The Role of Adelaide's Transit Oriented Developments Towards Creating a Low Carbon Transit Future City

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Abstract: The release of the 30 Year Plan for Greater Adelaide (30YPGA) in 2010 set out an ambitious plan to transform a car oriented city into a transit oriented city. This would ultimately be achieved by developing a network of over 30 centres built to transit oriented development (TOD) principles connected by densely developed transit corridors. The 30YPGA implies that this will result in an environmentally sustainable city in which transit induced carbon emissions will be greatly reduced. This should be achieved through a modal switch for work journeys from private car to public transit, cycling and walking and through people choosing housing that is co-located near or in TODs, thereby minimizing the need to travel by car. However, given that the 30YPGA reassures Adelaide's populace that at least two thirds of the metropolitan area will remain unchanged (i.e. low density car dependent residential development), the overall changes to Adelaide's urban morphology may be modest at best. This paper explores Census data to examine the scale of transport related carbon emissions reductions that can be achieved by the 30YPGA over three stages: (1) a CBD centric interim park and ride phase commuter model where existing car trips to the CBD are substituted with park and ride; (2) a CBD centric commuter model using a TOD and transit corridor network; and (3) a fully fledged TOD network where residents collocate their jobs and housing to minimize their need for carbon inducing urban transit. A caveat with this research is that it focuses only on the transport related component of greenhouse gas emissions and does not include carbon emissions related to housing and embodied energy. The paper concludes with suggestions for how the 30YPGA needs to be modified or improved if a low carbon transport future is to be achieved.

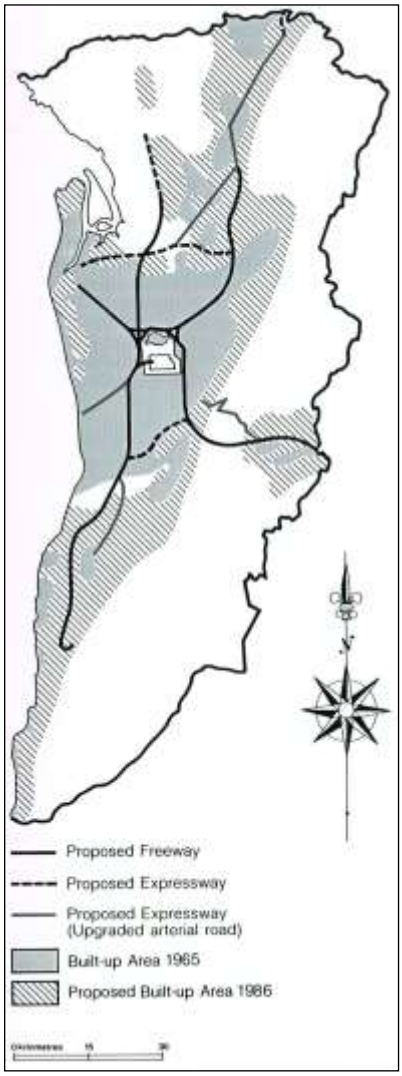
Background

Conscious efforts at modern metropolitan strategic planning for Adelaide, a middling mature Australian metropolis of approximately 1.23 million people (ABS, 2013 at www.censusdata.abs.gov.au) commenced with the 1962 Metropolitan Development Plan (Forster and McCaskill, 2007). Whilst the 1962 Plan may not have immediately clarified Adelaide's transport future in terms of providing a clear plan for how Adelaide's residents would travel around their metropolis, it did commission the Metropolitan Adelaide Transport Study (MATS), which was eventually released in 1968. The main intent of that Study was to propose a 96km freeway network, complete with grade separated interchanges, along the lines of a North American city, which implied a car oriented city with the majority of people travelling by private car to fulfill the bulk of their daily urban travel requirements. The Transport Plan set out in the 1968 MATS recognized that people would still use public transit for commuting trips and indeed envisaged a subway under King William Street, despite its overwhelming emphasis on the car. A significant characteristic of the 1968 MATS is that it did include a connected freeway/expressway network (see figure 1), however, it did not integrate this network with Adelaide's suburban centres in a coherent manner. At that time, Adelaide's economy was underpinned by automotive manufacturing with two large car plants, Chrysler at Clovelly Park (opened in 1964) in Adelaide's southern suburbs and General Motors-Holden (opened in 1958) at Elizabeth in Adelaide's north, so it was perhaps logical that the private car would dominate Adelaide's urban transport solutions for the forseeable future. In hindsight, the stillborn $436m MATS Plan ($6bn in 2013 prices), was an overly ambitious technocratic approach that ignored the intense community backlash over the impact on of the proposed freeways (Llewellyn-Smith, 2012; Badcock, 2001). The MATS Plan was abandoned in 1982/83 and to date, only the outer legs of the freeway network, the South-Eastern Freeway, Gawler by-pass and the Southern Expressway were eventually built. Within the built-up area of metropolitan Adelaide, the Plan envisaged in the MATS Scheme failed to come to fruition. Interestingly, in an echo of the MATS Plan, albeit with a different road alignment and road interchanges, the State's 2005 Infrastructure Plan did include a continuous north-south grade separated arterial road along the South Road alignment extending from the Southern Expressway to

connect with the Gawler bypass via east-west freeways linking Port Adelaide with the recently completed Port River Expressway (in 2008) and Northern Expressways (in 2010).

Figure 1: The Metropolitan Adelaide Transport Study (MATS) transport plan (left) compared with the transport infrastructure plan in the 30YPGA

Source: Hutchings (Ed) 2007

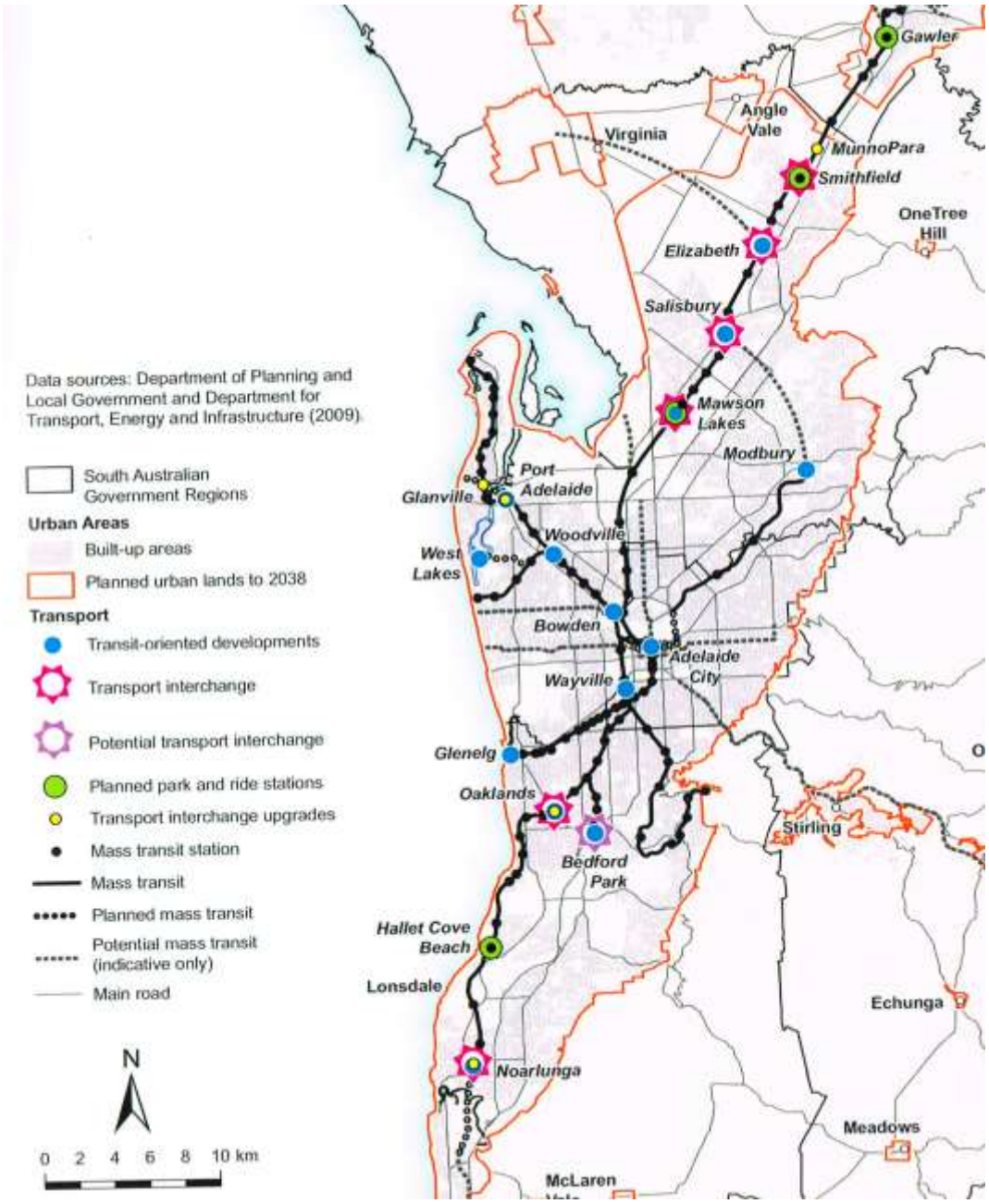


The 1994 Planning Strategy for metropolitan Adelaide attempted to shift Adelaide's transport emphasis away from the car through a more structured approach to guiding urban form and improvements in public transport. The shift in emphasis was encouraging with the Torrens Valley freeway proposal replaced with a 13km long high speed guided busway (the O-Bahn) connecting Adelaide's CBD with the regional shopping centre of Tea Tree Plaza in Adelaide's northeastern suburbs. However, although this Plan included a hierarchy of urban centres that provided structure to Adelaide's metropolitan area by nature of each centre's catchments, the 1994 Strategy did not attempt to decouple Adelaide deep embrace of the car. Although the life of this plan was intended to guide Adelaide's growth until 2020, by the early 2000's, it was apparent that it had shortcomings, particularly with regard to its vagueness about future investment in transport infrastructure. The South Australian government had intended releasing a Transport Plan in

an attempt to redress the transport shortcomings of the 1994 Strategy, but with the election of the Rann State Labor government, this proposal was quietly shelved by the incoming government.

Figure 2: The transport infrastructure plan in the 2010 30 Year Plan for Greater Adelaide

Source: Hutchings (Ed) 2007 (left) and Government of South Australia (right) 2010



Fast forwarding to 2013, the implementation of the controversial 2010 30 Year Plan for Greater Adelaide (30YPGA) was underway, and this document consciously advocated a metropolitan city vision for 2040 which was to be demonstrably public transit oriented with a network of 5 major transit corridors linking up

14 Transit Oriented Developments including Adelaide's Central Business District (see figure 2). An additional 20 sites were also identified in the 30YPGA that were intended to incorporate transit oriented development principles and design principles. The 30 YPGA is specific in stating that the proposed TODs would accommodate 60,000 new homes (adding potentially 88,200 people based on the current average household occupancy ratio for medium density accommodation in the 2011 ABS Census for Adelaide of 1.45 persons/dwelling).

The controversy surrounding the 30YPGA centred on its central tenet of adding 560,000 people to Adelaide's 2010 population of 1.15million, largely through increased urban densities rather than in building new housing beyond the urban fringe. An Urban Growth Boundary was intended to ensure that this happened but this has already been relaxed since the introduction of the plan with new greenfields site beyond Adelaide's northern extremities at Buckland Park, Concordia and Roseworthy. The 2010 Strategy was also notable for making specific claims about the expected level of greenhouse gas emissions reductions that Adelaide should enjoy in future as a result of policy measures to reduce urban sprawl and create a more compact city. For example, in table 1, Appendix 2 from the 30YPGA it was noted that given that 40% of transport emissions are sourced from household travel in metropolitan Adelaide, a saving per household of 25% (presumably metropolitan wide), could be expected from a more compact city. The basis for this estimate was Peter Newman's forecast of a 50% reduction in carbon emissions from car travel as residents of TODs switched to mass transit (see www.sustainability.curtin.edu.au/local/docs/Resilient_cities.pdf accessed 4/1/2010), which was then discounted by 25% to reflect the more limited opportunities for mass transit travel in metropolitan Adelaide.

The 30YPGA also aimed to have 60% of houses within 500m of a transit node. The 30YPGA does not provide a definition of a transit node, but the inference appears to be that it would either be a bus stop, tram stop or train station. Medium density housing is also planned for up to 800m of either side of the nominated transit corridors, although concentrated around activity centres in a manner that would ensure walking access to a transit node. The definition of a transit corridor is fairly broad, and can include any road that is serviced by several bus routes. Ambitious greenhouse gas emission reductions are also expected from more efficient six star rated residential buildings, a higher proportion of smaller dwellings and more efficient air conditioning.

The plan calls for an additional 258,000 dwellings to house the expected population growth of 560,000 persons at an average dwelling occupancy ratio of 2.17 persons/dwelling (down from 2.3 persons/dwelling in the last 2011 ABS population and housing census, although given the greater proportion of medium to high density residential development with low occupancy ratios proposed in the 30YPGA, this would result in a shortfall of 76,250 unhoused persons. The 30 YPGA envisages new dwelling stock to comprise of 14% as high density housing dwellings (i.e. 36,000 homes); 36% (as medium density dwellings i.e. 41,000 homes); and 50% as detached housing (i.e. 129,000 homes). Table 1 compares the changes in dwelling stock planned for in the 30YPGA with population and housing census data for metropolitan Adelaide in 2011. It illustrates that significant change will occur with conventional single dwellings, the key culprit in contributing to urban sprawl, reducing to 58.9% from 70.5% in 2011, whilst the share of high density housing stock increases from 3.3% to 6.7% (an increase of 235%) and medium density housing stock increases from 19.0% to 23.5% (an increase of 107%). The definition of "high density" in the census is taken to mean flats of 3 or more storeys and attached housing (i.e. townhouses) of 2 storeys. Medium density housing is defined as single storey attached housing. By international measures (Newman and Kenworthy, 1989), the official definitions of density as they relate to Adelaide in the 30YPGA and in the ABS Census, are very modest and caution is needed in making inferences about dramatic improvements in travel related carbon emissions and travel behaviour on the basis of urban density.

Unless residents both work and reside in the same TOD, long distance commuting is likely to continue, with many residents simply substituting long urban car trips with public transit trips over similar distances. Adelaide's non-CBD centres to date have never been much more than retail centres with limited opportunities for employment and limited services. Employment in Adelaide is concentrated in its CBD accounting for 20% of metropolitan employment (ABS 2011 Census), but outside the CBD, it is highly dispersed throughout the metropolitan area. Nevertheless, the proposed changes will have a dramatic

effect on Adelaide's urban form particularly in creating the impression of a city that is much more urban in character in its centres and major travel corridors than is currently the case. By the conclusion of the 30YPGA, improved local planning controls should result in transit oriented centres with mixed-use development developed at significantly greater densities than is currently the case, thereby ensuring viable catchments for services and businesses and offering a sufficient range of services to satisfy most residents' needs locally.

Table 1: Changes in metropolitan Adelaide's housing stock as anticipated in the 30YPGA

Source: ABS (2011); 30YPGA (p200)

TYPE OF DWELLING	2011	2011 (%)	New housing stock to be built by 2040 in 30YPGA	Total New housing stock by 2040	2040 (%)	Percentage Change (%)
High density	15,299	3.3	36,000	51,299	6.7	235
Medium density	87,174	19.0	93,000	180,174	23.5	107
Low density	323,102	70.5	129,000	452,102	58.9	39.9
Other	32,427	7.1	*52,086**	*84,513**	*11.1*	NA
TOTAL	458,002	100.0	310,086	768,088	100.0	67.7

Notes:
*Pro rata estimate to maintain relativity in the comparisons between 2011 and 2040. In practice, the "Other" category, which includes caravan parks and unoccupied housing, could be reduced or higher.
High density: flats in buildings of three or more storeys; attached housing of 2 storeys (e.g. townhouses)
Medium density: single storey attached housing such as townhouses and villa homes.
Low density: unattached freestanding dwellings on individual allotments.

The pathway to lower transport related carbon emissions as outlined in Adelaide's 30YPGA is seen as a combination of more efficient smaller homes developed at higher residential densities, located within a networked public transit rich urban setting of connected transit oriented developments. Although the nominated TODs may not provide sufficient housing stock for the projected population growth in the 30YPGA, the nominated 5 mass public transit corridors provide significant potential for accommodating a densified Adelaide. Table 2 details the main mass transit corridors in metropolitan Adelaide and admittedly crude approximations of the potential to increase Adelaide's housing and population, according to the density decision criterion set out in the 30YPGA (i.e. a gross minimum density of 25 dwellings/ha compared to the current 15 dwellings/ha). Table 2 demonstrates that the planned housing projections in the 30YPGA (50% of total planned housing growth) are comfortably accommodated by the Plan's proposed combination of transit corridors and TODs, without necessarily requiring the densification of the other 24 corridors (mostly bus routes on suburban arterials). What is less certain is whether 50% of the predicted population growth will be accommodated in these higher density areas given that housing occupancy ratios for medium to high density accommodation are about a third lower than for low density residential development according to the recent 2011 ABS population and housing census for metropolitan Adelaide.

There are three types of travel behaviour scenarios that could emerge in Adelaide in 2040 with an urban form densified around a skeletal framework of transit corridors connected by TODs and transport nodes to form an integrated transit network that allows personal travel anywhere within metropolitan Adelaide, quickly and efficiently. The first scenario is where commuting by private car is substituted with travel by mass public transit to essentially the same work and study places that Adelaide's residents currently commute. This is similar to park and ride commuting which occurs at most public transport interchanges across metropolitan Adelaide today. The second scenario is a CBD centric model using a TOD and transit corridor network, but where commuters walk and cycle to the transport interchange rather than drive. The third scenario is a fully-fledged TOD network where residents co-locate their jobs and housing choices to minimize their need for mechanized urban travel. Complicating speculation about the future nature of personal urban travel in Australian cities is that future cars are likely to utilize very different technologies to the petrol and diesel powered vehicles that dominate Australia's current motor vehicle fleet. Automotive technologies such as pure plug-in electric vehicles, plug-in petrol or diesel-electric

hybrids and electric induction charging of roadways and parking areas for electric vehicles paradoxically have the potential to perpetuate the current status quo of low density suburban development in Australia's cities.

Table 2: Opportunities to increase density in Adelaide's mass transit corridors

Source: 30YPGA (2010

TRANSIT CORRIDOR	PRIORITISED IN THE 30YPGA	LENGTH (km)	ADDITIONAL POPULATION POTENTIAL*	ADDITIONAL HOUSING POTENTIAL**
Gawler rail corridor	yes	40	46,400	32,000
Adelaide OBahn (busway)	yes	13	15,080	10,400
Seaford rail corridor	yes	31	35,960	24,800
Port Adelaide rail corridor	yes	20	23,200	16,000
Grange spur rail corridor***	yes	13	15,080	10,400
Glenelg tram line	yes	5	5,800	4,000
Glenalta rail Line	no	18	20,880	14,400
Adelaide CBD		NA	27,300	15,040
13 MAJOR TODs	No, except for 3****	NA	9,425	6,500
20 SMALLER TODs	no	NA	14,500	10,000
Designation of 24 other transit corridors	no	NA	unknown	unknown
TOTAL		140	213,625	143,540

Notes:
*Assumes only 50% of the 1600m wide transit corridor is taken up for development because of various developmental constraints.
**Assumes a housing occupancy ratio of 1.45 persons/dwelling (as determined in the 2011 ABS Census for Adelaide for medium density accommodation)
***This line branches off from the Port Adelaide rail line. ****Mawson Lakes, Bowden and Bedford Park

An interesting aspect of private electric vehicles is that they would complement a switch in electricity generation from fossil fuel derived sources to renewable energy from wind and solar. This would allow charging of private electric vehicles with electricity that is without carbon emissions. The theoretical attraction for Australian suburban households that are fortunate enough to already have domestic photovoltaic systems is that an electric vehicle could be powered with their own carbon emissions free electricity. Assuming Australian and international public policy eventually enforces a move towards zero carbon emissions in electricity generation, the business case for electric vehicles becomes more certain and raises the spectre of future urban travel by private car having minimal carbon emissions, at least from a vehicle operational perspective.

Even if commuters do not switch to electric cars in the future, petrol and diesel vehicles are likely to become significantly more efficient than what has currently been achieved, with emissions and fuel economy likely to halve what it is now, partly through downsizing of the size of cars in the private vehicle fleet and also through more efficient engines. The termination of large passenger car production in Australia, highlighted by the closure of Mitsubishi's Australian operations in Adelaide in 2008, the recent decision of Ford Australia in Melbourne this year to stop manufacturing cars in Australia after 2016 and Holden carefully considering the future of its large car production in Adelaide after 2016, suggests a sea-change in consumer sentiment against large private cars. However, Australian consumer sentiment is still strongly oriented towards private car ownership as illustrated by record car sales in recent years exceeding 1 million vehicles/year in the Australian motor vehicle market. This paper does not attempt to predict what may transpire in the future for Adelaide's vehicle fleet, and in the interests of simplicity, assumes a business as usual scenario as far as the future efficiency of Adelaide's vehicle fleet in 2040, using 2010 as a baseline.

Research Context

The conceptualising of TODs is well established concept in urban planning literature, at least with regard to its key design principles in which transit nodes form the nucleus of TODs characterized by development of higher density in a mixed use format with a sufficient population catchments around the

interchange to support local employment and most day to day social needs, and which is serviced by a high frequency mass public transit network (usually rail or tram based, but it can be bus based) (Newman & Kenworthy, 1989; Cevero, 1998; Dittmar & Poticha, 2004; Curtis et al., 2009). The paradox in the concept of TODs is that although it implies an emphasis on transport within an urban setting, contemporary urban planning emphasizes the importance of minimizing mechanized travel with most activities such as employment, education, recreation, basic shopping and health services being undertaken locally by the residents within a TOD. Not all Australian researchers agree that increasing urban densities, either in TODs or generally, are desirable. Troy (1996), Gleeson (2006), Gleeson et. al (2005) and Hall have cautioned against urban densification because of its detrimental impact on the traditional suburban character of Australia's cities as characterized by the loss of the private backyard and potentially corrosive effects on community cohesiveness. Others such as the late Paul Mees expressed the view that urban densification would take far too long in securing a modal switch to public transit away from cars and instead he had advocated adapting low-density suburbia to a grid network of bus routes with coordinated 'pulse'scheduling'. The work of Curtis (2008) does discuss how a low density city such as Perth can effectively make the transition to a city of networked TODs, using park & ride as an interim stage towards achieving higher urban densities and integration of commuter rail corridors with cross radial bus routes.

Newman, Beatley and Boyer (2009) in their book "Resilient Cities" have discussed the challenges posed by Peak Oil and Climate Change faced by cities and the responses needed to achieve "resilience" in cities, through the identification of 10 planning principles that emphasis the importance of TODs in achieving lasting resilience. However, their work does not have detailed empirical evidence of case study cities that quantifies the carbon emissions impacts of current travel behaviour in car oriented cities, nor do they provide detailed studies of the extent to which carbon emissions could be reduced by reconfiguring cities which are local in character and with a reliance on public transit, cycling and walking for urban travel. Gilbert and Perl's (2007) work did make an attempt at the national level with case studies of China and America to project what the national transport scene would be in 2025 based on current assumptions of oil availability, production capacity and global demand. Their work focused on transport solutions rather than changes to urban form, and their projections were that personal local travel in the US would have to reduce by 45% through the use of substantial modal shifts to electric cars and electric public transit (11.9% of trips).

In the context of Australian cities, the landmark study of Dodson and Sipe's (2008) entitled "Unsettling Suburbia: The New Landscape of Oil and Mortgage Vulnerability in Australian Cities", employed GIS to map a vulnerability assessment of the potential for economic stress posed by mortgage repayments, petrol prices and inflation (described by the acronym VAMPIRE) on Australian households in Melbourne, Sydney, Brisbane, Perth and Adelaide. Their work drew upon the 2001 and 2006 Australian Bureau of Statistics population and housing census data to derive an index that quantified these factors for Australian households for the purposes of highlighting the socio-economic impacts of rising oil prices, inflation and what had been escalating mortgage costs. Whilst VAMPIRE was useful in showing localities in Australian cities that were economically vulnerable to the effects of rising oil prices based on their estimated fuel usage through private car travel, it did not directly reflect the impact of fuel consumed in terms of the carbon emissions emitted for households in Australia's capital cities. The work of Randolf et. al (2006) investigated the effect of urban density and location on the energy profile of various suburbs in Australian cities (including Adelaide).

In light of the shortcomings identified in the literature in exploring the effect of TODs on carbon emissions from urban travel, this paper attempts to investigate this issue in the context of the 30YPGA's strategy to transform metropolitan Adelaide into a transit oriented city with networked TODs that encourage a localized approach to urban living.

Methodology

Journey to Work and Education data was obtained from a cross-tabulation of the 2006 ABS Population and Housing Census for the 13 non CBD TODs for metropolitan Adelaide. The 13 TODs include: Bowden and Keswick (inner suburban); Bedford Park, Glenelg, Mawson Lakes, Oaklands, West Lakes, and Woodville (middle suburban); and Elizabeth, Modbury, Noarlunga, Port Adelaide and Salisbury (outer

suburban). In 2006, only Glenelg had urban densities at significantly higher concentrations than the commuter catchments surrounding their transit interchange. The remaining nominated TODs in the 30YPGA are characterised as transit interchanges with some retailing, commercial or industrial activity. All of the proposed 13 TODs are centres that either attract or generate trips, but few of these are residential area sourced trips from within the walking catchment of the TODs' respective pedestrian catchments. However, by the date of the 2011 ABS Census, new high density residential developments had been incorporated around the transit interchanges of Mawson Lakes and Port Adelaide, which meant that the 2006 ABS Census was the most appropriate baseline of metropolitan Adelaide prior to the adoption of the TOD policy as set out in the 30YPGA. It should also be noted that the 30YPGA was based on statistical analysis of the 2006 ABS Census. From the 30YPGA, urban density increases across all of the 13 non metropolitan TODs would rise from 15 dwgs/ha to 35 dwgs/ha, an increase of 2.3 times, however, average household occupancy would decline from 2.3 persons/dwg to 1.45 persons/dwg, resulting in a net increase of trips of 45%.

Statistical Suburb Districts (SSD) in the 2006 Census with a transit interchange as central as possible to the TOD concerned as set out in the 30YPGA, were selected to represent the residential commuting catchment around each TOD. The limitation in this approach is that none of the SSD approximated a perfect 800m pedestrian catchment around a TOD, thereby compromising accurate comparisons of data between TODs. This data was used to examine the extent of car usage in existing areas nominated as TODs, before any increase of urban density had occurred (see table 3). This information was seen as useful in examining the effect of public transit network improvements on existing residents in the nominated TODs swapping their car based urban commute to a park and ride commute. Car commuting travel distances from each TOD centroid to the Adelaide CBD centroid (taken as Victoria Square) were computed using Apple's IPad3 mapping function along the most practical and direct main road corridor. For non-Adelaide CBD commuting, it was assumed that the balance of commuting trips for residents of each TOD would travel an average commuting distance, based on whether their TOD location was inner suburban (6.6km), middle suburban (8.2km) or outer suburban (13.5km) for metropolitan Adelaide. Because there is a lack of contemporary research documenting average commuting distances for metropolitan Adelaide, BITRE's (2010) recent study for Perth's commuting flows was used as a proxy for Adelaide, given that Perth has similarities to Adelaide with its elongated urban form along a north-south axis and heavy reliance on the private car for urban travel, despite having a population that is 55% larger than Adelaide's. Indeed, according to the 2011 ABS census, the average commuting trip distance for Adelaide's residents at approximately 12km is similar to that of Perth's residents (11km).

The basis for selection of the 2006 ABS data (rather than the 2011 Census data) is that it formed a useful baseline for these types of trips prior to the effect of any significant urban densification policies occurring in Adelaide. Although in Adelaide's inner suburbs and the CBD, the process of urban infill and densification with large apartment blocks (particularly within the City of Adelaide), has been underway since the mid 1990s, Adelaide's metropolitan public transit network is notable even now for its absence of significant TODs with urban densities across the metropolitan area, even in public transit rich locations such as the beachside resort style suburb of Glenelg being the only significant exception. After the 2006 ABS Census, change becomes evident, particularly at Mawson Lakes, Lights View, Bowden and Newport Quays (Port Adelaide), with new development occurring at much higher densities and co-located with a public transport node or interchange.

Carbon emissions in are generated through the burning of fossil fuels such as petrol or diesel. By knowing the average fleet fuel economy and distances travelled by commuters (available from ABS Census data), it is possible to provide a reasonably accurate estimate of the likely carbon emissions. Table 4 provides a summary of the distance commuting characteristics for car drivers within the immediate catchment of the 13 TODs. The following formulas were applied in estimating the carbon emissions generated:

$$\sum Fuel_{(1 \text{ to } n)} = (\sum Commuters_{(1 \text{ to } n)}) * E_{avg.} \times RD_{(sub. \text{ centroid to CBD})} \quad (1)$$

Where:

Fuel=total fuel in litres; Commuters=commuters who drive a car; n=number of commuters

E avg = Average fuel economy for the Australian passenger vehicle fleet in 2010 (11.3 litres/100km);

RD = Direct road distance from centroid of an Adelaide suburb to Adelaide CBD (i.e. Victoria Square)

An estimate for the average carbon dioxide emissions produced for South Australia's passenger vehicular fleet was estimated to be 272.5g/km in the formula (2) below:

$$CO_{2\text{passenger fleet average g/km}} = (84\%_{\text{petrol}} * 11.1_{\text{l/100km(petrol)}} * 2.354_{\text{kg CO2/litre.petrol}}) + (8.4\%_{\text{diesel}} * 11.4_{\text{l/100km(diesel)}} * 2.681_{\text{kg CO2/litre.diesel}}) + (7.5\%_{\text{other}} * 13.6_{\text{l/100km(other)}} * 2.354_{\text{kg CO2/litre.petrol eq.}}) = 272.5 \text{ grams/km/passenger vehicle} \quad (2)$$

Note: 'other' refers to LPG and CNG automotive fuels and petrol powered hybrid cars.

Average fuel consumption figures for South Australia's passenger fleet were taken from the national survey of motor vehicle use (ABS 2011)

The analysis chose car drivers as the basis for estimating carbon emissions, because this most accurately reflected the number of motor vehicles being used in the journey to work as set out in the ABS Census. A caveat in making a projection of motor vehicle fleet carbon emissions in 2040 is that advances in motor vehicle technologies are likely to be substantially reduced on a per capita basis, due to a tougher international regulatory environment for new motor vehicles. This paper has assumed that the 2040 motor vehicle passenger vehicle fleet average remained unchanged from its 2011 estimate as detailed in equation (2).

In all three scenarios, the purpose of the research was to investigate the substitution of car based commuting trips with public transit trips. Obtaining representative emissions data for rail mass transit was somewhat more problematical. As the South Australian electricity grid de-carbonises, and more electricity is sourced from renewables such as wind and solar (up to a third of current electricity production capacity in 2013), providing a meaningful measure of the carbon emissions impact of electric trams and trains is difficult. Adelaide still operates diesel electric trains, but these are due to be phased out over the next decade in favour of electric trains. The State of Australian Cities 2013 Report, drawing on experience in the United States with rail mass transit, estimated rail transit to consume 1.7MJ/passenger.km, and from this, it was possible to derive the likely carbon emissions, given that the bulk of Adelaide's trains are diesel-electric. The rate of carbon emissions for rail based public transit in this research was estimated to be 114 grams/km/passenger.

In the first scenario, it was assumed that motorists would drive on average 1km to park at the transit interchange within their local TOD, and then catch transit into the city centre, given the city centric nature of metropolitan Adelaide's urban form. This scenario also assumed that an increase in urban density had not yet occurred. The 30YPGA (2010) assumed that existing urban densities near transit interchanges and along transit corridors was 15 dwellings/ha, however, in practice, it is probably quite a bit less than this, particularly in TODs dominated by commercial land and non-residential uses such as in Elizabeth. Because of the dispersed nature of commuting in Adelaide, a surprising finding for the outer suburban TODs was that only a small proportion of the commuting was to Adelaide's CBD. The proportion of residents commuting to Adelaide's CBD was assumed to remain the same in 2040 as it had been in the 2006 baseline ABS census data.

In the second scenario, a similar modal switch to public transit on the transit corridor was explored, but with the maximum TOD residential densities of 35 dwellings/ha assumed to be in place, and only for CBD destinations. The methodology assumed that the number of commuting trips increased in proportion to the population growth. As with any assumptions, a wide range of demographic factors could influence the actual numbers of persons that work and undertake commuting. The exploration of this scenario in this manner reflects the fact that the radial nature of Adelaide's public transit network does not permit easy cross metropolitan commuting. Hence, a modal switch from cars to public transit is not practical for the bulk of non-CBD destinations, unless they lie along the transit corridor itself which are mostly bi-directional, rather than multi-directional in the way that the road network is. As in scenario 2, it was assumed that the proportion of residents commuting to Adelaide's CBD was assumed to remain the same in 2040 as it is was in the 2006 baseline ABS census data.

The third scenario similarly assumed that TODs are developed to the maximum level as set out in the 30YPGA. Commuting trips are assumed to increase by the same proportion, but these are likely to be via local modes such as cycling and walking. The savings in travel related carbon emissions reflect the baseline 2006 commuting situation projecting the trends through to 2040 as a "business as usual" arrangement, which were then discounted in full to reflect completely localised commuting using non-mechanised travel modes. The difference is in a localised lifestyle, with mixed uses provided at sufficient densities in which all jobs and housing are co-located. In theory, this would dispense with the need for cross-metropolitan travel with TOD communities largely able to rely on walking and cycling to get around. Electric vehicles would meet the needs of personal travel and because they can utilise renewable energy, they could operate without producing carbon emissions. Inter-regional travel via the TOD network would be minimal in this scenario and largely for recreational or special business purposes. Given that transit could be powered by electricity from renewable sources, carbon emissions would be negligible. This scenario offers the prospect of genuinely carbon emissions free living, at least from a transport perspective. The challenge in comparing this scenario is that if it is carbon free, how does one compare it with other developments? The approach taken in this research was to increase development from the TOD baseline in 2006 to an envisaged scenario of a business as usual case, where existing travel behaviours carried through to 2040, the sunset date for the 30YPGA. Housing was predicted to increase by 130% but with the trend to much smaller household occupancy rates (63% of what it was in the 2006 ABS Census), the actual increase in population was a relatively modest 45%, which if commensurate with commuter travel growth would not create undue stress on the transport network or justify massive investments in transit. Commuting trips were assumed to increase at the equivalent rate of population growth (i.e. to 45% over the 2006 baseline level by 2040). Added to this uncertainty, the aging of metropolitan Adelaide's population may result in less travel demand unless older persons opt to remain economically active.

Table 3: Estimate of daily commuter trips from nominated TODs (2006 baseline)

Source: ABS Population and Housing Census (2006)

ADELAIDE'S TODs	DAILY CAR DRIVER COMMUTER TRIPS TO ADELAIDE CBD FROM TOD	TOTAL DAILY COMMUTER TRIPS TO ADELAIDE CBD FROM TOD	CAR DRIVER SHARE OF TOTAL DAILY COMMUTER TRIPS TO ADELAIDE CBD FROM TOD	NON-CBD COMMUTER TRIPS BY CAR DRIVERS FROM TOD	TOTAL NON-CBD COMMUTER TRIPS FROM TOD	PUBLIC TRANSIT COMMUTER TRIPS TO CBD FROM TOD	NON CBD PUBLIC TRANSIT COMMUTER TRIPS FROM TOD	CAR DRIVER SHARE OF TOTAL DAILY NON-CBD COMMUTER TRIPS FROM TOD
Bedford Park	40	91	43.96%	299	376	33	49	79.52%
Bowden	22	89	24.72%	127	144	33	12	88.19%
Elizabeth	7	24	29.17%	167	236	17	8	70.76%
Glenelg	129	317	40.69%	692	1259	188	1	54.96%
Mawson Lakes	193	463	41.68%	1818	2090	270	0	86.99%
Modbury	112	331	33.84%	1117	1367	219	0	81.71%
Noarlunga Downs	43	117	36.75%	688	842	74	7	81.71%
Oaklands Park	63	221	28.51%	692	803	158	43	86.18%
Port Adelaide	35	82	42.68%	291	322	46	0	90.37%
Salisbury	86	271	31.73%	1560	1923	170	18	81.12%
Keswick	46	104	44.23%	164	233	47	0	70.39%
West Lakes	282	516	54.65%	1793	1806	222	12	99.28%
Woodville	67	170	39.41%	508	625	69	0	81.28%
TOTAL	1125	2796	40.24%	9916	12026	1546	150	82.5%

Table 4: Daily trip car driver commuter distances from nominated TODs (2006 baseline)

Source: ABS Population and Housing Census (2006)

ADELAIDE'S TODs	Number of Car driver commuters daily: TOD-Adelaide CBD by road	Distance (km) by road : TOD-Adelaide CBD	Number of Car driver commuters daily: TOD-non CBD locations by road	Assumed distance (km) by road: TOD-non CBD locations by road (1)	Aggregate work commuter trip distances (km/day): TOD-Adelaide CBD (2)	Aggregate work commuter trip distances (km/day): TOD-non CBD locations (2)	Aggregate work car commuter trip distances (km/day) (2)
Bedford Park	40	12.1	299	8.2	968	4904	5872
Bowden	22	4.9	127	6.6	216	1676	1892
Elizabeth	7	27.9	167	13.5	391	4509	4900
Glenelg	129	11.1	692	8.2	2864	11349	14213
Mawson Lakes	193	15.7	1818	8.2	6060	29815	35875
Modbury	112	15	1117	13.5	3360	30159	33519
Noarlunga Downs	43	33.5	688	13.5	2881	18576	21457
Oaklands Park	63	13.2	692	8.2	1663	11349	13012
Port Adelaide	35	15.7	291	13.5	1099	7857	8956
Salisbury	86	20.2	1560	13.5	3474	42120	45594
Keswick	46	3.9	164	6.6	359	2165	2524
West Lakes	282	14.3	1793	8.2	8065	29405	37470
Woodville	67	9.5	508	8.2	1273	8331	9604
TOTAL	11250		9916		32673	202215	234888

Notes:
(1) Assumptions taken from BITRE paper on commuter traffic flows, using Perth as a proxy for Adelaide (6.6km for inner suburbs; 8.2 for outer suburbs; 13.5km for outer suburbs) (Australian Government, 2010)
(2) Return trip daily distances.

Discussion

Column A in table 5 details the park and ride scenario for each of the 13 TODs defined in the 30YPGA for the three possible scenarios described in the Methodology section. The table illustrates the likely transport carbon emissions reductions possible from a modal switch to public transit (i.e. in scenarios A and B) or a complete avoidance of carbon emission inducing transport modes (i.e. scenario C). The variability in performance of each of the proposed TODs reflects the state of development in 2006 (or lack of it particularly in the cases of Bowden and Keswick generating savings of only 0.2kg/day/commuter), in 2006, and it is also a function of distance from the Adelaide CBD and the intensity of development surrounding the transit interchanges (such as in the cases of Modbury, Port Adelaide and Noarlunga Downs). Interestingly, West Lakes and Mawson Lakes are both modern master planned residential estates (reflecting urban planning practice from the 1970s and 1990s respectively), but have the poorest performance with regard to current commuter travel induced carbon emissions. This partly reflects a high level of car dependency that seems to accompany affluent living, despite the planners' best intentions in the latter case to create a TOD, but paradoxically, it also reflects the success of the planners in concentrating residential development in reasonable densities around the transit interchange. A further factor is that employment opportunities are minimal which results in long distance commuting usually by private car. Elizabeth's apparently strong performance is misleading and closer inspection shows that it has low commuter carbon emissions because it lacks residential development around its transit interchange, and it is surrounded by a large retail and commercial district in a vast moat of at-grade parking lots. The remaining TODs with relatively low travel related carbon emissions do not reflect high environmental performance, but rather a lack of critical mass of residential development that manifests itself in modest travel demands along the transit corridor. The carbon emissions travel signatures, as they currently stand in this scenario with rail in the form of diesel powered trains actually highlights a

surprising lack of activity, while at the same time suggesting that there is considerable potential for increased development in most of the nominated TODs in Adelaide's 30YPGA (see table 2).

Table 5: Metropolitan Adelaide TOD Commuting Models Compared

Sources: Derived estimates using ABS (2006); DIT (2013)

TODs	A. TOD to CBD park & ride model (substituting car driving with rail transit) circa 2040 See notes (2) (3) (4) and (5)	B. TOD to CBD full transit commuting model with TOD density increases to 35dwgs/ha circa 2040 (7) and (8)	C. Carbon emissions reduction with jobs and housing co-located in TODs circa 2040 with TOD densities at 35dwgs/ha (7) and (8)
	Total CO_2 emissions (kg/day) (1)reduction using fossil fuel derived electricity. Per capita emissions reductions across all commuters for the TOD are shown in brackets.	*Total CO_2 emissions (kg/day) reduction for trips from new TOD dwellings (kg/day) (6) using sustainable electricity for public transit. Per capita emissions reductions across all commuters for the TOD are shown in brackets.*	*Total CO_2 emissions (kg/day) reduction for trips from new TOD dwellings (kg/day) (6) using sustainable electricity. Per capita emissions reductions across all commuters for the TOD are shown in brackets.*
Bedford Park	176 (0.4)	490 (0.7)	2586 (3.8)
Bowden	46 (0.2)	132 (0.4)	828 (2.5)
Elizabeth	66 (0.3)	260 (0.7)	2128 (5.6)
Glenelg	526 (0.3)	1496 (0.7)	6308 (2.8)
Mawson Lakes	1068 (0.4)	3216 (0.9)	15576 (4.2)
Modbury	596 (0.4)	1992 (0.8)	14330 (5.8)
Noarlunga Downs	482 (0.5)	1694 (1.2)	9330 (6.7)
Oaklands Park	298 (0.3)	1080 (0.7)	5948 (4.0)
Port Adelaide	194 (0.5)	576 (1.0)	3778 (6.5)
Salisbury	600 (0.3)	2402 (0.8)	19230 (6.0)
Keswick	82 (0.2)	248 (0.5)	1058 (2.2)
West Lakes	1436 (0.6)	4288 (1.3)	15888 (4.7)
Woodville	238 (0.3)	822 (0.7)	4012 (3.5)
TOTAL	5808 (0.4)	20246 (0.9)	100998 (4.7)
Reduction in carbon emissions for the Adelaide Metro Area compared to 2006 levels	0.13% reduction in carbon emissions to 4.470 kg/day/commuter	0.49% reduction in carbon emissions to 4.454 kg/day/commuter	2.431% reduction in carbon emissions to 4.367 kg/day/commuter

Notes:
(1) Assumes average 1km car trip to park at TOD location transport interchange
(2) No public transit substitution occurs for non-CBD commuter trips
(3) Expected emissions from public transit by rail deducted (1.7MJ/passenger km)
(4) Car passenger travel is assumed to be so small as to be negligible (i.e. within the margin of error)
(5) No increase in urban density occurs.
(6) Zero carbon emissions energy sourced from solar and wind power running electric rail/trams.
(7) Urban density increases from 15 dwgs/ha to 35 dwgs/ha as per the 30YPGA, an increase of 2.3 times, however, average household occupancy declines from 2.3 persons/dwg to 1.45 persons/dwg, resulting in a net population increase of 45%.
(8) Commuting trips increase by the equivalent rate of population increase to 2040.

Column B in table 5 presents the main policy intent of what the 30YPGA is attempting to achieve. Whilst the transit corridors as outlined in the 30YPGA (see figure 2) do not present a connected network of TODs, other than via the routes radiating out from the CBD, in this scenario, which is expected to be realised by 2040, the TODs are developed to their maximum residential density of 35 dwellings/ha, and it is highly probable that the rail transit services will be electrified and powered by a high proportion of electricity from renewable sources. Adelaide's success with its solar powered Tindo electric bus, suggests that it would be feasible for the Adelaide OBahn (i.e Busway) to be serviced by solar-electric buses. This scenario recognises that the same proportion of TOD residents would be commuting to the

CBD as in the 2006 base line case. The carbon emissions detailed in column B of table 5 demonstrates that dramatic savings in carbon emissions are possible in this scenario (39% less carbon emissions), despite the CBD centric nature of the transit corridors serving these TODs. This is all the more remarkable given that residential densities are more than double their current level. Interestingly, although the TODs of West Lakes and Mawson Lakes still dominate the carbon emissions league table for TODs circa 2040, their travel carbon emissions are almost half of what they currently are, despite accommodating a much larger population. What is perhaps difficult to explore effectively in this type of analysis is the extent to which the mindset of TOD residents becomes embedded in their locality with shopping, personal services, education, recreation and employment accessed locally by walking and cycling. Hence the actual reductions in travel carbon emissions may be even greater in practice if higher urban densities encourage a greater engagement in the community and lessen the need to for wider metropolitan urban travel to fulfil personal needs.

In table 5, column C, the effects on carbon emissions of the third and final scenario are presented. In this scenario, it is envisaged that massive reductions in carbon emissions are achieved as people choose to co-locate their abodes with where they work. The Adelaide CBD, which is also designated as a TOD in the 30YPGA has been excluded from this analysis, because it serves a pivotal role in the economy and life of metropolitan Adelaide and it is quite unlike the suburban TODs set out in the 30YPGA. Nevertheless, the Adelaide CBD does achieve the intent of the TOD scenario set out in scenario C by virtue of it being on a large enough scale to offer its residents almost all of their needs, including a diversity and volume of employment opportunities that Adelaide's current suburban centres fail to rival. Assuming that rail transit in this scenario were to operate without carbon emissions, and there would be little need to commute to other parts of the metropolitan area for employment, travel related carbon emissions could be reduced to zero, particularly if TOD residents walk and cycle within their TOD. This scenario demonstrates the potential to avoid a more than threefold growth in carbon emissions within the areas of the nominated TODs, assuming that there are no further technological improvements in the carbon emissions performance of private cars. For the TOD locations in the outer suburbs with long travel distances to the Adelaide CBD, there are dramatic savings in carbon emissions ranging from five to eight times what was suggested in the second scenario. Keswick presents something of an anomaly in this analysis because it is destined to become an office rather than a residential hub. Indeed, in practice, Keswick is likely to generate far greater carbon emissions than what is presented here because it is being developed as an office park with a large amount of on-site office car-parking for commuters. .

When the per capita carbon emissions savings for the 13 proposed TODs are averaged across the whole of metropolitan Adelaide, each of the three scenarios examined suggest that the overall impacts of the TODs will be minimal at best, ranging from a 0.13% reduction in scenario A, to a 0.49% reduction in scenario B and a 2.43% reduction in scenario C. However, whilst these improvements in transport carbon emissions appear to be negligible, the 30YPGA ultimately proposes 4 times as many TODs and "activity centres", a doubling of Adelaide's CBD residential population and extensive transit corridors, which could conceivably reduce carbon emissions by five times the level of reductions that have been estimated in this paper (i.e. from 0.7% to 12.2%).

Policy Implications

The above analysis has demonstrated that Adelaide's proposed TODs to play an important role in reducing transport rewithin their web of transit corridors, in combination with urban densification, as a turn-key strategy towards achieving a future world of reduced carbon emissions. However, by themselves, the TODs will not result in massive reductions in travel related carbon emissions with a modest 2.5% reduction expected for 13 main TODs described in the 30YPGA and indeed, if the TODs remain as suburban retail centres serving clusters of slightly higher density residential development, then the benefits of carbon emissions reductions will be very modest. Whilst the optimal residential density for TODs was not examined in this paper, the analysis presented here suggests that unless the transit corridors play a major role in collocating as many households close to public transit interchanges, the TODs proposed in the 30YPGA will be too small and not sufficiently numerous to result in significantly less reliance on private cars across metropolitan Adelaide.

The radial structure of Adelaide's transport network with transit corridors fanning out into the metropolitan area still encourages dispersal of residents and the perpetuation of urban sprawl, but if people can be encouraged to build local communities in their TODs and integrate both their social and working lives within the TOD that they choose to reside in, then the detrimental effects of urban sprawl can be minimised. What may prove to be a challenge for future policy-makers is the increasing efficiency of private cars rivalling that of public transit (particularly with bus based systems), and falling rates of household occupancy, that require much higher levels of housing density to provide viable population catchments for public transit, social services and businesses. In theory, and from the empirical evidence explored in this research, the 30YPGA has the potential to transform Adelaide into a public transit oriented environmentally sustainable metropolis because it provides the transport 'skeleton' on which a denser more transport efficient city can be developed over the life of the strategy. A further avenue for future research would be to investigate the extent to which the transit corridors proposed within the 30YPGA will realise the transport carbon emissions reductions highlighted as being required by the Intergovernmental Panel on Climate Change (IPCC) and to at least satisfy Australia's international obligations on carbon emissions reductions.

This research did investigate the issue of an interim approach to developing TODs, through the use of park and ride commuting. This approach is not new, and indeed, Curtis (2009) had highlighted this approach being taken in the development of Perth's metropolitan commuter rail network, particularly at Bull Creek Station and Cockburn Central along the Mandurah to Clarkson commuter rail corridor. The 30YPGA does not explicitly advocate an interim approach for initiating TODs, apart from a proposal announced in 2013 by South Australia's State Planning Minister John Rau to introduce designated precinct plans that would take precedence over local Development Plans. Further investment in Park and Ride facilities was until 2013 discouraged by Rob Hook, the CEO of South Australia's Infrastructure Department, because the preference was to encourage feeder bus services to suburban transport interchanges. This stance appears to be weakening with a recent commitment to invest in several park and ride car-parks including Tea Tree Plaza and at Klemzig on the OBahn.

A major failing of the 30YPGA since its release is that it was only broadly schematic in its layout and apart from providing strategic intent in relation to the urban form and structure of its transit networks, it lacked the support of a transport plan to direct future public transport investment needed to support the Strategy's densification objectives. Hence, it remained uncertain how the massive investment in public transport, let alone urban densification in the TODs and TCs would occur and according to what timeframe.

Subsequent to the preparation of this paper, in October 2013, the South Australian Government released a draft document, entitled "The Integrated Transport and Land Use Plan" (TITLUP), which will assist the long-term implementation of the 30YPGA over the next three decades. However, the $36bn Transport Plan has been introduced in a climate of a severely constrained state budget with significant deficits, low business and consumer confidence in the state and the incoming Abbott Coalition Government's abandonment of the previous federal Rudd-Gillard-Rudd Labor Government's (2007-2013) commitment to co-funding of commuter rail projects. South Australian consumer and business confidence also lags substantially behind the rest of Australia, with both householders and businesses extremely risk averse, meaning that for policy makers, a critical challenge is in convincing the wider community of the value and benefits in moving to housing in TODs and in Transit Corridors. The current State Government Policy focus is in developing and up-grading public transport infrastructure in the main transit corridors and developing a few exemplar TODs (such as Bowden and Mawson Lakes), that theoretically should act as a catalyst for further investment by housing, retail and commercial property markets in the 30YPGA's other TODs. For householders, despite the conscious efforts of the 30YPGA and TITLUP (draft) to realise metropolitan Adelaide as a city of networked TODs, the policy signals that will resonate with ordinary Adelaidians are not apparent, apart from modest state government attempts at stamp duty relief subject to very low sale price caps in a few targeted locations in and near the Adelaide CBD.

Conclusions

This paper has touched on the historical background to the strategic planning that guided and provided a robust template for the development of modern metropolitan Adelaide. The paradox with Adelaide is that despite its uniqueness amongst the mainland Australian capital cities in not developing a freeway network, the car nevertheless facilitated rapid urban expansion to wherever easily developable land was. Indeed, in a recent study by Mees and Groenhart (2012), Adelaide was noted as being the most car dependent Australian city and appeared to be drifting away from public transport in an opposite trend to that experienced by other Australian cities where public transit was undergoing a renaissance. Perhaps having a major car manufacturing presence since the early 1960s may have had something to do with encouraging Adelaide's deep love affair with the car. The relative ambivalence of past metropolitan plans in dealing with the role of the car in urban development (Adelaide's 1962 and 1994 Plans) still lingers on today, with a plethora of major new road projects coming on stream, but not under the umbrella of the current metropolitan plan (30YPGA), and instead under the auspices of a State Strategic Infrastructure Plan. The October 2013 release of the TITLUP for public consultation by the South Australian Government potentially redresses past transport policy strategic plan-making shortcomings, although it is yet to be gazetted in the South Australian Parliament and faces the test of a State election scheduled for early 2014,

The current metropolitan plan does not present as yet a detailed transport plan that will re-orient metropolitan Adelaide to public transit, however, it does have an impressive strategic transport aim that confers on Adelaide, a précis of a networked transit oriented city with a myriad of connected and integrated TODs. TITLUP would assist (if adopted) in articulating the 30YPGA by highlighting the scale, timing and classifying the nature of future transport infrastructure investments required. The research finding in this paper illustrated that in the key proposed TODs of the 30YPGA, most commuters (80-90%) preferred to drive rather than use public transit. Breaking this mindset will be difficult in a city where the average commuting trip is around 12km, and where cross metropolitan commuting routes are rarely aligned with public transit routes. However, if Adelaide's residents can embrace living in TODs and TCs, then significant transport related carbon emissions savings are possible. These savings in carbon emissions would become even greater if South Australia became carbon neutral with future electricity generation sourced largely from wind and solar and powering clean, pollution free transit. The limitations of this research are that the commuting catchment for various travel modes around TODs is somewhat uncertain, and the potential for public transit to substitute for car based cross-metropolitan commuter trips is poorly understood in the Adelaide context. This research has not investigated how the large stretches of transit corridors that connect the TODs would affect travel behaviour of residents residing in the TCs. Further research would be needed to determine the level of travel emissions carbon reductions that TCs would contribute to. Data for Perth was used as a proxy for estimating average urban commuting distances in Adelaide, however, further original survey research of commuter travel behaviours within the catchment of the studied Adelaide TODs would be needed to determine the transport carbon emissions savings for all TOD related urban commuter trips. The main finding of this paper is that TODs in isolation will only contribute to a minimal reduction in transport carbon emissions however further research is needed to determine how a network of TCs would affect overall transport carbon emissions.

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