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Research agenda for low-carbon mobility: Issues for New World cities

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ABSTRACT

Low-carbon mobility (LCM) features strongly in debates about the sustainability of cities and their resilience in the face of demographic, economic, and climate change. Transport is a major source of carbon emissions and there are indications that these continue to increase, despite the considerable recent advances in vehicle, engine, and fuel technologies. Reducing carbon emissions from transport may become more difficult, not easier. A particular issue relates to the New World cities, typified by those of North America and Australasia, which largely developed from the latter half of the nineteenth century onward and whose transportation systems were largely based around private vehicle ownership and usage. These cities are typically composed of low-density, dispersed suburbs, which are highly car dependent and resource and carbon emission intensive. This article develops a research agenda directed at determining and testing policy and planning measures relevant to the quest for low carbon mobility in New World cities. It suggests a rich agenda for essential research on LCM. Much of this agenda falls within the realm of the integration of transport and land use, with attention to urban design details to enhance the perceptions of and opportunities to use low carbon transport alternatives. Research topics identified for LCM research include (1) urban design and land use–transport integration (LUTI), (2) low carbon mobility policies directed at achieving widespread behavior change, (3) opportunities for new technology and its application, including requirements for systems and infrastructure, and (4) analysis and tools for informed decision making, including modeling, measurement, visualization, and especially assessment.

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Introduction: Carbon, transport, and urban precincts

Over 80% of carbon dioxide emissions originate in urban areas (Grubler, 1994; O'Meara, 1999), which occupy less than 2.4% of the global land mass (Churkina, 2008; Potere & Schneider, 2007). The global rate of migration toward cities is three times greater than the rate of population growth (UN, 2006). In 2007, for the first time in human history, more than half of the world's population was living in urban settings (UN, 2007). Cities have been recognized as major contributors to global greenhouse gas emissions (International Energy Agency, 2008; Grimm, Faeth, & Golubiewski 2008), as well as a critical part of the solution in reducing these emissions (Chavez & Ramaswami, 2011). A particular issue relates to the so-called New World cities, typified by those of North America and Australasia, which largely developed from the latter half of the nineteenth century onward and whose transportation systems are largely based around private vehicle ownership and usage.

By way of example of New World urban development, Australian cities are typically composed of low-density, dispersed suburbs, which are highly car dependent. This is resource and carbon emission intensive and therefore unsustainable in the long term (Rauland & Newman, 2011). Australia has one of the fastest growing populations for a developed country (Productivity Commission, 2010) and one of the highest per capita carbon and ecological footprints in the world (Garnaut, 2008; Global Footprint Network, 2010), with most of the population growth occurring in the major metropolitan areas such as Sydney, Melbourne, and Brisbane. There is an immediate need for Australia to transition its cities to a low-carbon alternative with more efficient form and function with respect to carbon emissions. A low-carbon city must improve the energy efficiency of its buildings and transport system (Chavez & Ramaswami, 2011). A key aspect of this transition is transportation.

Transportation systems guide our mobility, that is, our ability to move from one place to another in order to achieve our objectives. Transportation provides access to jobs, education, and social interactions, for example, all of which are fundamental to human development (Donoso, Martinez, & Zegras, 2006).

Urban form can have a significant effect on the carbon intensity of travel, with some urban forms showing a greater capacity than others to reduce the rate of carbon emissions per capita. Newton, Pears, Whiteman, and Astle (2012) underscore the importance of integrated land use and transport planning for growing cities, providing examples where transport planning and development planning have happened independently, resulting in reliance on private vehicles or excessive pressure on public transport services. A major transformation in the way transport planning is carried out is required with a new approach toward environmental and liveability aspects and a focus on achieving carbon efficiency in transport and urban precincts (Hickman & Banister, 2007).

Beyond reducing carbon emissions, changing the way we undertake urban and transport planning offers the potential to

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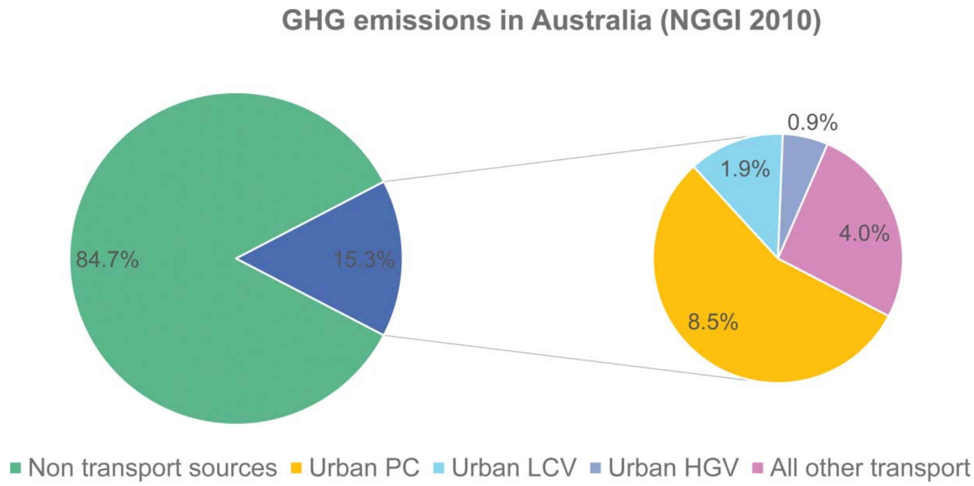

Figure 1. Contribution of passenger car usage in urban areas to Australia's total GHG emissions (PC, passenger car; LCV, light commercial vehicle; HGV, heavy goods vehicle), derived from data in DCCEE (2012).

generate other important long-term benefits, such as open space preservation, improved air quality and public health, and reduced infrastructure investments, leading to improved quality of life in urban areas (Donoso et al., 2006).

Transport is a major source of carbon emissions in Australia, accounting for about 15.3% of total greenhouse gas (GHG) emissions in 2010 (DCCEE, 2012), 86% of which came from road transport. Passenger cars were the largest single source of GHG emissions from road transport. Analysis of the 2010 National Greenhouse Gas Inventory data indicates that urban transport accounted for some 73.6% of the total road transport GHG emissions in Australia, or some 51.3 Mt CO_2-e per annum. Private car usage in urban areas was responsible for 55.5% (39.7 Mt CO_2-e p.a.), i.e., 45.3% of total transport GHG emissions and 7.3% of total GHG emissions from all sectors as recorded in the 2010 National Greenhouse Gas Inventory (DCCEE, 2012). Figure 1 shows the contribution of the transport sector to Australia's GHG emissions and the breakdown of the transport emissions into urban road transport emissions by vehicle type (PC, passenger car; LCV, light commercial vehicle; HGV, heavy goods vehicle) and all other transport.

Lenzen and Dey (2003) indicated that about 15% of total household GHG emissions were attributable to the travel activities of the households. Further, GHG emissions from the transport sector increased 32% between 1990 and 2010, despite the considerable advances in vehicle, engine, and fuel technologies over that period. Passenger car usage in Australian cities is thus a significant source of GHG emissions, and one that can be directly related to the shape and form of the built environment.

Similar findings for other countries emerge from a scan of the international literature (e.g., Banister, Anderton, Bonilla, Givoni, & Schwanen, 2011; Nakamura & Hayashi 2013). One reason for this increase in transport emissions is the increase in travel that has occurred during the period. Reducing carbon emissions from the transport sector is becoming more difficult, not easier.

Researching low-carbon mobility (LCM)

There is an emerging international consensus that significant research on low-carbon mobility (LCM) is needed, largely because of the complexity of the topic. An optimum blend of technological development, infrastructure adjustment, innovative policy developments, and community behavior change is required. Givoni and Banister (2013) identified three possible ways to substantially reduce the carbon associated with mobility and transport, either individually or in combination:

- to change social norms,
- to follow an economic growth model not coupled with transport volumes, and
- to switch to a different transport system.

Each of these areas requires substantial research in its own right, and then the optimum combination needs to be explored. An initial indication was provided by Bristow, Tight, Pridmore, and May (2008), who compared transport policy settings and developments in the United Kingdom with the national targets for carbon reduction to the year 2050. They concluded that even dramatic technological advances would not meet those targets without considerable behavioral change. Santos, Behrendt, and Teytelboym (2010) considered a wide range of low-carbon transport policy options, which they grouped into three categories:

- *physical policies*, concerning infrastructure and service provision,
- *soft policies*, aimed at bringing about behavioral change, and
- *knowledge policies*, emphasizing the role of investment in research and development (R&D) for future sustainable mobility.

They argued that policy integration was the key and that optimal blending of mutually reinforcing policies was essential. Banister (2011) discussed the concept of the sustainable mobility paradigm, which again required integrated, mutually supporting sets of policies. Banister and his colleagues then suggested a possible policy framework for LCM systems (Banister et al., 2011) but this still required determination of relevant policy sets. A major question is just what policies should be considered and how the policy settings can be optimized. Nakamura and Hayashi (2013) reviewed international developments on LCM policies and strategies and concluded that the specific development processes of individual cities significantly affected the feasibility and effectiveness of different policies. This suggests that measures specific to different types of cities and perhaps individual cities are required; hence the need for research on how to encourage, facilitate, and implement low carbon mobility in the New World cities in particular.

Vehicle technology and vehicle ownership or access to vehicles emerge as particular areas of concern for LCM, both in terms of actual carbon emissions and the propensity of people to use private motor vehicle transport (e.g., see Brand, Anable, & Tran, 2013). Policy instruments that affect vehicle selection, ownership, and usage are important concerns, especially with regard to long-term impacts (on government revenues in particular) and policy mixes.

Strategies to encourage, facilitate, and maintain travel behavior change are also important and may take a variety of directions (Taylor, 2007; Line, Chatterjee, & Lyons 2012) depending on the community or sociodemographic groups involved. Methods now exist for evaluating the short- to medium-term effects of voluntary travel behavior change programs, and the potential for success of the programs is gaining better understanding (Zhang, Stopher, & Halling, 2013). A particular area of research interest for the CRC is in the potential health cobenefits for LCM, which is also the subject of international research (e.g., Mindell, Cohen, Watkins, & Tyler, 2011; Mackett, 2013).

Physical design of precincts is also recognised as a key area for LCM research, especially in design for pedestrian movement and cycling to local facilities and for access to public transport services. Dong, Dong, and Wang (2011) describe the research issues well, in terms of so-called last-mile movement, the access or feeder services to main line public transport.

Synthesis of research needs on low-carbon mobility

Good planning practices with political will and institutional capability will allow low-carbon mobility to become a reality. To this end the authors undertook a synthesis of research needs to indicate and map out the needs for LCM research and to formulate a systematic research agenda on this broad topic. The study was part of a scoping research project for the Cooperative Research Centre for Low Carbon Living (CRCLCL), to assist the center in determining its research priorities and program for the period 2014–2019. The synthesis involved reviews of previous international and local research and a research workshop designed to capture current thinking by both researchers and practitioners. The workshop was held in October 2013.

Planning for personal mobility and the required transport infrastructure and service provision to meet mobility needs is an important component of precinct design in the built environment. Research issues flagged for the workshop included health cobenefits of active transport modes, utilization of electric vehicles, travel behavior change programs, urban form and land use–transport interaction, and travel substitution. These issues are best represented under the banner of mobility, as a significant subset of human activity within the built environment, and so the research agenda focuses on research needs for LCM with special reference to urban areas. Five topics were identified for investigation:

- land use–transport integration and urban design,
- LCM policy and behavior change,
- systems and infrastructure,
- new technology and new approaches, and
- modeling, measuring, and visualizing.

The major outcome of the study was thus a research agenda for the area of LCM (Philp & Taylor, 2014), which serves to inform and guide research on planning for low-carbon urban developments and redevelopments where transport dimensions are of importance. The research agenda includes precinct demand estimation and precinct design, technologies and systems for low-carbon living, land use–transport interaction in urban design, and voluntary behavior change programs.[1] In addition, a set of research areas spanning the previously defined research topics was identified.

Identifying research synergies

A review of the session summaries allowed several key research areas to be identified across the research topics of importance in LCM. These areas can be summarized under the following topics:

- data
- integration
- evaluation
- urban design and planning
- technology
- safety

Data

Data issues are a recurrent theme. Reliable data are essential in proving the value of low-carbon transport options, understanding why and how people travel in the manner that they do, and further identifying how to promote increased transition to low-carbon transport options. Several data issues are relevant to furthering research regarding low-carbon mobility.

The first data issue relates to data collection. Developing a reliable, standardized method for travel data collection, employing a less resource-intensive method than current techniques, was identified as important in the future of LCM research.

Conversely, there is also a requirement to better understand the data that have already been collected and realise their full potential application. For example, many travel behavior studies have been undertaken across Australia. A repository for travel data from these studies would be useful to many researchers, and more in-depth analyses across a wide number of studies may allow new insight into travel behavior. Using the data we have to full capacity would reduce the burden of new data collection. For instance, most major cities have substantial household travel survey (HTS) databases, which include activity–travel diaries of individuals in households. These data sets could be subject to more in-depth analysis to indicate household mobility patterns, e.g., as done for trip chaining by Primerano, Taylor, Pitaksringkarn, and Tisato (2008). Perhaps

[1] The outcome of the full study was reported to the CRCLCL as Philp and Taylor (2014), which is available for download at the website, www.lowcarbonlivingcrc.com.au.

even more importantly, the extensive (longitudinal) data sets collected in evaluations of large-scale travel behavior change programs, such as the Perth Individual Marketing program and the Adelaide Travelsmart program (Zhang, Stopher, & Halling, 2013) contain much in-depth data on personal mobility, attitudes to travel, and individual mobility trends over time that have never been fully analyzed. In the Adelaide case several waves of data were collected from a survey panel over an 8-year period. These data include household sociodemographics and travel behavior, the latter measured using GPS devices, and thus provides a high level of detail and accuracy about travel. The relationships between personal mobility and the usage of services and facilities at different locations relative to place of residence could be explored in some detail using these existing data sets, a most effective and efficient way to gain greater understanding of behavior and the opportunities for low-carbon mobility policies and programs. This is an important area for future research by the CRC.

In addition, new data sources are emerging with the widespread implementation of new technologies for transport services. For example, so-called smartcard fare payment systems for public transport—now operating in most of Australia's capital cities—are providing an ongoing source of data on public transport usage, collected routinely in the operations of the public transport system. These data can be made suitable for research and investigation on travel behavior and the propensity to use public transport. With suitable research and development the data can be linked to the sociodemographic and locational characteristics of the card users (subject to necessary privacy constraints). Opportunities for research on the utility and application of these data sets for information on access needs to public transport (and hence precinct design) and on service provision in suburban areas need to be fully explored by the CRC.

Modern advances in the use of stated preference (SP) methods and discrete-choice modeling (Hensher, Rose, & Greene, 2005; Rose, Bliemer, Hensher, & Collins, 2008) and the coupling of advanced discrete choice models with GIS analysis (Meng, Taylor, & Scrafton, 2016) are providing enhanced opportunities for the exploration of the factors influencing people's lifestyle, location, and travel decisions, the identification of relevant target groups in society (including geographical locations), and the formulation of policies and plans to suit the needs of and influence specific groups. Modern SP sampling and data collection methods offer far greater efficiency in new data collection and, when coupled with advanced choice models, offer powerful new tools for informed policy and planning decisions.

Integration

The research theme of integration relates to how low-carbon mobility can be integrated into existing infrastructure, behavior, and policy making. These research areas are discussed in what follows.

Integrating LCM and infrastructure

To successfully and efficiently transition to a low-carbon transport future it is important to consider how and where LCT technology can be integrated into existing supporting infrastructure to improve low-carbon mobility. Two examples are provided here from the literature.

Singh and Strømman (2013) analyzed the potential for reducing the global warming potential from the passenger vehicle transport sector in Norway through the large-scale transition to electric vehicles. The potential benefit was found to be between 3% and 15% when the complete lifecycle of the vehicle type was considered. However, as hydropower, a low-carbon energy source, was the primary energy source for electric vehicles (EVs) in Norway, the benefit was more pronounced. For countries such as Australia, electricity used to charge EVs is predominantly sourced from high-carbon sources such as coal, gas, or oil, perhaps significantly reducing the potential benefits of EV transition. In these countries, an important consideration for the transition towards LCM will be what can be done to integrate EVs with the existing infrastructure in order to maximize the potential benefits. Taylor, Pudney, Zito, Holyoak, Albrecht, and Raicu (2010) analyzed the potential GHG impacts of EVs in Australia, accounting for the sources of electrical energy (i.e., power generation technologies) in different states and regions, finding significant differences across the nation depending on the source of the electrical energy.

Traut, Cherng, Hendrickson, and Michalek (2013) provide a second example regarding the interaction between LCM transport options and infrastructure. They found the one potentially significant limiting factor for any significant growth in plug-in electric vehicles (PEV) numbers in the USA was the ability of households to charge vehicles at home. Less than half of US vehicles have reliable access to a dedicated off-street parking space at an owned residence where charging infrastructure could be installed. This fact is important for two key reasons. First, consumers were found to be less likely to purchase PEVs if they do not have at home charging. Second, off-peak electric load times take place overnight, so more people charging during the day if they have access at their workplace will increase pressure on the existing electrical infrastructure.

Considering the best practice methods to allow the integration of LCM options within existing infrastructure restraints will be important in the transition to a low-carbon urban future.

Integrating LCM and travel behavior

Givoni (2013) states high-carbon mobility is more of a social problem than a technological one, and so technology alone cannot fix it. As such we need to understand how and why people travel in various ways and what is needed to transition to low-carbon mobility options.

Public awareness and perception are two major barriers for the transition to low-carbon transport. Banister (2013) emphasizes the need to understand the importance of time and how people want to use time in travel compared to other activities. Aditjandra, Mulley, and Nelson (2013) suggest residents have to be well informed of the available opportunities for them to pursue sustainable travel choices. Hackbarth and Madlener (2013) found that despite the fact that most European Union countries have implemented programs to accelerate the diffusion of alternative fuel vehicles, predominantly electric vehicles, German car buyers are still very reluctant to use these vehicle types. Jensen, Cherchi, and Mabit (2013) investigated changes to individual preferences and attitudes after individuals experienced an EV in their daily life. While the results showed that individual preferences do change after exposure to the EV, driving range is a major concern. One of the key findings of their study was that the concerns individuals had about driving range were not due to misconceptions, but a true mismatch between the range they thought they required in their daily life and what the EVs provide.

The future of low-carbon mobility relies on determining how we go about breaking down people's perceptions, misconceptions, and barriers to change.

Furthermore, traditional behavioral framework models may not provide the best fit for behavior related to low-carbon transport options. Hensher, Greene, and Chorus (2013) found people's behavior with respect to decisions surrounding LCM options fit alternative behavioral framework models better than those traditionally used. Alternative models may provide a better predictive framework with respect to nontraditional transportation options.

Integrating LCM with policy making

Policy interventions are required in order to achieve a LCM future. The complex nature of the interaction between transportation and other urban systems, and the lifecycle of transport related infrastructure, means that traditional static planning practices may not achieve the desired outcome for reducing carbon emissions. Ramjerdi and Fearnley (2014) highlight the importance of adaptive and flexible policy-making frameworks, favoring methods of dynamic planning where decisions are made continuously and based on a steady flow of new information. A widely popular and accepted trend found to increase the success of policy implementation is the formulation of integrated policy packages, rather than policy measures that are considered and deployed in isolation (May & Roberts, 1995; Banister et al., 2000; Feitelson, 2003; OECD, 2007; Justen, Fearnley, Givoni, & Macmillen, 2014; Justen, Schippl, Lenz, & Fleischer, 2014; Givoni, Macmillen, Banister, & Feitelson, 2013; Taeihagh, Bañares-Alcántra, & Givoni, 2013). Justen, Fearnley, et al. (2014) support the use of policy packaging where there is a lack of public acceptability. For example, they discuss how urban road pricing schemes may be theoretically effective in encouraging modal shift from private car travel to public transport, but generally receive significant opposition from motorists. Policy packaging options to reduce opposition to the scheme could include public transport improvements or directing revenue from the scheme to other road improvements.

However, it is not always clear what the best option is and which of methods and tools can be used for which purpose and at what stage in the process of policy making (Justen, Schippl, et al. 2014; Ramjerdi & Fearnley 2014). Whitehead (2013) discussed an example from Stockholm, Sweden, where a congestion charging scheme was introduced with an exemption for low-emission vehicles, in conjunction with the introduction of financial incentives for the purchase of low-emission vehicles. As the number of low-emission vehicles increased, the effectiveness of the congestion reduction charging was severely diminished. As such, the exemption policy was phased out less than 18 months after being introduced. Ramjerdi and Fearnley (2014) raise several questions with respect to the uncertainties and risk with transportation policies, including the following:

- what are the best sets of policies?
- how should the policies be phased in and out?
- how should the government address the choice among technologies?
- what are the variables/factors that need to be taken into consideration for decision making?
- what is the right time to take a position on a necessary regulatory framework?

Taeihagh, Bañares-Alcántra, and Givoni (2014) developed a virtual environment for the exploration and analysis of different configurations of policy measures in order to build and assess alternative policy packages. Packages such as these and decision support systems are required to assist policy makers to develop effective policies with respect to low-carbon mobility.

Evaluation

A major concern raised throughout the workshop was the current focus on the economic side of evaluation related to low-carbon transport schemes. It was suggested in the workshop that based on economic merits alone, LCM schemes often do not perform well enough to garner support to be instituted. This opinion is also supported in current literature. Akyelken (2013) indicated that the empirical evidence from past transport projects demonstrates how the lack of sustainability elements in current project appraisal methods requires significant attention and that the application of existing assessment methods may yield misleading conclusions for future developments.

Ramjerdi and Fearnley (2014) summarised the issues associated to taking a purely economic perspective as being related to trying to distil the complexity of the transport system into relatively simple existing economic models, resulting in certain aspects being lost. Often it is the societal and environmental costs and benefits that get lost in this process.

Recent research in New Zealand has shed some new light on this topic. Wedderburn (2013) sought to provide decision makers with a robust basis for cost–benefit evaluation of measures to improve the integration of public transport with walking and cycling. His study reviewed the available international evidence on access to public transport, including analysis of trip chains from the New Zealand Household Travel Survey. This provided indications of the likely impacts of improved access on mode choice and trip generation. A major output of the study was a framework for the cost–benefit analysis of integrating public transport with walking and cycling.

Social inclusion and public health are two major benefits that could potentially outweigh the results of purely economic assessments of low-carbon transport schemes. For example, subsidies for public transport might be disputed from an economic perspective but may provide social benefits, such as social inclusion and accessibility that can outweigh the loss of revenue (Justen, Fearnley, et al., 2014). Active transportation modes such as walking and cycling are widely recognised for their zero carbon impact and the benefits associated with them with regard to public health. Many studies have investigated the impact of these transportation modes on public health (Giles-Corti & Donovan, 2002; Sallis, Frank, Saelens, & Kraft, 2004; Wen & Rissel, 2008; Woodcock et al., 2009; Hickman, 2013; Philp, Taylor, & Thompson, 2015). The task remains to find an effective way to evaluate these benefits.

Justen, Schippl, et al. (2014) found that monetizing benefits for cost–benefit analysis or establishing impact weightings for multiple criteria analysis, two methods traditionally used in the evaluation of transport schemes, can be a source of conflictive debate and prove difficult where there is a lack of empirical evidence. Lopez-Ruiz, Christidis, Demirel, and Kompil (2013) attempted to explore the impacts and effects that different urban measures may have in planning for transportation sustainability on a European-wide level. The major challenge attempted by the study was to clearly identify the common elements in each planning measure in order to develop a general scoring template that normalized scores coming from various sources.

GHG emissions are also a relevant externality in the transport sector, especially when evaluating LCM schemes. Nocera and Cavallaro (2014) found that feasibility assessments do not always take these effects into account because of the difficulty and uncertainty in reliably estimating unitary CO_2. Future research needs to consider how to establish a framework for the evaluation of low-carbon mobility plans and furthermore be able to report this in terms of carbon metrics.

Urban design and planning

The travel decisions people make have been found to be significantly associated with built environment factors such as density, location, mix of land uses, and precinct design (Hickman, 2013). Changes are starting to occur in the structure of cities, as the cities are reaching a limit to car use growth and there are shifts away from traditional urban culture and economic paradigms (Newman, Kenworthy, & Glazebrook 2013). As such there exists the potential for urban design and planning to play a major part in establishing a low-carbon transport future. This is of especial concern in the New World cities of Australasia and North America.

Many theories exist regarding the ideal layout for low-carbon cities; however, there has been found to be a huge gap between theory and practice (Hickman, 2013). The current understanding is that urban form and layout set the envelope of possibilities for travel, and residential layout and supporting facilities have a complex relationship with resident attitudes, preferences, and perceptions (Aditjandra, Mulley, & Nelson, 2013; Hickman, 2013). The compact city approach attempts to bring activities closer to residents so that they can fulfil their needs and using low-carbon options such as active travel or public transport (Aditjandra et al., 2013). The problem exists in maintaining quality of life and space in high-population-density environments and what options for built environment interventions are available where high-density living is not feasible. Aditjandra et al. (2013) found that the specific layout of towns and cities in a low-carbon world was as yet unclear.

Research is required to establish the combination of factors in urban planning that are supportive of low-carbon transport modes and the built environment interventions that are capable of achieving this in our future city structures.

Technology

Technological improvement of vehicles and the way they are operated is a direct way to reduce the carbon emissions from the transport sector. However, are these technological advances enough to negate the continued increase in the volume of vehicles on our roads? Radical technological and operational innovation is required to increase efficiency, but the improvements to carbon emissions will be generally limited to the long term because of consumer behavior, fleet turnover, physical infrastructure constraints, regulations, and long-term industry practices (Bishop, 2013).

There are two general paths future innovations may take in order to realize a low-carbon future: (1) improvements of current technology focused on meeting current travel demands in alternative ways and (2) development of new technology that can change the ways in which future users, owners, and operators behave and value transport activities.

Safety

Safety is an ongoing issue for all transportation modes. Commonly the move toward a low-carbon transportation future is visualized through zero-carbon active transport styles such as walking or cycling, or with low mass transportation modes such as e-bikes and smart car type vehicles (Martens, 2004; Tight et al., 2011; Jones & Azevedo, 2013; Jones et al., 2013; Luo, Jia, Liu, Lam, Xingang, & Gao, 2015). The safety concerns involved with these mode shifts is often involved with the interaction with traditional motor vehicles (i.e., cars, trucks, and buses), where there is traditionally high mass and high speed relative to the low-carbon alternatives (Wegman, Zhang, & Dijkstra 2012; Schepers, Hagenzieker, Methorst, Wee, & Wegman, 2014). Ideally there would exist a physical separation between these mode types; however, this is not always feasible and interactions between the traditional and low-carbon transport options will occur (Luo et al., 2015). Effective methods to maintain public safety while using low-carbon transportation options is a significant research requirement for the future of LCM and transportation in cities.

Future research priorities

As detailed earlier, the National Greenhouse Gas Inventory (DCCEE, 2012) identifies transport as a major contributor to carbon emissions in Australia, second only to electrical power generation. Further, as discussed in the introduction, the significance of private car usage in areas as the source of nearly half (45.3%) of total transport GHG emissions in Australia clearly indicates the importance of that activity in a carbon emissions reduction strategy.[2]

The shape and form of our built environment along with lifestyle choices strongly influence the use of the private car in urban areas. Newton and Newman (2013) addressed this issue in their consideration of the carbon benefits that can accrue

[2] To reiterate, urban road transport is responsible for 7.3% of Australia's total GHG emissions from all sectors as recorded in the 2010 National Greenhouse Gas Inventory, with a total transport emissions output of 39.7 Mt CO_2-e p.a.

from more compact urban forms where public and active transport modes can be of most benefit. They considered the need for urban design innovation in Australia, largely focusing on energy demands in housing and transport, and available alternative energy technologies and fuel types. The postwar suburbs (i.e., those areas of our cities first developed in the latter half of the twentieth century), which are heavily car dependent, provide the most challenges in transitioning to lower carbon cities.

Newton and Newman (2013) developed a model framework for low-carbon technology interventions in urban and suburban forms of the built environment, based around the consideration of appropriate low-carbon technologies applied to housing and transport in suburban and inner urban areas of our cities. This framework is presented in Figure 2. Given the known trade-off between housing type and location, with resulting impacts on demand for transport, which are largely met at present by the private car for suburban locations, strategies to reduce the carbon emissions of our cities need to be directed at providing substantial alternatives to that mode, based around greater use of active modes and public transport. To make this direction feasible will require in-depth consideration of built form; land use–transport interaction; land use mixes; location and intensity for services, facilities, and the supporting infrastructure; and precinct planning and design including the relationships between neighboring precincts and between precincts and major activity centers such as the central business districts.

The Newton–Newman framework identifies key differences in consideration between higher density urban regions and suburban developments. As such it provides an underlying blueprint for studies concerned with reduced carbon emissions in Australian cities, and one that is capable of extension to the New World cities more generally. In a subsequent paper Newton (2014) stressed the need for urban precinct design assessment tools and clearly defined benchmarks for low-carbon urban developments, noting that variability in housing and transport attributes of different suburbs leads to variations in carbon emissions by as much as 50% (see also Newton et al., 2012).

The significant contribution to carbon emissions by private car usage in urban areas suggests that this is an area of particular scope for carbon reductions, and that precinct planning and design, with the potential for redevelopment and reorganisation of activity–facility locations, could play a substantial role in this. A set of sensitivity tests were conducted using the data from the 2010 National Greenhouse Gas Inventory, supported with other information from Australian metropolitan travel demand (household travel survey) databases (e.g., BTS 2013), to provide some broad indications of the potential reductions in carbon emissions from some different planning initiatives.

An analysis of the 2010 National Greenhouse Gas Inventory data indicated that the average GHG emission for all travel (driver and passenger) by private car in urban Australia was 212.2 g (CO_2-e) / person-km. Taylor et al. (2010) indicated that a generic figure for per capita emissions by public transport passengers in Australian cities is 124.1 g (CO_2-e) / person-km. A 10% switch of person-km by car to public transport could therefore yield a reduction in carbon emissions of 0.78 Mt CO_2-e p.a., based on the National Greenhouse Gas Inventory analysis. A more significant impact could be achieved by a reduction in average car trip length, for instance a 10% reduction in car trip length in urban areas could yield a 2.78 Mt CO_2-e p.a. reduction—a more substantial result and one that may be easier to achieve given current travel preferences (e.g., see McCarney, 2013).

This article suggests a rich agenda for essential research on LCM. Much of this agenda falls within the realm of the integration of transport and land use, with attention to urban design details to enhance the perceptions of and opportunities to use

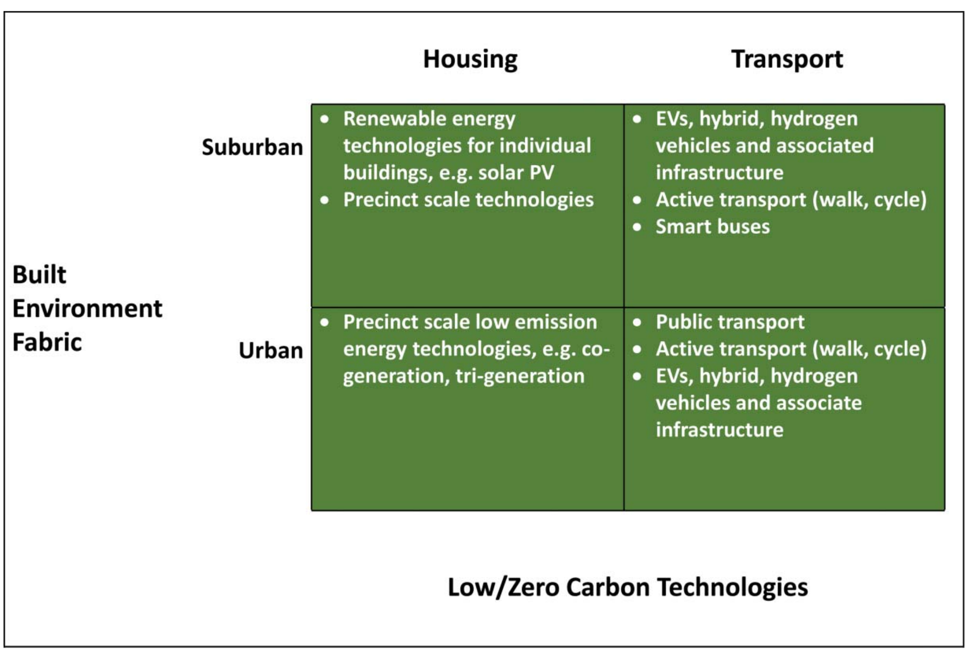

Figure 2. Newton–Newman model framework for low carbon technology interventions in urban and suburban forms of the built environment. *Source*: Newton & Newman (2013).

low-carbon transport alternatives. Research topics identified for LCM research are the following:

- urban design and land use–transport integration (LUTI)
- low-carbon mobility policies and behavior change
- opportunities for new technology and its application, including requirements for systems and infrastructure
- analytical methods and tools for informed decision making, including modeling, measurement and assessment, and visualization

The following functional areas span these research topics:

- *data*, with both availability and reliability of relevant data emerging as key concerns
- *integration*, enabling considerations of LCM in the context of infrastructure, behavior, and policy making
- *evaluation*, with the need to consider how LCM initiatives may be better considered within existing evaluation frameworks (which may often seem biased toward short-term factors) and the development of new but still rigorous evaluation frameworks
- *urban planning and design*, to seek better integration of land use and transport, through factors including intensity, location, and mix of land uses and precinct design, and considering the potential wider benefits of integration (e.g., in public health and economic productivity and well as environment)
- *technology improvement*, including the system-wide impacts and consequences of the adoption of new technology and implications for urban planning and impacts on congestion and the environment
- *safety* issues related to the wider adoption of more vulnerable transport modes (e.g., walking and cycling)

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