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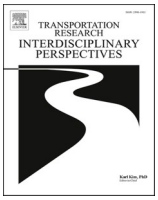

Travel behaviour and greenhouse gas emissions during the COVID-19 pandemic: A case study in a university setting

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ABSTRACT

The year 2020 was characterized by a marked shift in daily travel patterns due to the COVID-19 pandemic. While we know that overall travel decreased, less is known about modal shift among those who continued to travel during the pandemic or about the impact of these travel-behaviour changes on transport-related greenhouse gas emissions. Focusing on a university setting and drawing from a travel survey conducted in Fall 2020 in Montreal, Canada (n = 3358), this study examines modal shifts and quantifies greenhouse gas emissions at three time periods in the year 2020: pre-pandemic, early pandemic, and later pandemic. The pandemic resulted in a sharp reduction in travel to campus. Among those who continued to travel to campus (n = 1580), car-to-final destination mode share almost tripled at the start of the pandemic. The largest modal shift seen was the transition from walking, cycling, and transit, to driving at the beginning of the pandemic. Reductions in overall travel resulted in lower overall transport-related greenhouse gas emissions. However, if modal changes persist once students, staff, and academics return to campus, the transport carbon footprint is projected to increase above pre-pandemic levels. These results highlight the importance of putting in place policies that support a return to sustainable modes as universities and businesses reopen for in-person activities.

Introduction

Outbreaks of COVID-19 began in late 2019 and spread to many countries by early 2020. On March 11, 2020, the World Health Organization declared the outbreak a pandemic. In Canada, the setting of this study, community transmission was confirmed in mid-March 2020, followed shortly by the announcement of states of emergency in all provinces (Tian et al., 2021). Reducing mobility has been a key focus of the COVID-19 public health response: At their core, common policies such as work-from-home orders, closures of non-essential businesses, and social/physical distancing aim to reduce the interactions between people to reduce the spread of the virus (De Vos, 2020; Tian et al., 2021). Further, global analyses support that social distancing through mobility restrictions reduced virus transmission (Nouvellet et al., 2021). As such, it is perhaps no surprise that the COVID-19 pandemic and the ensuing public health response have resulted in drastic changes in travel behaviour globally (Nouvellet et al., 2021; Warren and Skillman, 2020; Borkowski et al., 2021; Gao et al., 2020). Even with these policies in place, almost two million Canadians contracted COVID-19, and approximately 30,000 (at the time this paper was written) have lost their lives to the virus (Government of Canada, 2021).

Some studies have begun to parse out the impacts of the pandemic on travel behaviour. Overall, it has become clear that the public health emergency resulted in reduced travel demand, both in terms of international travel and daily travel patterns (Nouvellet et al., 2021; Tian et al., 2021; Warren and Skillman, 2020). Take, for instance, the commute to work. While only 4.1% of Canadians teleworked before the pandemic, 21.6% did so in June 2020 (Savage and Turcotte, 2020). This transition to working from home resulted in a decrease in overall commuting (Savage and Turcotte, 2020). Overall, this resulted in lower traffic congestion levels. For instance, peak rush-hour congestion in Montréal decreased 75% at the beginning of the COVID-19 restrictions (Tian et al., 2021). When the City began to re-open, traffic levels did increase again, though not enough to match pre-pandemic levels (Tian

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et al., 2021). Similar trends have been identified in the United States where median travel distance dropped drastically in March 2020 and bounced back during reopening periods, however, geographic heterogeneity exists across the country (Gao et al., 2020).

Not everyone, of course, can work from home. Essential workers continued to commute during the COVID-19 pandemic. Many people, for example, were still obligated to travel for essential purposes, such as grocery shopping or to attend in-person doctors' appointments. Evidence is emerging that certain travel modes were favoured, while others were avoided, for these essential trips. Public transit, in particular, has been altered by the pandemic. Many cities experienced a sharp decline in public transit use, and a resulting drop in revenues (Tirachini and Cats, 2020; Liu et al., 2020). Results from Statistics Canada's Canadian Perspectives Survey Series found that 94% of those who used transit before the pandemic and who said they were not comfortable going back to their usual place of work pointed to public transport as one of their concerns (Savage and Turcotte, 2020). While car use for the commute to work declined in Canada in absolute terms, this drop was far less pronounced than for public transit (i.e., from 74.5% to 67.5% vs 12.7% to 3.1%) (Savage and Turcotte, 2020). A study in Sicily, Italy, found that those who express more concern and anxiety around COVID transmission in public transport were more likely to walk post-lockdown (Campisi et al., 2020). Cycling, on the other hand, witnessed a small boom in many cities. Increased cycling rates in many cases were accompanied by supportive infrastructure and policies (Kraus and Koch, 2021; Buehler and Pucher, 2021; Dunning and Nurse, 2021).

Though we know that travel behaviour change occurred during the pandemic, researchers have just begun to examine the relationship between travel behaviour and greenhouse gas emissions during the pandemic. Looking across 69 countries, Le Quéré et al. (2020) found that emissions from surface transport fell by 36% by April 2020, representing approximately half of total emissions change due to the pandemic. Further, Lokesh and Marsden (2021) calculated how commute length and resulting CO_2 emissions changed in the UK between February 2020 and June 2020 drawing on cell phone data. High car ownership and the presence of occupations that can easily transition to working from home were associated with larger CO_2 reductions relative to the period before the pandemic. In another study, microscopic simulation was used to quantify the effects of reduced traffic demand during COVID-19 on air pollution and emissions (Du and Rakha, 2020). Results indicated that vehicle emissions decrease at a higher rate than traffic demand (e.g., a 55% reduction in traffic demand can result in a 65% reduction in emissions). The impacts of travel behaviour change, i.e., the shift from one mode to another, on the sustainability of daily travel patterns during and after COVID-19 remains unclear. For instance, while lower overall travel and higher cycling rates may lead to lower total greenhouse gas emissions, lower public transport use and higher proportional car use may result in higher emissions as more people return to work. This paper responds to this knowledge gap by quantifying the greenhouse gas (GHG) emissions based on travel mode throughout the pandemic.

This paper contributes to the small, but emergent, literature on the impact of the COVID-19 pandemic on daily travel behaviour and transport-related greenhouse gas emissions. Focusing on essential workers and students who continued to travel to a university setting during the pandemic, this paper examines modal shift and quantifies transport-related greenhouse gas emissions across three 2020 time periods: pre-pandemic, early pandemic, and later pandemic. The University setting in question is McGill University, a publicly funded higher education institution located in Montréal, Canada with approximately 40,000 students, faculty, and staff. The paper also presents greenhouse-gas-emission projections based on two mode-share scenarios after reopening. Beyond contributing to the literature by exploring the impacts of COVID-19 in a university setting, a site that yet to be studied, this paper also adds a temporal dimension to current work by examining modal shift and emissions at three time periods. The hope is that this research will help inform universities and large businesses about how best to return to campus with sustainable travel in mind.

Data and methods

Survey tool

This study draws on the 2020 McGill Sustainability Survey. This 15-minute, online survey was developed and distributed by the McGill Office of Sustainability and covered topics including perceptions of McGill sustainability efforts, interest in incorporating sustainability concepts into course content, and commuting patterns. Questions focused on commuting included the average number of weekly trips to a McGill-related destination during three time periods in 2020, as well as the following factors: home and McGill destination locations; university affiliation; typical travel mode for trips to McGill affiliated locations; and vehicle make, model, and year used for motorized portions of commutes.

McGill is a publicly funded research-intensive university attended by approximately 40,000 students, 69% of which are undergraduate students. While almost half of McGill students originate from Quebec, 30% are international students (McGill University, 2021). We considered these trends across McGill's different locations, which include the primary downtown campus, the McGill University Health Center which is also located downtown, but in the western end of the city's core, and the secondary Macdonald campus (Fig. 1). The three time periods sampled were designed to capture seasonality and differences in COVID-19-related restrictions; they were: pre-pandemic (January 2020), early pandemic (April 2020), and later pandemic (September 2020). Because March 2020 represented the period of greatest disruption, travel information for this month was estimated based on previous and subsequent periods. The McGill destination locations considered are displayed in Fig. 1.

An email invitation was sent to all faculty and staff, as well as a subset of 10,000 students to avoid survey fatigue among students, who generally receive several surveys per year from various offices at McGill University. Faculty, staff, and students on a leave of absence, as well as those visiting from another university were excluded. The survey recorded 3358 total responses. Of these, 1580 responses were retained for use in this analysis based on sufficiency of the provided information to estimate commute-related greenhouse gas emissions and reasonableness. These are students, faculty or staff who traveled to McGill at least once in the three study periods. A total of 778 responses were removed because people provided no home location or reported a home location too far outside the Montreal region to constitute a reasonable commuting distance to a Montreal-region destination (Commuters to

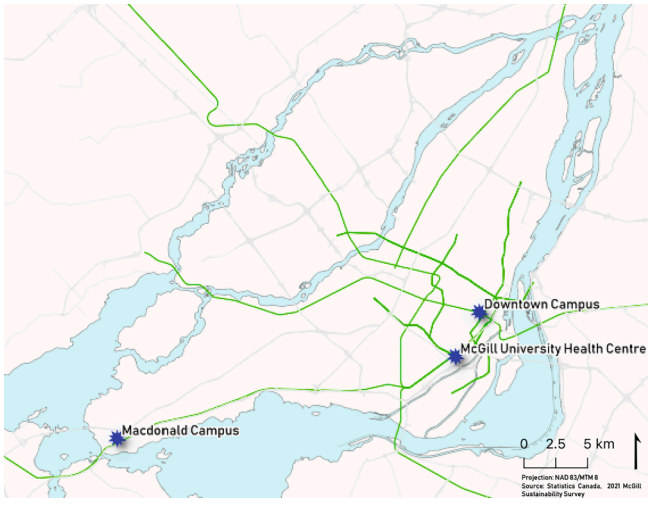

Fig. 1. Study area description.

McGill's Outaouais campus were not included). Another 820 people reported no travel at all to any campus location in January and February, well before the COVID-19 pandemic began to alter daily patterns of life in Quebec. Given the presumed unreasonableness of this response—particularly among full-time employees and faculty—these people were removed from the sample. Finally, eight respondents indicated they used transport services in January and February that were unavailable during the winter months, i.e., Bixi the local bicycle sharing service in Montreal, which operates from April to November, these were also removed. Of note, many responses removed for other reasons also contained absurd or unreasonable answers regarding vehicle ownership and transport services (e.g., asserting ownership of a Sherman M4 tank). After preliminary cleaning, another 172 responses were removed because they did not contain sufficient information regarding travel modes for use in estimating total annual commuting GHGs or had home addresses from which a travel route could not be calculated.

To ensure representativeness, retained responses were weighted based on home location and University affiliation using the *anesrake* package for the R statistical software program. The university provided the research team with an anonymized summary of the number of faculty, employees, and students by home address postal code to establish target weights. These, in turn, were aggregated to seven larger regional zones to which survey respondents also had been assigned. Expansion factors were then calculated based on the total McGill population and the sample response weight. The resulting expanded responses are only an approximation of the actual McGill population because of various exclusions from the university summary. For example, unpaid and casual appointments, as well as non-credit, exchange, and visiting students were excluded. In addition, many home postal codes for students in the summary reflect permanent addresses, not local Montreal addresses.

Variables

Commuting patterns (weekly trips, mode) and university affiliation were self-reported in the travel survey while greenhouse gas emissions were calculated.

To generate the greenhouse gas emissions, travel distances and emission factors were calculated. Travel distances for GHG-emissions-generating trips were modeled using the *r5r* package for the R statistical software program, which provides a link to the java-based R5 multimodal routing engine developed by Conveyal (Pereira et al., 2021). Travel time and distances were not modeled for nonmotorized or transit portions of trips. Transit was excluded from the greenhouse gas calculations as regularly scheduled public transport service emissions are not affected by the number of people using the service, at least in the short term. In other words, whether McGill's essential workers were using transit or not, the service would emit the same quantity of GHG.

For non-transit, motorized trips to final destinations, routes were selected based on the shortest available travel time from respondents' home locations to their campus destinations. A commuter's actual route may depart from the shortest-duration trip for a variety of reasons, including stopover destinations or personal preferences. Estimated trip distances were calculated from home locations directly to campus destinations, and do not therefore include additional driving distance and time spent searching for parking.

For non-transit, motorized trips to public transport, routes were calculated from a respondents' home location to the nearest boarding location for their selected service based on the shortest travel time. For example, travelers who indicated they took a car to a particular commuter train line (the exo service) were routed to the nearest exo train or bus station served by the line they indicated they used in the survey. In practice, travelers may not necessarily select the closest station, which is a limitation in our calculations as such information was not provided in the survey.

To calculate GHG emissions per kilometre, Natural Resources Canada's (NRCAN) vehicle fuel-consumption estimates were obtained from the Canadian government's open data portal (Government of Canada, 2021).[4] City, highway, and combined fuel economy figures expressed as litres per kilometre were then linked to survey respondents' reported vehicle makes, models, and years using a "fuzzy joining" software package to address input errors, such as misspellings. Matches were then manually confirmed. Where respondents provided only a vehicle make and year, the corresponding average fuel economy for the make and year from the NRCAN data was used. Where respondents provided only a model, the average for the model over the model years available in the NRCAN data (1999–2021) was used. Approximately 50 respondents taking motorized, non-transit trips provided no vehicle data, or their vehicle data could not be linked. For these, we relied on the average fuel economy of vehicles used by survey respondents with the same University affiliation. Because most reported trips took place under "city" or otherwise congested conditions we used city fuel economy ratings for each car. We similarly relied on calculated average survey values for vehicular travel by taxi or ride-hailing trips because the makes and models of these vehicles were unknown.

We then converted litres-consumed to the principal GHG emissions from motor vehicle fuel combustion—carbon-dioxide (CO_2), methane (CH_4), nitrous oxide (N_20)—using Environment and Climate Change Canada (ECCC) estimates. According to ECCC, one litre of gasoline burned results in 2307 g of CO_2, 0.100 g of CH_4, and 0.02 g of N_20. Relatively few respondents reported using a diesel-powered car. Although diesel fuel may generate more emissions per litre than gasoline, they often consume less fuel per kilometre. For simplicity, we relied solely on gasoline emissions.

Finally, we converted the GHG emissions to their CO_2-equivalent value (CO_2e). Each of the principal gases possesses a different global warming potential. Methane is approximately 25 times more powerful than carbon-dioxide and nitrous-oxide is approximately 298 times more powerful than carbon dioxide. Fully battery-electric motor vehicle GHG emissions were set at zero based on Quebec's hydroelectrical grid. In practice, this may underestimate actual emissions attributable to hydroelectric production.

None of the GHG exhaust emissions calculations for any vehicle type accounts for other harmful or environmentally damaging pollution, such as particulate matter from brake dust and tires.

For each respondent, CO_2e for each of the studied time periods—January to February, April to August, and September to December—was calculated according to the following formula:

> Total individual incremental CO_2e = Weeks in period * typical weekly one-way trips * 2 daily trips * (motorized, non-transit travel distance in km/number of people in a carpool to reflect proportional emissions) * CO_2e per kilometre

These results were then multiplied by the estimated survey response expansion factors to generalize the findings at the entire McGill University population.

March emissions were calculated based on one week of the January to February emissions plus one week of the April to August emissions. It was assumed that no travel took place during the first two weeks of March 2020 in response to initial COVID-19 restrictions lockdown as the University was adjusting policies and travel to campus was prohibited except in very special circumstances until the government announced the rules for large businesses. All expanded CO_2e emissions were summed.

We also generated projections of future annual transport-related greenhouse gas emissions to explore the potential impact of a prolonged shift in commuting mode share under two different scenarios for ongoing remote learning or remote work. For both hypothetical

[4] Fuel-consumption data on the site are stored in separate files for different model-year periods and fuel type. We manually combined the datasets.

scenarios, we assume that late COVID-19 travel mode share—represented by mode choice in September 2020—endures. In the calculation of mode share, we necessarily include only those people who reported making at least one trip to a McGill location during each of the studied periods. In other words, our projections assume that the people who continued to travel were representative of those who didn't travel but who will eventually return to campus by the end of the pandemic. For the first scenario, we assume that weekly campus visits to campus by students, staff, faculty will remain suppressed at their September 2020 levels thanks to a combination of ongoing remote instruction and work. In the second scenario, we explore the potential impact of a full return to on-campus instruction and work by assuming that the frequency of weekly campus visits reverts to its pre-COVID-19 level (as represented by the reported number of trips in January 2020), but using the modes observed during the pandemic. To generate annual projections, we calculated average individual weekly emissions for each category of university of affiliation, multiplied by the number of people in each category at the university, multiplied by 47 working weeks in a regular year.

Analysis

This paper analyzed the 2020 McGill Sustainability Survey following the steps outlines in Fig. 2. First, we calculated commuting patterns at three time periods in 2020: pre-pandemic (January- February), early pandemic (April-August), and later pandemic (September-December). This analysis is based off weekly trips, travel mode (i.e., sustainable modes (walking, cycling, and transit), car to destination, and car to transit), and university affiliation (faculty and other academic staff, administrative staff and trades, and students). Then, greenhouse gas emissions were calculated (as described above) at the three time periods. Descriptive statistics were used to assess GHG emissions and vehicle fuel economy differences across University affiliation. Finally, projected GHG emission were calculated for two scenarios. In the first scenario, the projection is based off later pandemic (September- December 2020) mode share and trip frequency. In the second scenario, the projection uses later pandemic (September – December 2020) mode share and early pandemic (September – December 2020) trip frequency.

Results

The study's results are presented in two sections. The first explores commuting patterns among essential workers and students with a need to be on campus in 2020, capturing pre-pandemic (January-March), early pandemic (April to August) and later pandemic (September to December) trends. Then, these trip characteristics are analyzed by university affiliation, namely across students, academic staff, and administrative staff. In the second section, estimated transport-related greenhouse gas emissions in 2020 are presented. Here, emissions are presented across 2020 for students, staff, and academics. Then, projected emissions under two scenarios for when the university returns to in-person activities based on 2020 travel behaviours are presented.

Commuting patterns

The number of commuters dropped dramatically from 34,562 to 11,206 to campus between January and April 2020. In other words, the number of people who reported visiting a McGill campus at least once during the studied time periods dropped approximately 65% after stay-at-home orders were announced in March 2020. This number of commuters did increase slightly between April and September (from 11,206 to 12,258), though it remained drastically lower than pre-pandemic levels. This slight increase is likely due to variations in the levels of lock-down due to the COVID-19 pandemic measures imposed on McGill across the year as the government of Quebec did change the restrictions and rules in a continuous manner.

The number of individual trips to McGill-related locations per week also declined sharply, falling more than 80% from 151,431 in January to slightly more than 25,000 in April (Table 1). In April, car-to-final destination mode share almost tripled from 9 to 26 percent. The substitution of less sustainable modes for trips to McGill locations continued—moderating slightly— when the fall academic term began.

The arrival of the pandemic and associated public-health measures also led to a profound shift in travel mode choice. As a proportion of individual trips, car-only mode share rose from 9 percent before the pandemic to more than 26 percent at its height. This trend toward less sustainable transport moderated slightly, dropping to 20 percent for

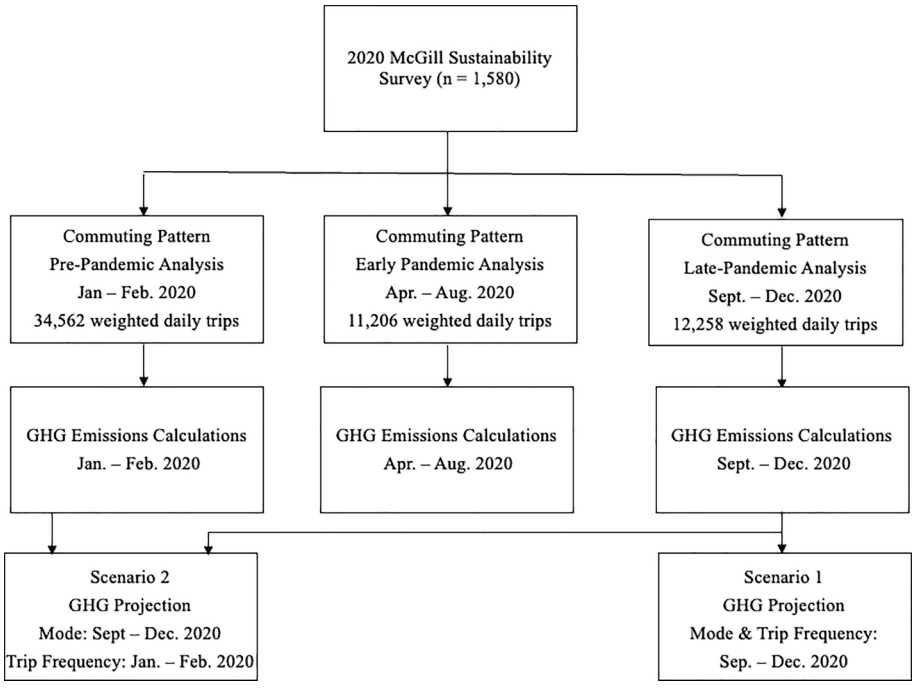

Fig. 2. Steps in the Research Project.

Table 1
Weekly one-way trips to McGill locations.

Trips to a McGill Location		
Estimated Weekly One-Way Trips Generated		
	Weekly Trips[1]	%
JAN		
Car to Final Destination	12,970	9
Car to Transit	9,639	6
Fully Sustainable	128,821	85
Total	151,431	100
APRIL		
Car to Final Destination	6,548	26
Car to Transit	1,190	5
Fully Sustainable	17,666	70
Total	25,404	100
SEPT		
Car to Final Destination	6,177	20
Car to Transit	1,398	5
Fully Sustainable	22,709	75
Total	30,284	100

Source: 2020 McGill Sustainability Survey/TRAM analysis.
[1]Estimated based on expansion factor applied to retained survey responses (n = 1580).

trips during an average September 2020 week from 26 percent in April 2020. The proportion of car-to-transit trips stayed relatively stable throughout 2020. On the other hand, fully sustainable trips—defined as those involving only transit or non-motorized modes such as bikes or walking—dipped to 70 percent in April 2020 from 85 percent before the pandemic. By later in the pandemic, sustainable modes as a share of total trips recovered slightly to approximately 75 percent.

At the level of the individual commuter, shifts in travel patterns were similarly pronounced. By April 2020, almost 45 percent of university faculty that had been traveling to campus in January 2020 reported making no trips to campus at all (Fig. 3). Among staff, almost 60 percent who traveled in January 2020 had stopped traveling to campus at all by April 2020. Among students, the percent who stopped traveling to campus was even higher: Almost 75 percent of those who had been traveling to campus in January 2020 said they didn't take a single trip to campus between April and August. Despite all teaching being online, some students were allowed on campus for research and lab work. The university also provided flexible space for students who had poor Internet service at home or required a quiet space to study. The flex space was offered at the university to help those students while maintaining physical distancing rules guided by the Quebec health directives.

Among survey respondents, the percent of people who reported driving for their trips remained relatively stable across all categories of university affiliation while the proportion of people reporting they took a car to transit or made wholly sustainable trips to campus declined (Fig. 3). Rates of those driving to campuses did decrease, albeit slightly, by September.

Among the essential workers or students who were required to make in-person visits to campus, the relative proportion of less sustainable mode choice increased dramatically (Fig. 3). Students experienced the highest rates of teleworking, followed by adminstrative and trades staff, and then academic staff.

Among those who traveled continuously to a McGill campus or affiliated facility throughout the pandemic, the largest shift in travel was away from sustainable modes—walking, cycling, and transit—to car-only trips at the beginning of the pandemic in April 2020 (Fig. 4). A less dramatic shift from sustainable modes to car-only trips also occurred between January and September.

Some commuters did return to sustainable modes by September, though not to levels seen previously. Similar proportions of people transitioned from car to sustainable modes in September as did from sustainable modes to car.

Finally, Fig. 4 highlights that the proportion of those using a car to reach transit remained relatively stable throughout 2020. Interestingly, a small but not completely insignificant share of car-only commuters shifted to car-to-transit between April and September. Perhaps concerns about contracting COVID-19 were slightly diminished by September thereby encouraging some people to begin to use transit.

Taken together, COVID-19 resulted in a drastic reduction in travel to campus that only recovered slightly by September 2020. Among essential workers and students who continued to travel to campus, car-to-final-destination mode share almost tripled in April 2020. When it comes to modal shift, the largest change seen was from walking, cycling, and transit, to car-to-final-destination at the beginning of the pandemic, which we expect to have a major impact on the University GHG emissions if the January 2020 commute frequency is sustained with the late pandemic mode choices.

Estimated 2020 actual greenhouse gas emissions

Shifts in commuting behaviour translated into significant declines McGill University's commute-related greenhouse gas emissions in 2020 relative to what they would have been under normal circumstances. Though the declines translate to greater sustainability when it comes to travel behaviour, they were almost entirely attributable to reduced commuting frequency, suggesting that reductions may be short lived. During the 2020 calendar year, university commuters were responsible for an estimated 3224 metric tons of incremental carbon-dioxide-equivalent (CO_2e) greenhouse gas emissions.

The total annual estimated incremental GHGs generated by commuting to McGill were significantly lower than what they would have been had prevailing commute patterns recorded for January and February continued throughout the year. Assuming similar commute patterns and frequencies, total annual incremental GHG emissions would have reached approximately 7500 metric tons of CO_2e. (This

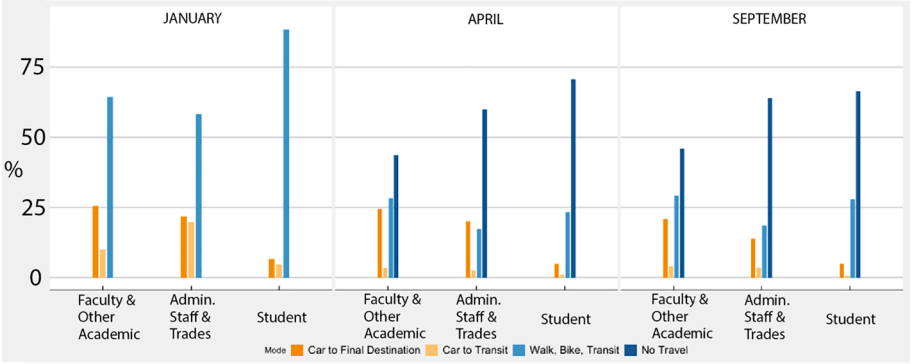

Fig. 3. 2020 commuting mode share by month and affiliation by individual, including those telecommuting.

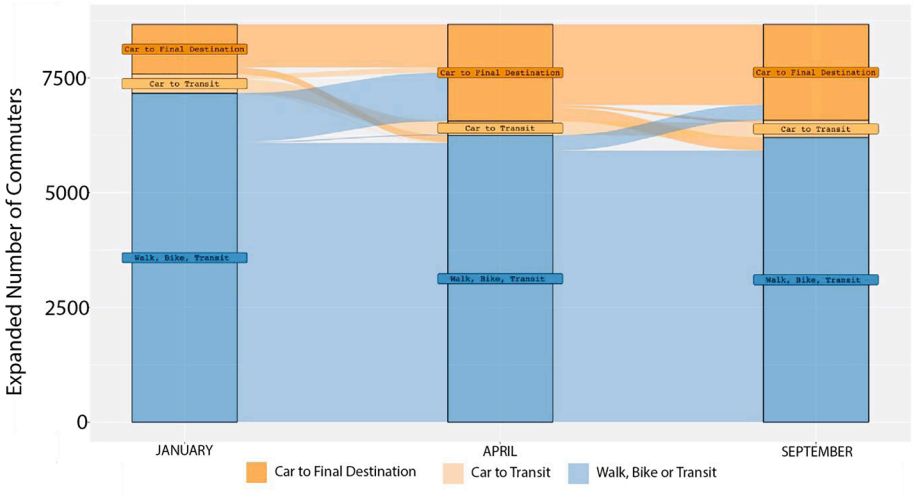

Fig. 4. Change in travel mode choice among continuous McGill commuters during COVID-19 (2020).

figure was estimated by multiplying January and February emissions by six). This represents a 57% reduction in anticipated emissions. As expected, this downward departure resulted from a marked decrease in campus visits after the beginning of the COVID-19 pandemic.

Estimated 2020 GHG emissions by affiliation type

Though students accounted for the largest proportion of total CO_2e emissions—1734 metric tons, or approximately half of the university total—their per-capita annual CO_2e emissions were the lowest at approximately 0.060 metric tons. Academics' per-capita CO_2e emissions were more than three times higher at 0.226 metric tons; administrative staff's per-capita emissions were even higher at 0.291 metric tons of CO_2e (Table 2). This trend, i.e., that students' per capital travel is more sustainable, is due to differences in mode share across affiliations: few students opt for unsustainable modes compared to academic and administrative staff (Fig. 1).

Mode choice appears to be the single most important factor driving emissions intensity across different groups of campus commuters. Nevertheless, a combination of geographic factors (Fig. 4) and vehicle characteristics (Table 3) among those who drive explains some inter-group differences in emissions intensity.

Regarding geographic factors, commute distances were found to vary across affiliation (Fig. 5). Students' residences are strongly concentrated around the downtown campus. Academic faculty residences are concentrated near both the downtown campus and the McGill University Health Center, with lower concentrations in suburban areas such as the West Island, on the South Shore, and on the North Shore. Administrative staff and tradespeople's homes are the most widely and evenly distributed. The highest concentrations can be found at the same two locations as that of faculty (near the downtown campus and McGill University Health Center) as well as in the suburban South Shore. Higher concentrations of Administrative and Trade staff's residences can be found throughout the City than that of faculty and students. These results suggest that Administrative and Trade staff have longer commutes, a trend confirmed in Table 3 which quantifies commute distance amongst drivers.

Indeed, the average one-way commute for administrative staff that drive to work is 26.46 km, which is approximately 5 km and 7.5 km longer than that for academic staff and students respectively (Table 3). Academics drive longer distances than students but must be generally located closer than administrative staff. Given that administrative staff tend to earn less than academic staff, perhaps their longer commutes are due to being priced out of adequate housing closer to campus. Students, on the other hand, may be located closer to campus than both administrative and academic staff because they more often rent, rather than own, their homes.

Though student drivers live closer than administrative and academic staff they generally have older, less efficient – and therefore less sustainable - cars (Table 3). Specifically, the average combined fuel economy of students' cars is 8.54/100 km compared to 8.47/100 km (academics) and 8.39/100 km (administrative). Given that older cars tend to me more affordable, students' limited income may explain their tendency to own older cars. When comparing between administrative and academic staff, academics' cars are newer, but on average less efficient than administrative staff. These geographic factors and vehicle characteristics help explain some of the observed differences between students, faculty, and administrative staff's transport-related emissions, however the effect is not as clear as that for travel mode choice.

Table 2
McGill 2020 per-capita annual GHG emissions by affiliation.

McGill 2020 Per Capita Annual GHG Emissions by Affiliation			
Estimated Carbon Dioxide Equivalent (co2e)			
Affiliation	Number[1]	Per capita annual co2e (metric tons)	Total annual co2e (metric tons)
Academics	2,731	0.226	618.381
Administrative Staff, Trades, Others	2,993	0.291	871.231
Student	28,838	0.060	1,734.255

Source: 2020 McGill Sustainability Survey/TRAM analysis.
[1]Includes people who did not travel to campus during one or more periods.

Table 3
Average commute distances and vehicle characteristics for commuters who drive.

Affiliation	Avg One-Way Commute (km)	Avg City Fuel Econ (l/100 km)	Avg Hwy Fuel Econ (l/100 km)	Avg Combined Fuel Econ (l/100 km)	Average Model Year
Academics	21.55	9.46105	7.25	8.47	2014.6
Admin Staff & Trades	26.46	9.34512	7.21	8.39	2014.1
Students	18.92	9.53533	7.34	8.54	2013.0

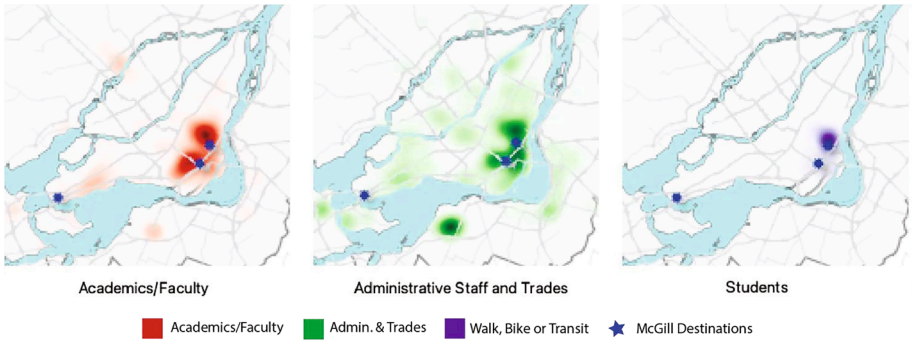

Fig. 5. Geographic distribution of home locations for faculty, staff, and students.

Projected future greenhouse gas emissions

As universities and other businesses resume more normal operations, the question remains whether the shifts in mode choice and commuting frequency that occurred during COVID-19 will endure. The answer is of particular importance for efforts to encourage more sustainable campuses by curtailing greenhouse gas emissions. Part of policymakers' response will depend on understanding the potential implications of different scenarios for the reestablishment of regular activities.

To assist in this endeavour, we projected greenhouse gas emissions based on two return-to-campus scenarios. For both, we explored the impact of a continuation of "late-COVID-19" mode choice, assuming a continuation of September 2020 mode selection. For the first scenario, we assumed that work-from-home and distance-learning options would also be preserved and selected at the same rate as in September 2020. Under this scenario, as shown in Table 4, greenhouse gas emissions would be more than double actual 2020 emissions (7217.146 vs 3223.867 metric tons of CO_2e), but slightly less than if we were to return to pre-pandemic commute patterns (7500 metric tons). Under the second, we explored what would happen if the frequency of campus visits returned to its pre-pandemic (January 2020) levels. Under the latter, greenhouse gas emissions would be 15,434.541 metric tons of CO_2e, more than double what we would anticipate if we returned to pre-pandemic commute patterns for both mode choice and trip frequency (7500 metric tons). This is a worrying result for those aiming to reduce the carbon footprint of universities.

Discussion and conclusion

Drawing on a campus-wide sustainability survey with a section focused on travel behaviour, this paper presented the results of an analysis of how travel behaviours and transport-related greenhouse gas emissions changed over the course of 2020 due to the COVID-19 pandemic, through concentrating on those who continued to commute during the pandemic time. In doing so, this paper contributes to the literature on the impacts of COVID-19 on travel behaviour change. Specific contributions include analyzing these impacts over three time periods and focusing on an under studied location: a university setting. Further, by considering the impact of vehicle type on emissions, this paper adds more detailed estimates of GHG emissions than other work based solely off travel behaviour or cell phone data.

Overall, results indicate that there was a dramatic drop in transport-related greenhouse gas emissions in 2020 compared to what might have been expected under normal circumstances. This sustainable trend, however, was largely due to a sudden decrease in the number of trips being made to campus. These trips sharply declined in April 2020 and only increased marginally in the later pandemic period (September 2020). Therefore, when it comes to the environment impact of the pandemic on travel behaviour, this study demonstrates how though total emissions decreased, the pandemic resulted in a shift toward less sustainable travel modes among those who continued to travel to campus and to correspondingly higher individual emissions intensity. A notable transition from fully sustainable modes to driving occurred.

These results led us to calculate projections of the anticipated emissions under two scenarios going into the future. Both used post-pandemic mode share, but the first assumed that work-from-home and distance-learning options would stay in place and the second assumed we would resume in-person activities to the same rate as before the pandemic. Under the first scenario, greenhouse gas emissions would be slightly less than if we were to return to pre-pandemic commute patterns (mode and trip frequency). Though this is more than double actual 2020 emissions (7217.146 vs 3223.867 metric tons of CO_2e), it is similar to what we would expect had the pandemic never occurred (7500 metric tons). These projections highlight an environmental benefit of continuing to provide options for online working and schooling.

The results for the second scenario are very concerning: If travel mode share is unchanged when the university returns fully to in-person activities, transport-related greenhouse gas emissions would be 15,434.541 metric tons of CO_2e. This represents approximately four times what was observed in 2020 and more than double what we would anticipate if we returned to pre-pandemic commute patterns for both mode choice and trip frequency (7500 metric tons). As more normal operations resume, policymakers must therefore redouble their efforts to make sustainable mode choices attractive. These efforts could include

Table 4
McGill University estimated carbon-dioxide equivalent in metric tons & projected annual commute-related GHG emissions by affiliation.

Affiliation	Number[1]	Actual 2020		Scenario 1: Projected based on Sept. 2020 mode choice & campus visit frequency		Scenario 2: Projected based on Sept. mode choice & Jan. 2020 campus visit frequency	
		Weekly Individual	Total Annual	Weekly Individual	Total Annual	Weekly Individual	Total Annual
Academics	2,731	0.005	618.381	0.007	865.322	0.014	1,836.061
Administrative Staff & Tradespeople	2,993	0.006	871.231	0.012	1,637.661	0.030	4,299.907
Students	28,838	0.001	1,734.255	0.003	4,714.163	0.007	9,298.573
Total	34,562	–	3,223.867	–	7,217.146	–	15,434.541

Source: 2020 McGill Sustainability Survey/TRAM analysis.
[1]Includes people who did not travel to campus during one or more periods.

approaches such as education campaigns directed at faculty, staff, and students designed to underscore the safety of public transport. They might also encompass financial incentives for commuting sustainably in the form of bonuses or prize drawings and corresponding penalties for unsustainable mode choices, including higher parking fees.

Though these projections serve as a warning, it is important to note that the per capita emissions reported in this paper, even those most stark, may still lower than that of the general population. Even amongst the highest emitters, administrative staff, projected annual Co2e emissions under the worst scenario (i.e., return to in-person activities at pre-pandemic levels but with pandemic mode share) are 1.437 metric tons per capita. For comparison, in 2007 in Canada, the average emissions from private vehicles were 1751 kg of CO2 equivalent per capita (Statistics Canada, 2007). Though the two numbers are not perfectly comparable (notably our projection figure only accounts for the commute while the average Canadian figure accounts for all travel per vehicle), this does suggest that those who commute to universities, either for work or school, may have lower transport-related carbon footprints than the general public.

Among drivers, we found that students have shorter commutes than administrative and academic staff, but drive older, less efficient cars. This may be explained by the fact that older cars not only tend to be less efficient, but also tend to cost less. Given that students tend to have limited incomes, they may not be able to buy newer or more efficient vehicles. Administrative staff's residences were found to be the most evenly distributed across the city, with high concentrations not only near the two McGill locations downtown, but also in the suburban South Shore. This indicates that these staff members have the longest commutes to campus, a finding that was confirmed when we calculated commute distance amongst drivers. Given that this trend may be due to the high cost of owning property near campus, a combination of policies that promote affordable housing near campus and reliable and connected transit options beyond the city center may reduce these staff members' transport-related carbon footprint.

The hypothetical future emissions described within this paper are not definitive. Rather, they mark what is likely the outer boundary of longer-term shifts in commute-related greenhouse gas emissions based on a rather blunt "what-if" worst-case scenario. A precise picture of post-COVID-19 travel patterns will necessarily rely on future research that can address the inherent limitations in the data upon which this paper relies. First and foremost: Because of the structure of the survey, we were forced to assume that the travel behaviours of those people who continued to visit university facilities during the pandemic are fully representative of those who did not but who will eventually return. In fact, significant differences may exist across these populations due to the specific nature of their work or studies or their geographic location. Relatedly, the survey did not inquire about people's individual perceptions of the risk of contracting COVID-19 during their commutes and how that might influence their future intentions. Even if it had, it is entirely possible that individual perceptions will evolve over time as vaccination rates increase and concerns about virus transmission diminish. Other external factors, such as lack of parking spaces as more on-campus activities occur may also impact future travel behaviour. Further, this paper calculated on-road operating emissions, and thus does not capture life-cycle emissions. Future work can generate more accurate greenhouse gas emissions by considering full life-cycle impacts of all travel modes, including electric cars and public transit.

Nevertheless, this paper does contribute to our understanding of travel behaviour and its environmental impacts during the COVID-19 pandemic. Furthermore, results from this paper can also be used to help inform return-to-normal policy. For instance, the current and potential move away from sustainable travel modes such as walking, cycling, and transit and toward driving-only trips and the ensuing increase in greenhouse gas emission is concerning. Universities alongside municipalities, public health agencies, and transit agencies should consider taking concrete steps to encourage the return to sustainable modes as they prepare for the return to in-person activities.

Author contributions

The authors confirm contribution to the paper as follows: Conceptualization: DeWeese, Ravensbergen & El-Geneidy; Data curation: DeWeese & El-Geneidy; Formal analysis: DeWeese, Ravensbergen & El-Geneidy; Funding acquisition: El-Geneidy & DeWeese; Investigation: DeWeese, Ravensbergen & El-Geneidy, Methodology: DeWeese, Ravensbergen & El-Geneidy, Project administration, Resources, Software and Supervision: El-Geneidy, Validation and Visualization; DeWeese, Ravensbergen & El-Geneidy; Roles/Writing – original draft: Ravensbergen, DeWeese & El-Geneidy, Writing – review & editing: DeWeese, Ravensbergen & El-Geneidy.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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