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Sustainable urban logistics: issues and impacts of economic, organizational and environmental optimization.

Ibrahim Savadogo

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Ibrahim SAVADOGO

Sustainable urban logistics.

Issues and impacts of economic, organizational and environmental optimization.

Devant le jury composé de :

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UNIVERSITÉ DE LYON
UNIVERSITÉ LUMIÈRE LYON 2
ÉCOLE DOCTORALE SCIENCES ÉCONOMIQUES ET DE GESTION

**SUSTAINABLE URBAN LOGISTICS : ISSUES AND IMPACTS OF
ECONOMIC, ORGANIZATIONAL AND ENVIRONMENTAL
OPTIMIZATION**

A THESIS PRESENTED BY
IBRAHIM SAVADOGO

IN FULFILLMENT OF THE REQUIEREMENTS
FOR THE DEGREE OF DOCTOR IN SCIENCES

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Lyon, France
March 28th, 2022

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Abbreviations

€	: Euro
AHGVs	: Articulated Heavy Goods Vehicle
BAU	: Business As Usual
BCR	: Benefit-Cost Ratio
CBA	: Cost Benefit Analysis
CO	: Carbon Monoxide
CO ₂	: Carbon Dioxide
EMD	: Enquête Ménages Déplacements
ETMV	: Enquête Transport de Marchandises en Ville
EU	: European Union
GHG	: Greenhouse Gas
GPS	: Global Positioning System
HCJ	: Daytime Off-Hours
HGV	: Heavy Goods Vehicle
HPAM	: Morning Peak Period
HPPM	: Afternoon Peak Period
IGN	: Institut Géographique national
INSEE	: Institut national de la statistique et des études économiques
LAET	: Transport Urban Planning Economics Laboratory
LEZ	: Low Emission Zone
LGVs	: Light Goods Vehicle
LMA	: Lyon Metropolitan Authority
LOM	: Loi d'Orientation des Mobilité
LUA	: Lyon Urban Area
LUTI	: Land Use and Transport Interaction
NO _x	: Nitrogen Oxides
NYC	: New York City
OD	: Origin Destination
OH	: Off - Hours
OHD	: Off - Hours Deliveries
PC	: Private Car
PCE	: Private Car Equivalency
PM	: Particulate Matters
RH	: Regular Hours
RHGVs	: Rigid Heavy Goods Vehicle
SMEs	: Small and medium enterprises
UDC	: Urban Distribution Center
UGM	: Urban Goods Movements
VKM	: Vehicle Kilometers
VOC	: Volatile Organic Compounds
VRP	: Vehicle Routing Problem

Abstract

This thesis is part of the research agenda on the need to propose relevant tools and methodologies for the ex-ante evaluation of measures implemented to improve the sustainability of urban logistics. The thesis approaches this problem by questioning the issues and the impacts of the measures at the economic, organizational, environmental and social levels for all the actors involved in urban logistics. The research is applied to off-hours deliveries (OHDs) and low emissions zones (LEZ), with the urban area of Lyon as a case study. The thesis is made of 3 distinct papers. The first paper proposes an evaluation of the environmental impacts of a large-scale adoption of OHDs. The second paper proposes an evaluation of the economic-environmental balance of a LEZ. The third paper presents a qualitative analysis allowing to understand in depth the issues of the OHDs and the LEZ for the actors and the way they integrate these two measures in their strategy. In the first chapter, coupling several simulation tools allows us to evaluate five scenarios of OHDs according to the percentage of deliveries to be shifted from regular to off-hours. The results show that the adoption of OHDs will have a positive but modest environmental impact on the whole Lyon urban area. The results analysis shows that OHDs lead to a maximum annual reduction in external costs related to pollution of about 4.25 million euros and a saving in travel time of 2.5 million hours per year. In the second chapter, in order to evaluate the economic-environmental balance of the LEZ in Lyon, a cost-benefit analysis was performed to balance the environmental gains from pollution reduction against the costs of renewing vehicles that do not comply with the LEZ requirements. The benefits and costs were obtained through the coupling of a transport demand simulation model, a delivery route simulation model, and an emissions model, all of which were fed by processing data from urban goods movement surveys. According to the NPV criterion, the results show that the LEZ scheme implemented in the city is a second best. The socio-economic balance of this scheme can be improved by extending the LEZ perimeter to Greater Lyon. The NPV analysis shows that over the first five years of implementation, in none of the LEZ schemes investigated do the benefits of reduced pollution offset the costs of vehicle renewal. In the third chapter, the analysis of interviews with various urban logistics actors allows an in-depth understanding of the issues raised by the two measures (OHDs and LEZs) for the actors, and the way in which they integrate them into their strategy. The results show that, in addition to traditional aspects - cost-benefit, route optimization and profitability of activities - competitive issues are central to the actors' concerns: (i) the largest actors with significant *financial power* see in these measures the opportunity to increase their market share. They therefore do not hesitate to use their *power of influence* to obtain from the public authorities a tightening of the measures in the urban area, in order to oust weaker competitors with little *financial power*. (ii) for the smaller, more fragile actors, these measures are perceived as constraints and threats to which they cannot always adapt because of their weak *financial power*. Their strategies are more defensive, and their survival is sometimes threatened. (iii) public authorities, at the various levels - national and local - must not be naive in their understanding of these competitive issues and must play a central role in ensuring that the implementation of measures does not constitute an opportunity for predation by actors with high power on actors with low power.

Keywords: Sustainable urban logistics; *ex ante* impact evaluation; Off-hours deliveries; Low emissions zone.

Résumé

Cette thèse s'inscrit dans l'agenda de recherche sur la nécessité de proposer des outils et méthodologies pertinents d'évaluation *ex ante* des mesures déployées pour l'amélioration de la durabilité de la logistique urbaine. La thèse aborde cette problématique en ayant la particularité d'interroger les enjeux et les impacts des mesures tant au niveau économique, organisationnel, environnemental et social pour l'ensemble des acteurs impliqués dans la logistique urbaine. L'application de la problématique est faite sur les livraisons en horaires décalés (LHDs) et la zone à faibles émissions (ZFE), avec l'aire urbaine de Lyon comme cas d'étude. La thèse se compose de trois papiers distincts. Le premier papier propose une évaluation des impacts environnementaux d'une adoption à grande échelle des LHDs. Le second papier propose une évaluation du bilan économique-environnemental d'une ZFE. Le troisième papier présente une analyse qualitative permettant de comprendre en profondeur les enjeux des LHDs et de la ZFE pour les acteurs et la manière dont ils s'emparent de ces deux mesures dans leur stratégie. Dans le premier chapitre, le couplage de plusieurs outils de simulation permet d'évaluer cinq scénarios de LHDs suivant le pourcentage de livraisons à reporter des horaires réguliers aux horaires décalés. Les résultats montrent que l'adoption des LHDs aura un impact environnemental positif mais modeste sur l'ensemble de l'aire urbaine de Lyon. L'analyse des résultats montre que les LHDs conduisent à une réduction annuelle maximale des coûts externes liés à la pollution de l'ordre 4.25 millions d'euros et d'une économie des temps de trajets de 2.5 millions d'heures par an. Dans le second chapitre, afin d'évaluer le bilan économique-environnemental de la ZFE de Lyon, une analyse coût-bénéfice a permis de mettre en balance les gains environnementaux liés à la réduction de la pollution et les coûts liés au renouvellement des véhicules non conformes aux exigences de la ZFE. Les gains et les coûts ont été obtenus à travers le couplage d'un modèle de simulation de la demande de transport, un modèle de simulation des tournées de livraison, et un modèle d'émissions, le tout alimenté par des données issues du traitement des enquêtes sur le transport de marchandises en ville (ETMV). Suivant le critère de la VAN, les résultats montrent que le schéma de ZFE mis en place par la métropole est un second best. Le bilan socioéconomique du schéma peut être amélioré en élargissant le périmètre de la ZFE jusqu'aux limites du Grand Lyon. L'analyse de la VAN montre que sur les cinq premières années de mise en œuvre, dans aucun des schémas de ZFE étudiés, les bénéfices retirés de la baisse de la pollution ne compensent les coûts liés au renouvellement des véhicules. Dans le troisième chapitre, l'analyse des entretiens avec divers acteurs de la logistique urbaine permet une compréhension profonde des enjeux que soulèvent les deux mesures (LHDs et ZFE) pour les acteurs, et la manière dont ils s'en emparent dans leur stratégie. Les résultats montrent, qu'au-delà des aspects traditionnellement évoqués - bénéfiques-coûts, optimisation des tournées, rentabilité des activités - les enjeux concurrentiels sont au cœur des préoccupations des acteurs : (i) les plus grands acteurs dotés d'un pouvoir financier important voient dans ces mesures l'opportunité d'accroître leurs parts de marché. Ils n'hésitent donc pas à utiliser leur *pouvoir d'influence* pour obtenir des autorités publiques un durcissement des mesures sur le territoire urbain, afin d'évincer les plus faibles concurrents ayant un *pouvoir financier* faible. (ii) pour les plus petits acteurs, plus fragiles, ces mesures sont perçues comme des contraintes et menaces auxquelles ils ne peuvent pas toujours s'adapter du fait de leur faible *pouvoir financier*. Leurs stratégies sont plus défensives, et leur survie parfois menacée. (iii) les pouvoirs publics, aux différents niveaux, communautaire, national, local, doivent sans naïveté appréhender de manière fine ces enjeux concurrentiels et jouer un rôle central en veillant à ce que la mise en place des mesures ne constitue pas des occasions de prédation des acteurs ayant un *pouvoir* élevé sur les acteurs ayant un faible *pouvoir*.

Mots clés : Logistique urbaine durable ; Evaluation d'impacts *ex ante* ; Livraisons en horaires décalés ; Zone à faibles émissions

INTRODUCTION

Context

Urban logistics, defined as the art of moving goods in, out and within the city in the best possible conditions (Patier and Routhier, 2009), is a good indicator of a city's economic dynamism. Through the incoming, outgoing and internal flows of a city, it is possible to draw a picture of the consumption and production levels of the city. The more the city's need for goods increases, the greater the flows. This increase in flows creates more difficulties in urban mobility, as infrastructure capacities are limited and passenger mobility shares these same capacities with goods mobility. The findings of the last few years show a growth in urbanization and a rapid increase in e-commerce with its corollary, the multiplication of home deliveries. These two factors together are sources of an increase in flows (Gardrat, 2021), an increase in the number of parcels and a decrease in the size of deliveries (Rodrigue, 2020). Unfortunately, this configuration makes urban logistics a generator of nuisances, because the increase in vehicle routes for deliveries and pick-ups leads to congestion, road occupation, noise, pollution, road insecurity, etc. (Taniguchi et al., 2016). As an illustration in France, for the emission generated by urban transport, urban goods movement (UGM) is responsible for about 15% of greenhouse gas (GHG) emissions, and about 40% of NO_x and 50% of particulates (Albergel et al., 2006; CERTU, 2013). Focusing on the case of the Paris region, Coulombel et al. (2018) find that UGM accounts for 20% of CO₂ and 30% of NO_x and PM emitted by road traffic while it represents only 8% of distances traveled.

However, this “chaos” caused by freight flows in urban areas is less and less considered as an inevitability linked to the growing metropolization of societies (Chanut et al., 2012). Indeed, in recent years, there have been strong demands from the population for more action from public authorities to reduce the nuisances generated by transport in general and urban freight transport in particular. Issues related to urban logistics are increasingly integrated by local authorities in city planning. This is reflected in the inclusion of measures to reduce the nuisance generated by urban logistics in their projects and planning documents. It is becoming imperative for the public authorities in charge of cities to continuously guarantee the attractiveness of urban areas for both residential and productive (tertiary, secondary and even primary) functions. Efficient urban logistics is a source of greater attractiveness and productivity for an urban area (Taniguchi et al., 2014). The attractiveness for residence is closely related to the quality of the living

environment, measured by, among other things, the level of pollution, noise, immediate accessibility for residents to a wide range of products. Competing with each other to attract residents, businesses and sometimes tourists, cities have committed themselves to *sustainable city* projects. Thus, the management of urban logistics is now considered as an element of *territorial marketing*.

Actions to reduce the nuisances generated by urban logistics are diverse. Ogden (1992) in his seminal research identified six classes of urban freight management measures, related to: network (dedicated infrastructure and other prohibitions); parking and loading/unloading operations; location of activities and land use planning; permits and regulations; pricing (roads, parking, etc.); and terminals and intermodal facilities. Over time, several other categorizations have been proposed, depending on the needs of the analyses that were to be carried out, the perceived relevance of the measures, or the emergence of new measures. PIPAME (2009) distinguishes five classes of measures in the form of levers to be activated in order to deal effectively with the problems caused by urban logistics. These are: action on pooling, vehicles, logistics real estate, delivery vehicle reception and commercial structure. Russo and Comi (2010), focusing on the measures applied in European cities as a result of various projects and programs aimed at improving UGM, propose four categories of measures relating to: physical infrastructure (linear and surface); non-physical infrastructure (telematics or ITS); equipment (transport unit and handling equipment); and traffic governance (regulations in force). Allen et al. (2010) identify seven categories of measures across the literature: infrastructure management; parking/loading area management; vehicle strategies; traffic management; pricing, incentives, and taxation; logistics management; and freight demand/land use. Patier (2011) summarizes the categories of measures under the heading of *good practices* for urban logistics that could be found through regulation, shared use of roads, modal shift and mutualization, with a declination of adapted urban logistics spaces. Gardrat (2017) outlines four levers through which public authorities can act on UGM to make it sustainable: land use and space; regulation of practices; construction and management of infrastructure; and economic and financial incentives.

The categories of measures proposed in the literature cover more or less the same aspects of freight transport supply and demand and their interaction with the territory.

The implementation of these measures may disturb the existing economic, organizational and social equilibrium. Indeed, the urban segment of freight transport accounts for only 1% of the

cargo route, but it can represent up to 25% of logistics costs (CERTU, 2013). Thus, acting on this segment through the adoption of measures to reduce its nuisances can very quickly have an economic and even social impact on the overall city (for producers and consumers).

Urban logistics involves a diversity of actors who differ both in their characteristics and in their objectives. The implementation of measures in urban logistics impacts these actors differently and raises issues of varying magnitude for each of them. Indeed, while for some the implementation of a measure is a constraint that they can overcome by modifying their organization, for others the same measure may threaten their survival in the economic sphere. It is therefore essential that, upstream of the implementation of any measure, an inventory be made on: the actors involved, their characteristics, their objectives, and the issues raised by the measure for each category of actor. This holistic approach makes it possible to identify the systemic character of urban logistics and the dynamics of interactions between actors in the presence and absence of a measure. This inventory should serve as a basis for a relevant *ex ante* evaluation of the impacts of each measure, both on the environment in which it is implemented and on all the actors involved. This must be the posture of the “*benevolent planner*”. To do this, there is a need for relevant evaluation tools and methodologies. The complexity of the task and the relative unknowledge of the sector have often led researchers and practitioners to adopt a partial approach in *ex ante* impact evaluations of measures. This consists of evaluating the measure: through a single effect (most often environmental, sometimes economic, organizational and social); for a part of the actors involved; on a limited scale; without fully considering the inter-organizational and often competitive dynamics within actors. Some measures are not subject to any *ex ante* study before being implemented.

Several studies have highlighted the need to produce relevant *ex ante* evaluation tools and methodologies to inform decision-making regarding the choice of measures to be implemented (Dias et al., 2016; Filippi et al., 2010; Russo and Comi, 2011b). In the absence of such tools and methodologies, for the implementation of UGM measures, public authorities have often not carried out the *ex ante* evaluation (Filippi et al., 2010) or have carried it out in a non-in-depth manner (Lindholm, 2012). As a result, measures were found to be ineffective and/or inoperative, or evidence of their effectiveness in reducing the negative impacts of UGM could not be established (Filippi et al., 2010; Lindholm, 2012).

According to the literature, the main reasons for not carrying out *ex ante* evaluations or carrying them out in a superficial manner can be found at two levels. Russo and Comi (2011b) point out that performing a good *ex ante* evaluation requires a simulation model that is both relevant for simulating the current situation but also for predictive analysis. They note that many models do

not sufficiently perform the second function and are not very effective in evaluating the potential impacts of measures. The second level is the availability of large-scale data. Indeed, the scarcity of data on UGM at the urban scale is mentioned as a difficulty by several studies (Crainic et al., 2004; Kanaroglou and Buliung, 2008; Muñuzuri et al., 2012). Data is a big issue because collecting accurate data is often costly and difficult to do (Muñuzuri et al., 2012). In addition, it is often necessary to combine several data collection methods (stakeholder interviews, traffic count data, in-vehicle survey, etc.) in order to develop effective models for decision making (Ambrosini et al., 2010).

Considering these difficulties and the issues raised by the implementation of measures for all actors involved, it is more than necessary that research can provide innovative and relevant methodologies to help decision-making. This thesis is part of this trend. Before introducing the central research problem of the thesis, it is appropriate to present the vision of sustainability pursued by the implementation of the measures through: a presentation of the different actors involved in urban logistics through their characteristics and their objectives; explain regarding their objectives, what they will understand by sustainable urban logistics; and synthesize to establish our vision of sustainability in this thesis, which fits into the posture of the *benevolent planner*.

What is sustainable urban logistics?

To answer this question, it is appropriate to first present the actors who are impacted by measures aimed at achieving sustainable logistics. Given the diversity that characterizes these actors, several groupings are possible and identifiable through the literature. In this thesis we choose to group them according to two spheres: public and private.

The actors of urban logistics and their interactions

The public sphere includes public authorities, such as State and local authorities (regional, departmental, communal), as well as representatives of users of the public space and civil society. In a larger dimension, this public sphere can include Supranational authorities, such as the European Union Commission, which has the capacity to adopt directives that are then transposed into national legislation. In the private sphere, we can distinguish, through their main function (Production vs. Consumption) two groups of actors directly involved in urban logistics. The first includes professionals: shippers, logistics service providers, transporters, and

receiving establishments. The second group includes the final consumers: residents, customers, tourists, etc.

There are interactions between actors in the same sphere, but also across the two spheres. On the one hand, there are mainly goods flows between the different groups of actors. On the other hand, there are the decisional flows that govern and impact the relationships between groups of actors, as well as their activities. Unlike the goods flows, the decisional flows are almost unidirectional. They are strongly dependent on the power that each group of actors has over the others, but also on the prerogatives of each of them. For example, decisions taken by actors in the public sphere (State and local authorities) are imposed on those in the private sphere through their activities. This distribution of power can be found within groups of actors in the same sphere. For example, for professional actors, the distribution of power determines to a greater or lesser extent their ability to impose their decisions on their partners in business relationships.

What are the issues of logistics for the groups of actors

Urban logistics raise a variety of issues including economic, environmental, social, societal, functional, regulatory, political, competitive and spatial issues. These different issues reflect the specific objectives and interests pursued by the different groups of actors involved in urban logistics. For public actors, the main objective is the pursuit for collective well-being, through the reduction of nuisances generated by urban logistics (congestion, noise, pollution, energy consumption, accidents), while taking care not to penalize urban areas. This means: controlling logistics costs since they influence the final cost of goods; maintaining jobs, if not creating them (social issue); guaranteeing economic development and a good quality of life.

Within the private sphere, the objectives, interests and demands are very diverse. For professional actors, the objective can be summarized as the pursuit for economic efficiency, i.e., cost control while improving the quality of service, since it should be emphasized that the sector remains highly competitive. These actors pay attention to the environmental issues, but this does not seem to be of primary importance.

The interests of the final consumers are focused on the need to access the products they need in the vicinity (functional issue) and at the best price (economic issue). They also have demands regarding noise, road safety and pollution generated by the transport of goods (environmental issue).

The contradiction in the objectives pursued by the actors in the private sphere can be materialized as follows. Carriers aim to deliver/collect goods in the best conditions of time and cost in order to meet their customers' (shippers, receivers) needs. To do so, they have an interest in access to and availability of delivery/pick-up areas. However, they must often comply with the requirements of their customers (receivers), for example with regard to delivery schedules. This reduces their flexibility in terms of optimizing their tours and also increases the inconvenience they cause to residents and other road users during delivery/pickup operations. As for the receivers, their objective is to have the right product delivered, at the right time, at the lowest cost. They have an interest in fulfilling this objective in order to satisfy their customers (local residents, tourists). This example illustrates the systemic nature of the issues that govern the relationships between the different groups of actors in urban logistics.

Considering this, it seems obvious that the concept of sustainability of urban logistics will be perceived in different ways by the actors, depending on the group they belong to. It can be observed that the economic, social and environmental aspects, which are included in the concept of sustainability, do not appear in the same way in the objectives of the different actors.

The concept of sustainability in urban logistics

Based on the objectives pursued by the different groups of actors outlined above, we propose in this thesis to translate the definition of urban logistics proposed by Patier and Routhier (2009) into the objectives of the groups of actors. We consider that the public actor group acts in the interest of the private consumer group, since the former derive their legitimacy mainly from the vote of the latter. Thus, for the group of private consumer actors (residents, customers, visitors) and public authorities, the sustainability of urban logistics refers to the question: "*how to ensure the flow of goods into, out of and within the city, while keeping the total social cost (the sum of private costs and costs related to externalities) as low as possible?*". For the group of private professional actors (producers), the question is the same as for the previous ones, with the difference that for them it is the *minimum of private costs* that is primordially sought.

The search for the sustainability of urban logistics also mobilizes attention beyond the groups of actors directly involved in the two spheres. Indeed, scientific researchers are paying attention to the issue, at least at a double point. On the one hand, there is the need to develop and propose measures that respond adequately to the question posed by the city's actors. Thus, their question can be summarized as follows: "*what measures will be effective in ensuring the flow of goods*

into, out of, and within the city, while keeping the resulting total social cost as low as possible?”

On the other hand, there is a need to develop and propose relevant tools and methodologies for evaluating (*ex ante* and *ex post*) the impacts of these measures. In this thesis, we position ourselves at these two points, since the answer to the first point is largely found in the second point: relevant tools and methodologies for evaluating the impacts of measures.

From a generic point of view, *sustainable urban logistics* is the application of the concept of sustainable development to the urban logistics sector. Thus, the search for the minimum total social cost in the urban logistics sector refers to the search for triple economic, social and environmental efficiency. More specifically, based on the common definition of sustainable development¹ and the definition of urban logistics proposed by Patier and Routhier (2009) in this thesis we will understand sustainable urban logistics as “*the art of moving, with economic, environmental and social efficiency, the flows of goods that enter, leave and circulate in the city.*” Thus, in this thesis, we choose to approach sustainability as a pathway (Goldman and Gorham, 2006), rather than as an end-state (Goldman and Gorham, 2006).

It is therefore a question of making urban logistics *more sustainable*. This suggests a relative sustainability that is sought over time and space. The complexity of urban logistics and its dynamic nature require that sustainability objectives be set from one step to the next and revised as urban dynamics evolve. Such an approach to sustainability seems to us to be more appropriate to address the issues related to urban logistics, given the importance of the latter for life in the city and, by extension, for countries, since cities will concentrate about 75% of the world's population by 2050.

From the above, it would be appropriate to dissociate the three types of efficiency pursued in the search for sustainability of urban logistics: economic, environmental and social. In this thesis, economic (or environmental or social) efficiency of urban logistics is defined as the reduction of economic (or environmental or social) costs generated by urban logistics, while maintaining or improving the quality of service. Thus, when an improvement is achieved for one type of efficiency, we will consider it as an improvement of the sustainability of urban logistics, provided that the other two types of efficiency are not degraded or corrective actions are applied to mitigate their degradation. Such an approach to sustainability is consistent with that proposed by Allen et al. (2010), who consider that efforts to increase the sustainability of

¹ Definition from Brundtland Report: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (CMED, 1987).

urban logistics can focus on improving one or more of the economic, social or environmental impacts of its activities, without worsening the impact of the others.

In order to evaluate the impacts of measures to be implemented or already implemented, several types of indicators are available. Throughout the literature, there is a wide list of indicators that can be used to evaluate the sustainability of urban logistics (Anderson et al., 2005; Awasthi and Chauhan, 2011; Gonzalez-Feliu et al., 2014; McKinnon et al., 2010; Melo and Costa, 2011; Omrani and Gerber, 2009, 2009; Patier and Browne, 2010; Quak, 2008; Russo and Comi, 2011a). From an economic perspective, these include operational costs, logistical costs, and return on investment. For environmental considerations, these include emissions of local pollutants and GHGs, as well as noise. From a social perspective, we can find the rate of stress management, the rate of night work, the level of safety at work, the rate of accidents. Although there is a tendency to look for a standard list of indicators (Patier and Browne, 2010) to be used in (*ex ante* and *ex post*) evaluations of urban logistics measures, it must be recognized that in practice there is a need to choose only a few. This choice may be guided by the evaluation methodology used, data availability constraints, the relevance of indicators, the nature of the measure being evaluated, or the focus of the evaluation. However, the evaluation must be able to consider the main impacts that the measure to be implemented might have. This is in order to achieve a balance that integrates both the benefits and the costs generated by the implementation of the measure. Thus, if the benefits generated by the measure for one of the three aspects of sustainability do not compensate for the costs generated for the other two, we would have an idea of the extent of the corrective action required to ensure the sustainability of the measure.

Research problem

We have observed that a large number of cities in Europe and the Americas are implementing measures to improve the sustainability of urban logistics. The context presented in the first section has shown that the implementation of measures suffers from a lack of relevant *ex ante* evaluation to guarantee the achievement of the objective of improving the sustainability of urban logistics. Putting these facts in perspective with the scope of the issues raised by urban logistics for the groups of actors involved, we agree with several authors (Dias et al., 2016; Filippi et al., 2010; Russo and Comi, 2011b) that there is an urgent need to propose relevant tools and methodologies to inform decision making in the implementation of these measures. The central research problem of this thesis are part of researches that contribute to filling this

need. By questioning the relevance of tools and methodologies, the research problem has the particularity of questioning the issues and the impacts of the measures to be deployed at the economic, organizational, environmental and social levels for all the actors involved. In order to apply the central research problem of the thesis to specific cases, we choose to focus on two of the most widely deployed measures (Allen et al., 2010) in Europe and the Americas: off-hours deliveries (OHDs) and low emission zones (LEZ). Briefly defined, OHDs involve postponing deliveries to periods when urban traffic is less dense, outside peak passenger traffic periods (Holguín-Veras et al., 2016; Mommens et al., 2018; Savadogo and Beziat, 2021; Verlinde, 2015). A LEZ is a defined geographic area into which only vehicles meeting certain emissions standards can access (Allen et al., 2010; Browne et al., 2005; Watkiss et al., 2003). Applying these two measures, the research problem is broken down into three research questions that are investigated in three scientific papers that form the thesis manuscript:

- **RQ1:** What are the potential environmental impacts of a large-scale adoption of shift deliveries?
- **RQ2:** What is the economic-environmental balance of the implementation of a LEZ?
- **RQ3:** What are the issues raised by the OHDs and the LEZ as measures for urban logistics actors and what changes can be observed in their strategy when facing these two measures?

The choice of these two measures is motivated by four main reasons. First, there is the widespread deployment of these two measures or projects in Europe and the Americas. There are currently over 200 LEZs across Europe. OHDs have also been piloted or implemented in many cities on both continents (Lyon, Paris, Barcelona, New York, Bogota, Sao Paulo, etc.). Second, in terms of analyses, the two measures are quite distinct. While they are both driven by public authorities, OHDs generally emerge as a suggested measure, while LEZs are an imposed measure. Third, the main issue that each of the measures raises for the actors involved. OHDs raise primarily organizational issues, while LEZs raise economic issues. Fourthly, the challenge of evaluating the impacts of these two measures *ex ante*. This last reason is purely methodological. Most *ex ante* evaluations of OHDs have been done on a small scale and their results extrapolated (Sánchez-Díaz et al., 2017). Therefore, we find it interesting, useful and relevant to propose an approach to evaluate the potential impacts of OHDs at different scales (small, medium and large). For LEZs, the relative unknowledge of urban freight transport has been a handicap for the few previous studies on the *ex ante* evaluation of LEZs regarding this transport. The availability of urban freight survey data and tools that are the result of several

years of knowledge production by the researchers of Transport Urban Planning Economics Laboratory (LAET) provides an opportunity to tackle LEZ issues in a comprehensive manner. The thesis develops an original hybrid methodological approach that combines quantitative and qualitative approaches from economics, management science and business administration. All the impacts evaluated are always translated into monetary values and/or cost-benefit analysis over several periods. The thesis uses simulation and data generation tools such as SIMBAD (Nicolas et al., 2009) for the estimation of passenger transport demand, FRETURB (Routhier and Toilier, 2007) for the estimation of freight transport demand, SIMTURB (Gardrat and Pluvinet, 2021) for the simulation of vehicle routes, VISUM for the simulation of traffic conditions, and COPERT V (Ntziachristos et al., 2009) for the calculation of emissions. These tools are essential and are at the core of the quantitative methodological approach of this thesis. Next to these tools, the analysis of large-scale survey data (Toilier et al., 2015) allows to produce a fine knowledge of urban freight transport characteristics, anything that is paramount for the understanding of the current situation but also for the forecasting. A qualitative approach adopted from the management sciences and business administration allows the thesis to better address in depth some phenomena that the quantitative approach via simulations fails to capture alone. To do so, we follow an original methodological approach based on the theoretical framework of the political economy of channels (Reve and Stern, 1986; Stern and Reve, 1980). From this theoretical framework, a material of 19 interviews with a variety of urban logistics actors was analyzed through a *thematic content analysis* (Mucchielli, 1984), following an *interpretivist approach*. The combination of these approaches allowed for a more in-depth analysis and understanding of the impacts and issues of the two measures for the actors involved, and to provide useful information for decision-making. This increases the chances of having a better efficiency of the urban logistics measures during their deployment, but also to foresee the necessary adjustments during their implementation.

The case study chosen to investigate this research problem is the city of Lyon or, more broadly, the Lyon urban area. The choice of the urban area of Lyon as a case study has a triple interest. First of all, the city of Lyon is committed to improving ambient air quality, in particular by acting on the UGM. The city of Lyon has been experimenting with various urban logistics measures for 20 years. It has drawn up a 2017-2030 Urban Transport Plan which provides for the study, experimentation and eventual implementation of several types of initiatives including: off-hours deliveries and a low emission zone (SYTRAL, 2017). Evaluating the potential impacts of these two measures on this perimeter would therefore be useful for decision making. Second, the availability of data at the scale of the Lyon urban area is facilitated by the

fact that the modeling tools used in this thesis have been calibrated to this scale. Finally, the urban area of Lyon is the second largest in France after Paris. It represents 1,916,149 inhabitants, 275,687 businesses and 3,325 km².

Thesis contribution

In order to propose *an ex ante* socio-economic evaluation of the sustainability of urban logistics measures in the urban area of Lyon, the thesis manuscript is structured around three papers already published (Chapter 1) or in the process of submission (Chapters 2 and 3) in international peer-reviewed journals. In order to allow the reader to understand the contributions of this thesis and the way in which they are articulated to answer the questions of the research problem, we present below each of the three papers that compose the manuscript

Contribution 1

Chapter 1²: Evaluating the potential environmental impacts of a large scale shift to off-hour deliveries

This paper builds on the fact that very few studies have focused on large-scale evaluation of the impacts of off-hours deliveries (Bertazzo et al., 2016; Delaître, 2010; Holguín-Veras et al., 2016; Niches, 2006; STRAIGHTSOL, 2014). Most of the studies were conducted on a small scale and yielded promising results. These results suggest that large-scale adoption of OHDs will have significant positive environmental impacts for urban areas. On this basis, OHDs are among the measures proposed to improve the sustainability of urban logistics and are included as a measure in the urban mobility plans of several cities. However, their implementation raises organizational, financial and social issues for all actors involved in urban logistics. Before adopting OHDs on a large scale, it is therefore necessary to ask whether the benefits obtained will be sufficient to compensate for the possible costs generated by the issues mentioned above. Thus, the objective of this paper is to answer the following question: ***does postponing a large share of goods movements during the off-hours leads to a significant reduction of freight-related emissions?***

We propose, using modeling tools, a simulation evaluating the potential of OHDs to reduce the emissions generated by urban freight movements in the Lyon urban area. Based on the

² This chapter is an edited version of the following article: Savadogo, I., Beziat, A., 2021. Evaluating the potential environmental impacts of a large scale shift to off-hour deliveries. *Transportation Research Part D: Transport and Environment* 90, 102649. <https://doi.org/10.1016/j.trd.2020.102649>

percentage of freight movements postponed to off-hours, five scenarios have been studied. Focusing on CO₂ emissions and four local pollutants (PM, NO_x, VOC, and CO), the results of this research show that OHDs have a positive environmental impact for the Lyon urban area. The results also show that OHDs have a greater impact when deployed in the densest areas of the urban area. The impact of OHDs in the Lyon urban area is relatively small compared to those found by other research conducted on larger, more congested cities (Holguín-Veras et al., 2016). Our research confirms that OHDs have a smaller impact when deployed in relatively small, low-congestion areas. The results of this research are useful to the local authority in that they inform decision-making by providing an overview of the potential gains that could be made from large-scale adoption of OHDs.

Contribution 2

Chapter 2: Environmental and economic evaluation of a low emission zone for urban freight transport

The European Commission's Directive 2008/50/EC requires local authorities to guarantee a certain ambient air quality by setting pollution exposure thresholds that must not be exceeded. This requirement partly explains the increasing number of LEZs set up in European cities in recent years. Indeed, there are more than 200 LEZs across Europe (Mudway et al., 2019; Sadler Consultants Ltd, 2019). This trend is also observable in France with several projects of LEZs in several large and medium-sized cities in the country. Lessons learned from several already implemented LEZs show that LEZs can result in environmental impacts that are sometimes positive, sometimes nil or insignificant (Holman et al., 2015; Jiang et al., 2017; Watkiss et al., 2003). Several factors have been cited to explain the mixed impacts of previously implemented LEZs, including the greater or lesser tightness of the standards (Boogaard et al., 2012) and the size of the area covered (Invernizzi et al., 2011). In addition to these factors, there are also methodological difficulties that would impact the accuracy of predicted outcomes in *ex ante* evaluations. These difficulties include the data on the vehicle fleet (André et al., 2018, 2017), the use that is made of the fleet, the dynamics in the evolution of the fleet (Ellison et al., 2013). The implementation of a LEZ has important financial and organizational impacts for private and public actors. The pursuit of socio-economic efficiency in public action now requires that, prior to the implementation of a LEZ, its impacts in terms of costs and benefits for all the actors involved can be evaluated in a relevant manner. The objective of this paper is to answer the

following question: *What is the economic-environmental balance of the implementation of a LEZ?*

To answer this question, we have estimated the demand for freight transport by coupling two tools, the first, FRETURB (Toilier et al., 2018), allowing the simulation of transport demand in OD matrix format, the second, SIMTURB (Gardrat and Pluvinet, 2021), allowing from Markov chains to characterize this demand in the form of delivery tours. The processing of data from the UGM surveys has made it possible to characterize the vehicle fleet by size, age, and use, among other things. These data allowed us to identify the behavior of the actors in terms of transport and to build delivery tours that are as close as possible to reality. From a cost-benefit analysis, we can evaluate the economic and environmental balance of several LEZ scenarios by comparing the benefits related to the reduction of pollutant emissions with the costs related to the fleet renewal. Applied to the LEZ of Lyon, our results show that the LEZ scheme implemented in the city of Lyon since January 2020 could be improved for more collective efficiency. This research has methodological and practical interest in helping the local authority in its decision making when it comes to changing the scheme of its current LEZ.

Contribution 3

Chapter 3: Stakeholders' strategies towards two urban logistics innovations

Urban logistics is characterized by its multi-actor nature, as it involves and impacts several groups of actors whose objectives may be different and often conflicting. The pursuit of a more sustainable urban logistics implies finding an equilibrium that reconciles the expectations of the different groups of actors. Among the measures implemented for a more sustainable urban logistics, we are interested on the one hand in the OHDs as a suggested measure and in the LEZ as an imposed measure. These two measures have an inter-organizational character since they influence, impact and concern several actors at the same time, and in a different way. They therefore raise different issues from one actor to another, depending on their own characteristics. In view of this, actors will not have the same reaction towards these measures in terms of perceived advantages and disadvantages, adoption investments, obstacles to overcome, organizational changes, integration into the strategy. We found that most previous studies on these two measures have addressed issues mainly related to their operational implementation and environmental and economic impacts (Cesaroni et al., 2012; Holguín-Veras, 2008; Holman et al., 2015; Sánchez-Díaz et al., 2017; Watkiss et al., 2003). Based on this observation, we believe that there is a need to *understand in depth the issues of these two*

innovations for urban logistics stakeholders, and how these stakeholders integrate these innovations into their strategy. In particular, we seek to identify the issues for the groups of stakeholders of these innovations in terms of power and competition.

For the analysis of the issues, we used an original methodological approach based on the theoretical framework of the political economy of channels (Reve and Stern, 1986; Stern and Reve, 1980). This approach allowed the construction of an analytical grid characterizing the actors and the issues. The approach being qualitative, it is based on a set of 19 interviews with a diversity of urban logistics actors in the Lyon urban area, and secondarily on a documentary review. The *thematic content analysis*, using an *interpretivist* approach, showed that beyond the cost-benefit aspects of the two measures, competitive issues are central to stakeholders' concerns: (i) the largest actors with significant financial power see in these measures the opportunity to increase their market share. They therefore do not hesitate to use their power of influence to obtain from the public authorities a tightening of the measures in the urban area, in order to oust weaker competitors with little financial power. (ii) for the smaller, more fragile stakeholders, these measures are perceived as constraints and threats to which they cannot always adapt because of their weak financial power. Their strategies are more defensive, and their survival is sometimes threatened. (iii) public authorities at different levels - community, national and local - must not be naïve in their understanding of the competitive issues and play a central role in ensuring that the implementation of measures does not constitute an opportunity for predation by actors with high power on actors with low power.

Thesis outline

The thesis manuscript is organized in three chapters. Each chapter addresses one of the three specific research questions. Since we are investigating two sustainable urban logistics measures, the first two chapters respectively offer an analysis on OHDs and LEZ. Chapter 1 evaluates the environmental impacts of a large-scale adoption of OHDs. Chapter 2 proposes an economic-environmental evaluation of the implementation of a LEZ. Chapter 3 provides an analysis to understand in depth the issues of these measures for the actors and how they integrate them into their strategy. In this thesis, the term “innovation” used in Chapter 3 is synonymous with the term “measure”. The sequence of the chapters is not the sequence in which they were produced. In fact, the interviews started very early and fed into Chapters 1 and 2, even though it is in the chapter that they are analyzed in detail. Each chapter has been inserted into the manuscript as it was published or as it will be submitted to a journal. The general conclusion

recaps the main contributions of the thesis, presents some policy recommendations, discusses the limitations of the thesis, and outlines future research directions.

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CHAPTER 1

EVALUATING THE POTENTIAL ENVIRONMENTAL IMPACTS OF A LARGE SCALE SHIFT TO OFF-HOUR DELIVERIES³

1. Introduction

Urban areas are highly exposed to pollutant emissions (UN-Habitat, 2015). For example, it is estimated that 40% of the population in the centre of Lyon's Urban Area (LUA), the second French conurbation, are frequently exposed to regulatory threshold exceedances: 69 days at more than 50 µg/m³ of PM₁₀ in 2013 when the maximum should be of 35 days/year (SYTRAL, 2017). Considering the sanitary risks related to environmental pollution, it is urgent to find solutions to decrease these emissions. One available lever is to regulate the transport sector, which has been steadily increasing its share of pollutant emissions in the last several years (European Environment Agency, 2018). Among all urban traffic-related emissions, it is estimated that goods movements are responsible for about 15% of greenhouse gas (GHG) emissions, as well as a large share of pollutant emissions: 40% of nitrogen oxides (NO_x) and 50% of particulate matter (PM) (CERTU, 2013). Therefore, improving the environmental efficiency of Urban Goods Movements (UGM) is an absolute necessity and requires the use of all possible approaches (Holguín-Veras et al., 2016a).

In recent years, there has been a growing awareness among city stakeholders (public and private) of the need to act on UGM in order to reduce the negative effects of transport. But this action should not negatively impact the city's economic vitality. This challenge mobilizes the reflection of researchers and experts in urban logistics around the search for solutions to achieve this.

Off-hour Deliveries (OHD) could be one of those solutions. The principle consists in postponing deliveries to periods when urban traffic is less dense, outside peak passenger traffic periods. The expected effects of the adoption of OHDs, in terms of environmental impacts, stem from the assumption that carrying out a share of goods movements during periods of low infrastructure demand, and therefore lower congestion, improves urban traffic conditions in general and particularly freight traffic conditions. As goods movements take place under

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better traffic conditions, several chain effects should be observed: reduction of travel times, reduction of energy consumption, reduction of GHG and pollutant emissions, reduction of accidents, reduction of inconvenient parking, etc. (Holguín-Veras, 2011; Holguín-Veras et al., 2016a; Sánchez-Díaz et al., 2017; Verlinde, 2015). On the other hand, this measure may have drawbacks that should be kept in mind. The most cited is the noise from engine, refrigeration units, handling (Douglas, 2011; Verlinde and Macharis, 2016). This can be tackled by using silent vehicles and handling equipment and providing to drivers a special training on silent deliveries (Delaître, 2010; Verlinde, 2015). For example, the Certibruit label guarantees the use of PIEK-certified engines, handling equipment, premises and staff practices for low-noise night deliveries (Sánchez-Díaz et al., 2017). There are also potential reorganization costs for some stakeholders (Holguín-Veras, 2011; Silas et al., 2012) as well as social costs (health, social life, and safety) of nightshift work (Verlinde et al., 2010).

Several OHD experiments have been conducted in cities around the world (Bertazzo et al., 2016; Delaître, 2010; Holguín-Veras et al., 2016a; Niches, 2006; STRAIGHTSOL, 2014). These experiments, conducted at different scales, but mostly at small scale, lead to promising results in some of the largest cities in the world. However, they raise the question of whether they can be efficient to reduce emissions in a context of large-scale deployment of OHDs, since general traffic conditions will be affected, especially in the case of a small-sized city (less than 2 million inhabitants). The purpose of this paper is to answer the following question: in this context, does postponing a large share of goods movements during the off-hours (OH) leads to a significant reduction of freight-related emissions? Answering this question would help to better guide the decision-making of all the actors involved in UGM, since such a postponement would lead economic and organizational changes that would have a cost for all of them.

A scenario-based simulation relating to the LUA is used to accurately evaluate the potential of OHDs to reduce emissions generated by UGM. It contributes to extend the short body of literature on the impacts of OHDs deployment at large scale. The choice of the LUA as a case study has a two-fold interest. First, the metropolis of Lyon is committed to improving ambient air quality by acting on freight transport in particular. Its Urban Mobility Plan 2017–2030 envisages the study of several types of initiatives in order to evaluate the conditions for successful new temporal or spatial cohabitation such as experiments in zones with the potential for “late evening” and “early morning” silent deliveries (SYTRAL, 2017). Assessing the potential impacts of OHDs on this perimeter would be helpful in decision-

making. Secondly, the availability of data at the LUA scale is facilitated by the fact that the tools used have been calibrated at this scale.

The paper is organized as follows. After a brief review of the literature on OHDs experiments, we describe the methodology. Then the results are presented and discussed before the conclusion.

2. Literature review

Little research has accurately evaluated the environmental performance of OHDs (Holguín-Veras et al., 2016a), and even less so on a citywide scale. This is partly due to the difficulty of collecting data at this scale. However, there is an abundant literature on the impacts of small-scale OHDs (Sánchez-Díaz et al., 2017). Here we use *small-scale* to refer to the part of freight movements concerned by the study and not to the size of the city in which the study is conducted. The results of the small-scale experiments are, in some cases, used to estimate the performance that could be achieved by deploying OHDs on a larger scale.

Holguín-Veras et al. (2011) estimate the potential impacts of a wide adoption of OHDs (7 PM to 6 AM) in New York (NYC). The study is based on a pilot experiment conducted with 33 establishments (transporters, receivers and vendors) over a one-month period in Manhattan. Vehicles' routes are tracked using a GPS system. The results of the experiment show a significant increase in speeds between depots and first customers when switching from regular hours (RH) to OH (+71%). They go from 19 km/h during the peak hours of the day (6–9 am) to 32.5 km/h between 7 pm and 6 am. The gain is even more important between two delivery points (166.7%, from 4.8 km/h to 12.8 km/h). Based on these promising results, a simulation of the wide adoption of OHDs across Manhattan was conducted. It estimates that a 10% shift in transport from RH to OH reduces travel time by more than 6% during daytime hours. When the increase in travel time during OH is considered, this figure drops to 4% (Holguín-Veras et al., 2012). Based on these results, Holguín-Veras et al. (2014) estimate that a 20.9% carry-over of NYC traffic in OH would result in annual environmental gains of 202.2 tons (t) of CO, 11.8 t of NO_x, and 69.9 kg of PM₁₀. These results from extrapolating the performance achieved in the Manhattan pilot experiment are well below those obtained for the same city in the study conducted by Holguín-Veras et al. (2016a). Using data from the test and implementation phases of two 2009 OHD projects, all carried out in NYC, the authors estimate that a 10% shift from RH to OH would allow an annual reduction of: 8.9 million t of CO₂, 25,273.5 t of CO, 3616.3 t of NO_x and 591 t of PM₁₀. This very large

gap with the previous studies carried out in Manhattan could be explained by the assumptions used in the second study. The latter is part of a major study of three cities: NYC, Bogotá and Sao Paulo. 38 routes (including 6 in NYC, 15 in Bogota and 17 in Sao Paulo) were monitored using GPS systems for two to four weeks at RH and OH. Based on the characteristics of the fleet of vehicles used, the transfer of goods flows to OH routes achieve reductions of 13%, 64% and 48% in emissions per km travelled for Bogotá, NYC and Sao Paulo respectively. These average reductions are used to move from the scale of the routes followed to the scale of cities. On this basis, the annual pollutant emission reductions for the city of Sao Paulo are 2.9 million t of CO₂, 9015 t of CO, 1197 t of NO_x and 221 t of PM₁₀. For Bogotá, they are 1.7 million t of CO₂, 4762 t of CO, 671 t of NO_x and 114 t of PM₁₀ (Holguín-Veras et al., 2016a). The experiments were carried out in highly congested areas of the case studies leading to high-speed variations when switching from RH to OH. The environmental impacts of OHDs would tend to be greater in areas with high levels of congestion.

Mommens et al. (2018) propose an assessment of the potential impacts of the adoption of OHD by all supermarkets in the Walloon region (Belgium). Although the study is intended to be large-scale, the impact analysis is not comprehensive. Indeed, changes in the quantities of pollutants are estimated in relation to the supermarket sector alone. This does not make it possible to assess the effectiveness of such a measure on the performance of the entire UGM at the regional level. This could have been done if the effects of the adoption of OHDs by supermarkets on traffic conditions throughout the region had been estimated. This last point seems to be one of the difficulties to be overcome in the transition from small to large scale. Iyer et al. (2011) estimate, using a macroscopic and mesoscopic model, the impacts that OHDs could have on traffic conditions in NYC. Both models show that with an increase in the percentage of OHD, traffic conditions tend to improve during regular hours and deteriorate during off-hours. However, the gains to be made from the improvement of traffic conditions in regular hours are greater than the losses generated by their deterioration in off-hours. OHDs would therefore benefit for traffic conditions and consequently decrease pollutant emissions, since these two elements are linked.

The beneficial trend of OHDs in terms of improving overall travel time over the whole day is also observed by Ukkusuri et al. (2016) through their macroscopic and mesoscopic models used in the NYC case. Sathaye et al. (2010) investigate the evolution of pollutants concentration over the course of the day in the case of a postponement of share of traffic flow on off-hours. To do this, they built OHD scenarios in two cities in California. They estimate

that OHDs would lead to an increase in the average concentration of pollutants over the entire 24 h. However, according to them, OHDs would be an effective measure when peak-hours speeds are very low.

This brief review shows, using micro or meso data, that large-scale OHDs most often produce a positive environmental impact, but this varies in magnitude from one case to another. This paper proposes an assessment of the magnitude of this impact using simulation methodology directly at the macroscopic scale.

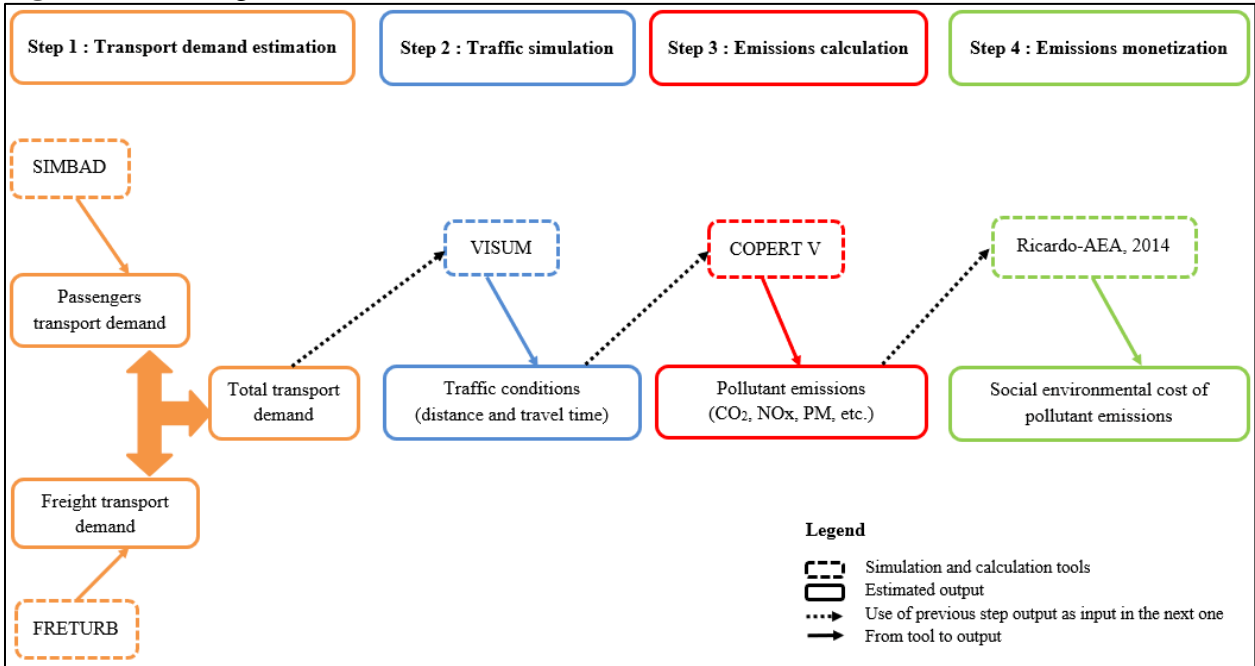
3. Methods

This section includes the methodological framework description and the main characteristics of the study area through the presentation of data.

3.1 Description of the methodological framework

The assessment of the potential impact of OHDs is based on a four-step methodology illustrated by Fig. 1.

Fig. 1. Methodological framework



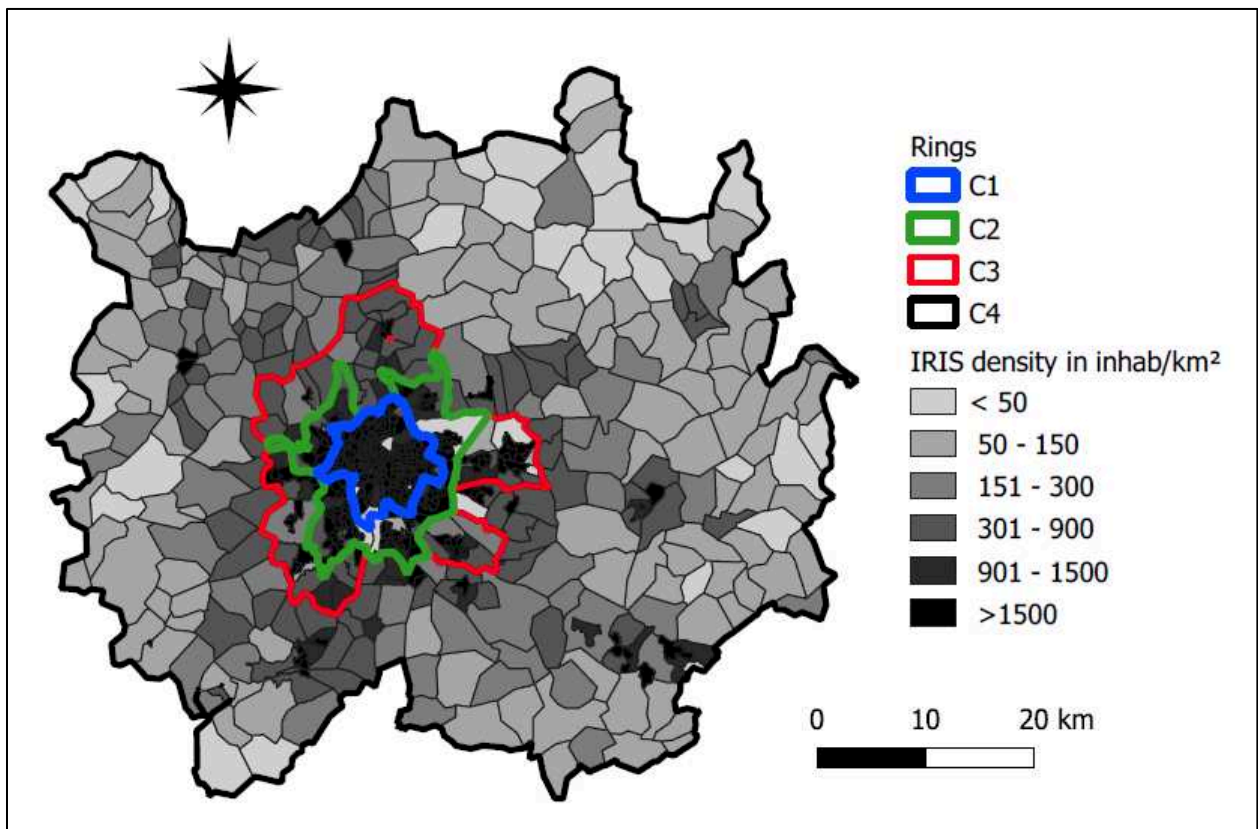
Source : authors’ elaboration

3.1.1. Step 1 Transport demand estimation

Our case study is the LUA within its 1999 limits (see Fig. 2). It is divided in 777 IRIS (the smallest geo-statistical unit in France) which are the origin and destination areas of passenger

and freight flows in the context of our analysis. In order to generate origin-destination (OD) matrices representing the total transport demand of the LUA, we use two tools developed by the Transport Urban Planning Economics Laboratory (LAET): SIMBAD and FRETURB. They respectively provide OD matrices for passenger and freight movements. The OD matrix of the total traffic is obtained by aggregating these two OD matrices. It is not our aim to explain in detail the methodology of the two tools: readers can refer to the papers mentioned below to have more information.

Fig. 2. Lyon Urban Area in its 1999 limits



Source: authors' elaboration from IGN

SIMBAD (Nicolas et al., 2009) is a Land Use and Transport Interaction (LUTI) model calibrated on the LUA and whose household and establishment location choices are built on the URBANSIM model (Waddell, 2002). The passenger transport model used is based on four-step modeling. The application of the model to the data from the Lyon household mobility survey (EMD 2015) makes it possible to obtain the OD matrix of motorized trips expressed in private cars (PC) and according to the periods of the day.

Goods flows are obtained through the FRETURB model (Routhier and Toilier, 2007). It allows to quantify and characterize freight flows of a given urban area (Toilier et al., 2018) on the basis of two main inputs: an establishment file and a zoning file. By running the model

within our study area, we obtain, for each OD pair, the flow distribution by period of day and for three types of vehicles: light goods vehicles (LGVs), rigid or articulated heavy goods vehicles (HGVs). A private car equivalency (PCE) is introduced in order to aggregate the two matrices obtained. It is 1.5 PCE for 1 LGV, 2 PCE for 1 rigid HGV and 2.5 PCE for articulated HGV, which is consistent with PCE values usually observed in the literature (Webster and Elefteriadou, 1999).

3.1.2. Step 2 Traffic simulation

The simulation of traffic conditions is performed using the VISUM software. It is calibrated for simulations of hourly road network load. The transport demand obtained in *step 1* is a daily demand. It is therefore necessary to derive the demand by hour or by homogeneous periods of the day. In order to reduce computation time, we choose four homogeneous periods based on 2015 EMD Lyon data. The morning peak period (HPAM) between 7 and 9 am, and the afternoon peak period (HPPM) from 5 to 7 pm. Off-hours are separated between day off-hours (HCJ) from 9 am to 5 pm and 7 pm to 9 pm, and night off-hours (Night) from 9 pm to 7 am. In this paper, for the simulation, we refer to Night (9 pm–7am) when we mention Off-hours. For each of the four specified periods, VISUM assigns the demand on the network, which determines the traffic conditions and speeds (travelled distance / travel time) for each OD. It is therefore not an instantaneous speed but an average speed. Nevertheless, it can be used to measure changes in traffic conditions, since it reports on possible delays on the same OD from one period to another (Yannis et al., 2006). Of course, these average speeds do not capture traffic dynamics (acceleration and deceleration) as accurately as the instantaneous speeds that would be obtained with GPS track data, for example (Gonzalez-Feliu et al., 2013; Holguín-Veras et al., 2016a; Laranjeiro et al., 2019). However, instantaneous speed data are not available for all traffic in the Lyon urban area.

Scenario generation can be done in several ways. It may be based, where appropriate, on a preliminary statement indicating the consent of the actors to adopt OHDs (Holguín-Veras et al., 2008, 2007). Another way may be to characterize flows in order to identify the types of flows most likely to be deferred and the percentage of flows that could be affected (Verlinde, 2015). Our aim is to estimate the maximum potential of OHDs to reduce emissions throughout the LUA. Thus, we deliberately choose carry-over rates ranging from 0% to 100% of deliveries, all sectors combined. On the basis of a reference scenario “*Scen ref*” which

describes the current situation, five scenarios are built in order to capture the effect of postponing deliveries from day to night:

- Scen 20%: 20% of deliveries carried out during the daytime are postponed to the *Night*.
- Scen 50%: 50% of deliveries carried out during the daytime are postponed to the *Night*.
- Scen 80%: 80% of deliveries carried out during the daytime are postponed to the *Night*.
- Scen 100%: of deliveries carried out during the daytime are postponed to the *Night*.
- Scen 0%: All deliveries are carried out during the daytime, between 7 am and 9 pm. It represents a situation without off-hour deliveries. This allows to know what would happen if no deliveries were carried out at Night.
- Scen Ref: it describes the current situation with 66% of trips take place in HCJ, 17.6% in HPAM, 7.3% in HPPM and 8.9% in Night. More details on this situation are available in the Section 3.2.

We therefore assume that all flows can be subject to OHDs and exclude the issues of stakeholder consent and acceptability of the measure from the scope of the study. This way of formulating our scenarios has the advantage of measuring the potential extent to which OHDs could be effective in terms of reducing the environmental pollution generated by UGM. Readers should keep in mind that above a certain threshold, the percentage of OHDs becomes unrealistic, but we simulate it anyway to estimate the environmental performance. Indeed, there are some flows that are well-suited OHDs and others that are slightly less (e.g. pharmaceuticals) or not at all (e.g. medical wastes). For example, in the case of NYC, an OHD project is estimated to be able to switch between 20% and 40% of the deliveries in the retail and accommodation and food sectors to the off-hours (Holguín-Veras et al., 2016b). The estimates produced for New York City indicate that the optimal amount of staffed off-hour deliveries is between 14% and 21% and more than 40% for un- assisted off-hour deliveries (Holguín-Veras, 2011). We also reason all other things being equal. This means that regarding the demand for passenger transport, we assume that it remains constant. Therefore, there is no induced demand or modal shift from public transport to private cars as a result of reduced freight traffic during peak hours. For goods movements, it is assumed that OHD scenarios do not impact either the quantities to be delivered or the size of tours. This hypothesis makes it possible to know what the potential gains are at constant delivery

quantities. Of course, OHDs are expected to save time, since the flows will operate under better traffic conditions, and therefore at higher speeds. Since VISUM is a deterministic simulation model, we simulate each scenario once instead of averaging the results of several simulations for each scenario.

3.1.3. Step 3 Emissions calculation

We calculate GHG and pollutant emissions based on COPERT V emission standards (Ntziachristos et al., 2009) for goods transport vehicles. This model, developed by the European Environment Agency, is used in most EU countries. COPERT V is a macro-scale vehicle emission model built around the average-speed approach (Ntziachristos et al., 2009). To calculate total exhaust emissions, COPERT V distinguishes hot emissions and cold-start emissions, taking into account the effect of driving behavior and climatic conditions (European Environment Agency, 2019). By using data from the bench test made in EU countries, COPERT V provides emission factor functions for most vehicle technologies in the European stock (Ntziachristos et al., 2009). Our estimation considers a typical fleet of trucks and vans based on the 2012 French National Fleet Surveys, and the Copcete tool (Coulombel et al., 2018). Our typical fleet is 100% diesel for rigid or articulated HGVs, 99% diesel and 1% petrol for LGVs (see **Table A.1**). The COPERT V model allows the calculation of several types of emissions but for brevity reasons, we will only focus on CO₂, CO, PM, NO_x and volatile organic compounds (VOC).

3.1.4. Step 4 Emissions monetization

Pollutant emissions are translated into monetary terms from the most recent European guideline on external transport costs (Van Essen et al., 2019). The use of these standards allows the calculation of the environmental cost associated with the UGM, as well as its variation following the implementation of a measure such as OHD. This guideline provides costs for each type of pollutant and GHG emissions according to the areas in which they are emitted: urban, *peri*-urban and rural. The differentiation of these areas is based on population density. We apply these costs to all the routes carried out between the different OD. The detail on these costs is provided in **Table A.2**.

3.2 Data

The LUA has 1.9 million inhabitants and more than 1.2 million jobs over an area of 3325 km² i.e. an average density of 576 inhabitants and 381 jobs per km² (see **Table 1**). Even if Lyon is the second biggest conurbation in France, the LUA can be classified as a small metropolitan area compared to the large metropolitan areas found throughout the world.

The population data are from the database of the French national institute of statistics and economic studies (INSEE) for the year 2018. To obtain data on establishments and jobs, we use a geo-coded SIRENE dataset (the National System of Identification and Register of Companies and their Establishments), the repertory of French economic establishments produced by INSEE for the year 2018. Assuming that OHDs can have different impacts from one area to another, depending on their population density, we divided the LUA into four rings (C1 to C4) according to the IRIS population densities around the city centre of Lyon (see **Fig. 2**).

Table 1: Characteristic data of Lyon urban area (2018)

	LUA	C1	C2	C3	C4
Inhabitants (1,000)	1,916.1	704.2	351.6	249.9	610.4
		36.8%	18.3%	13.0%	31.9%
Area (km ²)	3,325	73.3	129.7	253.5	2,868.5
		2.2%	3.9%	7.6%	86.3%
Inhabitant/km ²	576.3	9,612.2	2,711.6	985.8	212.8
Jobs (1,000)	1,267.1	562.3	207.4	182.0	315.5
		44.4%	16.4%	14.4%	24.9%
Jobs/km ²	381.1	7,674.9	1,599.2	717.9	110
Establishments (1,000)	275.7	117.3	41.9	36.7	79.7
		42.5%	15.2%	13.3%	28.9%
Jobs/Establishment	4.6	4.8	4.9	5.0	4.0

Source: authors' calculations from FRETURB and SIMBAD, IGN, SIRENE (Insee)

Note: Percentage data represent the proportional share of each area in the whole LUA

Thus, the densest area (ring C1) concentrates 36.8% of the population, 44.4% of jobs and 42.5% of establishments on only 2.2% of the surface area of the LUA (see **Table 1**). The least dense area (ring C4) concentrates 31.9% of the population, 24.9% of jobs and 28.9% of establishments. These shares are explained by the fact that this area represents 83.6% of the LUA surface. The size of establishments (ratio jobs/establishment) increases as one moves away from the centre, except in ring C4 (see **Table 1**). Activities located on the outskirts of the cities are those that require more space and are labor-intensive (wholesale, logistics and industry), while services activities are more located in downtown.

Simulations from SIMBAD and FRETURB provide the traffic data (passengers and goods) reported in **Table 2**. 719,271 PC trips per day are generated in the LUA, of which 31.7% within the C1 ring. This figure rises to just over 1.1 million trips per day when considering the total number of trips (passengers and goods) in PCEs. In terms of freight traffic, there are 119,910 for LGVs, 74,980 for rigid HGVs and 24,685 for articulated HGVs. We note the large share of LGVs in dense areas (C1 and C2) while rigid and articulated HGVs are used more often in the C4 ring.

Table 2: Daily distribution of trips by ring and vehicle type (1,000)

	LUA	C1	C2	C3	C4
PC	719,271	227,869 31.7%	112,396 15.6%	96,216 13.4%	282,791 39.3%
LGV	119,910	45,759 38.2%	17,647 14.7%	16,127 13.4%	40,378 33.7%
Rigid HGV	74,980	25,115 33.5%	10,933 14.6%	11,050 14.7%	27,882 37.2%
Articulated HGV	24,685	6365 25.8%	3897 15.8%	4220 17.1%	10,203 41.3%
Total (PCE)	1,110,808	362,648 32.6%	170,475 15.3%	153,056 13.8%	424,630 38.2%

Source: authors' calculation from FRETURB for freight vehicle and SIMBAD for PC

Note: Percentage data represent the proportional share of each area in the whole LUA; For each ring (C1 to C4), the figures refer to internal, incoming, outgoing and transit trips

C4 has a larger portion of the freight trips (36.2% in PCE) even more than the densest area (34.4% in PCE). When looking at the total traffic these figures are respectively of 38.2% et 32.6% (see **Table 2**). This is partly explained by the strong presence of wholesale, logistics and industrial activities in the area. Such activities generate multiple vehicle movements to and from the area. Indeed, the wholesale, logistics and industrial activities generate inbound traffic of raw materials and finished products in large quantities and very regularly, but also outbound traffic to the city of Lyon and neighboring cities. In addition to this, there is the traffic generated by the product needs of the 32% of the LUA's population who live in the C4.

The analysis of vehicle use by OD shows that LGVs and rigid HGVs are widely used for short trips while articulated HGVs are used more for long trips (see **Table A.3**). Indeed, for trips starting from the C1 ring and carried out with LGVs, 59% are intra-C1, and only 16% go to the C4. Conversely, for articulated HGVs, 25% of these trips are intra-C1 and 50% go to C4 ring.

If we look at the periods of day during which these trips take place, we note on the LUA that 58.3% of trips take place in HCJ, 18.5% in HPAM, 14.9% in HPPM and 8.3% in Night.

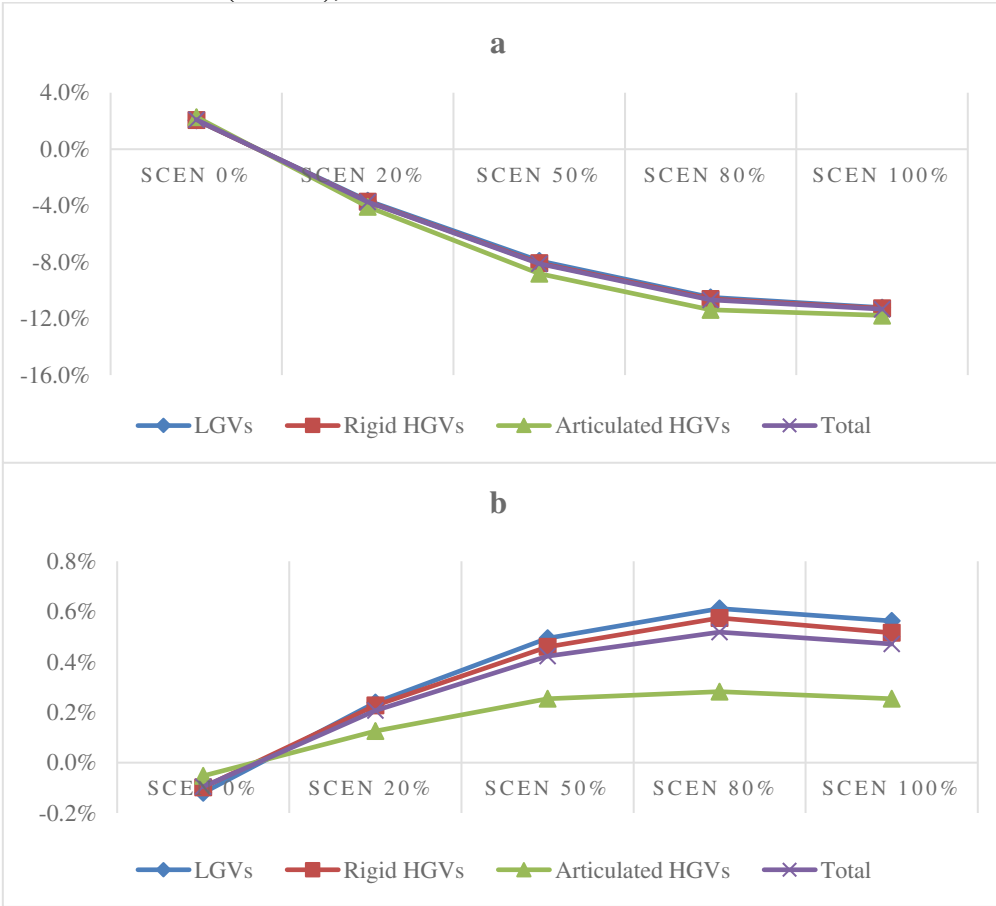
When we look specifically at freight transport, these figures are 66%, 17.6%, 7.3% and 8.9% respectively.

4. Results

4.1 Distances and travel times evolution

Fig. 3a shows a decrease in the total travel time at the LUA scale of 11.3% for the 100% OHD scenario, representing a maximum absolute gain of 2.5 million hours per year (see Table A.4). The minimum time saving is obtained with 20% OHD and amounts to 827,106 h per year, or 3.7% less than the reference scenario. We notice that the larger the size of the vehicle, the greater the reduction in time (see Table A.4). The relative evolution of these gains, from one OHD scenario to another, is more important in C1 (14.6% gain with 100% OHD) than in C4 (8.5% gain with 100% OHD). The time saved is undoubtedly an economic gain for carriers, since it can represent fewer working hours or be used to increase the number of points affected in each vehicle tour. The value of these hours of work gained is another argument in favor of OHDs.

Fig. 3. Variation from the reference scenario of: travel time (a) in hour and distance traveled (b) in Vehicle kilometers (VKMs); Source: authors’ calculation from VISUM



We observe a growth in distances travelled as the percentage of OHDs increases (see **Fig. 3b**). However, this growth remains very low (0.5% for 100% OHD) and can be considered as insignificant. This is explained by the slight changes in the routes chosen by the vehicles as their tours are optimized according to the traffic conditions. The major roads are prioritized (main roads and highways) in the routes used in the model as in the real world. The city of Lyon is accessible from all sides without great obstacles that would reduce traffic flow and require major detours. Thus, traffic conditions are comparable at all entrances to the city during peak and off-peak hours. This characteristic of the city limits the number of bypasses to access the city. Thus, between off-peak and peak hours, the sum of the distances travelled remains more or less the same (see **Table A 5**), but there is a reduction in travel time due to the better traffic conditions at night compared to daytime. Mommens et al. (2018) also found that OHDs do not have a significant impact on distances travelled in the case of Brussels. In contrast, in the case of New York City, Holguín-Veras et al. (2018) assume that the distance travelled by drivers who take OHD routes is 10% shorter than the distance in the daytime delivery routes, because drivers are able to take the shortest path to their destinations during the off-hours. This assumption has an influence on the impact of OHDs because, in addition to having better traffic conditions at night, the distances travelled are shorter. This tends to further reduce emissions, all other things being equal.

4.2 Freight traffic emissions in the whole LUA

In order to calculate the annual quantities of emissions, we considered five working days per week, for a total of 260 days per year. Thus, in the current situation (Scen Ref) the LUA UGM generates 382,778 t of CO₂, 195 t of CO, 2,462 t of NO_x, 8 t of PM and 20 t of VOC per year (see **Table 3**). OHDs lead to a reduction in pollutant emissions as the percentage of postponed flows increases.

CO₂ emissions decrease by 1.1%, then by 2.5% and 3.4% respectively when the percentage of goods flows reported in OHD increases to 20%, then 50% and 100%. On the other hand, if the flows now carried out at night (8.9% of the total flow) were carried over to daylight hours (Scen 0%), emissions would increase by 0.6% for CO₂, 0.8% for NO_x and 1.1% for PM. These results show that there is no threshold effect in relation to the gains in pollutant emissions that would be achieved by increasing the percentage of OHDs. As this percentage increases, so do the environmental gains, but less than proportionally. The maximum gains are obtained when 100% OHD is reached. These gains are partly explained

by the relative improvement in traffic conditions as the percentage of OHD increases. Indeed, there is an increase in the average speed of 1.9% during the morning peak period when we have 20% OHD. This increase is 4.8% for 50% OHD and 9.6% for 100% OHD. At the same time, there is a decrease in the average speed during the night period due to the increase in traffic. However, this decrease does not have a significant negative impact on environmental gains. The daytime flows that are postponed to night were already occurring at lower average speeds than those reached at night, despite the decrease observed following OHDs.

Table 3: Emissions (tons/year) and average speed (km/h) in the whole LUA

	Scen 0%	Scen Ref	Scen 20%	Scen 50%	Scen 80%	Scen 100%
CO ₂ (tons/year)	385,246	382,778	378,468	373,360	370,384	369,584
	0.6%		-1.1%	-2.5%	-3.2%	-3.4%
CO (tons/year)	197	195	191	186	183	183
	1.2%		-2%	-4.4%	-5.8%	-6.1%
NO _x (tons/year)	2,481	2,462	2,428	2,388	2,364	2,358
	0.8%		-1.4%	-3%	-4. %	-4.2%
PM (tons/year)	9	8	8	8	8	8
	1.1%		-2%	-4.3%	-5.6%	-5.9%
VOC (tons/year)	20	20	19	19	18	18
	1.4%		-2.6%	-5.6%	-7.3%	-7.6%
HCI Speed (km/h)	41.7	42	42.5	43.2	43.9	44.3
	-0.6%		1.2%	3%	4.5%	5.5%
HPAM Speed (km/h)	35.5	35.9	36.6	37.6	38.6	39.3
	-1%		1.9%	4.8%	7.6%	9.6%
HPPM Speed (km/h)	37.7	37.9	38.2	38.6	39	39.3
	-0.4%		0.8%	1.9%	3%	3.8%
Night Speed (km/h)	46.8	46.8	46.7	46.5	46.1	45.7
	0.0%		-0.1%	-0.6%	-1.5%	-2.4%

Source: authors' calculations

Note: Percentage data represent variations from the reference scenario (Scen Ref)

4.3 Freight traffic emissions: densest area vs. least dense area

A great advantage of our simulation approach is that it allows us to isolate a portion of the study area and see the impact of OHD deployment on that portion alone. In order to assess the disparities in the results obtained at various scales, we chose to focus on traffic-related CO₂ and pollutant emissions in the densest and least dense areas (C1 and C4). C1 corresponds to the core of the urban area and C4 to the outskirts. In each ring, we consider the emissions generated by internal, incoming, outgoing and transit traffic.

Table 4 shows, as expected, that traffic conditions are the least favorable in C1, given the high population and employment density. Under current conditions, the average speed is 24 km/h in HCJ (42% less than in LUA), 19.2 km/h in HPAM (47% less than in LUA), 20.9 km/h in HPPM (45% less than in LUA) and 28.4 km/ in Night (39% less than in LUA). Within this ring, in the current situation, we have as emissions 78,828 t of CO₂ (20.6% of LUA emissions), 39 t of CO (20.3% of LUA emissions), 548 t of NO_x (22.3% of LUA emissions), 2 t of PM (21.4% of LUA emissions), 4 t of VOC (or 21.1% of LUA emissions). By looking at the evolution of the quantities of CO₂ and pollutants emitted with OHDs, we can see that at the first ring scale, any increase in the percentage of OHD leads to a relatively larger decrease in CO₂ and pollutant emissions than at the LUA scale. At this scale, similarly to the LUA scale, the maximum reduction in emissions is also achieved when 100% of deliveries are carried out in OH, i.e. 5% for CO₂, 8.2% for CO, 5.8% for NO_x, 8.3% for PM and 10% for VOC. These levels of decline are partly explained by the relatively larger variations in speed at this scale than at the LUA scale.

Table 4: Emissions (tons/year) and average speed (km/h) in C1

	Scen 0%	Scen Ref	Scen 20%	Scen 50%	Scen 80%	Scen 100%
CO ₂ (tons/year)	79,534 0.9%	78,828	77,560 -1.6%	76,093 -3.5%	75,169 -4.6%	74,884 -5%
CO (tons/year)	40 1.5%	39	38 -2.7%	37 -5.8%	36 -7.6%	36 -8.2%
NO _x (tons/year)	554 1%	548	538 -1.9%	526 -4.1%	518 -5.4%	516 -5.8%
PM (tons/year)	2 1.5%	2	2 -2.7%	2 -5.8%	2 -7.8%	2 -8.3%
VOC (tons/year)	4 1.8%	4	4 -3.3%	4 -7.1%	4 -9.4%	4 -10%
HCJ speed (km/h)	24.1 -0.7%	24.3	24.7 1.4%	25.2 3.5%	25.6 5.4%	25.9 6.5%
HPAM speed (km/h)	18.9 -1.6%	19.2	19.8 3.1%	20.7 7.8%	21.5 12.4%	22.1 15.5%
HPPM speed(km/h)	20.8 -0.6%	20.9	21.2 1.1%	21.5 2.9%	21.9 4.6%	22.1 5.8%
Night speed (km/h)	28.4 0.1%	28.4	28.3 -0.3%	28.1 -1%	27.7 -2.2%	27.5 -3.2%

Source: authors' calculations

Note: Percentage data represent variations from the reference scenario (Scen Ref)

For all four periods, in C4, we note that the average speeds are relatively higher than those observed for the LUA, and even higher than for C1 (see **Table 5**). In the reference scenario,

traffic generates 185,506 t of CO₂ (or 48.5% of LUA emissions), 94 t of CO (or 48.1% of LUA emissions), 1164 t of NO_x (or 47.3% of LUA emissions), 4 t of CO₂ (or 47.6% of LUA emissions) and 9 t of VOC (or 47.3% of LUA emissions). The results show a low sensitivity of the quantities of CO₂ and pollutants emitted into this ring as the percentage of OHDs increases. Indeed, by transferring 100% of the flows to the OH period, the reduction in CO₂ emissions is only 2.6%, that of CO 4.8%, that of NO_x 3.2%, that of PM 4.5% and that of VOC 6%. As this area is peripheral, these results were partly predictable since traffic conditions are already good. They are therefore slightly sensitive to deliveries postponing, as shown by the increase of only 3.1% and 1.2% respectively in HPAM and HPPM speeds for the 100% OHD scenario. The peripheral location of this area and low population densities lead to long delivery routes. In addition to this, as mentioned above, there is a greater presence of articulated vehicles. These elements partly explain the relatively high share of C4 in total emissions.

Table 5: Emissions (tons/year) and average speed (km/h) in C4

	Scen 0%	Scen Ref	Scen 20%	Scen 50%	Scen 80%	Scen 100%
CO ₂ (tons/year)	186,432	185,506	183,896	182,006	180,987	180,737
	0.5%		-0.9%	-1.9%	-2.4%	-2.6%
CO (tons/year)	94	94	92	90	89	89
	0.9%		-1.6%	-3.6%	-4.6%	-4.8%
NO _x (tons/year)	1,172	1,164	1,152	1,137	1,129	1,127
	0.6%		-1.1%	-2.3%	-3%	-3.2%
PM (tons/year)	4	4	4	4	4	4
	0.9%		-1.5%	-3.3%	-4.3%	-4.5%
VOC (tons/year)	9	9	9	9	9	9
	1.2%		-2.1%	-4.5%	-5.8%	-6%
HCJ speed (km/h)	52.0	52.2	52.5	53.0	53.5	53.8
	-0.3%		0.6%	1.7%	2.6%	3.1%
HPAM speed (km/h)	49.0	49.1	49.4	49.9	50.3	50.6
	-0.3%		0.7%	1.6%	2.4%	3.1%
HPPM speed (km/h)	50.0	50.0	50.1	50.3	50.5	50.6
	-0.1%		0.2%	0.5%	0.9%	1.2%
Night speed (km/h)	55.4	55.4	55.4	55.2	54.8	54.6
	0.0%		-0.1%	-0.3%	-1%	-1.5%

Source: Authors' calculations

Note: Percentage data represent variations from the reference scenario (Scen Ref)

4.4 Environmental social cost

The environmental social cost for the entire LUA is calculated based on the average density of the four rings. Thus, the first and second rings are considered as “urban area”, the third ring as “peri-urban” and the fourth ring as “rural” within the meaning of the reference frame (Van Essen et al., 2019). Since the PM calculated from the COPERT V standards does not distinguish between PM₁₀ and PM_{2.5}, we use the considerations of Airpatif (2016) according to which 65% of the PM is composed of PM_{2.5}. Only CO₂ emissions and the following pollutants NO_x, PM_{2.5}, PM₁₀, and VOC are considered in this calculation. In the reference scenario, the annual cost generated by freight transport in the LUA is around € 106.45 million.

Table 6: Environmental social cost of CO₂ and pollutant emissions (€ million /year)

	Scen 0%	Scen Ref	Scen 20%	Scen 50%	Scen 80%	Scen 100%
Cost by component						
CO ₂	38.52	38.28	37.85	37.34	37.04	36.96
NO _x	67.50	66.97	66.04	64.95	64.30	64.13
PM _{2.5}	1.17	1.16	1.13	1.10	1.08	1.07
PM ₁₀	0.02	0.02	0.02	0.02	0.02	0.02
VOC	0.03	0.03	0.03	0.03	0.03	0.03
Total cost by area						
LUA	107.24 0.7%	106.45	105.06 -1.3%	103.43 -2.8%	102.47 -3.7%	102.20 -4.0%
C1	23.52 1.0%	23.28	22.86 -1.8%	22.38 -3.9%	22.07 -5.2%	21.98 -5.6%
C2	15.35 0.9%	15.22	14.99 -1.5%	14.71 -3.3%	14.54 -4.5%	14.49 -4.7%
C3	17.61 0.8%	17.47	17.24 -1.3%	16.96 -3.0%	16.80 -3.9%	16.76 -4.1%
C4	50.76 0.6%	50.48	49.97 -1.0%	49.38 -2.2%	49.06 -2.8%	48.98 -3.0%

Source: authors' calculations

Note: Percentage data represent variations from the reference scenario (Scen Ref)

CO₂ accounts for 36% of this cost, followed by NO_x, which accounts for 63%. PM_{2.5}, PM₁₀ and VOCs represent the remaining 1% (see **Table 6**). The annual cost of € 102.2 million of the 100% OHD scenario represents the minimum of the cost that can be achieved with OHDs on the LUA. This corresponds to a maximum gain of €4.25 million per year, a decrease of 4% compared to the reference scenario. The scenario 0% OHD leads to an increase in the environmental social cost of 0.7%. **Table 6** shows that C4 is responsible for the highest share

of the total cost, with 50.48 million euros, or 48% of the total cost. It is followed by C1, C3 and C2 respectively, with 22%, 16% and 14% of the total cost. The most significant variations in cost according to the percentage of OHD are recorded in C1. They decrease as we move further away from the centre of LUA.

5. Discussion

The results show that OHDs have a positive environmental impact in the case of LUA, although this is much lower than those obtained in some pilot experiments. Indeed, with a maximum reduction of 3.4% in CO₂ emissions, this is a far cry from the savings between RH and OH routes achieved of 13%, 64% and 48% per km travelled for Bogotá, NYC and Sao Paulo respectively (Holguín-Veras et al., 2016a). However, some factors limit the comparability of the results obtained from one case study to another. These include the characteristics of the cities studied (e.g. population size, traffic conditions, density, etc.), the research methodology and the vehicle fleet involved.

Regarding the city's characteristics, in Holguín-Veras et al. (2016a) the case studies are NYC, São Paulo and Bogotá, all large metropolitan areas, and respectively the third, fourth and sixth most congested cities in the world. This high congestion implies significant differences between peak and off-peak traffic conditions. This is not the case for LUA which is a small and not very congested metropolitan area. As shown in the data in **Table 3**: the lowest average speed is observed in HPAM and is 36 km/h for the reference scenario, while for the scenario 100% OHD, the average speed at night is 46 km/h. This 10 km/h gap is not enough to drastically reduce fuel consumption and emissions. In addition, the hypercentre of the LUA is probably different from the American-style city with its wide avenues. Indeed, there is a strong presence of 30 km/h zones in the city of Lyon. This tends to limit the speed gaps between day and night, as shown in **Table 3**. The variation in total travel time gives an idea of the level of improvement in traffic conditions that can be achieved with OHDs. While 10% of OHD in NYC reduces total travel time by 4% over a day (Holguín-Veras et al., 2012), only 3.7% of this time is reduced with 20% OHD on the LUA (see **Fig. 3a**). The number of inhabitants and density have an impact on the efficiency of OHDs. Holguín-Veras et al. (2016a) estimate that a population of at least 2 million inhabitants in a city is needed for OHDs to be a practical solution. They add that OHDs could still be feasible in a city of less than 2 million inhabitants if it experiences high levels of congestion. LUA does not meet these

conditions, as it has less than 2 million inhabitants and is not very congested, which may therefore explain the low environmental impact of OHDs. Our results confirm the effect of density on the impact of OHDs. Indeed, in C1 which concentrates 37% of the population on 2.2% of the surface area of the LUA, the impact of OHDs is much greater (5% of CO₂ for 100% of OHD) than in C4 which concentrates 32% of the population on 86% of the surface area (2.6 of CO₂ for 100% OHD). In addition, traffic conditions are not as good in the densest areas (in C1 the speed is 19 km/h in HPAM and 21 km/h in HPPM) as they are in the least dense areas (in C4 the speed is 49 km/h in HPAM and 50 km/h in HPPM). Hence, OHDs are more relevant in larger, dense and congested urban areas.

The methodological aspects that may explain the differences in results are related to the method of capturing traffic conditions. While we use data from aggregate model, Holguín-Veras et al. (2016a) use GPS data. The advantage of GPS data is that they better capture traffic dynamics (acceleration and deceleration) and more accurately track the routes of every vehicle. Since emission calculation models are very sensitive to these factors, the GPS data approach allows a better estimate of emissions. However, the drawback of using GPS data is that it is difficult or even impossible to obtain them for all the traffic in a city. This constrains the studies to be based on a limited number of vehicle routes. Aggregate model, since it provides average speeds, therefore has the disadvantage of capturing less traffic dynamics. This could lead to an underestimation of emissions and their variation from one scenario to another. However, it is important to remember that the emissions model COPERT V is built around the average-speed approach, so that it can estimate emissions from average speeds with a minimum of bias (Ntziachristos et al., 2009). The advantage of an aggregate model is that it allows to take into account a diversity of situations such as simulating the traffic generated by deliveries/pick-ups of all the establishments of the LUA. The choice between these two methodological approaches is therefore a trade-off between a fine method that allows to get very accurate estimations but over a limited number of routes, and an aggregate method that takes into account a wide range of situations but captures less accurately the traffic dynamics.

An additional factor that could explain the difference in results is the composition of the vehicle fleet from one case study to another. Considering that emission factors are highly sensitive to the vehicle in terms of emission standards or weight categories (Coulombel et al., 2018). It is then obvious that the total emissions from freight transport depends on the characteristics (size, age, type of fuel, etc.) of the vehicle fleet used. These characteristics are not the same from one country to another. Since we do not have enough information to allow

a comparison between our vehicle fleet and the fleets in the other case studies, we cannot say more about how much of any difference in the results can be explained by the influence of the vehicle fleets. Emission factors are a central element in emission calculations. Thus, the emission model used is also a factor that influences the results obtained. Indeed, by comparing two emission models (CMEM and MOVES), Zhang and Ioannou (2016) find that they have different characteristics that can affect the evaluation results.

All in all, these are all parameters that limit the comparison of our results with those of the other case studies. On the one hand, this overview of the factors influencing the effectiveness of OHDs nevertheless makes it possible to affirm that the environmental impacts of OHDs will be low in LUA, given its small size and low level of congestion. Their impact would be greater if one concentrated only on its most congested area (C1), i.e. the core of the LUA. On the other hand, it has raised some limitations to our paper. The first is the use of aggregate models for estimating traffic conditions. As mentioned above, the aggregate model does not capture accurately the traffic dynamics on which emissions are highly dependent. This could lead to bias in our results by underestimating emissions. The second limitation is related to the vehicle fleet used. Due to the lack of recent data at city level, we use the fleet from the 2012 French National Fleet Surveys. The composition of the fleet according to the distribution in Euro standard is no longer the same today because of the renewal that takes place over time. This can influence the total emissions generated by the fleet and the results from one scenario to another.

One objective pursued by the metropolis of Lyon in its Urban Mobility Plan for 2030 is the reduction of VKMs and emissions (SYTRAL, 2017). By putting our results in perspective with these objectives, we could think that OHDs, as a solution, will not help much to achieve them. Indeed, even if OHDs do not lead to a significant increase in VKMs, they do not induce their reduction. Two of our hypotheses could explain this fact: the assumption of a constant fleet and constant quantities of goods to be delivered. The first excludes the possibility of replacing small vehicles with larger ones at different times. The second one excludes the possibility of increasing the vehicle load factor, whereas this would allow more points to be delivered with the same vehicle. Since travel time is one of the constraints that limits the size of tours, these hypotheses impede the capitalization of time savings achieved with OHDs. The more time is saved, and assuming that this time saved on the trip is not lost at delivery points, the more it will be possible to deliver additional points in a tour. This is possible because vehicle load factor tends to increase with OHDs (Holguín-Veras, 2011) since

it leaves a fairly large margin in reference scenario. Thus, the assumption of equal cargoes between off-hours deliveries and regular hours deliveries is then a conservative assumption. Since the VKMs travelled impact the quantity of pollutant emissions, our results may therefore have underestimated the rate of emission reductions that could be achieved.

6. Conclusion

This paper assesses the potential environmental impacts of large-scale implementation of OHDs, focusing on CO₂ and pollutant emissions from UGM in Lyon urban area. The methodological framework developed is composed by four steps: transport demand estimation, traffic simulation, emissions calculation and emissions environmental social cost calculation.

The results show that the environmental impact of OHDs is positive and increases with the percentage of OHD. When this percentage varies from 20 to 100%, the reduction in emissions goes from 1.1 to 3.4% for CO₂, 2 to 6.1% for CO, 1.4 to 4.2% for NO_x, 2 to 5.9% for PM and 2.6 to 7.6% for VOC. This corresponds to a maximum reduction in the annual environmental social cost generated by the UGM of €4.25 million. Spatial analysis of the results shows that OHDs have a greater relative impact in the densest areas. It should be noted, however, that the environmental impacts of the OHDs recorded in this case study are low. Readers should keep in mind that this corresponds to an “unrealistic” shift of deliveries to off hours. Furthermore, these gains are much lower than what the literature attributes as the potential for OHDs to reduce the environmental impacts of UGM. Thus, we postulate that OHDs deployed at large-scale could have a positive but low environmental impact in small metropolitan area which are not very congested, such as the LUA. Knowing that Lyon is a medium-sized metropolitan area by European standards and the 26th largest urban area in Europe (United Nations, 2017), the question arises as to the environmental relevance of OHDs in most European cities. However, this result does not detract, on the contrary, from the relevance of implementing OHDs in LUA. Indeed, in the battle for climate emergency, each ton of CO₂ and pollutants saved by adopting a sustainable urban logistics measure is already in itself a positive step towards improving the sustainability of urban freight transportation. Compared to the results of other measures, such as the low emission zone in London, where several studies found no clear evidence of a reduction in either pollutant (NO_x, PM) that could be attributed to it (CITYLAB, 2015; Holman et al., 2015), these OHDs performances in the case of the LUA are a big step in the right direction. As we know that emissions

reduction could be improved by, for example, using larger vehicles for night deliveries, OHDs remain a relevant option for reducing the environmental impact of urban freight transport. This reduction in impact could be amplified if OHDs were combined with another measure such as electric vehicles.

In addition, the analysis reveals that the adoption of OHDs makes it possible to save travel time. Indeed, we could save 2.5 million hours of travel time per year with 100% OHD. This represents a decrease of about 11% in travel time compared to the current situation. These time savings augur a productivity gain for carriers and UGM operators in general. They could represent less working time or be used to extend the size of rounds if the vehicle load factor allows it. They could also allow for the use of heavier and / or longer vehicles. However, these gains must be weighed against the additional costs relating to silent vehicles and handling equipment, staff costs or investment in a delivery locker that the switch to OHD would entail. This opens study prospects through the simulation of the reorganization of tours with bigger vehicles and the calculation of net productivity gains.

Appendix

Table A.1: Vehicle fleet distribution (2012, in % of distances traveled)

	PC			LGV		HGV
	Petrol	Diesel	Others	Petrol	Diesel	Diesel
Euro 0	1.9%	1.3%	-	0.2%	2.1%	0.2%
Euro I	2.6%	3.1%	-	0.1%	3.6%	0.6%
Euro II	5.4%	6.3%	-	0.2%	7.0%	7.9%
Euro III	4.4%	19.9%	-	0.2%	23.5%	23.6%
Euro IV	7.7%	28.1%	-	0.2%	38.7%	33.6%
Euro V	3.7%	15.1%	-	0.1%	24.1%	34.1%
Total	25.7%	73.8%	0.5%	1.0%	99.0%	100.0%

Source : Copcete et « Enquête Parc Auto – IFSTTAR ». From Coulombel et al. (2018)

Table A.2: External costs of emissions

	Rural area	Peri-urban area	Urban area
CO ₂ (€/ton)	100	100	100
NO _x (€/ton)	16,200	27,200	27,200
PM _{2.5} (€/ton)	87,000	131,000	407,000
PM ₁₀ (€/ton)	5,900	5,900	5,900
VOC (€/ton)	1,500	1,500	1,500

Source: Van Essen et al.(2019)

Note: “Rural area” corresponds to areas with less than 300 inh./km² as population density ; “Peri-urban area” corresponds to areas with population density ranging from 300 inh./km² to 1500 inh./km²; Urban corresponds to areas with more than 1500 inh./km².

Table A.3: OD matrices for freight vehicle and private car trips

Vehicle	Origin	Destination			
		C1	C2	C3	C4
PC	C1	135391	42690	19230	17460
		63.0%	19.9%	9.0%	8.1%
	C2	43698	48951	21688	19382
		32.7%	36.6%	16.2%	14.5%
	C3	19989	22170	36675	29595
		18.4%	20.4%	33.8%	27.3%
	C4	22797	21747	29310	188499
		8.7%	8.3%	11.2%	71.8%
LGV	C1	27589	6915	4750	7408
		59.1%	14.8%	10.2%	15.9%
	C2	6915	5610	3024	3681
		36.0%	29.2%	15.7%	19.1%
	C3	4750	3024	4318	6149
		26.0%	16.6%	23.7%	33.7%
	C4	7408	3681	6149	18540
		20.7%	10.3%	17.2%	51.8%
Rigid HGV	C1	14602	3840	2863	4585
		56.4%	14.8%	11.1%	17.7%
	C2	3840	3577	2028	2455
		32.3%	30.1%	17.0%	20.6%
	C3	2863	2028	3353	4280
		22.9%	16.2%	26.8%	34.2%
	C4	4585	2455	4280	13345
		18.6%	10.0%	17.4%	54.1%
Articulated HGV	C1	2059	885	1224	4145
		24.8%	10.6%	14.7%	49.9%
	C2	885	707	537	1473
		24.6%	19.6%	14.9%	40.9%
	C3	1224	537	495	1223
		35.2%	15.4%	14.2%	35.1%
	C4	4145	1473	1223	2451
		44.6%	15.8%	13.2%	26.4%

Source : authors' calculation from FRETURB for freight vehicle and SIMBAD for PC

Note: Percentage data represent the share of each OD in the total trips starting from the same origin. The traffic external to the LUA perimeter is taken into account in the modeling in the following way: all incoming external flows originate from C4 and all outgoing external flows are destined for C4.

Table A.4: Travel time in hour per year (1,000)

		LUA	C1	C2	C3	C4
Scen 0%	LGV	11,586.6	3,303.2	1,728.4	1,762.3	4,792.7
	Rigid HGV	7,326.1	1,871.6	1,051.1	1,177.1	3,226.2
	Articulated HGV	3,695.4	724.5	555.2	682.8	1,732.9
	Total	22,608.1	5,899.4	3,334.7	3,622.2	9,751.7
Scen Réf	LGV	11,353.8	3,217.4	1,688.9	1,725.9	4,721.5
	Rigid HGV	7,177.0	1,823.2	1,027.2	1,151.9	3,174.6
	Articulated HGV	3,612.8	706.0	541.1	666.8	1,699.0
	Total	22,143.6	5,746.6	3,257.3	3,544.6	9,595.1
Scen 20%	LGV	10,940.1	3,065.4	1,618.7	1,661.5	4,594.5
	Rigid HGV	6,910.6	1,736.8	984.5	1,107.2	3,082.1
	Articulated HGV	3,465.8	673.0	515.9	638.3	1,638.6
	Total	21,316.5	5,475.2	3,119.1	3,406.9	9,315.2
Scen 50%	LGV	10,455.1	2,888.3	1,535.6	1,585.4	4,445.8
	Rigid HGV	6,598.9	1,636.3	934.1	1,054.3	2,974.2
	Articulated HGV	3,294.2	634.6	486.3	604.8	1,568.5
	Total	20,348.2	5,159.2	2,956.0	3,244.5	8,988.5
Scen 80%	LGV	10,162.2	2,777.9	1,483.7	1,540.0	4,360.6
	Rigid HGV	6,415.2	1,574.2	903.0	1,023.6	2,914.4
	Articulated HGV	3,201.4	612.5	469.4	586.8	1,532.7
	Total	19,778.8	4,964.6	2,856.1	3,150.4	8,807.6
Scen 100%	LGV	10,079.6	2,743.0	1,467.9	1,528.6	4,340.1
	Rigid HGV	6,367.9	1,555.2	894.1	1,016.8	2,901.7
	Articulated HGV	3,187.5	607.8	466.2	584.3	1,529.2
	Total	19,635.0	4,906.1	2,828.2	3,129.7	8,771.0

Source: authors' calculations from VISUM

Table A 5: Distances traveled in VKM per year (1,000)

		LUA	C1	C2	C3	C4
Scen 0%	LGV	2,491.0	544.7	344.6	386.9	1,214.8
	Rigid HGV	2,133.4	422.6	281.5	345.5	1,083.8
	Articulated HGV	1,493.5	249.5	213.7	278.4	752.0
	Total	6,117.9	1,216.7	839.8	1,010.8	3,050.6
Scen Réf	LGV	2,493.9	545.3	345.3	387.6	1,215.7
	Rigid HGV	2,135.5	422.9	282.1	346.1	1,084.4
	Articulated HGV	1,494.3	249.6	213.8	278.6	752.4
	Total	6,123.7	1,217.8	841.2	1,012.3	3,052.4
Scen 20%	LGV	2,499.9	546.3	346.8	389.2	1,217.6
	Rigid HGV	2,140.3	423.6	283.2	347.5	1,086.1
	Articulated HGV	1,496.2	249.7	214.3	279.1	753.0
	Total	6,136.4	1,219.6	844.3	1,015.8	3,056.8
Scen 50%	LGV	2,506.3	547.5	348.2	390.8	1,219.7
	Rigid HGV	2,145.3	424.4	284.2	348.8	1,087.9
	Articulated HGV	1,498.1	250.0	214.7	279.5	753.8
	Total	6,149.6	1,222.0	847.2	1,019.1	3,061.4
Scen 80%	LGV	2,509.2	547.9	348.9	391.7	1,220.6
	Rigid HGV	2,147.8	424.6	284.8	349.5	1,088.9
	Articulated HGV	1,498.5	250.0	214.8	279.6	754.1
	Total	6,155.5	1,222.5	848.4	1,020.9	3,063.6
Scen 100%	LGV	2,508.0	547.6	349.0	391.5	1,219.9
	Rigid HGV	2,146.5	424.3	284.8	349.2	1,088.2
	Articulated HGV	1,498.1	249.8	214.8	279.6	753.8
	Total	6,152.6	1,221.7	848.7	1,020.3	3,061.9

Source: authors' calculations from VISUM

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CHAPTER 2

ENVIRONMENTAL AND ECONOMIC EVALUATION OF A LOW EMISSION ZONE FOR URBAN FREIGHT TRANSPORT

1. Introduction

Urban anthropogenic activities are responsible for pollutant emissions that reduce air quality. Urban transport of passengers and freight is one of the main contributors to pollution within cities (European Environment Agency, 2018). In Europe, a Commission Directive (Directive 2008/50/EC) defines and sets objectives for ambient air quality. It informs cities on the extent of efforts to be made in terms of pollution reduction in order to avoid, prevent or reduce health and environmental risks. Cities are therefore adopting measures to meet this requirement.

Among the existing measures is the widespread use of low emission zone (LEZ) that prohibit access to a defined geographic area for any vehicle that does not meet certain emission standards (Allen et al., 2010; Browne et al., 2005; Watkiss et al., 2003). The expected direct effect is a renewal of the vehicle fleet (Dablanc et al., 2018; Ellison et al., 2013; Jiang et al., 2017; Rizet, 2018) operating within this zone, which would consequently lead to a reduction in the amount of pollutants emitted in the zone and thus lead to an improvement in ambient air quality. The first LEZ was implemented in 1996 in Sweden, in the cities of Stockholm, Gothenburg and Malmö (Holman et al., 2015). In Europe, it was not until 2002 that a LEZ was implemented outside of Sweden, that of the Mont Blanc tunnel between France and Italy (Holman et al., 2015). Since then, the LEZ has seemingly been widely adopted as a measure to improve urban air quality, with more than 200 LEZs reported across Europe (Mudway et al., 2019; Sadler Consultants Ltd, 2019; Settey et al., 2019). LEZs can take many forms depending on their implementation and enforcement (type of transport vehicles involved, emission standard requirements, area size, time slots). They may cover both passenger and freight vehicles, as is the case in Germany (Malina and Scheffler, 2015). They may also apply only to freight vehicles, as is the case in Denmark (Sadler Consultants Ltd, 2019). Also, the standards to be met to access the zone are more or less stringent from one LEZ to another. The enforcement system is characterized by an important heterogeneity, either through plate recognition by cameras or through visual control by stickers (ADEME, 2020).

This spectrum of possible schemes has produced various feedbacks regarding their implementation and effectiveness in terms of impacts in several European cities (Holman et al.,

2015; Pouponneau et al., 2019). In some cases, the achieved impacts of these implementations are positive, but in others they are insignificant or even null in terms of air quality improvement (Dias et al., 2016). Throughout the literature, several reasons are mentioned to explain this, including: the incomplete enforcement of the measure (lack of control), a too lenient enforcement (polluting vehicles continue to operate), the multiple derogations given to some users, the enforcement limited to a limited share of the traffic (a small area), etc.

In addition to these reasons, the accuracy of the *ex-ante* evaluation prior to the implementation of LEZs may be questionable. To predict the potential impact of LEZs, there is a need for a large amount of detailed local data, from vehicle fleet structure to traffic speeds (Holman et al., 2015). Previous studies have faced difficulties both regarding methodology and predicting the actors' response to the LEZs implementation. Regarding methodology, the main difficulty is the availability of data at the urban scale concerning: the composition of the vehicle fleet, the use of vehicles by actors, traffic conditions, the contribution of each type of transport (passengers vs. freight), etc. On the one hand, these difficulties do not allow an accurate evaluation of the reference situation in terms of pollutant emissions attributable to each type of transport. On the other hand, the lack of knowledge about the behavior and practices of transport actors makes it difficult to take into account their potential responses to the LEZs implementation. In the case of an *ex ante* evaluation, this could introduce a bias in the scenario to be evaluated and, in turn, in the impact that could be expected from the implementation of a LEZ. To assist local authorities in well-informed decision-making, there is an urgent need for tools and methodologies addressing the difficulties faced in the *ex ante* evaluations of the LEZs (Dias et al., 2016).

This paper aims to contribute to addressing this need. Through the literature on LEZs, we can see that few studies propose methodologies to address the difficulties mentioned above. Indeed, most of them rely on air quality measurement station data (Ellison et al., 2013; Holman et al., 2015; Invernizzi et al., 2011; Jiang et al., 2017) or manual traffic counting data (Boogaard et al., 2012; Carslaw and Beevers, 2002) or national vehicle fleet data (Cesaroni et al., 2012). Moreover, very few of them propose an environmental and economic evaluation of the LEZs, while economic costs related to this measure are nevertheless a key determinant of its adoption and then its effectiveness. Furthermore, few studies have focused specifically on freight, even though this type of transport raises very important issues. In France, for the emission generated by urban transport, urban goods movement (UGM) is responsible for about 15% of greenhouse gas (GHG) emissions, and about 40% of NO_x and 50% of particulates (Albergel et al., 2006; CERTU, 2013). Focusing on the case of the Paris region, Coulombel et al. (2018) find that

UGM accounts for 20% of CO₂ and 30% of NO_x and PM emitted by road traffic while it represents only 8% of distances traveled.

In comparison to these studies, we propose a methodological approach for *ex ante* evaluation of the environmental and economic impacts of a LEZ concerning only freight transport. This approach is based on integrated modelling. On the one hand, the simulation tools used allow us to simulate the characteristics of urban freight transport and the conditions under which this transport occurs. On the other hand, based on interviews with the actors involved in the UGM, their potential responses to a LEZ were collected and used for the design of our study scenarios and for the analysis of some results. This methodological approach makes it possible to evaluate the environmental and economic impact of several LEZ scenarios. Moreover, compared to the methodologies of most of the previous studies, our approach allows us to calculate the economic-environmental balance of the implementation of the LEZ over a time period of several years through a cost-benefit analysis (CBA). Thus, this paper provides both a methodological contribution for research and a practical contribution for decision-making. Our approach is applied to the case of the LEZ implemented by the Lyon Metropolitan Authority (LMA) in France.

The rest of the paper is organized as follows. After presenting a brief review of the literature on the evaluation of the impacts of LEZs in Section 2, we describe the methodology used in Section 3 and the case study in Section 4. Section 5 focuses on the Results, which are discussed in Section 6. Section 7 concludes the paper.

2. Literature Review

From the literature, three main categories of methodology for evaluation of the impacts of LEZs can be distinguished when focusing on the types of data used. The first category uses data from air quality monitoring stations. This category uses few or no data on the existing vehicle fleet within the study area. The second category mobilizes vehicle fleet data from manual traffic counts or camera plate recognition at certain points within the study area. The third category mobilizes more or less accurate data on the vehicle fleet. These are data from large sample surveys or from more or less comprehensive databases. Distinguishing between the methodologies by the type of data used makes it possible to highlight the way in which each of them addresses or does not address the limitations mentioned above that can affect the accuracy of the impact evaluation of the LEZs: the representativeness at urban scale of the data on the composition of the vehicle fleet, the use made of it in time and space, and the conditions under

which this use is made. The choice of one or other of these categories of methodology influences the accuracy of the results of the evaluation for which it is used. Even though we focus on the *ex ante* evaluation of the impacts of the LEZs concerning freight transport, we review here both *ex post* and *ex ante* evaluation methodologies for freight transport as well as for passenger transport.

Using data collected from several pollution monitoring stations over 2002 -2012, Jiang et al. (2017) measure the impact of the LEZs implemented in Germany since 2008 by comparing the average annual pollution concentrations inside and outside the LEZs before and after their implementation. The measurements show a 17% decrease in pollution inside the LEZs and 14% outside. This shows that regardless of the introduction of the LEZs, there was an overall reduction in pollution (PM₁₀, PM_{2.5}, NO, NO₂, and NO_x) which could be explained by the effectiveness of all measures (including LEZ) implemented during this period to address air pollution (Jiang et al., 2017). Results consider that the introduction of LEZs has nonetheless resulted in an additional, yet modest, emission reduction of about 1.4%. Overall, the Jiang et al. (2017) study concludes that LEZs: *i*- have a positive effect on the vehicle fleet composition; *ii*- have an overall positive effect on the reduction of pollutant emissions, which effect is more significant on the reduction of the number of days with exceedance of pollution thresholds than on the concentration of pollutants, *iii*- do not influence the emissions of all pollutants.

Ellison et al. (2013) evaluate the impacts of the LEZ implemented in 2008 in London by comparing pollution data collected inside and outside the LEZ over 2001-2011. The study shows a reduction in PM₁₀ concentration of 2.47 - 3.07% in areas inside the LEZ, compared to a 1% reduction outside. However, no significant difference was observed in NO_x concentration between the two areas. The study also found changes in the fleet, including a decrease in pre-Euro II vehicles, with a shift from rigid heavy goods vehicles (RHGVs) to light goods vehicles (LGVs) and articulated heavy goods vehicles (AHGVs). The moderate impact of the LEZ of London on the overall level of pollutant concentrations was predicted by the study of Watkiss et al. (2003). These predictions, however, foresaw a relatively larger impact on reducing the number of days with exceedance of pollution thresholds (Watkiss et al., 2003), similar to what has been observed for the LEZs in Germany (Jiang et al., 2017).

The moderate impacts of the LEZs on pollutant concentration are likely to be due to their own characteristics. The area size and its geographical location would have an impact on the effectiveness of the LEZ. Invernizzi et al. (2011) evaluate the impact of the Milan Ecopass Zone on PM concentrations (PM₁, PM_{2.5} and PM₁₀) and conclude that no significant difference in these concentrations can be identified between the areas inside the Ecopass Zone and those

outside. For the authors, this could be explained by the small size of the zone, which is only 8.2 km², or 4.5% of the municipality of Milan.

The level of standards required to enter the zone would also explain the effectiveness of the LEZs. According to Boogaard et al. (2012), the LEZs implemented in five Dutch cities (Amsterdam, The Hague, Den Bosch, Tilburg and Utrecht) did not substantially change the concentrations of traffic-related pollutants within the territories rather than outside. One reason for this is that these LEZs only targeted older trucks. Since the proportion of older trucks in the fleet was small, the effects of the LEZs would have been too small to produce significant decreases in pollutant concentrations (Boogaard et al., 2012). This observation is shared by Jiang et al. (2017) for whom tighter standards could improve the effectiveness of the LEZs in improving air quality.

The *ex post* evaluation cases presented above used data from pollution monitoring stations. While these data are reliable for measuring the level of pollution in an area, they may be inappropriate for evaluating the impact of the LEZs. They do not capture the dynamics that may occur in the organizational characteristics of transportation following the implementation of the LEZs. Indeed, the implementation of a LEZ can lead to an improvement in air quality in the same proportions within the perimeter concerned and outside, provided that this perimeter is sufficiently large and that it receives a significant proportion of vehicles whose starting point of the tour is located outside. Moreover, when actors switch from heavy goods vehicles (HGVs) to LGVs for urban freight transport, this may maintain or increase the level of pollution in the area. If such a switch occurs upon implementation of a highly restrictive LEZ for HGVs versus LGVs, pollution monitoring stations data would be inadequate to explain the results achieved by the measure.

As with *ex post* evaluations, *ex ante* evaluations lead to a variety of results. Carslaw and Beevers (2002) use traffic data from manual traffic counts on all major roads in London to evaluate the impact on air quality (NO₂) of two main potential schemes of LEZ in London: reducing vehicle flows and restricting the most polluting vehicles. The most effective scenario in this analysis predicted a decrease in NO₂ concentration ranging from 3.6% to 11.1%. The analysis shows that this result could have been achieved by maintaining the status quo for five years, while relying on natural fleet renewal. Using traffic data obtained from the National automobile database, Cesaroni et al. (2012) evaluate the impact on air quality (PM₁₀ and NO₂) and population health (years of life gained) of a future LEZ in Rome. The authors conclude that this LEZ would have a positive impact within the zone in terms of air quality improvement and

years of life gained. However, this impact would be small on a city-wide basis, given the limited reduction in pollutant concentration for the city as a whole.

The lack of city-scale fleet data often leads to the use of manual traffic counting data (Carslaw and Beevers, 2002) or national data (Cesaroni et al., 2012) to evaluate the impacts of LEZs. In the first case, this poses a problem of sample representativeness and thus the accuracy of the evaluation results. In the second case, it can lead to biases in the evaluation since spatial specificities in both the composition and use of the vehicle fleet are erased. André et al. (2018, 2017), who compare French national fleet data with camera observation data in the Ile-de-France region, note differences in their composition. They conclude that knowledge and consideration of the specificities and variability of local fleets are therefore important for the implementation of a spatially efficient and equitable LEZ (André et al., 2017).

In investigating the potential impacts of the London LEZ, Watkiss et al. (2003) had already noted that although reliable data on London traffic flows were available, it was crucial to have solid information on the number of vehicles operating in London. They therefore estimated these figures to obtain the number of vehicles that might be affected by a LEZ in London. This allowed them to estimate the environmental impact of renewing vehicles that would not meet the LEZ standards, both inside and outside the zone. By the same estimate, the cost of vehicle renewal could be calculated. This approach of Watkiss et al. (2003), while more interesting than approaches that use manual counting or pollution monitoring station data, is still somewhat imprecise. Indeed, the approach does not cover the use of vehicles. Therefore, the distribution of the average age of the national fleet was applied to the estimated fleet operating in London. On pollutant emissions and concentrations in the city of London, the LEZ scheme analyzed by Watkiss et al. (2003) would have moderate benefits in terms of pollution, but would contribute more to reducing exceedances of air quality thresholds.

Dias et al. (2016) evaluate *ex ante*, based on a modeling approach integrating a transport model, an emission model, and an air quality model, the environmental impact of a LEZ regarding private cars (PC) in the city of Coimbra, Portugal. The approach uses traffic and fleet data specific to the city of Coimbra. The main result is that PM₁₀ and NO₂ emissions from PCs would decrease significantly within the LEZ (63% and 52% respectively). However, the improvement in air quality would be small, and exceedances of the pollution thresholds adopted in the European Union (EU) would not be completely avoided. The approach used by Dias et al. (2016) has the advantage of using traffic, fleet composition, and vehicle age data at the scale of the studied city. However, the evaluation focuses on a LEZ regarding PCs, whose uses differ from those of freight vehicles.

We also note a gap between the predicted impacts *ex ante* and the results achieved *ex post*. In the case of the LEZ of London, while Carslaw and Beevers (2002) predicted a significant impact on the reduction of NO₂ concentration, the measurements carried out by Ellison et al. (2013) lead to the result of a non-significant variation in NO_x concentrations. It should be noted that the *ex ante* evaluation is a rather delicate task because of the assumptions on which it is based, but also and mainly because of the data used, or the failure to include certain changes. Fairly accurate knowledge of the vehicle fleet is a key determinant of the accuracy of the evaluation of the potential impact of LEZs (André et al., 2018). The limited impacts of LEZs in terms of air quality improvement, compared to what is often predicted, can be explained by the growth in the vehicle fleet between the period of the *ex ante* evaluation and the *ex post* measurement (Ellison et al., 2013). In addition to data on the characteristics of the fleet, knowledge of how it is used and how that use may change from time to time is needed. From the above, it can be seen that the *ex ante* evaluation of the impacts of a LEZ requires sufficiently precise knowledge of both transport supply (fleet composition) and transport demand (freight movements), since the latter somewhat determines the use of the fleet.

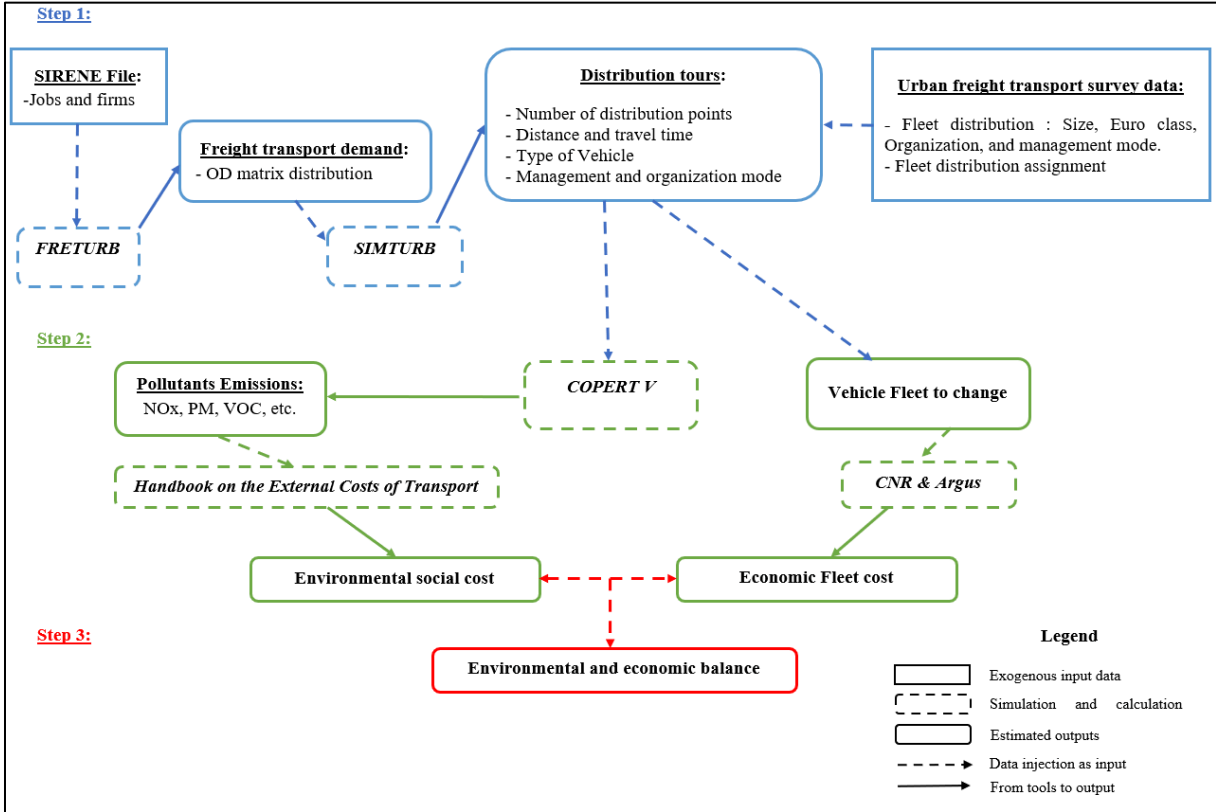
Through this brief review of the literature, we also note that most previous studies on the impacts of LEZs focus on environmental impacts (Carslaw and Beevers, 2002; Cesaroni et al., 2012; Invernizzi et al., 2011; Jiang et al., 2017; Zhai and Wolff, 2021), through air quality or human health. Few studies incorporate their economic impacts, even though their costs are a key determinant of their adoption and effectiveness. In their study, Watkiss et al. (2003) propose to balance the potential benefits and costs associated with the measure. They distinguish between the costs of implementing the LEZ, which mainly include the cost of the camera monitoring infrastructure for enforcement, and the costs of renewing the fleet. Comparing the benefits and costs of the proposed LEZ scheme, Watkiss et al. (2003) concluded that the benefits are likely to be broadly similar to the overall costs of introducing the LEZ. Using retrospective calculations, Wolff (2014) predicts the impact of LEZs implemented in 2008 in cities in Germany. To do so, author uses the "difference in difference" method to compare cities with LEZs (before vs. after implementation) to a set of control cities. This approach allows the author to carry out a CBA of the measure by comparing the health benefits related to the reduction of pollution (PM₁₀) and the costs related to the renewal of vehicles (PCs and freight vehicles). To estimate the cost of fleet renewal, Wolff (2014) uses localized registration data for PCs and freight vehicles from 2008 to 2010 from the German Federal Motor Transport Authority. For pollution, data from pollution monitoring stations were used. The study estimates that the implementation of LEZs would have a positive impact on health through the

reduction of pollution and that this corresponds to a gain of 2 billion euros (€). This gain is to be weighed against the billion € it would cost to renew the fleet. In retrospect, therefore, the CBA predicts that the introduction of LEZs in 2008 in Germany would yield a benefit of one billion € (Wolff, 2014). Börjesson et al. (2021) also use CBA for the *ex ante* evaluation of a proposed LEZ scheme in Stockholm for light vehicles. Their methodology estimates the economic costs of vehicle renewal as a welfare loss, which they compare with the benefits associated with externalities reduction. They conclude that the economic costs of vehicle renewal significantly exceed the benefits of improved air quality in this particular case study. This review of the literature shows that in the evaluation of the impacts of LEZs, few studies have focused on LEZs for freight transport and have addressed both the sensitive issue of fleet data and the economics of the measure. This paper aims at contributing to fill this gap.

3. Methods

This work relies on a variety of methods: **Fig. 4** describes the steps in the methodological framework developed to evaluate the potential impacts of a LEZ. It is an integrated modeling approach with three main steps.

Fig. 4. Methodological Framework



Source: author’s elaboration

3.1 Simulation of transport demand, supply and conditions

This step consists of characterizing the flows related to UGM. It involves estimating the transport demand in terms of the number of delivery and/or pick-up operations located in a given area. Then, this demand is characterized by grouping the operations into tours according to the management mode (third party logistics, own account transport shipper or consignee), the organization mode (direct or round trips) and the type of vehicles that carry them out. As these tours are located in time and space, they allow us to deduce the transport conditions in terms of time and distance travelled. From these data and a detailed knowledge of the logistic characteristics, we can finally deduce the transport supply required to meet this demand. This supply corresponds to the number of vehicles according to their size, organization mode, management mode, and Euro standard.

The estimation of freight transport demand within the area concerned is made using the FRETURB model (Routhier and Toilier, 2007). This model allows, mainly from a geocoded SIRENE file of establishments located on a given area, the quantification and characterization of the movements of freight carried out on this area (Toilier et al., 2018). It allows us to obtain the distribution of freight flows on this area as an origin-destination (OD) matrix for three types of vehicles: light goods vehicles (LGVs), rigid heavy goods vehicles (RHGVs) and articulated heavy goods vehicles (AHGVs). It is not our intention to explain the methodology of this tool in detail. Readers can refer to the articles mentioned above for more information.

The distribution obtained from FRETURB is then introduced as input in a second tool SIMTURB (Gardrat and Pluvinet, 2021). This is a model that allows, from Markov chains (see **Appendix 1** for a description of the model), to disaggregate the distribution matrices into the vehicle tours necessary to meet the transport demand provided by the FRETURB distribution. These tours are characterized according to the type of vehicles (LGVs, RHGVs and AHGVs), their loading rates, the start and end times of each tour, the time and distance travelled between each pair of points (establishments) successively reached in a same tour, the geographical coordinates of all these points (establishments), the number and duration of the stops within each tour, the management and organization mode of each operation, etc. Since a delivery and/or pick-up operation may start or end outside the LEZ area, or may be part of a tour that includes points both inside and outside the LEZ area, it is necessary to consider a larger area than the LEZ area for observation. One can therefore consider the metropolitan area of the city in which the LEZ is located or its urban area, which is by definition large enough to represent the city's attractiveness.

Since transport demand is now known in the form of tours characterized by vehicle type, management and organization, it is possible to determine the number of vehicles needed to meet this demand. Before determining this number of vehicles, a final characteristic is added to the transport demand: the Euro standard of the vehicles. This Euro standard, which can be deduced from the age of the vehicle, is essential for calculating the emissions generated by each type of vehicle. This requires detailed knowledge of the characteristics of urban freight transport. This knowledge is obtained from the processing of data from the most recent surveys on urban freight transport conducted by the Transport Urban Planning Economics Laboratory (LAET) (Bonnafous et al., 2016; Patier and Routhier, 2009; Toilier et al., 2016). For each type of vehicle, the distribution of Euro standards according to management mode and organization mode is computed. This distribution is then applied to all tours. Processing the same survey data gives us the average number of daily trips by vehicle type, management mode and organization mode. By applying this information to the tours, we determine the number of vehicles needed to meet the daily urban freight transport demand. This approach is innovative in that we have not found any study to date that has done this. More details on the processing of the vehicle fleet survey data are provided in subsection **4.3 Data**.

3.2 Economic and environmental impacts calculation

In the second step, we calculate the quantities of emissions generated by urban freight transport, as well as the external cost associated with these emissions. For the calculation of emissions, we use the COPERT V tool (Ntziachristos et al., 2009) developed by the European Environment Agency and used in most EU countries. It is a macroscopic vehicle emissions model built around the average speed approach (Ntziachristos et al., 2009). However, to calculate total exhaust emissions, the model distinguishes between hot and cold-start emissions, considering the effect of driving behavior and weather conditions (European Environment Agency, 2019). Since our simulations in *Step 1* provide us with average speeds and not instantaneous speeds, this type of model is therefore more appropriate for this study than other models such as HBEFA (Notter et al., 2019) that require instantaneous speeds. In addition, COPERT V provides emissions factor functions for most vehicle technologies in the European stock, as it uses benchmark test data conducted in EU countries (Ntziachristos et al., 2009). By associating these emissions functions with the traffic conditions of each tour, we obtain the estimate of the emissions for each vehicle movement between each OD. Thus, a major advantage of our methodological approach is that it allows us to see by area the contribution of each category of vehicle to the total quantities of emissions. This can be useful when we would like to implement

a measure targeting a specific type of pollutant or vehicle category. Various types of pollutants can be calculated from the COPERT V tool, but we choose to restrict ourselves to the pollutants targeted by the implementation of LEZs: PM₁₀, PM_{2.5}, NO_x, to which we add VOC and CO₂. The total pollutants emissions are then translated into monetary units to obtain the environmental external cost with and without LEZ. To do so, we use the most recent European guideline on external costs of transport (Van Essen et al., 2019). This guideline provides the cost of each type of pollutant according to the population density of the area in which they are emitted: urban, peri-urban and rural.

On the other hand, we calculate the economic cost associated with the accelerated renewal of the fleet required to meet the LEZ standards. This involves considering the fleet with the natural renewal that actors perform, to which we apply the standards required for access to the LEZ. From the number of vehicles determined in *Step 1*, we deduce the number of vehicles that need to be renewed in order to meet the LEZ standards. These are vehicles whose delivery tour reaches at least one point inside the LEZ and whose Euro standard does not meet the LEZ standards. The economic cost associated with this renewal is obtained by allocating the average costs of purchasing new vehicles and of disposal of used vehicles. In the economic cost, we consider only the cost of renewing the vehicles, because the costs of use are a priori the same for diesel vehicles whether they are new or old.

Our approach allows us to evaluate several schemes of LEZs, which we approach as scenarios. These scenarios are compared to the situation without LEZ.

3.3 Computation of the economic-environmental balance

To calculate the economic-environmental balance of the LEZ, we weight the environmental external cost and the economic cost of fleet renewal for each scheme with and without LEZ. This balance represents the benefit obtained or the cost to be borne by all the actors involved (public and private). The analysis of this balance makes it possible to identify the implications of the implementation of the LEZ for these actors and thus to contribute to the decision-making process, especially for the public actors. To do this, we analyze this balance over several periods by calculating the net present value (NPV) of each scheme with and without LEZ. Equation (1) illustrates the calculation of this NPV.

$$NPVTC_k = \sum_{t=0}^N \frac{n_{t,k}^n (R^0 - C^n) - CE_{t,k}}{(1+r)^t} + \sum_{t=0}^N \frac{n_{t,k}^n C^n (1-a)^{N+1-t}}{(1+r)^{N+1}} \quad (1)$$

In equation (1), $NPVTC_k$ is the *Net Present Value of Total Costs* in scenario k , N is the analysis period, $n_{t,k}^n$ is the number of new vehicles purchased in year t in scenario k , R^0 is the average disposal price of used vehicles, C^n is the cost of purchasing new vehicles, $CE_{t,k}$ is the total environmental external cost in year t in scenario k , a is the wear and tear rate of new vehicles, r is the social discount rate. The second term in equation (1) is the residual value over time of new vehicles purchased. The total fleet in year t in scenario k ($N_{t,k}^T$) is the sum of the new vehicles $N_{t,k}^n$, older vehicles that meet the LEZ standards $N_{t,k}^o$, and the vehicles that are so old to enter the LEZ but can be operated outside the LEZ $N_{t,k}^i$. We can also write:

$$CE_{t,k} = \sum_j w_j (N_{t,k}^n e_j^n + N_{t,k}^o e_j^o + N_{t,k}^i e_j^i) \quad (2)$$

Where j is the pollutant considered, w_j is the guideline value of pollutant j , e_j^z is the average emissions of j from the different types of vehicles. Following the NPV criterion, the best scenario k is the one with the highest $NPVTC$.

4. The Case Study of Lyon

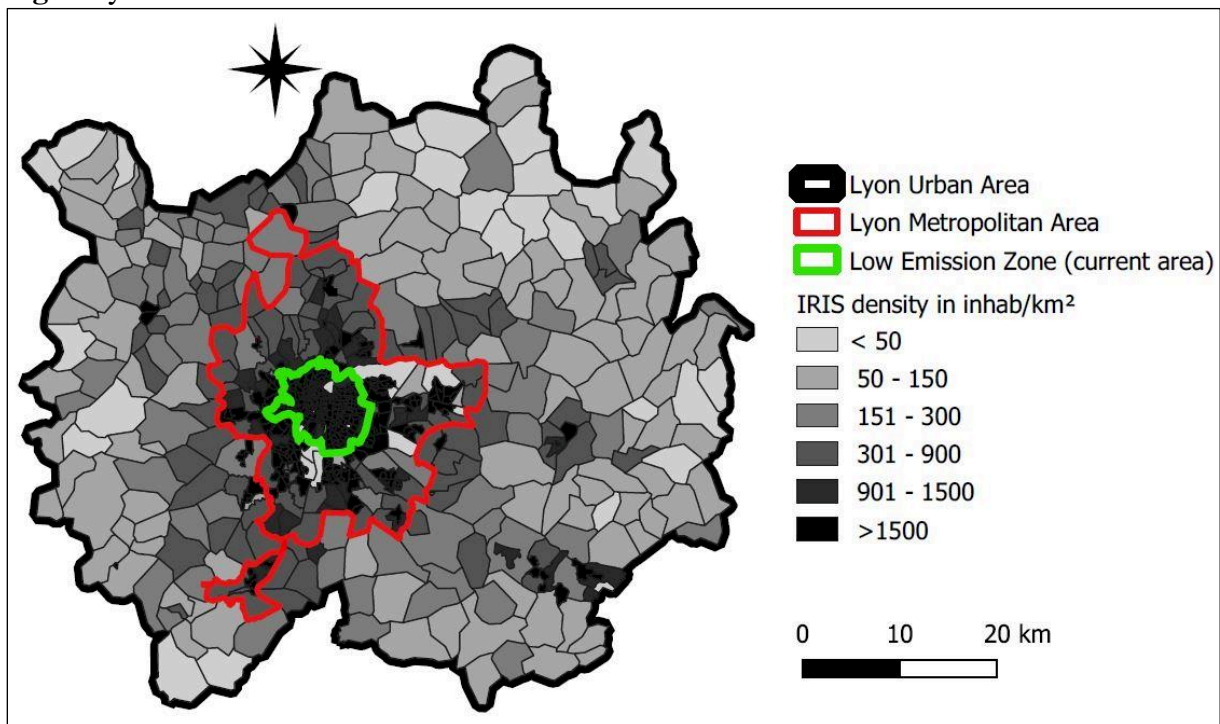
4.1 Scope of study

The case study in this paper is the LEZ of the city of Lyon. The Lyon Metropolitan Authority (LMA, also called Greater Lyon) has set up a LEZ whose main objective is the elimination of the pollution peaks to which the population is regularly exposed. This LEZ is part of its overall strategy "Oxygen Plan" aimed at improving air quality and combating air pollution mainly through the reduction of NOx and PM emissions (SYTRAL, 2017). The area concerned by the LEZ represents 1.9% of the Lyon urban area (LUA), i.e. all the nine arrondissements of Lyon, the municipality of Caluire-et-Cuire, as well as the parts located inside the Laurent Bonnevay ring road of Bron, Vénissieux and Villeurbanne (see **Fig. 5**). Regarding time restrictions, the ban on access, running and parking in the LEZ is permanent (24 hours a day, 7 days a week) and concerns only freight vehicles (LGVs and HGVs). The restriction is based on a system of stickers (Crit'Air) stuck on vehicles and is based on the size of the vehicles (HGVs and LGVs), the engine (electric, gas, diesel and gasoline) and the Euro standards (see **Table A 6**).

The LEZ was implemented in January 2020, with full implementation of the standards in January 2021. Thus, since January 1, 2021, only vehicles with Crit'air 1 or 2 stickers can enter the zone. This includes all 100% electric, hydrogen, gas and plug-in hybrid vehicles, whether they are HGVs or LGVs. For HGVs, these are Euro V and VI standards vehicles in gasoline

and EuroVI in diesel. For LGVs, this means Euro IV, V and VI gasoline vehicles and Euro V and VI diesel vehicles.

Fig. 5 Lyon Urban Area in its 1999 limits



Source: authors' elaboration from IGN and Lyon Metropole Authority

4.2 Scenarios

Several scenarios are analyzed to evaluate the impact of the current and alternative schemes of LEZs. Scenarios are designed to evaluate the effect of a variation in the standards of the LEZ and/or a variation in its size:

- *Scen 1:* represents a LEZ scenario as defined by the LMA in terms of area (see Cf. **Fig. 5** and **Table 7**) and Euro standards (see **Table A 6**).
- *Scen 2:* represents a LEZ scenario with the same size as defined by the LMA and stricter standards for access to the zone. In this scenario, only Euro VI vehicles, whatever their size, will be allowed to enter the zone. In reality, this tightening only concerns LGVs since the standards for HGVs were already set at Euro VI.
- *Scen 3:* represents a LEZ scenario in which the standards for access to the zone are those defined by the LMA, and an extended area to Greater Lyon (Lyon metropolitan area) (see **Fig. 5**). This scenario allows to evaluate the impact of an extension of the LEZ area.

- *Scen 4*: represents a LEZ scenario with area is extended to Greater Lyon and stricter standards for access to the zone (only Euro VI vehicles). This scenario evaluates the combined effect of an extension of the LEZ area and a tightening of the access standards.

These scenarios are compared to the reference scenario (BAU - *Business As Usual*), which corresponds to the scenario in which the natural renewal of the fleet would occur without the LEZ. The design of these scenarios is based in part on a series of semi-structured interviews with actors from various sectors involved in urban logistics and located in the LUA (see Chapter 3). Some actors believe that the standards of the current LEZ of Lyon are not sufficiently strict and propose their tightening. We introduce this by varying the standards of the LEZ in Scen 2 and 4. In the case of the Milan Ecopass Zone, Invernizzi et al. (2011) had shown that the size of the zone partly explains the impact of the measure on air quality. Echoing this, we introduce the variation in the size of the LEZ area in Scen 3 and 4.

In all scenarios, we assume that when actors renew their vehicles, they buy diesel vehicles and not green vehicles (gas, electric, etc.). This assumption is based on the fact that in the interviews we conducted, most of the actors stated that they would only comply with the strict minimum of the standards set for access to the LEZ, i.e., Euro VI for HGVs and Euro V and VI for LGVs. This statement was confirmed to us during our interview with the LMA, which provides a financial aid package of one million € to small actors to support the acquisition of green vehicles (gas, electric, etc.). When we interviewed the LMA, it had not received any applications for support for the acquisition of such vehicles. This means that the actors still prefer to acquire diesel vehicles, probably because of the +35% purchase cost differential for the acquisition of green vehicles.

4.3 Data

4.3.1. *Socio-economic characteristics of the case study*

The existing LEZ (Scen 1) covers an area of 62 km² and has a population of 684,185, a density of 11,028 inhabitants/km². The perimeter represents only 1.9% of the LUA, however it concentrates 36% of its population. Greater Lyon (Lyon Metropolitan Area) covers 16% of the LUA and concentrates 1.3 million inhabitants with a density of 2,554 inhabitants/km². **Table 7** shows the importance of the existing LEZ area, which concentrates in 1.9% of the LUA 43% of the jobs, 41% of the establishments and 35% of the estimated movements (delivery and/or pick-up). The demand for freight deliveries in the LUA corresponds to 51,355 tours, 72.3% of which are within the area of the LEZ, and 96.2% within the area of LMA.

Table 7: Characteristic data of Lyon urban area (2018)

	LUA	LEZ	Greater Lyon
Area (km ²)	3,325	62	537
		1.9%	16.1%
Population	1,916,149	684,185	1,370,676
		35.7%	71.5%
Inhabitants/km ²	576	11,028	2,554
Jobs	1,267,129	550,600	992,638
		43.5%	78.3%
Jobs/km ²	381	8,875	1,850
Establishments	275,687	113,182	202,696
		41.1%	73.5%
Number of movements	1,238,711	433,374	894,829
		35%	72.2%
Number of tours	51,355	37,138	49,408
		72.3%	96.2%

Source: authors' calculations from FRETURB, SIMTURB, IGN, SIRENE (INSEE)

Note: Percentage data represent the proportional share of each area in the whole LUA.

4.3.2. Characteristics of the freight vehicle fleet

A major challenge in the *ex ante* evaluation of the impacts of a LEZ is the composition of the vehicle fleet that will be affected by the measure. The accuracy of the evaluation depends both on knowledge of the composition of the vehicle fleet and on the use made of it. Indeed, vehicles vary in size, age and use depending on whether they are operated on own account/third party or on direct/round trips. The methodological approach adopted in this paper puts a particular emphasis on the characterization of the vehicle fleet according to its composition and use. To do so, we chose to use data from the most recent survey on urban freight transport (ETMV Bordeaux 2013) conducted in Bordeaux in 2013 (Toilier et al., 2015). The methodology of this survey considered the movement (delivery and/or pick-up performed by a vehicle) as the unit of observation. Data were collected simultaneously at three levels: face-to-face from a stratified sample of establishments generating freight flows, in order to collect information on the total movements carried out in one week; from freight vehicle drivers who receive, in the surveyed establishments, a questionnaire to describe their delivery tours; and from transporters, face-to-face, in order to understand their logistic organization (Bonnafeous et al., 2016; Patier and Routhier, 2009). The survey was conducted on 1,272 establishments, thus providing a good representativeness of the establishments located in the city of Bordeaux as well as their urban freight transport practices.

Based on these data, we characterized the fleet according to a set of criteria: vehicle size, age, management mode (third party logistics, own account transport shipper or consignee) and organization mode (direct or round trip). This characterization has made it possible to calculate the distribution of the fleet according to Euro standards, based on the age of the vehicles. It is based on the hypothesis that the size and age of a vehicle determine its use (Allen et al., 2018; Browne et al., 2010; Rizet, 2018). To test this hypothesis, chi-square tests were conducted for each of the variables for the three classes of vehicles (LGVs, RHGVs, and AHGVs). The result of these tests implies a dependence between age and size, age and management mode, age and organization mode, organization mode and management mode. Based on this, we calculated the distribution of the fleet according to age, size, management mode and organization mode. Since the survey was carried out in 2013, we considered the age structure of the fleet between 2013 and the end of 2019 as constant.

Table 8: Fleet characteristics in 2020: distribution of Euro standards by vehicle size, management mode and organization mode; average number of daily tours

Vehicle	MM	OM	Euro VI	Euro V	Euro IV	Euro III	Euro II-0	Average number of daily tours
LGVs	TP	DT	0.8%	0.4%	-	-	-	1.0
		RT	24.6%	12.5%	1.2%	-	-	1.5
	OAC	DT	9.2%	4.7%	1.0%	0.6%	0.4%	1.2
		RT	2.3%	1.2%	0.2%	0.4%	-	2.0
	OAS	DT	7.0%	3.5%	1.2%	0.2%	0.2%	1.2
		RT	16.5%	8.4%	2.9%	-	0.4%	1.5
RHGVs	TP	DT	4.4%	1.2%	-	-	-	2.9
		RT	44.2%	12.4%	2.8%	2.0%	0.8%	1.4
	OAC	DT	0.4%	0.4%	-	-	-	2.5
		RT	-	0.8%	-	-	-	1.0
	OAS	DT	1.6%	0.0%	0.4%	-	-	2.0
		RT	21.1%	3.6%	2.8%	0.8%	-	1.0
AHGVs	TP	DT	39.6%	4.2%	2.1%	2.1%	-	1.8
		RT	42.7%	1.0%	-	2.1%	-	1.4
	OAC	DT	-	0.0%	-	-	-	2.5
		RT	-	0.0%	-	1.0%	-	2.0
	OAS	DT	-	1.0%	-	-	-	2.0
		RT	2.1%	1.0%	-	1.0%	-	1.0

Source: Authors' calculations based on projected data from the ETMV Bordeaux 2013

Note: TP = Third party logistics; OAC = Own Account transport Consignee; OAS = Own Account transport Shipper ; DT = Direct Trip ; RT = Round ; MM = Management Mode ; OM = Organization Mode.

Based on the age of vehicles, we deduce the Euro standard of each vehicle. The correspondence between age and Euro standard is depending on the engine of the vehicle. We have made the

assumption that the fleet is 100% diesel. This assumption is based on the fact that the data from the survey ETMV Bordeaux 2013 show that 98% of distances traveled by LGVs are carried out with diesel vehicles, 1.6% with gasoline and 0.4% with other types of vehicles (electric, hybrid or NGV), and that 100% of distances traveled by HGVs are with diesel.

Table 8 shows the distribution of the Euro standard for each size of vehicle, by management mode and by organization mode. Assuming that the composition of the fleet and its use are the same between Bordeaux and Lyon, this distribution represents the structure of the freight vehicle fleet as it should be in January 2020. Applying the LEZ standards (see **Table A 6**) to this fleet gives the proportion of vehicles that will be eligible for the LEZ and the proportion that will not be eligible. The proportion of vehicles (see **Table 8**) that do not meet the LEZ standards is 8.9% for LGVs (Euro IV to Euro 0), 28.3% for RHGVs (Euro V to Euro 0) and 15.6% for AHGVs (Euro V to Euro 0). Any renewal of vehicles would therefore correspond to an accelerated renewal of the fleet, which is entirely attributable to the implementation of the LEZ.

A key piece of information for an accurate calculation of the number of vehicles needed to meet a transport demand is the daily use of each vehicle in terms of number of tours. The data in **Table 8** provide the average number of daily tours by vehicle type, management mode and organization mode. Applying these average values to the number of tours made to meet the freight transport demand, we obtain the number of vehicles needed to meet this daily demand, 25,961 LGVs, 3,528 RHGVs and 7,107 AHGVs (see **Table 9**). This is not the number of vehicles likely to be present in the study area, but rather the number of vehicles needed to perform the transport operations in this area. The methodology based on transport demand generation makes it possible to calculate the number of vehicles needed to meet this demand.

Table 9: Fleet size required to meet LUA's daily transport demand

Vehicle	Number
LGVs	25,961
RHGVs	3,528
AHGVs	7,107

Source: Author's calculation

This method has the advantage of evaluating the impact of the LEZ based on a realistic fleet size compared to the use of the registered fleet in the region. This is because using the registered fleet data does not provide information on the effective fleet operating in the region, since a vehicle registered in the region may not be operating in the region or may not be operating for

any reasons. The fleet approach to meeting demand allows for a better measure of the traffic impacts generated by that demand.

4.3.3. Other parameters

For the cost of vehicles, several sources were used. For new LGVs, we considered the weighted average prices of the top 10 best-selling LGVs in France in 2019. The average disposal value of LGVs was compiled in the same way through the Argus prices. The average ownership period of new LGVs is 4.9 years in France (OVE, 2018). Data for RHVGs and AHGVs are from regional freight surveys conducted by the National Road Committee (CNR, 2020a, 2020b). Data on the average purchase value, disposal value, and average ownership period of vehicles are displayed in **Table 10**.

Table 10: Average value of the vehicles (in €) and average ownership period (in years)

Vehicle	Value as new	Disposal value	Average ownership period (year)
LGVs	35 921	5 179	4.95
RHGVs	90 465	16 337	6.2
AHGVs (Tractor unit)	86 417	16 613	6.6

Source : Surveys (CNR, 2020a, 2020b), l'Argus (www.largus.fr), (OVE, 2018)

Note: For AHVGs, the values are for the tractor unit only, which is the only part of the articulated combination subject to the LEZ standards.

Table 11 provides the values of the external costs of emissions that are used for the calculation of the environmental external cost. These data are from the most recent European guideline on external costs of transport (Van Essen et al., 2019). The values are based on the population density of the area in which the emissions are produced.

Table 11: External costs of emissions (€/ton)

	Rural area	Peri-urban area	Urban area
CO ₂ (€/ton)	100	100	100
NO _x (€/ton)	16,200	27,200	27,200
PM _{2.5} (€/ton)	87,000	131,000	407,000
PM ₁₀ (€/ton)	5,900	5,900	5,900
VOC (€/ton)	1,500	1,500	1,500

Source: Van Essen et al. (2019)

Note: "Rural area" corresponds to areas with less than 300 inh./km² as population density ; "Peri-urban area" corresponds to areas with population density ranging from 300 inh./km² to 1500 inh./km²; Urban corresponds to areas with more than 1500 inh./km².

For the computation of the NPV, the value of the discount rate r in equation (1) is set at 4.5%, according to the recommendations of French guidelines provided in the Quinet report on the socio-economic evaluation of public investments in France (CGSP, 2013). The duration of the analysis N in equation (1) is set at 5 years (2020 to 2024) in reference to the average ownership period of freight vehicles (see **Table 10**).

5. Results

5.1 LEZ impact on the vehicle fleet

Table 12 shows an accelerating renewal of the vehicle fleet attributable to the implementation of the LEZ. Indeed, Scen 1 leads to a fleet renewal of 13.7% LGVs, 23.3% RHGVs and 16.5% AHGVs in 2020, compared to 6.6% LGVs, 6.7% RHGVs and 6.6% AHGVs respectively in the BAU scenario. This trend is confirmed when the LEZ standards are tightened in Scen 2, which increases the renewal rate for LGVs from 13.7% to 31.1%, leaving the renewal rate for RHGVs and AHGVs unchanged since the tightening of standards does not concern these vehicles.

Table 12: Impact of the LEZ on vehicle fleet renewal

	Number in 2020			Cumulative number in 2021-2024		
	LGVs	RHGVs	AHGVs	LGVs	RHGVs	AHGVs
BAU	1706 6.6%	236 6.7%	469 6.6%	4708 18.1%	506 14.3%	687 9.7%
Scen 1	3546 13.7%	824 23.3%	1170 16.5%	3741 14.4%	87 2.5%	198 2.8%
Scen 2	8061 31.1%	824 23.3%	1170 16.5%	1411 5.4%	87 2.5%	198 2.8%
Scen 3	4251 16.4%	948 26.9%	1478 20.8%	3375 13.0%	4 0.1%	21 0.3%
Scen 4	10339 39.8%	948 26.9%	1478 20.8%	220 0.8%	4 0.1%	21 0.3%

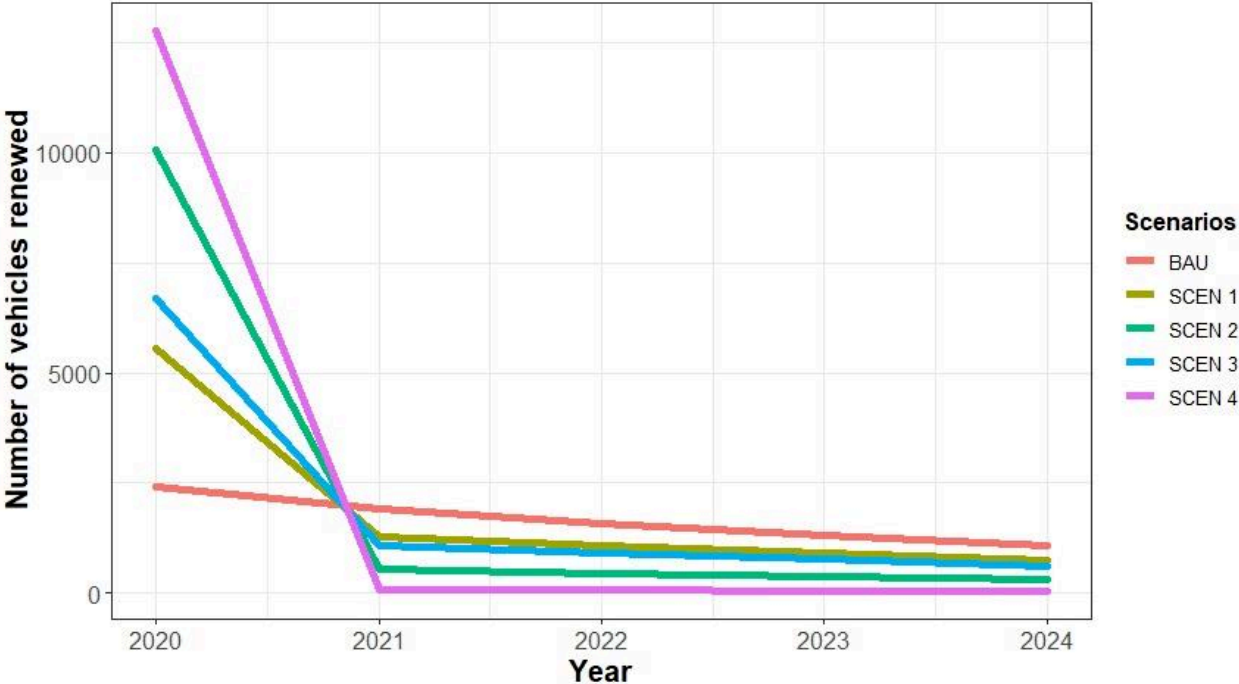
Source: Authors' calculation

Note: Percentage figures represent the proportion of vehicles renewed in the total fleet

This acceleration of fleet renewal is even more noticeable when the LEZ area is extended to Greater Lyon (Scen 3) and especially when the LEZ standards are tightened on that area (Scen 4). Combining the extension of the area with a tightening of the standards, the acceleration of the fleet renewal is reflected in the year 2020 by a renewal of 39.8%, 26.9% and 20.8% for LGVs, RHGVs and AHGVs respectively (Scen 4). **Fig. 6** shows the details of the fleet renewal evolution over the period 2020-2024, highlighting the importance of the fleet renewal in 2020. For the period 2021-2024, the figures (see **Table 12**) show that the rate of vehicle renewal is low in the scenarios with LEZ and lower when the area of the LEZ is extended and the standards are tightened. This is explained by the fact that the renewal was sudden and significant when

the LEZ was implemented in 2020, and the fleet suddenly got newer, thus reducing the need for natural renewal in the following years.

Fig. 6. Evolution of fleet renewal over the period 2020-2024



Source: Authors' calculation

The acceleration of fleet renewal implies a higher renewal cost in the first year (2020) and a decreasing cost over time (2021-2024) in the scenarios with LEZ. **Table 13** provides the total discounted cost of fleet renewal over the 2020-2021 period. In 2020, without the LEZ (BAU), the natural renewal of the fleet would have cost 117.9 million €. The implementation of the LEZ leads to a cost that varies between 290 million € (Scen 1) and 559.7 million € (Scen4). Compared to the scenario without LEZ (BAU), the four scenarios with LEZ increase the cost of renewal by 2.5 times for Scen 1, 3.8 for Scen 2, 3 for Scen 3 and 4.7 for Scen 4. When we look only at the scenarios with LEZ, we can see that with a constant size of area, the increase in cost is 1.5 times (Scen 1 vs. Scen 2 and Scen 3 vs. Scen 4), compared to a 1.2 times increase with constant standards (Scen 1 vs. Scen 3 and Scen 4). This increase is 1.9 times when we focus on the combined effect of tighter standards and a wider area than in the existing LEZ scenario (Scen 1 vs. Scen 4). The cost of renewal is largely explained by the cost of renewing LGVs, and even more so in the scenarios with tighter standards. When looking at the 2021-2024 period, the renewal cost is higher in the scenario without LEZ than in those with LEZ. Because of the accelerated fleet renewal in 2020, the cumulative cost of fleet renewal between 2021 and 2024 ranges from 8.7 million (27.3 times less than in the BAU scenario) to 138.2 million (1.7 times less than in the BAU scenario). Based on the cost of fleet renewal during the

period 2020-2024, Scen1 is the best scenario followed by Scen 3, 2 and 4, with costs in million € of 428.2, 457.4, 510.8 and 568.4 respectively.

Table 13: Total discounted economic cost (million €) of fleet renewal from 2020 to 2024

	Discounted cost (million €) 2020			Discounted cost (million €) 2021-2024		
	LGVs	RHGVs	AHGVs	LGVs	RHGVs	AHGVs
BAU	58.6 49.8%	20.4 17.3%	38.8 32.9%	146.4 61.5%	39.9 16.7%	51.9 21.8%
Scen 1	121.9 42.0%	71.3 24.6%	96.8 33.4%	116.4 84.3%	6.8 5.0%	14.9 10.8%
Scen 2	277.1 62.2%	71.3 16.0%	96.8 21.7%	43.9 66.9%	6.8 10.4%	14.9 22.7%
Scen 3	146.1 41.7%	82.1 23.4%	122.2 34.9%	105.1 98.2%	0.3 0.3%	1.6 1.5%
Scen 4	355.4 63.5%	82.1 14.7%	122.2 21.8%	6.8 78.5%	0.3 3.6%	1.6 18.0%

Source: Authors' calculation

Note: Percentage figures represent the share of renewal cost of each vehicle type in the total renewal cost.

5.2 Environmental impacts of the LEZ

Considering five working days per week, a total of 260 days per year, **Table 14** provides the quantities of pollutant and CO₂ emissions of the different scenarios of LEZ over the period 2020-2024. In order to better understand the environmental impact of each scenario, the results are analyzed at the level of three areas: LEZ area, which corresponds to the perimeter of the LEZ as presented in **Fig. 4**; GL area, which is the ring corresponding to the Lyon Metropolitan area (see **Fig. 4**) excluding the perimeter of the LEZ; LUA area, which is the ring corresponding to the perimeter of the LUA excluding the Lyon Metropolitan area (see **Fig. 4**).

Whatever the area observed, the quantities of CO₂ emitted are not significantly affected by the implementation of LEZ, regardless of the stringency of the regulations or the size of the perimeter concerned. This confirms that CO₂ emissions have been very little changed by the evolution of the Euro standards for diesel freight vehicles (Rizet, 2018). Since CO₂ emissions evolve linearly with fuel consumption, this result supports our choice to consider that operating costs are the same for new and old vehicles. For pollutants, the results show a reduction in PM emissions of 50% in Scen 1, 2, 3 and 4 within the LEZ area. Thus, the reinforcement of the

standards, although it only concerns LGVs here, does not influence PM emissions. This is explained by the fact that the change from Euro V to Euro VI did not improve PM emissions standards for LGVs (Williams and Minjares, 2016). This result is further supported by the fact that in GL and LUA areas, the reduction in PM emissions only shows variability depending on the size of the perimeter covered by the LEZ. Thus, in the scenarios with an extended LEZ perimeter (Scen3 and Scen 4), there is a PM reduction of -51% in GL area and -43% in LUA area. In the scenarios with a normal LEZ perimeter (Scen 1 and Scen 2), this reduction is about -27% in GL area and -28% in LUA area. The exposure of the population located in GL and LUA areas to PM can be reduced by 1.9 times and 1.5 times respectively when passing from a normal perimeter of LEZ to an extended perimeter. This result shows that the larger the size of the LEZ, the more the pollution reduction will benefit populations located outside its perimeter.

Compared to BAU, Scen 1 allows a reduction in NO_x emissions of 20% in LEZ area, 10% in GL area and 12% in LUA area (see **Table 14**). Unlike PM, NO_x emissions are sensitive to a tightening of standards because the transition from Euro V to Euro VI has significantly improved NO_x emission standards for LGVs (Williams and Minjares, 2016). With a constant perimeter, a tightening of standards allows a reduction in NO_x emissions within LEZ area (Scen 1 vs. Scen 2; Scen 3 vs. Scen 4) of 7 percentage points. Outside LEZ area, it allows a gain of 5 percentage points in GL and LUA areas (Scen 1 vs Scen 2; Scen 3 vs Scen 4). As with PM, the main issue is the number of people concerned by the reduction in emissions. It can be seen that expanding the boundary of the LEZ (Scen 3) results in almost identical reductions in NO_x emissions in the three areas, i.e. 20% for LEZ and GL areas and 19% for LUA area. These reductions, while remaining close to each other, are greater when the extension of the perimeter is combined with the tightening of standards (Scen 4). Thus, even if the first objective is to reduce pollution for the populations of the city center, a LEZ with the size of Greater Lyon (Lyon Metropolitan Area) will lead to a decrease in NO_x emissions in the same proportions for the populations of the whole LUA. The effects of the implementation of LEZ on VOC emissions follow the same pattern as for PM. Indeed, regardless of the level of the standards, the reduction in VOC emissions is -19% in LEZ area. The extension of the perimeter (Scen 1 & Scen 2 to Scen 3 & 4) improves this gain in the other two areas from -10% to -19% in GL area and from -10% to -16% in LUA area.

Table 14: Emissions (tons, 2020-2024)

		CO2	NOx	PM	VOC
BAU	LUA	704 674.4 0%	1 452.7 0%	9.4 0%	28.8 0%
	GL	790 250.5 0%	1 642.4 0%	10.3 0%	31.6 0%
	LEZ	560 444.5 0%	1 132.2 0%	7.3 0%	22.7 0%
	LUA	704 500.4 0%	1 273.8 -12%	6.8 -28%	25.8 -10%
	GL	790 494.1 0%	1 475.0 -10%	7.6 -26%	28.6 -10%
	LEZ	559 983.1 0%	905.8 -20%	3.6 -50%	18.4 -19%
Scen 2	LUA	704 517.1 0%	1 212.9 -17%	6.8 -28%	25.8 -10%
	GL	790 512.9 0%	1 400.3 -15%	7.6 -27%	28.5 -10%
	LEZ	559 983.1 0%	831.0 -27%	3.6 -50%	18.4 -19%
Scen 3	LUA	704 009.0 0%	1 183.7 -19%	5.4 -43%	24.2 -16%
	GL	789 681.1 0%	1 319.7 -20%	5.1 -51%	25.5 -19%
	LEZ	559 983.1 0%	905.1 -20%	3.6 -50%	18.4 -19%
Scen 4	LUA	703 983.9 0%	1 102.7 -24%	5.4 -43%	24.2 -16%
	GL	789 681.1 0%	1 209.0 -26%	5.1 -51%	25.5 -19%
	LEZ	559 983.1 0%	831.0 -27%	3.6 -50%	18.4 -19%

Source: Authors' calculations.

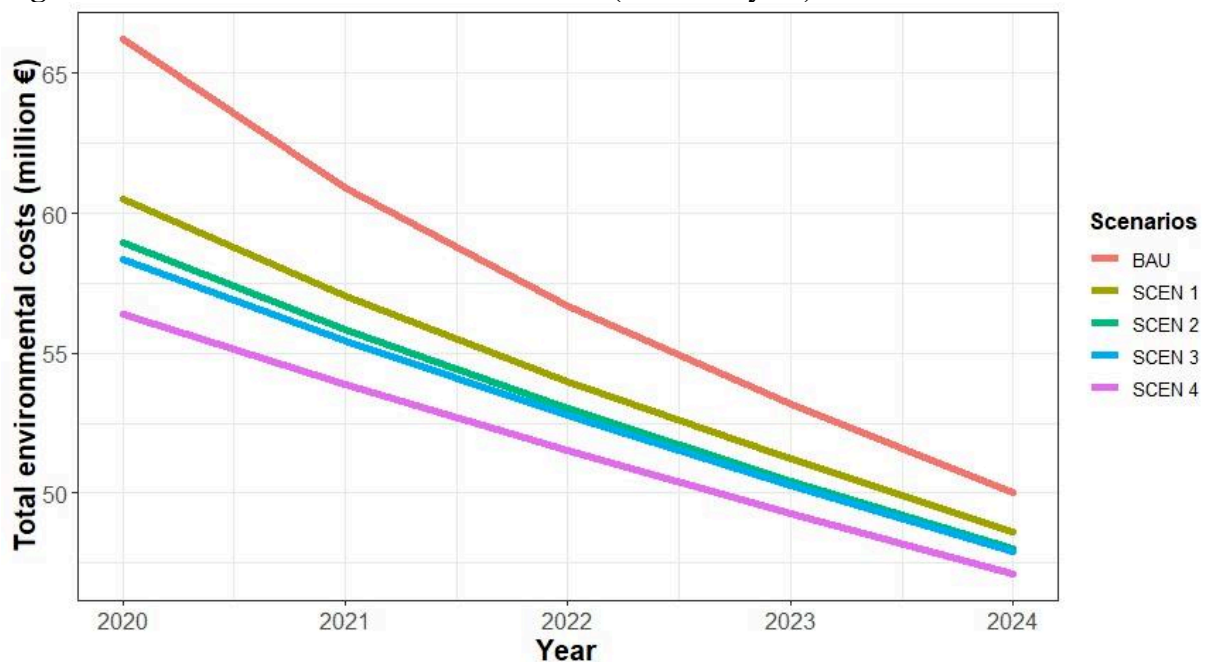
Note: Percentage data represent variations from the reference scenario (BAU). LEZ is the perimeter of the LEZ as shown in **Fig. 4**; GL corresponds to the Lyon Metropolitan Area excluding the perimeter of the LEZ; LUA corresponds to the perimeter of the LUA excluding the Lyon Metropolitan Area.

From the above, we can conclude that the implementation of the LEZ in Lyon will have a beneficial effect in terms of pollution reduction. The environmental impact of the LEZ improves when the perimeter is extended to Greater Lyon. A tightening of standards only improves the impact on NOx emissions, as the other pollutants remain unaffected. As the renewal of the fleet

is accelerated in 2020, the reduction of pollution is also more important during this year than during the rest of the period 2021-2024 (see **Table A 7**). For example, in 2020 the change in NOx emissions compared to BAU was respectively -20% in Scen 1, -26% in Scen 2, -28% in Scen 3 and -35% in Scen 4, compared to respectively -12%, -16%, -17% and -23% over the period 2021-2024 (see **Table A 7**).

The impact on the discounted environmental external cost associated with these emissions is relatively greater in 2020 compared to the 2021-2024 period. The significant renewal of the fleet in 2020 in the scenarios with LEZ leads to a drastic reduction of the pollutant emissions and consequently of the associated external cost, as shown in **Fig.7**. The deviation of the external cost curve in the scenario without LEZ (BAU) from the scenarios with LEZ (Scen 1 to 4) is larger in 2020 and decreases as time goes by (see **Fig. 7**).

Fig. 7. Discounted environmental external cost (million €/year)



Source: Authors' calculation

The cumulative discounted environmental external cost of emissions over the period 2020-2024 reaches a minimum of 258.2 million € in Scen 4 (see **Table 15**). On the environmental aspect, Scen 4 is therefore the best LEZ scenario as it achieves a maximum reduction of 12% of the external cost of emissions for the whole LUA over the period 2020-2024. It is followed respectively by Scen 3, Scen 2 and Scen 1.

Table 15: Cumulative discounted environmental external cost (million € 2020-2024)

	LUA	GL	LEZ	Total
BAU	98.0 0%	111.0 0%	78.0 0%	287.0 0%
Scen 1	93.3 -4.81%	106.4 -4.18%	71.7 -8.09%	271.3 -5.46%
Scen 2	91.8 -6.32%	104.6 -5.81%	69.9 -10.42%	266.2 -7.24%
Scen 3	90.9 -7.24%	102.1 -8.04%	71.7 -8.11%	264.7 -7.79%
Scen 4	88.9 -9.25%	99.4 -10.46%	69.9 -10.42%	258.2 -10.04%

Source: Authors' calculation

Note: Percentage data represent variations from the reference scenario (BAU). LEZ is the perimeter of the LEZ as shown in **Fig. 4** ; GL corresponds to the Lyon Metropolitan Area excluding the perimeter of the LEZ; LUA corresponds to the perimeter of the LUA excluding the Lyon Metropolitan Area

5.3 Economic-environmental balance of the LEZ

Table 16. presents the economic-environmental balance of the different scenarios of LEZ through the net present value (NPV) of their impact over the period 2020-2024. All scenarios, including the BAU scenario, have a negative NPV. This means that over the period 2020-2024, the costs of fleet renewal outweigh the gains from emissions reductions. The comparison of NPVs shows that Scen 3, with a NPV of -304.1 million €, is the best scenario of LEZ. The LEZ scheme proposed by the LMA (Scen 1) with a NPV of -306.7 million € is the second best scenario. In this scheme, each inhabitant of the LUA will bear a cost of 160.1 € over the period 2020-2024, compared to 158.7 € in Scen 3. Thus, the implementation of Scen 3 instead of Scen 1 would have allowed the LMA to save 2.6 million € over the period 2020-2024, a gain of 1.4 € per inhabitant. Scen 4 and Scen 2 are respectively the third and fourth best scenario of LEZ. However, it should be noted that BAU scenario has a higher NPV than the latter two scenarios. Another method of comparing all scenarios with the BAU scenario is to calculate the incremental Benefit-Cost Ratio (BCR), which determines the margin by which each scenario is more beneficial or more costly than BAU. Figures (see **Table 16**) confirm that Scen 3 is the

best scenario (BCR=1.49), followed respectively by Scen 1 (BCR=1.44), Scen 4 (BCR=0.97) and Scen 2 (BCR=0.95).

Following a pure accounting approach, BAU scenario would therefore be considered better than Scen 4 and Scen 2. This needs to be put into perspective because in both scenarios, LEZ leads to a rapid reduction in pollution as early as 2020, whereas BAU scenario only reduces pollution gradually over the period 2020-2024. In addition, the cumulative reduction in pollution is greater under Scen 4 and Scen 2 than it is under BAU. Since the primary objective of the implementation of a LEZ is to reduce pollution, Scen 4 and Scen 2 could be preferred to BAU on this basis.

Table 16: Net Present Value (NPV) and Incremental Benefit-Cost Ratio from 2020 to 2024

Scenarios	NPV (€ million)	NPV/inhabitant (€)	Incremental Benefit-Cost Ratio (€)
BAU	-311.5	-162.5	1
Scen 1	-306.7	-160.1	1.44
Scen 2	-312.6	-163.1	0.95
Scen 3	-304.1	-158.7	1.49
Scen 4	-312.5	-163.1	0.97

Source: Authors' calculations.

6. Discussion

Our results show, through the NPV calculation, that the best scenarios of LEZ are respectively Scen 3 and Scen 1. The NPV of Scen 3 is higher than Scen 1 which is the LEZ scheme implemented by the Lyon Metropolitan Authority since January 2020. This scheme is therefore in reality a *second best* if we consider the NPV criterion. Scen 3 is the *first best* on this same basis. Beyond the NPV criterion, Scen 3 allows, compared to Scen 1, to almost double the air quality improvement for the inhabitants located outside the current LEZ perimeter (see **Table 14**). The other two LEZ scenarios (Scen 2 and Scen 4) have a lower NPV than BAU scenario. For these reasons, the best option for the Lyon Metropolitan Authority in terms of future improvement of the efficiency of its LEZ is the extension of the perimeter to the Greater Lyon area.

Our results confirm that the size of the perimeter is a key determinant of the effectiveness of a LEZ (Invernizzi et al., 2011; Johansson et al., 2014; Wolff, 2014). Indeed, moving from Scen 1 to Scen 3 corresponds to an increase in perimeter from 62 km² to 537 km². In addition to reducing emissions, this decreases the risk of a concentration of pollutants around the LEZ that could limit the impact of the LEZ, as was the case for the Milan Ecopass Zone (Invernizzi et

al., 2011). On the other hand, since Greater Lyon area is relatively large, infrastructure use exemptions will have to be granted to non-compliant vehicles traveling on the highway network through Greater Lyon. This could impact the environmental effectiveness of the LEZ in Scen 3 and Scen 4.

The negative NPV value in all scenarios confirms that the implementation of a LEZ may induce economic costs that are not always balanced by the environmental and sanitary gains (Börjesson et al., 2021; Watkiss et al., 2003). These costs must be borne by the entire society and particularly by the actors involved in urban logistics. This raises the need for financial support for certain fragile actors who can hardly make the investment that the early renewal of their vehicles represents. Indeed, some actors clearly mentioned, during our interviews with them (see Chapter 3), their difficulty/inability to acquire new vehicles in advance. For them, if there is no substantial financial support, the LEZ constitutes a threat to their survival. Such support would reduce the risk that some of them will disappear from the sector because of their inability to invest to meet the standards of the LEZ. Such disappearances would result in an additional social cost associated with the LEZ. It would therefore be appropriate for the Lyon Metropolitan Authority to broaden the conditions of access to its financial assistance (envelope of one million €) by granting the subsidy even for the purchase of Euro VI diesel or gasoline vehicles.

Any further tightening of standards to allow only green vehicles (electric or gas) to operate in the LEZ will further worsen the condition of the fragile actors. However, there is every reason to believe that this is the solution that local authorities could consider to accelerate the improvement of the environmental impact of UGM. Through our interviews with actors (see Chapter 3), we have identified some reasons that explain the non-acquisition of green vehicles. The main reason is that a green vehicle costs about 35% more than a diesel vehicle. The other reasons are technical, related to the range of the vehicles and the availability of charging points (gas stations and electric charging terminals). In addition, the actors mentioned that the operating costs of green vehicles are generally lower after a certain number of kilometers traveled per month. The total cost of ownership (TCO) of green vehicles can therefore be lower than that of conventional vehicles (diesel and gasoline). Since the TCO is a key factor on which private actors base their decision to invest, public actors (local authorities or governments) must act to remove the constraints that make the TCO of green vehicles unfavorable, especially for fragile actors. This can be done by providing financial support for the acquisition of vehicles and assistance in setting up charging points (gas stations and electric charging terminals). This posture should be that of a *benevolent planner*, as it reconciles the main objective of private actors, which is the economic profitability of their activities, and that of the public actor, which

is to eliminate the pollution generated by UGM, since the use of green vehicles allows very significant environmental benefits.

Our results may be partly influenced by the methodological choices we have made, which are discussed in this section. First, the 5-year study period has an impact on the results. Indeed, analyzing the economic-environmental balance of the LEZ over a longer period of 10, 15 or 20 years could change the ranking of the most efficient scenarios. However, it should be kept in mind that the longer the study period, the greater the uncertainty in the accuracy of the parameters used in the calculations. Thus, we underline that the efficiency of the scenarios we present here is valid for our 5-year study period.

Second, since we use a fleet distribution obtained from a survey conducted in Bordeaux (Toilier et al., 2015) and not in Lyon, this could influence our results. However, this specific survey is representative of the French case of large cities except Paris. Thus, we consider that this parameter related to the fleet does not significantly influence our results. This is all the more true since we use data on the same scale, in this case urban. Indeed, from urban camera data in the Ile-de-France region, some authors have observed that the fleet obtained from the cameras presents differences with respect to national estimates and especially a significant geographical variability, among others on vehicle standards for all categories (André et al., 2018, 2017; Carteret et al., 2015). While camera data have the advantage of being representative, in the case of a good perimeter grid, they remain inaccurate regarding the vehicles' use. For example, 46% of LGVs are owned by private individuals or craftsmen (MTE, 2020) who use them more as private cars than as freight vehicles. The demand-side approach we use allows us to take these characteristics into account in characterizing the fleet that will be affected by the LEZ. It is difficult to distinguish this from camera data. Ideally, camera data should be augmented by survey data on the behavior of the actors involved in urban logistics in the same area. It is impossible to have such data in the case of the Lyon metropolitan area, since it does not have a sufficiently dense network of traffic monitoring cameras, given the regulatory constraints regarding the protection of private data. Thus, the demand-side approach to characterizing the fleet is an excellent alternative. However, this fleet will actually be smaller than the effective fleet, since in practice the actors have reserve vehicles to compensate for fluctuations in demand. This marginal fleet, which does not appear in our simulations, could lead to an underestimation of the economic cost of fleet renewal that we calculate in *Step 2*.

The third methodological choice that may influence our results is the assumption of no organizational change on which the study scenarios are based. Organizational change is one of

the most likely reactions that actors can have regarding a LEZ. The interviews we conducted with urban logistics actors (analyzed in detail in Chapter 3) show that several types of changes are made by these actors in response to a LEZ: the transfer of all or part of their own transport to third parties, the reassignment of newer vehicles to the LEZ perimeter, the pooling of transport means until non-compliant vehicles can be renewed, and the use of cargo bikes for last-mile deliveries within the LEZ perimeter. These potential changes lead to changes in routes, changes in traffic, changes in the structure of the fleet, and thus effects on pollutant emissions and the share of the fleet to be renewed. This may of course impact the NPV of the different scenarios of LEZ, and is worthy to be investigated. For example, we note the increasing use of cargo bikes for last-mile deliveries. This means of transport is less expensive than a freight vehicle (LGVs and HGVs) and makes it easier to comply with LEZ standards. This new practice replaces or combines the use of LGVs in some cases. Assuming increasing use of this mode of transport over time, a reduction in delivery-related emissions could be expected. This could improve the NPV of the LEZ scenarios.

In addition to the potential impacts of our methodological choices on our results, we recognize that in practice there are other costs that need to be included in the calculation of the economic-environmental balance of a LEZ. These are mainly the costs of implementing and operating a LEZ (Watkiss et al., 2003). In order to ensure that vehicles comply with the standards, a reliable enforcement system is required, and the cost of setting up such a system can be high. For example, in the case of London, Watkiss et al. (2003) estimated that the cost of setting up a camera network monitoring system would be between 9 and 15 million €, with an annual operating cost of 7.5 to 10 million €. However, they estimated that this monitoring system would generate annual revenues of 1.5 to 6 million €. In addition to this, there could be a social cost linked to the disappearance of actors with a fragile economic equilibrium who, either would not be able to renew their vehicles despite the public subsidies, or would not benefit from these subsidies due to the geographical location of their registered offices (Dablanc et al., 2015) or other conditions to be complied with to be eligible.

All of the potential impacts of our methodological choices analyzed above can be considered as limitations to this paper. However, these limitations are openings to research perspectives for improving the robustness of our methodology. Indeed, interviews with actors will allow us to understand their practices in terms of reserve vehicles, and thus to be able to estimate the marginal fleet that does not appear in our simulations and to integrate the cost of its renewal in the evaluation of the economic cost (Step 2). The same can be done for integrating cargo bikes.

In *Step 1*, our methodology allows us to identify tours whose characteristics (length, volume and weight of deliveries) make them potential candidates for a modal shift to cargo bikes or to green vehicles (electric/biogas) with a reduced range. We will then replace the vehicles that make these tours with cargo bikes (or green vehicle with a reduced range) up to the previously estimated proportion of their usage rate. Organizational changes as a reaction of the actors to the LEZ can be estimated and considered in *Step 1*. All these possibilities of taking into account changes in the dynamics of urban logistics testify to the flexible and innovative character of the methodology we propose in this paper.

7. Conclusion

This paper proposes, through an innovative methodology, an *ex ante* evaluation of the environmental and economic impacts of a LEZ for freight vehicles in the city of Lyon. To do so, we develop a methodological framework composed of three steps: 1) simulation of transport demand, supply and conditions, 2) economic and environmental impacts calculation, 3) computation of the economic-environmental balance through a CBA over a five-year period. The three main contributions of this paper are in the development of an evaluation methodology which proposes: *i*-an analysis that couples environmental and economic impacts unlike most of the previous studies that only analyzed the environmental issues; *ii*- an analysis of urban logistics with the delivery tour as the unit of analysis; *iii*- an analysis based on a deep knowledge of the vehicle fleet through its main characteristics and the use made of it.

By comparing four scenarios of LEZ to a situation without LEZ, our results show that all these LEZ scenarios have a positive environmental impact, reducing NO_x, PM and VOC emissions both within the LEZ area and in the rest of LUA. All of these scenarios therefore achieve the primary purpose of a LEZ implementation, which is to improve air quality. However, they have almost no impact on CO₂ emissions, confirming the very low influence of the evolution of the Euro standards on the CO₂ emissions for diesel freight vehicles. The economic-environmental balance over a five-year study period shows a negative NPV for all scenarios. This means that in none of the scenarios does the benefit of the pollution reduction outweigh the cost of fleet renewal. The comparison of scenarios shows that the LEZ scheme adopted by the Lyon Metropolitan Authority (Scen 1) since January 2020 is a *second best* because it is possible to improve the economic-environmental balance of this scheme by extending the perimeter of the LEZ to Greater Lyon (Scen 3). Scen 3, which is the *first best* scenario, makes it possible to double the improvement of air quality for the population located outside the LEZ. Nevertheless,

it generates a deficit of -304.1 million €, or a cost per capita of 158.7 € in LUA. The existing LEZ scheme results in a deficit of - 306.7 million €, or a cost per capita of 160.1 € in LUA. The other two scenarios that involve a tightening of standards (Scen 2 & 4) have a less attractive economic-environmental balance than the situation without LEZ (BAU). This leads us to recommend Scen 3 to the Lyon Metropolitan Authority as an alternative for a possible evolution of its LEZ scheme.

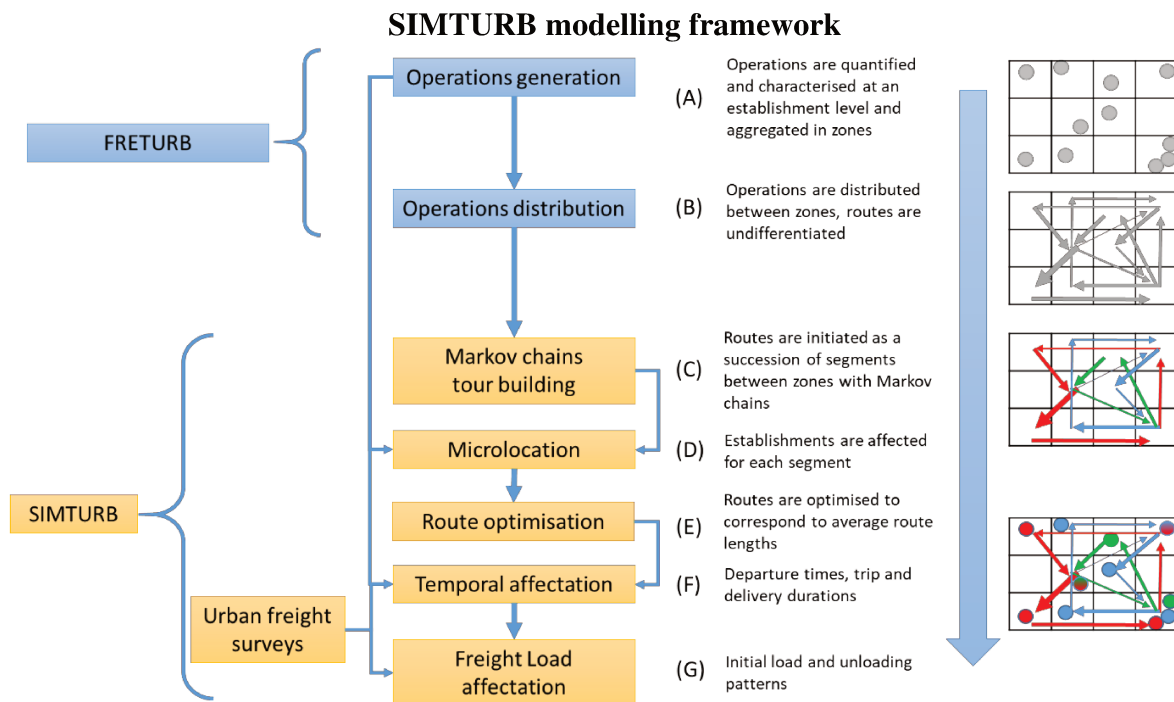
The results of this evaluation can only be achieved under certain conditions, mainly the full respect of the measure by the actors. As the Lyon Metropolitan Authority has chosen a system of visual control by sticker, compliance with the measure will probably be affected, since the enforcement system has an impact on the perception of the actors and, above all, on compliance with the legislation (Dablanc et al., 2015). For example, in the case of the Amsterdam *Milieuzone*, there was an increase in the compliance rate from 66% to 97% between 2008 and 2010, after the adoption of camera monitoring in 2009 (Boogaard et al., 2012). We therefore recommend the gradual implementation of a more reliable compliance monitoring system.

We have identified some limitations to our results that would stem from our methodological choices. However, the flexibility of the methodology we have developed offers the possibility of addressing these limitations. This opens up further research perspectives including, for example, the simulation of tour reorganization and changes in the structure of the freight vehicles fleet.

Appendix

Appendix 1. Description of SIMTURB model

The SIMTURB model (Gardrat and Pluvinet, 2021) is based on the results and is an extension of the FRETURB urban freight model. With an architecture based on a Markov process, this model offers a complement and to some extent an alternative to multi-agent simulation models, since it makes possible to characterize precisely the routes of freight transport vehicles in a conurbation and characterize the movements of each agent (e.g. vehicle). The basis of the modelling process of SIMTURB is the disaggregation of a freight distribution matrix into routes via Markov chains. In this case, the Markov process is used to build routes based on O-D matrices. Thus, routes are Markov chains of varying lengths for which transition matrices are in fact flow distribution matrices. To keep organizational consistency, the goods distribution matrix is subdivided into functionally homogeneous subsets that take into account the vehicle type (3 classes), the management mode (3 classes) and the length of the routes (7 classes). Coupled with geolocalized establishments and a road network, this approach makes it possible to spatially and temporally characterize the vehicle routes, without requiring complex multi-agent approach. Figure 1 sums up the different steps of the model.



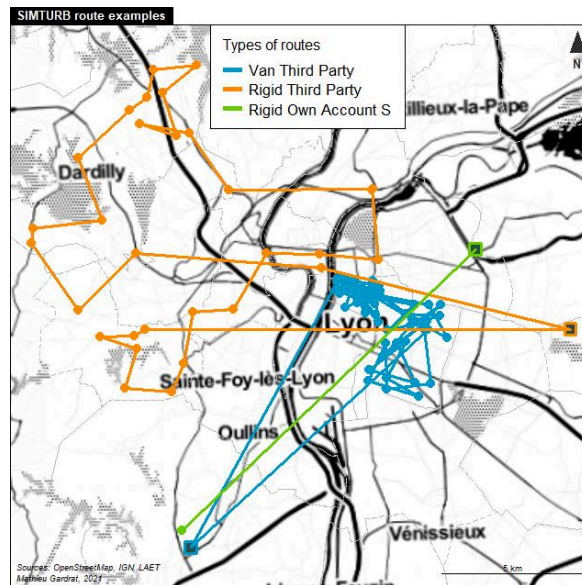
Steps A and B are carried out by the FRETURB model which consist of the generation, characterization and distribution of freight operations in an urban area. For more elements on the FRETURB model, please read the corresponding paper (Toilier et al., 2018). The distribution matrix produced by FRETURB are converted by SIMTURB into transition matrices which are used to build Markov chains. These chains are sequences of zones which give an estimate of the round tours origins and destinations (step C). Each sequence of the Markov chain (i.e. sequence of zones) is then affected to establishments to determine precisely the points touched by the vehicles (step D). The rounds then created are rearranged thanks to a VRP algorithm (step E) to fit transport behaviors observed in urban freight surveys (Patier and

Routhier, 2009). Steps F and G further characterize the routes by determining the temporal dimensions of the routes (departure time, stops and trips durations...) and the loading and unloading patterns of the delivery rounds. The variables produced by the model include:

- Tour identification number
- Origin and Destination area
- Type of vehicle (van, rigid truck, articulated)
- Vehicle weight class
- X and Y coordinates of the delivered point
- Distance between 2 points
- Duration of stop
- Cumulative travel time
- Trip duration
- Time of departure from the origin point
- Number of the operations in the tour
- Size of the establishment delivered (number of employees)
- Type of activity of the establishment delivered
- Vehicle load (kg)

Each point of each round is described by these variables. The results are produced for an entire day of freight transport in an urban area. This equals roughly to 50,000 daily routes for an urban area such as Lyon (pop. 2 mil.) and 200,000 routes for an urban area such as Paris (pop. 12 mil.).

Examples of 3 routes from SIMTURB simulation results in Lyon's urban area



Examples of routes from SIMTURB simulation results in Lyon's urban area

Vehicle	Management mode	Nb points	Length (km)	Total traffic time (h)	Total stopping time (h)	Total load (kg)	Mean distance between 2 stops (km)	Mean stop time (min)	Total tour duration (h)
LVGs	Third party	57	124.9	06:05	03:42	779.1	2.2	00:03:54	09:48
RHGVs	Third party	31	106.2	04:48	03:32	2088.0	3.4	00:06:51	08:20
RHGVs	Own account shipper	2	36.6	01:14	01:00	5476.0	18.3	00:30:00	02:14

Table A 6 : Details on the Low Emission Zone access standards
Source: Lyon Metropolitan Authority

	LGVs		HGVs	
	Euro standard	label Crit'air	Euro standard	label Crit'air
Full Electric or Hydrogen	-	Green	-	Green
Gas or plug-in hybrid	-	1	-	1
Petrol	VI ; V ; IV	1 ; 2	VI ; V	1 ; 2
Diesel	VI ; V	2	VI	2

Table A 7 : Total emissions in LUA (ton)
Source: Authors' calculations.

	Emissions 2020 (ton)					Cumulative emissions 2021-2024 (ton)				
	CO ₂	NO _x	VOC	PM ₁₀	PM _{2.5}	CO ₂	NO _x	VO C	PM ₁₀	PM _{2.5}
BAU	411,095	978	20	3	4	1,644,275	3250	63	8	12
	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Scen 1	411,177	781	15	2	2	1,643,801	2,874	57	6	8
	0%	-20%	-22%	-	-44%	0%	-	-9%	-	-
				44%			12%		29%	29%
Scen 2	411,176	722	15	2	2	1,643,837	2,722	57	6	8
	0%	-26%	-22%	-	-45%	0%	-	-9%	-	-
				45%			16%		29%	29%
Scen 3	410,771	707	14	1	2	1,642,903	2,702	54	4	7
	0%	-28%	-30%	-	-61%	0%	-	-	-	-
				61%			17%	14%	43%	43%
Scen 4	410,763	633	14	1	2	1,642,885	2,510	54	4	7
	0%	-35%	-30%	-	-61%	0%	-	-	-	-
				61%			23%	14%	43%	43%

Note: Percentage data represent variations from the reference scenario (BAU).

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CHAPTER 3

STAKEHOLDERS' STRATEGIES TOWARDS TWO URBAN LOGISTICS INNOVATIONS

1. Introduction

Urban logistics, defined as the organization of internal, incoming, and outgoing urban freight flows, is an essential component that determines the state and dynamism of urban areas. The velocity of urban freight flows is a good proxy for the economic vitality of an area. Moreover, for some years now, the efficiency of these operations has not been assessed simply in terms of this velocity alone, but also in terms of the level of respect for quality of urban life. We have gradually reached a period in which consumers, in addition to wanting to have commodities they need at hand and as quickly as possible, have become more aware of the negative impacts of freight transport on their well-being. Thus, nuisances such as noise, pollutant emissions, congestion, etc. are all negative externalities attributed to urban logistics. For a long time limited to the purely operational aspects of optimizing delivery routes in city centers, urban logistics now raises several economic and societal issues that cannot leave public and private decision-makers indifferent (Chanut et al., 2012).

This awareness has been translated in the academic, professional, and political world by the proposal of solutions to integrate urban logistics in the new paradigm of sustainable development. Thus, in addition to optimizing flows, it is now necessary to guarantee a healthy quality of life for citizens, while maintaining the economic dynamism and vitality of metropolitan areas, especially in their centers. Logistics is the fourth most important factor in the attractiveness of a city, after education system, social cohesion and innovation (CCI Lyon, 2010). Public authorities, and in particular local authorities, are now interested in urban logistics and how it affects cities. New schemes are expected and sometimes piloted for urban logistics, which are now considered as an element of territorial marketing. For example, mutualization solutions for last-mile deliveries have been piloted, with the creation of urban distribution centers (UDC), urban transport solutions combining railway, river, road, cyclo-logistics, etc. Such solutions are all the more expected as we are seeing an increase in the volume of urban freight flows driven by metropolization (Gardrat, 2021), the return of convenience stores to the detriment of hypermarkets and other out-of-town shops, the exponential growth of e-commerce, and also the development of immediacy and quick commerce, as consumers want to receive their orders quickly. For retailers, the reduction in storage space for sales areas has led to a

fragmentation of deliveries and a demand for shorter delivery intervals in order to avoid stock-outs. All these factors lead to an increase in freight movements in urban areas.

Among the solutions proposed and implemented are off-hour deliveries (OHD) and low emission zone (LEZ). The principle of OHDs is to postpone freight deliveries to periods when urban traffic is less dense and infrastructure is less loaded, i.e., outside the peak passenger traffic periods (Holguín-Veras et al., 2016; Mommens et al., 2018; Savadogo and Beziat, 2021; Verlinde, 2015). The expected effects are less congestion in the city, an improvement in urban traffic conditions in general, and in particular freight transport conditions (Savadogo and Beziat, 2021). The principle of LEZ is to prohibit access to a defined area, during defined periods, to vehicles that do not meet certain emission standards (Allen et al., 2010; Browne et al., 2005; Watkiss et al., 2003). The expected direct effect is a reduction in the quantity of pollutants emitted, through a renewal of the vehicle fleet operating in that area (Dablanc et al., 2018; Ellison et al., 2013; Jiang et al., 2017; Rizet, 2018). The goal is to improve ambient air quality. Both solutions can be viewed as logistics innovations in France. In the field of management sciences, an innovation is an idea, practice, or project that is perceived as new by a specific individual or other unit of adoption (Rogers, 2003). This is the case for the two solutions we study in this paper. There were certainly experiments conducted in the past - sometimes far away - or in other countries than France. For example, the "*Lex Iuliana Municipalis*" enacted by Julius Caesar in 45 BC, which aimed to prohibit the circulation of goods during daytime (Holguín-Veras et al., 2005). Or, in the contemporary era, OHDs were introduced in London in 1968 (Churchill, 1970; Holguín-Veras et al., 2005). As for LEZs, the first were implemented as early as 1996 in Sweden, in the cities of Stockholm, Gothenburg and Malmö (Holman et al., 2015). However, as solutions, OHDs and LEZs had not been implemented in France until recently. Therefore, they constitute innovations. An innovation may have been invented a long time ago, but if individuals perceive it as new, it constitutes an innovation for them (Rogers, 2003). The two innovations can be described as inter-organizational, since they involve a large number of stakeholders interacting with each other in urban areas.

First studies carried out on the two solutions (OHD and LEZ) are mainly technical in nature, with questions linked to their operability or to the evaluation of their impacts (on the environment, on human health). Regarding OHDs, studies have focused on characterizing the flows that would be most suitable for OHDs (Verlinde, 2015), the minimum proportion of flows to be shifted (Sánchez-Díaz et al., 2017), conditions that must be met for OHDs to be effective (Holguín-Veras, 2008), or stakeholders who would be most in favor of this measure (Verlinde and Macharis, 2016). Regarding LEZs, the majority of studies focus on evaluating their impacts

on air quality (Boogaard et al., 2012; Ellison et al., 2013; Holman et al., 2015; Jiang et al., 2017), or population health (Cesaroni et al., 2012; Host et al., 2020; Lebrusán and Toutouh, 2020; Malina and Scheffler, 2015; Mudway et al., 2019). While a few studies have looked at the economic and organizational impacts of OHDs (Holguín-Veras, 2008; Marcucci and Gatta, 2017) and LEZs (Börjesson et al., 2021; Dablanc et al., 2018; Griffin et al., 2020; Watkiss et al., 2003), few, to our knowledge, have analyzed in depth the competitive issues of these logistics innovations. Yet logistics innovations are likely to modify the competitive game of the stakeholders and market shares, whether they are imposed on stakeholders (as in the case of LEZs), or whether they are suggested, more or less strongly, and implemented by only a few stakeholders (as in the case of OHDs).

The objective of this paper is to understand in depth the issues of these two innovations for urban logistics stakeholders, and how these stakeholders integrate these innovations into their strategy. In particular, we seek to identify the issues for the groups of stakeholders of these innovations in terms of power and competition.

For the analysis, we adopted an exploratory methodology, using the theoretical framework of the political economy of distribution channels. The case study is Lyon Urban Area (LUA), the second largest urban area in France after Paris, in which the two innovations have been implemented. Our methodology is qualitative and based on an interpretivist and abductive approach, focusing on stakeholders' comments while drawing on conceptual material from previous researches. The findings show that, beyond the cost-benefit aspects and the consequences of the innovations in terms of route optimization and profitability of urban freight delivery activities, competitive issues are central to players' concerns. The largest stakeholders (large players) with substantial resources (financial power) see these innovations as an opportunity to increase their market share and power. Some are new players in the last mile delivery segment. They build their business model on the label of sustainability and invest massively in compliant equipment. Large players do not hesitate to use their power of influence to convince local regulators to tighten standards or enforce controls in urban areas, in order to oust weaker competitors and reinforce their competitive advantages. The smaller stakeholders (small player), who are more fragile, very numerous and dispersed throughout the city, are either own-account transporters or subcontractors. They see in these innovations constraints and threats to which they cannot always adapt because of their small financial size (financial power). Their strategies are more defensive, and their survival is sometimes threatened. Public authorities, at the various levels - international, national, and local - must not be naive in their

understanding of the competitive issues in order to better support the transitions when they impose innovations.

The rest of the paper is organized as follows. After presenting the theoretical framework (Section 2) and describing the methodological approach (Section 3), we detail the results of the analysis (Section 4). Results are then discussed, including the theoretical and managerial implications of the study, before concluding (Section 5).

2. Theoretical Framework

This section presents the theoretical framework for the methodological approach of the analysis in terms of the issues raised by all two innovations and the characteristics of the stakeholders.

2.1 Dual perspective: Analysis in terms of benefits/costs and in competitive terms

Logistics management is now a highly strategic perspective. Managing the related intra- and inter-organizational interfaces is no longer only a technical matter of optimizing flows (instrumental dimension) in order to achieve the “7Rs of logistics”: getting the Right product, in the Right quantity, in the Right condition, at the Right place, at the Right time, to the Right customer, at the Right price (CILT, 2019). It raises strategic issues, putting central concern on building a sustained competitive advantage (political dimension). This is true for the upstream urban logistics supply chain, but also for the last mile.

The originality of our approach is to mobilize the theoretical framework of the political economy of channels (Reve and Stern, 1986; Stern and Reve, 1980) to analyze the issues of these urban and inter-organizational logistics innovations. This integrative framework has made it possible to renew theoretical approaches to understanding the organization of distribution channels. It is equally relevant for understanding the challenges of multi-player urban logistics schemes. Before this framework, theoretical framework was that of classical microeconomics, focused on analyses in terms of benefits/costs (focus on cost and technologies) and efficiency (efficiency oriented). Stern and Reve (1980) proposed, in order to better understand the organization of distribution channels, to introduce into the analysis a socio-political component and a behavioral approach to organizations. They draw on research in social psychology and organization theory. Organizations are political animals, capable of political coalition (March, 1962) and strategic intent (Crozier and Friedberg, 1977). They are *socially* oriented, focused on power and conflict phenomena. They can also choose cooperation and mutual trust, by structuring their activities around stable, long-term relationships, as shown by relationship

marketing. Beyond the cost-benefit aspects, their choice may be motivated by objectives related to market power, control or influence. The concept of organization as a political system (Morgan, 2006) gives a central place to power of influence and its distribution among stakeholders. It emphasizes the crucial importance of the interplay of stakeholders, as well as the need to obtain control given the divergent interests and potential conflicts. Stern and Reve (1980) distinguish two subsystems in the political economy of distribution channels: the internal political economy and the external political economy of distribution channels. The first refers to how the channel is designed and its operating rules/power hierarchy. The second refers to the external environment and competitive issues.

Internal component of political economy of channels has enabled a better understanding of internal organization and decision-making mechanisms of the distribution channels, and in particular the vertical integration, or quasi-integration, observed in distribution channels. Thus, between the choice of the market, the choice of the hierarchy, and the choice of a hybrid form such as the contractual distribution networks (Williamson, 1986, 1975), there are costs aspects (reduction of transaction and production costs), but also aspects of control and reduction of uncertainty. In our study, this internal component makes it possible to classify players operating in the urban logistics ecosystem, depending on whether they are small and isolated, whether they belong to an integrated entity or to a contractual network (franchise model). The organizational form chosen determines the distribution of decision-making power over its internal ecosystem, defined as all the players interacting with each other in a business relationship (suppliers, customers, logistics service providers, etc.).

External component of political economy refers to the external environment, and to the power that an organization may seek to exercise over its competitors, regulators (public authorities) or trade associations. The concept of power refers to an actor's ability, which can come from various sources, to consciously and intentionally influence other actors in order to impose its own will on them (Weber, 1922). Channels not only adapt to their environment, but also influence and shape them (Pfeffer and Salancik, 1978). We can distinguish between market power (imposing its decisions thanks to its strength in the market) and power of influence (trying to influence the decisions of players in its own interest) (Milgrom and Roberts, 1990). The strategic stream, focused on the resources/value creation couple, has also highlighted the search by organizations for a favorable and sustained competitive position, and their capacity

to develop influence strategies to serve their own interests, sometimes to the detriment of the general interest.

Two other types of power can be added to the power of influence and market power. Decision-making power, which is related to both internal and external components of the political economy of channels. This type of power refers to the capacity of an actor to impose his will on others through fear (law, regulation, directives, etc.) - despite possible resistance - either by refusing to grant the usual rewards (exemptions, tax advantages, etc.) or in the form of a punitive action (fines, etc.), with each of these two ways of acting being a negative sanction (Blau, 1964). On the internal component, it refers to the capacity of an actor to impose his decision on his internal ecosystem. On the external component, it refers to the power that an actor has to impose his decision on other actors beyond his internal ecosystem. As for financial power, it integrates above all the internal component of the political economy of channels. It is the financial capacity of an actor, but also the capacity he has to easily raise funds to make investments if necessary.

Urban logistics, as the last segment of logistics of distribution channels, can be analyzed from the perspective of the management of inter-organizational relations in which political games are played in terms of power and leadership for sharing of operations and profits. Such a vision, inspired by Stern and Reve (1980), is both strategic and behavioral. **Table 17** shows the analytical grid used in this paper to highlight the strategic and competitive issues of the two innovations analyzed. We believe that the integrative theoretical framework, combining microeconomic cost-benefit approaches, behavioral approaches in terms of power, and political strategy approaches of organizations focused on competitive issues, is a relevant analytical grid to understand in depth the way urban logistics stakeholders deal with the two inter-organizational logistics innovations (LEZ and OHDs) analyzed in this paper.

Table 17: Analytical grid

	Focus on...	Type of Power	Definitions
Internal component of the political economy	Channel internal organization - organizational form (integrated entity, contractual network, isolated entity)	Decision-making Power on the internal ecosystem (Suppliers, customers, service providers)	Power to decide on the logistics organization of its internal ecosystem and to impose it on its partners
		Financial power	Power to invest through financial capacity and/or to raise funds
External component of the political economy	Organization's relationship with competitors, regulators	Market Power	Power to capture flows to the detriment of competitors
		Power of influence	Power to influence the decisions of regulators in its particular interest
		Decision-making Power beyond the internal ecosystem (public vs. private actors)	Power to decide on a measure and impose it to players beyond the internal ecosystem

Source: Authors' elaboration

2.2 Characterization of urban logistics stakeholders

Urban logistics, as a multi-actor system, mobilizes structured chains of stakeholders in competition with each other. It mobilizes the resources of a plurality of stakeholders with very different characteristics and objectives. We distinguish between flow regulators, flow generators, and finally flow and infrastructure managers (Chanut and Paché, 2014).

Flow regulators are mainly the public authorities (States, regions, municipalities) that represent the citizens/residents and the general interest. At the city level, the priority for local authorities is to reduce the negative externalities of freight transport operations. Competing with each other to attract inhabitants, companies and sometimes tourists, they have committed themselves to *sustainable city* projects. This implies regulating the anarchic organization of delivery rounds to the establishments in the city, in order to reduce nuisances (air pollution, noise, congestion and accidents) caused by goods movements. Flow regulators receive their legitimacy from the vote and have the power to make decisions that are imposed on private actors (*regulatory, coercive power*). For decades, local authorities have allowed private actors to develop logistics

structures and schemes in the city in an anarchic, uncoordinated manner, sometimes with redundant resources. Now they intend to impose decisions with the particular aim of significantly reducing the number of assets and vehicles circulating at any given time in their territories.

Flow generators are the establishments that benefit directly from the freight movements that are necessary for their activities. These are either the shippers who send freight to the city (agribusinesses, distribution networks, mortars or pure players) or their customers, i.e. the establishments located in the urban area and receiving freight. The complexity comes from the extreme diversity of these stakeholders, in terms of size, activities and associated constraints (volume, frequency, delivery times), and the characteristics of the goods handled. To illustrate the diversity of size, let us recall that among shippers there are multinationals (industrialists or distributors), regional SMEs and local producers. To illustrate the diversity of the activities of receiving establishments, let us list a few examples of customers: retail stores, craftsmen, health establishments, administrations, service providers such as hotels-restaurants, etc. Above all, it is important to distinguish, among the establishments receiving flows of goods in the city, between isolated independent establishments (e.g., bakers, restaurant craftsmen), those belonging to large groups (integrated establishments) and those belonging to a contractual network (associates, franchisees). Indeed, they are distinguished by two decisive criteria for our study: *financial power*, which translates into an ability to invest (or not), and *decision-making power* over the logistics organization. Financial power depends largely on the size of the parent company of the establishment (large group, intermediate size establishment, small structure). Decision-making power depends on the organizational form. Thus, a local isolated business will have full decision-making power over its logistics organization, while an integrated business will have none, with decisions being centralized by the network head. For contractual business, logistics organization is generally coordinated by the network head, except for some assets needed in the store. The decision-making is therefore more or less shared.

Flow and infrastructure managers are the traditional transport and logistics establishments that provide transport and storage services. They include carriers, logistics service providers, express carriers, and wholesalers. Once again, the last-mile players are very diverse, ranging from multinationals to small local carriers whose competitive advantage lies in their in-depth knowledge of the territory and neighborhoods in which they operate. Urban logistics is

characterized by a very high number of small operators who are not well organized and who operate on a subcontracting basis or on their own account.

Finally, it should be noted that the roles of flow generators and flow managers are not always separate and can be played by the same establishment. Let us give two examples. A craftsman or a restaurant owner in a given territory can play both roles when he buys himself supplies from a wholesaler (own account transport). At the other end of the chain in terms of size, an integrated or contractual distribution network that has its own warehouses and vehicle fleet also fulfills both roles. The plurality of stakeholders in urban logistics makes urban goods delivery particularly complex, because of their sometimes contradictory expectations and constraints. Conflicts results from divergent interests between actors who share the flows and profits of urban logistics, but also sometimes from internal contradictions of the same actor. For example, there is the contradictory injunction of local authorities who want to maintain city center commerce, but do not accept the negative externalities of urban logistics and want to relegate logistics activities and assets outside the centers. Based on these observations, we hypothesize that the reasoning of private and public actors is not the same with respect to these two innovations. Strategic groups of stakeholders can be identified, defined as a set of stakeholders with similar strategic characteristics and who follow comparable strategies or who rely on the same competitive factors (Fiegenbaum and Thomas, 1995; Porter, 1979). They will be described using the criteria detailed above and summarized in **Table 18**.

Table 18: Characterization criteria for urban logistics stakeholders

	Modes
Role in urban logistics	Flow Regulators; Flow Generators; Flow and infrastructure Managers
Size	Multinational company; National company; Local company
Organizational form	Integrated entity; Contractual networks; Isolated independent entity
Activity sector	Ordinary activity; Specialized activity

Source: Authors’ elaboration

3. Methodological Approach

Lyon urban area (LUA), the second largest in France after Paris, was chosen as case study. The choice of LUA is justified by its size. It represents 1,916,149 inhabitants, 275,687 companies

and 3,325 km². It was also chosen because the two urban logistics innovations investigated in this paper were recently implemented in the city of Lyon. OHDs were the subject of an experiment in Lyon between 2014 and 2015. The experiment involved only one category of players (large operators and integrated entities members of Club Demeter). This justifies an investigation of the solution with more diverse players. The LEZ has been implemented in the urban area of Lyon as of January 1, 2020. The boxes (**Box 1** and **Box 2**) outline the genesis and the schemes of the two innovations in the urban area of Lyon.

Box 1: OHD pilot in the city of Lyon (2014-2024)

Scheme: In 2014, the Metropolitan authority of Lyon piloted silent night deliveries in collaboration with organizations and associations of private actors involved in urban logistics (Club Demeter, Transport et Logistique de France). Deliveries were made between 10 pm and 7 am, except for the "dark night" period between 2 and 4 am. The entire PIEK-labeled process guaranteed a maximum noise threshold of 60 decibels.

Pilot results: The pilot report indicates that the OHDs had very positive impacts:

- a reduction in pollutant emissions (CO₂, NO_x, PM) of up to 37% between RHD and OHD routes
- an improvement in the reliability of deliveries by up to 16%
- an increase in commercial speed of up to 15%
- a reduction in drivers' stress due to reduced traffic
- a reduction in the number of trucks in rush hour traffic

However, some retailers have withdrawn from the experiment due to difficulties in organizing their teams.

Recommendations: Virtuous practice of OHDs requires significant investments in equipment and staff training. Some equipment increases the purchase cost of a vehicle by 10 to 15%. The cost of night work, with its social repercussions, has yet to be accurately evaluated.

Limitations: Scaling up the results remains difficult, as only large players took part in the experiment. The pilot does not include the views of independent and small actors.

Aids and subsidies: There was no payment of aids or subsidies to the actors involved in the pilot. The Metropolitan authority of Lyon supported the pilot by setting up a reflection framework and by coordinating the pilot.

Source: Club Déméter (2015) ; Diziain (2015)

Box 2: Description of the LEZ of Lyon

Genesis: Two key facts explain the conception of the LEZ project and its implementation. First, European Union (EU) calls for action in relation to European thresholds for local pollutant concentrations in urban areas (Directive 2008/50/EC) obliged the Metropolitan authority of Lyon to implement actions to reach these thresholds. Second, the Metropolitan Authority of Lyon was awarded in 2018 a call for projects by the Government of France in which it was imperative to integrate LEZ projects.

Objectives: LEZ is part of the Lyon Metropolis' Oxygen Plan, aimed at reducing pollution, improving urban air quality, and meeting the EU's thresholds.

Scheme: LEZ has an area of 62 km² with 684,185 inhabitants and includes Lyon and some neighboring municipalities. The initial scheme prohibits the driving and parking (24/7) of freight vehicles that do not meet the standards set for vehicle engine emissions. The standards are materialized by Crit'air stickers attached to the vehicles. Thus, as of January 1, 2020, vehicles with stickers 4, 5 and not classified were banned in the zone. The control of the respect of the measure by actors is based on a visual control of the stickers. The system will evolve with a tightening of standards over the years so that by 2026 only vehicles with a Crit'air 1 sticker will be allowed. Consultations around the project were held for two years between the Metropolitan authority and representatives of various stakeholder groups in order to co-construct the scheme and the implementation agenda.

Aides et subventions: For vehicles renewal, the Metropolitan authority has set aside a budget of one million euros to help the most vulnerable actors to purchase clean vehicles (100% gas, electric or hydrogen).

Source: Métropole de Lyon (2018) ; SYTRAL (2017)

This research is exploratory in nature and uses a qualitative methodology based mainly on material obtained through interviews and, secondarily, on a literature review. In particular, 19 semi-structured interviews were conducted between March 2019 and January 2020, with an average duration of one hour, conducted face-to-face and by phone, with stakeholders within LUA. In order to account for diversity, the sample (see *Table A 8*) includes several categories of actors located at different levels of the supply chain: shippers, logistics service providers (LSPs), transporters, receiver establishments (retailers and distributors), and public authorities (local authorities). In addition to these individual actors, there are also their associations and

the traffic regulation authorities. The sample covers various sectors of activity and types of organization (isolated independents/networks, large/small companies). Contact with the establishments was made mainly through the professional contacts of the researchers of the Transport Urban Planning Economics Laboratory (LAET) and also through direct and spontaneous contacts.

The interview guide (see **Appendix 1**) used in this research is articulated around three main parts. The first part deals with understanding the logistics organization and practices in place in the establishments interviewed. Parts 2 and 3 deal respectively with OHDs and LEZ as solutions for improving the sustainability of urban logistics. The actors were asked to express spontaneously their views on the consequences of adopting the two innovations for their own activities. The follow-ups concerned the investments, organization, advantages and disadvantages, market shares, challenges and competitive strategies. The interviews were conducted with managers, directors, transport and/or logistics directors, operations directors, heads of associations of actors, etc. The choice of the interviewee was made by the establishment with we contacted, which chose the person best suited to talk to us about the subjects briefly presented during the contact.

The material, made up of the complete transcripts of the interviews, was subjected to a *thematic content analysis*. This method is effective in revealing the meanings of the material collected (Mucchielli, 1984). The aim here is to systematically identify the elements in the actors' discourse that relate to the strategic, financial and organizational impacts, real or potential, of the two innovations. In an abductive approach, the elements, once contextualized, are put into perspective with the specific characteristics of the actors and with regard to the analytical grid exposed in the theoretical part. The literature is made up of scientific articles, specialized press articles, reports, planning documents, and documentation provided by certain interviewed actors. The exploratory approach adopted in this paper does not claim to generalize the observations it makes. The findings should be seen as generic knowledge in the sense of Avenier and Schmitt (2007), which can be used to open up reflections but also to help in decision-making. This research is in line with the *interpretivist paradigm*, which leaves an important place to actors' discourse, to the detailed understanding of the context in which they intervene, and which allows for the construction of knowledge from the actors' reality through a back and forth between contextualized discourse and literature.

4. Results

We present results in two parts, according to the analytical grid outlined in the theoretical part. The first part deals with the benefits/costs perspective of the two innovations, as mentioned by the respondents. The approach refers to the microeconomic approach and its perspective based on benefits/costs and operational efficiency. The second part deals with the issues expressed in terms of power and competitive advantages of the two measures and refers to behavioral and strategic theoretical framework of the political economy of organizations.

4.1 Microeconomic cost-benefit perspective to OHDs and LEZ

This section examines the results of the content analysis of the interviews independently of the type of stakeholders and of the competitive and power issues. Results are analyzed in terms of the benefits that could motivate actors to adopt each innovation. On the other hand, they are analyzed in terms of the costs that constitute as many brakes, disadvantages or constraints related to the adoption of these two innovations. The results, summarized in **Table 19**, are presented in the form of six groups of issues identified in the content analysis: *financial, organizational, relational, social and societal, environmental and regulatory issues*. A seventh group of issues emerged as central to the discourse of both public and private actors. These are strategic and competitive issues, which are discussed in the following section.

Table 19: Benefits/costs of both innovations (excluding strategic and competitive issues)

Benefits (+) Costs (-)	Off-hour deliveries (OHD) Suggested innovation	Low emissions zone (LEZ) Imposed innovation (external shock)
Financial issues	<ul style="list-style-type: none"> - Lower fleet costs - better fleet utilization, lower vehicle needs (+) - Faster tours, lower costs (+) - Higher salary costs - night work (-) - Delivery lockers installation costs (-) - Risk of loss/theft at night (-) 	- Significant increase in costs related to the total or partial renewal of the fleet (-)
Organizational issues	<ul style="list-style-type: none"> - Reorganization of routes, HR, work processes, safety processes (-) - Difficulty in finding night deliverers (-) 	- Reassignment of fleet and drivers to dedicate compliant vehicles to downtown (-)
Relational issues	- Decrease in the proximity of the customer-delivery relationship - commercial efficiency (-)	
Social issues	<ul style="list-style-type: none"> - Reduction of the painfulness of work, better parking conditions during off-hours (+) - Health impact of night work (-) - Noise - acceptability to local residents (-) 	<ul style="list-style-type: none"> - Impacts on penalized downtown retail businesses (-) - Risks of disappearance of fragile actors (-)
Environmental issues	<ul style="list-style-type: none"> - Not spontaneously mentioned - Skepticism: risk of duplicate tours (-) if the actors do not all adopt the scheme at the same time 	- Strong skepticism on 3 aspects: real emission reduction of compliant vehicle (manufacturers' lies); Mixed results of previous experiments; Absence of systematic, automated and exhaustive control of compliance with the standards (-)
Regulatory issues	- Little effectiveness of a scheme when it is not imposed by regulation and therefore adopted by all (-)	<ul style="list-style-type: none"> - Subcontracting of transport impossible for "dangerous" activities (-) - Inadequate regulation to really sanction the contraveners-lack of coercive power of public authorities (-)
Overall Rating	<p>Do cost decreases and increases offset each other?</p> <p>Efficient if massive adoption (threshold effect) and no duplication during the day, thus if the scheme is imposed by regulation</p> <p>Skepticism regarding the environmental impact</p>	<p>Cost aspects dominate (-) and are likely to threaten the economics of some players' activities</p> <p>Skepticism regarding the environmental impact</p>

Source: Authors' elaboration

4.1.1. Off-hour deliveries

OHDs are discussed as an innovation whose adoption is voluntary for the actors. Interviews confirm that, as for any innovation whose adoption is not constrained, the benefits that could motivate the adoption of OHDs are primarily financial and are expressed in terms of cost savings. OHDs would increase vehicle fleet utilization rates and therefore reduce the number of vehicles needed in a fleet. It would also make the routes faster and therefore less costly. The benefits are secondarily related to social issues, as OHDs would reduce the painfulness of the work of drivers, through better parking conditions during off-hours. It should be noted that

environmental issues are not spontaneously mentioned by the respondents, and this can be seen very clearly in the set of indicators that actors monitor to measure the performance of their activity. In most cases, these indicators are financial (gross transport margin, operating result, fuel consumption, etc.), when they exist, and very few are environmental (ton of CO₂ emitted). As for the factors that would make it difficult to adopt OHDs, the results identify four types of issues: *financial, relational, organizational, and social*.

Regarding *financial* issues, these are the salary costs related to the night work of the driver and the reception staff in case of assisted OHDs (Holguín-Veras et al., 2011); or the cost of installing delivery lockers in case of unassisted OHDs (Holguín-Veras et al., 2011). In the latter case, the cost can only be borne by the contracting actors since the Metropolitan authority of Lyon refuses to provide financial support for equipment - in this case delivery lockers - whose actual use it will not be able to control. The Metropolitan authority of Lyon fears that the delivery lockers will be diverted from its intended use (for example, to expand the sales or storage area). The alternative to this financial issue could be the adoption of unassisted OHDs, with the keys being made available by the receiver. Unassisted OHDs therefore do not necessarily require the use of delivery lockers. This raises the matter of mutual trust that must exist between parties, something that is facilitated in the case of an integrated or quasi-integrated network where actors are tied by common interests. This is the case, for example, of the relationship between a franchisee and its network head who is in charge of the delivery of the brand's products.

« There have never been any problems [...] there has never been any theft issues. What we have had are concerns about products being misplaced in a hurry, as I told you earlier. When this happens, we talk to them about it and there is not too much of a problem [...] we have a list of the number of complaints we make about forgetting items, breakages, etc. We keep these records and then the franchisee will talk about it directly with the head office (franchisor), which is responsible for finding ways to improve ». **FG2.**

In the case of an isolated or independent business, the relationship of trust must be established between the deliverer and the retailer. It is not easy to establish and maintain, especially in case of a previous incident of theft, loss or damage of the goods.

The second issue is *relational*. The analysis of actors' discourse reveals that some shippers are keen to maintain a “direct” relationship between the driver and customers. This is mainly due to the fact that the driver is the interface between the shipper and its customers. In his interface

role, in addition to making deliveries, he plays the role of customer relations agent by ensuring that the customer's needs are fully and completely satisfied, and that the customer's new needs are referred to his employer. He also plays the role of salesman in that he can present new items to customers and advise them on their choices. This relational issue underlines the need for the shipper to maintain physical contact between customers and the driver, making the latter a “boundary spanner” in the sense of Lancini and Sampieri-Teissier (2012) and Kiessling et al (2004). By maintaining social contact with customers, the driver learns about their needs and organization, valuable information that he brings back to his employer. The relational proximity (Capo and Chanut, 2013) that exists between them (driver and customers) is thus an indispensable factor of knowledge creation, and makes the business relationship more effective and efficient, especially in the case of a non-integrated channel (Tsai, 2002). Some shippers have understood this and train their drivers to act as salesmen and even customer advisers. Thus, the need for a *boundary spanner* (in this case, the driver) is a barrier to OHDs adoption for some firms.

« [...] for us it is important to have the proximity between our drivers and customers. Also, because it's actually a very relational business [...] we need to have this proximity so that they know their driver [...] I don't know if our customers would accept not seeing their driver anymore because the relational aspect is very important in our market. So, I wonder if our customers would appreciate not seeing the drivers anymore, to be able to ask them questions about the products, changes » **FM5**.

« We have some drivers who are rated according to how well they do customer development. This means that they will spend more time during the day developing customer relations, which allows them to get a bonus at the end of each month [...]. There is a lot of customer relations when you are in service at **FM12** and this relationship is almost more important than the delivery aspect. Routes planning is actually left to the driver » **FM12**.

This fear of breaking the direct relationship with the customer is also mentioned as a reason that leads actors not to adopt other innovations such as UDCs (Abdelhai et al., 2014; Janjevic, 2016).

Organizational issues are also raised as an obstacle to the adoption of this innovation. For some, it will mean reviewing the entire organization, i.e., that of routes, human resources, work

processes on the sending and receiving platforms, and security and safety processes. Finding a new organizational balance is not easy.

« *We have a daytime organization and I think that the introduction of night work will bring many changes to our organization [...] night work is a whole organization, in terms of HR, safety, and scheduling.* » **FM6**

Social issues raised by the actors are related to night work. The transport sector is already under pressure regarding availability of truck drivers. It is therefore difficult to find staff to work at night. Stakeholders are also aware that night work has a negative impact on staff health.

« [...] *it is necessary to remember that for people's health, the law recommends that night work be reduced, whereas in this case we are trying to extend it* » **FM8**.

In addition to social issues, there is the question of noise for the neighborhood during nighttime deliveries. This issue can be solved by the use of silent materials and equipment through the certification of the entire delivery process, but this has a cost. Some actors believe that even with this certification, night deliveries will hardly be accepted by local residents. Any noise is de facto associated with the presence of the delivery truck in the street at a late hour.

Concerning *environmental* issues, it should be remembered that this innovation is presented to actors as a sustainable urban logistics measure, and therefore as having the potential to reduce environmental nuisance from urban logistics. Nevertheless, the reaction of the actors shows their *skepticism* about the environmental efficiency of such a measure. The objections are that traffic conditions in off-hours do not allow to save sufficient quantities of fuel to reduce pollutant emissions. A partial adoption of OHDs makes all tours non-optimal: both daytime and nighttime tours. This leads to an adverse effect, i.e. more distance travelled for the same number of customers and therefore more emissions for the overall deliveries.

« [...] *now making night deliveries, if it means making a tour for one or few customers and doing the rest during the daytime, it is contrary to the concept, since it is said that we will deliver at night to limit pollution. In this case, the pollution is going to be double because the vehicle is going to run both at night and daytime. I find it difficult to see an ecological interest in this case. If someone tells me that delivering at night avoids parking problems, I am ready to hear it, but to tell me that it is ecological, no!* » **FM10**

Actors *skepticism* about the environmental effectiveness of OHDs is confirmed by scientific research. For example, by simulating the adoption of OHDs, even on a very large scale in the city of Lyon, Savadogo and Beziat (2021) show that the environmental impact would be low. They explain that the conditions for the environmental effectiveness of OHDs are partly determined by the physical characteristics of the area in which they are implemented (Savadogo and Beziat, 2021).

4.1.2. *Low emissions zone*

LEZ is perceived by actors as an exogenous shock, i.e., a logistics innovation that is imposed on them because it is the result of a decision by the Metropolitan authority. Although it raises more or less the same types of issues as OHDs, LEZ gives rise to different perceptions from actors. The question of the lack of co-construction of the LEZ scheme before its implementation was raised by several actors. This is in contrast to the public authorities, who state that they held consultations with actors representatives (association, unions, etc.) for two years before the implementation of the LEZ. These actors' associations claim to have been involved in the reflection process only after they had asked to be associated with it. There is therefore a feeling of having been presented with a *fait accompli* in part. Actors who are not members of these associations declare a total lack of co-construction, as they were not involved in the reflection process at any time. These remarks raise the need, for the acceptability of an innovation, to adopt a participative approach that includes all sensibilities (Barnaud et al., 2016).

Remember that for the public authorities, the main motivation for the implementation of this measure remains the improvement of air quality in urban area, mainly due to the injunctions of EU. It is therefore a mixture of environmental, health and regulatory issues. To this triplet of issues, a financial issue is added since in case of non-compliance with EU standards on air quality, the Metropolitan authority will be fined by EU. This fine will add to the €11 million fine that France has been sentenced to pay to EU for non-compliance with pollution thresholds. Facing the LEZ as an external shock, actors first raise the financial and/or organizational issues. Access to Lyon's city center reserved for clean vehicles requires a fleet that meets the standards of the LEZ. There are three possible scenarios. First, the player already has a fleet of vehicles that meet the standards of the LEZ or has the capacity to renew its entire fleet quickly. In this case, it is in favor of the LEZ as an opportunity to increase its competitive advantage and market share. This point will be developed in the following section. Second, the player has a fleet that is partially compliant with the LEZ standards. In this case, it can reassign the fleet to put the

newest vehicles on the routes that reach the LEZ perimeter. This raises an organizational issue and also, for some players, a social issue. In some companies, the staff are assigned to routes and vehicles according to their seniority. Thus, reassigning vehicles solely on the basis of the perimeter affected by the LEZ would be tantamount to ignoring this rule, at the risk of frustrating some staff.

«For me, the first problem is to adapt the vehicle to the geographical sector. [...] So we'll have to do an inventory and put the most recent vehicles in the Lyon area. [...] technically it's feasible [...] but it's complicated socially because as a result I'll have to change trucks according to the intervention zone. » FM13

Third, the player has no vehicles that meet the LEZ standards. Renewing the fleet represents a significant financial investment, if the fleet is owned, or an increase in rental costs, if the fleet is leased. Some players state that it is totally impossible for them to make such a financial investment. They have two options: relocate outside the zone, or transfer their transport to a third-party carrier. Relocation raises an issue of city attractiveness, increasing the risk of destroying downtown shopping and leading to the desertification of the city center. The transfer of own-account transport to third parties raises the issue of loss of control over a crucial activity. Some players say that it is inconceivable to outsource their transport to a third party for regulatory or relational reasons. For example, the medical waste collection business, which is highly regulated, precludes outsourcing. For another type of player, the dual role of driver and sales agents precludes outsourcing.

« [...] By contrast, outsourcing the transport service is science fiction for us at the moment. It's impossible at the moment, it's inconceivable. » FM12

The low financial capacity obliges some players to make strategic choices, which will be explained in the following section on strategic and competitive issues.

Even if most players consider the LEZ to be a potentially sustainable innovation, they express *skepticism* about the possibility of significantly reducing pollution in the city and at the global level by setting up LEZs. This skepticism is fueled by several arguments put forward by players. First, due to the recent scandals over vehicle emission standards, the measurements stated by car manufacturers cannot be trusted.

« [...] regarding the LEZ, you have seen the various scandals, tampered engines, standards that are not really good: it's just big blah-blah-blah. Many things are made to look like ecology [...] » *FM11*

Second, pollution in urban areas is more a result of passenger transport than of freight transport. Some players denounce a form of relentlessness on economic activity in general and on freight transport in particular. Third, some LEZ schemes implemented in other European cities have achieved mixed results. In several cities in Germany (Jiang et al., 2017), Netherlands (Boogaard et al., 2012), and Italy (Invernizzi et al., 2011), the implementation of LEZs has not resulted in a significant reduction in air pollution inside the perimeter compared to outside the perimeter. Fourth, public authority controls are insufficient to ensure that all players comply with the standards, which may distort competition if some comply and others do not. This *regulatory* issue is all the more important because players are aware that, as the regulations currently stand, it is impossible for public authority to carry out a systematic, automated and exhaustive control of compliance with the standards by all the players within the perimeter. Indeed, although the French Mobility Orientation Law (LOM) now authorizes the use of cameras for control, this is not yet effective. The law only allows the control of one vehicle out of forty, without being able to link the registration number to the Euro standards of the vehicle which is in another database. Interviewed players fear to be the “fall guys” if they make heavy investments that turn out to be not very efficient on the environment and if the effort is not shared because of exemptions or of lack of control.

4.1.3. Differences between the two innovations

The main difference between the two logistics innovations discussed here is the mandatory character of one (LEZ) compared to the other, which is merely being suggested (OHD). The analysis shows that the players are already in the process of adapting to the imposed innovation through actions at both the organizational and financial levels. Most of the actors have taken the strategic decision not to relocate but to stay in the city. In contrast, for OHD, which is a suggestion sometimes accompanied by an incentive, the analysis reveals that there is less adaptation, less willingness to adapt and more procrastination from players. However, analysis shows that a scheme adopted by only some of players can be largely counterproductive and lead to an increase in flows rather than a reduction. Indeed, if some of receivers refuse to adopt OHDs or do not make the necessary physical and organizational adaptations, transport service providers must double their tours. The key role of public authorities and their power of coercion

to impose new logistics schemes is underlined. In addition to the issues highlighted in this analysis in terms of benefits/costs and operational and environmental efficiency, public authorities must consider the strategic and competitive issues of urban logistics innovations. Especially when these innovations have intra- and inter-organizational consequences at a multi-actor level. To do this, the prerequisite is to understand how each actor changes its strategy in response to an innovation. This is the subject of the following section.

4.2 Strategic and competitive issues of OHD and LEZ

This section examines the strategic and competitive issues raised by OHD and LEZ, using the analytical grid centered on power, drawn from the political economy of organizations. Analyzing the discourse of the various actors interviewed made it possible to identify strategic groups of actors. The strategic groups can be distinguished according to their perception of the two logistics innovations in terms of competitive issues (opportunities or threats) and according to the nature of their power to “*consciously and intentionally influence other actors with a view to imposing their own will*”. The content analysis made it possible to distinguish several categories of power: regulatory power (decision-making power outside the internal ecosystem) to decide on an urban logistics system that is imposed on all actors; power to influence the decisions of public authorities, power to decide on the logistics organization of its ecosystem, power to influence the market thanks to its volume of flows, and financial power, defined as the ability to invest. The strategic groups are described using the criteria summarized in **Table 17**.

Five strategic groups were identified. The first is the local authority, Lyon metropolitan authority. This is the only *public actor* in the sample. The second is the *large player*, because of its relatively large size, measured by the number of employees, vehicles, customers, market share and significant financial capacity. The third is the *new player*, that is in the process of establishing itself on the market with a business model based on sustainable urban logistics services. The fourth and fifth type of actor are both so-called *small player* due to their size and strength on the market. The difference between the two is that the first belongs to an *ordinary activity* sector (restaurant owner, baker, convenience store, etc.) and the second to a *specialized activity* sector (medical waste collection).

4.2.1. Local authority: the public actor

Local authority, the only public actor in the sample, is a flow regulator. It has decision-making power over territorial logistics plans, within the framework defined by the national legislator, and coercive power to punish behavior that violates the regulations it determines. Its legitimacy comes from the vote of the citizens. It thus influences the activity and decisions of private actors by implementing measures and policies that impact urban freight transport. The metropolitan authority of Lyon is implementing its sustainable urban transport policy, which takes into account economic, environmental and social dimensions. First, the resources dedicated to urban logistics, particularly human resources, are particularly low, which makes it difficult to develop and implement urban logistics strategies and to handle several innovations simultaneously. This observation is not specific to the city of Lyon, but common to all French cities (Gardrat, 2017), whose resources and means focus more on passenger transport than on freight transport.

*« I work alone on all the issues related to freight transport in the Lyon metropolitan area, which does not make things any easier. For example, when I was preparing the LEZ project, for a year I could only do that and nothing else. This poses problems of disruption when the only person in charge of these issues is no longer there. [...] In each of the larger municipalities, there is only one person working on freight transportation compared to approximately forty (40) people working on passenger transportation » **FR2***

Second, the implementation of the sustainable urban logistics policy is subject to electoral temporalities as well as to the sensitivity of the elected management team towards sustainability issues. This does not facilitate the continuity of policies and projects, and certain periods, such as the year before elections, complicate decision-making. The strategic approach of the Metropolitan authority of Lyon differs according to the two innovations. Under pressure from EU, it has decided to impose the LEZ on actors, but not to impose the OHDs, even though the latter is included as action in the city's transport policy. It feels that the measure is impossible to generalize and to control.

*« If the public authority were to take a general approach to night deliveries by saying that it prohibits all daytime deliveries, which is not possible because I do not know how it controls, it cannot do things on a case-by-case basis » **FR2**.*

In addition, for public actor, providing financial aid for the construction of delivery lockers for the reception of goods at night in individual establishments poses more problems, for regulatory reasons. It is indeed difficult to control that the lockers will be used for the reception of goods, and not for other purposes, such as storage.

The implementation of the LEZ materializes the decision-making power of the public actor, in this case the Metropolitan authority of Lyon, itself constrained by a supranational power, in this case a decision of EU. The LEZ is a response by the public actor to the dispute with EU, which demands that measures be taken to reduce air pollution in the urban environment. However, before taking the decision, the actor carried out a two-year consultation phase in order to take into account the opinions of the actors affected by the LEZ. Through these consultations, the public actor claims the co-constructed character of the innovation, an essential factor for the acceptability of any innovation. The timing of the gradual implementation of the scheme, as well as the adoption of provisional exemptions, were discussed with actors. In addition to the consultations, an information campaign was carried out one year before the implementation of the LEZ.

*« We have been consulting with players (construction, logistics, trade, waste, etc.) for two years now. Regarding the questions of exemption, we have taken into account the requests of certain players. Regarding the subsidy proposed by the metropolitan authority, we have tried to make the system work. That is why the system is also progressive according to the standards between 2020 and 2021 [...] All the associations were aware of this and cannot turn around today to say that they were not [...] they all worked with the metropolitan authority for 2 years. The exemptions were worked out with these associations: how? why? how they are justified, etc. All of this is documented. » **FR2***

The decision-making power of the public actor is, however, limited in its operationality by the weakness of its coercive power. The French Mobility Orientation Law (LOM) limits the possibilities of vehicle control. In addition, the metropolitan authority has not set up a superstructure, with a camera system for example, because of its high cost.

*« ...In addition, for the camera control system, all the studies have not been done to know in terms of profitability (control/investment) if you reach a break-even point. Budget constraints are also a barrier. [...] The existing camera system for traffic control in the metropolitan area (PC Criter) is not allowed to read the entire license plate, let alone link the license plate number to a name » **FR2***

To help the most vulnerable players to renew their vehicles, the metropolitan authority has set up an envelope of one million euros, in derogation of national regulations, since subsidies are normally the responsibility of the Region authority and not of the metropolitan authority. The amount of subsidies is capped by limits imposed by EU to avoid distorting competition between private actors in the community space. These restrictions underline the relative weakness of the financial power of the public actor with regard to the needs of private actors located on its territory. It should be noted that in order to justify aid to the most fragile actors, the metropolitan authority does not directly mention the issues of competition between large players and smaller ones. However, it does mention the financial constraints that threaten the most fragile players.

« For the subsidy, legally, according to the European directives, we can only cover 40% (all national and regional aids combined) of the additional cost between a thermal vehicle and a green vehicle ». **FR2**

However, it should be noted that this aid does not generate much interest from eligible actors. Less than 10 applications had been received by the Metropolitan authority at the time of our interview. According to private actors, the additional cost of purchasing a green vehicle compared to a diesel vehicle is about 35% and is largely not covered by the subsidy granted by the Metropolitan authority. Technical issues related to the autonomy of the vehicles, the lack of charging points (gas station, electric charging point) would also explain in part the low number of applications received.

In summary, the public player takes hold of the LEZ in its strategy mainly through its decision-making power. However, thanks to consultation upstream of its decision, it can give a co-constructed character to the innovation and thus ensure its better acceptability by the actors. Its financial power allows it to provide financial aid to the most vulnerable players, even if it remains limited. However, the competitive issues between large and small players do not seem to be directly addressed. One of the challenges is to impose the respect of the measure on all the actors. This questions its coercive power when it is limited by technical aspects (camera infrastructures) or regulations (restricted access to private data).

4.2.2. The large player

The large player is characterized by the fact that it has a significant impact on the market due to its size, its staff, its economic weight, its market share, its financial resources and its expertise. As a large group or subsidiary of a large group, it can be a flow generator, or a flow

or infrastructure manager. It has decision-making power over its internal ecosystem (legitimacy, expertise). For example, a large food distributor decides on the assets allocated to logistics and designs the logistics organization for its outlets. The network head franchisor also handles the logistics organization for its franchised stores. In its role as network organizer, it has a power of influence over the franchisees and acts as a *broker* in the sense of Miles and Snow (1986). The large player can also be a federated group of players whose interests it defends.

In addition to the aspects linked to cost-benefit, the large player analyses logistics innovations in the light of competitive issues. It is in favor of schemes that are likely to strengthen their competitive advantage. It can use its power of influence on the local authority and on its internal ecosystem. It takes part in upstream consultations with public actors in the design of measures and policies whose outcome are logistics innovations. Its staff resources allow it to allocate resources for participation in consultations, so as to influence the decisions of public actors, even if it means obscuring the points of view of the less influential actors (Barnaud et al., 2016; Faysse, 2006; Leeuwis, 2000). For example, this type of actor has contributed to the design and adoption of the existing LEZ scheme in Lyon. It has therefore had time to prepare itself to integrate this imposed innovation into its strategy. Its lobbying activities can take place at different levels: local, national and even at the EU Commission.

« The association is an umbrella organization of trade unions [...] we have offices everywhere, even in Brussels (EU Commission). Representatives participate in discussions. We have elected representatives who take care of bringing up the concerns of our members. There is a lot of lobbying work that is done both in Brussels and at the level of the ministries » FM9

Few of the large players in our sample have adopted OHDs. The reason they give is the lack of demand from their customers and the lack of support from public authorities. Those who have adopted it, for at least part of their deliveries, have two profiles. First, they are integrated or quasi-integrated distribution networks (contractual franchises), with centralized decision-making by the head of the network and a centralized and controlled logistics organization for all of the chain's sales outlets, even if adaptations to specific territorial contexts are possible. Thus, OHDs can be excluded for stores or franchisees with specific constraints. Second, it is those who operate for major customers, with truck deliveries in full loads, in direct trip or in short rounds reaching two or three points to be delivered. In both cases, these players have the financial capacity to make the necessary investments to create delivery lockers and carry out

silent deliveries. Their motivations are expressed in terms of efficiency and cost-benefit advantages, with little mention of competitive issues.

Competitive issues, by contrast, are widely discussed with regard to the LEZ. Large players see it as an opportunity to increase their market share and market power, because they anticipate the disappearance of the most fragile players, who will not be able to renew their fleets for lack of financial power. Despite their skepticism about the environmental efficiency of the current LEZ scheme, they even use their power of influence to advocate for stricter standards in order to increase their competitive advantage. Their strategy is one of predation.

« Regarding pollution, the trucks' refrigeration units are not clean. Because I participated in meetings with the metropolitan authority on the project of the low emission zone, we were interested, because as we are a big operator, if it is necessary to make investments, we will be able to do it. Our small competitors won't be able to do it. So, if the access is a little higher, it's fine with us [...] » FM8

4.2.3. The new player

The new player is distinguished from the large player by its business model, which was built from the outset around the concept of sustainable urban logistics. This strategic group is composed of only one company in our sample (see **Box 3**), which is a flow and infrastructure manager. It is the subsidiary of a historical player in mail and parcel distribution, with solid financial power and particularly well introduced into national and regional consultation bodies (power of influence). This gives the subsidiary privileged access to strategic information, which it provides at the level of its territory.

« Cities have committed themselves and have received subsidies, including from the European Union. At some point, they would be told either to return the money or to implement measures. So, I think that the famous LEZ will definitely happen ». FM7

The new player is focusing its energies on local authorities as part of its implementation strategy. The aim is to convince them of the urgent need to put in place effective regulations to ensure sustainable urban logistics for all the population. It presents itself as the actor who could provide such a service if the existing actors on the ground were not immediately capable of doing so. This is clearly in line with its strategic objectives:

« We work with local authorities through agreements in which we undertake to enter cities with clean vehicles, and the authorities undertake to enforce the regulations they have put in place: LEZ, Restricted Traffic Zone. Except that between politics and economics, there is a lapse of time during which we must wait. » FM7

Box 3: Profile of the new player

It is a relatively small company, operating in B2B and B2C, with a city-wide scope of action, i.e. on the last or first mile segment depending on whether freight is entering or leaving the city. It is a subsidiary of a large group specialized in the distribution of parcels and mail, whose experience and distribution network in urban areas it capitalizes on. With the growth of e-commerce and the fragmentation of parcels, the large group created this player to position itself in this segment. Its business model was built around the sustainable urban logistics label through the provision of sustainable urban logistics services. From a center located at the entrance to the city, its aim is to pool deliveries as much as possible and to deliver to the city center with clean, full vehicles.

In its activity, the time slots for deliveries are from 7am to 1pm and secondarily in the afternoon (2pm to 8pm), because of customer time constraints. It does not exclude the possibility of delivering at night or early in the morning if the need arises. It has a fleet of Euro VI leased vehicles and plans to acquire a fleet of clean vehicles as soon as the freight handled is substantial.

Its strategic objectives include: influencing current regulations and their effective application; increasing its market share; improving its economic balance; implementing environmental indicators; and improving its environmental balance.

For the new player, the increase in market share depends on stringent and effective regulations for sustainable urban logistics. The more stringent and effective the regulations, the less some players will be able to deliver in the city center, and the more they will transfer last-mile delivery to the new player, since it is able to invest in clean deliveries.

Despite its business model built around the sustainability of urban logistics, its performance indicators are currently only financial. However, other indicators are under preparation.

Source: Author's elaboration

For this player, logistics innovations are growth opportunities. It presents itself as a very flexible player when it comes to adapting to the possible new needs of cities in terms of sustainable urban logistics.

« Our business model will evolve in the future by integrating activities that I may not even know about: for example, bio-waste. It will depend on the dynamics in each metropolitan area ». FM7

The new player is in favor of OHDs because they offer both economic and environmental opportunities. For this player, to make OHDs effective they must be combined with desynchronized infrastructures (such as his own!) located near cities, from which large-capacity trucks make nighttime deliveries in the city center. To do this, regulations must allow these trucks to enter the city at night.

He is also in favor of LEZ, which he sees as an opportunity to increase his market share and market power, although he is skeptical about the environmental effectiveness of the current LEZ scheme. Indeed, he hopes to be able to recover the flows of small players who will not be able to comply with the tightened standards and who could switch to him to deliver to customers in city centers.

« For the LEZ, for those who were already transporting, there are two alternatives: either they have enough flows that would justify the investment in new vehicles, or they will transport through us or another structure such as ». FM7

All in all, this new player, backed by a large group with considerable financial and influence power, analyzes the two measures in terms of competitive issues. It sees the tightening of regulations as an opportunity to increase its market power and its currently modest revenues.

4.2.4. The small player in an ordinary activity sector

A small-scale establishment, this actor is either a receiver of flows at the end of the chain (store, restaurant, small business), or a local carrier with a deep knowledge (spatial and social) of the urban area in which it operates. At the end of the logistics chain, its decision-making power over its ecosystem depends on its status. The integrated establishment has little influence and follows the decisions and logistics plans dictated by its management. The franchisee has more say and can dialogue with its network head on proposed logistics solutions that are difficult to implement. It shares the decision with its network head, at least for the aspects related to its store. The isolated independent store is free to make its own logistics decisions and thinks in

terms of cost-benefit, for example for OHDs. For the carrier or its principal, the question is to know if there is enough flow to justify a night tour. For the receiver, the question is whether the additional cost of staff dedicated to receiving deliveries does not threaten its fragile financial balance. Aspects of mutual trust also come into play when considering unassisted OHDs. The financial power of the small player is limited, as is its power of influence on local authorities. The small player is not well informed about sustainable urban logistics policy projects, whether they are being designed or are about to be implemented. It rarely participates directly in consultations on these issues, as it has few human resources. However, information is available to them through trade unions, federations and retailer associations when they are members.

Small players analyze the two logistics schemes in terms of cost-benefit, when they are decision-makers, but also in competitive terms. What dominates then is the threat that imposed innovations represent when they imply substantial financial or organizational investments. LEZs imply a de facto renewal of the fleet and therefore a heavy financial investment. This creates a competitive disadvantage for a financially fragile establishment, which is the case for small isolated establishments, whereas large players have an advantage. Small integrated or franchised establishments backed by large players are hardly concerned.

*« Regarding this (the LEZ), the strength of being a franchise of a big brand like **FG2**, is that in all cases all the choices and modifications will be made so that you never miss a single delivery. This is what I have noticed while working with this brand, that all the means are made available so that the service goes on and the customers are served. If we have to change carriers or trucks, it will be done even in the emergency if necessary » **FG2***

By contrast, the isolated establishment is more affected by the measure. There are two possible scenarios. Either the player is able to make the investment to bring its fleet into compliance on its own. Or it is not able to do so and its survival is threatened, especially when the transport segment cannot be outsourced due to its strategic nature. In this case, the deadlines, exemptions and financial aid from the local authority for fleet renewal will be decisive.

« No, I can't buy another vehicle. We already have little margin, if we have to buy a new vehicle, it's better to stay at home and not do anything. "We can't get by with that. [...] We can consider changing our truck with the support (financial assistance from the city), but I confess that it will be very difficult for us to make such an investment. But such a solution is still possible compared to the idea of subcontracting the transport. We can make the purchase of the new

vehicle profitable over time, but I don't think we can recoup the cost of outsourcing. We can also consider relocating to a dirty area » FG3.

This is why it is essential that the public authorities put in place a support system for the most vulnerable players so that they can make the investment required to renew their fleet. This can take the form of deadlines, exemptions and financial aid. This will prevent the negative social impact that the disappearance of these players from the economic sphere would represent.

4.2.5. The small player in a specialized activity sector

Small players in our sample operates in a specialized sector of activity, namely the collection of healthcare waste with infectious risks. This player is a flow manager whose clients are hospitals, vaccination centers and other dispensaries. The activity is governed by rather restrictive regulations, such as the requirement of the presence of a health professional during the waste pick-up or the prohibition to move the waste on the sidewalk beyond a certain distance. This specificity may have an impact on the way in which it takes up the two logistics innovations. Like a small player in ordinary activity sector, this player has little power to influence local authorities, nor does it take part in consultations, and its financial power is weak because of its size. On the other hand, its power to influence its ecosystem is not nil: few players are present in this very specific segment. This gives it a medium level of market power. It can impose a logistics organization on its client, such as time slots for waste collection.

For this player, OHDs are difficult to implement, mainly because of the strict regulations governing this player's activity, particularly in terms of staff presence. There are also aspects of additional costs and organization. Concerning the LEZ, competitive issues are not mentioned by this player, and this is a notable difference with the small player in the ordinary activity sector. The regulations require frequent renewal of vehicles transporting dangerous products, so the player's fleet is up to standard. This player, who is not very concerned, was surprisingly unaware of the implementation of LEZs in cities. Thus, even with weak financial power and power of influence, this actor does not suffer from the innovation. It is therefore the counterfactual of the small player in the ordinary activity sector.

After detailing the strategic and competitive issues of the different strategic groups identified in the sample, we present in **Table 20** the levels of power and the analysis in competitive terms of the two innovations.

Table 20: Overview: Player- Type and level of Power – competitive issues

Strategic group (Players)	Decision-making Power beyond the internal ecosystem	Power of influence	Decision-making Power on the internal ecosystem	Market Power	Financial Power	How players considers innovations	
						OHD	LEZ
Public actor	★★★	-	-	-	★★☆	Innovation suggested	Imposed innovation
Large player	☆☆☆	★★★	★★★	★★★	★★★	Opportunity (some initiatives)	Opportunity (predation)
New player	☆☆☆	★★★	★★☆	★★☆	★★★	Opportunity (In favor for)	Opportunity (Growth)
Small player (ordinary activity)	☆☆☆	☆☆☆	★★☆	★★☆	★★☆	No voluntary adoption	Threat to survival (Need for support)
Small player (specialized activity)	☆☆☆	☆☆☆	★★☆	★★☆	★★☆	No voluntary adoption	Neither threat nor opportunity

Source: Authors’ elaboration

Note: Filled stars represent the power level of the actor, determined from his discourse.

5. Discussion and Conclusion

This research has highlighted the variety of issues associated with two urban logistics innovations, one suggested (OHD) and little adopted; the other imposed (LEZ) by public authorities. Private actors analyze these systems in terms of cost-benefit for their organizations. The issues are first of all financial, when the innovation implies new investments (renewal of the fleet of vehicles, fitting a delivery locker in a business premises). They are also relational and are likely to modify the organization of work (night tours) as well as the nature of the interfaces with the internal ecosystem (relations between partners in a logistics chain). However, the issues are also analyzed in competitive terms (threats and opportunities), and in terms of power (of decision on its ecosystem, of influence on the regulator, of market or financial power), especially when the system is imposed by the public authorities in view of their coercive decision-making power. Several strategic groups could be described, using the analytical grids proposed from the theoretical framework of the political economy of channels, and the roles of the actors.

Four main comments emerge from the empirical analysis. Firstly, the competitive issues are perceived differently depending on the strategic groups and the powers they have. Large players and the new player specialized in sustainable urban logistics spontaneously evoke the issues in terms of market power, more so than the public player and the small players. Aware that the two urban logistics schemes are likely to modify the competitive positions of the players, especially if they are imposed by the public authorities with a restrictive timeline, they see an opportunity to increase their market share on the urban territory. They hope to recover the flows of the most financially fragile players, particularly those who operate urban goods transport on

their own account and who also own the oldest vehicles. Large players are in favor of restrictive measures and use their power of influence to try to obtain tighter standards and controls from the regulators. They mobilize human resources to do so, actively participate in consultations, conduct lobbying operations, and clearly express their strategic intentions. Smaller players have a less strategic and political vision of innovations. Their analysis is more myopic, focused on the benefits-costs, and expressed in financial, organizational, and relational terms. However, they clearly express their fear of disappearing and see the two measures as a threat to their activity, except when they feel safe in the belief that they will obtain an exemption due to the specificity and regulation of their activity. Some sectors of activity and products are indeed incompatible with the implementation of OHDs. This result is convergent with previous research (Verlinde, 2015 ; Holguín-Veras et al., 2011, 2005; Silas and Holguín-Veras, 2009). A distinction must be made, however, between small players in ordinary activity sectors, often receivers of flows, depending on whether they belong to a group (integrated entity or contractual network) in charge of logistics organization decisions for the network and investments at least in part, and isolated independent players who must alone assume the organizational and financial constraints of new measures. The power of influence and finance of the latter is weak, which makes them fragile and not very favorable to innovations (OHD and LEZ).

Secondly, environmental motivations, stated by the public actor to promote and justify sustainable urban logistics systems, imposed or suggested, are not spontaneously evoked by private actors. Financial, organizational, relational, and competitive aspects dominate the discourse. Other studies have shown that economic considerations prevail over environmental motivations. This was the case in the study by Ruel et al. (2021) about a cooperative involved in reverse logistics. Above all, whatever their size, their activity sectors, their powers, private actors express a certain skepticism about the environmental impact of the two innovations. On the one hand, they consider that only a massive adoption of the measures by all urban logistics actors, without exception, would be likely to reduce the negative externalities of urban deliveries. If daytime deliveries are accepted for actors who do not play the game of OHDs, the risk is to duplicate flows. If the public authorities cannot effectively sanction those who contravene the LEZ rules, or multiply the number of exemptions, the environmental impact will be marginal. There are other reasons for skepticism, including the “*dieselgate*” scandals over the veracity of vehicle engine emissions standards. This tends to make the call for stakeholders to make efforts to improve the sustainability of urban logistics less audible. In such a context,

private actors adopt innovation when it is imposed on them (LEZ), and they then only make the strict minimum of the effort required, even if they have the capacity to go beyond it. They rarely adopt it when it is simply suggested to them. Skepticism about the environmental efficiency of urban logistics innovations is a phenomenon that has already been observed, especially from actors who had not yet experimented them, for example for OHDs (Koutoulas et al., 2017), or UDCs (Björklund and Forslund, 2014; Heeswijk et al., 2019). Carriers see the latter as a threat: an addition of a new competitor to the market, likely to capture last-mile flows, with no real CO₂ savings. The skepticism is similar to that expressed by some consumers towards so-called “green” transport (Kessous et al., 2015).

Third, our results confirm that an innovation in urban logistics can only have a significant impact if it is massively adopted by a large number of actors and for a significant volume of flows. The reasoning can be likened to an *all or nothing* approach. If a scheme such as OHDs only concerns a small number of actors and flows, it risks being counterproductive in environmental terms, by leading to duplicate tours (night tours and day tours for customers who refuse or do not adopt the structures for OHDs). Verlinde and Macharis (2016) had already shown that it was very important for actors to switch a large proportion of their operations to off-hours. This point questions the role of public authorities in the implementation of new multi-actor urban logistics schemes. Whatever the nature of the innovation, public actors have a central role to play in making it more acceptable and effective. Private actors, regardless of their power and/or size, require greater involvement of the public actor in the implementation of innovations. This result is convergent with that of Verlinde et al (2010) who showed that public support for the implementation of OHDs was too weak. If public authorities have long been uninterested in the issue of urban freight deliveries, leaving private actors to organize deliveries according to the objectives of their respective internal ecosystems and in an anarchic, uncoordinated way, this time is over.

Fourth, three major roles of the public actor emerge: the public actor must assume an essential function by setting up a clear and stable institutional framework (Chanut and Paché, 2013). As *regulator*, it must exercise its decision-making power and impose on all stakeholders urban logistics schemes that are in the general interest, in this case the reduction of the negative externalities of urban logistics, since individual initiatives do not spontaneously lead to virtuous behavior. In addition to defining restrictions, coercive power requires the definition and effective application of sanctions (Chanut and Paché, 2013; Zhang et al., 2020). This requires political courage, as coercive measures are unpopular because of the changes in practices and

investments they induce for private actors. And while “goods don't vote”, it is not always easy for the public actor who receives legitimacy from the vote to desynchronize its urban logistics decisions with its political agenda. In the case of Brussels, Verlinde (2015) had shown that the legislative and political situation in Brussels would not allow for an immediate shift to OHDs. Courage was necessary to impose the LEZ in Lyon, although imposed from supranational power (EU), which made such an innovation possible.

The second role of the public actor is that of *coordinator and facilitator*. If it takes unpopular decisions in the general interest, it must nevertheless ensure that they are acceptable to the various strategic groups concerned. This requires a good knowledge of the actors in the urban logistics ecosystems of the territory, and a good understanding of the systemic nature of urban logistics, through the interplay of actors who drive it, their interests and their rationale (Ducret, 2014). Being able to predict and anticipate the preferences of groups of actors facilitates the design of urban logistics innovations, prevents possible negative reactions and avoids undesirable outcome of policies (Stathopoulos et al., 2012). The participative method is indicated, when it allows a wide consultation, or even the co-construction of the logistics innovation with private actors. Consultation is a key factor in the success of logistics measures involving a multitude of actors (Lindholm, 2010; Stathopoulos et al., 2012). It is in this logic that for the achievement of a sustainable city, Vuidel et al. (2012) considered that the best strategy is the one built around schemes involving both private actors (companies), public actors (local authorities) and users. Without this, the implementation of innovations can lead to failures in reality (Macharis and Melo, 2011). Consultation can be complemented by a facilitating role consisting of making logistics assets or investments available to facilitate pooling, such as premises for a UDC, for example. It should be noted, however, that regarding this aspect of consultation, the public player must be careful not to be naïve. It must fully understand what is at stake for the players, and in particular the competitive issues, in order to thwart the power of influence of the large players, when they seek to preserve their particular interests in the consultation phase, in a behavior of predation. The public player must mitigate the effects of the asymmetry of power that is exerted before, during and after consultations on logistics innovations.

Thus, the third role of the public actor is to *support*, in particular, the most fragile strategic groups that see urban logistics innovation as a threat to their survival. There is a tension for the public actor, between the desire to reduce the number of vehicles in the city, deliveries with polluting vehicles that are not always full, and the desire to help small businesses and shops in the city center, whose agility sometimes also depends on fluid and rapid deliveries. Support can

consist of a progressive calendar for the implementation of a restrictive innovation such as the LEZ, with key stages and dates. This is what is planned in the case of the LEZ in Lyon. Support can also be financial. For example, it can take the form of subsidies, conditional on the scrapping of polluting vehicles, the size of the company or its turnover, as was done for fleet renewal of private cars to electric vehicles in France in 2020. It could also involve tax credits, exemptions and longer deadlines granted to smaller players. The public actor could also facilitate the emergence of a second-hand market to allow access to clean vehicle investments for small players. It could also facilitate the setting up of financial arrangements with lease-purchase to allow the purchase of the fleet by a local authority or by a private agency that could lease the clean vehicles to the smaller players. However, the financial support is limited by the financial capacities of the public actor and European legislation.

5.1 Theoretical and methodological contributions

From a theoretical point of view, this paper presents two key contributions. The first contribution is to have mobilized the theoretical framework of the political economy of channels and integrated a socio-political component into the analysis. The vision by the power of organizations and their strategic behaviors (predation in particular), the apprehension of strategic and competitive issues is a key contribution. Indeed, most of the previous studies on logistic innovations were rather oriented on technical approaches of their operability. Regarding OHDs, studies had focused on characterizing the flows that would be most suitable for them (Verlinde, 2015), the minimum proportion of flows to be postponed (Sánchez-Díaz et al., 2017), conditions to be met in order for them to be effective (Holguín-Veras, 2008), or the actors that would be most in favor of this measure (Verlinde and Macharis, 2016). Regarding LEZs, the majority of studies had focused on measuring their impacts on air quality (Boogaard et al., 2012; Ellison et al., 2013; Holman et al., 2015; Jiang et al., 2017), or population health (Cesaroni et al., 2012; Host et al., 2020; Lebrusán and Toutouh, 2020; Malina and Scheffler, 2015; Mudway et al., 2019). By contrast, the strategic and competitive issues raised by these innovations had received little attention. Therefore, having analyzed these issues, beyond the classic cost-benefit approach, constitutes a key theoretical contribution of our research.

The second theoretical contribution of this research is the notion of skepticism, which is widely shared by the actors in our sample, and which has not been highlighted in previous studies. We cannot exclude the possibility that this skepticism about the environmental efficiency of the urban logistics innovations studied is expressed as a reason for rejection or criticism, even

though our data collection took place at the time of the announcement of the LEZ. Nevertheless, the consistency of the argument is noteworthy. Public authorities will have to become aware of this skepticism and help to overcome it.

Beyond the theoretical contributions, we emphasize the originality of our methodological approach. This exploratory and qualitative research, with an interpretivist approach, has the advantage and interest of complementing exclusively quantitative studies based on modeling and evaluation of the impacts of urban logistics innovations. It provides input to the modelling and helps to explain some of the results. While the semi-structured interview approach and method is standard in management science, it is less common in economic research on urban logistics. This is also a methodological contribution of our study. Indeed, understanding in depth stakeholders' interactions with the two innovations, the way they use them in their strategy, the conditions to be met for them to adopt them, the level of adoption they are ready to reach, and the adaptation alternatives they could use, enabled us to construct scenarios close to reality in order to simulate *ex ante* the impacts of the implementation of these innovations (see Chapter 1 and Chapter 2).

5.2 Managerial implications

Analyses allow us to identify some managerial implications, both for public actors and for the strategic groups of private actors. For the public actor, we will not repeat here in detail the three roles already identified in the discussion (regulator, coordinator/facilitator, support), which require courage in decision-making, an ability to desynchronize decision-making and the electoral agenda, a willingness to understand the systemic nature of urban logistics and the constraints and issues of each strategic group, without naivety, and with resources. Nevertheless, we will make three recommendations. The first concerns the human and financial resources allocated. Our data have shown that the human resources allocated by the public actor for issues related to freight transport are very low (1 person) given the issues raised and in comparison with the resources allocated to the passengers transport (40 people). We advise cities and local authorities to make freight flow issues strategic for their territories and to allocate human and financial resources to meet the challenges. The institutional environment is favorable to this increase in the consideration of urban logistics issues. Reports have been published on sustainable urban logistics, recommending that the place given to urban logistics in regional planning, sustainable development and territorial equality schemes be strengthened (Bonnetoy and Pointerau, 2021). However, we should not underestimate the difficulty that the

public actor has in adequately fulfilling the role of facilitator. It remains to construct a kind of *modus operandi* that cannot be standard for all metropolitan areas because there are different configurations and problems, there are no magic formulas, and schemes must be adapted to each territory. Second, in order to respond to the skepticism of urban logistics actors about the environmental efficiency of schemes put in place, a solid system of evidence must be established. The local public actor has the duty to convey the perception of private actors to the central authorities (State) and supranational authorities (EU). Since the first receives injunctions from the latter two when an imposed innovation has to be implemented, it must also be the conveyor belt of the skepticism of the actors impacted by these innovations to the central authorities. In the case of the LEZ, for example, it is a matter of drawing the attention of the central authorities to the need to demand greater transparency and truthfulness on the part of car manufacturers regarding vehicle emission standards. Scandals on these issues are not likely to improve the acceptability of restrictive innovations based on vehicle engines. We also call for transparency and large-scale sharing of the results achieved (air pollution, noise, traffic accidents, traffic fluidity, etc.) after the implementation of innovations in different metropolitan areas. Third, public actors can conduct communication campaigns to “educate” urban consumers to be aware of the negative externalities of their consumption behavior. They can encourage deliveries to outlets and other grouping places and discourage home deliveries, which increase the number of trips and lengthen delivery tours, and make people aware of the harmful effects of quick commerce and “everything right away”. This role of educating the urban population can be just as effective as measures such as OHDs or LEZs.

For private actors, managerial recommendations are formulated according to strategic groups and their levels of power and influence. For small players, who have a weak decision-making power in their ecosystem, a weak market power, and a weak power of influence on the regulator, we can advise them to speak out more in consultations through their representative bodies (associations, unions), in order to raise the competitive issues of the planned schemes, and to discuss the appropriate support options for their businesses. They can also develop a resilience strategy by reducing the fragmentation of their flows, for example by pooling their resources (infrastructure and equipment). However, it must be recognized that the practice of pooling comes up against concrete difficulties. On the one hand, some players want to keep their own fleet, which makes pooling difficult or impossible. On the other hand, pooling is subject to organizational, material and technical constraints (Michon, 2014). It comes up against issues of

reluctance, due to the lack of trust or consent to share information (Chanut et al., 2011, 2010; Michon, 2014).

For large players, we have seen that innovations represent opportunities for them, due to their power (financial, decision-making power over their internal ecosystems, influence). However, the effectiveness of improving the sustainability of urban logistics depends heavily on their involvement, whether they are flow generator or flow managers. Thus, on the one hand, they must invest more in the provision of sustainable logistics services, beyond the minimum required by the public actor. Whether they are integrated networks, contractual network heads, or new players specializing in urban logistics, the flows they control are substantial or will become so rapidly. They can therefore use their decision-making power over their ecosystems to implement and promote virtuous behaviors among their partners. On the other hand, their influencing efforts can be directed at both public actors and citizens, but this time with the aim of convincing them to choose providers on the ecological basis of the service offered. Retail shippers can participate in educating the end-customer through delivery pricing, or the implementation of sustainable urban logistics labels.

5.3 Limitations

This study has some limitations. First, the size and composition of the sample studied for the two innovations could limit the scope of the results. However, the fact that an association of actors was included in the sample mitigates this limitation. Indeed, the actors' association integrates a synthetic vision of its members with a certain consensus. Second, the exploratory and qualitative nature of the research does not allow for the generalization of results. Moreover, the assessment of the strength of the actors' powers was evaluated qualitatively, based on the actors' discourse. An accurate measurement, with power measurement scales, among a large sample of the urban logistics actors, could extend this research. Third, this study focused on two logistics innovations, OHDs and LEZs, which are highly topical and considered major innovations for reducing the negative externalities of urban goods delivery. The study lays the groundwork for thinking about logistics innovations in general - how the interplay of actors and power impact the way they use them in their strategy. However, the results cannot be generalized to other multi-actor urban logistics schemes such as shared platforms, reserved lanes, pedestrianization of certain city centers, multimodal combinations such as tram-freight or the combined use of river, railway and bicycle, the use of part of existing urban real estate

during certain hours of the day as storage space, etc. These are all complex schemes to implement that can be explored in a research agenda, in order to address climate emergency.

Appendix

Appendix 1: Semi-structured interview guide

Part I: Establishment Characteristics

1- Overview of the establishment

- Activity sector, size, number of employees
- Organizational form

2- Description of the logistics organization

- Origin and destination of products - Operation frequency
- Equipment and premises
- Operational difficulties
- Key performance indicators

3- Major logistics objectives in short, medium and long terms

Part II: Off-hour deliveries

1- Adoption: Yes or no? Why or why not?

2- Issues regarding adoption or non-adoption

3- OHD as a sustainable urban logistics solution: What do you think ?

Part III: Low Emission Zone

1- What are the impacts on your business?

2- LEZ as a sustainable urban logistics solution: What do you think ?

Table A 8: List of interviewees

Source: Authors' elaboration

Stakeholder	Organizational form	Product	Number of interviews	Code
Flow and infrastructure Manager	Integrated entity	Electrical products	1	FM1
Flow and infrastructure Manager	Integrated entity	Products of great distribution (food product)	3	FM2, FM3, FM4
Flow and infrastructure Manager	Integrated entity	Beverages	2	FM5, FM6
Flow and infrastructure Manager	Integrated entity	All packaged products except dangerous products	1	FM7
Flow and infrastructure Manager	Integrated entity	Food products under controlled temperature	1	FM8
Flow and infrastructure Manager	Association	All types	1	FM9
Flow Manager	Isolated independent	Health care waste collection (Specialized activity)	2	FM10, FM11
Flow Manager	Integrated entity	Flat Linen and hygiene service	2	FM12, FM3
Flow Generator	Contractual network	Products of great distribution	1	FG1
Flow Generator	Contractual network	Fast Food	1	FG2
Flow Generator	Isolated independent	Deli products	1	FG3
Flow Generator	Integrated entity	Food service	1	FG4
Flow Regulator	Public authority	Roads and urban mobility	1	FR1
Flow Regulator	Public authority	Urban freight transport	1	FR2

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CONCLUSION

The thesis is part of a research agenda related to the urgent need to propose relevant tools and methodologies for the *ex ante* evaluation of measures aimed at improving the sustainability of urban logistics. The thesis dealt with this topic with the particularity of questioning the issues and the impacts of the measures at the economic, organizational, environmental, and social levels for the actors involved in urban logistics. The research focused on two measures: OHDs and LEZ in the Lyon urban area (LUA). Through a hybrid methodology, combining a quantitative and a qualitative approach, the thesis contributes to the literature by successively analyzing the environmental impacts of a large-scale adoption of OHDs (Chapter 1), the economic-environmental balance of a LEZ (Chapter 2), and the dynamics in the strategies of urban logistics actors towards OHDs and LEZ (Chapter 3).

Recap of the main results of the thesis

The first chapter of the thesis investigates the environmental impacts of a large-scale adoption of OHDs. Using a methodology based on integrated modeling, we estimate the environmental impacts of several OHDs scenarios at various scales, depending on the proportion of deliveries shifted from regular to off-hours. Our results show that an adoption of OHDs in the LUA will lead to a decrease in urban freight emissions. This decrease in emissions is due to the improved traffic conditions under which OHDs are operated. Analysis of the results at various scales shows that the impact of OHDs is greater in densely populated areas. The valuation of the environmental impact of the measure shows that the adoption of OHDs will allow a maximum annual reduction of the external cost related to pollutant emissions of 4.25 million euros. In addition to this gain, there is a maximum saving of 2.5 million hours of travel time per year. Valued at the minimum growth wage (SMIC) for the transport sector in France, which is 10.25 euros per hour (CNR, 2021), this saving is valued at 25.7 million euros per year. This brings the total gain to about 30 million euros per year.

However, these gains must be weighed against the potential costs of adopting OHDs. These could include the costs of night work, the costs of noise if deliveries are not made silent, or the costs of changes needed to make all these night deliveries silent. To improve the acceptability of nighttime deliveries to local residents, it is essential to make deliveries silent. This requires making vehicles, equipment, and operations very silent, through a certification process such as the PIEK label. All this has a cost that can increase the purchase price of a vehicle by 10 to 15%

according to the report on the OHDs experiment in Lyon (see **Box 1**). In addition to these costs, there may also be costs related to the installation of delivery lockers in the case of unassisted OHDs.

Comparing the potential environmental gains from OHDs in the LUA with those that would be expected for other cities, it can be seen that these gains are relatively small. The analysis of the LUA's characteristics has allowed us to identify the reasons for this low level. Firstly, there is a strong presence of 30km/h speed limit zones in the city of Lyon, which limits the speed differences between regular and off-hours. Secondly, there is a relatively low level of congestion in the city of Lyon. Despite this modest environmental impact, the climate emergency and the need to improve urban air quality make it advisable to adopt OHDs in the LUA, since every ton of emissions reduced is a step towards improving the sustainability of urban logistics.

The second chapter proposes an *ex ante* evaluation of the environmental and economic impacts of a LEZ, applied to the case of the city of Lyon. Using an innovative and relevant methodology, we computed the economic-environmental balance over five years of four scenarios of LEZ, including the LEZ scheme already implemented by the Lyon Metropolitan authority. Our results indicate that the current LEZ scheme in the city of Lyon is the second best option because it is possible to have a LEZ scheme with a better economic-environmental balance. This is the scheme in which the perimeter of the LEZ will be extended to Greater Lyon area. However, when considering only the primary objective of the LEZ, which is to improve air quality, the current LEZ scheme is the least effective of the four LEZ scenarios studied. Indeed, on this last consideration, the scenario in which the LEZ standards are tightened while extending its perimeter to Greater Lyon will maximize air quality improvements. However, this will result in high fleet renewal costs, making this scenario less efficient from a socio-economic perspective.

The methodological approach proposed in this chapter allows, using the delivery tour as a unit of observation, an *ex ante* analysis of the impacts of LEZ with the possibility of identifying the impacts by zone and by type of vehicle. It is very useful for decision-making for at least three reasons: (i) it allows us to predict the impact of the implementation of LEZ and the contribution of the different types of vehicles; (ii) it allows us to quantify the impact of the LEZ within the perimeter concerned but also outside the targeted area; (iii) it allows us to measure the economic effort to be made by the community as a whole over a relatively long period of time after the implementation of the LEZ. Results obtained from our methodological approach allow us to

make contributions to decision making. This is illustrated, among other things, by the recommendation to the Lyon metropolitan authority to consider extending the perimeter of the LEZ to Greater Lyon as a future development of the LEZ scheme. This recommendation is based on the economic-environmental balance.

On the other hand, taking into account only the criterion of air quality improvement, we recommend an evolution of the LEZ scheme towards the scheme combining the tightening of standards and the extension of the perimeter. The scheme will be made even more attractive if the public authorities provide substantial financial support to the most vulnerable actors to enable them to bear the cost of fleet renewal. Such support is also necessary to mitigate the competitive issues related to the redistribution of market shares between private actors (large actors with high financial power vs. small ones with low financial power) when an urban logistics measure entails a substantial investment.

The advantage of our methodology is that it is very flexible. This allows to integrate a wide range of new dynamics that can appear in the urban logistics sector: an organizational change in the practices of the actors facing a new measure (e.g., transfer of transport on account to the account of third parties); a change in the environment such as the appearance of a new type of goods transport vehicle (e.g., cargo bike). This feature of our methodology offers the possibility of addressing any limitations that may have affected the results of this case study. This opens the field for interesting future research.

The third chapter analyzes the issues related to OHDs and LEZs in order to deeply understand the issues of these measures for the actors and how they integrate them into their strategy. In particular, the chapter seeks to identify the issues of these measures for groups of actors, in terms of power and competition. To do this, we used a qualitative approach, with an original methodological approach based on the theoretical framework of the political economy of channels. The working material consists of 19 interviews with different types of actors in urban logistics in LUA. The analysis of the material allowed us to identify and understand the issues of the two measures for the five strategic groups of actors identified. Results show that, beyond the aspects traditionally mentioned in the literature - cost-benefit, route optimization, profitability of activities - competitive and power issues are central to the actors' concerns.

Actors integrate the measures into their strategy as opportunities to grow or as threats to disappear, depending on whether they have high or low power respectively. For actors with high financial power, measures are perceived as opportunities to increase their market share

and power. These actors therefore do not hesitate to use their power of influence to obtain from the public authorities stricter standards or controls on the urban territory, in order to oust weaker competitors and strengthen their competitive advantages. For smaller actors with weak financial power, the measures are perceived as new constraints and threats to which they cannot always adapt. Their strategies are more defensive, and their survival is sometimes threatened. In view of this, the public authorities, at the various levels - community, national and local - must not be naive in understanding these competitive issues and play a central role in ensuring that the implementation of measures does not constitute an opportunity for predation by actors with high power on actors with low power. Playing this role also allows for better acceptability, efficiency and also equity in the implementation of measures, whether they are suggested or imposed on actors. This research has shown that actors, regardless of their level of power, are skeptical about the environmental effectiveness of measures. This tends to limit the level of adoption of the measures by the actors, especially when it is a suggested measure.

Methodological and Decision-making contributions

The hybrid approach adopted has allowed the thesis to make contributions at two levels. The first level is methodological and theoretical. The modeling chains used in chapters 1 and 2 made it possible to go beyond many previous studies. The simulation of the impacts of OHDs on a large scale, whereas most previous studies have done so on a small scale, is a significant methodological contribution to the subject. The same is true of the methodology for *ex ante* evaluation of LEZ impacts. This methodology has included the economic aspects of the LEZ, whereas most studies have been limited to the environmental aspects. In addition, the methodology relies on a detailed understanding of the characteristics of freight transport in the city, with the delivery tour as the unit of observation. This was made possible thanks to the processing of data from the exhaustive survey on UGM and the simulation tools developed within LAET, which capitalize on a long-term experience on urban logistics issues.

By identifying the strategic and competitive issues of the two measures, in addition to their traditional issues, the results of this study enrich the methodological aspects of the *ex ante* evaluation of the measures. Indeed, they allow the design of scenarios that are closer to reality and, above all, to take into account the potential reactions of actors to the measures. This improves the relevance and accuracy of *ex ante* evaluation tools and methodologies and allows for even better decision making.

At the theoretical level, the thesis mobilized the theoretical framework of the political economy of channels and integrated a socio-political component into the analysis. This original approach allowed us to highlight the relationship between the power of actors and their strategic behaviors. This allowed us to understand the strategic and competitive issues raised by the measures. These issues are rarely mentioned in the literature on the implementation of measures in urban logistics. The research also identified the concept of skepticism, which is widely shared by the actors in our sample, but which has not been highlighted in previous studies. Overall, this thesis has enriched the brief literature on: the evaluation of the impacts of OHDs deployed on a large scale; the *ex ante* evaluation of the impacts of LEZs on freight transport and taking into account economic aspects; the strategic and competitive issues raised by OHDs and LEZs for actors involved in urban logistics.

The second level of contribution lies in decision-making. The measures analyzed in this thesis are of great interest to metropolitan authorities, as evidenced by their occurrence in terms of implementation and experimentation across Europe and the Americas. For the case study of this thesis, the results of this thesis allow for recommendations to be made to the actors involved. The quantitative approach of the first two chapters allowed the identification of the best scenarios for the implementation of OHDs and LEZs. As the LEZ was implemented in January 2020, the operational recommendation focuses on the evolution of the current scheme. The analysis of the scenarios showed that an extension of the LEZ perimeter to Greater Lyon will have a greater environmental impact and for a larger population than a tightening of the standards. We therefore recommend this alternative to the Lyon metropolitan authority. The CBA results have shown the extent of the financial effort required to make the economic-environmental balance of each LEZ scheme balanced. We recommend that the public sector plays a supporting role in helping the most vulnerable actors to bring their vehicles into compliance. Such support is essential, especially since the qualitative analysis showed predatory behavior by actors with high financial power on actors with low financial power. The qualitative analysis showed a low allocation of human resources to urban logistics issues within local authorities. In view of the importance of the issues raised by this sector and of these evolutions with metropolization, we recommend that public authorities allocate more specialized human resources specifically dedicated to urban logistics issues.

For private actors, in the case of small actors, who have little power, we recommend greater participation in consultations prior to the implementation of measures so that their specificities are taken into account in the co-construction of measures. This can be done through their representative bodies (federations, trade unions), which will be able to raise the competitive

issues of the measures planned and discuss the support methods adapted to small actors. We recommend that large actors with a high degree of power use their decision-making power over their ecosystems to implement and promote virtuous behavior among their partners.

Since at the end of the urban logistics chain is the final customer, the latter can have an important role to play in the quest for sustainability in urban logistics. To do so, we recommend that they can commit to becoming aware of the close link between their consumption behavior and the negative externalities caused by urban logistics.

Limitations

A thesis is a time-limited project. This leads to make choices and be realistic in its realization. This thesis therefore has limitations linked to our choices and to the various constraints we had to face. Considering the works in the sequence in which they appear in the manuscript, without being exhaustive, here are some limitations of the thesis.

Concerning the OHDs, we have evaluated the environmental impacts without taking into account the issue of noise. The investments to be made to make silent deliveries must be evaluated and weighed against the environmental gains. In addition, there is the issue of the acceptability of the measure both by the receiving establishments and by the local residents, which has not been addressed.

Concerning the LEZ, given that the system of control of the respect of the standards is a visual system based on stickers, it is obvious that the rate of respect of the measure by the actors will be relatively weak. Therefore, we could have estimated the fraud rate and considered it in the different LEZ scenarios, since it affects the emission reduction.

In addition, we assumed that all actors were able to renew their non-compliant vehicles and that the routes remained the same. The qualitative analysis found that in reality, when faced with a LEZ, actors can make changes in their organization. If they are not able to renew their vehicles, they can: transfer own-account transport to third-party transport; reassign the cleanest vehicles to the LEZ perimeter, which will lead to a high concentration of dirty vehicles on the outskirts; introduce cargo bikes for last-mile deliveries in order to comply with LEZ standards at lower cost. All of these potential reactions are likely to challenge the results of our simulations.

With respect to the results of the qualitative analysis, it must be recognized that the exploratory nature of the research does not allow for generalization of the results. Moreover, the

measurement of the strength of the actors' powers was assessed qualitatively, based on the actors' discourse. An accurate measurement, with power measurement scales, among a large sample of urban logistics actors, could extend this research.

Future Research and Perspectives

As I conclude this thesis, further directions for research emerge from the limitations of this work. As established above, potential organizational changes are an important aspect that deserves to be considered in order to improve *ex ante* evaluations of measures. This is the focus of our future research. The flexibility of the methodologies developed in this thesis allows for these changes to be considered at various stages of the modeling process. The next tasks for this work are already being defined or started. On the one hand, from the qualitative analysis, we have drawn up a more or less exhaustive mapping of the potential reactions of the actors to the two measures. The next step is the design of scenarios integrating to varying degrees these potential reactions in the modeling of the *ex ante* evaluation of the measures' impacts.

On the other hand, the use of cargo bikes for last-mile delivery, which is increasingly observed, is also being investigated. We have already identified the tours whose profile makes them potential candidates for the use of cargo bikes. The next step will be to integrate them into the fleet to replace the vehicles that used to operate these tours and to simulate their impact in the presence of the LEZ.

Finally, the third work idea concerns the probable shift of a part of own-account transport to third-party transport. We plan to estimate the proportion of transport that is likely to be shifted. Once this is done, we can integrate this change into our freight demand simulation. This will allow us to simulate another LEZ scenario.

These are some of our future research perspectives that we are considering for the next few months. The climate emergency and injunctions from various sources are leading to the preparation of new measures within cities. This suggests that the need for tools and methodologies to evaluate the measures will remain on the research agenda. A related challenge is modeling for impact evaluation in an environment in which there will increasingly be simultaneous implementation of multiple sustainable urban logistics measures. This simultaneous implementation of measures to address the climate emergency is a trend that seems to have no return, as people are becoming increasingly aware that there is no one-size fits all measure to solve all problems.

Abstract

This thesis is part of the research agenda on the need to propose relevant tools and methodologies for the ex-ante evaluation of measures implemented to improve the sustainability of urban logistics. The thesis approaches this problem by questioning the issues and the impacts of the measures at the economic, organizational, environmental and social levels for all the actors involved in urban logistics. The research is applied to off-hours deliveries (OHDs) and low emissions zones (LEZ), with the urban area of Lyon as a case study. The thesis is made of 3 distinct papers. The first paper proposes an evaluation of the environmental impacts of a large-scale adoption of OHDs. The second paper proposes an evaluation of the economic-environmental balance of a LEZ. The third paper presents a qualitative analysis allowing to understand in depth the issues of the OHDs and the LEZ for the actors and the way they integrate these two measures in their strategy. In the first chapter, coupling several simulation tools allows us to evaluate five scenarios of OHDs according to the percentage of deliveries to be shifted from regular to off-hours. The results show that the adoption of OHDs will have a positive but modest environmental impact on the whole Lyon urban area. The results analysis shows that OHDs lead to a maximum annual reduction in external costs related to pollution of about 4.25 million euros and a saving in travel time of 2.5 million hours per year. In the second chapter, in order to evaluate the economic-environmental balance of the LEZ in Lyon, a cost-benefit analysis was performed to balance the environmental gains from pollution reduction against the costs of renewing vehicles that do not comply with the LEZ requirements. The benefits and costs were obtained through the coupling of a transport demand simulation model, a delivery route simulation model, and an emissions model, all of which were fed by processing data from urban goods movement surveys. According to the NPV criterion, the results show that the LEZ scheme implemented in the city is a second best. The socio-economic balance of this scheme can be improved by extending the LEZ perimeter to Greater Lyon. The NPV analysis shows that over the first five years of implementation, in none of the LEZ schemes investigated do the benefits of reduced pollution offset the costs of vehicle renewal. In the third chapter, the analysis of interviews with various urban logistics actors allows an in-depth understanding of the issues raised by the two measures (OHDs and LEZs) for the actors, and the way in which they integrate them into their strategy. The results show that, in addition to traditional aspects - cost-benefit, route optimization and profitability of activities - competitive issues are central to the actors' concerns: (i) the largest actors with significant *financial power* see in these measures the opportunity to increase their market share. They therefore do not hesitate to use their *power of influence* to obtain from the public authorities a tightening of the measures in the urban area, in order to oust weaker competitors with little *financial power*. (ii) for the smaller, more fragile actors, these measures are perceived as constraints and threats to which they cannot always adapt because of their weak *financial power*. Their strategies are more defensive, and their survival is sometimes threatened. (iii) public authorities, at the various levels - national and local - must not be naive in their understanding of these competitive issues and must play a central role in ensuring that the implementation of measures does not constitute an opportunity for predation by actors with high power on actors with low power.

Keywords: Sustainable urban logistics; *ex ante* impact evaluation; Off-hours deliveries; Low emissions zone.