Development of a Prototype Co-Benefits Calculator for Low-Carbon Precinct Design

Final Report

Authors	Professor Mark Stevenson and Dr Jason Thompson
Title	Development of a prototype co-benefits calculator for low-carbon precinct design: Final Report
ISBN	
Date	
Keywords	
Publisher	
Preferred citation	

Australian Government
Department of Industry, Innovation and Science

Business
Cooperative Research Centres Programme

Acknowledgements

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

Disclaimer

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

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

Peer Review Statement

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

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

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

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

Contents

Acknowledgements 3
Contents 4
List of Figures 5
Acronyms 6
Executive Summary 7
Background 8
Methods 10
Summary, challenges and case studies 19
Case Study: Small-scale precinct assessment using the LCL-CBC 20

List of Figures

Figure 1. A deterministic model for understanding the relationship between urban land-use, transport, risk exposure and injury / disease outcomes, which helped form the conceptual basis of the LCL-CBC. 11

Figure 2. Depiction of the parcel-level approach undertaken, which captures land-use data within a radius surrounding parcel centroids. 12

Figure 3a and 3b. Depiction of the 5 identified land-use clusters across the Melbourne metropolitan region shown at macro (left panel) and medium (right panel) scale. 13

Figure 4. Manual interface of the LCL-CBC where users can input land-use data relevant to their chosen precinct as well as download results in .csv format for further analysis. 14

Figure 5. Output from the calculator web interface showing the mean performance of each identified land-use cluster across health, wellbeing, and productivity variables. 15

Figure 6. The information and data collection area for model inputs expands in an 800m buffer beyond the centroid of any land-parcel contained within the precinct under analysis. 15

Figure 7. Areas of analysis and manually coded features contained within each of the living laboratory precincts of White Gum Valley, WA, and Bowden, Tonsley, and Lochiel Park, SA. 16

Figure C1. The information and data collection area for model inputs expands in an 800m buffer beyond the centroid of any land-parcel contained within the precinct under analysis. 20

Figure C 2. Differences in access to public transport depicted across the selected areas of analysis. 20

Acronyms

CCM Compact Cities Models

DALY Disability-adjusted life year

LCL-CBC Low-Carbon Living Co-Benefits Calculator

Executive Summary

Cities across the globe are faced with combined issues associated with large-scale population growth, transportation system change, and re-configuration of urban form in the areas of housing, transport and industry. Research has demonstrated that the design of cities directly affects population health and is also positively associated with levels of population productivity. Based on this evidence, the current project developed and trialled a prototype low-carbon precinct co-benefits calculator (LCL-CBC). The calculator was developed to be used by planners and developers across both public and private sectors with the purpose of better understanding how health and productivity co-benefits could be integrated into low-carbon urban precinct designs.

Background

It is estimated that by 2050, 70% of the world's population will live in cities. This is a drastic increase from 51% in 2007(United Nations, 2014). Population growth estimates predict that the world's inhabitants will increase by 66% from 7 billion people in 2013 to 10.5 billion people over the next 40 years. As a consequence, cities, globally, are now being forced to deal with challenges associated with rapid urbanisation. In addition, cities are increasingly recognising their role, not just as centres of economic productivity but as facilitators of population (ill) health.

An important factor in enhancing urban sustainability is the urgency to reduce the incidence, prevalence and costs associated with chronic illness and injury; the design of cities and related infrastructure plays a significant role in achieving this (Bai, Nath, Capon, Hasan, & Jaron, 2012). The World Health Organization (2017) recognises that the health of populations is directly associated with urban design. Moreover, governments are become increasingly aware of the effects of land use on transport plans and population health (Council of Australian Governments, 2011; McCormick, Anderberg, Coenen, & Neij, 2013).

It is well documented (Stevenson et al, 2016, Thompson et al 2019) that the absence of public transport infrastructure leads to an over-reliance on private motor vehicle transport. Low -diversity in land use also restricts public and active transport alternatives and increases both travel time and distances to places of work, recreation, family, shopping and other core activities (Currie & Senbergs, 2007; Trubka, Newman, & Bilsborough, 2010). In turn, this increases exposure to health risks associated with vehicle use, including traffic speed and volume, vehicle pollution and physical inactivity (British Medical Association, 2012; Solatani & Primerano, 2005) which translates into increased rates of road injury and death (Stevenson, Jamrozik, & Spittle, 1995), as well as chronic health conditions such as cardiovascular disease (Borrell, Roux, Rose, Catellier, & Clark, 2004), respiratory illness (Jackson, 1988), and obesity (R. Ewing, Meakins, Hamidi, & Nelson, 2014) together with its related conditions such as diabetes (Frank et al., 2006; Li et al., 2008; Lopez, 2004).

Based on the above causal links, a Low-Carbon Living Co-Benefits Calculator was proposed hereafter referred to as the LCL-CBC Project. The objective of the LCL-CBC Project was to create a tool that could assist planners and developers across both the public and private sectors to understand and promote co-benefits namely health and productivity co-benefits associated with low-carbon urban precinct design.

The tool was not designed as a guideline for low-carbon design – this was left to other experts. Instead, it focused on potential co-benefits of low-carbon urban design across:

- General health
- Physical health
- Social capital, connection and cohesion
- Uptake of active transport, including walking and cycling
- Access to public transport
- Access to education
- Access to community facilities and services
- Mental health
- Road safety, including road trauma associated with car, pedestrian and cycling injuries
- Productivity and time lost in unproductive transport (e.g., driving)
- Health behaviour, including incidental exercise and food consumption

The project used existing datasets available for Victoria, Australia to create a prototype model for examining the relationship between urban design and population health outcomes.

It was produced in a web-based, interactive form. Combined with comprehensive, interactive, web-based background information, it enabled users to compare and estimate potential co-benefits associated with a range of alternative precinct designs.

This report describes the outcomes from the Low Carbon Living CRC trial. It describes the development of the tool, itself, and some of the challenges faced in its development, construction and deployment.

Explainer:

The impact of land-use is consequential for the way individuals and populations move around a city or urban environment. Higher density land-use, smaller distances between households and services, as well as greater land-use diversity reduces the requirement for private vehicle (car) transport. When distances are smaller, people are more likely and able to walk, ride, or take public transport to reach desired destinations.

Similarly, proximity to train stations enables people who need to travel longer distances to do so via rail rather than by private car. The way land is allocated and used, therefore greatly affects the way in which people choose, or are arguably forced (Currie & Senbergs, 2007), to move around the city. This influence on movement patterns has implications for risk exposures (e.g., road trauma & pollution), as well as individual transport costs, and the productivity and efficiency of the transport system as a whole.

Methods

Many studies (e.g., Reid Ewing & Cervero, 2010; R. Ewing et al., 2014; Giles-Corti et al., 2005; Stevenson et al., 2016) have highlighted the relationship between urban design and health that emphasise selected urban features (e.g., block size, access to amenity, access to urban green space, etc.) as important in determining exposure to health risks and consequent health outcomes. In this project, a broad approach was taken whereby we observed an extensive range of urban features available within datasets accessible via the Australian Urban Research Infrastructure Network (AURIN) and then assessed their relationship to a similarly broad range of health and productivity outcomes available from the Victorian Government's Local Government Health and Wellbeing Survey.

Selection of modelling approach

There were two modelling approaches considered for the project: 1) Linear, 'deterministic' model, and 2) non-linear 'dynamic' models.

Deterministic models tend to produce identical outputs for trials with the same input conditions. The benefits of deterministic models include simplicity, transparency, communication, and speed. However, deterministic models are also associated with various shortcomings such as over-simplification of reality and the inability to capture real-world issues such as transitions of inputs and outputs over time and more complex feedback mechanisms related to the presence of urban features (e.g., induced traffic demand produced by building road networks). Examples of linear, deterministic models include mathematical models such as regression equations that enable consideration of relationships in terms of 'dose-response' associations (e.g., 30% more bus-stops will result in 20% more bus patronage and 10% fewer cars used).

By contrast, dynamic modelling procedures can add dimensions of order, path dependency, timing and transition dynamics within urban systems, providing greater insight into the mechanisms of change under certain scenarios. Examples of dynamic models include agent-based models (ABMs) and System Dynamic Models (SDMs). In most cases, dynamic models are live and interactive, contain realistic representations and elements of probability, individual decision-making, and feedback. The complex interdependencies present within dynamic models also lead to challenges in model design, definition, interpretation, predictability, computational resources, time-scales, and uncertainty regarding the mechanisms driving model outputs. Together, this makes them challenging for clear presentation and communication to policy-makers without significant ongoing administrative support that guides people through their use and application.

In the early stages of tool development, we applied both agent-based and system dynamic modelling approaches to the data. However, this modelling approach was found not to be amenable, in the short-term, to developing a calculator so we applied a deterministic modelling approach on the basis that communication of the relationships between urban design and health parameters rather than exploration of mechanisms were most important for the project.

Model description

The basis for the LCL-CBC was an adaptation of the compact cities and health model developed by Stevenson et al (2016),.The compact city model, which formed part of the Lancet Series on Urban Design and Health, was both a conceptual and operational model developed to estimate the health benefits associated with macro-scale urban design, social and policy changes. The model (shown in Figure 1) incorporates four main land-use elements – density, diversity, distance and design – to demonstrate the relationship between urban-land use, transport, risk exposures and injury/disease outcomes.

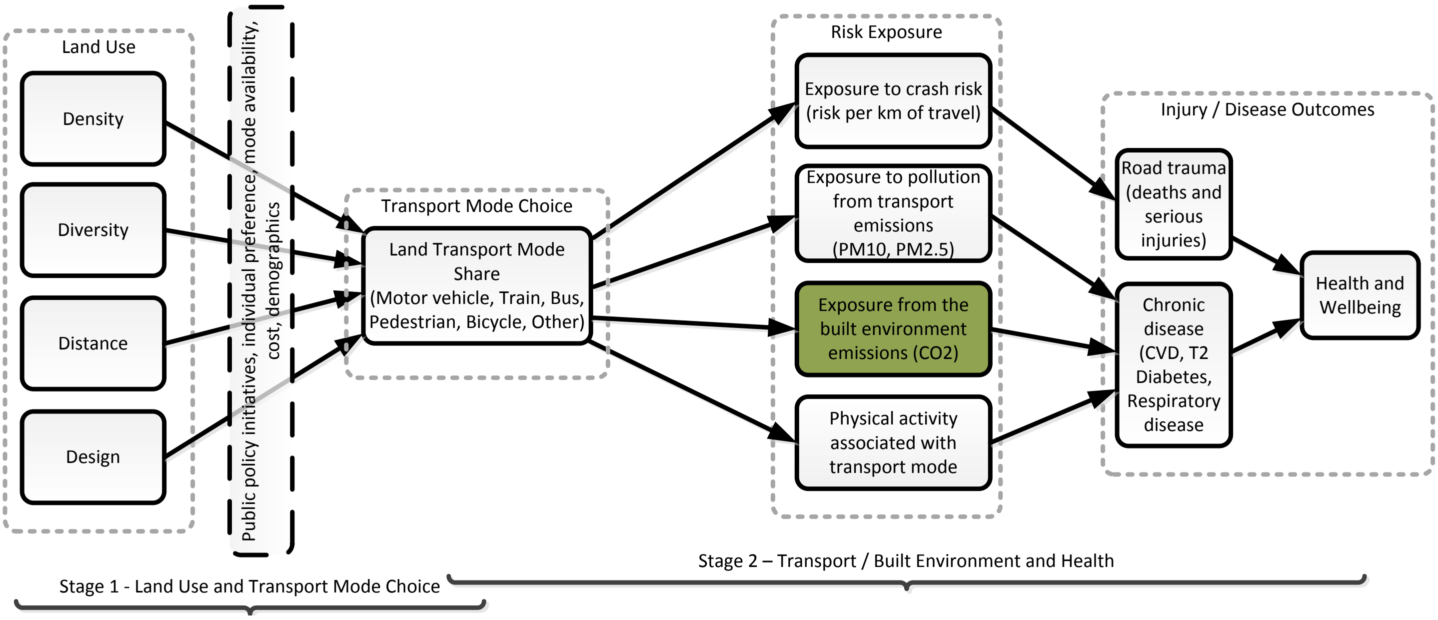


Figure 1. A deterministic model for understanding the relationship between urban land-use, transport, risk exposure and injury / disease outcomes, which helped form the conceptual basis of the LCL-CBC.

Data sources

The data for this project was gathered via two existing and publicly available sources: 1) the PSMA (https://www.psma.com.au/) urban features dataset for the Melbourne Metropolitan Area, obtained from the Australian Urban Research and Infrastructure Network (AURIN), and 2) the Department of Health and Human Services Victorian Population Health Survey – a de-identified, population-weighted dataset containing health, geographic and demographic information for approximately 30,000 people.

The overall analysis for the study consisted of four stages aimed at determining the influences of the various changes in urban form on health and productivity.

Analysis

The basic premise of the LCL-CBC is that individual and population health and well-being are influenced by the urban environment. The proximity of individuals to urban design features such as public transport, roadways, recreational facilities, schools, shops, workplaces and other services influences people's day-to-day behaviour and exposure to risk and illness.

Characteristics of the urban environment are commonly referred to as land-use elements. There are up to 10 land-use elements with 3 of the most reported and influential land-use elements, namely; Density, Distance, and Diversity represented in the calculator. Density represents the population and/or dwelling density of a given area, distance represents the proximity of dwellings or precincts from services or features of the urban environment (e.g., schools, shops, transport stops) and diversity represents the number of land-uses for a given area for example, an area with low levels of diversity may be one that is 'only' used for residential housing or perhaps 'only' used as an industrial site (as described previously). High levels of diversity may reflect areas where housing, commercial buildings, industry and community facilities are intermingled. These land-use elements are noted in the left-hand column of Figure 1, alongside 'Design', which refers to particular accommodation made for safe, low emission active transport (e.g., separated bicycle infrastructure that encourages cycling, footpaths, etc.).

It is important to note that there is a level of interdependency between the land-use elements measured and incorporated in the calculator. For example, areas of high land-use diversity are also likely to have smaller distances between households and essential services. Similarly, areas of high density may incorporate great diversity of land-use within a smaller area.

The following approach captured the variation in land-use across metropolitan Melbourne. The basis for calculation occurred at the point of household land-parcels. Firstly, a 400-800m radius around the centre of 1.2 million individual land parcels was drawn that captured land use and feature data within the catchment of that parcel. Captured counts of features drawn from the PSMA database were then associated with each land parcel, describing its characteristics across;

- Population Density
- Household Density
- Public transport stops (trains, trams and bus-stops)
- Educational Facilities
- Community Health Facilities
- Sporting and Recreational Grounds
- Commercial Premises
- Industrial Premises
- Number of Intersections
- Government and Public Service Buildings
- Community Care Facilities
- Hospitals
- Cultural Facilities, and
- Number of different land-uses in catchment

Counts of characteristics above were used rather than gravity measures (although these were calculated) because; i) results obtained through both techniques were qualitatively similar, and ii) counts were deemed to be simpler for subsequent users of the tool to incorporate into their own analyses.

Figure 2, provides a diagrammatic representation of the way in which the LCL-CBC measured and analysed variation in land-use across the Melbourne metropolitan area, which formed the test-bed of the tool. These characteristics formed a set of precinct independent variables that were used to estimate health and productivity outcomes in the area of interest.

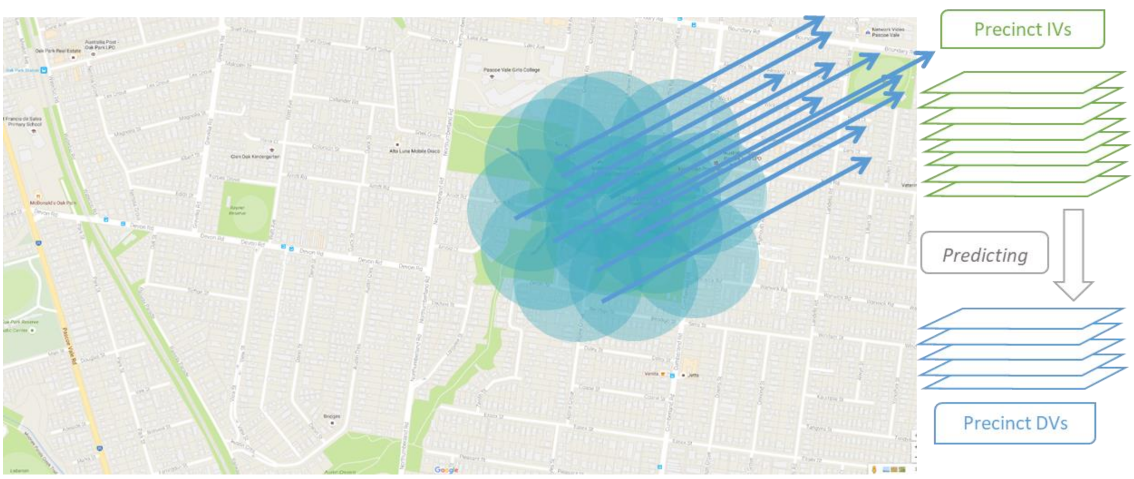


Figure 2. Depiction of the parcel-level approach undertaken, which captures land-use data within a radius surrounding parcel centroids.

The collection of these variables also demonstrated that, taken together, the way in which land was used and allocated across the Melbourne metropolitan region showed patterns that could be defined across 5 main land-use types. As demonstrated in Figure 3a and 3b, these areas were:

1. High Density Inner City (green)
2. Inner Urban (blue)
3. Connected Pockets (orange)
4. Middle Suburbia (red), and
5. Urban Fringe (pink)

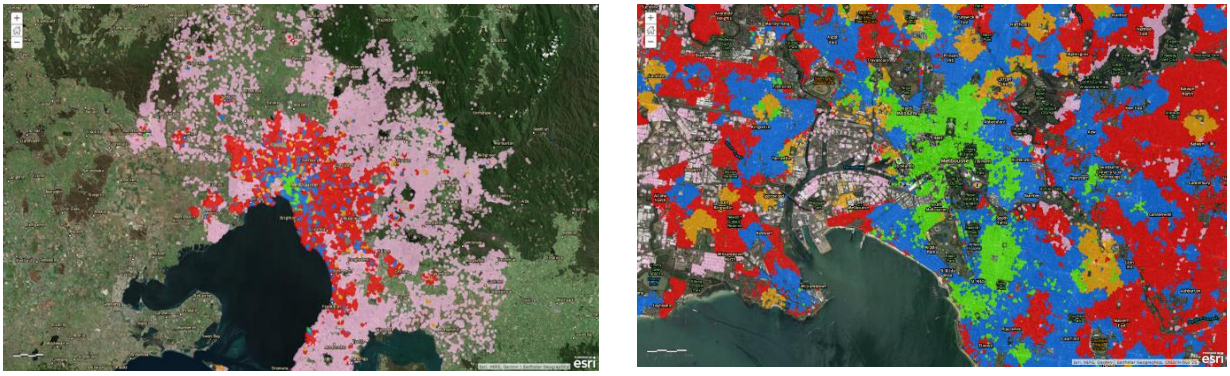


Figure 3a and 3b. Depiction of the 5 identified land-use clusters across the Melbourne metropolitan region shown at macro (left panel) and medium (right panel) scale.

The health and productivity outcomes (assessed using data from the Victorian Department of Health and Human Services, Victorian Public Health Survey). provided information relating to individual health of a sample of 30,000 Victorians along with their health behaviour across items of relevance including;

- Height
- Weight
- Body Mass Index
- Smoking status
- Transport behaviours (public transport, driving, walking & cycling)
- Social capital
- Self-rated physical health
- Psychological health
- Perceptions of trust and social cohesion
- General life satisfaction
- Feeling safe after dark
- Education and income status

From here, we developed a set of linear regression equations that could be used to estimate the health and wellbeing of all 1.2 million measured land-parcels across Melbourne. Linking both the land-use characteristics and health characteristics, while controlling for demographic characteristics of education and income, enabled us to then isolate risk exposure and health factors that were associated with the location in which individuals lived.

With the unique data and set of equations, the LCL-CBC tool was developed such that planners and developers could assess and compare either existing, or proposed developments, and their potential impact on health, wellbeing and productivity. The type of data used to create the LCL-CBC is a combination of parcel-level, geo-coded land-use data, combined with an overlay of health and wellbeing data. It is the combination of these two data sources that enables the creation of regression equations that can go on to estimate the likely effects of precinct design on health for a given population or community.

Scope of Application

The questions that the LCL-CBC can address relate to specific health and productivity benefits associated with precinct development decisions; decisions such as:

- Where should a precinct be located?
- Proximity to what land-use features influence health?
- Development or inclusion of which features will be beneficial to the community that resides there?
- What is the health and productivity performance of a given area?
- How does the performance of a proposed development precinct compare with another?

The tool is most useful at the precinct level that includes at least 30 households. It is not suitable for areas smaller than this because individual behaviour is subject to too much variability to model at the individual scale.

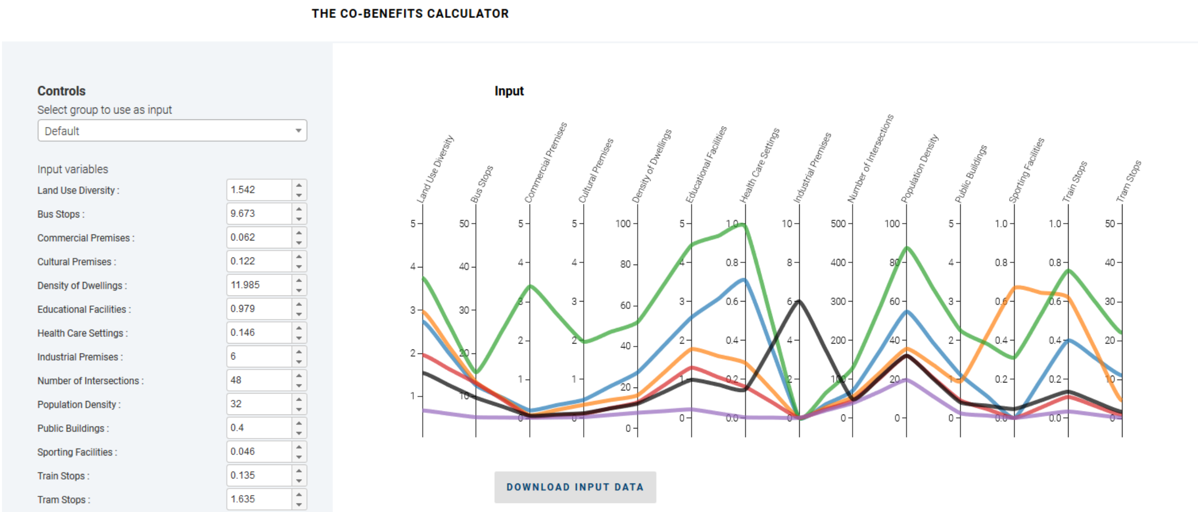


Figure 4. Manual interface of the LCL-CBC where users can input land-use data relevant to their chosen precinct as well as download results in .csv format for further analysis.

Beyond Victoria, the data required for the LCL CBC is limited. Consequently, the broad-scale analysis of entire metropolitan regions in other cities is currently not possible.

Instead, assessment of individual locations relied on a combination of datasets that either were available (i.e., much of the transportation infrastructure information relating to the location of train and bus stops, etc., is available across states), as well as either input gathered on the ground, or through alternative open-source information (e.g., Google Maps, Open Street Maps, Near Maps, etc.).

Once collected in these alternative manners, the LCL-CBC enables a user to enter this data into a web interface and assess raw or comparative results between precincts. Model input data can be entered into the calculator and downloaded from a web interface as shown in Figures 4 and 5.

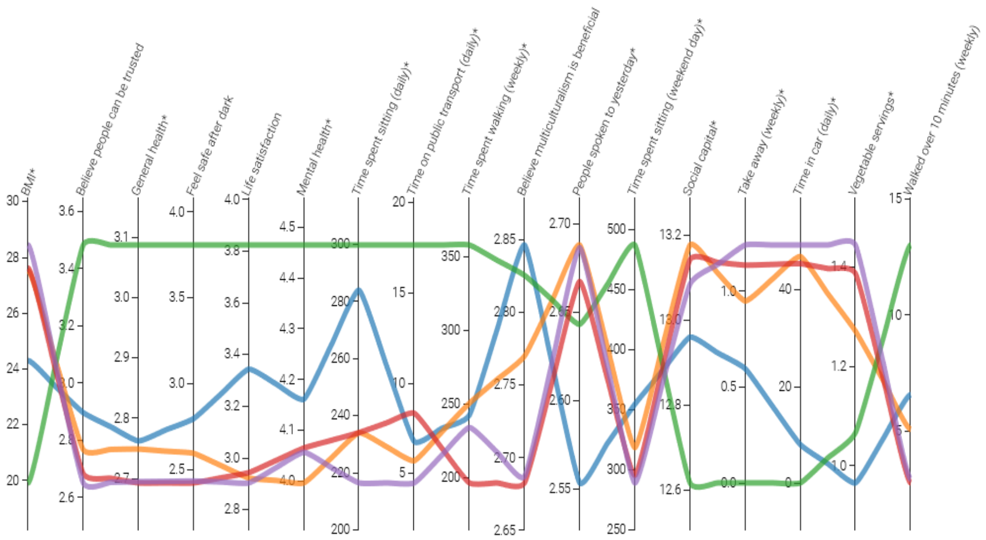


Figure 5. Output from the calculator web interface showing the mean performance of each identified land-use cluster across health, wellbeing, and productivity variables.

Application outside of Melbourne

Figure 6 shows the scale of analysis of the Lochiel Park Living Laboratory precinct in Adelaide. Observable in the figure is that analysis not only needs to consider the 15HA area containing the precinct's approximately 100 residences, but an additional 800m buffer zone around the precinct. This buffer area appreciates that people do not live solely within their own precinct but that the characteristics and quality of areas surrounding a development are also influential in relation to health, behavioural and productivity outcomes.

Despite the ability of the tool to effectively and efficiently estimate the potential health-effects of urban form in the context of Melbourne, utilising the tool in novel domains is currently challenging. This, in part, is because the dataset used to create the estimates and relationships in the Melbourne example are not consistently collected or available elsewhere. This limitation also applies when the calculator is applied to the remainder of the CRC's living laboratory locations of Fremantle, WA, and Lochiel Park, Tonsley, and Bowden in South Australia.

Figure 6. The information and data collection area for model inputs expands in an 800m buffer beyond the centroid of any land-parcel contained within the precinct under analysis.

Due to the above limitation, we sent researchers to travel to each of the 4 living laboratories in Fremantle and Adelaide and manually record land-use and urban feature data using a custom-designed app. Data was gathered from one precinct in Fremantle: White Gum Valley and three precincts in South Australia: Bowden, Tonsley, and Lochiel Park (shown in this order, in Figure 7, below). Each precinct was surrounded by an 800m buffer within which urban features were recorded. The labels for different land types were obtained through the PSMA *Features of Interest* documentation. The buffer areas for each Living Laboratory alongside recorded location of features are shown in Figure ?

Following this, the collected data was compared against the data from the PSMA data sets. It was discovered that the data collected on the ground in Fremantle and Adelaide was far more detailed than that available through PSMA and could therefore only be used for comparisons between areas, rather than for direct calculations of potential health effects or comparisons with Melbourne data.

On this basis, however, the area of Bowden was considered to provide the greatest comparative benefits to health, closely followed by Tonsley. Due to their distance from amenities, single land-use configurations, and lower comparative population and housing densities, both Lochiel Park and White Gum Valley were estimated to be less conducive to positive health and productivity outcomes, despite their green building credentials.

Figure 7. Areas of analysis and manually coded features contained within each of the living laboratory precincts of White Gum Valley, WA, and Bowden, Tonsley, and Lochiel Park, SA.

Interactive Map Interface

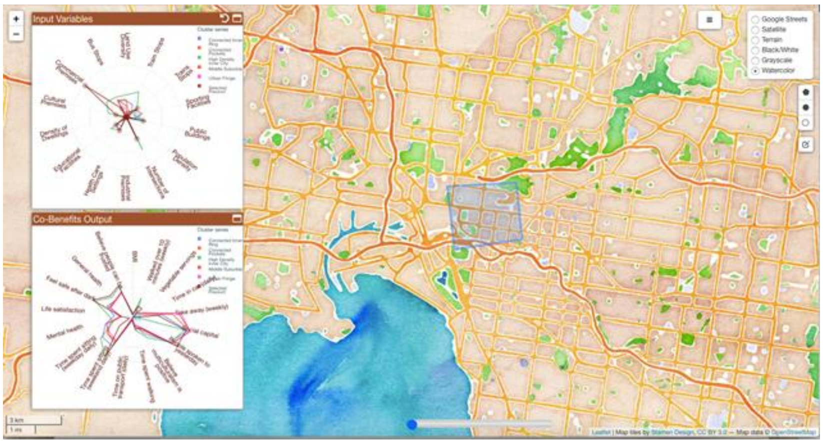
The Low-Carbon Living Co-benefits Calculator interface is web-based and built upon a combination of both ArcGIS Online and custom-built servers. An extensive introduction, background and 'explainer' to the project for users is available here: http://arcg.is/0bP9X4 .This website has been visited over 4000 times since its development in 2017 and is connected to another website established under the project exploring major crash locations for active transport in Victoria and its relationship to urban form, here: http://arcg.is/1evGrD . This website has been viewed over 2500 times since 2017.

> The tool for manually entering land-use data and estimating health impacts is located here:
>
> https://thud.msd.unimelb.edu.au/tools-and-models/co-benefits-calculator
>
> The interactive drawing tool for estimating health impacts for the Melbourne metropolitan area is here:
>
> https://www.crcprecintanalyser.com.au/

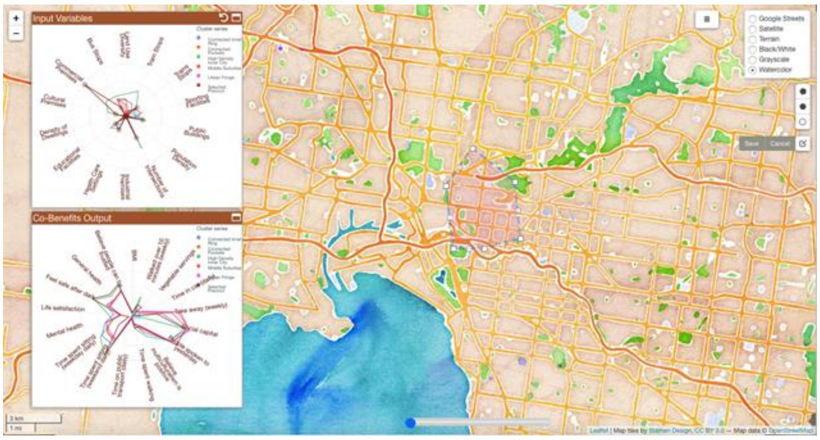
Table 1. A step-by step guide to using the LCL-CBC.

A step-by-step demonstration of the Melbourne metropolitan tool can be seen in the following sequence of figures.	
Step 1. Navigate to the LCL-CBC web page **crcprecintanalyser.com.au**	

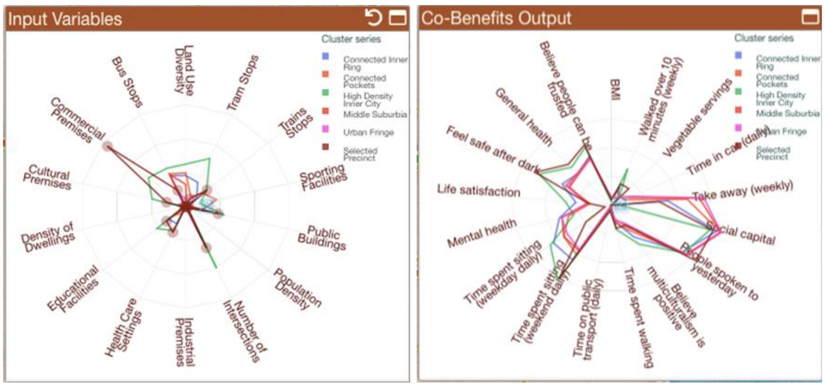
Step 2. Identify and draw the polygon or area of interest or upload your own shapefile.



Step 3. Adjust, move or fine-tune the area of interest.



Step 4. Observe and download both the input and output variables for your polygon or area. Compare the qualities of your selected area to the 5 urban typologies discovered by the low carbon living co-benefits calculator project



Summary, challenges and case studies

This project accessed unique data and utilised a variety of approaches and techniques from public health and geographic information sciences into a single interface tool. As well as producing a series of highly detailed maps and interactive resources that have been accessed thousands of times by the public and professionals, alike. The LCL-CBC provides potential users with a host of alternative avenues for promoting the benefits of low-carbon precinct design that go beyond carbon, itself.

The interactive nature of the interface developed here is a departure from previous guidelines that have adopted a more manual and static 'tick-box' style using .pdf forms, etc. In this way, the developed LCL-CBC is a user-centred tool that delivers on a need for a valid, acceptable, and viable tool (Rouse, 2015). By 'valid', we intend the tool to accurately reflect and provide solutions for the purpose it was intended. By 'acceptable', we mean that it solves these problems in a manner that users easily understand and embrace. By 'viable', we intend that the cognitive and financial costs of learning and using the tool are low, thereby facilitating its uptake.

Challenges

There were two challenges in developing and deploying the LCL-CBC. The first, described above, was to find a modelling mechanism and interface that was sufficiently broad in nature, but also valid and easy to understand and communicate that it could be deployed in the manner described here. Given these constraints, we believe that this has been achieved.

The second was to engage industry partners in an analysis of current precinct developments. Despite our best efforts, no commercial projects were willing to have their projects 'officially' assessed under the banner of the project.

Dissemination

The tool is readily available on a number of web-sites that have been accessed thousands of times by users. The datasets developed as part of the project have also made their way into numerous other research efforts and publications currently underway linking urban form and health. The tool has attracted the interest of organisers of the of the capacity building workshop "Integrating Health into Urban Planning towards Sustainable Development Goals in Developing Countries" (https://japan-asean.cseas.kyoto-u.ac.jp/2017-workshop/) which is funded by the Asia-Pacific Network for Global Change (http://www.apn-gcr.org/). Here, we will be presenting the LCL-CBC to an international audience keen to hear about its development and how they can use similar processes in their own context.

Case Study: Small-scale precinct assessment using the LCL-CBC

This case study examines differences in expected co-benefits of a proposed small-scale redevelopment of approximately 4000m² proposed for a location equal distance from the central business district (~13 km) but located on either side of a major Melbourne arterial road, the Monash Freeway. These two nearby locations were chosen to demonstrate the potentially large impacts small distances between locations of proposed re-development precincts can have on the way people use and interact with the precinct. A surface analysis of the two areas exhibited comparable characteristics of equal distance from the CBD, medium-density housing, similar distances to the freeway and grid-based roads. The two proposed precincts for analysis are shown in Figure 11.

Figure C1. The information and data collection area for model inputs expands in an 800m buffer beyond the centroid of any land-parcel contained within the precinct under analysis.

However, the outputs of the LCL-CBC demonstrated that the land-use characteristics of these areas were in fact very different. The analysis showed that Area 1 fell into the 'Connected pockets', or 'Inner Urban' cluster as described in the sections, above. Conversely, Area 2 showed better access to public transport, commercial buildings, public facilities, educational facilities, and other local services that were not present in Area 1 (See Figure C2).

Figure C 2. Differences in access to public transport depicted across the selected areas of analysis.

Despite their close proximity and equal distance to the CBD, the differences between the two areas in urban form highlighted that residents of a regenerated Area 1 were more likely than residents of Area 2 to:

- Drive an average of around 84 minutes less per person per week, improving productivity, and reducing vehicle pollution
- Walk for an average of 80 minutes per person per week more
- Walk for more than 10 minutes at a time on 3 or more occasions per week
- Spend around 140 minutes less time sitting per person per week

References

Bai, X., Nath, I., Capon, A., Hasan, N., & Jaron, D. (2012). Health and wellbeing in the changing urban environment: complex challenges, scientific responses, and the way forward. *Current Opinion in Environmental Sustainability, 4*(4), 465-472.

Borrell, L. N., Roux, A. V. D., Rose, K., Catellier, D., & Clark, B. L. (2004). Neighbourhood characteristics and mortality in the atherosclerosis risk in communities study. *International Journal of Epidemiology, 33*(2), 398-407. doi:Doi 10.1093/Ije/Dyh063

British Medical Association. (2012). Healthy transport equals healthy lives.

Council of Australian Governments. (2011). *Review of capital city strategic planning systems*.

Currie, G., & Senbergs, Z. (2007). *Exploring forced car ownership in metropolitan Melbourne.* Paper presented at the 30th Australasian Transport Research Forum.

Ewing, R., & Cervero, R. (2010). Travel and the Built Environment. *Journal of the American Planning Association, 76*(3), 265-294. doi:10.1080/01944361003766766

Ewing, R., Meakins, G., Hamidi, S., & Nelson, A. C. (2014). Relationship between urban sprawl and physical activity, obesity, and morbidity - Update and refinement. *Health & Place, 26*, 118-126. doi:10.1016/j.healthplace.2013.12.008

Frank, L. D., Sallis, J. F., Conway, T. L., Chapman, J. E., Saelens, B. E., & Bachman, W. (2006). Many pathways from land use to health: associations between neighborhood walkability and active transportation, body mass index, and air quality. *Journal of the American Planning Association, 72*(1), 75-87.

Giles-Corti, B., Broomhall, M. H., Knuiman, M., Collins, C., Douglas, K., Ng, K., . . . Donovan, R. J. (2005). Increasing walking: How important is distance to, attractiveness, and size of public open space? *American Journal of Preventive Medicine, 28*(2, Supplement 2), 169-176. doi:http://dx.doi.org/10.1016/j.amepre.2004.10.018

Jackson, G. P. (1988). Asthma Mortality by Neighborhood of Domicile. *New Zealand Medical Journal, 101*(854), 593-595.

Li, F., Harmer, P. A., Cardinal, B. J., Bosworth, M., Acock, A., Johnson-Shelton, D., & Moore, J. M. (2008). Built environment, adiposity, and physical activity in adults aged 50–75. *American Journal of Preventive Medicine, 35*(1), 38-46.

Lopez, R. (2004). Urban sprawl and risk for being overweight or obese. *American Journal of Public Health, 94*(9), 1574-1579.

McCormick, K., Anderberg, S., Coenen, L., & Neij, L. (2013). Advancing sustainable urban transformation. *Journal of Cleaner Production, 50*, 1-11. doi:http://dx.doi.org/10.1016/j.jclepro.2013.01.003

Rouse, W. B. (2015). *Modeling and visualization of complex systems and enterprises: Explorations of physical, human, economic, and social phenomena*: John Wiley & Sons.

Solatani, A., & Primerano, F. (2005). *The travel effects of community design*. Paper presented at the Australasian Transport Research Forum.

Stevenson, M., Jamrozik, K., & Spittle, J. (1995). A Case-Control Study of Traffic Risk-Factors and Child Pedestrian Injury. *International Journal of Epidemiology, 24*(5), 957—964. doi:Doi 10.1093/Ije/24.5.957

Stevenson, M., Thompson, J., de Sa, T. H., Ewing, R., Mohan, D., McClure, R., . . . Woodcock, J. (2016). Land use, transport, and population health: estimating the health benefits of compact cities. *Lancet, 388*(10062), 2925-2935. doi:10.1016/S0140-6736(16)30067-8

Trubka, R., Newman, P., & Bilsborough, D. (2010). The costs of urban sprawl: physical activity links to healthcare costs and productivity. *Environment Design Guide, 85*, 1-13.

United Nations, D. o. E. a. S. A. (2014). *World urbanization prospects. 2014 revision, Highlights.* (9211514932). Retrieved from New York:

World Health Organization. (2017). Noncommunicable diseases: progress monitor 2017.