The Brisbane River is a mixed blessing for travel behaviour and commuting emissions

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Abstract

The University of Queensland is a large regional attractor located in the western suburbs of Brisbane - a city divided by a river with very few crossings. This paper quantifies greenhouse gas emissions associated with commuter travel to the University of Queensland (UQ), and investigates the impact of the Brisbane River on commuter travel behaviour. Indirect non-organisation greenhouse gas emissions (Scope 3) associated with UQ staff and student commuter travel were estimated using emission factors combined with survey data on transport mode, travel distance, and attendance. The suburbs with the highest commuter emissions can be grouped into three categories: close to campus with moderate car use but high populations; very far from campus with high car use; or suburbs with poor public transport connections and high car use driving medium or long distances. Less than one quarter of commuters used private vehicles, but these accounted for two-thirds of emissions. Many of the commuters driving lived very close to campus. Travel time is a key driver for commuter travel mode choice and was the number one barrier to both public and active transport. Different travel behaviours were observed north and south of the Brisbane River. Commuters were more likely to drive to UQ from north of the river, and more likely to walk or cycle from south of the river. Sustainable travel modes (public and active transport) are better connected with more convenient services to the east/south of the Brisbane River, as evidenced by public transport use, active travel popularity and travel time mapping, and limited vehicle crossings. Geographic features, such as rivers and hills, are often a barrier to public or active transport, but when coupled with strategic sustainable transport infrastructure, can encourage more sustainable forms of travel.

Keywords: greenhouse gas emissions, commuting, university, sustainable transport, river crossings

1. Introduction

Transport is a major contributor to greenhouse gas emissions, particularly in Australia. 97.5 Mt CO_2-e, or 18% of Australia's 2016 total carbon account, were generated from the transport sector (DOEE, 2018). Passenger cars account for 45% of Australia's greenhouse gas transport emissions (DOEE, 2018). According to the 2015 Australian Energy Statistics (DIS 2015) report, transport overtook the electricity supply sector as the largest energy user in Australia during 2013–14. While vehicle use per capita is largely declining across Australia it is on the rise in Queensland (CTEE, 2012).

Commuting choices are a complex combination of planning, economic and behavioural factors (Garcia-Sierra et al, 2014; Zhou, 2012, Mathez et al, 2013). Key strategies for reducing commuting related GHG emissions often include increasing the share of active transportation

and public transport, increasing vehicle occupancy rates and reducing urban vehicle kilometres travelled (Stanley et al., 2011).

Reduced parking availability has been one of the key strategies in recent parking reforms successfully implemented across a number of European cities. The reforms have resulted in reduced private car trips, reduced air pollution and GHG emissions, revitalised town centres and improved quality of life (Kodransky & Hermann, 2011). Effective public and active transport infrastructure and services are required to support this type of change.

Pricing mechanisms are also important, both in terms of travel and parking costs. Appropriate parking fees are very effective at managing parking occupancy rates and reducing car usage (Kodransky & Hermann, 2011; Garcia-Sierra et al, 2014; Zhou, 2012; Weinberger et al, 2010). In one study, doubling parking fees achieved a 20% reduction in car usage, while halving the supply led to a 30% drop (Kodransky & Hermann, 2011). Road pricing is another possible mechanism for managing car usage. Several examples of road pricing, particularly congestion taxes, have been implemented in cities across the world, including: Singapore, London, Milan, and Stockholm. These schemes have also had significant impacts on car usage, with the Stockholm congestion tax reducing car traffic by over 20% within the first 12 months of implementation (Borjessen & Kristoffersson, 2017).

Another strategy for reducing the number of cars on the roads, and therefore relieving congestion and parking issues, is to increase vehicle occupancy rates (car-pooling) (Bruglieri et al, 2011). A number of car-pooling websites already operate in Australia (MyCarpools, Carpool One, Shareyourride, Coseats, Catchalift, Jayride, Needaride), but some commuters perceive issues with these services, including: personal safety, and reliability/flexibility (Bruglieri et al, 2011; Correia & Viegas, 2011).

A switch to active transport can have the greatest potential emissions reduction impact, in addition to also delivering health and wellbeing benefits for commuters (DIRD, 2015). Mode switching, however, is not a simple linear process as lifestyle choices affect transport mode decisions as well as perceptions (Prato et al., 2016). Four lifestyle typologies have been identified: car oriented, bicycle oriented, public transport oriented and public transport averse. The public transport oriented and public transport averse have been found to be the most amenable to switching travel modes, and to bicycle in particular (Prato et al., 2016).

This paper quantifies GHG emissions associated with commuter travel to the University of Queensland (UQ), a large regional attractor in the river constrained city of Brisbane. The study was undertaken using a survey to quantify travel behaviour, scaling up survey responses across the UQ population. Greenhouse gas emissions per trip were calculated from trip distance, using appropriate emissions factors for different modes. Through spatial analysis and survey questions targeting attitudes, we investigated the main determinants of commuting travel behaviours to UQ in order to identify strategies for reducing commuting emissions and encouraging sustainable transport, which we define as active travel (walking and cycling) and public transport.

2. Methodology

2.1. Study site

The University of Queensland (UQ) is a large university in Brisbane, Queensland, with a total population of staff and students of 57,621, of which 89 % are based at the St Lucia campus.

Figure 1: Location of UQ St Lucia campus next to the Brisbane River in Brisbane, Australia
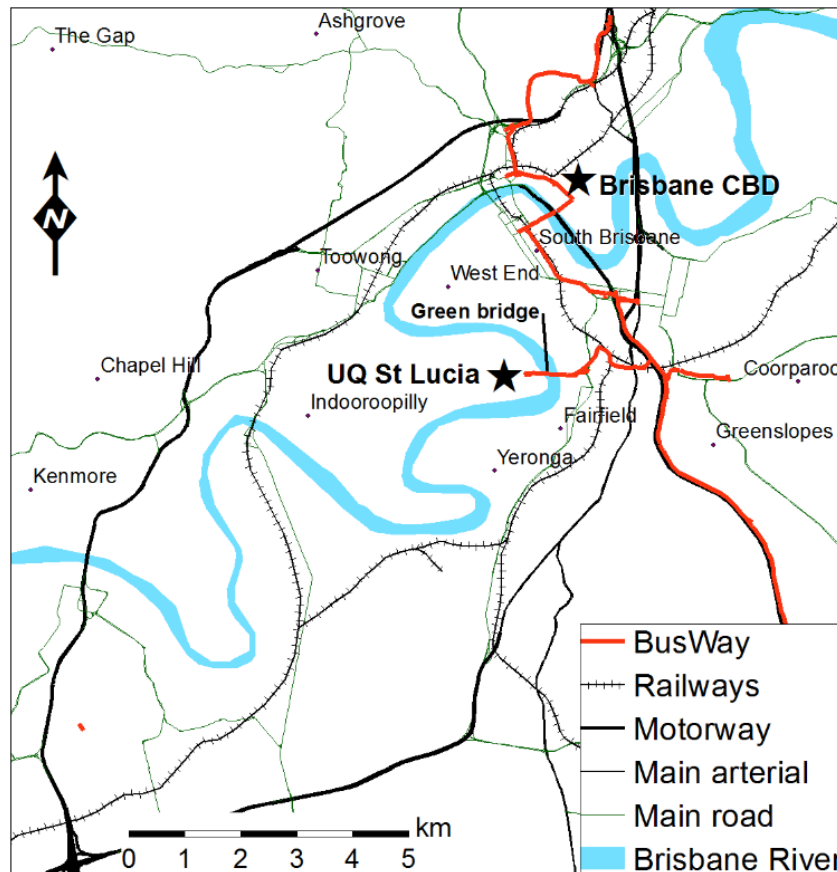
UQ's campus at St Lucia is a regional attractor and is the second largest commuter destination in South East Queensland after the Brisbane CBD. It is located in a peninsula on the Brisbane River, with road access from the west, river access via the CityCat ferry service, and the Eleanor Schonell Bridge, a "green" bridge for buses, bicycles and pedestrians, to the east (Figure 1). Since this bridge opened in 2006, it has improved uptake of sustainable transport to UQ and shifted the residential distribution of staff and students (Charles-Edwards et al, 2014). It is well serviced by bus routes using the Eastern and South-Eastern busways, and the majority of UQ bus passengers now alight at the UQ Lakes bus terminal rather than Chancellors Place, the main bus stop on the western side of the St Lucia campus. There is no train station on campus. Bus connections are available at Indooroopilly, Toowong and Park Road train stations.

Brisbane is a low density, dispersed city with high urban sprawl. According to our survey data, staff and students may travel over 100km each way to access UQ. Road congestion continues to be a major issue in Brisbane, with the 2017 TomTom Traffic Index estimating that the average commuter in this city loses 104 hours per year to road congestion (TomTom, 2018). It should also be noted that commuting to UQ contributes more than 10% of the total carbon footprint of the university, highlighting the importance of promoting more sustainable forms of travel for UQ staff and students (Lambert & O'Brien, 2017).

2.2. Survey

An online population and transport survey was used to collect data on commuter travel and attendance from UQ staff and students for a typical semester week between the 13th and 19th of August, 2016. Business travel was excluded from this study. The survey questions centred

on establishing the origin (home) suburb, UQ campus, days attended and the main transport mode utilised to undertake the journey. Participants identified as either a staff member, undergraduate or postgraduate student. Students indicated whether they were domestic or international. 8,030 raw responses were received from the total UQ population of 57,621, equating to a 14% raw response rate. This paper presents the results for the largest campus, St Lucia. After data checking and cleaning, where incomplete or unclear responses were removed, and filtering for St Lucia attendees only, 5,783 responses were considered valid out of a population of 51,420. The response rate was higher for staff (30%) than for students (9%) (based on valid responses). Females make up 55% of the total UQ population, but had a higher survey response rate than males, contributing almost two thirds (63%) of the survey responses.

In order to determine total emissions, participant emissions were scaled up by campus population. The staff population was made up of full time equivalent (FTE) academics (teaching and research) and professional staff. Undergraduate and postgraduate student populations used the official unduplicated head count. The approach assumes that the survey sample provides sufficient representation of the campus populations, i.e. that the travel behaviour of survey respondents was representative of commuters across the campus. Given the large numbers of respondents, across the different groups, this seems a reasonable assumption.

2.3. Attendance

University business hours are from 8am until 5pm Monday to Friday, and lectures are scheduled between the hours of 8am and 9pm on weekdays. Weekday commuting of both staff and students represents the vast majority of commuting to UQ and weekend travel was treated as being outside the scope of this study. Average weekly attendance was determined from the number of days each participant attended during the survey week. It was assumed that the UQ Population and Transport Survey data was collected in an unbiased manner for a representative week of commuter travel.

Annual commuter GHG emissions were calculated assuming a characteristic week of survey travel data could be linearly scaled to the number of weeks each participant category attends UQ. The staff and postgraduate population were assumed to take 4 weeks of leave each year (i.e. absences due to illness, conference travel etc. were neglected) and therefore commute to UQ 48 weeks of the year. A limitation of this approach is that it relies on the assumption that travel patterns do not vary between semester and non-semester periods for staff and postgraduate students. Each undergraduate student only attends two semesters per year. Each semester includes 13 teaching and 3 revision/exam weeks where student university attendance is one third of the 3 revision/exam weeks, giving a total of 28 weeks of attendance per year. Weekly emissions from undergraduate students commuting to UQ were multiplied by 28 weeks to estimate their emissions over the year.

2.4. Mode of transport

Survey participants were asked to nominate their main mode of transport to UQ for each day of the survey week from the following options: walk; bicycle; motorcycle/scooter; car (driver); car (passenger); bus; train; ferry. Participants who drove to UQ were asked how many people were in the car, including the driver. For private vehicle travel, it was assumed that all passengers and the private vehicle driver were travelling to either work or study at UQ.

Multi-mode transport, where a commuter may drive to a train station, board a train then catch a bus, is common for commuters to the UQ St Lucia campus. To minimise the time burden of the survey and maximise response rate, a streamlined approach was adopted. The survey asked for limited details of multi-mode travel (such as "how do you get to your bus/train/ferry stop?" and "where do you board public transport?"), and knowledge of commuter behaviour and analysis of previous years' travel patterns (typical multi-mode transport combinations) were applied based on the nominated main mode of transport. Options for pre-board transport mode were: walk, bicycle, car (park'n'ride), car (drop off) and motorcycle/scooter.

2.5. Distance travelled

The distance travelled to UQ was estimated from survey location questions. Participants were asked to specify the suburb they were travelling from (origin suburb), the suburb/station/ferry terminal where they boarded public transport (if applicable) and their main mode of transport. Their final destination was the UQ St Lucia campus. Survey data was collected for one-way travel to UQ with the underlying assumption that return trips would follow the same route using the same transport mode.

Travel distances were determined from Google Maps. Distances to campus and between suburbs for road traffic were estimated by using the 'Get directions' function in *Google Maps*. This was done by specifying a) the starting suburb and b) the destination suburb, then selecting the icon for the relevant mode of transport. The distance travelled was generally assumed to be the shortest route from the centre of each suburb to UQ as identified by *Google Maps,* unless a more efficient route was known (although toll roads were generally avoided). Distances between train stations were sourced from Queensland Rail data (Queensland Rail, 2007). Ferry distances were estimated using the *Google Maps* distance feature.

2.6. Emission factors

Emissions vary between different modes of transport and commuter GHG emissions were calculated by multiplying distance travelled by greenhouse gas emissions factors (g CO_2-e per passenger-kilometre) based on the mode of transport used to make the journey.

While emissions factors for fuel combustion and electricity consumption were readily available in the National Greenhouse Account Factors (NGAF) (DoE, 2015b), determining GHG emissions per passenger km for vehicle transport was more difficult, because emissions factors can vary widely between different literature sources and in different locations. In the absence of readily available emission factors for passenger transport in Queensland, emission factors were derived for each mode of transport as documented below.

2.6.1. Car, motorcycle and bus

Emission factors for road users (car, motorcycle, bus) were derived based on national fleet statistics that incorporate CH_4, N_2O, and CO_2 emissions, with an oxidation factor of 1. These are 'full-fuel cycle' emission factors which incorporate emissions associated with fuel combustion process for each mode of transport (Scope 1), as well as extracting, refining, and production of the fuel (Scope 3).

Queensland fuel consumption and average efficiency data for the 12 months ending October 2014 by fuel type and vehicle type were available from the ABS *Survey of Motor Vehicle Use* (2015). Average emission factors for car, motorcycle/scooter and bus were calculated from the

emissions factors, energy content and efficiency for each of the three fuel types f (petrol, diesel, LPG), weighted by the relative usage of each fuel type for each mode as follows:

$$EF_{j,R}\left[\frac{kgCO_{2\_e}}{passenger.km}\right] = \sum_f EF_f\left[\frac{kgCO_{2\_e}}{GJ}\right] \times EC_f\left[\frac{GJ}{kL}\right] \times \eta_{f,j}\left[\frac{L}{km}\right] \times \frac{1}{1000}\left[\frac{kL}{L}\right] \times \frac{C_{f,j}}{TC_j}\left[\frac{L/yr}{L/yr}\right] \times \frac{1}{Oc_j}\left[\frac{vehicle}{passenger}\right]$$ (1)

$EF_{j,R}$	=	Emission factor for road transport mode j	(kgCO₂-e/passenger.km)
EF_f	=	Emission factor for fuel f	(kgCO₂-e/GJ)
EC_f	=	Energy content factor of fuel f	(GJ/kL)
$\eta_{f,j}$	=	Efficiency of fuel f for mode j	(L/ vehicle.km)
$C_{f,j}$	=	Total annual Qld consumption of fuel f by mode j	(L/yr)
TC_j	=	Total annual Qld consumption of fuel by mode j	(L/yr)
Oc_j	=	Occupancy for mode j (=1 for motorcycle)	(passengers/vehicle)

Occupancy for cars was sourced from the survey data, *i.e.* participants who nominated "Car (driver)" as their main mode of transport also specified the number of occupants, while participants who nominated "Car (passenger)" as their main mode of transport were assumed to have two occupants in the vehicle.

There is large variability in bus occupancy data between sources. *Queensland Transport Facts 2015* (CTEE, 2015) reports a low occupancy of 4.87 passengers per bus, while estimates based on go-card data during the survey week for disembarking passengers (16,221 passengers/day) at UQ bus stops (660 buses/day) during semester is high with 24.6 passengers per bus. Data from BITRE (2009), reporting 1,040 million passenger kilometres in Brisbane over 61.2 million bus kilometres, gave an average occupancy of 17.0 (compared to 13.9 in Sydney and 8.8 in Melbourne). Resultant emission factors ranged from 28g CO₂-e/passenger.km to 142 g CO₂-e/passenger.km.

Lenzen (1999) reported Brisbane Transport bus occupancy of 10 passengers per bus, which corresponds to an emission factor of 73 g CO₂-e/passenger.km (using Eqn 1 with information from ABS *Survey of Motor Vehicle Use* (2015)). This is in line with the International Association of Public Transport findings in the Climate Action for Public Transport report (UITP, 2014), collating data from 110 public transport organisations around the world (including Brisbane Transport), that public transport is four times more efficient than private vehicles for CO₂ emissions. Therefore based on the available information, an emission factor for buses of 73 g CO₂-e/passenger.km was determined to be reasonable and therefore adopted for this analysis.

2.6.2. Rail

Rail occupancy data was not readily available, so an emissions factor was derived based on Queensland urban electric operation data. Emission factors for urban rail travel were determined by adjusting total Queensland rail transport emissions (CTEE, 2015) by the proportion of energy consumed in urban passenger trails compared to overall Queensland rail energy consumption, and adjusting for passenger task as follows:

$$EF_{rail}\left[\frac{kgCO_{2\_e}}{passenger.km}\right] = EM_Q\left[\frac{kgCO_{2\_e}}{yr}\right] \times \frac{C_Q}{TC_Q}\left[\frac{PJ/yr}{PJ/yr}\right] \times \frac{1}{Pk_Q}\left[\frac{yr}{passenger.km}\right]$$ (2)

EF_{rail}	=	Emission factor for rail	(kgCO₂-e/passenger.km)
EM_Q	=	Annual emissions estimate for Qld rail transport	(kgCO₂-e/yr)
C_Q	=	Urban passenger rail electric energy consumption in Qld (PJ/yr)	

| TC_Q | = | Total energy consumption for rail in Qld | (PJ/yr) |
| Pk_Q | = | Electric urban passenger kilometres in Qld | (passenger.km/yr) |

The rail emissions factor calculated from Eqn 2 and CTEE rail statistics (CTEE, 2015) of 68 g CO_2-e/passenger.km (slightly lower than that of buses) is similar to other reported literature values and in line with the four times efficiency factor (compared to private vehicles) as reported by the International Association of Public Transport (UITP, 2014).

2.6.3. Ferry

Several sources quote similar energy consumption for ferries in MJ/passenger.km in a Queensland context: 5.8 MJ/passenger.km (Lenzen, 1999), 5.71 MJ/passenger.km (CTEE, 2008), and 5.89 MJ/passenger.km (CTEE, 2015). Averaging these and multiplying by a diesel emission factor of 74.1 kg CO_2-e/GJ (DOE, 2015) resulted in an emission factor of 430 g CO_2-e/passenger.km.

2.7. Emissions calculation

Table 1 summarises the emission factors for each transport mode. Greenhouse gas emissions of individual commuter travel to UQ were calculated in Matlab using Equation (3) where emissions were calculated for each mode of transport j (car, motorcycle, bus, rail, ferry) used by each survey participant i.

$$GHG_{i,j} \left[\frac{kgCO_2-e}{yr.passenger}\right] = D_{i,j}\left[\frac{km}{trip}\right] \times F_i\left[\frac{days}{wk}\right] \times EF_j\left[\frac{kgCO_2-e}{passenger.km}\right] \times A_i\left[\frac{wks}{yr}\right] \times 2 \ \left[\frac{trips}{day}\right] \tag{3}$$

$GHG_{i,j}$	=	Annual emissions from participant i using mode of transport j	(kgCO$_2$-e/yr. passenger)
$D_{i,j}$	=	Distanced travelled per trip to UQ by participant i using mode of transport j	(km/trip)
F_i	=	Days attended per week by participant i	(days/wk)
EF_j	=	Emission factor for mode of transport j	(kgCO$_2$-e/passenger.km)
A_i	=	Annual attendance for participant i (based on whether staff, u/g or p/g student)	(wks/yr)

The factor two in Equation 3 accounts for the return trip, assuming the reverse route is taken home using the same transport mode.

Greenhouse gas emissions were then summed for each group of survey participants (i = staff, undergraduate and postgraduate students), and scaled up to determine overall commuter GHG emissions for the UQ campus GHG_{UQ} as follows:

$$GHG_{UQ} \left[\frac{kgCO_2-e}{yr}\right] = \sum_i SF_i \times \sum_j GHG_{i,j} \tag{4}$$

where SF_i is a scale factor dividing the population of staff, undergraduate and postgraduate students by the number of survey participants for each group (i = staff, undergraduate and postgraduate students).

Table 1: Emission factors used to calculate greenhouse gas emissions by commuter transport mode

Transport Mode	Walk	Bicycle	Motorcycle /Scooter	Car (driver)	Car (passenger)	Bus	Train	Ferry
Emission Factor (gCO₂-e/passenger.km)	0	0	138	270	135	73	68	430

2.8 Limitations

There were a number of limitations and uncertainties associated with the overall GHG calculation. Emission calculations assumed the survey week was representative of travel behaviour throughout the year, with some adjustments for holidays and semester breaks, but seasonal variations, e.g. affecting active travel during the warmer summer months, were not accounted for. Participants nominated their main travel mode, with multi-modal trips inferred rather than explicitly documented. Only data for the journey to campus was collected, with return journeys assumed to be the reverse. Uncertainties associated with these assumptions, and with variables used to calculate emissions were estimated and combined using quadrature to yield an overall error of ± 20% associated with the GHG emissions estimate for 2016. We also note that the travel survey has been repeated with similar results across four years, which adds confidence to the results, notwithstanding the above limitations.

3. Results and discussion

Annual greenhouse gas emissions associated with commuting to and from the UQ St Lucia campus were estimated to be 20.6 ± 4 kt CO_2-e for 2016 (Table 2). Emissions per capita averaged 0.40 t CO_2-e/person.yr, however this varied by a factor of 8 between highest (staff generated 0.88 t CO_2-e/person.yr) and lowest per capita emitters (international students generated 0.10 t CO_2-e/person.yr). 59% of commuter trips to and from UQ were made via public transport. 23% of journeys were made by car, contributing a disproportionate 66% of commuting greenhouse gas emissions. 66% of cars had a single occupant. 18% of commuters walked and/or cycled to campus. Bus was the most popular mode of transport followed by car and train. Commuters travelled 164 million km to the St Lucia campus in 2016, over half of these by public transport, 36% in private vehicles (including motorcycles and scooters) and 8% walking or cycling. 14 kilometres was the average journey distance.

Table 2: 2016 St Lucia campus GHG commuting emissions by transport mode and participant type

Transport mode		Active Travel		Private Vehicle			Public Transport			Total
		Walk	Bicycle	Motorcycle /Scooter	Car (driver)	Car (passenger)	Bus	Train	Ferry	
Emission Factor (gCO₂-e/passenger.km)		-	-	138	270	135	73	68	430	-
Average Distance (km)	Staff	1.2	6.1	14.9	14.7	9.3	8.6	25.9	3.1	13.6
	Undergraduate	1.2	3.9	9.9	13.3	6.8	8.5	29.2	5.5	15.8
	Postgraduate	1.2	4.8	8.9	16.0	9.1	6.3	23.7	3.3	9.1
	OVERALL	1.2	4.4	10.3	14.1	7.7	8.0	27.5	4.7	14.0
Mode Share (%)	Staff	4%	11%	1%	44%	4%	25%	8%	2%	100%
	Undergraduate	9%	5%	1%	17%	3%	47%	16%	1%	100%
	Postgraduate	15%	12%	1%	14%	3%	47%	5%	3%	100%
	OVERALL	10%	8%	1%	19%	3%	44%	13%	2%	100%
Annual GHG Emissions (tCO₂-e/yr)	Staff	-	-	66	3866	191	445	309	69	4945
	Undergraduate	-	-	59	5947	545	2426	2006	215	11198
	Postgraduate	-	-	46	2721	227	955	298	188	4436
2016 EMISSIONS (tCO₂-e/yr)		-	-	170	12533	963	3827	2614	472	20579
% of Total Emissions		-	-	<1%	61%	5%	19%	13%	2%	100%

Undergraduates generated over half of UQ's commuting emissions but staff were the highest emitters per capita with more than double that of the students. Staff commuted to campus more frequently (4 days/wk) than students (3.3 days/wk). Staff were up to three times as likely to drive to campus, but due to their large numbers, undergraduates made up the bulk of vehicles driving to UQ. Most students, but only one third of staff, caught public transport to and from UQ. Staff often (19%) "carry equipment/ tools/ passengers/ children", preventing them from utilising public transport (versus 7-9% of students). Postgraduate students travelled the shortest distances, often via active travel. Staff were the least likely to walk (4%) and undergraduates the least likely to cycle (5%). "Travelling with children" as a barrier for walking or riding to campus was much more common for staff (15%) than students (1 to 4%). "Late/early classes" prevented one third of undergraduates from walking or riding.

Emissions per capita for domestic students were more than four times those for international students, even though international students travelled to campus more frequently. International students travelled one third the distance of domestic students and had the highest rate of active travel (36%), compared to 12% of domestic students. Domestic students were over four times more likely to drive than international students and had lower vehicle occupancy rates. "Parking concerns" was the number one reason two thirds of domestic students caught public transport while most international students (60%) used public transport as they did not "own a motor vehicle".

Emissions per capita were similar for males and females. Men were twice as likely as women to cycle to UQ: 13% of men and only 6% of women commuted by bicycle. More women (30%) had "concerns about safety" while walking/cycling than men (25%). Twice as many females (7% versus 3%) cited "travelling with children" as a barrier to active transport. 6% of women were "concerned about personal safety" on public transport compared to only 1% of men.

3.1. Factors affecting commuter emissions

Greenhouse gas emissions from commuter travel were strongly related to suburb of origin. UQ's main campus is located in St Lucia, on a peninsular in the Brisbane River. More than twice as many commuters originate from St Lucia than from any other suburb. Indooroopilly, Toowong and Taringa (western suburbs adjacent to St Lucia) were the next most common suburbs of origin (Figure 2).

Figure 2: Suburbs with the highest populations of commuters travelling to St Lucia campus, and distance
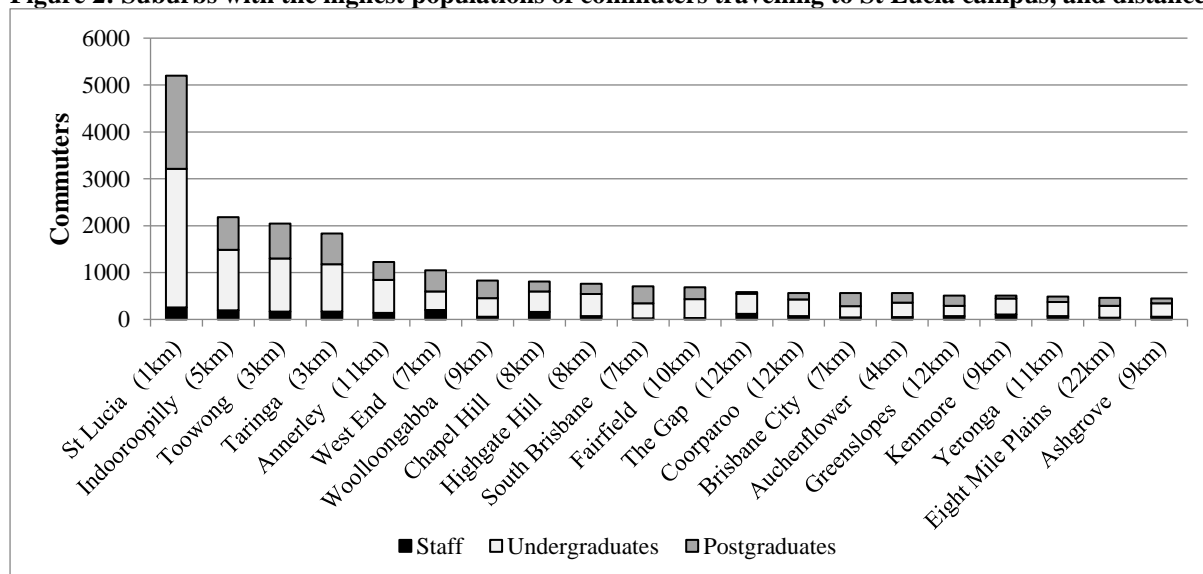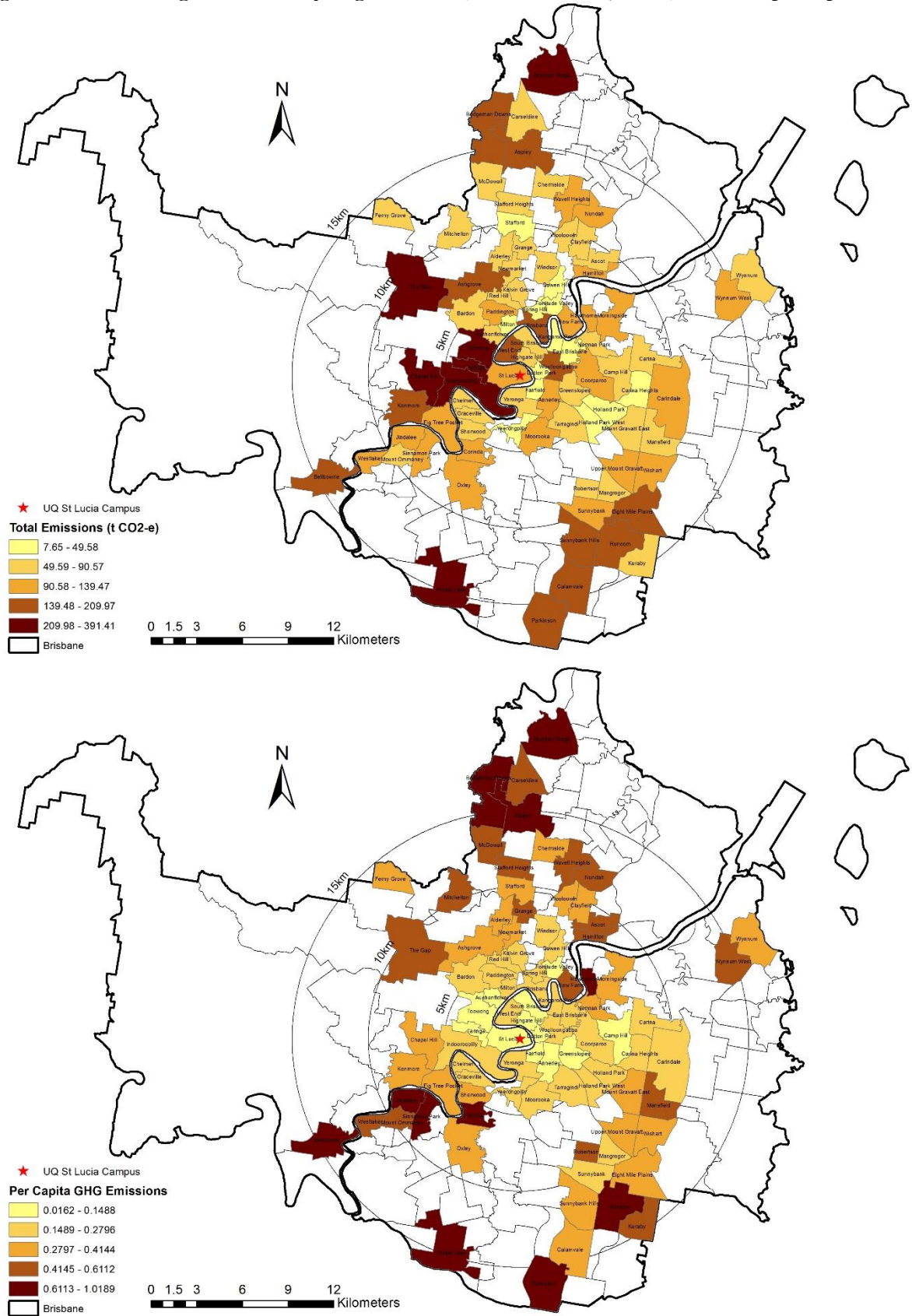
Figure 3: Greenhouse gas emissions by origin suburb a) total emissions; and b) emissions per capita

17% of commuting emissions originated from only 20 of the 881 South-East Queensland suburbs included in the survey. The top polluting suburbs of origin can be grouped into three categories: close to campus (less than 5 km) with moderate car use but high populations (many people travelling short distances: Indooroopilly, Toowong, Taringa); very far from campus (over 30 km) with high car use (few people driving very long distances: Greenbank, Jimboomba, Narangba, Ipswich, Cleveland); or suburbs with poor public transport connections to campus and high car use (some people driving medium distances (up to 15km): The Gap, Chapel Hill, Kenmore, Ashgrove; or longer distances (up to 30km): Belbowrie, Forest Lake, Albany Creek, Eight Mile Plains). Emission hot spots (Figure 3) occur where there are many commuters, long travel distances, poor public transport or a combination of all three.

3.2. Factors affecting use of sustainable transport

With the exception of St Lucia, commuters from the top 20 most common origin suburbs were more likely to drive to UQ from north of the Brisbane River, and more likely to walk or cycle from suburbs south of the river (Figure 4). River crossings clearly affect transport choice and the Eleanor Schonell "green" bridge, connecting UQ St Lucia to buses, cyclists and pedestrians from suburbs south of the river, appears to be facilitating greater active and public transport from these areas. Uptake of cycling from suburbs south of the Brisbane River is directly related to distance with up to 45% of commuters cycling (Figure 5). Cycling is less prevalent in suburbs north of the river, at 15% or less, even within close proximity to campus. The relationship between percentage of cyclists and distance is almost flat, indicating little to no impact of distance on cycling uptake. Factors other than distance are clearly important, and could include route connectivity, safety (on/off road), and topography. It is worth noting that Toowong, Taringa and Indooroopilly, although within 5 km of St Lucia, are hilly suburbs with a lack of off-road bicycle infrastructure.

Over 50% of undergraduate students commuting from Indooroopilly, Toowong and Taringa report not having access to a bicycle as a key barrier, compared to the participant average of less than 30%. Over 50% of staff using public or private transport from Toowong and Taringa to UQ cited concerns about safety as one of the major barriers to active travel, compared to less than 30% average across participants from all suburbs. Thus improving safety for active travel

Figure 4: Main mode share for most popular origin suburbs ordered by increasing distance from campus a) north of the Brisbane River b) south of the Brisbane River
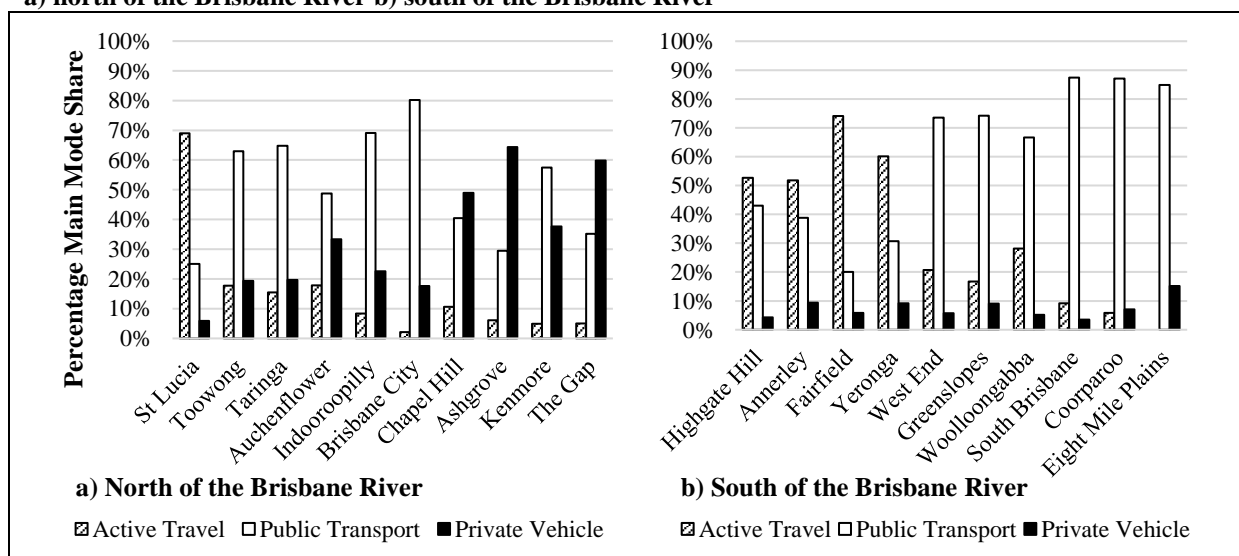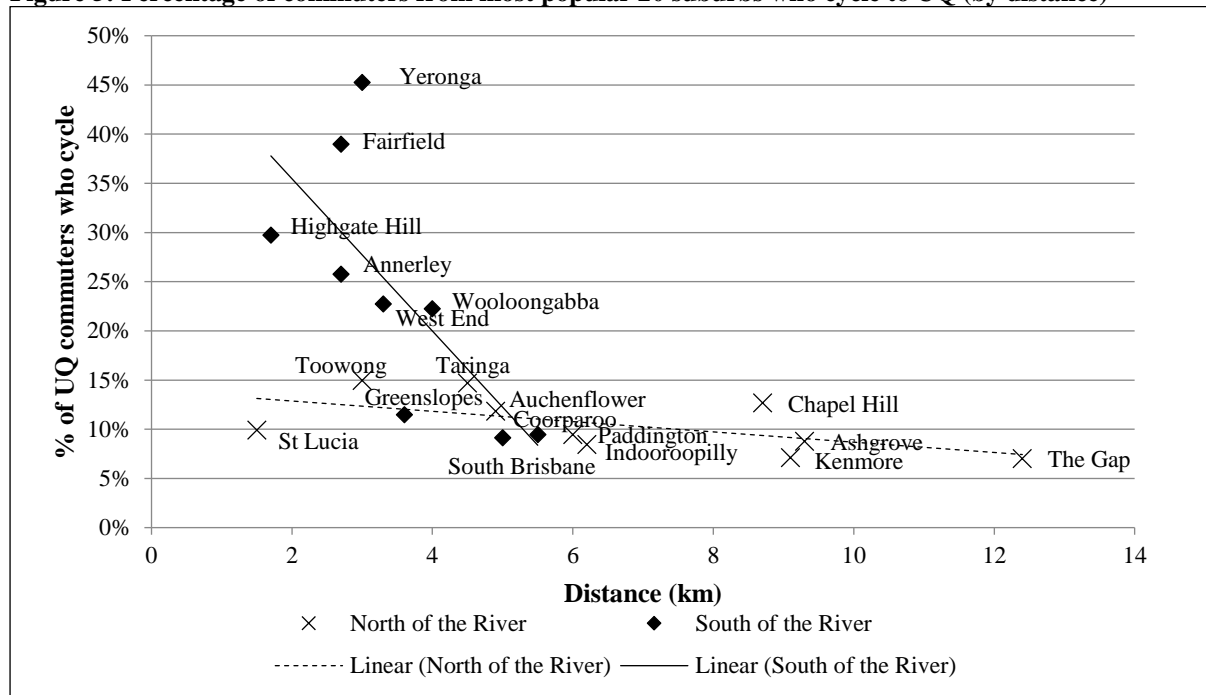
Figure 5: Percentage of commuters from most popular 20 suburbs who cycle to UQ (by distance)


from adjacent suburbs is an obvious priority for increasing uptake of active travel, and reducing commuter emissions.

Less than 20% of commuters overall use active travel as their main mode, but almost 35% occasionally cycle or walk. Statistics show that pedestrians and cyclists are safer when a higher proportion of the population walk or cycle (Jacobsen, 2003). Moreover, the cycling participation rate of females has been identified as an indicator of how cycle friendly a city is (Garrard, 2006). Studies have shown that separation from motorised traffic is preferred by female cyclists (Garrard et al., 2008, Beecham & Wood, 2013). Increasing active travel to the St Lucia campus may therefore take two strategies: 1. encouraging occasional cyclists and walkers to actively commute more often; and 2. making active travel more convenient and safer for those living in close proximity to campus. Increasing safe (off-road), accessible routes to campus is therefore likely to be important in increasing active travel by commuters.

Suburbs adjacent to UQ on the north side of the Brisbane River (Indooroopilly, Toowong, St Lucia and Taringa) are the largest source of private vehicles (Figure 6), and dominate greenhouse gas emissions from UQ commuters. Indooroopilly is not only the source of the highest emissions but the proportion of cars commuting to UQ from this suburb has also increased each year for the past 4 years, based on previous survey results. In contrast, active and public transport usage are much higher for neighbouring suburbs south of the river. Travel time is a key driver behind transport choice and survey participants have consistently nominated it as the number one barrier to both public and active transport. Suburbs with high private vehicle use also have high complaints about public transport taking too long, particularly in the inner-most north/western suburbs. Mapping *go*-card travel times by suburb indicated that travel times to the east are much quicker than the west (Liu, 2017). For example, driving from Indooroopilly takes less than 10 minutes, while public transport takes at least twice as long.

Figure 6: Origin suburbs with highest private vehicle use
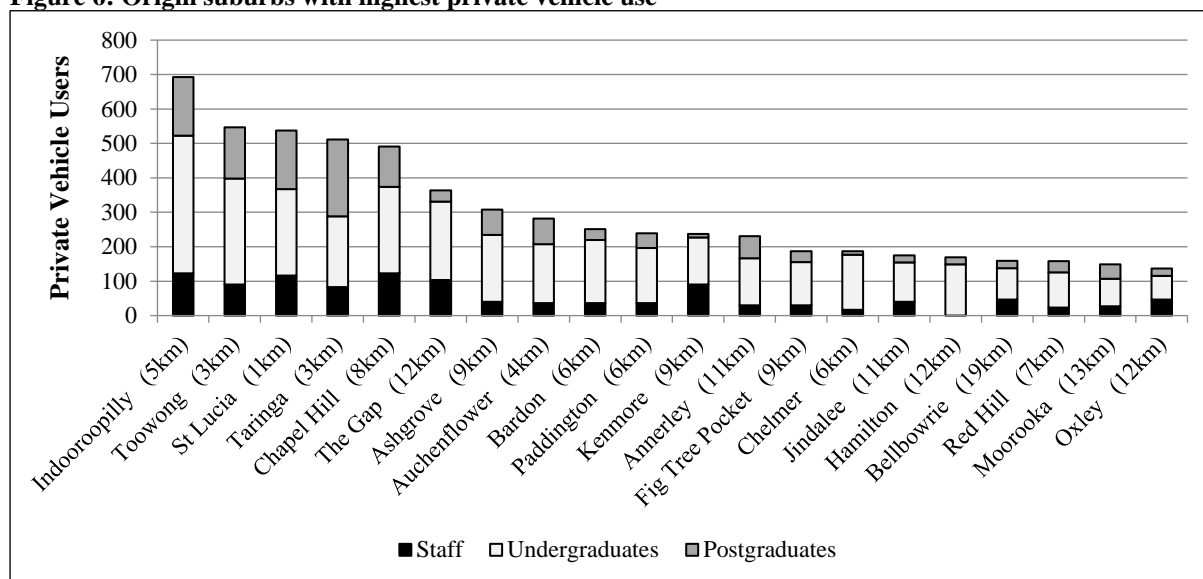
Mapping of public transport users showed a higher proportion of respondents living in the south-eastern suburbs use public transport compared to those living in the western and north-west suburbs (Figure 7). The south-east is well serviced by high frequency separated busways, while there are no dedicated busways in the west. For undergraduate and postgraduate students travelling from Indooroopilly (the highest vehicle source), overcrowding/unreliability was the major barrier to catching public transport (55% and 43% respectively), compared with 23% average across all suburbs and participants. Direct and frequent connections to UQ from Indooroopilly train station and/or Indooroopilly Shopping Centre, either via a dedicated shuttle service or public transport, could encourage modal shift for these drivers.

26% of respondents said they would catch public transport more often if it was cheaper. However, parking fee increases to date have not deterred staff from driving, as day rates ($5.00/day) still compare favourably to full priced public transport fares ($6.50 or more per day). Car commuters often fail to recognise the sunken and operating costs of vehicles and simply compare parking fees to public transport fares, ignoring fuel, maintenance, registration, insurance, and depreciation.

3.3 Policy implications

Travel behaviour differed between staff and students, between international and domestic students, and which side of the river travel commences. Changing staff travel behaviour should be the priority for reducing per capita emissions; whereas the largest overall reductions are likely to come from changes in behaviour of undergraduate students, due to the much larger numbers. The very high rates of car travel from neighbouring suburbs suggests a clear opportunity for improving public and active travel close to the university. Regardless of these differences, however, travel time is a key driver for commuter travel mode choice and was the number one barrier to both public and active transport.

Congestion is a significant issue in Brisbane, and the peak Queensland motoring body, the RACQ, are campaigning for governments to invest in new river crossings to – in their view – help to address this issue. Some of the proposed new bridges are in close proximity to UQ's St Lucia campus, including connections between West End and St Lucia, and Toowong and West End, and the expansion/duplication of the Walter Taylor Bridge connecting Indooroopilly to

Figure 7: Percentage of commuters whose main mode is a) private vehicle; and b) public transport
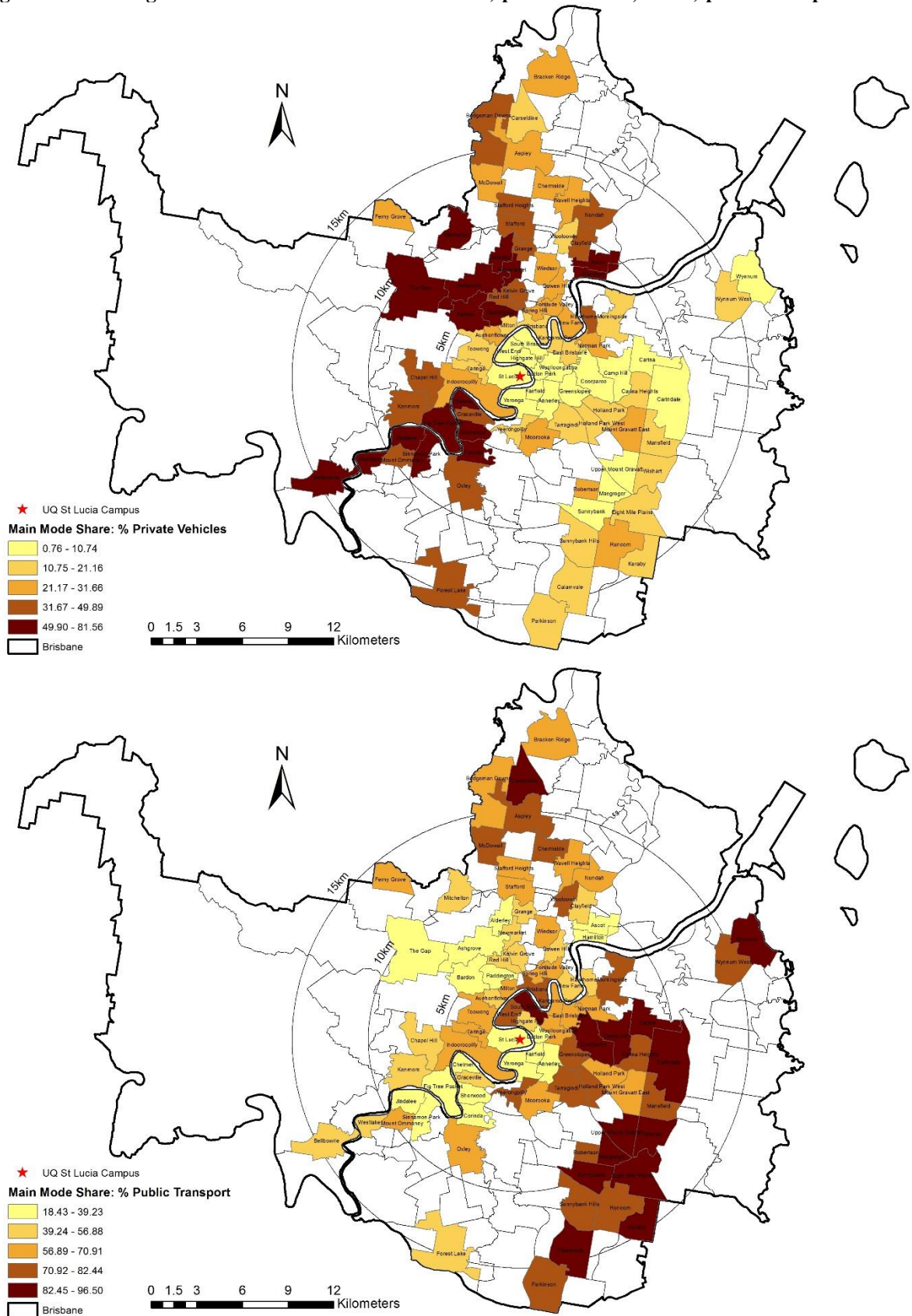
Chelmer. If these were to be open bridges with general lanes for all traffic, it may increase private car travel to UQ from cross-river suburbs, with associated negative implications such as congestion and emissions (with cars four times more emissions-intensive than public transport). In contrast, the Eleanor Schonell "green bridge" to the UQ campus has increased the use of public and active transport from nearby suburbs (Charles-Edwards et al., 2014).

New bridges are unlikely to affect mode choice for UQ commuters living on the north side i.e. the same side as the St Lucia campus. Although the advent of new mobility vehicles, such as electric vehicles, will reduce the emissions component of private transport, they will not address congestion. As such, it is important that other forms of transport are still encouraged. Since private vehicles dominate greenhouse gas emissions, and the adjacent suburbs are the main source of private vehicles, the biggest opportunity for reducing commuter emissions lies in increasing the uptake of public and active travel. Cost and travel time were identified as the main barriers to public transport from these neighbouring suburbs; safety as one of the main barriers to cycling. The number of regular cyclists and walkers was less than half the number of occasional cyclists and walkers. Therefore policies to make nearby public transport cheaper and faster, and active travel safer, are important for reducing private vehicle travel from adjacent suburbs. Further parking fee increases could also be implemented as a deterrent to driving.

Public transport patronage was high in areas well serviced by busways, e.g. the South East Busway, Eastern Busway and Northern Busway. **There is no equivalent in the western suburbs** (e.g. Chapel Hill)**,** where commuters often complain of slow, indirect, and crowded bus routes. Mt Coot-tha also acts as a physical barrier, with no direct public transport routes to UQ from the Gap and adjacent suburbs, and two-stage journeys via the city centre add to travel time. The hilly topography of St Lucia could also act as a barrier to cycling, alongside a lack of safe off-road bike paths immediately west of the St Lucia campus. Electric bikes will go a long way to overcoming some of these barriers, but this will require support for electric bike infrastructure on campus and other support mechanisms such as incentives.

4. Conclusion

Commuter travel to UQ is clearly constrained by the Brisbane River. The lack of river crossings is a mixed blessing, increasing distances, travel times and congestion for road travel, and making active and public transport more attractive.

Through this study it was observed that commuters were more likely to drive to UQ from the same (north) side of the river, and were more likely to walk or cycle from the other (south) side of the river. **Thus the river as a geographic barrier is funnelling commuters from across the river towards sustainable transport options.**

In other areas, pockets in the river (affluent suburbs/residents) have poor public transport connections and high car use – **the river in this instance is a major barrier to sustainable transport**. Thus, increasing river crossings, without addressing local barriers to use of public and active travel, may not benefit commuters in the long run or induce any shift in mode choice.

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