RP2021e: Greening Inner-urban Travel with Sharing Economy Mobility Services

Estimating the GHG Emission Impact from Sharing Economy Mobility Services

Final Report

Authors	Charles Ling and John Boland
Title	Estimating the GHG Emission Reduction from Expanding Sharing Economy Mobility Services in the City of Adelaide
Date	June 2019
Keywords	Shared mobility, ridehailing, bikesharing, carsharing, GHG emissions, City of Adelaide
Publisher	CRC for Low Carbon Living
Preferred citation	Ling, C. & Boland, J., 2019, *Estimating the GHG Emission Reduction from Expanding Sharing Economy Mobility Services in the City of Adelaide,* CRC for Low Carbon Living, Australia.
Revision History (Final – v1.0)	Final Version – Issued to UniSA Research Node.

Australian Government
Department of Industry, Innovation and Science

Business
Cooperative Research Centres Programme

Acknowledgements

This research is funded by the CRC for Low Carbon Living Ltd supported by the Cooperative Research Centres program, an Australian Government initiative.

Disclaimer

Any opinions expressed in this document are those of the authors. They do not purport to reflect the opinions or views of the CRCLCL or its partners, agents or employees.

The CRCLCL gives no warranty or assurance and makes no representation as to the accuracy or reliability of any information or advice contained in this document, or that it is suitable for any intended use. The CRCLCL, its partners, agents and employees, disclaim any and all liability for any errors or omissions or in respect of anything or the consequences of anything done or omitted to be done in reliance upon the whole or any part of this document.

Peer Review Statement

The CRCLCL recognises the value of knowledge exchange and the importance of objective peer review. It is committed to encouraging and supporting its research teams in this regard.

The author(s) confirm(s) that this document has been reviewed and approved by the project's steering committee and by its program leader. These reviewers evaluated its:

- originality
- methodology
- rigour
- compliance with ethical guidelines
- conclusions against results
- conformity with the principles of the Australian Code for the Responsible Conduct of Research (NHMRC 2007),

and provided constructive feedback which was considered and addressed by the author(s).

Contents

List of Figures and Tables

Acronyms

ABS	Australian Bureau of Statistics
ACC	Adelaide City Council
ASM	Adelaide shared mobility
AV	autonomous vehicle
CBD	central business district
CO2-eq	carbon dioxide equivalent
CofA	City of Adelaide
EV	electric vehicle
FY	financial year
GHG	greenhouse gas
kg	kilogram
km	kilometre
kWh	kilowatt-hour
LCV	light commercial vehicle
LGA	local government area
PV	petrol vehicle
SA	South Australia
SAV	shared autonomous vehicle
VKT	vehicle kilometres travelled
VMT	vehicle miles travelled

Executive Summary

In Australia, various City Councils, including the City of Adelaide, are pursuing carbon neutrality at municipal-scale based on their operational greenhouse gas (GHG) emissions. As passenger transport is a major component of city operational GHG emissions, there is an opportunity for shared mobility services to play a role in reducing those emissions. This preliminary carbon modelling report has focussed on the GHG benefit from expanding shared mobility services in the Adelaide Local Government Area, although the results should be equally valid in other similar inner-urban precincts.

The Adelaide Shared Mobility (ASM) GHG model was constructed in Microsoft EXCEL using only publicly available data from the City of Adelaide's annual community GHG emissions reporting and the Vehicle-Kilometres-Travelled (VKT) projections published in a report titled, *Carbon Neutral Adelaide - Foundation Report*. Seven shared mobility services were considered with regard to their potential impact over a 20-year period on reducing operational or embodied emissions or acting as a catalyst to reduce GHG emissions including – ridehailing, carsharing, carpooling, bikesharing, ridesplitting and using autonomous vehicles.

The results of the modelling showed that the current state-wide decarbonising strategy of reducing electricity grid emissions coupled with the expected uptake of electric vehicles will have a significant impact on reducing transport GHG emissions, and to a certain degree will cannibalise the potential emission impact of shared mobility services. The combined GHG savings of the considered sharing economy mobility services was found to be less than 1% of the total Adelaide LGA transport emissions for each of the modelled years. The opportunities for shared mobility services for lowering embodied emissions or being a catalyst to reduce other GHG emissions related to the Carbon Neutral Adelaide goal were also found to be not significant.

The possible reasons for the low GHG impact from expanding sharing economy mobility services included:

1. Not all shared mobility trips provide a net GHG emission benefit (e.g ridehailing);
2. Some shared mobility trips displace low carbon modes such as walking and public transit (e.g bikesharing);
3. Some shared mobility trips are a displacement of other shared mobility modes (e.g e-scooters); and
4. The ASM GHG model used conservative growth factors of expanding carshare and bikeshare services consistent with their low growth history to date in the Adelaide LGA.

While the modelling found that expanding shared mobility services had little impact on reducing the direct emissions from private car usage, there is scope to develop the ASM GHG model further to include a more detailed analysis of the embodied emissions from firstly, reducing the number of vehicles and secondly, reducing the related road and parking infrastructure in Adelaide. The ASM GHG model has focussed primarily on reducing private car usage. As more drivers move to using public transit in the future, the ASM GHG model could be expanded from its private car focus to include a detailed analysis of public transit modes to better understand the mode-switching within and between the private usage, public transit and shared mobility sectors.

The opportunities for the future research with the ASM GHG model include:

1. Integrate public transit data into the shared mobility GHG model to better understand the mode-switching within and between the private usage, public transit and shared mobility sectors; and
2. Investigate the benefit of the first mile shared mobility at selected Adelaide suburban transit stations to delay/avoid the future construction of car parking buildings for 'Park n Ride' commuters.

Project Overview

RP2021e Greening Inner-urban Travel with Sharing Economy Mobility Services

The sharing economy is undergoing massive expansion, with exemplars like the car sharing market expected to involve millions of consumers globally by 2020. Increasingly, consumers consider public sharing systems a viable alternative to product ownership, a paradigm that competes with the dominant logic of private ownership and control. Sharing systems have evolved as a disruptive technology driven business concept on the premise of providing end-users with access to the benefits of product ownership, but without the commitment to capital expenditure.

This research project is designed to investigate the potential social, economic and carbon benefits of the sharing economy mobility services by answering the question: To what extent can sharing economy services deliver the low-carbon mobility needs of those who live, work or play within inner-urban precincts?

The project has four main parts:

- Work Package 1: Barriers to the provision of sharing economy mobility services
- Work Package 2: Servicing the needs of major inner-urban trip generators
- Work Package 3: Mapping demand for sharing economy mobility services
- Work Package 4: Quantifying the carbon abatement impact

This represents the Final Report of Work Package 4 and draws on the findings from Work Packages 1, 2 & 3 to quantify the carbon abatement potential due to greater commercial provision and user participation in sharing economy mobility services. The Carbon Neutral Adelaide region will be used as a case study to highlight the abatement potential for other similar inner-urban regions.

1. Introduction

The transport sector was the second largest contributor (19.1%) to Australia's greenhouse gas (GHG) inventory in June 2018 and transport emissions have been rising steadily over the last decade (Department of the Environment and Energy 2018b). Cars and light commercial vehicles are responsible for 59% of transport sector emissions which is equivalent to 11% of the Australia's national GHG inventory (Department of the Environment and Energy 2018a), and a higher share of transport emissions in inner-city situations. Opportunities to reduce private car travel will have a significant impact on reducing the nation's future GHG emissions.

Personal mobility including the use of private vehicles and public transit is forecasted to change rapidly over the next 10-15 years as major disruptors flow through the road transport sector including: the uptake of electric vehicles, shared mobility and the emergence of autonomous vehicles (Kane & Whitehead 2017; Sprei 2018), with the greatest disruptive potential occurring when all three disruptors coincide (Sprei 2018). The term, shared mobility, is evolving and is still being defined by the policy and academic audiences. Byars et al, (2017, p. 4) have sought to standardise the emerging transport terminology in their glossary of sustainable transport terms and they have defined 'shared mobility' as "a transportation mode that is used by more than one person either for moving a person or personal goods". In some situations, a vehicle, bicycle or other mode will be shared sequentially among users such as carsharing or bikesharing, or the ride will be shared amongst users such as ridesplitting (Sprei 2018). The terms, ridehailing, ridesourcing and ridesharing, have been used interchangeably to describe trips provided by transport network companies such as Uber and Lyft where rides offered for profit by drivers of personal vehicles. While Byars et al. (2017, p. 4) prefer to use 'ridesourcing' to describe the above form of personal mobility, this report has used the term 'ridehailing' as it aligns more often with the report's referenced literature.

In the literature, there are varying views on how shared mobility services will impact on future urban transport and especially, future urban transport GHG emissions. With the expected increase in convenience and the decreased cost of shared mobility services, people may make more trips resulting in more GHG emissions (Clewlow & Mishra 2017; Currie 2018; Jung & Koo 2018). Or the presence of multiple and integrated transport options provided by shared mobility may break the nexus between travelling and owning a vehicle, that is, achieving the same mobility service outcomes with fewer private cars and the related car infrastructure (Greenblatt & Saxena 2015).

In Australia, various City Councils, including the City of Adelaide, are pursuing carbon neutrality at municipality-scale based on their operational GHG emissions. As passenger transport is a major component of the City of Adelaide's operational GHG emissions, there is an opportunity for shared mobility services to play a role in reducing those emissions. The Research Node for Low Carbon Living (Research Node) based at University of South Australia has been investigating the opportunities for, and barriers to, shared mobility in achieving a low carbon future in Adelaide, South Australia.

Adelaide has been selected for the GHG modelling to integrate with the other shared mobility research completed by the Research Node. Currently in Adelaide, the main shared mobility services are: GoGet carshare, Uber and Shebah ridehailing and various share bike and e-scooter schemes. Soltani, Nguyen & Allan, (2018) have posed the question on how the expansion of shared mobility services could potentially reduce the level of car dependency in Adelaide noting that it is one of the most car-dominated capital cities in Australia, and how much shared mobility can a contributory role in Adelaide City Council to achieve its carbon neutral status. This modelling report has focussed on the possible GHG impact from expanding shared mobility services in Adelaide, especially their role in supporting the Adelaide City Council's Carbon Neutral Adelaide goal.

As a high-level review, only publicly available data has been used in this preliminary modelling study. It is expected future funding will be available for a more detailed modelling study.

This modelling study has considered the following three mechanisms of GHG reduction from the expansion of shared mobility services in the Adelaide LGA.

- Operational based - GHG reduction derived from achieving less emissions per travelled kilometre. Examples include fuel switching, uptake of electric vehicles, carpooling, switching modes from private car to public transport and to active transport such as walking and cycling.
- Embodied based - GHG reduction derived on reducing the number of vehicles and their embodied emissions in the general community. For example, car-share schemes remove around ten vehicles from the community for every active car-share vehicle. Also applies to reducing car-related infrastructure such as parking lots.
- Catalyst based - GHG savings derived from shared mobility enabling people to pursue low carbon

transport such as integration of share bikes with public transit to address the so-called first-mile last-mile problem or creating a sufficiently diverse transport sector so people have confidence in downsizing their vehicle holding.

The following shared mobility services have been incorporated in to the Adelaide Shared Mobility GHG model including current and future services. The current mobility services to be modelled include:

- Ridehailing – Uber and Shebah (women/children only);
- Carsharing – GoGet (membership model);
- Carsharing – DriveMyCar (peer-to-peer model); and
- Carpooling – Adelaide Carpool.

The future shared mobility services to be modelled include:

- Bikesharing – Docking sharebikes;
- Ridesplitting – UberPool; and
- Autonomous – Single ride and shared ride options.

While Adelaide has the Adelaide Free Bikes service, it is an older generation of bikesharing without any interaction with smart-phone applications and has been geared to supporting the visitor market. For the GHG modelling, it is assumed that a new generation of docking sharebikes similar to Brisbane and Melbourne may be established to better support the city's resident and working populations as well as the city's visitors. UberPool is a ridesplitting service well-established overseas and it has been recently trialled in Melbourne and Sydney. For the GHG modelling, it is assumed that an UberPool service will be introduced to Adelaide in financial year, FY2020. There are no commercial autonomous vehicles operating in Adelaide, but it is expected they will be introduced to Adelaide during the 20-year modelling period, FY2020 – FY2039.

The modelling study develops plausible shared mobility scenarios from the different shared mobility services and determines the amount of GHG emissions decreased (or increased) within the geographical boundary of the Adelaide LGA.

2. Methodology

2.1 – GHG Model Construction

The Adelaide Shared Mobility (ASM) GHG model was constructed in Microsoft EXCEL using data from the City of Adelaide's (CofA) annual community GHG emissions reporting spanning the financial years (FY), FY2007 to FY2017 (Adelaide City Council 2018) and the Vehicle-Kilometres-Travelled (VKT) projections spanning from FY2013 to FY2050 published in a report titled, *Carbon Neutral Adelaide - Foundation Report* (Harrington 2015, p.31). The Pitt & Sherry report divides the total VKT into the following categories: Cars and Light Commercial Vehicles, Motorcycles, Trucks for the private transport sector and Buses, Trains and Trams for the public transport sector. As the transport GHG emissions and VKT are known for the past five years, the emission rate per kilometre (kgCO2-eq/km) was back-calculated for each category and then re-applied to the projected VKT values out to FY2050. As the VKT values were listed at seven yearly intervals in the Pitt & Sherry report, the published VKT forecasts were interpolated to create VKT values on a yearly basis. This was achieved by fitting a polynomial curve to the series of VKT data points for each category.

The ASM GHG model has only focussed on the emission impact on the Cars & Light Commercial Vehicle (LCV) category by the shared mobility services as this category is the highest contributor to the CofA's VKT values and its related operational transport GHG emissions. Due to the lack of access to historical and projected public passenger numbers, the ASM GHG model has not incorporated the emission impact of mode switching between the public transport modes or the emission impact of shared mobility services on the public transport modes. While the GHG model has VKT values calculated out to FY2050, the modelling report has only focussed on the next twenty years (FY2020 to FY2039) where the other modelling assumptions are still reliable.

To assess the concurrent influences in decarbonising the passenger transport sector in the Adelaide Local Government Area (LGA), the ASM GHG model incorporated the following functions:

- Adjusting the emission intensity of grid electricity at a state level (i.e. South Australia);
- Adjusting the rate of electrification of the suburban train lines; and
- Adjusting the uptake of electric vehicles, all out to year FY2050.

As the impact of decarbonising the state electricity grid, the private vehicle fleet and the public transport sector is expected to be significant relative to the expansion of shared mobility services, the ASM GHG model incorporated the three following decarbonising scenarios:

- The FROZEN or NO CHANGE baseline scenario - In this case, all the decarbonising functions in the model are held at FY2019 values for the modelled range FY2020 to FY2050. The state electricity grid's emission factor was held at 0.60 kgCO2-eq/kWh, the percentage of private electric vehicles (cars and motorbikes) and the percentage of public electric buses was held at 0%, and the electrification of passenger trains was held at 20%. This is an unlikely scenario for Adelaide, but it provides the baseline for comparing two future decarbonising scenarios.
- The MODERATE scenario - In this case, the state electricity grid's emission factor reduces by 2.50%/year out to FY2050. The percentage inventory of electric vehicles (cars and motorbikes) follows the moderate EV proportion forecast as shown in Figure 1 below. The public bus fleet is partially electrified, 2% by FY2030, 20% by FY2039 and 42% by FY2050. The electrification of the remaining suburban train lines is completed by FY2029. This is a more likely scenario for the Adelaide LGA as it assumes the future rate of decarbonisation is similar to the past rate of decarbonisation in South Australia.
- The ACCELERATED scenario - In this case, all the function parameters have been accelerated to create a zero (net) emission transport sector in the Adelaide LGA by FY2050. It assumes that the state electricity grid's emission factor reduces by 10.0%/year out to FY2050. The percentage inventory of electric vehicles (cars and motorbikes) follows the accelerated EV proportion forecast as shown in Figure 1 below. The electrification of the remaining suburban train lines is completed by FY2029 and the public bus fleet is 100% electric by FY2050. This is a possible scenario for Adelaide, but it would need strong policy and financial support by all tiers of government - local, state and national - to achieve it.

As trams are already 100% electric, they remained unchanged through the three decarbonising scenarios. Also, the uptake rate of electric motor bikes is set to be identical to the uptake of electric cars in each scenario.

Based on the electricity emission factors for full fuel cycle (Scopes 2 & 3) published in the annual Australian Government *National Greenhouse Accounts Factors*, it can be seen that the emission factors for the mainland states have been decreasing as thermal power stations are being retired and replaced by renewable energy generation. In this case, Scope 2 covers the emissions from the generation of electricity while Scope 3 covers the emissions from the transmission and distribution network losses. For the ASM GHG modelling, the weighted average percentage reduction was calculated for the last five years for all of the mainland states. As Tasmania generates mostly hydro-electricity with some importing of thermally generated electricity, it did not reflect the current pattern of the mainland states retiring thermal generation and replacing with wind and solar electricity. For the modelling, a weighted average reduction factor based on mainland state populations gave a value of 2.50% reduction/year so the value of 2.50% reduction/year was used to model the rate of decarbonising the state electricity grid. SA had a 2.67% reduction/year in the emission factor, so the modelled scenario is a more conservative choice.

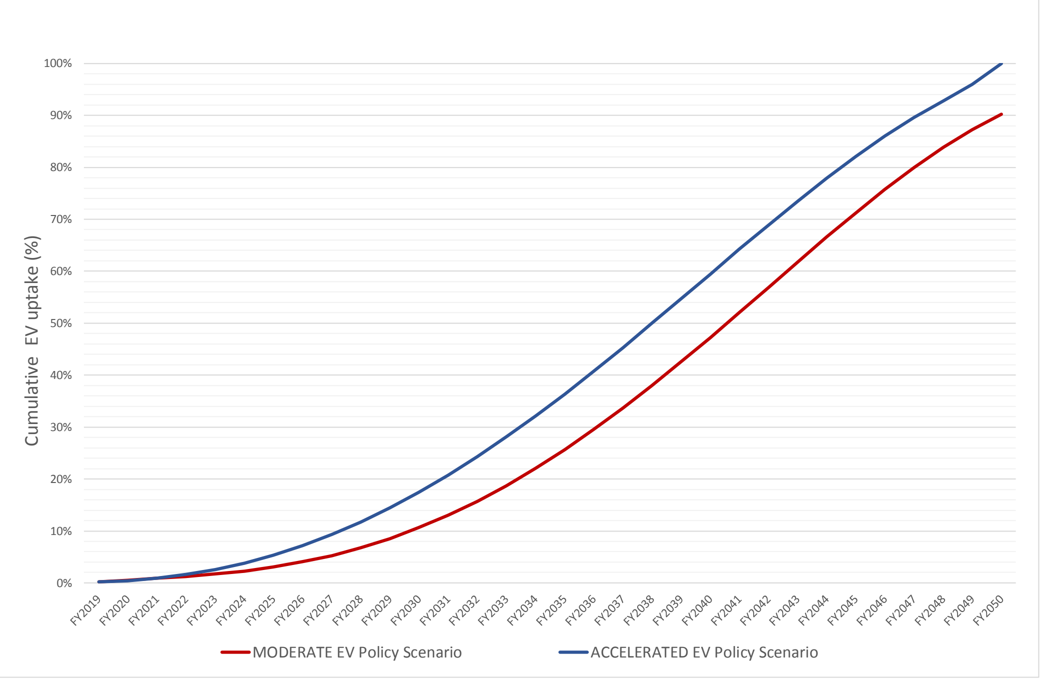

Figure 1 - Forecasted proportion of electric vehicles in Australia's car fleet (Chart adapted from (Energeia 2018, p. 7))

In 2017, 2284 electric cars were sold in Australia which makes up 0.2% of the national car sales (ClimateWorks Australia 2018, p. 6). While the percentage of new electric cars to new cars sold is quite low to date, it is expected to change dramatically over the next 10-15 years.

To model the transition to electric vehicle ownership, the electric vehicle cumulative uptake has been sourced from Figure 1 above, which was based on modelling trends from a recent Australian electric vehicle market report prepared by Energeia (Energeia 2018, p. 7).

To model the emission intensity of the electric vehicles, information was sourced from a research paper comparing the direct and indirect emissions from a Nissan Leaf electric vehicle and a Toyota Corolla internal combustion engine vehicle (Stasinopoulos, Shiwakoti & McDonald 2016). It was assumed that the emission intensity for the petrol and diesel vehicles was 0.255 kgCO2-eq/km.

For the electric vehicles, the decreasing emission factor of state electricity grid was included in the ASM GHG model. At the emission factor of 0.60 kgCO2-eq/kWh, the emission intensity of the electric vehicle starts at 0.141 kgCO2-eq/km for direct or operational emissions and reduced to 0 kgCO2-eq/km when the electricity grid reached zero (net) emissions.

2.2 – Shared Mobility Services

Seven shared mobility services were considered with regard to their potential impact on reducing operational or embodied emissions or acting a catalyst to reduce GHG emissions. Seven shared mobility options, (a) to (g), have been reviewed for inclusion in the ASM GHG model and are summarised in Table 1 below. The review and modelling details for each shared mobility service have been included below.

Table 1 – Summary of shared mobility options considered in this GHG modelling study

Shared Mobility Service	Operational	Embodied	Catalyst
1. Ridehailing	*Literature unclear (Assumed neutral)*	*Possible reduced car ownership*	*No known catalyst impact*
2. Carsharing (Membership)	***a. Minor reduction of car trips***	***e. Reduces 10 owned cars per 1 share car***	***f. Possible accelerated EV uptake***
3. Carsharing (Peer-to-peer)	*No reduction in car trips*	*Possible reduced car ownership*	*No known catalyst impact*
4. Carpooling	***b. Increases passengers per trip***	*No reduction in car ownership*	*No known catalyst impact*
5. Bikesharing	***c. Only 19% trips displaced from cars***	*No reduction in car ownership*	***g. Possible first/last mile transit uptake***
6. Ridesplitting	***d. Increases passengers per trip***	*Possible reduced car ownership*	*No known catalyst impact*
7. Autonomous Vehicles	*Literature unclear (Assumed neutral)*	*Possible reduced car ownership*	*Possible less parking infrastructure*

RIDEHAILING (Uber and Shebah are currently active in Adelaide) - Uber has the majority share of the ridehailing market in Adelaide and both companies mostly compete with existing taxi services and to a lesser extent, public transport. Clewlow and Mishra (2017, p. 27) stated the following points as part of their key findings in their ridehailing research report:

- *After using ride-hailing, the average net change in (public) transit use is 6% reduction among Americans in major cities.*
- *We find that 49% to 61% of ride-hailing trips would not have made at all, or by walking, biking or (public) transit.*
- *Ride-hailing users have similar vehicle ownership rates as everyone else.*
- *Directionally, …, we conclude that ride-hailing is currently likely to contribute to growth in vehicles miles travelled (VMT).*

Based on the outcomes of the UC Davis research report above, ridehailing trips have been considered as a neutral scenario, i.e. no change to operational or embodied GHG emissions from the presence of ridehailing services as most trips are car trips substituting private car trips, taxi trips or public transport trips. While Clewlow and Mishra (2017, p. 27) noted an increase in the ridehailing VMT, the percentage of ridehailing trips to private car trips is quite low and so the overall VMT contribution is considered to be close to zero.

CARSHARING (Membership based) - GoGet is currently active in Adelaide and has 18 vehicles available for short-term hire in the Adelaide CBD at the start of this study. Carsharing has the potential to reduce operational GHG emissions by members reducing their travelled kilometres after joining a carshare program (Cohen & Shaheen 2016; Martin & Shaheen 2011a; Nijland & van Meerkerk 2017). Martin and Shaheen noted in their study of carsharing GHG emissions in North America that VKT had reduced on average when households joined a carshare program, but the changes in VKT were not consistent across all households. For some carshare members who were previously carless increased their car-based travelled kilometres after joining the program while other carshare members who had sold their vehicle on joining the program and they had reduced their VKT by using less car trips than previously (Martin & Shaheen 2011b). To model the GHG emission benefit from reducing carsharing VKT, the following assumptions have been sourced from an Australian carsharing report (Phillip Boyle and Associates 2016, p. 93) – Reduced VKT per member = 1,947km and members per sharecar = 24.15 persons. As the considered vehicles are based in the Adelaide CBD, it was assumed that 50% of carshare trip kilometres were made within the Adelaide LGA.

Carsharing services has the capacity to reduce vehicle ownership as well as travelled kilometres, resulting in less embodied emissions from less vehicles being manufactured (Chen & Kockelman 2016; Jung & Koo 2018; Nijland & van Meerkerk 2017). Typically, the reduction in vehicle ownership includes both, vehicles sold after becoming a carshare member (vehicles shed) or from avoiding a future purchase (vehicle avoided). For calculating the potential benefit of avoiding embodied emissions, it has been assumed that 10 cars are removed for each additional sharecar brought into operation resulting in a net reduction of nine cars in line with a major Australian carsharing study (Phillip Boyle and Associates 2016, p. 6). The saved embodied emissions per shed/avoided car used in the model is 7.7 tonnesCO2-eq/car (Wu et al. 2018) so a total of 69 tonnesCO2-eq is saved for each additional sharecar.

CARSHARING (Peer-to-peer based) - Private car owners in Adelaide can monetise their low vehicle utilisation by making their vehicles available for peer-to-peer car rental using websites such as www.drivemycar.com.au. A review of the website in mid-December 2018 showed there were only 2 cars available for a 2-day hire and 21 cars available for a 7-day hire in Adelaide, so it is set up for providing medium-term car rental. While falling within the definition of 'shared mobility', the medium-term hire would suggest the service was supporting intrastate travel rather than the short-term CBD trips carried out by membership-based sharecars. The operational emission impact of peer-to-peer carsharing in Adelaide was considered not significant enough to include in the GHG modelling as most trips would be a substitution of existing car rental trips with a similar GHG emission profile. In terms of embodied emissions, there may be a case for reduced vehicle ownership from the commercial rental vehicle fleet rather than private vehicle fleet but there is insufficient data to confirm.

CARPOOLING - The modelling study has only focussed on the formal carpooling program currently trialled by the SA Government with the support of the Adelaide City Council. Public data about informal carpooling arrangements was not available and it has not been considered in this modelling study. Adelaide Carpool website listed 465 registered users in mid-December 2018. The carpooling modelling took into account the GHG benefit of decarbonising grid electricity and the increasing percentage uptake of electric vehicles over the next twenty years. The carpooling GHG emissions savings were modelled with the following assumptions: a 3.5% annual growth rate in the number of registered users, a 40km return trip with 5km occurring in the Adelaide LGA study area and each carpool trip had 1.5 carpool passengers (on average) for 200 business days per year. The use of carpooling is not expected to significantly reduce the level of vehicle ownership in the carpooling user group.

BIKESHARING - Adelaide Free Bikes is an older generation of bikesharing originally established by the Adelaide City Council and now managed by the community organisation, Bike SA. Adelaide has had two unsuccessful episodes of dockless bikesharing, with both *oBikes* and *ofo* starting in 2017 and withdrawing in 2018. For the GHG modelling, it was assumed that a fully docking service will be established in FY2020 similar to the bikesharing schemes operating in Melbourne (Melbourne Bike Share) and Brisbane (CityCycle). Detailed studies of Melbourne and Brisbane docking bike schemes found that they were utilised much less than forecasted (0.63 & 0.32 trips/bike/day respectively) and only 19% & 21% respectively of shared bike trips displaced private car trips(Institute for Sensible Transport 2016, p. 42). Most shared bike trips were switching from walking and public transport so the GHG emission benefit was limited.

The calculation of bikesharing emission reduction follows a similar methodology as outlined in Table 4 in the bikesharing report, *Bike Share - Options for Adelaide Stage Three: Design and Options Assessment* (Institute for Sensible Transport 2016, p. 42). The ASM GHG model values have been based mostly on the Melbourne case study. Starting with 200 docking bikes in FY2019, it was assumed that the growth rate of docking bikes was 3.5% per year, the average trip length was 4.4 km (approximately twice the width of the Adelaide CBD) and trip utilisation will improve over the study period, starting at 0.60 trips/bike/day in FY2020 and finishing at 1.2 trips/bike/day in FY2039. The private car substitution rate of 19% has remained constant over the 20-year modelling period but similar to other modelling options, the emission intensity of the substituted cars will fall each year in line with the broader decarbonising scenario.

RIDESPLITTING - In Australia, UberPool enables a single ridehailing trip to be split into two concurrent trips by two unrelated customers giving financial benefits to both riders. To date, the UberPool service only operates in inner-suburbs of Sydney and Melbourne. For the ASM GHG modelling, it has been assumed that UberPool will start in Adelaide in FY2020 and Uber has 2% of the Adelaide's passenger car VKT based on the following CityLab webpage (Bliss 2018), "*Vehicle miles traveled are rising across the U.S. for all kinds of reasons, and ride-hailing still makes up a very small portion of the U.S.'s overall VMT—somewhere between 1 and 2 percent, according to Coriell (though other estimates suggest it's larger)"*. Uber has said that 20% of its ridehailing trips globally are now shared rides on UberPool (Lunden 2016).

For the GHG modelling, it was assumed that 1/3 of the pre-UberPool trips have been 'converted' to shared trips resulting in a reduction of 1/6 in pre-UberPool trip. These calculations result in a 1/5 or 20% share of post-UberPool trips after the ridesplitting service has been activated. The background increase in electric vehicles and the decrease in the electricity grid's emission factor has been included in the modelling.

AUTONOMOUS VEHICLES - Based on the literature, the GHG emission impact of Autonomous Vehicles (AV) is unclear. It may increase VKT and that those increased trips will be mostly switched from public transport resulting in higher GHG emissions (or neutral if all options are 100% electric). For the ASM GHG modelling, it has been assumed improvements in operational emissions are negligible or higher than baseline scenario. Lennert & Schönduwe (2017, p. 231) notes that "*While automation, in particular of mass and ride-share transit, has great potential, it does not a priori provide a strategic decarbonisation lever for urban mobility, which will have an increasingly dominant share of global transport emissions. …. They can strongly support a shift to transport decarbonisation, or further lock in unsustainable travel behaviour and infrastructure design.*" The embodied GHG benefit is better than the operational GHG benefit with less private owned vehicles but it is not clear in the literature, how many private vehicles will be reduced by the future presence of autonomous vehicles.

Autonomous vehicles (AV) with single rides have been considered as neutral scenario, that is, no decrease or increase in operational and embodied GHG emissions similar to the ridehailing scenario. For shared autonomous vehicles (SAV), there is an operational GHG benefit from splitting rides. For the ASM GHG modelling, it is assumed that the SAV shared trips will eventually replace the existing UberPool shared trips as the autonomous vehicle technology matures. To avoid double counting, the ASM GHG model has assumed that ridesplitting will continue in vehicles with drivers to the end of the 20-year modelled period even though they may be mostly replaced by SAVs by then.

To summarise, the seven shared mobility options considered for the GHG modelling include:

1. Carsharing – Membership based (Operational emissions);
2. Carsharing – Membership based (Embodied emissions);
3. Carsharing – Membership based (Catalyst opportunity with accelerating EV uptake);
4. Carpooling (Operational emissions);
5. Bikesharing (Operational emissions);
6. Bikesharing (Catalyst opportunity with first mile last mile problem); and
7. Ridesplitting (Operational emissions).

3. Results

The results of the ASM GHG modelling have been grouped into the following four sections: decarbonising scenarios, operational emissions, embodied emissions and lastly, using shared mobility services as a possible catalyst for enabling further GHG emission reductions. As expected, the impact from the state-wide decarbonising agenda influenced the ability of shared mobility services to reduce transport GHG emissions in Adelaide. The activity or operational emissions are of particular interest as they relate directly to the emission reporting of the Carbon Neutral Adelaide program. While the modelling of the operational GHG emissions was the primary focus of this study, the secondary GHG emission benefits such as reducing embodied emissions or enabling new opportunities for accelerating a low carbon transport future were also considered.

3.1 – Decarbonising Scenarios

The ASM GHG model operated with three different decarbonising scenarios and they are summarised below:

- FROZEN - All key aspects of electricity grid's emission factors, transit electrification program and electric vehicle proportion are 'frozen' at FY2019 levels for the duration of the modelling period. This is a possible but unlikely scenario given the momentum for decarbonising in South Australia as evidenced by the Carbon Neutral Adelaide vision.
- MODERATE - All key aspects of electricity grid's emission factors, transit electrification program and electric vehicle proportion will continue to decarbonise at the rate experienced in the last 5 years. This is a possible and likely scenario.
- ACCELERATED - All key aspects of electricity grid's emission factors, transit electrification program and electric vehicle proportion have been accelerated to achieve a zero (net) emission electricity grid and zero (net) emission transport fleet by FY2050. An unlikely but a possible scenario if all levels of government support a rapid decarbonisation future.

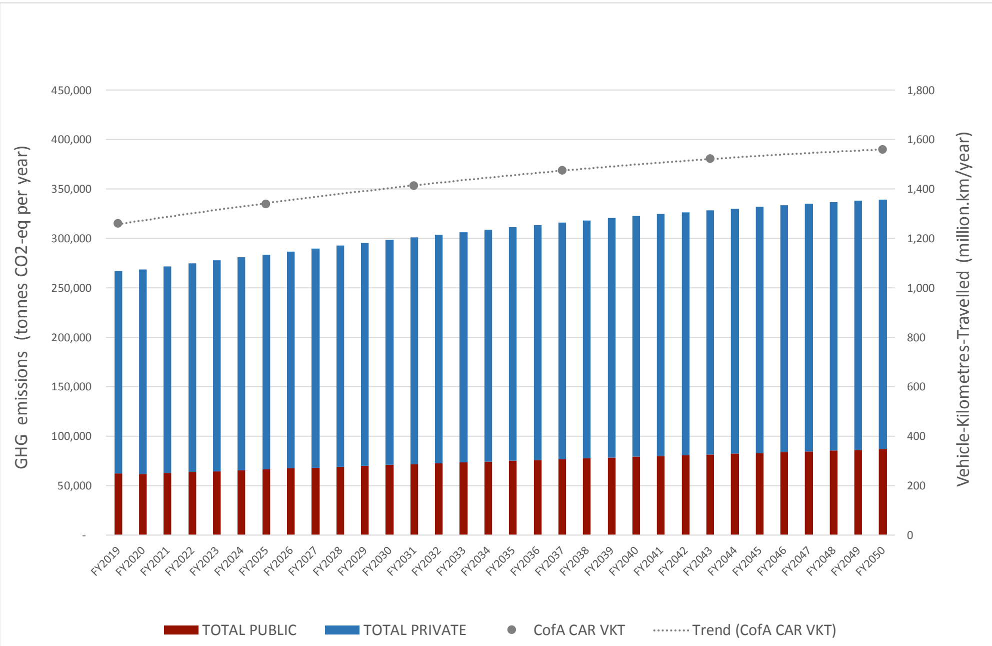

Figure 2 - Annual GHG emissions in Adelaide LGA under a FROZEN or NO CHANGE decarbonising scenario

Under the FROZEN decarbonising scenario as shown in Figure 2 above, the annual transport GHG emissions rise each year through to FY2050, which is the end of the modelling period. As all the key decarbonising aspects are frozen, the rises in GHG emissions are due to the increase in VKT in the Adelaide LGA, which in turn, is related to the increasing residential and working populations in the Adelaide LGA over the next thirty years. There are rises in both, private and public transport from the projected increase in VKT. For comparison, the chart shows the increasing private car VKT trendline which covers 96% of the combined private and public transport VKT categories.

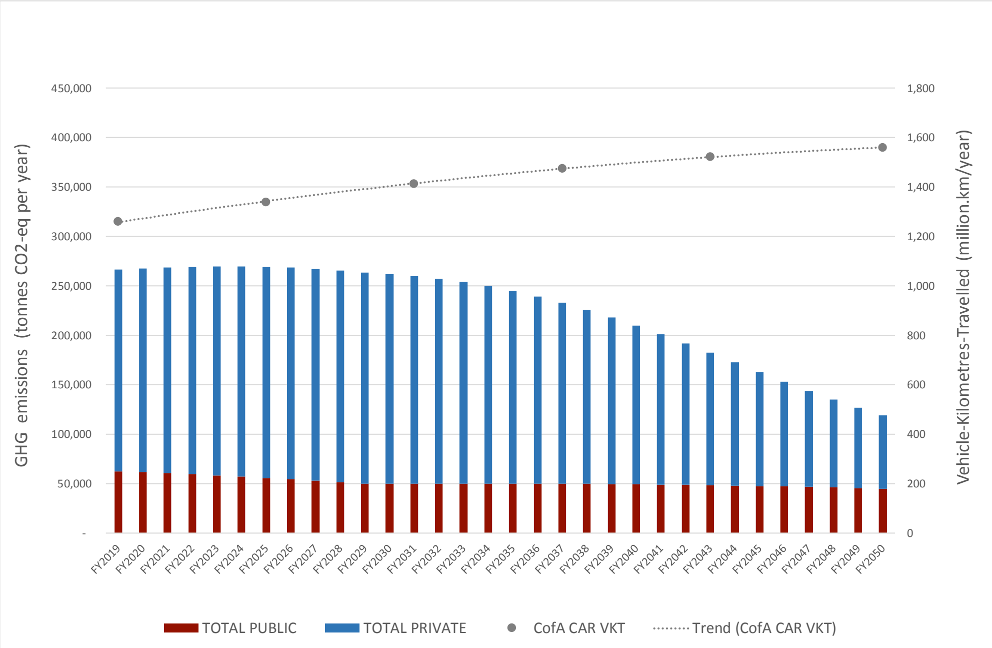

Figure 3 – Annual GHG emissions in Adelaide LGA under a MODERATE decarbonising scenario

Under the MODERATE decarbonising scenario as shown in Figure 3 above, the annual transport GHG emissions peak at 269,070 tonnesCO2-eq in FY2024 and then reduce to 119,050 tonnesCO2-eq by FY2050. The falling annual emissions in the private transport sector are due to both, the decarbonising of the state electricity grid and the percentage uptake of electric vehicles in Adelaide. The smaller falling annual emissions in the public transport sector are due to both the final electrification of the train network and the related drop in train and tram emissions as the electricity grid's emission factor keeps reducing over the thirty-year study period. The chart demonstrates clearly that under a moderate decarbonising scenario, there is a decoupling effect between the increasing vehicle kilometres and the resulting transport GHG emissions.

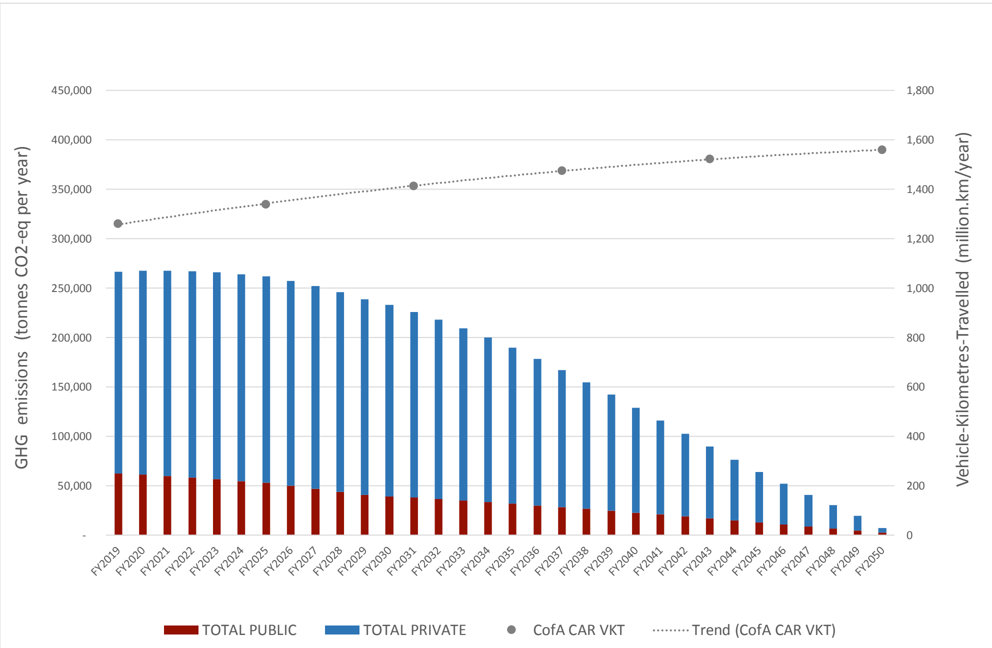

Figure 4 - Annual GHG emissions in Adelaide LGA under an ACCELERATED decarbonising scenario

Under the ACCELERATED decarbonising scenario as shown in Figure 4 above, the annual transport GHG emissions peak at 267,445 tonnesCO2-eq in FY2021 and then reduces by 100% by FY2050 (ignoring the model rounding errors). The rapid annual emissions reduction is primarily due to the accelerated decarbonising of the state electricity grid and the accelerated uptake of electric vehicles in Adelaide. The chart demonstrates that there will be negligible transport emissions if the city achieves both, a zero (net) emission electricity grid and a zero (net) emission vehicle and transit fleet by FY2050. With the decoupling of transport GHG emissions from the growth of vehicle kilometres, the chart highlights how a rapidly decarbonising transport sector cannibalises the GHG benefit of shared mobility services as there are less operational GHG transport emissions to displace as each year passes.

3.2 – Shared Mobility Operational Emissions

The emission profiles of the four operationally-focussed shared mobility options are shown in Figure 5 and Figure 6 below.

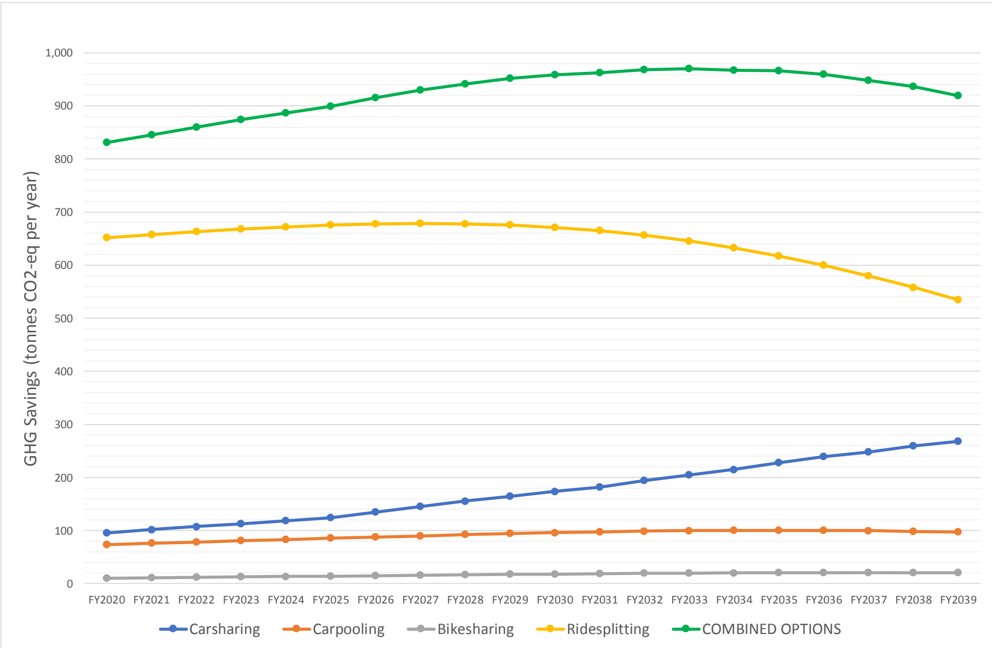

Figure 5 - Annual GHG operational emissions for shared mobility services in Adelaide LGA in a MODERATE scenario

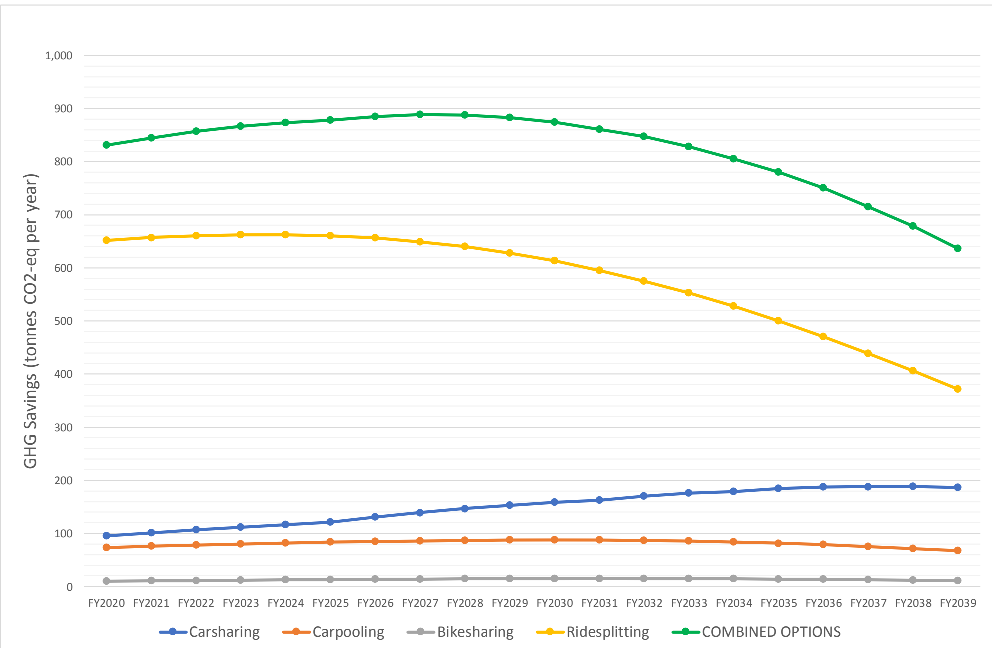

Figure 6 - Annual GHG operational emissions for shared mobility services in Adelaide LGA in an ACCELERATED scenario

All four shared mobility options had a positive impact in reducing the GHG transport emissions albeit quite low (<1.0% combined) when compared with the total GHG transport emissions in the Adelaide LGA for each modelled year. The combined shared mobility emission reductions peak in FY2033 in the MODERATE decarbonising scenario and peak in FY2027 in the ACCELERATED decarbonising scenario. The GHG emission benefit of shared mobility services is higher in the MODERATE scenario and lower in the ACCELERATED scenario which highlights how much other emission reduction strategies cut into the potential GHG emission impact of shared mobility services.

Ridesplitting was found to have the highest GHG emission benefit as ridehailing services already have a strong presence in Adelaide and the transition to splitting rides is expected to be rapid once a service such as UberPool is activated in Adelaide. However, as the ridehailing vehicle fleet is expected to follow the same uptake of electric vehicles as the general community fleet, then the GHG benefit of ridesplitting reduces in line with the projected decoupling of the city's transport GHG emissions. The GHG benefit of ridesplitting is inversely dependent on the rate of decarbonising – the faster the transport fleet in Adelaide decarbonises lowers the GHG benefit of ridesplitting.

Carsharing was found to have the next highest GHG emission benefit. The carshare modelling starts from a low base of 16 vehicles in the Adelaide CBD and grows at 9.6% vehicles per year to achieve a fleet of 64 vehicles by FY2039, a four-times increase. The higher growth rate enables at least one whole vehicle to be added per annum in the earlier years of the modelling period. In this case, the selected high growth rate for carsharing exceeds the GHG emission impact from the discussed decarbonising agenda. Coming off a low base of sharecar numbers available for use, the overall GHG impact of carsharing is marginal compared to the total GHG transport emissions.

The carpooling option had the second lowest GHG benefit. In this case, the user growth rate (3.5% user increase/year) of the carpooling program just exceeds the rate of declining GHG emissions from electricity and vehicle decarbonisation. While carpooling has an obvious GHG benefit, the ASM GHG model only included the portion of the modelled carpooling trip that travelled inside the Adelaide LGA, i.e., 5km of the 40km return trip.

The bikeshare option had the lowest impact on reducing transport GHG emissions which is consistent with the observation by Fishman et al. (Fishman, Washington & Haworth 2014, p. 18) that only a minority of bikesharing trips are replacing private car trips. The majority of bikesharing trips were replacing either walking or using public transit that has a negligible GHG benefit. For the bikeshare option, the modelled growth of 3.5% bikes/year enables the Adelaide bikeshare fleet to double by FY2039. At this growth rate of bikes/year, the beneficial GHG emission impact from increasing bike numbers is equivalent to the reducing GHG emission intensity of the vehicles displaced by bikesharing.

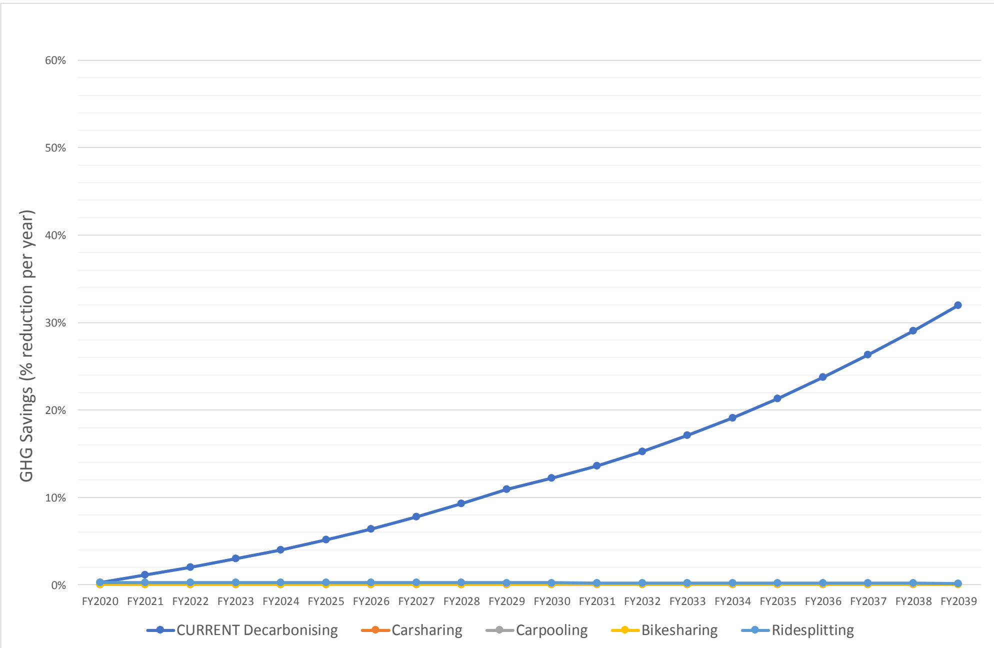

Figure 7 - Emission reduction from expanding shared mobility in a MODERATE decarbonising scenario

Figure 7 shows the relative GHG emissions impact, on a percentage basis, of the modelled four shared mobility options compared with the GHG emission benefit of the MODERATE decarbonising scenario. The chart highlights clearly that even in the likely MODERATE decarbonising scenario, shared mobility GHG impact at CBD scale will be insignificant compared with the emission reduction brought by decarbonising the electricity grid and partially electrifying private vehicles and public transport fleets.

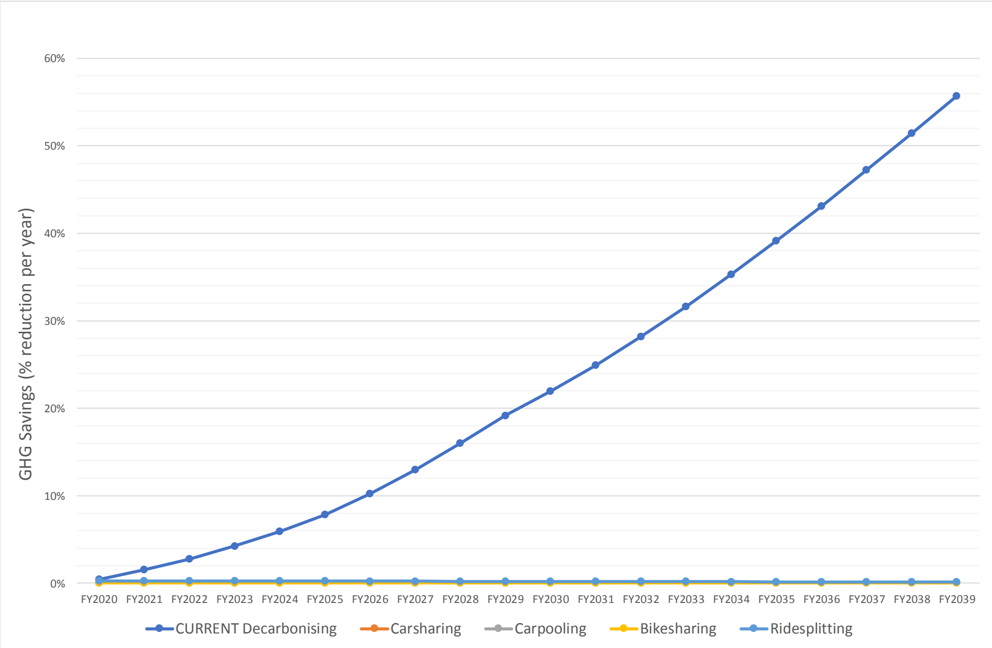

Figure 8 - Emission reduction from expanding shared mobility in an ACCELERATED decarbonising scenario

Figure 8 shows the relative GHG emissions impact, on a percentage basis, of the modelled four shared mobility options compared with the GHG emission benefit of the ACCELERATED decarbonising scenario. The chart highlights how accelerating decarbonising initiatives at state level have an adverse impact on the ability of shared mobility to reduce the declining transport GHG emissions.

3.3 – Shared Mobility Embodied Emissions

The membership-based carsharing services have been noted for their ability to reduce vehicle ownership amongst its members (Chen & Kockelman 2016; Martin & Shaheen 2011b). To determine the relative impact between reducing carsharing operational emissions and reducing carsharing embodied emissions, a modelling scenario was run with ten private cars reduced for every additional sharecar and allocating the embodied emissions across the relevant economic lifespan of the vehicles. To enable the comparison of the different type of emissions on an annual basis, it was assumed that the economic limit of a vehicle was 210,000 kilometres and that typical private usage was 14,000 km/year giving an economic lifespan of 15 years for a private car (Stasinopoulos, Shiwakoti & McDonald 2016). Based on travel figures for City of Sydney's carsharing program (Phillip Boyle and Associates 2016, p. 6), the lifespan of a sharecar was shortened to 10 years, based on high usage in the first 3 years as a share car and the following 7 years as private car with typical private usage. For the comparison, the embodied emissions from manufacturing a car was assumed to be 7.7 tonnesCO2-eq/car (Wu et al. 2018).

There was a GHG embodied benefit from the sold and avoided cars of 5.1 tonnesCO2-eq/sharecar/year. However, there was a GHG embodied cost that comes from wearing out sharecars at a faster rate than private cars so the net GHG embodied benefit was reduced to 4.4 tonnesCO2-eq/sharecar/year. The GHG benefit of embodied emissions, 4.4 tonnesCO2-eq/sharecar/year, was in the same magnitude as the modelled GHG benefit for operational emissions, 6.0 tonnesCO2-eq/sharecar/year. While there was a GHG emission benefit from selling cars and avoiding future purchases of cars, the saved embodied emissions from carsharing services are not included in operational emission based zero (net) carbon targets such as the Carbon Neutral Adelaide's carbon target.

3.4 – Shared Mobility as a Catalyst

The modelling considered two options where shared mobility services could act as a possible catalyst for the future reduction of operational and embodied emissions. The first catalyst option considered was the replacement of the existing Adelaide fossil-fuelled sharecars with new electric vehicles to enable more Adelaide drivers to experience driving electric vehicles and to influence their next car purchase decision towards an electric vehicle. The concept was to normalise the driving of electric vehicles while the number of electric vehicles is still quite low in Adelaide.

The main drawback to this option is that the current carshare members are a group of people characterised as reducing their existing vehicle holdings or avoiding future purchases of private vehicles and hence have a low probability of purchasing new vehicles compared with the general community. It would be expected that the same number of electric vehicles in a corporate or government car fleet would have a greater impact in both normalising the driving of electric vehicles and influencing future vehicle purchases towards electric vehicles.

The other problem is the timing of the catalyst opportunity. The current GoGet fleet of 18 cars in Adelaide equates to roughly 71,000 residents in metropolitan Adelaide to 1 sharecar. By the time the number of electric sharecars have reached a critical mass, the number of electric vehicles in the general community fleet will be much higher and have a greater role in accelerating electric vehicle purchases. A recent report on electric vehicle uptake in Australia states that South Australia had 957 new electric vehicles purchased for 2011 - 2017 (ClimateWorks Australia 2018, p26). Assuming that 10 sharecars are replaced with electric vehicles in the GoGet fleet in FY2020, there is already 100 times the number of electric vehicles currently in the general and commercial fleets in South Australia and so the strategic opportunity of electric sharecars to influence vehicle purchase will be limited and diminishing over time. Based on the review above, the GHG benefit for electric sharecars was considered insufficient to be included in the ASM GHG modelling.

The second catalyst option considered was the role of bikesharing to solve the so-called “first-mile last-mile problem” of public transport. Studies have shown that bikesharing services located at major transit hubs can increase their passenger catchment from 1 kilometre (15-minute walk) to 4 kilometres (15-minute ride) from the hub (Institute for Sensible Transport 2016, p17). If there is a strategic placement of shared mobility services at the beginning and end of the transit trip, then car drivers are considered more likely to transition to public transport (Tilahun et al. 2016). To test this, the percentage of workers in the Adelaide LGA working in a building within 750m (10-minute walk) of a major transit stop (train, tram and O-Bahn) was calculated using the 31 Australian Bureau of Statistics (ABS) statistical divisions in the Adelaide LGA.

Table 2 - Number of workers in the Adelaide Local Government Area working near a major transit stop

Areas	Workers (p)	<750m walk of a transit stop	>750m walk of a transit stop
Nth Adelaide	9,999	0	9,999
CBD Adelaide	107,556	102,622	4,934
Adelaide LGA	117,555	102,622	14,933
Adelaide LGA (%)	**100%**	**87.3%**	**12.7%**

Areas	Workers (p)	<750m walk of a transit stop	>750m walk of a transit stop
CBD Adelaide	107,556	102,622	4,934
CBD Adelaide (%)	**100%**	**95.4%**	**4.6%**

From Table 2, it can be seen that over 87% of workers based in the Adelaide LGA work at a building within 10-minute walk (<750 metres) of a major transit stop. If the working population in North Adelaide is excluded where more car parking options are available and only the workers in the Adelaide CBD are considered, then the percentage of workers within 10-minute walk of a major transit stop rises to 95%. Given that most of the working population in the Adelaide CBD works near a major transit stop, that is, much less than a mile, the likely market demand for a shared mobility service to complete the last mile is considered low. Also, with the recent extension of the Adelaide tram network within the CBD with free travel offered within the Adelaide LGA, the tram service has cannibalised a portion of the last mile opportunity that could have been covered by paid sharebikes.

4. Discussion

The discussion of the modelling results has been divided into two sections – Direct GHG emissions and indirect GHG emissions. For this modelling study, the direct or operational GHG emissions relate to the fuel or electricity consumed to operate the private vehicle or the public transit vehicle within the Adelaide LGA. While active transport modes such as walking and cycling require energy, food has not been included in this ASM GHG model due to the complexity of incorporating diet-based GHG emissions. As direct GHG emissions are the most relevant emissions to the Carbon Neutral Adelaide's carbon target, they have been the primary focus of this modelling study and, in some regard, the easiest to model as the modelling inputs are closely related to the actual transport activity.

Figure 9 shows the relationship between the different categories of emissions used in this modelling study, starting with direct vehicle emissions at the centre and moving outwards to embodied vehicle emissions, through to embodied infrastructure emissions and lastly to co-benefits (social, environmental and economic) which may include some GHG benefits. Quantifying the GHG emission benefits requires more complex modelling as one moves from direct emissions through to indirect emissions and co-benefits.

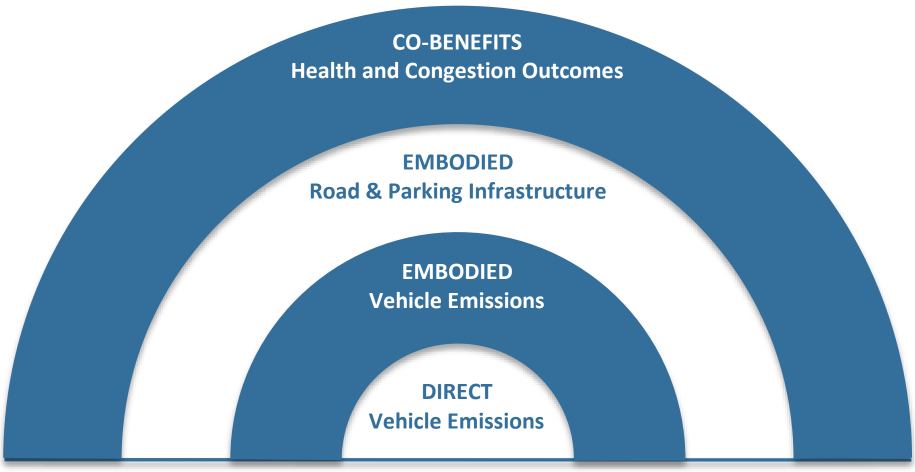

Figure 9 - *Graphic showing how the emission types are categorised in the modelling study.*

4.1 – Direct GHG Emissions

The ASM GHG model enabled a high-level investigation into the carbon benefit from expanding shared mobility services in the Adelaide LGA, focussing primarily on reducing the direct or operational transport GHG emissions from the use of private cars. Private car usage is the largest contributor of the vehicle kilometres and its related transport GHG emissions in the Adelaide LGA. The key observations from the GHG modelling are summarised below:

1. Shared mobility services had a low impact on reducing the CofA transport GHG emissions;
2. External decarbonising factors had a high impact on reducing the CofA transport GHG emissions; and
3. External decarbonising factors had a high impact on the GHG emission benefit of shared mobility services.

Starting with the first observation, the ASM GHG model forecasted that the operational GHG emission benefit from expanding shared mobility services in the Adelaide LGA was less than 1% of the total transport GHG emissions for each modelled year. This was an unexpected result given that shared mobility services are strongly associated with low carbon cities. The possible reasons for the unexpected low GHG impact will be discussed later but included here:

a. Not all shared mobility trips provide a net GHG emission benefit;
b. Some shared mobility trips displace low carbon transport modes such as walking and public transit;
c. Some shared mobility trips are a displacement of other shared mobility modes; and
d. The ASM GHG model used conservative growth factors of expanding carshare and bikeshare services consistent with their low growth history to date in the Adelaide LGA.

The second observation was the high impact of the external decarbonising factors in reducing the passenger transport GHG emissions in the Adelaide LGA. The ongoing reduction of the electricity grid's emission factor with the electrification of the private car and public transit sectors will bring a significant reduction in transport GHG emissions. The ASM GHG modelling showed that the transport GHG emissions will reduce by 32% by FY2039 under a MODERATE decarbonising scenario or by 56% by FY2039 under an ACCELERATED decarbonising scenario in comparison with the 1% reduction from expanding shared mobility services.

There is a likelihood, if the climate change agenda is reset at the national level, the rate of decarbonising will move past the modelled MODERATE scenario and be closer to the modelled ACCELERATED scenario. At a future point in time, the combination of a zero emission (net) electricity grid and a zero emission (net) vehicle fleet will mostly eliminate operational transport GHG emissions thus decoupling transport activity from its direct GHG emissions. As South Australia has the lowest electricity grid emission factor of the mainland states, it is likely to achieve the zero emission (net) electricity grid well before the other Australian states.

The third observation was how influential the external decarbonising factors were on the GHG benefit of the shared mobility services. As the city's electricity grid and transport fleet trends to zero (net) emissions and the transport GHG emissions decouple from transport VKM, then the opportunity for shared mobility to displace transport GHG emissions also reduces accordingly. This effect was quite evident in Figure 6 where the GHG benefit of shared mobility services decreases as the private and public vehicles move to electrification. For some of the modelled shared mobility services, they start from a low base and grow their membership base. Before those shared mobility services have reached a critical mass, they are overtaken by the decoupling of transport GHG emissions from external decarbonising factors.

Given the low GHG emission impact of the modelled shared mobility options, the selection of shared mobility services was reviewed to see if the modelled options covered the field sufficiently. For carsharing services, the company Maven Gig operates in Adelaide providing short-term rental cars for Uber drivers. As this carsharing enterprise is a business-to-business model rather than the typical business-to-consumer model and the additional VKT is already captured in the modelled ridehailing scenario, it has not been included in the ASM GHG model. For bikesharing, electric bikes and scooters were considered but left out of the modelling as they both likely to replace the trips made by pedal-based bikes rather than increasing the amount of bikesharing trips.

As listed previously in this section, there are several possible reasons for the unexpected low GHG impact of expanding shared mobility services in the Adelaide LGA, even if the decarbonising trend in the South Australia's passenger transport sector was paused. The first possible reason is that shared mobility trips do not inherently always provide a net GHG emission benefit to reducing operational emissions. Some shared mobility services are noted for reducing embodied vehicle emissions (Chen & Kockelman 2016; Martin & Shaheen 2011a) but this does not necessarily relate to reducing operational vehicle emissions as well. In some situations, shared mobility will replace an existing car trip with another car-based mode of similar GHG impact. An example would be services such as Uber and Shebah where the ridehailing trip by a contracted private vehicle replaces another vehicle trip such as a taxi trip or private car trip with possibly no change in the operational emissions. Similarly, peer-to-peer carsharing was seen as a neutral operational GHG emission outcome as the peer-to-peer sharecars were providing an alternative to conventional car rental resulting in similar vehicles being driven.

The second possible reason for the low GHG outcome was that the modelled GHG benefit of bikesharing was less than expected where the service was often displacing low-carbon travel modes. The modelling choices for bikesharing were mostly influenced by a review of the Melbourne and Brisbane bikesharing schemes (Fishman, Washington & Haworth 2014). In that study, research interviews showed that only 19% and 21% of bikeshare trips respectively, were displacing car trips with the majority of the bikeshare trips switching from walking and public transit trips. In this case, the bikesharing service was both displacing the low-carbon trips as well as the high-carbon trips. While not included in this model, a more detailed study would need to include the vehicle emissions from 'rebalancing' or redistributing the sharebikes particularly after 'tidal flows' from large events or commuting peak hours. Fishman et al (2014) reported that over 20% of Melbourne's displaced car travel from bikesharing is cancelled out by the increase in kilometres travelled from the rebalancing operations. In London, it was found that the kilometres travelled by the rebalancing operations was twice the amount of the kilometres saved by displacing car trips. This was due to both a low percentage of car travel reduction and a high percentage of bikesharing used for commuting trips.

Thirdly, the ASM GHG model has been designed with the understanding that there will be some internal competition or overlap between the shared mobility services over the modelling horizon. The total GHG benefit over the considered 20-year timeline is not the sum of all the individual GHG reductions from the modelled shared mobility scenarios as some newer forms of shared mobility will displace current shared mobility services. At the time of writing, dockless e-scooters were trialled in the Adelaide CBD during the 2019 Fringe Festival Season. For the GHG modelling, it has been assumed that share e-scooters and share e-bikes would be mostly mode-switching from pedal-based sharebikes rather than displacing private car trips. In a similar manner for cars, the introduction of driverless ridesplitting SAVs will replace the current ridesplitting services offered by Uber (UberPool) or Lyft (Lyft Line). While not included in the ASM GHG model, there is a possibility that the introduction of SAVs will compete with or merge with traditional carsharing business models (Fagnant & Kockelman 2014; Stocker & Shaheen 2017) .

The fourth possible reason for the low GHG outcome was that the growth assumptions do have an influence on the forecasted GHG impact of the shared mobility services. Given that Adelaide has had low growth in carshare relative to its population base and the lack of an IT-enabled bikesharing service, the modelled growth factors were chosen to be sufficiently ambitious in the future but still within the realm of their past performance. Bikesharing in Adelaide has some history where two dockless bikesharing schemes have started recently and were later withdrawn by the proponent. A city-wide IT-enabled docking bikesharing scheme does not exist in Adelaide. A report (Institute for Sensible Transport 2016, p. 54) prepared for the ACC stated that, *"This report has provided an assessment of options for a future Adelaide bike share program. The assessment has found that Adelaide does not currently have the necessary conditions to support a successful bike share program. There are a number of pre-conditions that require implementation before Adelaide is likely to support a well-used bike share program. Establishing a bike share program before these pre-conditions are met is likely to result in an underused system'.* Based on the advice to Council above, the size of the bike fleet, bike utilisation rate and the growth rate of the modelled bikesharing scheme has been intentionally conservative.

Carsharing in Adelaide has rolled out slower than other Australian cities with only sixteen GoGet sharecars located in the CBD with a two more sharecars located nearby at the Bowden redevelopment site. This equates to approximately 72,000 persons per GoGet sharecar – the highest ratio in Australia where GoGet is active. Sydney and Melbourne have 3,000 and 8,000 persons per GoGet sharecar respectively. It is the author's view that the required population density does not exist in Adelaide to make car ownership and car travel sufficiently expensive and inconvenient enough to make carsharing viable for a broad market as compared to its current niche inner-city demographic.

4.2 – Indirect GHG Emissions

While embodied emissions are not included in the Carbon Neutral Adelaide's carbon target, the benefits of reducing embodied vehicle emissions from the use of sharecars were considered briefly for the modelling report. A number of studies (Chen & Kockelman 2016; Martin & Shaheen 2011b) have noted that the use of sharecars reduced the ownership of private vehicles where the reduction of vehicles was the combination of selling cars (vehicles shed) and delaying car purchases (vehicles avoided). To analyse the GHG benefit of reducing vehicles from expanding the carsharing service, the embodied emissions from the sold and avoided vehicles were allocated over the economic life of the share car - first three years as a sharecar with high usage and the remaining seven years as a second-hand private car afterwards with low usage. The increased embodied emissions from the addition of the sharecar was adjusted for in the analysis.

Allocated net embodied GHG emissions of 4.4 tonnesCO2-eq/sharecar/year were in the same magnitude as the operational GHG emissions of 6.0 tonnesCO2-eq/sharecar/year. While the embodied vehicle emissions were significant compared with the operational vehicle emissions, they are not included in the operational emissions reporting framework of the Carbon Neutral Adelaide. Even if the scope of the Carbon Neutral Adelaide rating was widened, the embodied vehicle emissions could not be counted as they were generated offshore in the country where the vehicles were manufactured.

The modelling study also considered two scenarios where shared mobility services could act as a catalyst for further emission reduction – replacing existing sharecars in Adelaide with electric vehicles and secondly, addressing the first-mile last-mile problem. The first scenario with the introduction of electric sharecars would enable drivers of conventional vehicles to normalise their experience of driving electric vehicles and in doing so, persuade them to purchase an electric vehicle instead of another conventional vehicle. The dilemma was that the carsharing members have been reducing their vehicle holding through selling their cars or delaying the purchase of the next car, so they were not a relevant audience to facilitate the accelerated purchase of new electric vehicles. A recent carsharing report prepared for the ACC stated that, "*There would be no 'education' benefit such as increasing sales of electric vehicles, as car share users are in the service to avoid ownership*" (Phillip Boyle and Associates 2017). The advantage, if any, would be short-lived because there are already more than a 1000 private electric vehicles in South Australia (ClimateWorks Australia 2018, p. 26) compared to the 18 sharecars so the normalising of electric vehicles in the general community will quickly outpace the benefit of moving early to electric sharecars.

Shared mobility services can address the first-mile last-mile problem by providing integrated transport connections between public transit stations and the commuter's residence and work destination. As shown in the Results section, most workers in the Adelaide CBD work within 10 minutes-walk of a major transit stop so the case for expanding last-mile shared mobility services was not compelling especially when the trams already provide intra-CBD travel for free. While not within the geographic scope of the Adelaide LGA, there may be an opportunity for shared mobility services to address the first stage or first-mile of the commuting trip.

According to the Adelaide Metro's 'Park 'n' Ride' webpage (Govt of South Australia 2019), there are 72 locations in metropolitan Adelaide that offer more the 10,800 car parks to encourage car commuters to transfer to public transit. For some locations where the parking is fully utilised, there is the opportunity to construct multi-storey carparks to divert more commuters from private car use to public transit use. In this case, a targeted suburban shared mobility service such as electric share bikes or share scooters could enable more commuters living near the transit hub to leave their car at home thus freeing up car parks for new Park 'n' Ride patrons and possibly delay or avoid the construction of new parking infrastructure and its related embodied GHG emissions. In 2010, a survey by the Victorian Department of Transport "*found more than 60 per cent of weekday car trips to train stations were less than three kilometres, and 10 per cent were less than one kilometre*" (Phillip Boyle and Associates 2016, p. 6). While the survey was conducted in Melbourne, the survey results are likely to be replicated in Adelaide. As the majority of the connecting car trips are less than three kilometres, the trips could be covered by a targeted suburban bikesharing scheme with integration with the public transit payment card. This could provide the basis for further research where targeted suburban shared mobility services are displacing or delaying parking infrastructure builds.

5. Conclusions and Future Work

The ASM GHG model has provided a high-level investigation of the GHG emission impact on private car usage from expanding shared mobility services in the Adelaide LGA. Seven current and future shared mobility scenarios most relevant to the Adelaide LGA were reviewed for GHG modelling. Four of the shared mobility services (ridesplitting, membership carsharing, carpooling and bikesharing) had a minor benefit on reducing operational transport GHG emissions – less than 1% combined GHG reduction/year over the modelled FY2020-FY2039 timeline. After analysis, two services (ridehailing, peer-to-peer carsharing) were considered to have no significant impact on reducing operational transport GHG emissions. For the modelling, the use of shared autonomous vehicles was considered as a future version of the current ridesplitting service so only the ridesplitting service was modelled for the full twenty years to avoid double-counting the GHG emission reductions.

In contrast, state-based decarbonising factors (renewable electricity grid, EV uptake and full electrification of the public transit vehicles) will have a major impact of reducing Adelaide's transport GHG emissions. The modelled GHG emission reduction for the following scenarios over a twenty-year timeline (FY2020 – FY2039) were:

1. Frozen baseline scenario to a moderate decarbonising scenario —> 32% GHG emission reduction; and
2. Frozen baseline scenario to an accelerated decarbonising scenario —> 56% GHG emissions reduction.

Overall, shared mobility services are expected to have little impact on Adelaide LGA operational transport GHG emission (<1%) due to:

1. Not all shared mobility trips provide a net GHG emission benefit;
2. Some shared mobility trips displace low carbon transport modes such as walking and public transit;
3. Some shared mobility trips are a displacement of other shared mobility modes; and
4. The ASM GHG model used conservative growth factors of expanding carshare and bikeshare services consistent with their low growth history to date in the Adelaide LGA.

While the ASM GHG model found that expanding shared mobility services will probably have little impact on reducing the direct emissions from private car usage, there is scope to develop the ASM GHG model further to include a more detailed analysis of the embodied emissions from firstly, reducing vehicles and secondly, reducing the related road and parking infrastructure in Adelaide.

The ASM GHG model has focussed primarily on reducing private car usage as it is the highest contributor of transport GHG emissions in the Adelaide LGA. As more drivers move to using public transit in the future, the ASM GHG model could be expanded from its private car focus to include a detailed analysis of public transit modes to better understand the mode-switching within and between the private usage, public transit and shared mobility sectors.

The opportunities for the future research with the ASM GHG model include:

1. Integrate public transit data into the shared mobility GHG model to better understand the mode-switching within and between the private usage, public transit and shared mobility sectors; and
2. Investigate the benefit of the first mile shared mobility at selected Adelaide suburban transit stations to delay/avoid the future construction of car parking buildings for 'Park n Ride' commuters.

References

Adelaide City Council 2018, *City of Adelaide Community GHG Emissions Inventory*, Adelaide, Australia, <http://dmzweb.adelaidecitycouncil.com/agendasminutes/files08/Attachments/Council_27_March_2018_Item_12.4_Link_1.pdf>.

Bliss, L 2018, *Uber and Lyft Could Do a Lot More for the Planet*, CityLab, viewed 30 January 2019, <https://www.citylab.com/transportation/2018/04/how-uber-and-lyft-could-do-better-by-the-planet/558866/>.

Byars, M, Wei, A & Handy, S 2017, *Sustainable Transportation Terms : A Glossary*, Davis, CA, <https://itspubs.ucdavis.edu/wp-content/themes/ucdavis/pubs/download_pdf.php?id=2759>.

Chen, TD & Kockelman, KM 2016, 'Carsharing's life-cycle impacts on energy use and greenhouse gas emissions', *Transportation Research Part D: Transport and Environment*, vol. 47, pp. 276–284.

Clewlow, RR & Mishra, GS 2017, *Disruptive Transportation: The Adoption, Utilization, and Impacts of Ride-Hailing in the United States (Research Report UCD-ITS-RR-17-07)*, Davis, CA, <https://its.ucdavis.edu/research/publications/?frame=https%3A%2F%2Fitspubs.ucdavis.edu%2Findex.php%2Fresearch%2Fpublications%2Fpublication-detail%2F%3Fpub_id%3D2752>.

ClimateWorks Australia 2018, *The State of Electric Vehicles In Australia - Second Report*, Melbourne, Australia, <https://www.climateworksaustralia.org/sites/default/files/documents/publications/climateworks_australia_state_of_electric_vehicles2_june_2018.pdf>.

Cohen, A & Shaheen, S 2016, *Planning for Shared Mobility*, *PAS Report 583*, American Planning Association, Washington DC.

Currie, G 2018, 'Lies, Damned Lies, AVs, Shared Mobility, and Urban Transit Futures', *Journal of Public Transportation*, vol. 21, no. 1, pp. 19–30.

Department of the Environment and Energy 2018a, *Australia's Emissions Projections 2018*, Canberra, Australia, <http://www.environment.gov.au/system/files/resources/128ae060-ac07-4874-857e-dced2ca22347/files/australias-emissions-projections-2018.pdf>.

— 2018b, *Quarterly Update of Australia's National Greenhouse Gas Inventory - June 2018*, Canberra, Australia, <http://www.environment.gov.au/system/files/resources/e2b0a880-74b9-436b-9ddd-941a74d81fad/files/nggi-quarterly-update-june-2018.pdf>.

Energeia 2018, *Australian Electric Vehicle Market Study*, Sydney, Australia, <https://www.cefc.com.au/media/401923/australian-ev-market-study-full-report-jun2018.pdf>.

Fagnant, DJ & Kockelman, KM 2014, 'The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios', *Transportation Research Part C: Emerging Technologies*, vol. 40, pp. 1–13.

Fishman, E, Washington, S & Haworth, N 2014, 'Bike share's impact on car use: Evidence from the United States, Great Britain, and Australia', *Transportation Research Part D: Transport and Environment*, vol. 31, pp. 13–20.

Govt of South Australia 2019, *Park n Ride*, viewed 15 February 2019, <https://www.myrapid.com.my/traveling-with-us/park-n-ride>.

Greenblatt, JB & Saxena, S 2015, 'Autonomous taxis could greatly reduce greenhouse-gas emissions of US light-duty vehicles', *Nature Climate Change*, vol. 5, no. 9, pp. 860–863.

Harrington, P 2015, *Carbon Neutral Adelaide – Foundation Report*, Sydney, Australia, <https://www.cityofadelaide.com.au/assets/FINAL_REPORT_-_CARBON_NEUTRAL_ADELAIDE_-_FOUNDATION_REPORT_-_27_November_2015.pdf>.

Institute for Sensible Transport 2016, *Bike Share - Options for Adelaide Stage Three: Design and Options Assessment*, Melbourne, Australia, <https://sensibletransport.org.au/wp-content/uploads/2016/02/Bike-share-Options-for-Adelaide-Stage-3-Report-1.04.16DB_LR.pdf>.

Jung, J & Koo, Y 2018, 'Analyzing the effects of car sharing services on the reduction of greenhouse gas (GHG) emissions', *Sustainability*, vol. 10, no. 2, pp. 1–17.

Kane, M & Whitehead, J 2017, 'How to ride transport disruption – a sustainable framework for future urban mobility', *Australian Planner*, vol. 54, no. 3, pp. 177–185.

Lennert, F & Schönduwe, R 2017, 'Disrupting mobility: Decarbonising Transport?', in G Meyer & S Shaheen (eds), *Disrupting Mobility - Impacts of Sharing Economy and Innovative Transportation on Cities*, Springer International Publishing, Cham, Switzerland, pp. 213–237.

Lunden, I 2016, *Uber says that 20% of its rides globally are now on UberPool*, TechCrunch, viewed 30 January 2019, <https://techcrunch.com/2016/05/10/uber-says-that-20-of-its-rides-globally-are-now-on-uber-pool/>.

Martin, EW & Shaheen, SA 2011a, *Greenhouse gas emissions impacts of carsharing in North America*, MTI Report 09-11, San José, CA, <https://transweb.sjsu.edu/sites/default/files/Carsharing and Co2 %286.23.2010%29.pdf>.

— 2011b, 'Greenhouse gas emissions impacts of carsharing in North America', *IEEE Transactions on Intelligent Transportation Systems*, vol. 12, no. 4, pp. 1074–1086.

Nijland, H & van Meerkerk, J 2017, 'Mobility and environmental impacts of car sharing in the Netherlands', *Environmental Innovation and Societal Transitions*, vol. 23, pp. 84–91.

Phillip Boyle and Associates 2016, *The Impact of Car Share Services in Australia*, Melbourne, Australia, <http://carsharing.org/wp-content/uploads/2016/01/The-Impact-of-Car-Share-Services-in-Australia.pdf>.

— 2017, *Car Share Study - Background Issues & Opportunities*, Melbourne, Australia.

Soltani, A, Nguyen, MTP & Allan, A 2018, 'Shared-mobility Experience in the City of Adelaide : Insight from a Preliminary Study', in *Australasian Transport Research Forum 2018 Proceedings*, Australasian Transport Research Forum Incorporated, Darwin, Australia, pp. 1–19.

Sprei, F 2018, 'Disrupting mobility', *Energy Research and Social Science*, vol. 37, pp. 238–242.

Stasinopoulos, P, Shiwakoti, N & McDonald, SV 2016, 'Life-cycle greenhouse gas emissions of electric and conventional vehicles in Australia', in *Proceedings of the 23rd World Congress on Intelligent Transport Systems 2016, Melbourne, Australia, 10-14 October 2016*, Melbourne, Australia, pp. 1–10.

Stocker, A & Shaheen, S 2017, *Shared Automated Vehicles: Review of Business Models*, Discussion Paper No. 2017-09, Paris, France, pp. 1–29, <https://www.itf-oecd.org/sites/default/files/docs/shared-automated-vehicles-business-models.pdf>.

Tilahun, N, Thakuriah, PV, Li, M & Keita, Y 2016, 'Transit use and the work commute: Analyzing the role of last mile issues', *Journal of Transport Geography*, vol. 54, no. xx, pp. 359–368.

Wu, Z, Wang, M, Zheng, J, Sun, X, Zhao, M & Wang, X 2018, 'Life cycle greenhouse gas emission reduction potential of battery electric vehicle', *Journal of Cleaner Production*, vol. 190, pp. 462–470.