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The Constraints of Vehicle Range and Congestion for the Use of Electric Vehicles for Urban Freight in France

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Abstract

Electric vehicle is a solution to reduce pollutant emissions from road urban freight. This paper assesses the potential CO_2 reduction by transferring urban freight from diesel to electric vehicles while simultaneously looking at the two main technical constraints: electric vehicle range and the impact on congestion linked to change diesel heavy duty vehicles (with a load up to 25 tons) to much smaller electric vehicles. The data used has been computed from a survey (ECHO) that describes in details a very large sample of French shipments. Two scenarios were set up, which differ mainly by the type of available electric vehicle: In scenario E1, the electric vehicle has a payload of 2 tons, versus 6 tons in scenario E2.
The vehicle range is not very binding for urban deliveries in our scenario, except in the Paris Urban area. The CO_2 reduction is nearly the same in the two scenarios, but the congestion is much higher in scenario E1, showing that the payload is an important issue for the generalisation of electric vehicles in urban freight.

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Keywords: Urban freight; CO_2 emissions; Electric vehicle; Simulation

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1. Introduction

Road transport is the main mode in cities. It generates negatives impacts especially congestion and pollution, so it is necessary to consider other less pollutant solutions. Indeed, the last EU White Paper on transports (2011) points out the necessity to find a transport less pollutant and to save energy resources using transport.

Considering urban mobility of people, electric private car cannot be the general solution, because private cars, electric or not, are generating congestion. In cities, the requirements for vehicle range are lower and the population density higher, what makes public transport more adapted, as well as the option of walking and cycling. According to Agenda 21 (UNCED 1992) "Transportation strategies should reduce the need for motor vehicles by favouring high-occupancy public transport and providing safe bicycle and foot paths". But, for urban freight, electric road vehicles are probably part of the solution considering the necessity to spread the deliveries all over the town. The main benefits of electric vehicles are the reductions of local pollutants and noises, which are important items in town while the reduction of greenhouse gases emissions, is generally considered only as a co-benefit, because transport CO_2 could be reduced as well in the countryside as in town. In France, electricity mainly produced from nuclear power (73.3 % in 2013), is relatively few carbonised and electric vehicles have a high potential of decarbonising the transport.

This paper assesses the potential of electric vehicle to mitigate freight transport GHG emissions in France, using scenarios of electrification or urban freight. Our objective is to estimate the maximum CO_2 mitigation that could be obtained by the electrification of urban freight and to assess in parallel two important technical problems of electric vehicles for freight: vehicle range and urban congestion.

The paper is structured as follows: The section 2 provides a review about the use of electric vehicle for urban freight. The section 3 details the data and the methodology. Finally, the section 4 defines the electric scenarios and assesses the benefits of using this type of vehicle instead of heat engine.

2. Experimentations of electric vehicle in urban freight

Cities are the places of concentration of people and activities. Among these activities, urban freight transport is an important contributor of pollutants and greenhouse gases emissions. But urban freight is necessary to provide goods to population. Public authorities can't forbid the freight, because it allows the city live. As Van Duin et al. (2013) mentioned, "urban freight transport is a necessary daily activity in and around urban areas".

Several European projects (BESTUFS 2006; SUGAR 2011, and BESTFACT ongoing) make an inventory of best practices in freight especially in urban freight. Some of these best practices are linked with electric vehicles like electrically assisted cargo-cycles or urban consolidation centres from which the deliveries are made by electric vans. These inventories show a growing interest for the electric deliveries that become more and more popular in several cities.

Several experimentations conducted in European cities are described and assessed in these EU research projects: Elcidis Urban Distribution Center with electric vehicles in La Rochelle (France), Ikone project in Stuttgart-Ludwigsburg (Germany), Distripolis in Paris (France), Cargohopper, a dedicated inner city delivery service using clean freight vehicles in Utrecht, Netherlands, Citylog EMF is a new type of electric freight vehicle developed in Austria by a consortium led by HET, Citylogistik-kbh in the historical centre of Copenhagen (Denmark), using an Urban Consolidation Centre and electric vehicles for the last mile, Txita in San Sebastián (Spain), Eco-Logis a distribution service operational in the urban area of Brescia (Italy). FREVUE (2013), an ongoing EU project, is directly on the experimentation of electric vehicles for urban deliveries and their assessment.

The results of these experimentations are much contrasted according to the situations. For example in London, a company, Office Depot, decided in 2009 to reorganise their transport plan with an urban consolidation centre and electric vehicles (vans and cargo-cycles). The assessment by the university of Westminster points out a reduction of the quantity of CO_2 emitted by parcel (-62%) and a reduction of total miles covered to deliver (-54%) (Leonardi et al., 2012); this experimentation seems to be a success, both environmentally and economically.

Why don't freight operators use more electric vehicle? Vehicle range is often mentioned as a technical constraint of electric vehicles for freight today (Morganti and Dablanc, 2013; Van Duin et al., 2013). The range allowed by the battery wouldn't be enough, for example when there is more than one round trip per day in a big city. The literature describes many experimentations of electric vehicles in urban freight but there is no real assessment of generalising the use of these electric vehicles for urban freight at national scale. If we consider a large use of battery-driven vehicles for freight, then two important problems arise: the range and the payload of these vehicles. The supply of electric vehicle types on the market is still very limited, compared with the diversified supply of diesel vehicles.

Our paper aims to quantify the potential CO_2 mitigation that could result from a general use of electric vehicle for freight transport in big French cities and, at the same time, the impact on congestion and the range issue.

3. Methodology and data

The quantification of CO_2 emissions from freight transport in details is difficult because of the lack of data. An original database, the 2004 French shippers survey (ECHO Survey) allows us to estimate CO_2 emissions of each shipment. This survey describes a sample of 3 000 French shippers and the detailed characteristics of 10 000 shipments they sent. These 10 000 transport chains (a shipment correspond to a transport chain) correspond to 20 000 legs of the transport chains. Indeed, a shipment is rarely sent directly from their departure locations to their final delivery locations. Each time the shipment change of vehicle, there is an additional leg in the corresponding transport chain.

Each of these three statistical units (shipper, shipment and transport leg) has an associated questionnaire. The design of the survey and sampling protocol are described in Guilbault and Gouvernal (2010) and Rizet et al. (2002).

For this paper, we mainly used the questionnaire about transport legs that describes the transport chain from its origin (the shipper) to its destination (the consignee). This part of survey was carried out by telephone interviews, contrary to the shipper and shipment questionnaires that were carried out by face-to-face interviews. For each transport leg of the shipment, information has been collected about the mode, vehicle type, load, origin and destination.

The ECHO survey shows road is the main transport mode for 97% of shipments in 2004. So there is a high potential for decarbonisation if we use electric vehicle. In this paper, we focused on road transport and more specifically on urban road transport due to constraints of using electric vehicles as underlined in the previous section. We define the urban areas as the French municipalities belonging to an urban unit as defined by the National Institute for Statistics and Economic Studies (INSEE). This definition takes into account the number of inhabitants and the continuity of the buildings; because of this definition, we estimated urban CO_2 emissions, only for the French municipalities. Using a French road network and this definition of urban, the urban length was calculated for each leg of the network.

4. Electrification of urban freight: definition of scenarios and results

4.1. Definition of two scenarios of electrification of urban freight

The electrification of urban freight traffic can be targeted through two main types of policies.

Regulation : a limitation of access to diesel (or to most pollutant) vehicles in specific zones ; it is the so called "Low Emission Zone" (LEZ),

A priority or other incentive given to electric vehicles or an obligation to deliver by this type of vehicle: creating urban centres of consolidation i.e. Elcidis in La Rochelle (France), rent of battery-driven vehicles i.e. Ariamia in Emilie-Romagna (Italy); in Toulouse (France) electric vehicles are authorized to deliver during the whole day whereas other vehicles have restricted time slots.

To reduce CO_2 emissions in a consequent way, it is necessary to have a strong policy toward the more emitting vehicles. For this reason, we consider here the hypothesis of an implementation of LEZs in all the big French urban areas (> 100 000 inhabitants). In these zones, the circulation of non electric trucks or vans is forbidden. At the entrance of the big urban areas, platforms are set up on the main highways and, non-electric trucks and vans have to stop in these platforms before entering the town: The freight is unloaded from Diesel trucks and vans and reloaded in electric vans or small trucks. The freight coming from the city also has to be carried on these electric vehicles, at least up to the platform where it can be reloaded on a 'normal' (Diesel) truck. Fig. 1 shows the location of these platforms for the urban area of Paris. As the whole freight going from and to this zone must go through these platforms and use electric vehicles, these electric trucks have an excellent occupancy rate (80%) and a rate of empty backhauling of only 50% of total kilometres. In order to limit congestion, an exception is done for the traffic passing through the urban area when it is circulating on motorways: Diesel heavy vehicles are allowed for this transit traffic.

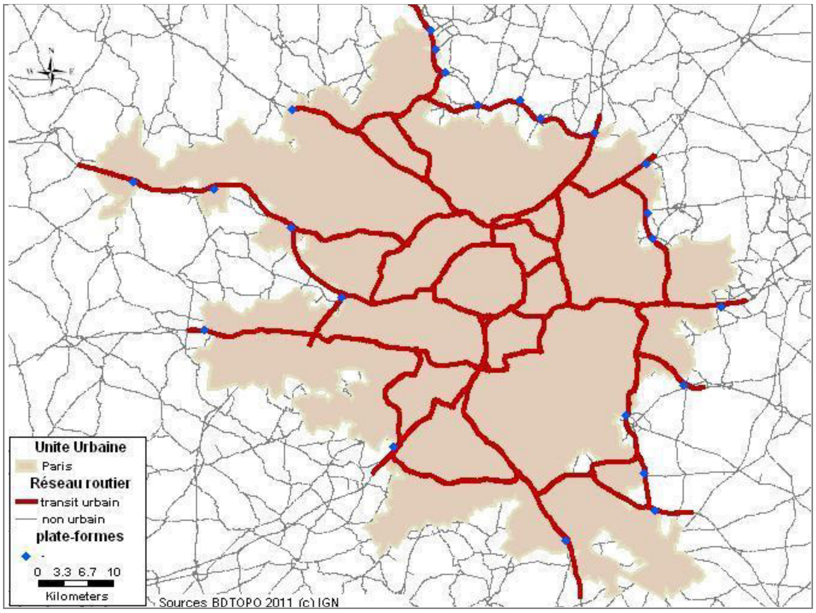

Fig. 1. Layout of the platforms around the urban area of Paris (using BDTOPO 2011© IGN)

The substitution of Diesel vehicles, which have up to 25 tons payload, by electrics vans or small truck, the capacity of which is much more limited, may quickly cause urban congestion. So, to highlight this issue, we built 2 scenarios of electrification of urban freight. These two scenarios are as follows:

- In scenario called E1, electric vehicles have a 2 tons payload which corresponds to the existing ‘Maxity’ of Renault Trucks
- In scenario called E2, electric trucks have a 6 tons of payload, which is over the capacity of commercially available trucks.

For both scenarios, when heavy shipments arrive in a platform, they are split into several electric trucks. For example a 25 t shipment needs 13 electric vehicles in scenario E1 and only 5 in scenario E2. This is why, in scenario E1, diesel trucks are authorized in urban areas for heavy shipments (20 tons and over), even if it doesn’t use a motorway, whereas in scenario E2, the only diesel trucks allowed in an urban area are the trucks transiting through the zone on a motorway. Our two scenarios of electrification of urban freight are very binding for the carriers but not so unrealistic with regard to the issue of local pollution in big towns. For example Paris is planning to forbid diesel vehicles for urban freight in a near future.

Energy consumptions and the CO_2 emissions of these electric trucks are then estimated from the data of ECHO Survey as follows: starting from "Zero Emissions Trucks" (Boer and al. 2013) who estimated consumptions of 1 kWh / km for a 10 t. truck of and 2 kWh / km for a 40 t. truck, we added a consumption supplied by Renault Truck of 0.96 kWh / km for one 16 t. and made the simplest hypothesis of a linear relation between energy consumption and weight. This linear relation between the consumption of the electric truck and its total weight is: (kWh/km) = 0.43 + 0.033 x W (ton), which gives a consumption of 0.55 kWh / km for a small truck of 3.5 t. of total authorized weight (2 t. payload) and 0.76 kWh / km for a truck of 10 t. of total authorized weight (6 t. payload).

Emissions of electric trucks are then the product of this electricity consumption by the emission factor of French electricity (53 gCO_2/kWh):

- For a 2 ton payload truck: 29 gCO_2 / truck.km or with an 80% load, 36.25 gCO_2 / tkm
- For a 6 ton payload truck: 40 gCO_2 / truck.km or with an 80% load, 8.3 gCO_2 / tkm.

These values are multiplied by 1.5 to take into account empty round trips. Thus, the emissions of one shipment on one transport leg are calculated as follows:

- For a 2 ton payload truck: 0.029 x km x 1.5 x weight of the shipment / weight of the load or
- For a 6 ton payload truck: 0.040 x km x 1.5 x weight of the shipment / weight of the load.

4.2. Calculation of the CO_2 per shipments

Starting from the French Shipper Survey (ECHO), we worked out the transport chains for the 10000 shipments of the survey, quantified the energy and CO_2 emissions. In this paper, we are using a "well-to-wheel format" to allow for comparisons between Diesel and electric vehicles but the CO_2 has also been calculated on "Kyoto format" in order to check our global emissions with the national "Kyoto" figures (Rizet et al. 2014).

We add these CO_2 emissions ($kgCO_2$ per shipment) and the corresponding carbon intensity ($kgCO_2$ per tkm) to the ECHO database. These data on the CO_2 per shipment establish a powerful tool for the detailed analysis of the freight transport emissions.

According to our estimates from this survey, CO_2 from shipments with a good carbon efficiency, i.e. emitting less than 100 g of CO_2 per tkm, only accounts for one fifth of the road freight transport emissions and CO_2 from shipments with a 'high or very high' carbon intensity (more than 600 gCO_2 / tkm) accounts for half of these emissions (Fig. 2).

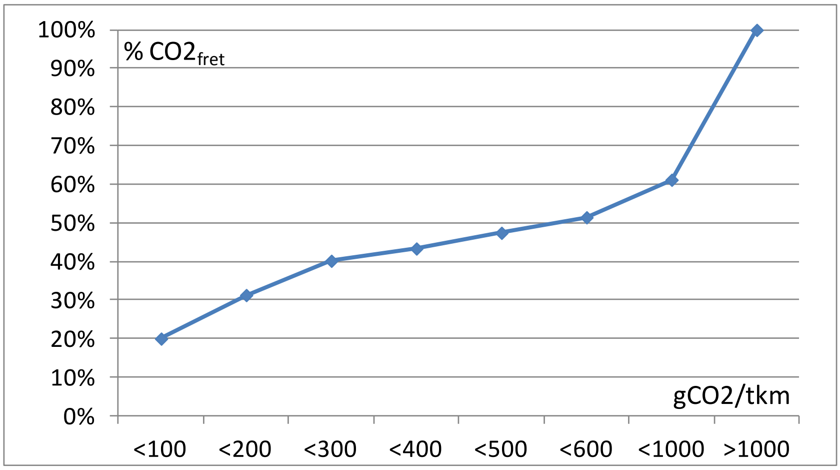

Fig. 2. Split of road transport CO_2 emissions according to the shipment carbon intensity. Source: Computed from ECHO survey, 2004

Then, using our ECHO database, the French road network with the 'urban' or 'non urban' characteristic of each leg and the 'Transcad' traffic assignment model, we estimated the urban CO_2 of each shipment (Table 1). In France mainland (and in the surveyed field), more than a quarter of road freight CO_2 (25.3%) is emitted in large urban areas of more than 100 000 inhabitants, while their surface only represents 4.3% of the French territory. Nearly half (48.8%) of these emissions are produced in all of the urban areas which represent less than one fifth of the surface of mainland France (18.9%). Electrification of the freight in the urban areas thus concerns approximately half the emissions from freight.

Table 1. Share of the urban part in the road freight CO_2 emissions

	CO2WW emissions		Surface	
	tons	%	km^2	%
France mainland	32 046 719	100	552 000	100%
All French urban areas	15 621 645	48.8	98 455	18.9%
Urban areas > 100 000 inhabitants	8 119 486	25.3	23 611	4.3%

4.3. Urban trip distances and electric vehicles range

The electric trucks range is an important limit for the electrification of urban freight: for every type of studied traffic and for the whole traffic electrified in the scenario 1, we analyzed the distribution of the traffic according to the distance of the legs. The graph below (Fig. 3) shows the distribution of the number of urban legs according to their distance and thus the proportion of these legs which could be electrified in the electric scenario, according to the maximal distance considered for electric trucks. Nearly 90% of the legs are less than 50 km long and most of the legs longer than 30 km are located in the Paris region. The figure below (Fig. 3) also shows the distribution of the urban CO_2 emissions according to this distance.

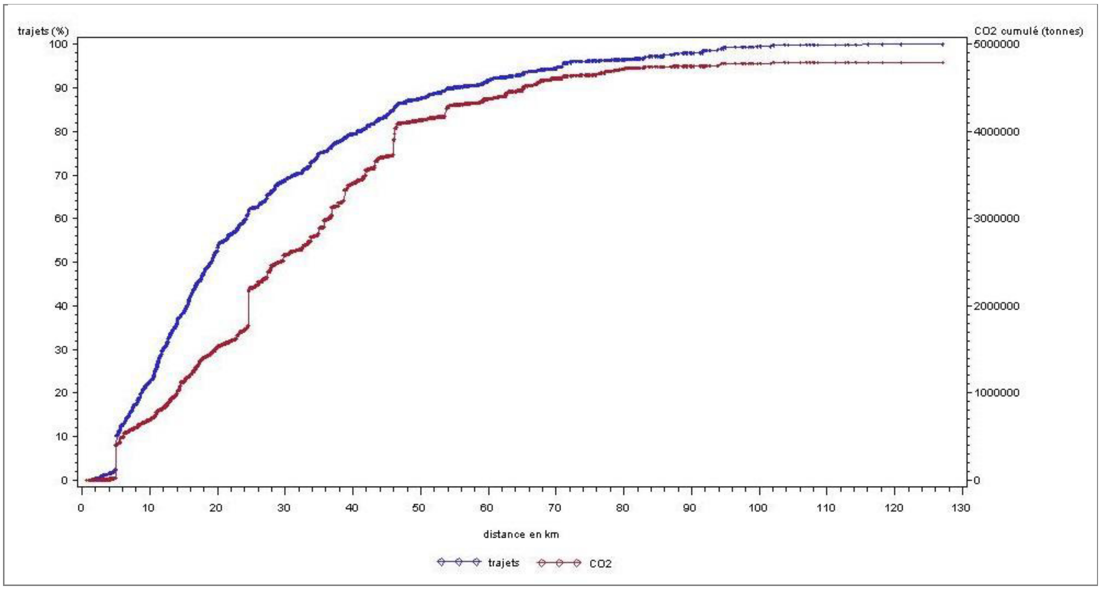

Fig. 3.Trip legs number and CO_2 distribution according to the trip leg distance.
Source: Computed from Echo Survey

The percentage of trip legs can be read on the left axis and the corresponding CO_2 emission level on the right axis: 87.6% of trip legs are less than 50 km and they emit 4,134 million tons of CO_2 that is 86% of the whole CO_2 of the urban freight in the data base. At the opposite, legs beyond 100 km only represent 0.45% of the legs and emit 0.010 million tons of CO_2. The range currently announced for electric vans (around 100 km) would thus allow covering approximately 90% of the return electric routes of our urban scenarios. For the remaining 10%, it would be advisable either to improve electric trucks range (up to approximately 140 km), or to find a way to recharge battery before ending the round trip, or still to optimize the location of platforms by agreeing to reduce the zones of limitation of the Diesel traffic of freight below urban areas.

4.4. CO_2 emissions and congestion resulting from our 'electric freight' scenarios

We assess both CO_2 emissions and congestion resulting from the use of electric vehicles for freight because the low payload of electric vehicles will add traffic in urban areas that are already congested. It is important to assess drawbacks of electrification of freight in terms of congestion.

The first scenario (E1, electric vans with a payload of 2 t) leads to a reduction of 4.0 million tons of CO_2 but the vehicles.km increases of 1.1 billion (+9%). In this first scenario the increasing urban congestion would probably not be bearable. The scenario E2 (electric vehicles with a payload of 6 t.) leads to the reduction in CO_2 emissions of 'only' 4.2 million, due to the extension of distances to avoid urban areas submitted to LEZ regulation (Table 2) and the total vehicles.km are reduced (-5%) compared with the initial situation.

Table 2. CO_2 emissions and congestion in the initial situation and in the 2 scenarios

	Initial situation	Scenario E1 (Payload 2t.)	Scenario E2 (Payload 6t.)
veh.km (billions)	41.7	42.8 (+ 3%)	39.6 (-5%)
of which v.km in urban areas >= 100 000 inhabitants	7.7	8.4 (+ 9%)	5.3 (-31%)
of which v.km in urban areas < 100 000 inhabitants	7.8	7.9 (+ 2%)	7.9 (+ 2%)
CO_2 emissions (millions of tons)	35.0	31.0 (-11%)	30.8 (-12%)
of which CO_2 in urban areas >=100 000 inhabitants	7.5	3.2 (-57%)	3.0 (-60%)
of which CO_2 in urban areas < 100 000 inhabitants	7.6	7.9 (+ 4%)	7.9 (+ 4%)

The reduction of CO_2 emissions is important in both scenarios in comparison with initial urban road emissions: -57% and -60% in the largest urban areas (> 100 000 inhabitants). This reduction within large urban areas is however limited by our hypothesis of not transferring on electric vehicles the freight transiting the city through motorways, in order not to impose an excessive number of loading and unloading. But this reduction in large urban areas is compensated by an increase in other parts of the network, including in smaller urban areas (+4% in urban areas < 100 000 inhabitants) and the resulting global CO_2 mitigation is limited to 11% (scenario E1) or 12% (E2) of the total initial road freight emissions. This reduction of CO_2 could be approximately twice as important if the electrification of the urban freight was spread to all the urban areas, including urban areas of less than 100 000 inhabitants. But in that case, the disturbance of the long-distance freight would be clearly with a clearly more important.

5. Conclusion

This analysis of CO_2 emissions of French shipments in a detailed way underlines two issues of for using electric vehicles in freight.

First, the trip length could be a constraint for the electrification of urban freight but only for a small part of it. Like in other experimentations, it is not always to do all of rounds of a day with the same electric vehicle and the same battery. The companies have to access to fast plug of refill or get another range. It is necessary for that purpose to authorities and even local authorities impulse a policy to develop infrastructures to answer well to electrification of freight. The results show that actions have to concentrate on bigger cities (more than 100 000 inhabitants) because it is in these areas that the reductions of CO_2 are the most significant. Moreover, these areas concentrate most of air quality problems and concentrate almost half of French people.

Secondly, the current payload of electric vehicles is very low and it is an important limit to generalise their use for urban freight. The electrification of freight is impossible in the present state of offer of electric vehicles. Indeed, the second scenario E2 with bigger electric trucks shows that the congestion decreases. The scenario E2, with 6 tons payload electric trucks, leads to a reduction of 31% of vehicles.km, mainly due to the high load rate of electric vehicles, linked with the obligation to unload and reload at the platforms. The congestion would benefit more than CO_2 emissions from the hypothesis of bigger electric trucks, as shown by the comparison of our 2 scenarios.

The success of these scenarios would be possible only if the cities implement binding policies to reduce the use of pollutant vehicles. Beyond the technologies and their limits, freight operators have to develop new strategies to optimise their urban organisations.

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