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Spatial and Energy footprints of Cars in Cities: New Metrics and Illustrations for the Montreal Area

Catherine Morency[a*], Jean-Simon Bourdeau[a]

[a] *Polytechnique Montreal, 2500, chemin de Polytechnique, Montreal, H3T 1J4, Canada*

Abstract

Private cars are a key component of personal mobility. They however consume a lot of space when parked or travelling and generate numerous externalities. They are among the most visible mode of transportation both due to their size, which has increased over time, and to the infrastructures on which they rely to park and move. This paper proposes new metrics to consider the space and energy consumption of cars in cities. Road network data is used to evaluate the network coverage. Car trips from travel surveys combined to car fleet datasets are used to evaluate the surface (2D) and volume (3D) footprints of cars over time and across space. The energy footprint of car trips is also evaluated, namely regarding the activity and the duration of the activity they allow to reach. Results show the important transformation of the car fleet and the increasing 2D and 3D footprint they have. They also demonstrate that larger cars reduce parking capacity, increase congestion, and prevent energy savings.

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Keywords: Private cars, Spatial footprint, Energy Footprint, Personal mobility, Congestion

1. Introduction

Private cars are a key component of personal mobility. In the last decennials, they have taken over a large share of our collective spaces and roads at the point where their needs have preceded those of the people they transport. Many cities and neighborhoods have been designed around cars (on-street and off-street parking spaces, wide roads to allow many of them to travel at the same time, gas station and now charging stations, etc.). Obviously, the share of trips relying on them has been increasing fast and dispersion of activity locations (housing, employment, shopping centers, etc.) has confirmed their influence on daily activities. The multiplication of cars, car trips and spaces dedicated to cars is however not without issues. A variety of negative impacts are associated with both the existence of these objects (resource consumption), their ownership (cost, space usage) and their use (energy consumption, space use, safety, congestion, costs).

However, in the recent years, more and more countries and cities are trying to shift trends by providing more

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efficient alternatives, allocating spaces to infrastructures for active modes, promoting changes in travel behaviors. Still, there is a lot of inertia in the current behaviors and things are not changing sufficiently fast. Hence, with the ever-critical climate change crisis, it is more than time to question the space and role cars have in our daily activities and neighborhoods.

This paper proposes new metrics to better quantify the spatial and energy footprint of private cars. It aims to further document how important the issue of increasing car fleet can be for cities and neighborhoods and provide additional tools to illustrate the scale of the problem. Cars are not monolithic meaning that their shape has changed and diversified over time, leading to lower relevance of typical metrics that are used such as the vehicle-kilometers. In this perspective, the paper first proposes some background elements with respect to the impacts of cars in cities. It then provides the main methodological elements relevant for the proposed estimation namely the data sources, the study area as well as a description of the various footprint indicators proposed. Trends on the fleet of personal cars are the examined, followed by results of the indicators. Three illustrations of the impacts of the transformation of the car fleet are also proposed. The main findings as well as perspectives with respect to the use of such metrics conclude the paper.

2. Background

The place of cars in cities is addressed in various ways in the literature. A disturbing concept is proposed by a French researcher (Lussault, 2009) as “spatiophagie” or “spatialphagia” referring to a person with important economical capital that shows his personal and social identity through the quasi-compulsive consumption of space. Cars in city has significantly exacerbate the ability individuals to consume space raising multiple social, economic, and environmental issues.

2.1. Spatial impacts of cars

In the recent years, we have seen a multiplication of research concerned with the equitable share of space (driven by works such as Lucas (2004) and Martens (2016) for instance) along with engagement from cities, through their planning documents, to rebalance how street space is allocated. This is in line with the concept of Link and Place, proposed by Jones et al. (2008), which also discusses the importance of adopting a people-centered planning approach to the redesign of streets at the benefit of people instead of cars. The concept of complete street refers to similar objectives, that of making sure streets accommodate all users. A review on complete streets by Hui et al. (2017) targets the definition and evaluation of the completeness of streets. Authors mention how important it is to go beyond typical vehicle-based metrics when assessing the features of streets and to account for needs of non-drivers as well as functions other than transportation such as place and environment.

Discussions on how to quantity the space allocated to various modes or users, metrics to determine how equitable the current share of space is and how to specify how to share space between users and usages are also proposed. Lefebvre-Ropars et al. (2021) propose a method to assess the balance between the three main functions of a street (link, place, environment) and demonstrates the discrepancy between supply and demand for cyclists and transit in some Montreal boroughs. As expected, the car has the highest share of space. Will et al. (2020) also propose a methodology to measure road space by mode of transportation to assess their efficiency but using the concept of space-time consumption in km^2.h both dynamic (on the road) and static (parked). Creutzig et al. (2020) propose a review on fair street space allocation and test theoretical allocation using 18 streets of Berlin. They conclude that on average car users have 3,5 times more space than non-car users which is a striking demonstration of the important amount of space allocated to cars and their use. In Bogota, there is a clear trend to provide more space to less sustainable modes such as cars and motorcycles and that it is even more amplified in low-income areas relying less on such modes Guzman et al. (2021). It seems that when we start quantifying how much space is dedicated to the various users, car drivers and cars always have the big end of the sticks. This is again confirmed in Melbourne: De Gruyter et al. (2022) confirm the lack of space for pedestrian but also a high variety of allocation among the examined locations. They also present the key results of previous studies around the world (13 cities) that all report a dominant share for car users (from 51% in Amsterdam to 92% in Los Angeles).

Spatial requirements of cars and car trips stem also through parking. Should has provided seminal research on parking (Should, 2011), discussing issues of parking requirements, impacts of parking search on congestion, prices and payment strategy. Most of the time, cars are parked – somewhere like 95% of the time (Morency et al., 2015, Litman, 2011). It means that they occupy space at the home location of their owners as well as when they are parked at a destination. The amount of space required to park a car on a street is typically around 2,4 to 3,0 meters wide and 5,5 to 6,0 meters deep, meaning that the typical 2D footprint of a parked car will range from 13 to 19 square meters. For off street parking it is necessary to consider driveways and access lanes which will increase the footprint up to 28 to 37 square meters (Litman, 2021). Some papers have quantified the aerial footprint of parking lots. For instance, Davies et al. (2010) conclude that there are around 2,2 parking places per car and that parking lots occupy some 6,6% of the total urban footprint of the county of Tippecanoe. Higher values of parking spaces per car have been found in other areas: three to four spaces per car (Should, 2011) or as high as 8 spaces per car for upper limit scenario (Chester et al., 2010).

2.2. Other impacts of cars in cities and factors of car dependency

In addition to consuming precious space when parked and travelling, cars generate other negative externalities (and we are excluding those due to their production and disposition since it is outside the scope of this paper). Gossling et al. (2019) includes 14 parameters to compare three cost-benefit analysis frameworks to assess transport projects. These parameters illustrate the diversity of impacts transport projects can have; they relate namely to climate change; air, noise, soil and water pollution, land-use and infrastructures, maintenance, resources, travel time, congestion, health impacts, accidents, safety and quality of life. Among the externalities most often related to car use we note air pollution, GHG emissions, oil dependency, traffic congestion, accidents (Parry et al., 2006) and socio-spatial inequalities (Aguilera and Cacciari, 2020). Parked cars in a city can namely have impacts on active modes. A survey made in Germany showed that residents most frequently observed conflicts where parked cars impeded walking and cycling (Kirschner, 2021). In line with the car fleet transformation observed in this research, Tyndall (2021) observes a similar transformation of the car fleet in the US and estimates how many pedestrian deaths could have been prevented by replacing Sport Utility Vehicles (SUVs) with cars, suggesting increased safety issues due to more imposing vehicles.

In line with the objective to reduce car use, various papers focus on car dependency and the factors that can reduce car ownership. Aguilera and Cacciari (2020) namely propose a review of what may drive de-motorization and the role of various transportation policies. In addition to social factors related to life-cycle stages, authors point the correlation between features of the home location and possibility to travel using other modes than the car. Albalate and Gragera (2020) have also found that introducing on-street paid parking to reduce visitor demand has a positive impact on the car ownership of residents echoing the importance of better managing parking spaces (Should, 2011). Similar results are obtained by Gonzalez et al. (2021) in Madrid where on-street parking regulation and low-emission zones reduced both car use and car ownership.

These research lead to common conclusions: private cars have a diversity of impacts (environmental, social, and economic), consume a lot of spaces and there is work to do to better balance the allocation of space so that more sustainable transportation options such as walking, cycling or more vulnerable people such as elderly, children and person with disability are better accounted for. This paper aims to provide new insights into the impact of cars and car trips in cities by proposing new metrics to quantify them.

3. Methodology

This section proposes a description of the various datasets used, the presentation of the study area as well as the definition of the various footprint indicators used for the analysis.

3.1. Study area

This research uses the Greater Montreal Area (GMA) as case study. As of 2018, year of the latest travel survey conducted in the region, the GMA covers an area of 9840 square-kilometers and a population of 4,47 million inhabitants. On a typical weekday, there are some 9,48 million trips conducted by the residents among which 70% rely on the private car (as driver or passenger) (ARTM, 2020). Two zoning systems are used in this paper to report results: the dissemination areas (DA) of the Canadian census (there are 6984 DA in the 2016 census covering the GMA) and eight regions as shown in Figure 1.

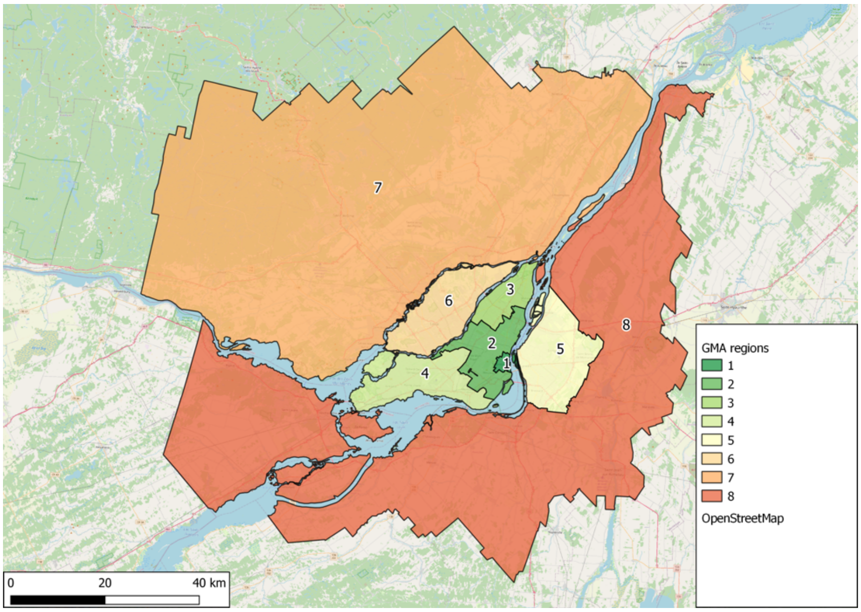

Figure 1 - Greater Montreal Area split into eight main regions

3.2. Data and processing approach

Various datasets are used in this research. They are detailed in this section.

<u>Road network</u>

Official data from the Statistics Canada were chosen to facilitate transfer to other metropolitan areas and census agglomeration even if more precise data were available for part of the GMA as well as to allow to analyze trends since those standardized files are available for the various census years. Road Network Files (RNF) from 2001 to 2016 are used (2001, 2006, 2011, 2016). Each RNF contains information about street names, types of roads, directions, and range of address (Statistics Canada, 2017)). It is also important to mention that for the census years prior to 2016, the RNF only contained a simplified geometry of the roads, meaning that for streets with a median separating the directions, there was only one street arc. This can have a huge impact when looking at the total length of the network.

<u>Car trips</u>

Data from the 2018 Montreal large-scale Origin-Destination (OD) travel surveys are used to analyze the movements of cars during a typical weekday (ARTM, 2020). These surveys have been conducted approximately every five years since 1970 and collect one-day trip diary among some 4-5% of the people aged 5 years and older. Car driving trips are extracted from the database and used to monitor the movement of cars over space during a typical weekday. Since only origin and destination points are collected, a trip routing algorithm is used to assume a plausible trajectory and estimate vehicle-kilometers. Hence, using time of departure and estimated travel time, it is possible to estimate, hourly, how many cars (as well as their footprint) are parked in various zones throughout the day. This process is based on the methodology proposed by (Diallo et al.2015).

<u>Private Car Fleet</u>

Three datasets are used to characterize the car fleet and its impacts. The first dataset consists of the car registration data from the Société de l'Assurance Automobile du Québec (SAAQ, 2020). This dataset contains, for each year, a list of all registered cars in the province of Québec with features such as make, model, model year, and weight. The second dataset consists of a database from Natural Resources Canada with a list of models for each year with the information about the fuel efficiency of car both in city and on the highway (Natural Resources Canada, 2022). The last dataset used consists of a database from the Canadian Vehicle Specification (Transport Canada, 2022) with a list of models for each year with the dimensions of the cars such as overall length, width, and height, among others. Combining these three datasets required some data processing, since the way the makes and models where codified in each of the three datasets is different. To do so, the trigrams method was used. This method uses the strings from the names of the makes and models and breaks them into smaller strings of three characters. Then all small strings are compared, and a percentage of similarity is computed. The higher the percentage, the more similar the strings are. For this analysis a threshold of 40 % of similarity for make and model was used to merge the three databases.

3.3. Footprint indicators

A diversity of indicators is proposed to quantify the spatial footprint of cars in cities, both immobile and when they travel. The energy footprint related to their use is also estimated but the life-cycle impact is not.

Network Coverage

Cars, among other types of vehicles, require transportation networks to be able to move. The first indicator is hence a road network coverage indicator that aims to report on the scale of the space dedicated to road network. To do this, a buffer is applied to the road segments to create a reticular space that approximates the footprint of streets across the region. A buffer of 50 meters is selected on the basis of the average built zone on both sides of an arterial street. Figure 2 illustrates the main steps applied to generate this sub-area, called the reticular area, representing footprint of the road network. In the left image, the RNF representing the center of the road segments is shown. In the center image, the buffer of 50 meters around the RNF lines is shown. Finally in the right image the reticular area which represents the area obtained when merging all the buffers is shown. The indicator is then the ratio of the reticular area and the raw area of a dissemination area. The highest the value, the highest the spatial footprint of the network. When the value reaches 100%, it means that the entire area is covered by the road network (with its buffer of 50 meters).

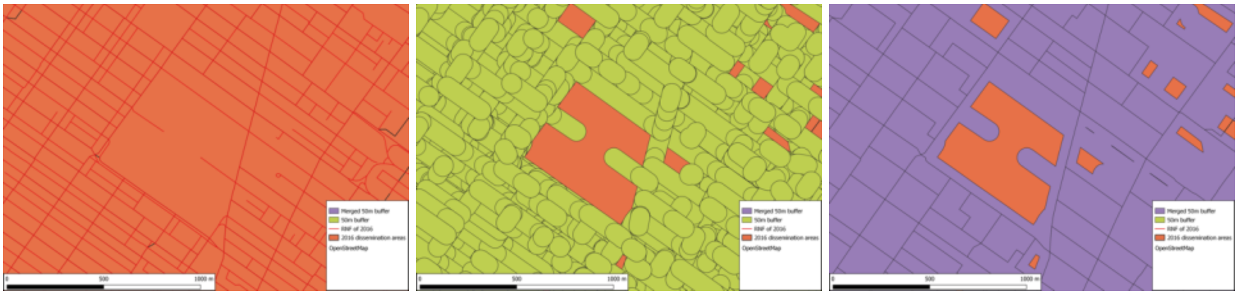

Figure 2 - Steps for the estimation of the network coverage

2D and 3D footprint

We typically count the number of cars and estimate vehicle-kilometers travelled. In the recent years, the shape of private vehicles has changed in all dimensions (length, height, width, weight) making such unit less adapted and not sufficiently precise to correctly assess the impacts of cars. In this perspective, we propose to examine the evolution and state of the spatial footprint of cars using their 2D and 3D dimensions.

It is possible to estimate how much space car use at the home location of their owners, when they are parked at a destination as well as over the kilometers they travel. Static footprint relates to when the cars are immobile while dynamic footprint refers to the trace they leave when travelling. For both points of view, we are using the square meters (m^2) or cubic meters (m^3) to report their static use of space and the m^2- kilometers or m^3-kilometers to assess their use of space. Figure 3 illustrate how the dimensions of a vehicle (length, height, width) are used to generate a 2D or 3D spatial footprint.

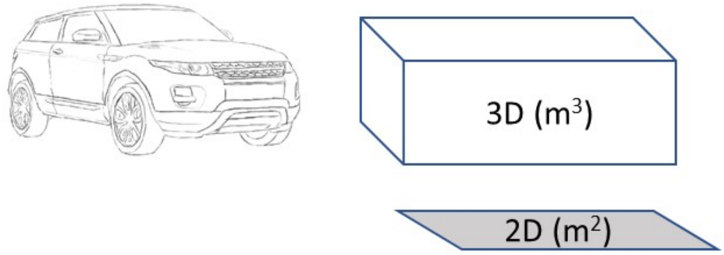

Figure 3 - Illustration of the conversion of a vehicle into 2D (m^2) and 3D (m^3) footprint

Analyzing the footprint at the home location is easy since we use the home location of the car owner to assess how much space is required. To analyze the use of space by cars at their destinations requires to process trip data.

Energy *consumption*

Energy consumption refers in this paper to the liters of fuel consumed for car driving trips. In addition to estimating the liters required to reach activity locations per type (work, study, leisure, shopping and others), an efficiency indicator is proposed. Using the duration of activity conducted at the destination, a liter of fuel consumed per hour of activity is estimated. Activity durations are obtained from regional travel surveys while liters consumed are estimated using plausible trajectories of car driving trips and average consumption rate of cars owned in the various zones of the area.

4. Results

This section first presents some important trends with respect to the private car fleet of the GMA and then presents the results of the indicators' estimation.

4.1. A priori trends on personal cars

First, we examine some important trends with respect to the private car fleet.

Evolution of the private car fleet

The numbers of cars registered in the Greater Montreal Area is steadily increasing. From 2001 to 2019, the number of private cars owned increased by 40% while the population aged 20 years and older (as reported by the population estimates proposed by ISQ (ISQ, 2022) only increased by 23,7%. Hence, the car population is increasing much faster that the adult population meaning that access to private cars has highly increased over the last 20 years (see Figure 4).

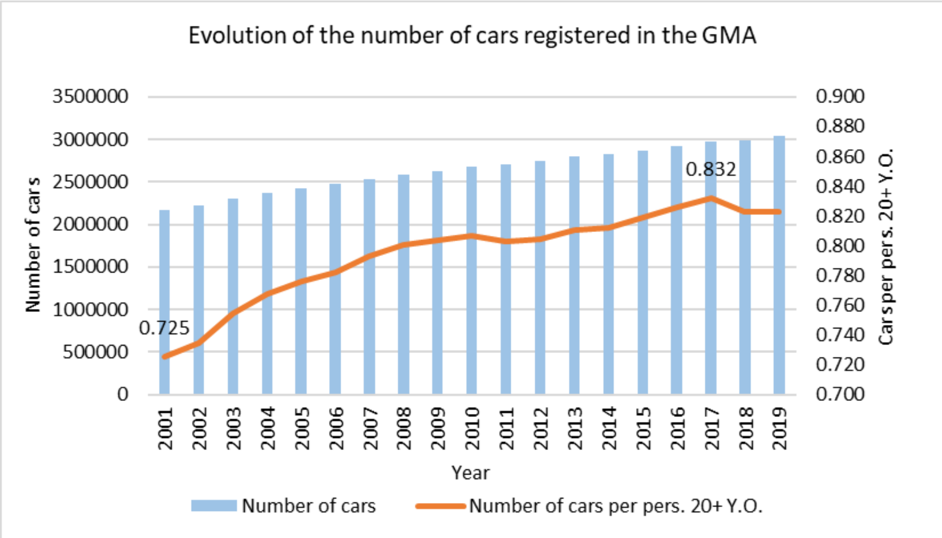

Figure 4 - Evolution of the number of registered cars and cars per 20 years old in the Greater Montreal Area

Share of SUV

In addition to being more numerous, car features have changed. We are seeing more and more SUV in the fleet of private vehicles used for daily trips. The share of light trucks in the fleet has increased from 20,2 % in 2000 to 40,8 % in 2020 (an increase of 294% in number of trucks).

Dimensions of personal vehicles

To understand how important the composition of the fleet is changing, we are examining the evolution of some of the main features namely length, height, width and weight of personal vehicles owned in the GMA. From 2000 to 2019, the average length of personal vehicles has remained quite stable at 458.2 cm (it has though increased by 0,24% at the Quebec province scale). However, other parameters have increased: cars are 2,84% larger, 5,55% higher and 17,48% heavier in 2019 than in 2000.

4.2. Network Coverage

From 2001 to 2016, the share of the Greater Montreal Area which is covered by the road network has increased from 21,8% to 22,0 % with a much more important increase in the suburban areas. This is, of course, at the detriment of green spaces and agricultural land. Maps of Figure 5 show that in 2016, values vary from 2.9% to 100% and that coverage is typically higher in the central areas.

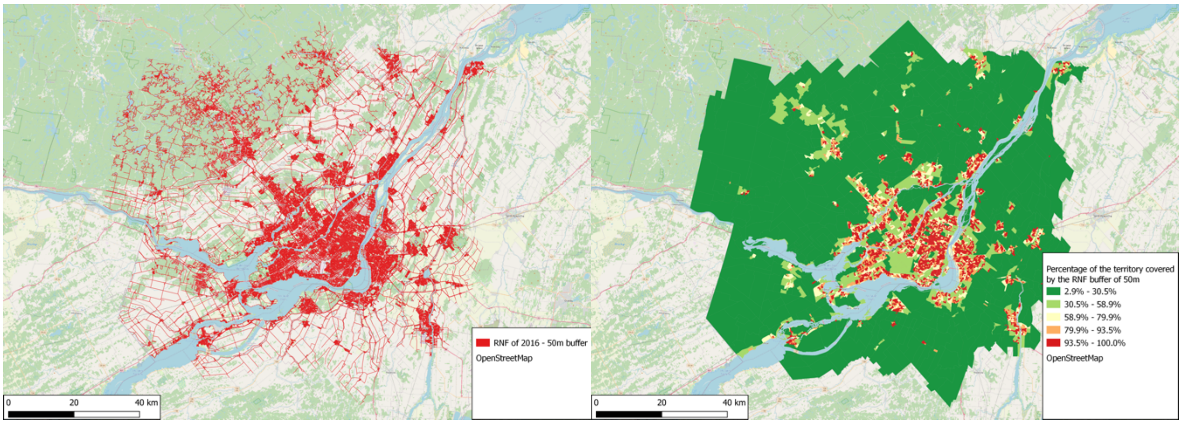

Figure 5 – Reticular area in 2016 (left) and network coverage indicator, per dissemination area, in 2016 (right)

4.3. Spatial Footprints of cars

The dimensions of the personal car fleet allow to assess the 2D and 3D footprint of cars in the GMA.

2D and 3D average footprints

Figure 6 presents the evolution of the average 2D and 3D footprints of private vehicles owned in the GMA. We see a constant increase in both metrics. From 2000 to 2019, the average 2D footprint increased by 2,68% to reach 8,31 m^2 per car on average while the 3D footprint increased by 8,38% to reach 12,82 m^3.

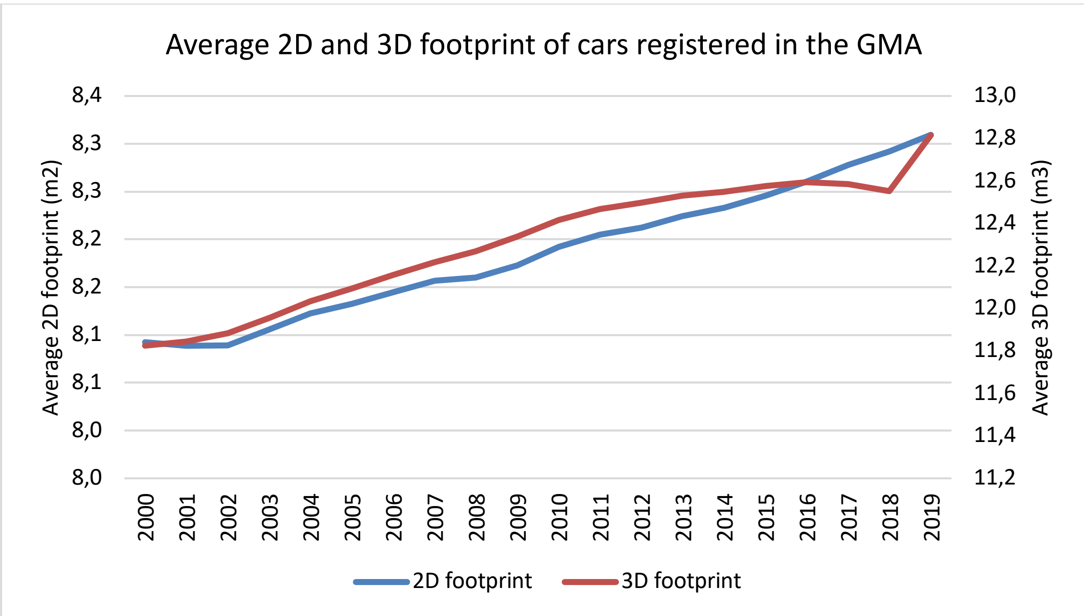

Figure 6 - Evolution of the average 2D and 3D footprint of cars registered in the Greater Montreal Area

Spatial distribution of 2D and 3D footprint of cars

It is possible to assess the area and volume occupied by cars at their home location (at night). Figure 7 presents the density of both metrics over space. Footprints are normalized by the area of the various zones to allow comparison.

We clearly see an important decreasing gradient of the density of both m^2 and m^3 of cars from downtown to the suburbs. Hence, while car ownership is higher in the suburbs, the density of car footprint is more intense in central areas.

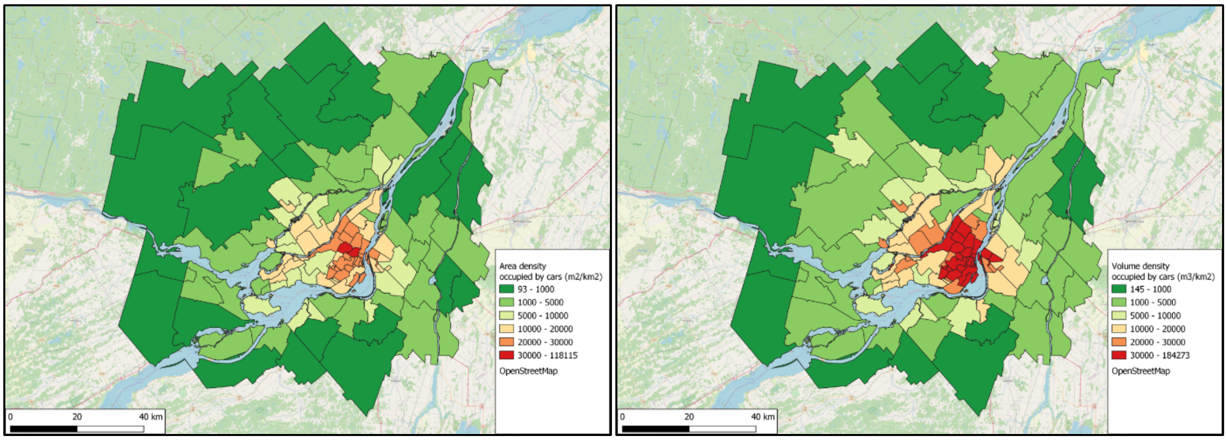

Figure 7 Area (m^2/km^2) (left) and volume (m^3/km^2) (right) density occupied by cars

Proposing new metrics aims to illustrate that the impacts of cars in cities are increasing faster than the number of cars itself. When we analyze the growth in the number of cars and the growth of their 2D and 3D footprints, we see a rising problem. Using 2001 as the starting point, we observe in Figure 8 that the percent increase in 2D and 3D footprints is higher than the percent increase in cars at any point in time and that the differences are increasing over time. Having more cars in cities in one thing but letting the footprint of each one increase exacerbates the negative impacts.

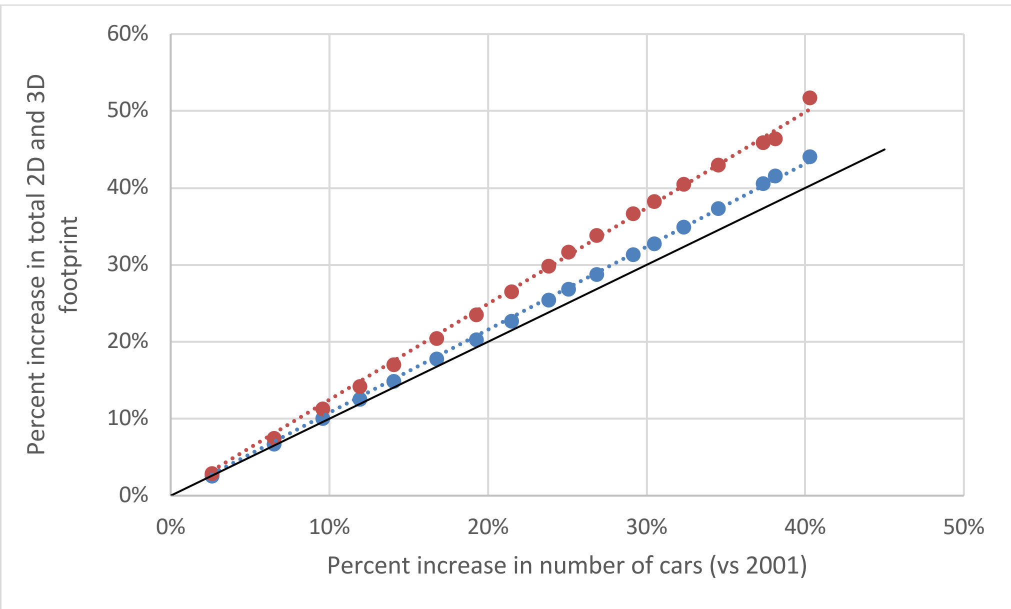

Figure 8 - Comparison between the percent increase in cars and the percent increase in total 2D and 3D footprints

4.4. Dynamic footprints of cars

The previous situation is even worse when we account for the daily movement of cars. Through daily travels (as observed by travel surveys), the number of cars in central areas is higher while suburban areas are emptied. The result is an increased 2D and 3D footprint of private cars in many of the areas. Figure 9 presents the fluctuation of the spatial footprint in the GMA regions over a typical weekday (in 2018). As expected, regions located further from downtown have a reduced footprint while the regions of the Montreal Island undergo increase impacts of traveling cars. For the central business district, the footprint of cars is 229% more important both for the 2D and 3D footprint at 1 pm than during the night. Three other regions have an increased footprint of cars during the day namely Montreal center, the west part of the island and Longueuil. This raises questions with respect to the unbalance between those who use and own cars and those who inherits the negative impacts of their presence.

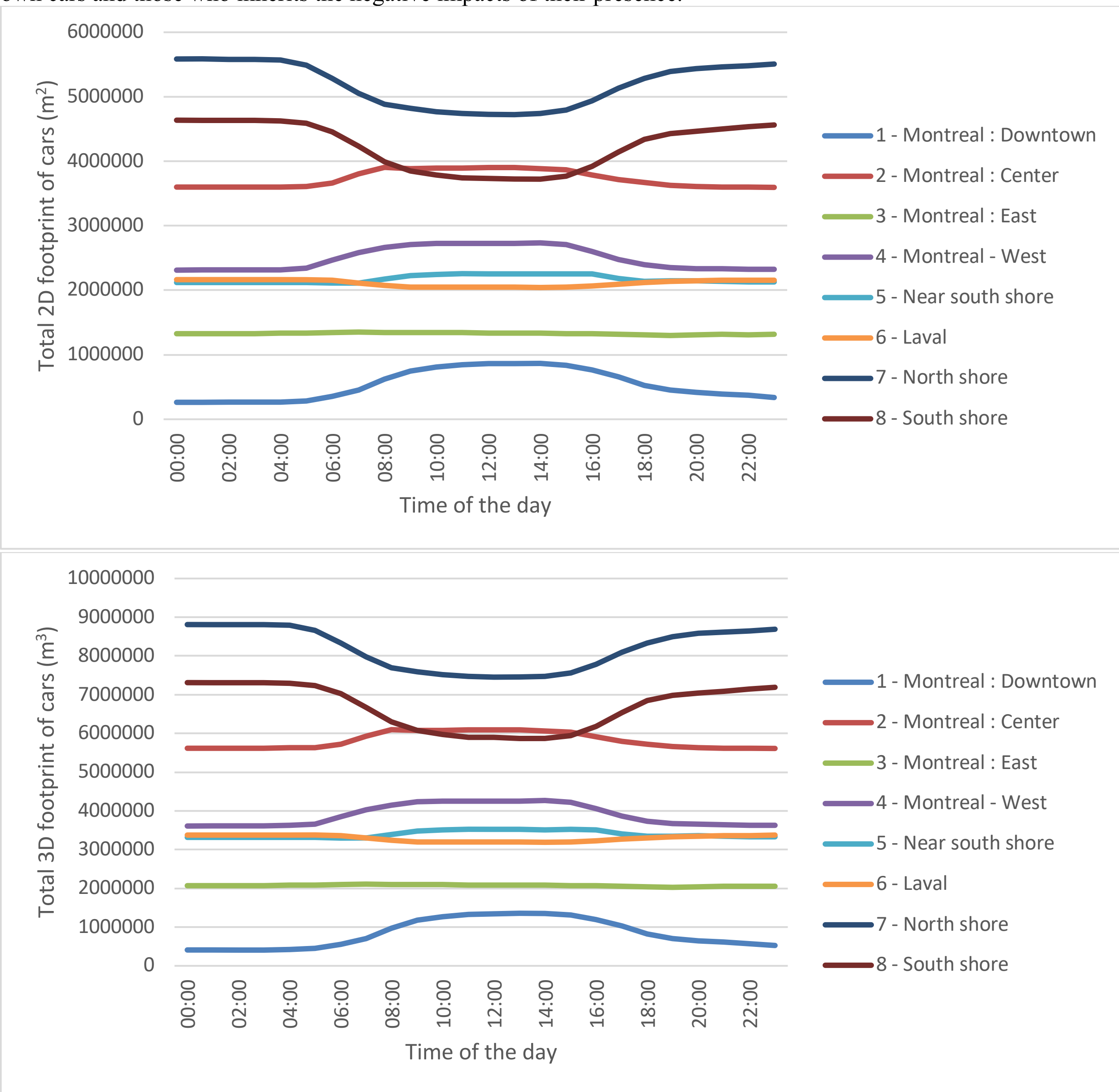

Figure 9 - Evolution of the total 2D (top) and 3D (bottom) footprints or cars over a typical weekday

In addition to consuming space at the home location and at their various destinations, cars use space when they travel. To improve the measurement of this space use over the road network, m^2-km and m^3-km are estimated. Using data from the 2018 OD survey (and the 2008 survey for trend analysis), we estimate that there are 74,7 million vehicle-kilometers travelled daily (car driving trips) which represents 34% increase in comparison with 2008. In 2018, this represents 619,3 million m^2-km and 972,1 million m^3-km with respective increases of 37% and 41% respectively. This further confirms that the 2D and 3D footprints increase much faster than the vehicle-kilometers travelled and that the global spatial impact of car use is more important than expected due to important transformation of the personal car fleet.

It is also possible to estimate how much car space and volume are consumed by residents of the various areas. The scale of the footprint is quite different depending on home location. Figure 10 presents the amount of m2-km and m3-km consumed per person based on home location. People residing in the north shore have a footprint which is five times more important that residents of the central part of the area. Again, we see an important gradient with important increase of 2D and 3D footprints of car trips.

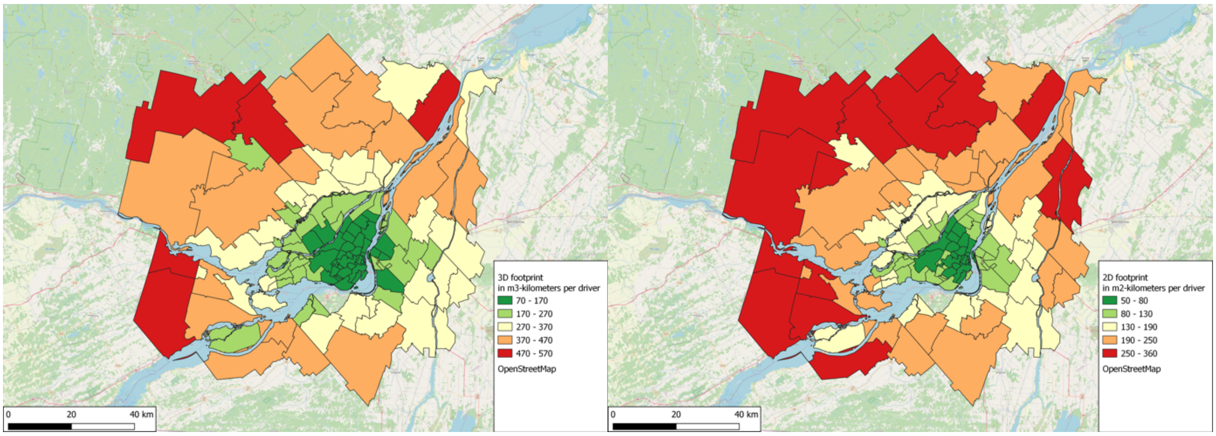

Figure 10 – m2-kilometers per driver (left) and m3-kilometers per driver (m^3/km^2) (right) based on home location

4.5. Energy footprint

Of course, in addition to consuming space, cars consume energy. In this paper, we are neglecting the impacts of car construction and are focusing on the energy due to travelling. To further the view, we estimate energy consumption of car trips by activity type as well as the liters of fuel consumed by hour of activity conducted at the destination.

Energy consumption to reach activities

Again, using data from large-scale OD surveys of 2008 and 2018, we estimate the energy consumed daily to reach main activity locations (see Table 1). All activity types have seen important increases in liters of fuel consumed and work is the most energy consuming activity daily.

Table 1 - Liter of fuel consumed daily for various types of activities (2018) and percent increase vs 2008

Activity type	Liters of fuel per day (millions)	Percent increase vs 2008
Work	2.04	12.6%
Study	0.23	20.3%
Leisure	0.64	34.4%
Shopping	0.41	34.8%
Other types	0.75	29.5%

Energy consumption per hour of activity

To further assess energy consumption, the liters per hour of activity conducted is estimated. This can be viewed as an efficiency indicator. Hence, travelling 45 kilometers for an 8-hour activity may seem more efficient than travelling the same distance for 10 minutes one. To compare efficiency of energy consumption, we compare the liters of fuel consumed per hour of activity for the various activity types. Figure 11 first shows that for all regions, work and study activity have the highest efficiency and that the energy consumption per hour has slightly increased from 2008 to 2018 (+1,1% for work and +2,1% for study). The other types of activity (mostly drive someone somewhere and go get someone) have the highest energy footprint per hour of activity. In average, the energy consumption for this type of activity has increased by 22,3% over 10 years. Those activity are typically short (around 1,3 hours in 2018) and the distance travelled long (9,3 km on average). Shopping activities also have an important energy footprint per hour especially in the suburbs where distances travelled to reach shopping locations are larger than in other regions while durations are similar or shorter.

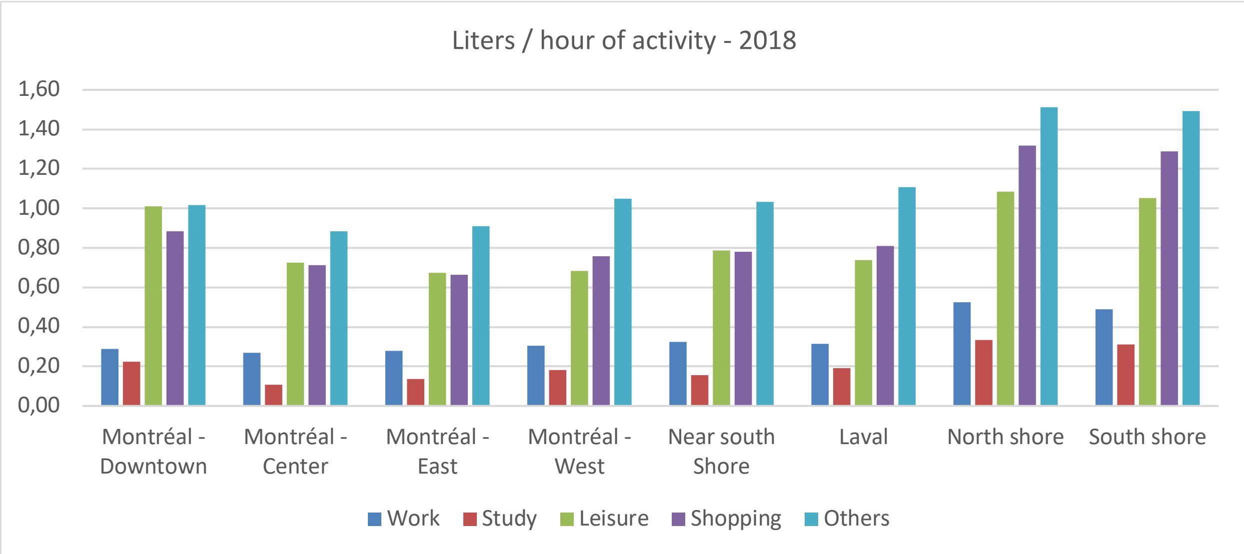

Figure 11 - Liters of fuel consumed per jour of activity based on home location (2018 OD survey)

4.6. Other impacts of car fleet transformation

To further demonstrate how important accounting for the transformation of the fleet is in assessing the impacts of cars in cities, we are proposing three illustrations. The first one shows the impacts of larger cars on parking capacity, the second one estimates the impact of fleet composition, namely the presence of SUV, on congestion levels while the third one estimates the fuel savings that would have occurred if residents had made different car choices.

Longer cars mean less parking spaces

To estimate the impacts of longer cars on parking capacity, we simulated the impact of different car spatial footprint on number of parking spaces available in three boroughs of the Montreal Island. Using the methodology developed by Bourdeau (2014), number of on-street parking is estimated using three different parameters of space requirement to park a car. When the average space requirement per vehicle increases from 5 to 5,5 meters, the number of parking space available is reduced by 9,9%, while it is further reduced by 5,9% when requirements reach 6 meters and an additional 11,6% reduction for 6,5 meters requirement. There is hence, on average, a quarter fewer parking spaces if car require on average 6,5 meters to park instead of 5 meters.

Longer cars and SUV mean more congestion

Road capacity is typically quantified using the "passenger car equivalent" unit to account for the presence of diverse types of vehicles such as buses and trucks. With the transformation of the car fleet, conversion factors are becoming necessary as well for personal vehicles. Zahiri and Chen (2018) suggested conversion factors for three types of cars (small cars, SUVs and standard cars) and two weather conditions (sunny and rainy). Due to their scale (namely width and height) which limit visibility of the following cars, authors propose a conversion factor of 1,26 for SUVs in sunny conditions (1,31 when it rains) meaning SUVs consume more road capacity than a standard car. For a theoretical road segment (one road segment with a capacity of 4000 pce/hour) and using the 2019 fleet composition as reference, we estimate that accounting for the proposed conversion factor for SUVs translates into reaching congestion threshold with 2,65% less vehicles (6,54% in rainy conditions). Just due to fleet composition, under constant demand, travel time would increase.

Lost fuel savings

Over time, the fuel efficiency of cars has improved significantly. One particular car brand and model today consumes less than it used to ten years ago. Unfortunately, this improved efficiency was not used to reduce fuel consumption but instead to buy larger cars. It is possible to estimate the scale of this lost opportunity to reduce fuel consumption by comparing the liters of fuel consumed daily with the current fleet to an optimal fleet composition. To do this, we identify, in each sector (based on home location), the ten most fuel-efficient cars owned and assume that residents of the same sector could have chosen these cars. For the Greater Montreal Area, a reduction of 37,8% liters of fuel daily would have been possible under this scenario (some 7,9 million liters per day), a significant amount of energy savings all without changing travel behaviors.

5. Conclusion

This paper proposed innovative ways to account for the spatial and energy impacts of cars in cities. Time-series data illustrated how importantly the features of private cars have evolved over time and how changing the metrics used to measure their movement across space can offer better precision. Various estimations showed that just monitoring the number of cars owned or the vehicle-kilometers travelled is insufficient to fully capture the spatial impacts of cars over an area, namely their increasing impacts. Accounting for the features of cars using their 2D and 3D footprints is one way to report these impacts at the home location, at the various destinations reached by cars as well as the consumption of road capacities. The paper also proposed ways to quantify the efficiency of energy consumed by cars to reach and conduct various types of activities. While there were plenty efforts to convince people to shift modes for work trips, it shows that shorter activities such as those related to shopping and others (namely drive people around) would benefit from improve energy efficiency. The paper also proposed illustrations of potential impacts of longer cars and increased share of SUV.

There are many limitations to this research, some due to data limitation and others to methodological choices. Among them, we can note the lack of precision for road data that limit the ability to adjust the buffer to specific types of roads and better report their footprint (road and built surrounding) over space. The private car fleet data also required to merge three different datasets using the trigrams method, meaning that not all vehicles, makes and models were considered in the estimations. Vehicle-kilometers were estimated using a routing algorithm since only origin and destination points are collected during surveys. They may be under or overestimated.

Developing innovative ways to quantify impacts is a step forward in more precise reporting and opens the door to other strategies to mitigate these impacts. Future work should focus on the refinement of the estimations, for instance using more precise data for the road network coverage. Another important aspect that was not covered in the paper is the life cycle of car use, from the car plant to the landfill site, as well as the resources consumed for infrastructure construction, exploitation, and maintenance. This will become increasingly important with the increasing share of electric cars on the road.

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