Environmental Impacts of Commuter Trips using Motivation Perspective – a case study of Global Warming Impact in Saint-Etienne, France

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Introduction

For a few decades, environmental impacts of human activities have become an increasing subject of interest for political decision-makers. New regulations, plans and objectives on Greenhouse Gas (GHG) emissions have been defined to reduce global warming. In particular, cities and urban environment were considered to be responsible for a major part of GHG emissions (Kennedy et al., 2009). Aiming at evaluate and reduce these emissions, new strategies are developed (Heinonen and Junnila, 2011). In France, transportation represents 27% of GHG emissions (Verdon et al., 2008) and more precisely 34% of CO_2 emissions. Within transportation sector, urban mobility represents 47% of these CO_2 emissions (Verdon et al., 2008; CITEPA[1]).

The environmental impact assessment of transportation and transport modes requires getting a model encompassing numerous parameters. These parameters can be obtained through measures and calculation:

- Calculation is provided by crossing traffic simulations and specific results for every vehicle direct emissions. These vehicle results are obtained by measure on test beds using real – ARTEMIS[2] (Andre, 2004) – or homologation – NEDC[3] – driving cycles.
- Measures – in France – are assigned to regional air quality agencies that are in charge of publishing daily previsions for air quality. They follow the recommendations of CITEPA.

However, the scope of these methodologies only includes direct emissions. An accurate description of the system under study, encompassing multiple parameters such as its different transport modes, sources of energy or infrastructures leads to notice that direct emissions but also indirect emissions should be considered. Indeed, for instance, if electric transport modes tend to spread, the environmental impacts linked to electricity generation should not be neglected when studying environmental impacts of transportation. Car manufacturing, building of roads or tires' end of life management also emit pollutants that are not counted when considering only direct emissions.

A second limit of this approach is that it does not directly take into account trip motivations and their specificities. Indeed, trip motivation can have an impact on the way to travel and consequently on environmental impacts.

Being regular, daily and numerous, commuter trips – worker and student daily trips – have been precisely described within several studies related to modal shares, travel times and distances (Talbot, 2001; Baccaïni et al., 2007; Dupré and Rigollet, 2011). Nevertheless, to our knowledge, no environmental studies have been performed taken into account both direct and indirect emissions. This paper aims at proposing a methodology to study the impact of commuter trips on global warming taking into account direct and indirect emissions. A first application of this methodology is proposed for the case of the Agglomeration of Saint-Etienne, France.

[1] In France, CITEPA is in charge of identifying, analyzing and spreading data and methodology about atmospheric pollution. http://www.citepa.org/fr/pollution-et-climat/analyse-sectorielle/transports
[2] Assessment and Reliability of Transport Emission Models and Inventory Systems
[3] New European Driving Cycle

Material and methods

Life Cycle Assessment (LCA) and trip motivation

When studying urban mobility, travel times and costs, convenience, travellers' value of time and the level of services offered by networks are identified as the main elements to be taken into account (Cascetta, 2009; Morfoulaki et al., 2011). However, the trip motivation may also influence on transport mode choices (De Solere and Certu, 2009). Every trip is made for a specific reason that could be classified into categories such as professional trips, scholar trips, purchase trips, etc. This paper presents a method that aims at studying commuter trips, for an average case of French cities with a population higher than 250'000 inhabitants (excluding particular cases such as Paris), and especially at assessing the environmental impacts of these travels.

With the objective of considering direct and indirect aspects, Life Cycle Assessment (LCA) methodology was chosen. LCA is a standardized methodology (ISO14040; ISO14044) that aims at assessing environmental impacts of a good or a service all over its life cycle. A LCA is calculated for a specific Functional Unit (FU) (Fleischer and Schmidt, 1996) in order to compare different solutions that fulfil the same function. Several indicators can be calculated by LCA, depending on the required level of characterization (Haes et al., 1999). In this study, a global FU was defined as "allow inhabitants from an average French big city to realise their professional and scholar trips during one year". This FU can be subdivided in several partial FUs (Figure 1).

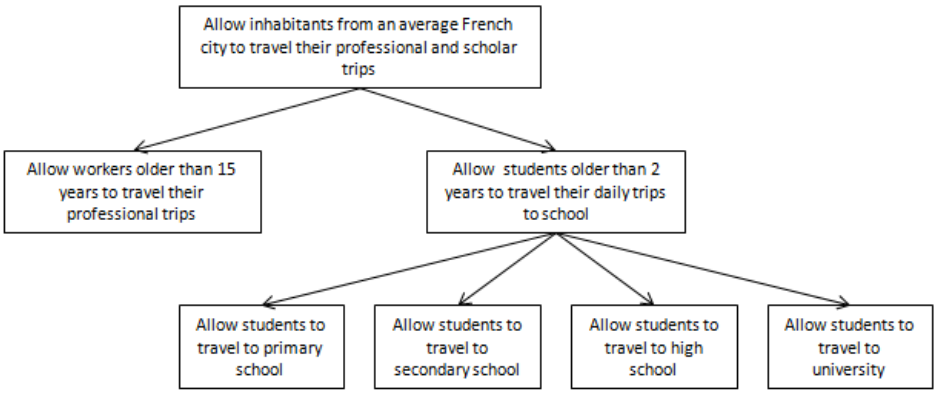

Figure 1: Functional unit subdivision proposed of commuter trips

The proposed methodology consists in crossing modal share data for commuter trips and LCA database including elementary environmental assessments for each transport mode.

Data collection

Two types of data are necessary to assess urban mobility. First, data on trips are required: trips must be geographically (distances, type of urban area, etc.) characterized and modal shares must be associated to each type of trip motivation. Second, more specific data about environmental impacts that are generated by the various transport modes provide new information to complete the generic data that are provided by environmental impact databases.

Trip distance data collection

The French National Institute for Statistics and Economical Studies (INSEE) provides numerous statistical data about transports and mobility. Every year, population census contains specific questions about commuter trips. Departures and arrivals are asked for every daily trip for both workers and students. Consequently, each flow counting more than one hundred people between two different cities is known – INSEE specifies that the statistic accuracy is not

guaranteed for fewer than hundred people flows. By analyzing database on mobility flows given by INSEE[4], four types of flows have been defined:

Table1: classification of commuter trips depending departure and arrival locations.

Départure	Arrival
Living city A inside the agglomeration	Working city A inside the agglomeration
Living city A inside the agglomeration	Working city B inside the agglomeration
Living city A inside the agglomeration	Working city B outside the agglomeration
Living city A outside the agglomeration	Working city B inside the agglomeration

Modal share data collection

The modal share calculation has been done by using the results of French surveys about households and trips called “Enquêtes Ménages Déplacements“ (EMD). These surveys take a census of trips for a given urban population. 17 EMDs realized from 2001 to 2007 including 14 urban areas with more than 250 000 inhabitants and 3 counting between 100 000 and 200 000 inhabitants[5] were used to define an average modal share by trip motivation. This analyse only gives a first level of classification and a specific collect has been necessary to improve data specificities for the case under study.

Environmental impacts of transport modes data collection

LCA methodology provides several databases. This study is mainly based on Ecoinvent 2.3 database. However, this database needs to be adapted to the case study. For instance, most of the data are based on Swiss case which can present some significant differences with the French situation. Indeed, for each transport mode, some influent parameters are defined by default and supplementary data must be collected and taken into account to adjust the generic database to the specific situation. Next figure lists for each transport mode the influent parameters that were adjusted in this study. These parameters have been identified in the literature and by sensitivity analysis on transport modes inventories of Ecoinvent 2.3 database using SimaPro 7.3.3 software.

Table 2: Most influent parameters by transport mode (V means “influent”. Any of the parameters are only influent for a specific part of the mode category).

Parameters	Bus[6]	Car[7]	Tramway	Bike	Motorbike
Occupancy rate (Gaudry and de Lapparent)	V	V	V		V
Kilometric lifespan (Walsh et al., 2008)	V	V	V	V	V
Fuel consumption (He et al., 2005)	V	V			V
Electricity consumption (Ou et al., 2011)	Only for trolleybus	Only for electric cars	V	Only for electric bikes	Only for electric motorbikes
Electricity generation mix (Santoyo-Castelazo et al., 2011)	Only for trolleybus	Only for electric cars	V	Only for electric bikes	Only for electric motorbikes

[4] Centre Maurice Halbwachs (CMH), and Insee Recensement de la population 2009 : bases de données sur les flux de mobilité.
[5] De Solere, R., and Certu (2009). Répartition modale des déplacements selon le motif.
[6] This category comprises all buses and coaches (standard, articulated, etc.).
[7] This category comprises all cars (petrol, diesel, electric, etc.).

Case study: Saint-Etienne Agglomeration, France

The perimeter of the study is Saint-Etienne Agglomeration. It includes 43 cities with 374 680 inhabitants. It corresponds to the perimeter served by public transport, also taken as perimeter for the EMD in 2001, reported by Epures[8].

For each trip category of the classification (table 1), French 2009 census provides travel flows realized by more than 100 workers (or students) between two different cities, covering 60% of all trips. The other trips were assumed to follow the same distribution. In the same datasheet the entire flows occurring in a same city is known.

Distances between two cities of the agglomeration have been estimated by using dedicated Internet websites for itinerary calculation. The kilometric average of first recommended itineraries given by three websites[9] is taken as distance, accepting an average standard deviation equal to 10%. To estimate distances between a city inside the agglomeration (respectively outside) and another one outside (inside), last (first) crossed city of the agglomeration has been taken as arrival (departure). Then, average distance of 4.2 kilometres for a trip inside the same city is given by INSEE.

The number of workdays is fixed to 253, corresponding to the French regulation. The part-time worker proportion is equal to 16.9% in France provided by INSEE[10]. Knowing the daily distance D_d (in km) and the part-time worker proportion T_p (in %), the annual distance D_a (in km) is given by:

$$D_a = 2 \times D_d \times 253 \times \left(1 - \frac{T_p}{2}\right)$$

The number of study days comes from the French Ministry of Education[11] and is equal to 180 for secondary school, high school and university students (representing 81% of all students) and 144 for primary students (19% of all students).

All these data enable obtaining an estimated annual distance covered by a person, therefore expressed in pkm (passenger.kilometre).

Modal shares

Modal shares (Figure 2) have been collected following three steps, each giving additional details:

- First a specific report about commuter trips in Rhône Alpes Region (Dupré and Rigollet, 2011) presents modal shares function of the urban categorization of the departure city and the trip distance. Five modal shares are proposed: personal car, public transportation, walking, bikes (including motorbikes) and other modes.
- Thanks to EMDs compilation public transport can be divided in two categories: public transportation and other common carriers (mainly coaches). It also enables distinguishing bikes and motorbikes.
- Then, data by modes were provided by the Saint-Etienne Agglomeration Transportation Society (STAS) for public transportation. Kilometric data about the different public transport modes – tramway, standard bus, articulated bus, medium-sized bus, minibus and trolleybus – were then collected. In figure 2, for a matter of clarity, urban public transportation category regroups all public transportation modes.

[8] Epures (2010). Comment se déplacent les habitants de la communauté d'Agglomération de Saint-Etienne Metropole ?
[9] http://www.viamichelin.fr/ ; http://maps.google.fr/ ; http://fr.mappy.com/
[10] Insee (2009). Insee - Travail-Emploi - Temps partiel subi 29 000 personnes souhaitent travailler plus.
[11] Ministère de l'Education Nationale (2012). Questions générales écoles-collèges-lycées. http://eduscol.education.fr/cid48401/questions-generales-ecoles-colleges-lycees.html

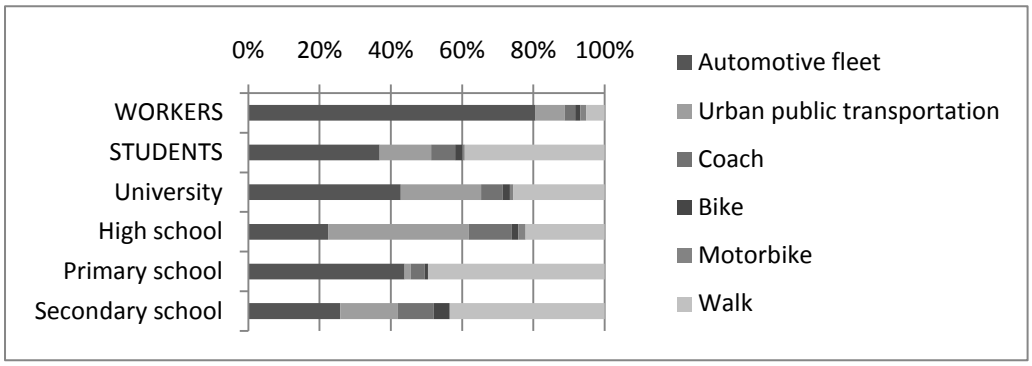

Figure 2: Modal shares by trip motivation

Adaptation of Ecoinvent 2.3 database (ED)

LCA has been conducted with SimaPro 7.3.3 software. Ecoinvent 2.3 database was used, adapting inventories to the Saint-Etienne case (Table 3). For instance, an automotive fleet was created, using types of fuel and Euro norms in the French case proportions[12].

Table 3: Influent parameters for the agglomeration of Saint-Etienne, France

Transport mode	Bus and coach	Car	Tramway	Bike	Motorbike
Occupation rate (person)	Urban: 11 Periurban: 13 Coach: 20 (Quin et al., 2011)	Average: 1.4 Professional trips: 1.07 (CGDD, 2010)	30.7 (region Ile-de-France) (Quin et al., 2011)	1	1.1 (ED[13])
Kilometric lifespan (km)	Minibus: 300 000 Urban bus: 1 000 000 Coach: 1 500 000 (ADEME, 2010)	Petrol: 157 070 Diesel: 250 190 (Jeger, 2001)	1 450 000 (Stas)	15 000 km (Del Duce, 2012)	>50cm^3: 150 000 (Lacour and Joumard, 2002) <50cm^3: 50 000 (Del Duce, 2012)
Fuel consumption (L/100km)	Minibus: 19 Standard bus: 49 Articulated bud: 66.5 Medium-sized bus: 19 Trolleybus: 10 (Stas)	Petrol: 7.8 Diesel: 6.58 (SECODIP, 2006)	0	0	3.5 (ED)
Electricity consumption (kWh/km)	Trolleybus: 2.35 (Stas)	0.2 (ED)	Tramway: 2.58 (Stas)	Electric bicycle: 0.01 (ED)	Electric scooter: 0.03 (ED)
Electricity mix	France	France	France	France	France

[12] Union Routière de France (URF) (2011). Chapitre II : véhicules. In Faits et Chiffres : Statistiques des Transports en France et en Europe.
[13] Spielmann et al., Ecoinvent report No. 14, Transport Services, December 2007

Results

IPCC characterization factors were used to calculate the global warming impact (Houghton et al., 2001).

Comparison of worker and student trips

Commuter trips emit $1.43*10^8$ kg CO_2eq per year in the Agglomeration of Saint-Etienne of which 89.2% are produced by workers and 10.8% by students. However, worker trip distances represent only 78% of total distances. Thus, it can be concluded that an average school trip emits 87 g CO_2eq per kilometre while an average worker trip emits 190 g CO_2eq/km.

Several reasons can explain this difference between student and worker trips:

- These two trip categories present different modal shares (Figure 2). Car is used for 76.9% of worker trips when it is only 36.7% of student trips. On the other hand, 39.1% of student trips are done by walking and only 5% for workers.
- The way of using transport modes is different depending on trip motivation. The occupancy rate of worker trips by car is equal to 1.07. In contrary, the major part of school trips include at least two people (unless until student is in age to pass the driver licence). As no specific data were available, it has been considered to be equal to 1.4 that is the national average.

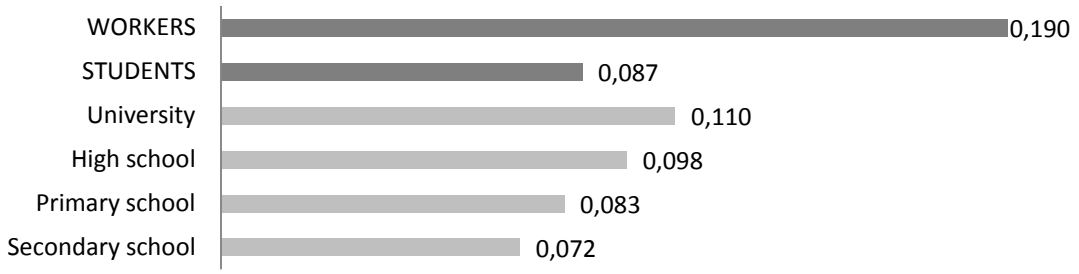

Figure 3: GHG emissions per person per kilometer by trip motivation in kg CO_2eq/pkm

Focus on student trips

Regarding the student trip results, differences appear between the categories under study in terms of:

- Modal shares (Figure 2): car is used by more than 40% of university and primary school students when less than 30% of secondary and high school students. Walk is used by nearly 50% of secondary and primary school students when about 25% of university and high school students. The greatest disparity appears for public transportation that is used from 1.7% (primary school students) to 39.1% (high school students).
- GHG emissions (Figure 3): per person per kilometre range from 72 g CO_2eq for secondary school students to 110 g CO_2eq for University students.

Differences on modal shares between categories can be explained by several parameters linked with age. First, autonomy of children enables them switching from car – as a passenger – to public transportation (when they enter the secondary school) then to car – as a driver at university. Moreover, distances gets longer with age, also influencing modal choices (Paulo, 2006). Living and working places can also be a determinant offering a restraint panel of choices to travel.

Differences on GHG emissions cannot only be attributed to car utilization. Despite car is the most used transport mode for both university and primary student categories, theirs GHG emissions differ. It appears that there is no correlation between CO_2 emissions per person per kilometre and car share in the modal split. Studying other modal shares will permit to understand these disparities. When nearly half of primary school student trips are done walking,

only a quarter of university students choose it – preferring public transport[14] not used by primary school students. In the same way, half of high school students use public transportation against a quarter of secondary school students – preferring walking. As emissions are calculated in pkm, distances are not a direct influent parameter. However, it can be a second order influent parameter influencing modal shares.

To sum up, if car is designed as responsible to the major part of CO_2 emissions of urban mobility, it does not permit alone to explain disparities in GHG emissions. Second orders have to be taken in account.

Conclusion and perspectives

Studying commuter trips shows large disparities between trip categories. First, it appears that worker trips emit more than two times more GHG than student trips per person and per kilometer. That is partly due to different modal shares – predominance of car for worker trips – and also to different ways to use transport modes for a specific trip motivation – especially a very low occupancy rate in cars for worker trips.

Looking more deeply at student trips, large differences on GHG emissions appear too. However, these differences cannot be entirely explained by predominance of car for one or another category. All the modal split need to be analyzed. Two additional factors seem to be important: the access difficulty to the school and the student autonomy. The age of the student determines the ability to use one or another transport mode.

As a perspective, the same methodology will be applied to assess global warming impact of urban mobility in Saint-Etienne. Commuter trips will be considered as well as every trip realized in the Saint-Etienne Agglomeration's perimeter. The aim is to identify and explain differences between a kilometer travelled for one or another trip motivation. Second, the case study will be enlarged to a generic French city. Then, after validate the methodology on GHG emissions, other indicators will be analyzed, using LCA.

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[14] Public transport comprises here both traditional public transportation and school buses.

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