IMPACTS OF CARSHARING ON URBAN MOBILITY: ENVIRONMENTAL AND BEHAVIOURAL EVIDENCES

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TRÉPANIER, Martin
Polytechnique Montréal, dept. Mathematics and Industrial Engineering
2900, boul. Édouard-Montpetit, Montréal, QC, Canada, H3T 1J4
mtrepanier@polymtl.ca

MORENCY, Castherine
Polytechnique Montréal, dept. of civil, geological and mining engineering
2900, boul. Édouard-Montpetit, Montréal, QC, Canada, H3T 1J4
cmorency@polymtl.ca

NOURI, Pegah
Polytechnique Montréal, dept. of civil, geological and mining engineering
2900, boul. Édouard-Montpetit, Montréal, QC, Canada, H3T 1J4
pegah.nouri@polymtl.ca

BRAHAM, Amira
Polytechnique Montréal, dept. Mathematics and Industrial Engineering
2900, boul. Édouard-Montpetit, Montréal, QC, Canada, H3T 1J4
amira.braham@polymtl.ca

ABSTRACT

The climate change and global warming is one of the major issues of the 21th century, greenhouse gases being the main factor. Among various industries, transportation has the highest share of greenhouse gas (GHG) emission. Carsharing as a mode choice could contribute to the environmental performance of transportation industries. In this study, the effect of carsharing system has been examined using the Quebec's carsharing system "*Communauto*". The results of this study confirm the positive environmental performance of the system to reduce GHG emission both by inducing a reduction in kilometers travelled and providing more fuel efficient vehicles for them. Also, the mobility behaviour of the carsharing users according to their age, gender, time of the month and week is demonstrated.
Keywords: carsharing, GHG emission, sustainability, travel behaviour

INTRODUCTION

In the context of global economic uncertainty that widely threatens the habitats of metropolitan areas, finding an alternative to private car ownership is a very interesting avenue to healthier neighbourhoods and individual, family and institutional finances. Carsharing has become more and more popular since the service was introduced for the first time in the late 1940s. Ever since, it has expanded in more than 1100 cities in 26 countries. Now more than a million users across the globe use carsharing service as a mainstream transportation mode, especially in urban areas where other alternatives are also easily accessible (Shaheen & Cohen, 2012; Shaheen, Cohen, & Roberts, 2006). In most studies the comparison of users' travel behaviour before and after implementation of service shows significant environmental improvements. Research show that carsharing can reduce greenhouse gases (GHG) emissions by decreasing personal vehicle millage and providing more fuel efficient vehicles. In this study we compare the behaviour of users before and after subscribing to the carsharing service available in Quebec.

The Quebec (Canada) carsharing service, *Communauto*, was founded in 1994. Since then, it has been providing service to the citizens of the major cities in the province. The number of subscribers has been increasing drastically ever since. *Communauto* is the oldest and one of the largest service in North America with 27,242 users and 1,146 vehicles in 2012.

This study is organized in four sections. First, previous studies and examples of other carsharing services are presented; then, details on data collection methods and analysis are provided. In section 3, the results of the analysis are examined. Finally, an overall conclusion is provided.

BACKGROUND

Concept and trends

In the context of this research, carsharing is a service that provides vehicle for the subscribers during a determined time (short-term or long-term). It is also defined as a mobility service that give members an access to a private car without paying for the fuel, insurance and other costs, except for mileage and time offering a more flexible alternative than public transportation (Shaheen, Cohen, & Chung, 2009; Zheng et al., 2009). It is important to note that carsharing is different from carpooling. Carpooling is basically sharing car journey for a pre-planned trip, whilst carsharing is more adaptable to almost any journey like when you simply rent a car.

Individuals generally can have access to shared vehicles by joining an organization that owns, manages, and maintains a vehicle fleet in a network of locations called points of departure (PODs) or stations. Most of these organizations charge an annual membership fee and hourly/distance-based-use fees. They benefit from advanced technologies including automated reservations, instant reservations, vehicle class/POD reservations, smartcard vehicle access, real-time vehicle tracking (GPS tracking), and equipment that facilitates one-way trips (borrowing from one POD and returning in another one) (Shaheen & Cohen, 2012).

A key emerging trend in carsharing industry is adding plug-in hybrids (PHV) or full electric vehicles (EV) into the fleet to improve the environmental performance of the system. For instance, the all-electric vehicle program in Paris (*Autolib*) has planned to expand its EV fleet

to 5000 by 2013 (Shaheen & Cohen, 2012). One of the main objectives of carsharing is providing a healthier and less pollutant urban environment by reducing the negative impacts of cars on public spaces.

Impacts

In spite of the significant growth of carsharing service, the evaluation of its impact on car dependency, car ownership, and GHG emission is still not fully covered (Sioui, Morency, Trépanier, Viviani, & Robert, 2009). On the other hand, Shaheen and Cohen (2012) indicate that differences in methodologies, data collection techniques and limited samples have often resulted in inconsistent outcomes.

Carsharing impacts are categorized into environmental, land use, social, and transportation. Reduction in vehicle ownership and Vehicle Kilometres Travelled (VKT) [or Vehicle Miles Travelled (VMT)] as well as mode shift toward active and collective transportation are the factors frequently associated with carsharing's environmental performance (Katzev, 2003; Martin & Shaheen, 2011; Martin, Shaheen, & Lidicker, 2010; Shaheen & Cohen, 2012; Shaheen, Meyn, & Wipyewski, 2003; Shaheen, Schwartz, & Wipyewski, 2004; Strid, 1999).

Different studies have discussed the environmental benefits of carsharing. Ryden and Morin (2005) stated an average of 39% to 45% reduction in CO_2 emission. In another study, Martin et al. (2010) conducted a North American survey of 2,088 carsharing members; their study revealed an average of 0.58 tons of GHG emissions reduction per household in a year for the observed impact (sold car and decreased kilometres travelled) and a reduction of 0.84 tons over this same period for the full impact (observed and avoided emission). In the study of environmental performance of carsharing services users' behaviours are usually discussed; such as users and household's transportation habits, member-vehicle ratio, and total vehicle's numbers and VKT.

Users and household habits

The transportation habits and budget of the people influences the choice of their mode of transportation. According to a survey by Shaheen and Cohen (2012), based on interviews with carsharing experts around the world, 58.3% of the countries providing the service reported saved costs as the most important motivation to use a carsharing service; also 20.8% countries mentioned other reasons like location and access convenience.

To follow the rapid evolution of the market, the carsharing companies should permanently evaluate the users' types and habits. Study of the characteristics of the members in an 800 meters radius shows that the households living closer to the stations are the main users of the service (Grasset & Morency, 2010). In general, for the companies also, the residential neighbourhood market is the most profitable rather than other business markets (Shaheen & Cohen, 2007). According to Sioui et al. (2009), 87% of households having at least one *Communauto* membership, do not possess any private vehicle, while 11.8% have one and the rest (only 2.2%) have more than one vehicles. Shaheen et al. (2009), according to a survey, argued that 62% of households have had a vehicle before joining carsharing and after using the service, the percentage of households without any cars increased to 80%. Somehow, carsharing definitively influences car ownership; however, some authors think it may encourage households to own more cars in the short term. In the case of San

Francisco, California, Cervero, Creedman, Pai, and Pohan (2002) argued the city's carsharing program led to an increase in car ownership in the first year of operation. However, two years later they explained that carsharing service could have helped 30% of households to get rid of one car or changed their plans for owning one (Cervero & Tsai, 2004).

Member-vehicle ratio

Member-vehicle ratio indicates the relation between supply and demand in the carsharing market. Comparing this ratio with total urban or metropolitan figure shows us how carsharing changes the mobility habits of individuals and households. In recent years, global member-vehicle ratio has steadily increased. In their study, Shaheen and Cohen (2012) have confirmed that the member-vehicle ratio has increased from 30:1 in 2006 to 40:1 in 2010. They also explain that this ratio generally tends to be lower in newer markets where operators must locate vehicles to gain members. In contrast, mature markets have higher ratio which indicates an increase in membership growth, market diversification (e.g. governmental or university/colleges fleets), and movements towards outside capital investment. Still, this ratio will vary a lot according to membership requirements (it may be free in some areas to become a member). Estimating active members –vehicle ratios would facilitate the comparison between systems but it is rarely available,

Total Vehicle Numbers and VKT

Other major carsharing impacts on the transportation network include a reduction in vehicle ownership, foregone vehicle purchases and a reduction in VKT. Carsharing has been documented to substitute the need for 7 to 10 privately owned vehicles in Australia, 4 to 10 cars in Europe, and 9 to 13 cars in North America (Martin et al., 2010). European studies also indicate a large reduction in VKT, ranging from 28% to 45% (Katzev, 2003; Ryden & Morin, 2005; Shaheen et al., 2003). In North America, VKT reduction ranged from 7.6% to 80% (Katzev, 2003; Shaheen et al., 2004). A recent survey also found a decline/year of 27% (observed impact) and 43% (full impact) in the before and after mean driving distance (Martin & Shaheen, 2011; Martin et al., 2010). Estimates vary substantially between members that gave up vehicles after joining carsharing and those that gained vehicle access through carsharing in both Europe and North America (Shaheen & Cohen, 2012).

METHODOLOGY

Data collection

This study is examining the environmental performance of the Quebec carsharing service "*Communauto*". Two types of databases have been used to conduct the analysis; the stated data (surveys), and the observed data (transaction and GPS). The stated data refers to the information gathered from the satisfaction surveys in 2006, 2008, and 2010, and also the "123" web survey focusing on new members. The observed data is the transaction database and GPS traces.

The *Communauto* satisfaction survey is conducted annually with the help of an on-line survey software. In 2010 the survey was conducted from May 26th to December 1st and gathered data from a total of 3160 respondents (because of an interruption in the software only 2855 of the entries were retrieved). For the 2008 survey, the data collection was done between June 13th and July 31st with 2955 respondents. The first web survey was conducted between March 21st and May 15th 2006 with 2489 participants. The number of questions was reduced from 27 in 2008 to 23 in 2010. The average survey duration was also reduced from 18 minutes in 2008 to 16 minutes in 2010. The 2006 survey reached 24% of the members (about 39% of the active members) whereas; this ratio reduces to 17% (28% of active members) in 2008 and 13% (19% of active members) in 2010.
Furthermore, the "123" survey which is focusing on new subscribers, studies the impact of carsharing on their travel habits. It includes 11 questions which allow collecting information on trip habits and reasons for joining the service. The other questions are related to the socio- professional characteristics of the members such as their main occupation, job and car ownership. The database used in this study is the data collected between March 13th 2009 and January 31st 2011.
Transaction database records the VKT, time of the travel, its duration, and the vehicle used. This database includes just the members that have used the service. Therefore, the information on members which VKT is null is not available in this database. The entries of this database are based on monthly VKT of each member with a specific type of vehicle. Regarding the observed information, there are also GPS traces available for some vehicles which are more precise and can illustrate the spatial and chronological profile of each trip. However, in this study GPS data is only used to illustrate the daily distribution of VKT of the users.

Estimating GHG emission

For calculating the GHG emission, we estimate the CO_2 emission which is considered the main source of greenhouse gases. To estimate CO_2 precisely there are many different factors to consider, however it requires a detailed database on vehicle characteristics, speed profile, vehicle's location, and some other factors. These data was not available, therefore, we limited the precision of our calculation to the make, model and year of the vehicles. The fuel consumption of each vehicle in city and in highway has been extracted from Natural Resources Canada database (2012). The average fuel consumption of each vehicle is then calculated from equation 1. This equation is also used in annual Canadian vehicle survey analysis to report average fuel consumption of each province which is used in this study to demonstrate the impact of fleet characteristics of *Communauto*.

$$FC_{Ave.} = 0.55 \times FC_{City} + 0.45 \times FC_{Highway} \quad \text{equation 1}$$

Where, $FC_{Ave.}$ is the average fuel consumption of each vehicle in Litre per 100 km and FC_{City} and $FC_{Highway}$ are the fuel consumption of the vehicle in city and in highway respectively.
In the next step, the CO_2 emission is calculated using equation 2.

$$CO_2\ emission = FC_{Ave.} \times VKT/100 \times 2.4 \quad \text{equation 2}$$

Where, CO_2 emission is in Kg, VKT is the total kilometers traveled by a specific car and 2.4 is the amount of Kg CO_2 produced from one litre of gasoline. The average fuel consumption of

Communauto vehicle is 6.5 L/100 and average fuel consumption of Quebec light duty passenger vehicle is 10.4 L/100 km.

RESULTS

As mentioned earlier, different studies have confirmed that the carsharing system can significantly improve the environmental performance through different modification in users' trip habits such as shifting toward active and public transportation, decrease in their vehicle ownership and reduction in their annual VKT. Moreover, it can reduce the GHG emission by providing more fuel efficient vehicles for the users. In this section we are going to analyze these findings in Quebec.

Users' travel habit

The mode choice of the users is an important indicator of the environmental performance. The surveys of *Communauto* in 2006, 2008, and 2010 include the questions on the travel habits of the member and modification to their habits after their subscription to the service that can enable us to analyse their mode shift if any (Figure 1).

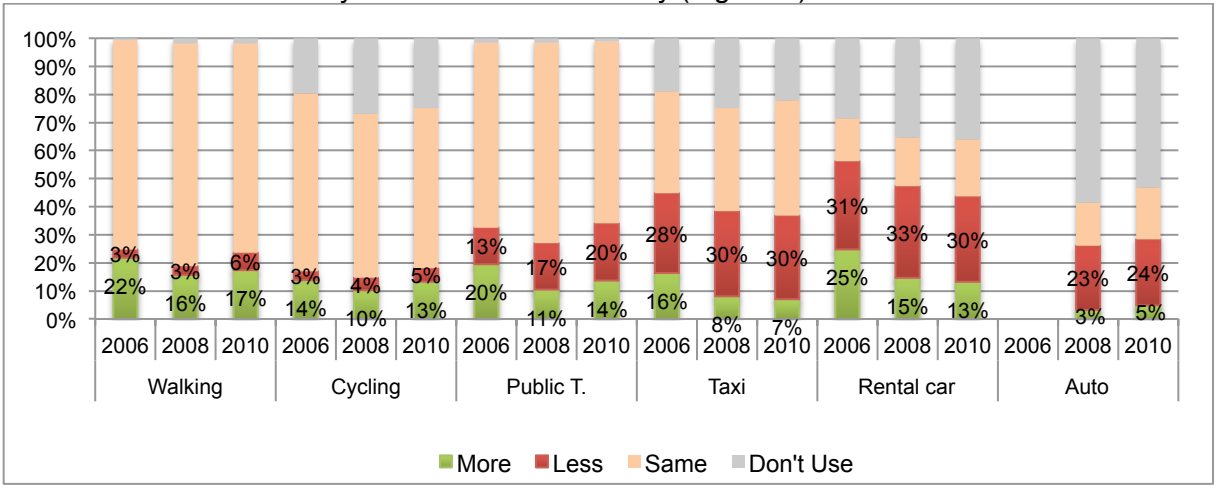

Figure 1: Mode choice of the members before and after joining to the service in 2006, 2008, and 2010

The graphic demonstrates clearly that more users have shifted to greener modes. For example on average the users have increased their walking trips (19% in 2006, 13% in 2008, and 11% in 2010). Also the clients are cycling more than before (11% in 2006, 6% in 2008, and 8% in 2010). However, this trend changes in the case of public transportation. There can be two arguments in justification of this behaviour: the clients have shifted to more active modes, or they are using "private" motorized modes. To validate these two assumptions, we have analyzed the members that are less using public transportation to see how they have changed their mode choice (Figure 2). As demonstrated, they have used rental car, taxi and other cars (no data is available for 2006 since the private vehicle was not questioned) significantly less than before; therefore, they have not shifted toward motorized transportation. Also, they are walking and cycling more; however, the difference between the number of people increasing their walking and cycling trips, and the ones that are decreasing is not very significant.

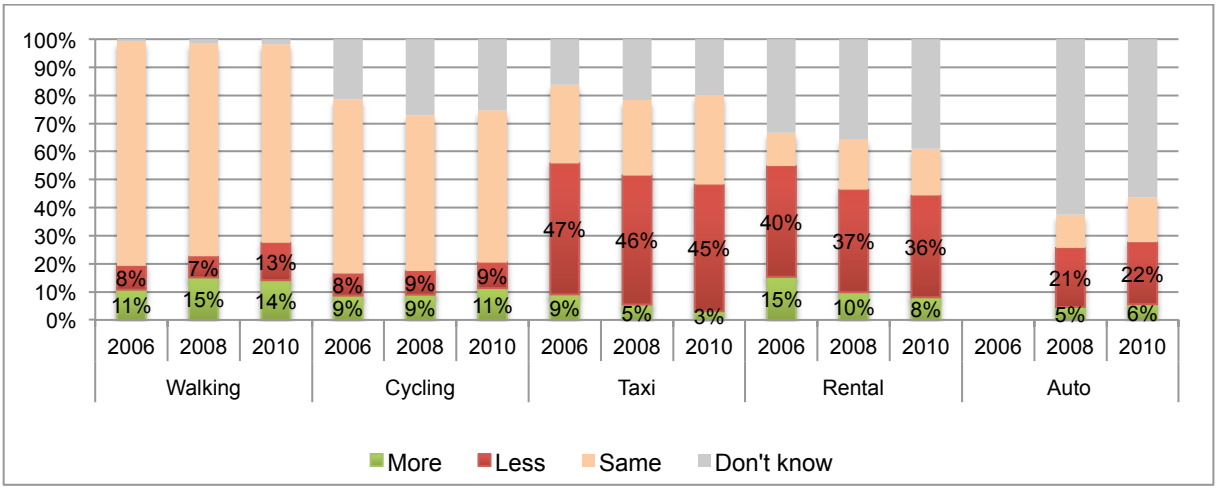

Figure 2: Mode shift distributions of the users that are using less public transportation

Going back to the Figure 1, the use of taxi, rental car and private car shows a significant decrease. Also, the overall percentage of the users using less taxis and rental cars has increased constantly during this period (2006-2010). But the use of private vehicles in 2008 and 2010 has not changed considerably.

Car ownership of the household

Car ownership of the households is another indicator that can define the environmental performance of the carsharing system. The majority of the users are from the households that do not own any vehicle. It is also interesting to see if using a carsharing service can influence the users' decision about purchasing or selling a vehicle.

The result of the 2010 survey presented in Table 1 explains that 41.2% of the users could dispose one of their private vehicles and 72% postponed their buying. In addition, 78.9% of the subscribers have been discouraged to buy a vehicle. Therefore, without this service 90% of the users would have bought their first or second vehicle or have kept their vehicle which is about 2853 more cars on streets. This result confirms that there is a significant tendency to share vehicle instead of owning one.

Table 1: Number of vehicles replaced by *Communauto* vehicles in 2006, 2008, and 2010

		2006	2008	2010
% Disposed their car		27%	30%	41%
% Postponed vehicle purchase		52%	52%	72%
%Cancelled buying a vehicle		69%	69%	79%
% Disposed, cancelled or postponed purchase		83%	83%	90%
User/carsharing vehicle		22	21	20
Reduction of the number of vehicles due carsharing	Sold their car	717	821	1302
	Postponed vehicle purchase	1402	1424	2283
	Cancelled buying vehicle	1856	1868	2491
	Sold, cancelled or postponed purchase	2048	2250	2853
Rate of the vehicles replaced by *Communauto*		18	17	18

Regarding the total fleet of *Communauto* in 2010 and the number of cars that have been reduced (or not added), each *Communauto* vehicle has been substitute for about 18 private vehicles.

Before and after study of vehicle's kilometers traveled

For better evaluation of the impact of carsharing service, we examined the annual VKT before and after subscription to the service. Three situations can be observed regarding VKT before and after subscribing to the system: increase, maintain, and decrease. The variation in annual VKT after subscription to *Communauto* is illustrated in Figure 3.

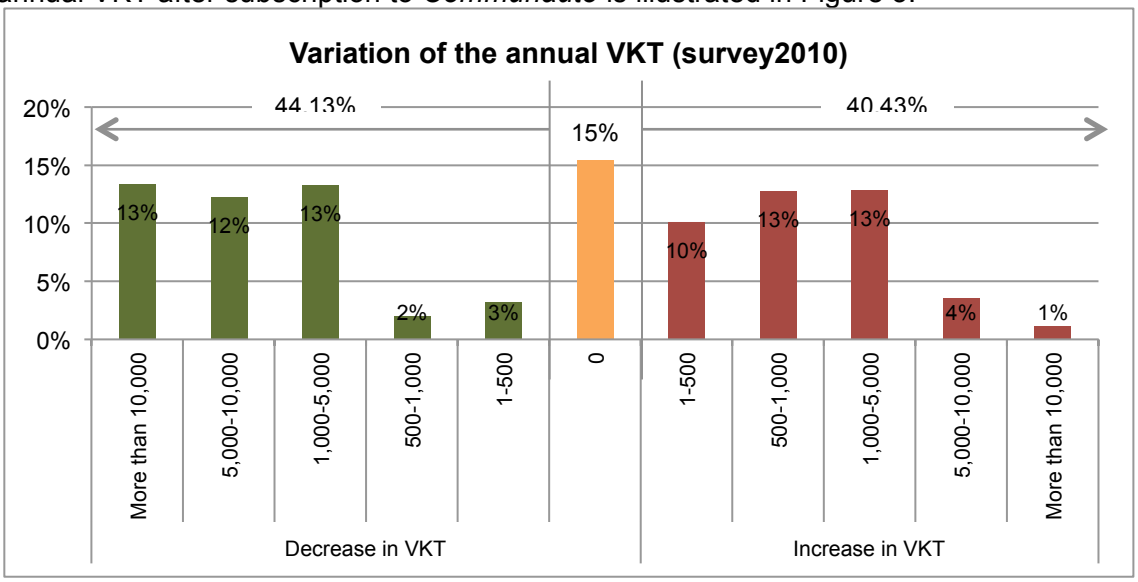

Figure 3: Proportion of the *Communauto* users based on annual VKT before and after subscription to the service

As demonstrated, overall, 44.13% of the respondents have reduced their annual VKT; about 15% maintained their mileage and a total of 40.43% have increased their car use. The reduction is more significant in the high (more than 5,000 km) VKTs; which is about 25% of the users; whereas, on the other side, only 5% of the respondents have increased their annual VKT more than 5,000 km. This behaviour is completely reverse for the lower VKTs (less than 1,000). This group generally gathers clients that did not have access to any private vehicle prior their subscription to the service. About 51% of the users that have increased their mileage do not have access to any private vehicle.

Also, Table 2 compares the total annual VKT of the members before and after subscription in 2010. In this table, like the previous figure, the members are classified into three separate groups; the users that have increased their VKT, the ones who have decreased it, and the one that have maintained their mileage.

Table 2: Members' annual VKT before and after joining *Communauto* (survey 2010)

Variation in the total annual VKT		Clients	Average annual VKT		Variation of annual VKT		
		%	Before	After	Total km	%	Total km
Decrease	More than 10,000	13.39%	2,362,500	467,985	-1,894,515	-80	-3,028,400
	5,000-10,000	12.24%	1,252,100	481,900	-770,200	-62	
	1,000-5,000	13.27%	775,000	424,400	-350,600	-45	
	500-1,000	2.04%	47,200	35,860	-11,340	-24	
	1-500	3.19%	6,235	4,490	-1,745	-28	
The same	0	15.43%	1,143,400	1,143,400	0	0	0
Increase	1-500	10.08%	70,605	86,743	16,138	23	680,950
	500-1,000	12.76%	120,950	200,850	79,900	66	
	1,000-5,000	12.88%	161,900	399,436	237,536	147	
	5,000-10,000	3.57%	99,399	281,000	181,601	183	
	More than 10,000	1.15%	31,600	199,000	167,400	530	

The results demonstrate that overall the users have reduced the annual VKT of 2,347,450 km. The clients that have reduced their mileage more than 5,000 km are the highest contributors to the total reduction of VKT since they are both numerous and used to drive a lot. All the statistics confirmed the total reduction of the annual VKT of the households. To discover the real environmental performance of the system we will also discuss the fleet characteristic of the system in the following section.

Fleet Characteristics

In addition to reduction in VKT, it is widely discussed that one other major contribution of carsharing system to environmental performance is the use of fuel-efficient vehicles in the fleet. Table 3 demonstrates how much more CO2 would have been emitted if the total annual VKT of *Communauto* was made with an average Quebec light duty vehicle each year. In this table, total CO_2 emission is calculated based on VKT of *Communauto* users using *Communauto* and Quebec fleet composition (explained in the methodology section).

Table 3: Comparison of total annual VKT of *Communauto* fleet based on fleet characteristics of *Communauto* and an average Quebec passenger vehicle

	Total CO_2 Emission (kg/year)			
	Communauto	Quebec fleet	Difference	Difference%
2007	3,355,507	5,277,575	1,922,067	-57%
2008	4,174,112	6,384,356	2,210,244	-53%
2009	4,367,681	6,762,474	2,394,793	-55%

If we modify Table 2 with the information on the CO_2 emission of the fleet we would have a more comprehensive statistics explaining the full impact of the system (Table 4). As we can see the in the case of the users with the same before and after VKT and the ones that have increased their VKT less than 500 km, the total CO_2 emission has been decreased, because of accessibility to more fuel efficient vehicles.

Table 4: Members' annual CO_2 before and after joining *Communauto* (survey 2010)

Variation in the total annual VKT		Clients	Average annual CO_2 emission		Variation of annual CO_2		
		%	Before	After	Total CO_2	%	Total CO_2
Decrease	More than 10,000	13.39%	245,700	30,419	-215,281	-88%	-370,124
	5,000-10,000	12.24%	130,218	31,324	-98,895	-76%	
	1,000-5,000	13.27%	80,600	27,586	-53,014	-66%	
	500-1,000	2.04%	4,909	2,331	-2,578	-53%	
	1-500	3.19%	648	292	-357	-55%	
The same	0	15.43%	118,914	74,321	-44,593	-38%	-44,592
Increase	1-500	10.08%	7,343	5,638	-1,705	-23%	25,474
	500-1,000	12.76%	12,579	13,055	476	4%	
	1,000-5,000	12.88%	16,838	25,963	9,126	54%	
	5,000-10,000	3.57%	10,337	18,265	7,928	77%	
	More than 10,000	1.15%	3,286	12,935	9,649	294%	

This impact can become more and more significant by introduction of the electric vehicles into the *Communauto* fleet in 2012.

Demographic characteristics and CO_2 emission

In the study of users' behaviour, it is helpful to understand the characteristics of the clients and their habits. The demographic characteristics of the users can influence their trip habits

and consequently the CO_2 emission. Therefore, in this section we measured the average CO_2 quantity reduced per age group. A good understanding of the clients' habits and demands can help improve the system.

As we can see in the results young clients [20-30] have increased their CO_2 emission more than the other age groups. They are the only group that the percentage of the increase of CO_2 is more than decrease. However, the overall emission still decreases. As we can see the total reduction of CO_2 emission increased with age and this reduction in the younger group [20-30] is much less than among the other groups.

Table 5: Assessing the impact of members' age on CO_2 emission using car sharing service

Age group	Comparative dist. traveled	Average Annual VKT		Fuel consumption		CO_2 emission		Variation	
		Before	After	Before[4]	After[5]	Before	After	kg CO_2	%
20-30	Less[1]	16,082	5,469	1,673	355	4,014	853	-3161	-79%
	Same[2]	5,527	5,527	575	359	1,379	862	-517	-38%
	More[3]	1,236	3,794	129	247	309	592	283	92%
	Total	4,607	4,310	479	280	1,150	672	-478	-42%
31-40	Less	15,259	4,547	1,587	296	3,809	709	-3099	-81%
	Same	8,158	8,158	848	530	2,036	1,273	-764	-38%
	More	1,405	3,338	146	217	351	521	170	48%
	Total	7,393	4,528	769	294	1,845	706	-1139	-62%
41-50	Less	13,479	4,128	1,402	268	3,364	644	-2720	-81%
	Same	10,700	10,700	1,113	696	2,671	1,669	-1002	-38%
	More	1,453	3,490	151	227	363	544	182	50%
	Total	9,039	5,376	940	349	2,256	839	-1417	-63%
51-60	Less	13,203	4,558	1,373	296	3,295	711	-2584	-78%
	Same	10,444	10,444	1,086	679	2,607	1,629	-978	-38%
	More	1,568	2,828	163	184	391	441	50	13%
	Total	10,612	5,212	1,104	339	2,649	813	-1836	-69%
More than 60	Less	10,388	3,013	1,080	196	2,593	470	-2123	-82%
	Same	8,042	8,042	836	523	2,007	1,255	-753	-38%
	More	1,694	3,634	176	236	423	567	144	34%
	total	8,363	3,946	870	256	2,087	616	-1472	-71%

[1] Less than before
[2] Same as before
[3] More than before
[4] based on Quebec average fuel consumption in 2010 (10.4 L/100 km)
[5] based on average fuel consumption of *Communauto* vehicles (6.5 L/100km)

The other important demographic characteristic is gender of the clients, which can affect emission. Table 6 shows the distribution of CO_2 emission for male and female before and after subscription to the service. As presented, females have increased their emission more than men due to their low VKT before subscription to the system.

Table 6: Assessing the impact of sex of the members on CO_2 emission using carsharing service

Average comparative distance traveled		Average Annual VKT (km)		Fuel consumption (L/year/member)		CO_2 emission (kg/year/member)		Variation	
		Before	After	Before	After	Before	After	kg CO_2	%
Less than before	Male	14,955	4,716	1,555	307	3,733	736	-2,997	-80%
	Female	12,020	3,761	1,250	244	3,000	587	-2,413	-80%
Same as before	Male	9,644	9,644	1,003	627	2,407	1,504	-903	-38%
	Female	7,094	7,094	738	461	1,771	1,107	-664	-38%
More than before	Male	1,709	3,931	178	256	427	613	187	44%
	Female	1,121	3,143	117	204	280	490	210	75%

Chronological distribution

The chronological profile of CO_2 emission of users is illustrated in Figure 4. As we can see, there is a significant increase during summer (where carsharing is used for long vacation trips) which starts to reduce in September. Although there are inconsistencies along the diagram, the overall trend confirms this idea.

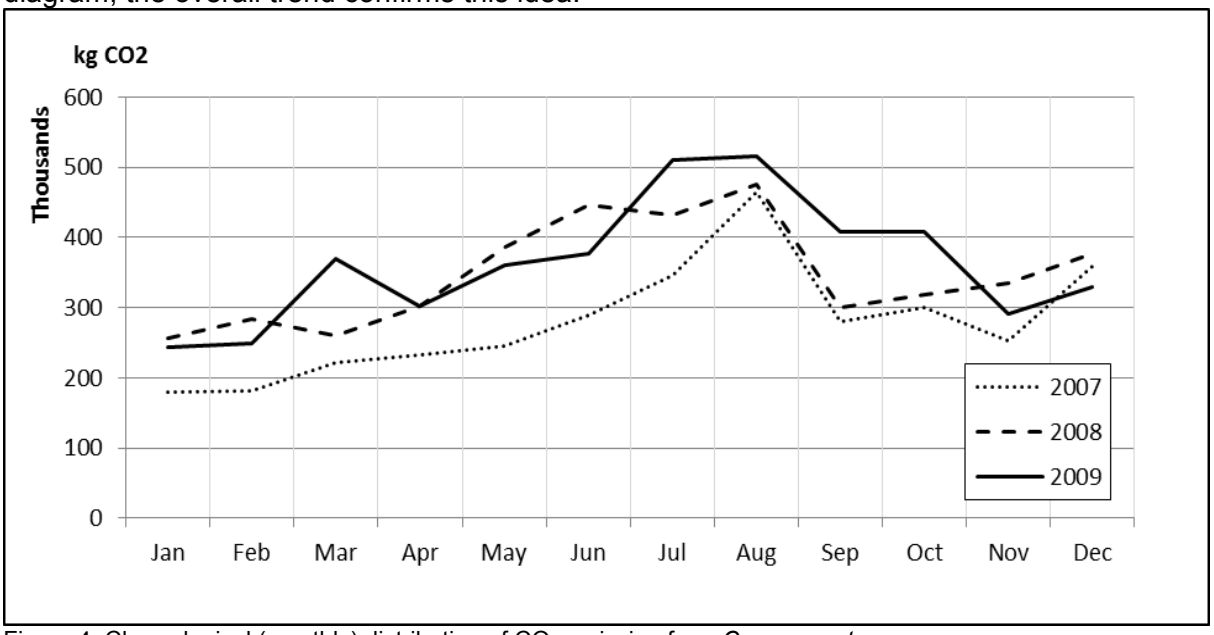

Figure 4: Chronological (monthly) distribution of CO_2 emission from *Communauto*

Furthermore, Figure 5 illustrating the total CO_2 estimated for Feb-Apr 2010 shows an increase in CO_2 emission over weekends. This finding and the results from the previous figure explains that the users drive more during the weekends for vacation and utility trips.

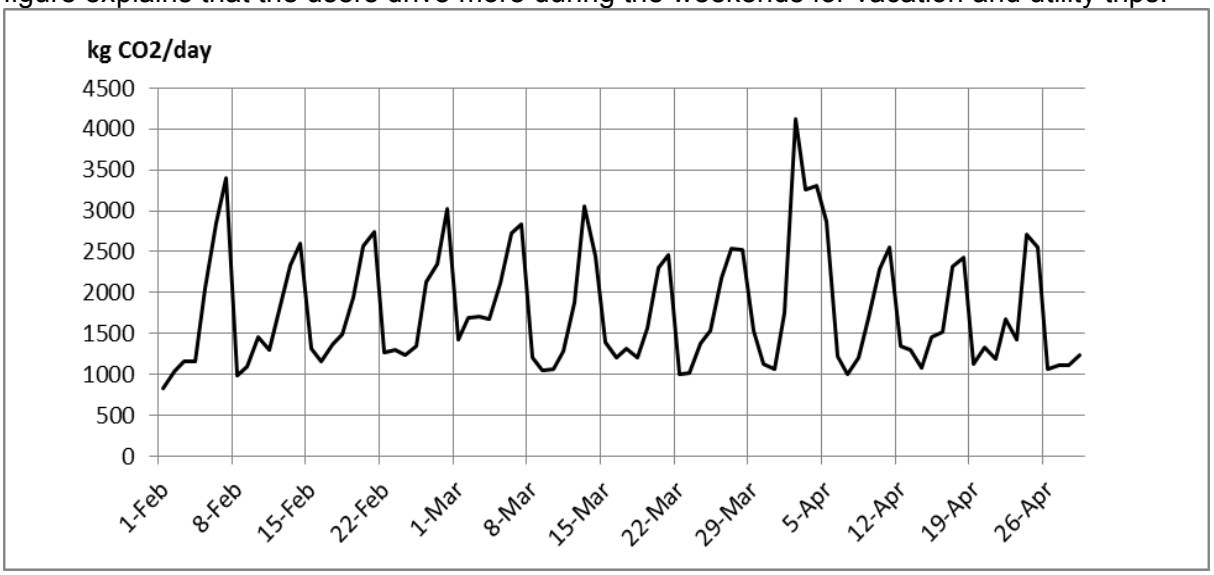

Figure 5: Chronological (daily) distribution of CO_2 emission from *Communauto*

DISCUSSION AND CONCLUSION

This study contributes to development of tools for evaluating environmental impact of carsharing. Its novelty is providing enhanced estimation of CO_2 emission comparing to

previous studies by including the model and year of the vehicles. The methodology of this study is started with adjustment and combination of different databases.
Concluding, the carsharing system can have a major impact on environmental performance of transportation. The results demonstrated the positive impacts, which can be classified into the following factors:

- Encouraging active and public transportation;
- Reducing the number of privately owned vehicles;
- Reducing the total vehicle kilometers traveled (VKT);
- Providing more fuel efficient vehicles.

Also, the analysis of the chronological distribution of CO_2 and assessing demographic characteristics of the users and their fuel consumption can help us understand the users' habit. Moreover, the results confirm that females and users between the ages of 20-30 tend to have increased their VKT more than other groups.

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