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Abstract

This paper seeks to assess the growing usage of bicycles and tricycles for goods movement in Paris city and the resulting savings in CO_2 emissions between 2001 and 2014. Results from a regional household survey are evaluated to estimate the growth in consumer shopping trips made via bicycle. To quantify new commercial goods movements via human-powered or electrically-assisted bicycles or cargo cycles, results from an original survey of nine couriers and delivery companies are presented. After identifying growth in cycle freight volumes and the modes by which these trips previously moved, CO_2 savings are estimated.

INTRODUCTION

To address growing environmental concerns, most current urban transport policies seek to incentivize a modal shift from polluting modes towards “clean” ones. Various policies have been implemented to increase the attractiveness of non-motorized modes that offer both environmental and health benefits compared to motorized modes. As a result, bicycles have been experiencing a revival in many countries, particularly in Europe and in North America (1, 2). It is noticeable, however, that while freight is essential to - and a by-product of - urban dynamism, policies to promote the use of human-powered vehicles rarely address goods movement.

A number of European researchers have recently examined the operations and impacts of cargo cycles for last-mile urban goods movement; however, these studies in Paris (4), London (5), and Brussels (6) have focused on individual operators. The 11-country EU-funded CycleLogistics project (7), and studies by Transport for London (8), Reihle (9), and Gruber, Kihm, and Lenz (10) have examined the broad potential for use of bicycles and tricycles for goods movement in different sectors

PROJECT OBJECTIVE

This paper focuses on the potential for bicycles to move goods and to reduce CO_2 emissions in cities. To study this, the recent evolution of the “pro-bikes” policy in Paris city and the related increase in bicycle usage for goods movement between 2001 and 2014 are examined.

While socioeconomic assessments of this Paris “pro-bikes” policy have been performed for private passenger mobility (3), no known work has focused specifically on the effects of this policy on goods movement via bicycle and related externalities.

For this study, a broad definition of goods movement is adopted, as benefits could be achieved not only by freight professionals substituting their vans or trucks with bikes or cargo-bikes, but also by households changing their mode of travel to buy goods.

PROJECT DESCRIPTION

This research paper is organized as follows. As background information, the next sub-section describes recent transportation policies implemented in Paris. We pay a special attention to bicycle and freight interventions. Next, we present our research approach aimed at assessing the evolution of bike mobility from 2001 to 2014, with a focus on shopping trips, as well as the volume of delivery and courier mileage realized in Paris using bicycles and tricycles. Later results rely on an original survey conducted with nine freight operators in the central Paris area in 2014. Finally, a tentative estimate of CO_2 savings due to increasing goods movement by bike in Paris over 2001-2014 is proposed. Given the many uncertainties impacting estimates, sensitivity analyses are also performed and discussed.

THE PARIS TRANSPORT (AND PRO-BIKES) POLICY

The Paris case is illustrative of the challenges of a modern, multi-modal city. As one of the most densely occupied areas worldwide, the city generates an impressive volume of passenger and goods movements. In 2001, around 6.3 M person trips originating in and/or destined to Paris were realized daily with the use of mechanized modes (including bicycles), and economic activity generated 300,000 daily goods movements (shipments or deliveries) (11). A sizable share of these trips are made by motor vehicles for both passengers (35% by car) and freight (90% by van or truck); however, Parisian streets are inadequate to accommodate this intensive motor vehicle use. To address the externalities resulting from motor vehicle operations and congestion, a new municipal team elected in 2001 began to actively promote passenger mode switches to public transportation and non-motorized modes.

Unlike London or Stockholm, where "pricing regulation" has been used to encourage drivers to leave their vehicles, Parisian transport policy is mainly based on "quantity regulation" (12). Urban space dedicated to cars was narrowed by approximately a third between 2001 and 2012, with resulting free space then redistributed to cleaner transport modes. An enhanced network of dedicated bus lanes was installed rapidly, with more than 10 km of lanes added between 2001 and 2003. Streetcars also returned to the city with the late 2006 opening of a new service. In addition to lane reductions, authorized traffic speeds were reduced to 30 km/h in many neighborhoods where investments in "green areas" were realized.

TABLE 1: Evolution of Travel Lane and Parking Supply

Infrastructure Type	**2003**	**2012**
Travel Lanes	**Supply (km)**	
Total bus lanes (km)	189	172
Same direction	*117*	*99*
Contra-flow	*13*	*18*
Physically separated	*59*	*55*
Total streetcar lanes (km)	0	16
Total bicycle lanes (km)	312	677
Physically separated	*43*	*180*
Striped	*95*	*79*
Contra-flow	*4*	*221*
Shared bus lanes	*118*	*159*
Others (canals, parks…)	*52*	*38*
Parking	**Supply (# spaces)**	
Car parking spaces (free and metered)	172,794	147,812
Mixed parking spaces (bicycle & motorized two-wheels)	22,212	15,700
Bicycle-only parking spaces	n/a	23,700
Bikeshare (Velíb) parking spaces	0	20,000
Total freight delivery areas	9,528	9,299
Mixed delivery areas[1]	*n/a*	*7,493*
Dedicated delivery areas	*n/a*	*1,806*

[1] Cars may park in mixed delivery spots during evening hours

Source: Authors' calculations from 2003-2012 editions of "Bilan des Déplacements" (11)

As made clear in Table 1, the bicycle network has been extensively developed, with an increase of 355 lane-kilometers between 2003 and 2012. This mileage includes both dedicated and shared facilities; nearly 60% of the growth corresponds to the 2009 opening of many roads to contra-flow bicycle traffic, and another 11% to new shared bus lanes (in which bicycles have been permitted to operate since 2001). Most of the remaining growth is in protected bicycle lanes. The number of parking places for bicycles has also jumped, with more than 20,000 additional places provided for private bikes between 2003 and 2012. Notably – and different from some other cities where there operate – electrically-assisted cargo cycles in Paris are treated as bicycles and permitted to use this infrastructure (13). As can be seen in Table 1, space for this new parking supply for bikes mainly comes from a reduced parking supply for cars.

The Paris municipality also introduced a bikeshare service (Vélib) in July 2007. To do so, a 10-year Public-Private Partnership (PPP) contract was signed with JC Decaux, a major international provider of urban equipment (public benches, bus stations) and advertising. The private company agreed to bear the initial cost of the 20,000 bikes parked in about 1,400 stations in exchange for the right to operate the service, transfer fare revenues to the municipality, and receive discounted access to more than 1,600 advertising billboards in Paris streets. While the PPP has been subject to criticism because of its high cost for public finance (3), the Vélib sharing service has met with popular success; however, as noted by Ripert and Brown (13), use of the system for goods movement has been limited by the current vehicle design.

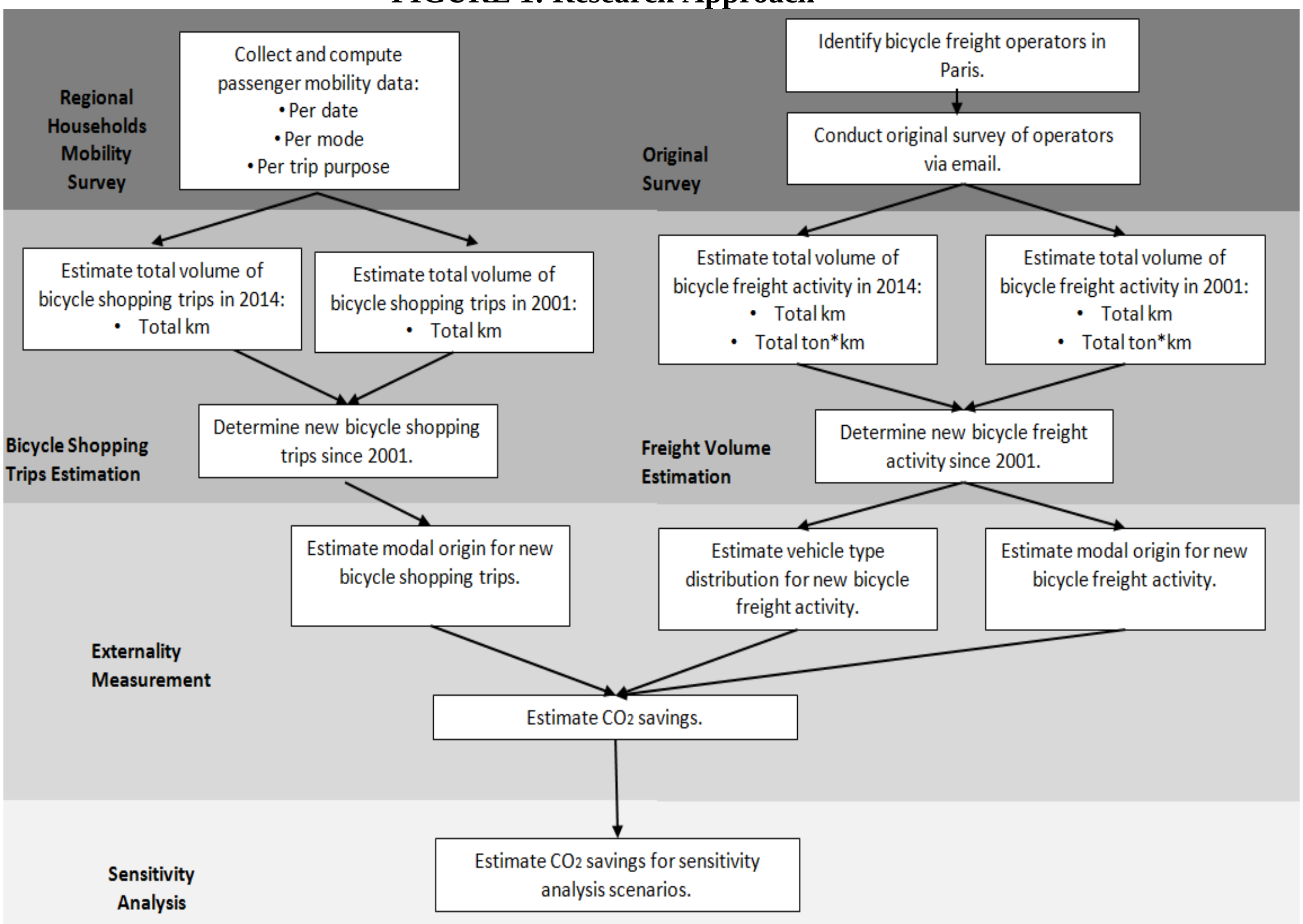
Freight policy in Paris has also undergone a major paradigm shift since 2002. With about 31.5 M tons moved each year (11), freight has a considerable footprint in the city. According to 2011 estimates by the City of Paris, freight contributes 26% of CO_2 emissions and consumes 15-25 % of road space (14). During and prior to 2001, freight was only considered in planning for its negative traffic impacts (13). As a result, new infrastructure was inadequate to accommodate freight; for example, when curbside sheltered bus lanes were installed, the need for freight loading areas was not recognized. In response to major concerns from the freight industry, formal consultation between the City of Paris and freight stakeholders began in 2002, culminating in the 2006 signing of a three-year, non-binding "Freight Charter" outlining specific commitment for 47 participating stakeholders to reduce externalities from freight and accommodate efficient freight activity. Dablanc, Diziaian, and Levifve (15) provide a detailed summary of the progression of city and regional consultations from 2002 until 2010. In 2013, building from previous efforts, a new charter was signed outlining guiding principles and defining concrete actions to be undertaken (16).

Consultations have resulted in major changes in freight regulation. Time-based restrictions were established to limit vehicle entry during specific time periods based on size and emissions performance (15). Parking disks were introduced to limit maximum loading times, and enforcement of violations has increased. While previously many loading areas could be used by either freight or passenger vehicles, new restrictions reserve use of many of these for freight vehicles only (see Table 1). New designs to accommodate freight in dedicated bus lanes have been developed (13). Requirements for new construction projects and in existing developed areas regulate the size and number of loading spaces according to the needs of adjacent businesses. To address the challenge of warehouse sprawl (17) (and related externalities), the city has also invested in "urban logistics spaces" – small areas in the central business district reserved for logistics activities that are provided to operators at a reduced rent (4). Importantly, these spaces provide a central location where goods can be transferred from trucks and vans to smaller, cleaner vehicles for last-mile delivery; at least one cargo cycle operator – La Petite Reine – has benefitted from this measure. Although it is difficult to isolate the impacts of specific policies from the effects of other market and cultural changes, as is generally done in standard cost-benefit analyses, the influence of these policies on bicycle use for goods movement can be examined by studying changes is consumer and commercial operator mode choice since 2001.

RESEARCH APPROACH

This study seeks to develop a method to evaluate the influence of Paris' efforts to promote cycling on usage of bicycles and tricycles for goods movement, and for estimating the resulting impact on CO_2 emissions. Figure 1 illustrates our research approach.

FIGURE 1: Research Approach



First, we rely on the two last waves of one extensive household mobility survey conducted in the Paris region to quantify the evolution of passenger mobility performed by bikes ("Enquête Globale Transport" (18)). At this step, we focus mainly on the private bike trips realized for shopping purposes. In order to determine modal origins of new bike trips performed in Paris to purchase goods, we rely on the study by Koning and Kopp (3) who asked directly to bikers in the Paris region which travel mode did they use before switching towards bicycles.

Then we describe an original survey conducted during the spring 2014 as part of this study to characterize and estimate goods movements by bike in Paris City in 2014 and 2001. Using this empirical material, we quantify cargo bike freight activity in Paris in both years and we identify the modes by which freight trips made by non-motorized cycles in 2014 would have moved in 2001.

Once biking for goods trips have been assessed, CO_2 emissions factors for various transport modes are presented. This enables us to propose benchmark estimates of CO_2 savings due to increasing goods movement by bikes and cargo-bikes in Paris. As the estimation methods are subject to many uncertainties, sensitivity analyses are also performed.

DATA

BIKING FOR SHOPPING

Evolution of Passenger Mobility

Assessment of the evolution of individual mobility in Paris relies on regional household surveys conducted in 2001 and in 2010 ("Enquête Globale Transport" (18)). The figures in Table 2 have been estimated by multiplying the number of daily trips realized by each mode and for each O-D pair by the average distances traveled. For passenger cars, a vehicle occupancy of 1.3 persons/vehicle was assumed.

TABLE 2: Evolution of Passenger Mobility, 2001-2010

	Distance Traveled (million pkm/day)								
	Paris-Paris			Paris-Suburbs			Total		
Mode	**2001**	**2010**	**% change**	**2001**	**2010**	**% change**	**2001**	**2010**	**% change**
All purposes									
Buses	1.3	1.33	2.3	0.73	0.66	-9.6	2.03	1.99	-2.0
Rail-based PT	4.97	6.28	26.4	24.2	36.7	51.6	29.2	43	47.3
Cars	3.19	2.1	-34.2	18.9	18	-5.1	22.1	20.1	-9.3
Motorbike	0.34	0.42	23.5	0.85	1.28	50.6	1.19	1.7	42.9
Total Bicycle	0.19	0.5	163.2	0.05	0.13	160.0	0.24	0.63	162.5
Private bicycle	*0.19*	*0.33*	*73.7*	*0.05*	*0.1*	*100.0*	*0.24*	*0.43*	*79.2*
Rental bicycle	*0*	*0.17*	*n/a*	*0*	*0.03*	*n/a*	*0*	*0.2*	*n/a*
Total	10.2	11.1	9.4	44.8	56.9	26.8	55	68	23.6
Shopping only									
Buses	0.19	0.25	31.6	0.06	0.08	33.3	0.25	0.33	32.0
Rail-based PT	0.49	0.82	67.3	1.31	2.35	79.4	1.8	3.17	76.1
Cars	0.18	0.16	-11.1	1.04	1.26	21.2	1.22	1.42	16.4
Motorbike	0.01	0.03	200.0	0.04	0.07	75.0	0.05	0.1	100.0
Total Bicycle	0.03	0.06	100.0	0.01	0.01	0.0	0.04	0.07	75.0
Private bicycle	*0.03*	*0.05*	*66.7*	*0.01*	*0.01*	*0.0*	*0.04*	*0.06*	*50.0*
Rental bicycle	*0*	*0.01*	*n/a*	*0*	*0*	*n/a*	*0*	*0.01*	*n/a*
Total	0.92	1.39	51.1	2.46	3.78	53.7	3.38	5.17	53.0

Source: Authors' calculations from "Enquête Globale Transport" (18).

Several lessons can be drawn from Table 2. First, the overall volume of person-kilometers (pkm) increased between 2001 and 2010, by 9% for Paris-Paris trips and by 27% for Paris-Suburbs trips respectively. Such an evolution is consistent with the growth of jobs and population observed in central Paris over the last decade (+4% and +11% over 1999-2008 respectively). The on-going sprawl process in Ile-de-France, as the rise of "inverse commuters" from Paris to the suburbs, also explains why the growth is more pronounced for longer connections. Results indicate that the "anti-car" policy was successful; due to reduced door-to-door traffic speed, the Paris-Paris pkm performed by cars has decreased by 34% while the Paris-Suburbs journeys fell by 5%. In 2010, cars represent a smaller 30% of the pkm related to Paris city.

While bus infrastructure improvements coincided with a moderate patronage increase (+2%), rail public transit (PT) has received most of the modal shift from cars, especially for Paris-Suburbs pkm (+50% vs. +26% for trips within Paris). Also, an impressive increase of the motorized two-wheel usage is observed, especially for Paris-Suburbs trips (+51%). Policies implemented to encourage bicycling also appear to have been highly effective; the number of pkm realized with bikes grew by 160% between 2001 and 2010, with private bikes used for twice as much mileage as bikeshare vehicles. While such a modal evolution is impressive, bicycle travel as a share of total mobility is still very small; in 2010, only 1% of the Paris daily pkm was completed by bicycle.

Evolution of Shopping Mobility

Shopping trips represent 7.6% of the total pkm related to Paris city in 2010. By mode, the share of trips for shopping purposes varies from 5.9% for motorized two-wheels to 16.6% for buses. Importantly, around 11% of the total pkm driven by bicycles in 2010 were for shopping purposes. This seems logical; bikes, like buses, are often used for short distance trips, and much shopping is completed close to home. This is especially true in Paris where the density of shopping places is high (>55,000 retail shops). As noted in Table 2, most bicycle pkm for shopping is completed via private bikes rather than by shared bikes.

Examining the evolution of travel for shopping, we find tremendous growth (53%) in total distance traveled between 2001 and 2010; however, this average increase hides several different trends. The highest growth is observed for motorized two-wheels, whose volume of shopping pkm has doubled. Shopping travels by bus increased by only 32% while rail PT pkm increased by 76%. Importantly, the same growth rate is observed for bikes. Even if this mode supports only a small fraction of the total Paris mobility realized to buy goods (1.4% in 2010), this mode shift produces positive impacts. For Paris-Suburb trips, shopping travel by car increased by 16%, while bike pkm remained constant.

Some uncertainty in calculation of the increase of 30,000 daily bicycle pkm for shopping trips should be noted. It is possible that some observed growth is "artificial" due to a change in design of the household mobility survey between 2001 and 2010. In the 2001 survey, the Ile-de-France region was divided into 17 zones; in 2010, the number of zones increased to 108. Since intra-zonal trips were not well informed within the 2001 survey, such a design change means that short-distance mobility estimates are improved in 2010. Due to the reduced size of interview zones, the latest version of the survey also considers more accurately the trips between adjacent zones; as a consequence, the estimated volume of short trips is expected to increase, notably for shopping trips that are essentially intra-zonal and/or between close locations. However, it is noticeable that the 75% growth of the pkm biked for shopping is lower than the total change measured for all purposes (+160%). Despite this uncertainty, the 30,000 pmk is assumed to be correct for benchmark scenario calculation of CO_2 savings.

Emissions calculations must also rely on some discretionary assumptions. Estimated savings are sought for the period between 2001 and 2014; however, mobility data is unavailable for 2013 and 2014. Since bike mobility was almost stable between 2010 and 2012, i.e. the last date for which municipal statistics are available, the 2010 figures are considered as relevant for 2014. Next, this growth in bicycle mileage must be distributed with respect to modal origins of passengers. First, it should be noted that a share of the current pkm realized by bikes corresponds to past walking trips as well as to a new demand "induced" by changes in population, jobs, and available commodities in Paris. Importantly, these pkm did not produce CO_2 in 2001. Using field survey data, Koning and Kopp (3) have shown that 10% of the new pkm performed in Paris over 2010-2006 used to be walked and that around 15% of the new pkm correspond to an induced demand. Because these authors were interested in the evolution of total bike mobility, and not only shopping trips, the benchmark case in this study assumes a higher rate of substitution for previously walked trips (20% of shopping bicycle trips). After subtracting the estimated mileage for previously walked trips and the 15% percent of mileage assumed to be induced demand, 19,500 pkm/day remain to be distributed across other (polluting) modes.

As made clear in Table 2, buses and cars have experienced lower growth rates of shopping pkm than the average (+32% and +16% respectively vs. +53%); as such they constitute obvious candidates for substituted mileage. Koning and Kopp (3) show that the majority of new bikers in Paris (50%) used to travel by subway, and that the shift from buses to bikes in Paris (18%) is about four times larger than that from cars (5%). However, as subways are mainly used for long-distance trips, the share of shopping pkm previously completed by subway travel is likely lower. Considering these findings, the benchmark scenario assumes that 10% of the 19,500 remaining pkm were performed by cars (1,950 pkm), 50% by buses (9,750) and 40% by subways (7,800). Such a choice can be justified by the fact that shopping trips are essentially short-distance and that buses in Paris are mainly used for this kind of short-range mobility.

As benchmark calculations rely on a number of assumptions, it is clear that they suffer many uncertainties. To address these, alternate scenarios are tested against this benchmark. The first alternate scenario (Table 4) assumes a lower growth rate of shopping pkm, equal to 40% over 2001-2010 (instead of 75%). Starting from 2010 pkm and using the same partitioning method as above, estimated modal shifts from buses, cars and subways are equal to 6,500 pkm/day, 1,300 pkm/day and 5,200 pkm/day respectively. The second scenario considers that 65% of the new 30,000 shopping pkm - net of walking and induced trips - were previously traveled by subways, 5% by cars and 30% by buses. Modal shifts from buses, cars and subways then amount to 5,850 pkm/day, 975 pkm/day and 12,675 pkm/day respectively.

BIKING FOR FREIGHT

Assessing the evolution of commercial freight mobility in Paris - especially that performed by bikes and/or cargo-bikes - is difficult given a lack of available data. While results from a new comprehensive freight survey are expected this year, the most recently published demand estimates date from 1997, when freight volumes moved by bicycle were negligible. As discussed above, these data indicate that in 1997, around 90% of the freight volume moved in Paris was carried by vans or trucks, 7% by boats, and 3% by railways (11).

To address this data gap, an original survey was conducted during the spring of 2014 to assess freight activities using bikes in Paris. First, an internet search was conducted to identify businesses providing delivery and/or courier services by bicycle – two wheeled vehicles with little on-board capacity - and/or cargo-bikes – which include both bicycles and tricycles that are built to carry larger volumes of goods. Either vehicle type may or may not be equipped with an electric-assist motor. Delivery services are distinguished from courier services in that they move goods from a storage facility rather than directly from an origin to a destination. Importantly, search results exclude individual companies, such as supermarkets or restaurants, that may perform business-to-customer (B2C) deliveries via bicycle; they include only companies providing courier or delivery services to multiple customers. Interviews were also conducted with professionals familiar with the sector to ensure that all "players" were included. In total, 15 relevant companies were identified; of these, nine agreed to complete a survey via email. The nine participants included: Coursier.fr, La Petite Reine, Novea SAS, La Poste (the French postal service), Urban Cycle, SCS Dragonet, The Green Link, Team Distribution Logistique, and Vert Chez Vous. Table 3 provides a summary of survey results.

A large majority of the participating companies perform delivery services (89%) and a third of companies perform both delivery and courier services. Notably, 78% of participants use other modes in addition to bikes. Nevertheless, freight services by bikes represent an average turnover of 2.2 M euros/year (54% of total firms' revenues). On average (excluding La Poste, whose operations differ considerably), these businesses serve 226 clients and employ 53 individuals, including 25 bicycle or cargo cycle drivers. The majority of firms within the sample (5) use either standard bikes (whose average maximum load reaches 22 kg) or electric cargo-bikes (205 kg); electrically-assisted bicycles are negligible (only 1 firm owns this type of vehicle). These vehicles are mainly used to move mail (53%) or material goods (31%), primarily within Paris (88% of trips). Each bicycle or cargo-bike operator performs about seven tours per day corresponding to 27 movements (8 shipments and 19 deliveries), with an average individual weight of 8 kilograms. Tour distances average 12 kilometers driven over a tour duration of 2 hours. Reflecting variability in the size and maturity of the participating companies and their willingness to answer individual questions, it should be noted that these delivery and tour characteristic estimates are non-weighted averages, and that across the sample, large standard deviations not presented here can be observed. Consequently, the following calculations rely directly on individual responses.

Freight Activity Estimation

To measure the importance of freight activities realized thanks to bikes in Paris in 2014, two indicators can be calculated. First, $TotKm$ represents the total distance traveled by bikes to move goods. Summing the results found for all firms i, $TotKm$ is the product of the number of bikers per firm ($Nbiker_i$), the number of daily tours per biker ($Ntour_i$) and the average distance per tour ($Dtour_i$):

$$TotKm = \sum_i Nbiker_i \times Ntour_i \times Dtour_i \quad (1)$$

The second indicator, expressed in ton*kilometers (tkm) corresponds to the total weight of goods carried by bikes in Paris multiplied by the total distances traveled. In order to find $TotWKm$, the number of movements per tour ($Nmouv_i$) and the average weight of a single movement ($Wmouv_i$) must additionally be considered:

$$TotWKm = \sum_i Nbiker_i \times Ntour_i \times Dtour_i \times Nmouv_i \times Wmouv_i \quad (2)$$

TABLE 3: Survey Descriptive Statistics

Variables	Responses	
Company Characteristics	**Share of Responses**	**No. of Responses**
Delivery services	89%	9
Courier services	44%	9
Both services	33%	9
Operating bike-only freight services	22%	9
Operated bike services in 2001	22%	9
Average turnover from bikes	2.2 M euros/year	6
Share of turnover from bikes	54%	4
Previous modes used		
Previously used motorized two-wheels	28%	6
Previously used vans	64%	6
Previously used trucks	8%	6
Operating Characteristics	**Mean**	**No. of Responses**
Number of clients	226	7
Number of employees	53	8
Number of employees performing bike deliveries	25	8
Number of tours/biker/day	7	8
Number of shipments/tour	8	9
Number of deliveries/tour	19	9
Total distance/tour	12 km	9
Total time/tour	2 hr	9
Paris-Paris connections	88%	8
Paris-Suburbs connections	8%	8
Suburbs-Suburbs connections	4%	8
Fleet characteristics		
Standard bicycles	20	9
Number of electric bicycles	7	9
Number of cargo-bikes	0	9
Number of electric cargo-bikes	19	9
Load characteristics		
Maximum bicycle load	22 kg	5
Maximum electric bicycle load	50 kg	1
Maximum cargo bike load	n/a	n/a
Maximum electric cargo bike load	205 kg	5
Mean load per movement	8 kg	8
Commodities		
Share of mail/parcels	56%	8
Share of food	13%	8
Share of other material goods	31%	8

The $TotKm$ indicator can be calculated with rather good precision thanks to the answers of the nine responding firms. Summing the results of individual companies, a total of 10,816 km daily driven by bikes for freight activities is found. This figure is not negligible; accounting only for nine businesses (of a total of 15 identified), it is equivalent to about 15% of the total bicycle pkm (70,000 pkm in 2014 in the benchmark case) performed by individuals for shopping purposes in Paris.

Concerning the second indicator ($TotWKm$), robust information on the weight of individual movements is unfortunately missing for the biggest participating firm, the French Postal service. Nevertheless, a tentative estimate can be proposed. According to the survey, Postal service employees complete around 300 bike tours (of 6 km) in Paris every day, with 1,500 households receiving mail during a tour and 20 additional movements (5 shipments and 15 deliveries per tour with an average price of 5.5 euros, i.e. 0.25 kg). Assuming that each mail weighs 20 grams and that each household receives two pieces of mail per day, a Postal service driver carries about 65 kilograms per tour. Summing results found for each individual firm, $TotWKm$ is equal to 691 tkm per day in 2014. This represents about 105 tons moved by bikes in Paris everyday (by the nine participating firms).

To examine CO_2 impacts, the distribution of $TotWKm$ with respect to the type of vehicle used is needed. Standard bikes generate no CO_2 emissions; electric cargo bikes do generate some emissions, even in France where the electricity is mainly produced with nuclear power, since energy is required for their operation. Assuming for each firm that the ratio of goods moved via each vehicle type is equivalent to the ratio of maximum vehicle capacities, and multiplying this load by the firm's average distance traveled, an estimated 60% of $TotWKm$ relies on the usage of electric cargo-bikes, 34% on standard bikes and only 6% on electric bikes. For the sake of simplicity in CO_2 calculations, the latter movements are included with those performed by electric cargo-bikes.

Since only nine firms responded to the survey, results do not directly describe the total freight activities performed by bikes in Paris. Assuming that the six remaining companies have a similar level of activity to those surveyed, benchmark performance measures can be estimated - $TotKm$ equal to 18,027 km/day (26% of the pkm driven by bikes for shopping purposes) and $TotWKm$ equal to 1,152 tkm/day (175 tons moved by bikes, which would correspond to 0.15% of total daily tonnage for Paris). To estimate CO_2 savings, the distribution between standard bikes and electric cargo-bikes calculated previously can be applied to these results. However, as for the passenger mobility, these results are subject to uncertainties. As a consequence, scenario 3 considers that the six remaining firms move 25% more goods than those surveyed. By contrast, scenario 4 assumes that the missing firms have a 25% lower level of activities.

Discussion of the 2001-2014 Evolution

In order to calculate the CO_2 savings due to the increased usage of bikes to move goods in Paris, the additional km and tkm realized in 2014 compared to 2001 must be estimated and the modal origin of transferred trips identified. Table 3 illustrates that only two surveyed firms - the French Postal services and Urban Cycle - operated bike services in 2001; none of the remaining participants and none of the businesses who did not participate in the survey used bikes or cargo cycles in 2001.

To estimate savings, the 2001 level of freight activities using bikes must first be estimated from survey results. For Urban Cycle, the necessary information to directly calculate distance traveled and tkm carried in 2001 was identified through the survey. For the French Postal service, information was available only about the evolution of the vehicle fleet, whose load capacity has increased by 23%. For the sake of simplicity, this growth rate is applied to the km-tkm found for 2014. Doing so - and summing results for Urban Cycle and the Postal services - the $TotKm$ and $TotWKm$ are estimated to equal to 1,763 km/day and 125 tkm/day respectively in 2001. Therefore, these calculations suggest that the freight activities using bikes in Paris have dramatically increased since 2001. Total km traveled increased by a factor of about 10. The $TotWKm$ indicator has been multiplied by a factor of 9.2.

The last step of the freight analysis concerns the modal origins of the km and tkm that were not previously realized by bikes. First, 10% of the increase observed over the period (1,662 km/103 tkm) is assumed to be linked to the growth of population and jobs in Paris during the last decade. To allocate the remaining km and tkm across past modes, firms' individual answers are directly considered; tkm are allocated using stated percentages of past trips performed with motorized two-wheels, cars, or trucks. When this information is unavailable, notably for the six firms that did not take part in the survey, the averages presented in Table 3 are applied. Finally, tmk of previous modes is estimated; 5,876 km/202 tkm used to be moved by motorized two-wheels in 2001, 7,880 km/664 tkm by vans and 882 km/58 tkm by trucks. Sensitivity analyses are adjusted with respect to these modal origins.

CO_2 EMISSIONS FACTORS

Having estimated the total distance traveled, tkm carried, and share of trips carried by each previous mode, the volume of CO_2 saved daily by the growing usage of bikes to move goods in Paris can be calculated. Since savings rely on changes in mobility, the 2001 level of bike usage is not reproduced in Table 4. Because information on the weight of goods moved by private passengers during their shopping trips is unavailable, calculations rely on pkm measures in that case; by contrast, the analysis of freight activities is based on tkm figures.

Several official reports propose pollutant parameters to estimate CO_2 emissions generated by private passenger mobility in France; estimates here rely on factors from the French Agency for Environment and Energy Management (ADEME) (19). These estimates focus only on the CO_2 generated during vehicle operations, not on the emissions linked to the production/recycling of vehicles and/or the provision of energy. Emissions factors for freight vehicles are taken from another ADEME publication (20) in which parameters are expressed in tkm considering average load factors for vans and trucks. Since these emissions parameters were first expressed in gCarbon/tkm, they have been converted into a gCO_2/tkm unit. Unfortunately, this publication (20) only presents a parameter expressed in gCarbon/km for the motorized two-wheels (33 g Carbon/km). As a consequence, an average weight of 30 kilograms (0.03 ton) is assumed for the goods moved by motorized two-wheels in Paris, resulting in one (theoretical) pollutant parameter equal to 4033.3 gCO_2/tkm.

As already stressed, the analysis should carefully consider the energy efficiency of electric cargo-bikes. These vehicles indirectly generate some CO_2 via their consumption of electricity. CITEPA (21) proposes average emissions of 56.8 gCO_2/kWh for electricity production in France. It is much more complicated to find reliable figures for the energy efficiency of electric cargo-bikes. To develop an estimate, manufacturer's product descriptions for 11 different commercially available cycles were examined; based on findings from this web-based review, electric cargo-bike batteries were estimated to stock an average of 375 Wh for a mean autonomy of 42 km. Thus a parameter of 112 km/kWh – or 0.507 gCO_2/km - can be deduced. Finally, survey results suggest that around 150 kilograms (0.15 ton) are moved by electric cargo-bikes during a tour, resulting in an energy efficiency parameter of 3.4 gCO_2/tkm.

ANALYSIS AND RESULTS

Crossing the emission parameters with the mode shift figures, an estimated 3.5 tons of CO_2 are found to be avoided daily in the benchmark case due to the increased usage of bikes and cargo-bikes to move goods in Paris. The greatest change is linked to the reduced number of tkm realized with vans over 2001-2014 (-910 kg CO2/day), and the next from motorized two-wheels (-815 kg). Savings from past trucks movements are moderate (-50 kg) due to the low share of deliveries/shipments that used this mode in 2001. The CO_2 emissions linked to the energy consumption of electric cargo-bikes is almost negligible, around 2.6 kg/day. Importantly, individuals' modal changes for shopping purposes represent 49% of the total CO_2 savings estimated. Such a result consequently highlights that commercial operators are not the sole "freight" polluters in cities and that inhabitants can also change their habits to enjoy a "greener" environment. For individual shoppers, savings are greatest from the reduced usage of buses (-1.2 tons CO2/day), and from less car traffic for shopping purpose (-402 kg/day).

TABLE 4: Estimates of Daily CO_2 savings

	Emissions Rate[1]	Scenario					
		Benchmark	1	2	3	4	5
Passenger Mode	**CO_2 (g/pkm)**	**Distance Traveled (pkm)**					
Bicycle	0	30,000	20,000	30,000	30,000	30,000	30,000
New	0	4,500	3,000	4,500	4,500	4,500	4,500
From Walking	0	-6,000	-4,000	-6,000	-6,000	-6,000	-6,000
From Car	206	-1,950	-1,300	-975	-1,950	-1,950	-975
From Bus	129.7	-9,750	-6,500	-5,850	-9,750	-9,750	-5,850
From Subway	3.3	-7,800	-5,200	-12,675	-7,800	-7,800	-12,675
Freight Mode	**CO_2 (g/tkm)**	**Ton*Kilometers Carried (tkm)**					
Bicycle	0	391	391	391	419	363	363
Electric cargo-bike[2]	3.42	760	760	760	814	706	706
New	0	103	103	103	110	96	96
From Motorized 2-wheel	4033.3	-202	-202	-202	-216	-188	-188
From Van	1371.3	-664	-664	-664	-711	-617	-617
From Truck	865.3	-58	-58	-58	-62	-58	-58
Total CO_2 Savings (tons/day)		3.5	2.9	2.8	3.6	3.3	2.6

1 Source: Modal emissions rates from Ademe (19, 20)

2 Emissions rate estimated from authors' review of commercially available cargo bikes

As already stressed, these calculations suffer many uncertainties. The benchmark logically has to be tested against alternative scenarios. Table 4 illustrates that the overall CO_2 savings do not depend excessively on the working assumptions. For alternate scenarios, the decreases in CO_2 emissions range from 2.8 tons/day to 3.6 tons/day. Scenario 5 combines the worst scenarios for individual passengers (Scenario 2) and for freight activities (Scenario 4); in this (most conservative) case, the CO_2 savings amount to 2.6 tons/day.

To put these results in perspective, annual savings can be estimated; assuming 300 businesses days/year, yearly CO_2 savings total 1,039 tons. Such a change appears moderate; applying the "official" value of CO_2 in France (40 euros/ton), the monetized social benefit resulting from the growing usage of bikes to move goods in Paris only amounts to 42,600 euros. However, results seem to be of greater importance if the CO_2 emissions linked to the individual mobility realized for shopping purposes (see Table 2) are considered; the 3.5 tons saved every day thanks to bikes or cargo-bikes represent around 30% of the CO_2 emitted by these trips made by subways (10.5 tons/day) or motorized two-wheels (12 tons/day). Clearly, this evolution is not negligible and deserves attention from policy makers, shippers, and Paris inhabitants whose habits could adapt towards a more sustainable city.

CONCLUSIONS

This research has focused on the CO_2 savings resulting from the increased usage of bikes and cargo-bikes for goods movement in Paris city. Despite data limitations and related uncertainties, the results from this study indicate that CO_2 savings from goods movement via bicycle are considerable, and that bicycle freight should be explicitly considered by local decision-makers when developing policies to encourage non-motorized travel.

The policies implemented over the last decade to restrict car traffic in Paris city have been highly effective, producing massive modal shifts, particularly towards bikes, whose usage for shopping and for moving goods increased by 75% between 2001 and 2014. Results from an original survey conducted in 2014 with nine freight businesses indicate that bikes and cargo-bikes are being increasingly used to ship and to deliver goods in the Paris area. Whereas only two firms moving 125 tkm daily conducted courier and delivery services by bikes in 2001, 15 firms that move about 175 tons per day over 1,152 tkm are now operating in that sector. Linking these evolutions to their modal origins, CO_2 emissions savings of 3.5 tons per day, or 1,040 tons per year, are estimated between 2001 and 2014.

About half of this environmental gain is due to the mobility of individuals for shopping purposes. This conclusion stresses that freight professionals are not the only economic actors whose goods movements contribute to cities' pollution, and indicates that policy makers should also target households when trying to modify freight travel behavior. Considering that the majority of shopping pkm is completed using personal vehicles rather than bikeshare vehicles, one example of greater consideration for freight movement in bicycle policy might be the inclusion of freight-carrying vehicles in bikeshare programs. Results also indicate that commercial operators in the sector rely heavily on electrically-assisted cargo cycles, which support around 60% of the tkm carried out by bikes. This is an important consideration for cities seeking to regulate the operations of and infrastructure used by this vehicle type.

While this study has focused on quantifying growth in the use of cycles for freight, a number of related areas warrant further exploration. Some areas of research need include understanding the factors that drive consumer and customer mode choices, understanding the costs associated with cycle freight supply chains, and understanding the price competitiveness of cycle freight compared to motorized alternatives. To address data uncertainties, estimates employed in this study should be compared with the findings from Paris' recent comprehensive freight survey, which are expected to be released later this year. Since this study does not consider bike deliveries by supermarkets and restaurants in Paris, results likely underestimate total CO_2 savings; future studies should include this type of B2C service. Future works should also examine not only the CO_2 benefits estimated in this study, but also the broader social and economic impacts of increasing goods movements by bicycle, including but not limited to local pollutants, noise, and time (through reduced car congestion). Recognizing the wide breadth of impacts, ultimately a comprehensive socio-economic appraisal should be undertaken to determine the true responsibility of the public policy within the observed changes.

REFERENCES

1. Pucher, J., R. Buehler, and M. Seinen. Bicycling Renaissance in North America? An Update and Re-Assessment of Cycling Trends and Policies. *Transportation Research Part A: Policy and Practice*, Vol. 45, No. 6, 2011, pp. 451-475
2. Pucher, J., and R. Buehler. Making Cycling Irresistible: Lessons from the Netherlands, Denmark, and Germany. *Transport Reviews*, Vol. 28, No. 4, 2008, pp.495-528.
3. Koning, M. and P. Kopp. Are Bicycles Good for Paris? *Journal of Transportation Economics*, Vol.41, n°3, pp. 399-434.
4. Dablanc, L. *Transferability of Urban Logistics Concepts and Practices from a Worldwide Perspective - Deliverable 3.1 - Urban Logistics Practices – Paris Case Study*. Prepared for the European Commission. Lisbon: TURBLOG Consortium.
5. Browne, M., J. Allen, and J. Leonardi. Evaluating the Use of an Urban Consolidation Centre and Electric Vehicles in Central London. *IATSS Research*, Vol. 35, 2011. pp. 1-6.
6. Kok, M., Macharis, C., and Verlinde, S. *Mobile Depot for Last-Mile Deliveries and Pick-ups*. From STRAIGHTSOL Website. http://www.straightsol.eu/demonstration_B.htm. Accessed June 1, 2014.
7. Barber, E. and G. Wood. D2.3 Feasibility study; screening of business to business and business to customer deliveries. CycleLogistics Project Website. http://cyclelogistics.eu/docs/119/d2_3_business_to_business_business_to_customer_v_2_Sept2013.pdf. Accessed June 1, 2014.
8. *Cycle Freight in London - A Scoping Study.* Transport for London, 2009. https://www.tfl.gov.uk/cdn/static/cms/documents/cycle-as-freight-may-2009.pdf. Accessed June 1, 2014.
9. Riehle, E. (2012). Das Lastenfahrrad als Transportmittel für städtischen Wirtschaftsverkehr. Eine Untersuchung europäischer Beispiele zur Abschätzung von Rahmenbedingungen und Potenzialen für deutsche Städte. Master's Thesis, Technical University, Dortmund, 2012.

10. Gruber, J., A. Kihm, and B. Lenz. A new vehicle for urban freight? An Ex-Ante Evaluation of Electric Cargo Bikes in Courier Services. *Research in Transportation Business & Management*, In Press.
11. Le Bilan des Déplacements a Paris en 2001-2012. City of Paris. http://www.paris.fr/pratique/deplacements-voirie/dossier/bilan-des-deplacements-a-paris/rub_7096_dossier_103374_port_16333. Accessed June 1, 2014.
12. Prud'homme. R. and P. Kopp. Worse than a Congestion Charge: Paris Traffic Restrain Policy." In *Road Congestion Pricing in Europe: Implications for the United States*. H. Richardson and C. Bae (ed.). Edward and Elgar Publishing, Northampton, MA, 2008, pp. 252-272.
13. Ripert, C. and M. Browne. La DeMarche Exemplaire de Paris Pour le Transport de Marchandises en Ville. *Les Cahiers Scientifiques du Transport*, No. 55, 2009. pp. 39-62.
14. Salzenstien, Bernard. City of Paris Freight Policy. Presented at SUGAR Project Meeting, Palma de Mallorca, Spain, September 22, 2011.
15. Dablanc, L., D. Diziain, and H. Levifve. Urban Freight Consultations in the Paris Region. *European Transport Research Review*, Vol. 3, 2011. p. 47–57.
16. *Charte en faveur d'une logistique urbaine durable*. City of Paris, September 18, 2013.
17. Dablanc, L., and Rakotonarivo, D. The Impacts of Logistics Sprawl: How Does the Location of Parcel Transport Terminals Affect the Energy Efficiency of Gods Movements in Paris and What Can We Do about It? *Procedia - Social and Behavioral Sciences*, Vol. 2, 2010. pp. 6087-6096.
18. *Enquete globale de transport*. Regional and Interdepartmental Directorate of Public Works and Planning, Île-de-France, 2001-2010.
19. *Les Chiffres Cles 2013 Climat, Air, et Energie*. French Agency for Environment and Energy Management (ADEME), 2013.
20. *Guide des Facteurs D'Emissions – Version 6.1 - Chapitre 4: Prise en Compte des Transports.* French Agency for Environment and Energy Management (ADEME), June 2010.
21. *Inventaire des Emissions de Polluants Atmospheriques et de Gaz a Effet de Serre en France – Series sectorielles et Analyses Etendues*. Interprofessional Technical Centre for the Study of Atmospheric Pollution (CITEPA), French Ministry of Ecology, Sustainable Development and Energy, April 2010.

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