commerce demand forecast

To calculate the potential demand for e-commerce packages delivered daily to residents of the LEZ of central Madrid, the chain proportions method (Kotler & Keller, 2012) is used. As shown in Table 1, the formula starts from the number of residents in this district. By applying different filters, it obtains the daily e-commerce orders of physical goods of these residents. It is assumed that online orders are not delivered on the same day. Table 1 shows the potential daily demand for e-commerce packages for residents of LEZ located in the Madrid central district. The results indicate sufficient potential daily demand to justify using a system such as M4G.

Table 1. Daily online demands for LEZ residents in Madrid.

District	Residents	Internet users (93.5%)	Online shoppers (79.40%)	Daily shopping (9.86%)	Physical products (40.27%)
Palacio	19 706	18 425	14629	1443	581
Embajadores	40 368	37 744	29 969	2956	1190
Cortes	9 244	8643	6863	677	273
Justicia	15 435	14 432	11 459	1130	455
Universidad	28 562	26 705	21 204	2091	842
Sol	6 932	6481	5146	508	205
Total Online Daily Demand	120 247	112 430	89 270	8 805	3546

3.3. Selection lines and stations

Seven different Metro lines run through the Madrid central district LEZ (Figure 3), and 25 stations are located in this area (see Table 2).

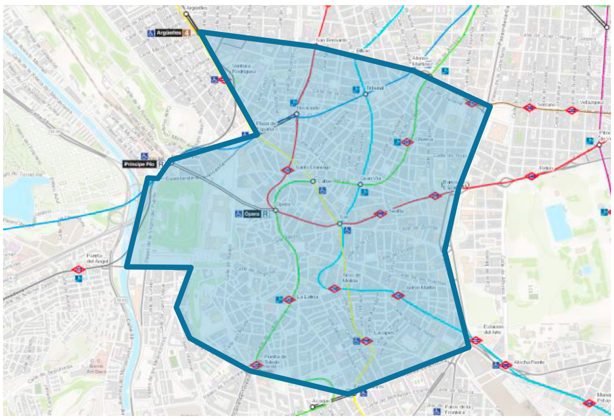

Fig. 3. Madrid Center District (LEZ)

Table 2. Stations in Center District

Stations in Center District		
A. Martínez	E. del Arte	S. Bernardo
Antón Martín	Gran Vía	S. Domingo
Argüelles	La Latina	Sevilla
B. de España	Lavapies	Sol
Bilbao	Noviciado	T. Molina
Callao	Ópera	Tribunal
Chueca	P. España	V. Rodríguez
Colón	P. Pío	
Embajadores	P. Toledo	

Following the criteria defined in point 3.1., the first selection corresponds to the lines and stations that use the wide gauge in the Metro de Madrid network (criteria i, ii and v). In this gauge, trains are 2.8 m wide, and platforms are approximately 115 m long. Of the total of 25 stations, 6 meet these criteria.

The following requirement is the availability of lifts (vi). Of the remaining 6 stations, 4 have lifts connecting the station to the surface. These are as follows: Argüelles (L6), Plaza de España (L10), Príncipe Pío (L6 and L10) and Tribunal (L10). Concerning the use of shared trains or dedicated trains for freight transport, Metro de Madrid considers that the most viable alternative is the exclusive use of trains before or at the end of the passenger service (criteria iii and viii) so as not to interfere with the service provided to its customers.

Finally, the station location requirements for further parcel delivery and the premises available for use as a microhub are assessed (criteria iv, vii and ix). Argüelles station is discarded because it is the worst geographically located station for delivery in the central district through cargo bikes. In terms of in-station storage, Príncipe Pío station has the most extensive premises available as a microhub. Considering the ease of access and electric cargo bike charging, Príncipe Pío station also has better conditions than Plaza de España station and Tribunal station.

Assuming the above considerations, Príncipe Pío station (L6 and L10) is the station that best meets the criteria and specifications defined in section 3.1. for the delivery of packages by Metro de Madrid in the central district.

3.4. External cost analysis per parcel.

In the following, we compare the external costs of delivering a parcel to a resident's home in the central district (LEZ) through the current light commercial vehicle delivery model with the costs incurred through the M4G model. To make this comparison, it is necessary to define the parameters of the current standard e-commerce parcel delivery model in the Madrid LEZ.

Table 3. Parameters in the e-commerce delivery in Madrid LEZ.

Parameters in a standard e-commerce delivery in Madrid LEZ	
Total demand for e-commerce for LEZ zone (parcels per day)	1000
Daily distance travelled on the route by a (km)	100
Daily enroute packages per LCV	90
Daily delivered packages per van	70
Distance from e-fulfilment center to Metro de Madrid Depot (km)	25
Truck load optimization from the e-fulfilment center to the Metro Depot	> 80%
Capacity of Metro microhub (parcel)	1000
Kg per parcel	2

Based on the Handbook on the external costs of transport (European Commission, 2020), Table 4 shows the value of the environmental and social costs per parcel (€) for each e-commerce delivery alternative analysed in the case study. Table 4 details the type and mode of transport generating externality, the unit in which the marginal cost is measured and the external cost per e-commerce package generated for each model.

Table 4. External cost per e-commerce parcel (LCV Vs. M4G) in Madrid LEZ

	External cost type	Mode	External cost unit	LCV model	M4G model
	Noise	LCV Euro 4 Diesel	1.7 €-cent/vkm	0.0206	
		HGV Rigid 20–26 t EIV	1.3 €-cent/tkm		0.0017
	Air pollution	LCV Euro 4 Diesel	4.19 €-cent/vkm	0.0509	
		HGV Rigid 20–26 t EIV	1.75 €-cent/tkm		0.0023
		Metro	1.14 €-cent/ train km		0.0005
Environmental	Climate change	LDV Euro 4 Diesel	2.58 €-cent/vkm	0.0313	
		HGV Rigid 20–26 t EIV	1.1 €-cent/tkm		0.0014
	Total Environmental (€/parcel)			**0.1028**	**0.0059**
	Accident	LCV Euro 4 Diesel	0.76 €-cent/vkm	0.0092	
		HGV Rigid 20–26 t EIV	0.1 €-cent/tkm		0.0001
		Cargobike	4.42 €-cent/vkm		0.0155
Social	Congestion	LDV Euro 4 Diesel	26.1 €-cent/vkm	0.3169	
		HGV Near capacity	34.9 €-cent/tkm		0.0349
	Total Social (€/parcel)			**0.3261**	**0.0505**

3.5. Operational cost per parcel.

Although this paper focuses on calculating external costs, it is essential to consider operational costs to be feasible. According to Melo, S., & Baptista, P. (2017), a 1:1 substitution ratio between Vans and cargo bikes can be assumed. In addition, Villa (2021) studied the costs of delivery by a multimodal system of Metro + cargo bikes in a city like Madrid, and the economic costs were between €2.30-2.33 per parcel. These costs, for the case of LCV delivery in 2019, were €2.07 and €2.27. The M4G model costs are very similar to current delivery costs (LCV).

4. Results and conclusions

Figure 4 details the externalities (environmental and social) of the two alternatives analysed and compares the total external cost per e-commerce delivered parcel in the central district of Madrid. Aggregating all externalities, the M4G model represents a very significant external saving compared to standard delivery with diesel vans. In particular, the external costs per LCV delivered parcel (0.4289 € per parcel) are 7.59 times higher than those generated by the M4G model (0.0564 € per parcel). The environmental externalities of the LCV model are 17.25 times higher than the M4G model. From a social point of view, the LCV model is 6.45 times more costly than the M4G model.

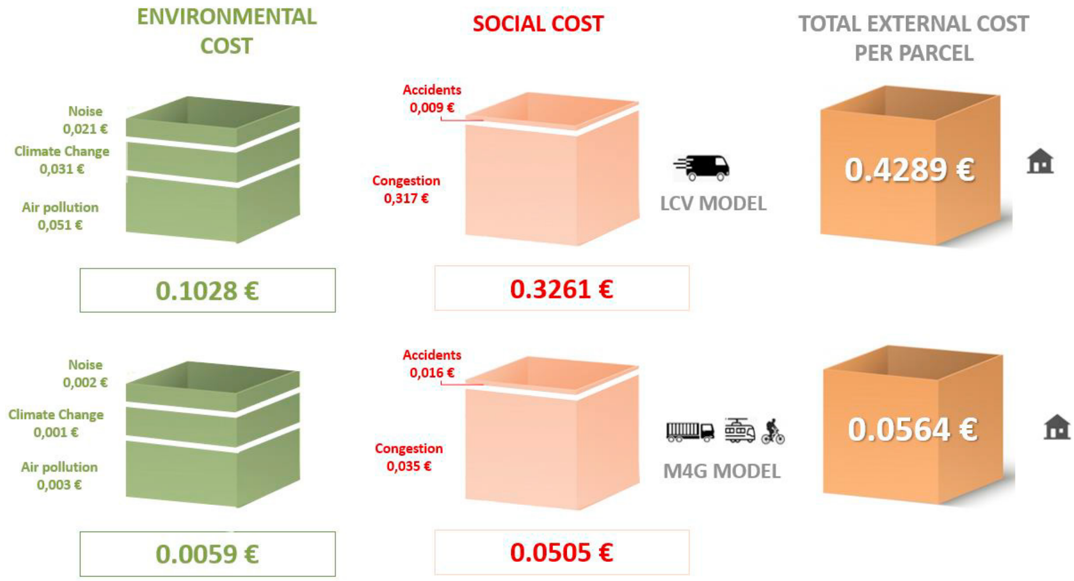

Fig. 4. External cost per parcel (LCV Vs M4G)

The item that produces the most considerable externalities in the LCV model is congestion, which accounts for ¾ of the total external costs in the LCV model. In the M4G model, the most significant weight of external costs also falls on congestion (61.4%) and it results from heavy trucks transporting parcels from the logistics centre to the metro depot. However, the M4G model drives vans out of the city centre, and, as a result, external congestion costs are only 11.04% of the total congestion costs of the LCV model.

In conclusion, this paper studies the alternative of using surplus or unused capacity in public passenger transport that can be used for goods distribution activities in the city. The results show that the alternatives of delivering e-commerce parcels to the customer's home using a multimodal system: HGV + dedicated trains + cargo bikes are a better social and environmental option than e-commerce delivery by vans (LCV). In order to implement the M4G model, a minimum volume of parcels is necessary to justify the use of Metro for logistics activities. In the case studied, the demand for e-commerce packages for the Madrid LEZ is sufficient to study the possibilities of the M4G model.

It would be essential to study in depth the economic costs of the M4G model in more detail and compare them with the current parcel delivery model. This study focuses on the environmental and social aspects of the problems faced by urban logistics. In addition, it would be recommended to analyse how the M4G model can affect city logistics in other areas: policy and regulation, new demands from e-commerce customers, and logistics operators' needs.

References

Ayuntamiento de Madrid (AMAD). (2021). Portal de datos abiertos del Ayuntamiento de Madrid. https://datos.madrid.es/portal/site/egob

Civitas. (2015). https://civitas.eu/es/about

Comisión Nacional de los Mercados y la Competencia (CNMC). (2021). Data.

http://data.cnmc.es/datagraph

Dampier, A. and Marinov, M. (2015). A study of the feasibility and potential implementation of metro-based freight transportation in Newcastle Upon Tyne. Urban Rail Transit, 1(3), 164-182. https://doi.org/10.1007/s40864-015-0024-7

European Commission. (2019). The European green deal (Document 52019DC0640).

https://eur-lex.europa.eu/legal-content/EN/TXT/DOC/?uri=CELEX:52019DC0640&from=EN

European Commission. (2020). Handbook on the external costs of transport: Version 2019-1.1. Oficina de Publicaciones de la Unión Europea.

http://op.europa.eu/en/publication-detail/-/publication/9781f65f-8448-11ea-bf12-01aa75ed71a1

International Post Corporation. (2020). Cross-Border E-Commerce Shopper Survey 2019. https://www.ipc.be/services/markets-and-regulations/cross-border-shopper-survey

Kotler, P. y Keller, K. (2012). Dirección de marketing (14.ª ed.). Pearson.

Leung, L. C., Waiman Cheung, y Yer Van Hai. (2000). A framework for a logistics e-commerce community network: The Hong Kong air cargo industry. IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans, 30(4), 446-455. https://doi.org/10.1109/3468.852438

Macharis, C. and Nocera, S. (2019). The future of freight transport. European Transport Research Review, 11(1), https://doi.org/10.1186/s12544-019-0359-3

Macharis, C. and Kin, B. (2017). The 4 A's of sustainable city distribution: Innovative solutions and challenges ahead. International Journal of Sustainable Transportation, 11(2), 59-71. https://doi.org/10.1080/15568318.2016.1196404

Marinov, M., Giubilei, F., Gerhardt, M., Özkan, T., Stergiou, E., Papadopol, M. y Cabecinha, L. (2013). Urban freight movement by rail. Journal of Transport Literature, 7(3), 87-116. https://doi.org/10.1590/S2238-10312013000300005

Melo, S., & Baptista, P. (2017). Evaluating the impacts of using cargo cycles on urban logistics: Integrating traffic, environmental and operational boundaries. European Transport Research Review, 9(2), 30. https://doi.org/10.1007/s12544-017-0246-8

Ontsi. (2022). El comercio electrónico B2C en España. Edición 2021.

https://www.ontsi.red.es/es/estudios-e-informes/Hogares-y-ciudadanos/El-Comercio-Electronico-B2C-en-Espana-2019-%28Edicion-2020%29

Taniguchi, E., Thompson, R. G. and Yamada, T. (2014). Recent trends and innovations in model-ling city logistics. Procedia, 125, 4-14. https://doi.org/10.1016/j.sbspro.2014.01.1451

World Economic Forum. (2020). The future of the last-mile ecosystem. https://www.weforum.org/reports/the-future-of-the-last-mile-ecosystem

Villa, R.. (2021). Alternativas sostenibles para la Logística urbana en la era del comercio electrónico: sistema M4G. Doctoral disertation, UCJC.