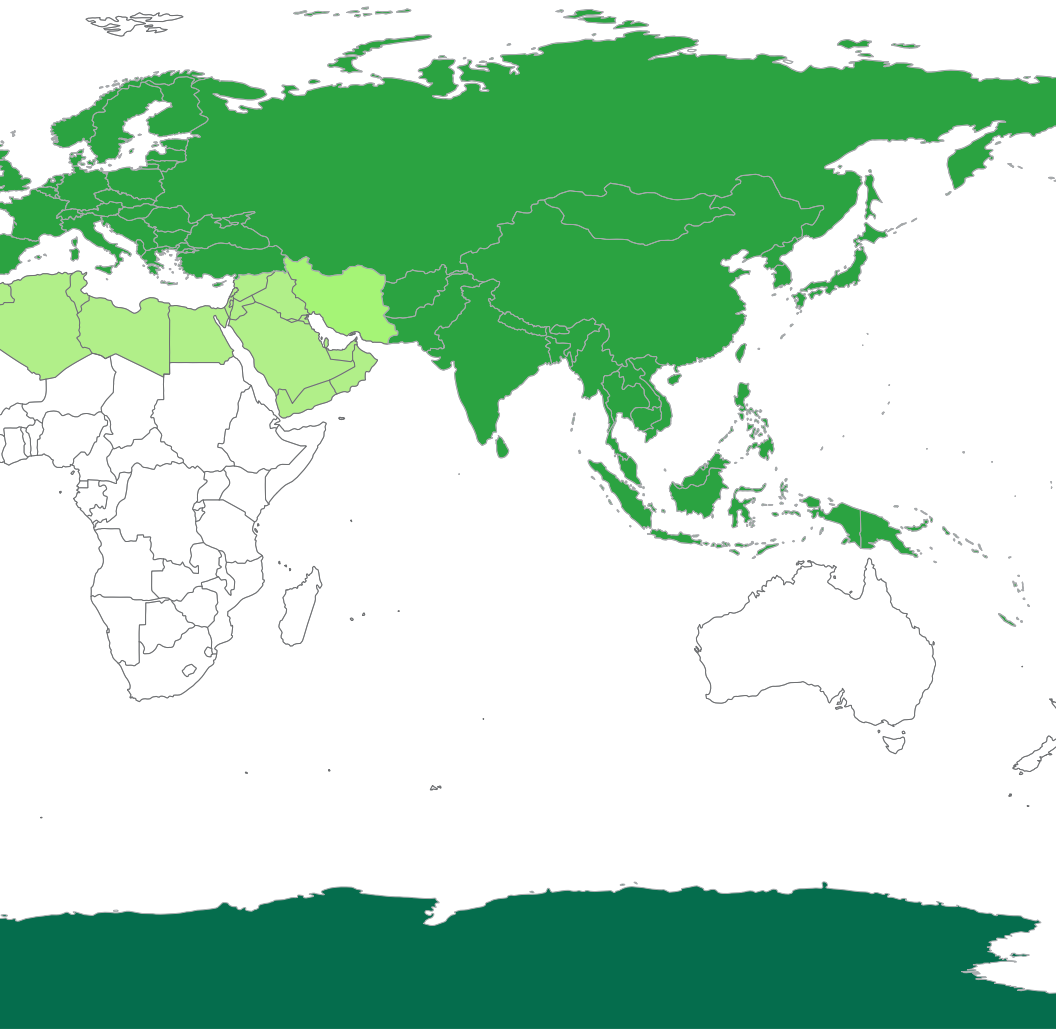


SUSTAINABLE TRANSPORTATION

AN INTERNATIONAL PERSPECTIVE



A NOTE OF THANKS Editorship is an adventurous journey. I learned a lot and enjoyed it – and it could not have been possible without my mentors and supporters. First, I would like to thank Larry Vale, my faculty advisor, for his support, his guidance and practical advice throughout the process of bringing this *Projections* volume to life. I am also grateful to Ezra Glenn for pushing forward this volume and the journal's future.

I would like to thank the authors, who contributed through their knowledge to this volume, iterated patiently through several revisions, and showed tremendous passion for their fields of expertise. I also would like to thank the editors for giving advice that improved this *Projections* volume significantly.

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- EVA KASSENS, 2009

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SUSTAINABLE TRANSPORTATION

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COVER IMAGE Map courtesy of Eva Kassens; data courtesy of World Resources Institute, 2005. This map shows CO₂ emissions by transport as a percentage of emissions. The more grey the continent, the higher the CO₂ transport emissions in relation to total emission of that continent; the more green the continent, the lower the CO₂ transport emissions in relation to total emission of that continent.

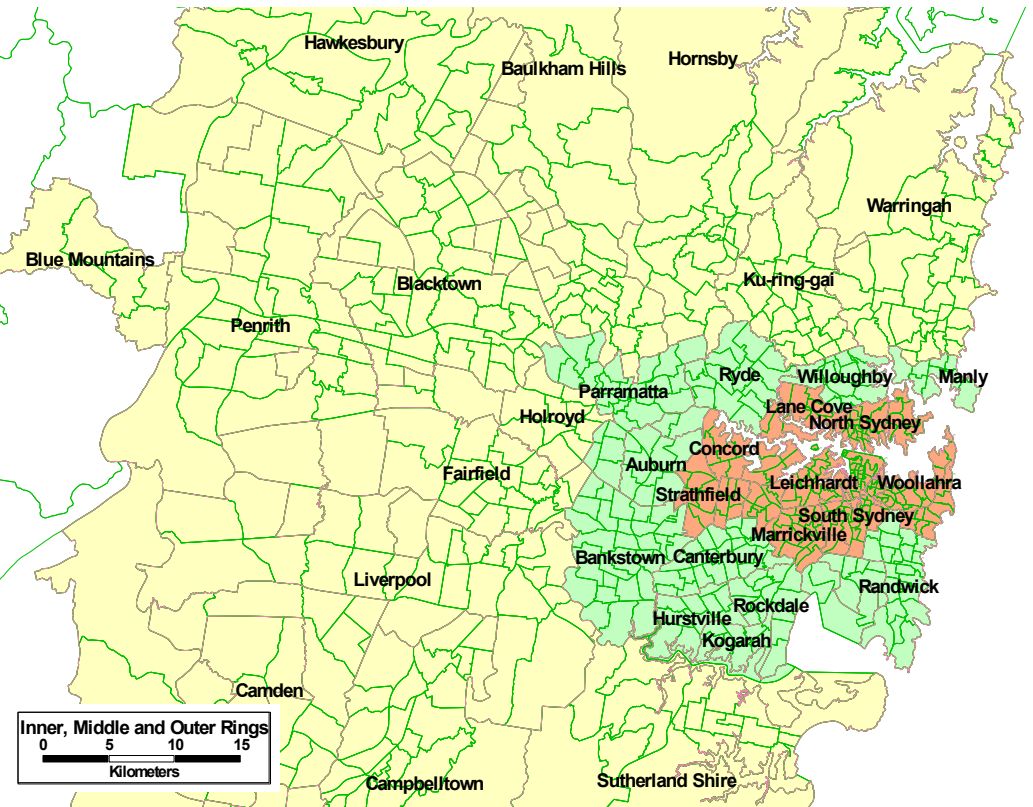
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Dr. Ken Doust
Professor John Black

A HOLISTIC ASSESSMENT FRAMEWORK FOR URBAN DEVELOPMENT AND TRANSPORTATION WITH INNOVATIVE TRIPLE BOTTOM LINE SUSTAINABILITY METRICS



ABSTRACT

An urban sustainability framework is proposed for the strategic planning and assessment of the location of land-use activities and transportation facilities that incorporates the three pillars of sustainability: environmental stewardship, social equity and economic efficiency. Part of this framework is illustrated with the interactions amongst urban housing markets, labor markets and transportation linkages, in particular automobile travel and greenhouse gas emissions. The framework is applied to a case study of metropolitan Sydney using census data for a twenty-year period, and the results are used to assess the effectiveness of post-war strategic planning in metropolitan Sydney.

INTRODUCTION

In Australia, when an Inter-Governmental (Federal, State and Local) Agreement was reached on ecologically sustainable development (ESD) in 1992, it was agreed that economic, social and environmental matters must be considered in any major development proposal. This includes assessment by the determining authority as part of the approval process. At the macro level, the periodic State of the Environment Reports provide quantitative evidence of the change of key indicators over time. In NSW, the latest is the *NSW State of the Environment Report, 2006*¹. However, for transport infrastructure development and for metropolitan land-use and transport planning in Australia, there is still a need for quantitative indicators of sustainable development (Hutabarat, et al., 1998), as argued by Hidas and Black (2001) and Holliday (2008).

Building on previous methodologies, this paper reports on a holistic assessment methodology with practical outcomes:

- identify the system elements and interactions that determine the sustainability performance of the city (what to measure);
- formulate measures which are objective and traceable (how to measure);
- formulate methods of assessing mutual performance of the three pillars of sustainability in a manner that engages community and decision makers (how to assess).

The elements and interactions of importance for urban sustainability assessment are identified through a new framework - the "urban sustainability framework". The explanation of original metrics to quantify the three pillars of sustainability – economic, social and environmental – is the contribution of this paper.

The metrics are based on:

- accessibility to employment (social spatial equity)²;
- accessibility to labor markets (economic efficiency)³;
- greenhouse gas emissions from car trips (environmental load)⁴.

Authentic journey-to-work travel data and environmental data for the period of 1981 to 2001 (the latest data at the time of the research, although recently the 2006 data has been released) in the Sydney metropolitan region are used to demonstrate the practical utility of the metrics. Interpretation of the results offers evidence on whether or not successive, post-war planning policies have met their spatial equity and environmental improvement objectives.

URBAN SUSTAINABILITY FRAMEWORK

A key to urban sustainability is that the three pillars of sustainability - environmental stewardship, social equity and economic efficiency are interdependent and need to be mutually reinforcing (United Nations, 2002). Good sustainability in this context requires all three pillars to have complementary rather than competing outcomes. Urban form, transportation and interactions with communities, are the central drivers of sustainability in cities. Understanding of interactions between urban form, transportation and community is essential to meaningful interpretation

of sustainability performance in terms of the three pillars of sustainability. A challenge for researchers is to develop methodologies that are not only objective but can also be easily understood, and meaningfully used by the community and governments.

An Urban Sustainability Framework is proposed in Figure 1 as a means of making visible the elements that drive the transport related urban sustainability outcomes. The “Urban System” is the physical aspect of the framework, consisting of the “Urban Form” and “Transport” elements which define the structural configuration of the city. Interaction between these two elements shows their interdependencies. “Urban Form” is characterised by density and spatial distribution of land-use. “Transport” on the other hand is characterised by the transport network spatial layout and the specific mode characteristics.

The system function is to provide for the needs of the community (including industry). Response of the community to the “Urban System” produces interactions that result in selection of location of residence and workplace, industry and trips and so on. These interactions are collectively known as “Urban Dynamics”. It is an iterative process as indicated by the circular arrow having feedback effect between each element. The resulting “Urban Dynamics” outcomes generate the sustainability performance in terms of the three pillars included as elements in Figure 1. Each pillar has a feedback to the “Urban Dynamics” and consequently the “Urban System”. This is indicated by the double headed arrows in the figure.

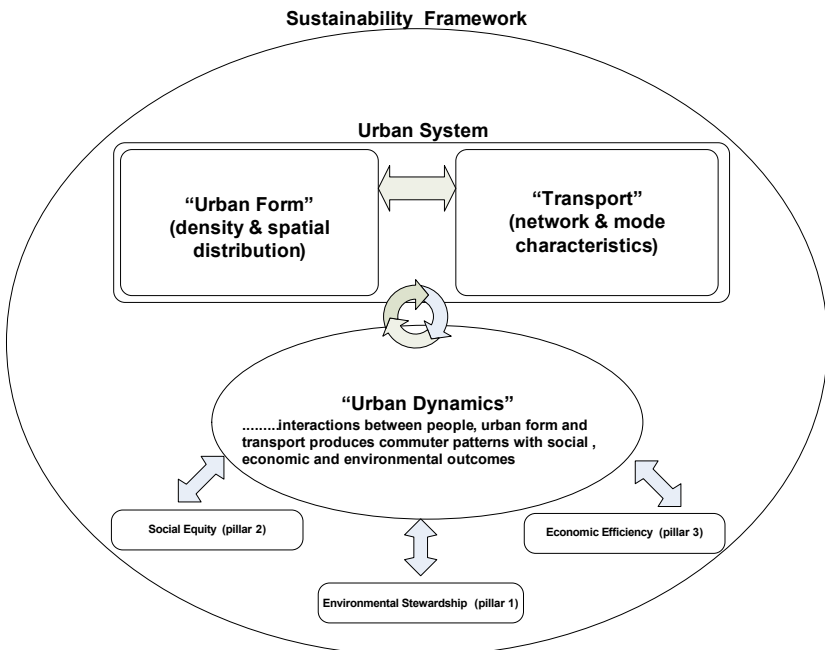


FIGURE 1. The Urban “Sustainability Framework.” *Source:* Doust, 2008, Figure 4.1, p. 136.

A top down logic is evident in tracing the driving influences on sustainability performance through this framework. However, it is also evident that community expectations and sustainability requirements flow from bottom to top in this framework when it comes to enabling new or changed urban systems or policies to provide an improved sustainability performance. Understanding the elements within this framework and their relationships requires application of the traditional Transportation Planning Models (TPM) and Integrated Land Use Transportation Models (ILUTM) and methodologies. These models and methodologies remain the strongest building blocks for a quantitative methodology for assessing the sustainability of cities, particularly when coupled with GIS visualization. In modeling the Urban System, accessibility to land-use activities (as operationalized by the Hansen model of potential accessibility – see Black, 1981, Chapter 1, Blunden and Black, 1984, Chapter 2), is an approach that brings the sustainability performance of the three pillars together. It provides a mechanism to visualize the complementary performance as well as the individual performance of the three pillars of sustainability.

An ideal planning goal is to have high accessibility with a low environmental footprint. A city's sustainability performance in relation to this goal can be analytically quantified and simply visualized in plots on what we define as the "environmental sustainability-accessibility space" (Figure 2). This figure refers to "Sustainability" as meaning environmental sustainability (stewardship) and "Accessibility" as meaning accessibility of workers to places of employment, shopping schools and so on, or, alternatively, accessibility of employment to workers – the spatial labor market.

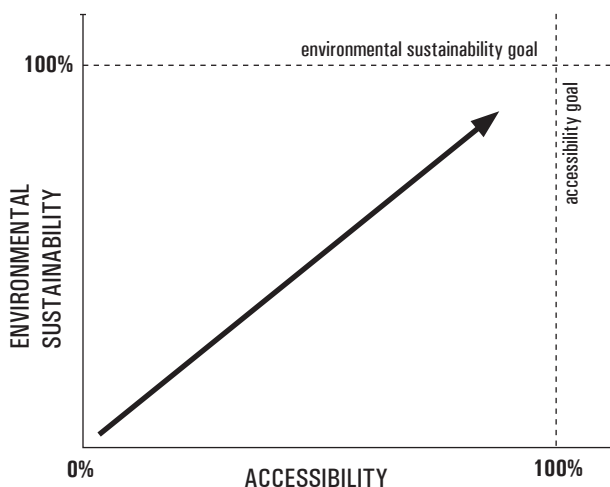


FIGURE 2. Environmental Sustainability - Accessibility pace. *Source:* Doust, 2008, Figure 4.2, p. 138.

For either type of accessibility, the figure shows that the environmental sustainability performance on the ordinate can be plotted with the corresponding accessibility performance on the abscissa for any pair of land-use zones where interaction takes place. The concept enables both a quantifiable measure and a visual representation of the mutual performance. A goal or target for environmental sustainability and accessibility can be applied and visually represented in the same space. Note that the 100% goal position may vary depending on the relative weighting or priority of the two dimensions.

The two dimensional environmental sustainability-accessibility space has a parallel to the geographical information system (GIS) for geographic space. In geographic space, spatial disaggregation enables a visual appreciation, for example, of land-use distribution. In the environmental sustainability-accessibility space, the spatial disaggregation enables a visual appreciation of the sustainability performance distribution. One example is the sustainability distribution for land-use zone pairs in a city. The environmental sustainability measure adopted is the inverse urban CO₂-e measure ⁵,

METROPOLITAN SYDNEY CASE STUDY

Measures of the three triple bottom line sustainability pillars and tested metrics have been calculated using Sydney, Australia, as a case study of a metropolitan area.

Sydney was selected because of its characteristic of being a low density, sprawling car-dependent city and its legacy of having transportation and population data over many years. Of particular value is the Census of Population and Housing with Journey to Work Trip (JTW) tabulations of trips to work for the whole Sydney population over a period from the 1961 to the present day. (The latest data available for analysis is 2001 with the 2006 Census expected for release soon.) The Sydney metropolitan region was partitioned into inner, middle and outer rings (see Figure 3) for convenience in presenting the aggregate results, but the software written for this analysis allows visualization of results for very fine geographical resolution (for each pair of zones in the urban system).

Existing building block methods for measuring accessibility ⁶ from residential original zones to places of employment and accessibility from places of employment to labor markets provided the foundation to ensure quantifiability and traceability in the metrics. 1) Accessibility to jobs is one measure of social equity. 2) Accessibility to the labor force for an industry is a measure of economic efficiency. 3) Environmental sustainability can be defined with many different measures, but to illustrate the general approach a CO₂ equivalent (CO₂-e) was adopted that includes both energy embodied in transportation construction and maintenance, and in the energy consumed in making the journey by automobile.

The steps in developing the metrics through derived data are shown in Figure 4. Zonal land-use data and a highway network are the inputs for the analysis. The zone sets include destinations in up to 792 travel zones. TRANSCAD GIS-T was used to generate the multiple shortest path matrix (MSPM), transportation impedance tables and trip tables amongst these zones.

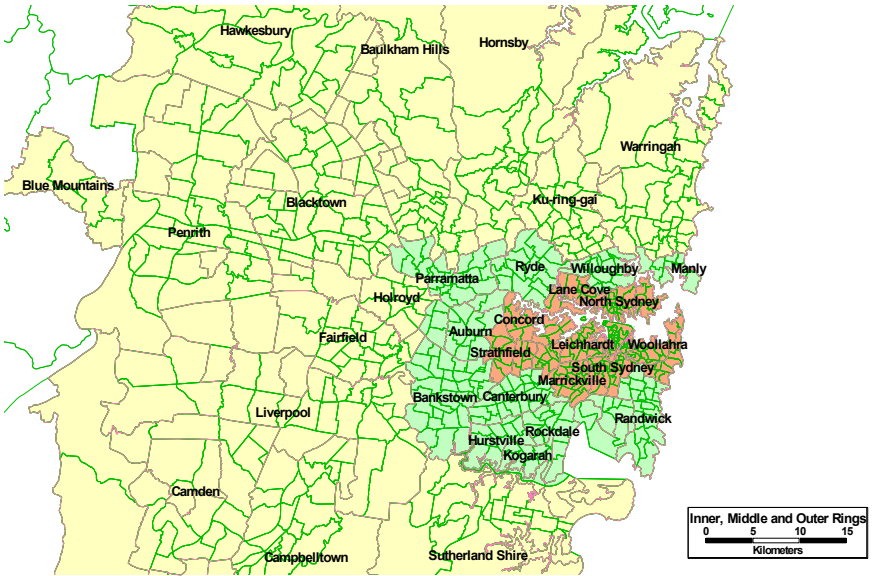


FIGURE 3. Sydney Case Study Ring Partitions. *Source:* Doust, 2008, Figure 5.1, p. 174.

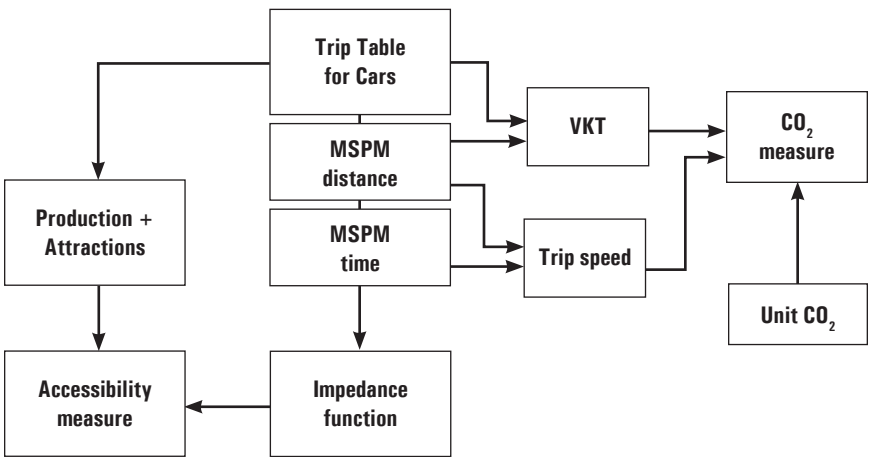


FIGURE 4. Accessibility measures and environmental sustainability measures estimations. *Source:* Doust, 2008, Figure 4.7, p. 154.

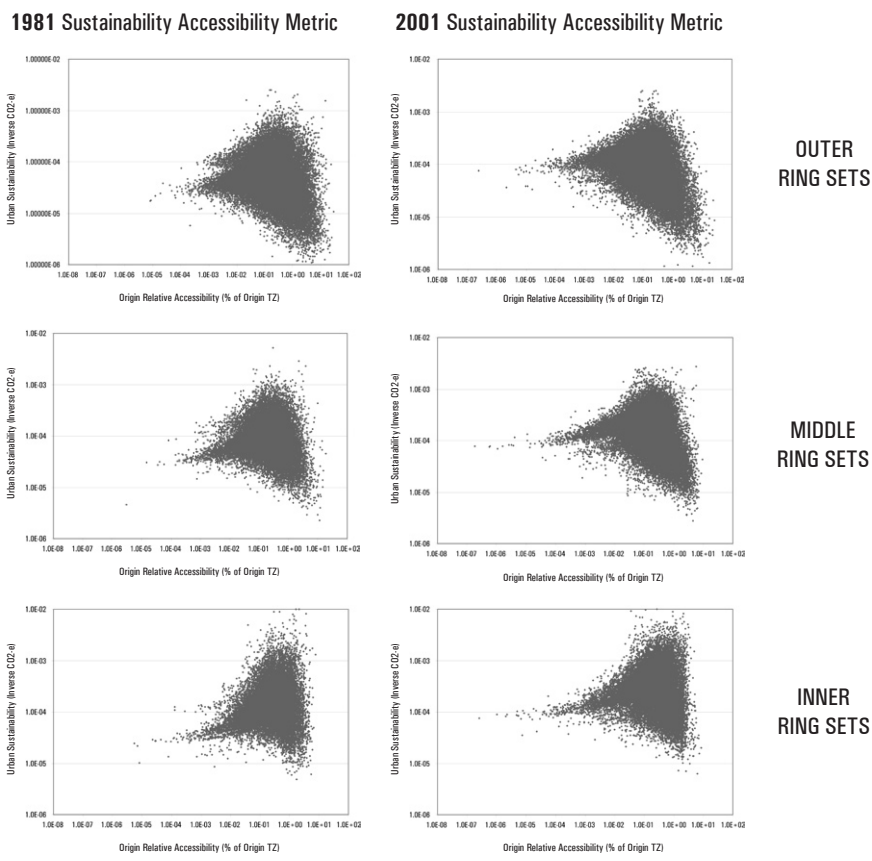


FIGURE 5. Visualizations of residential sustainability: three rings of the Sydney Metropolitan Area. *Source:* Doust, 2008, Figure 6.17, p. 271.

Spatial Equity

Figure 5 provides a series of visualizations of the environmental sustainability and accessibility to jobs for the residential travel zones in an outer, middle and inner ring partitioning of the Sydney Metropolitan Area for the census years of 1981 and 2001. The ring partitions represent three different urban expansion periods of Sydney during the 20th Century, with the inner ring being the metropolitan limit until the 1950s. The outer ring is the most recent, occurring from the 1970’s and characterized by lower residential density and less access to public transportation.

The visualizations are for car-based trips across the whole Sydney Metropolitan Area to employment travel zones with journey to work trip ends. Each travel zone pair is represented by a metric point. The census year data sets for 1981 and 2001 are plotted in these figures, to allow interpretation of the spread and distribution in environmental sustainability – accessibility space and the changes across a twenty-year timeframe. The plot scale is logarithmic for both the

environmental sustainability and the relative accessibility measures.

Each scatter plot visualization represents the relative accessibility measure plotted with an urban environmental sustainability measure (1/CO₂-e) for each travel zone pair. Over the twenty-year time frame from 1981 to 2001, a reduction in environmental sustainability for each ring is evident. A larger reduction is noticeable for the outer ring in comparison to the other rings. This is consistent with a larger increase in vehicle kilometers for the journey to work travelled in the outer areas of Sydney over the same time frame (Suthanaya and Black, 2001). Over the same time frame, the spatial equity as measured by the spread in relative accessibility has not deteriorated for any of the rings. However, the inner ring has the least spread and the outer ring the greatest spread.

Economic Efficiency

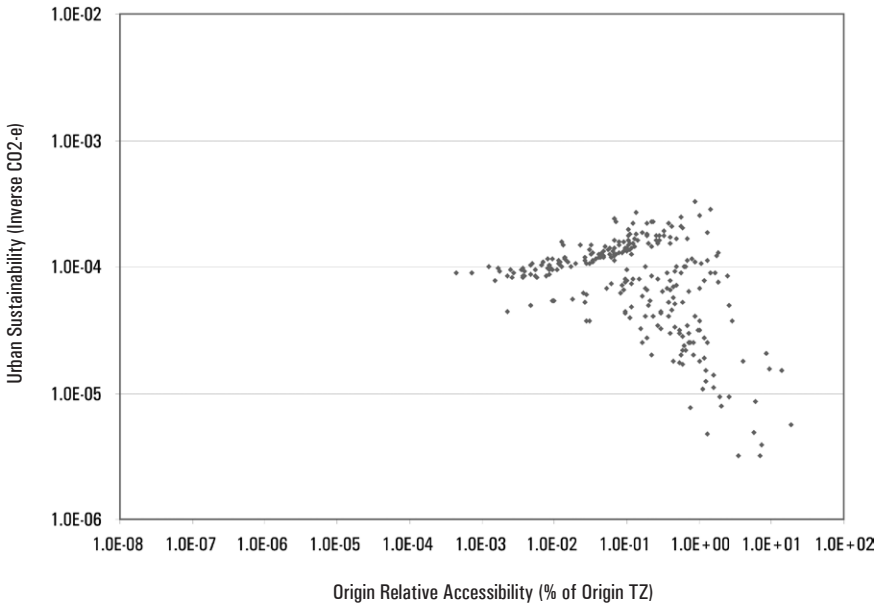
Figure 6 provides a series of visualizations of the environmental sustainability and accessibility to the workforce for the employment travel zones in the outer suburban Penrith 'River City' precinct, some 45 km from the Sydney CBD. Figure 7 provides the same visualizations of the Sydney CBD 'global city' for comparison. The visualizations are for car-based trips to all travel zones with worker residences, right across the Sydney Metropolitan Area. Each travel zone pair is represented by a metric point. The census year data sets for 1981 and 2001 are plotted in these figures, to allow interpretation of the spread and distribution in environmental sustainability – accessibility space and the changes across a twenty-year timeframe. The plot scale is logarithmic for both the environmental sustainability and the relative accessibility measures.

Each scatter plot visualization in Figures 6 and 7 represents the relative accessibility measure plotted with an urban environmental sustainability measure (1/CO₂-e) for each travel zone pair. Over the twenty-year time frame from 1981 to 2001, a reduction in environmental sustainability is noticeable for both centres. However, there is a greater reduction in the Penrith environmental sustainability. This is consistent with a larger increase in vehicle kilometres for the journey to work travelled in the outer areas of Sydney over the same time frame (Suthanaya and Black, 2001). In comparison to the Sydney CBD employment zones, the Penrith scatter plot displays a similar degree of spread (left to right) in relative accessibility, at least four orders of magnitude.

COMMENTARY

The practical application of the assessment framework is demonstrated using metropolitan Sydney as a case study. Each of these elements of the sustainability framework work together and can connect the planning instruments (especially, Winston, 1957; New South Wales Government., 1968, 2005) through to the outcomes that drive the sustainability performance. The visualizations of the sustainability metrics provide the measure of performance in terms of the three pillars of sustainability (environmental sustainability, social equity and economic

1981 Sustainability Accessibility Metric



2001 Sustainability Accessibility Metric

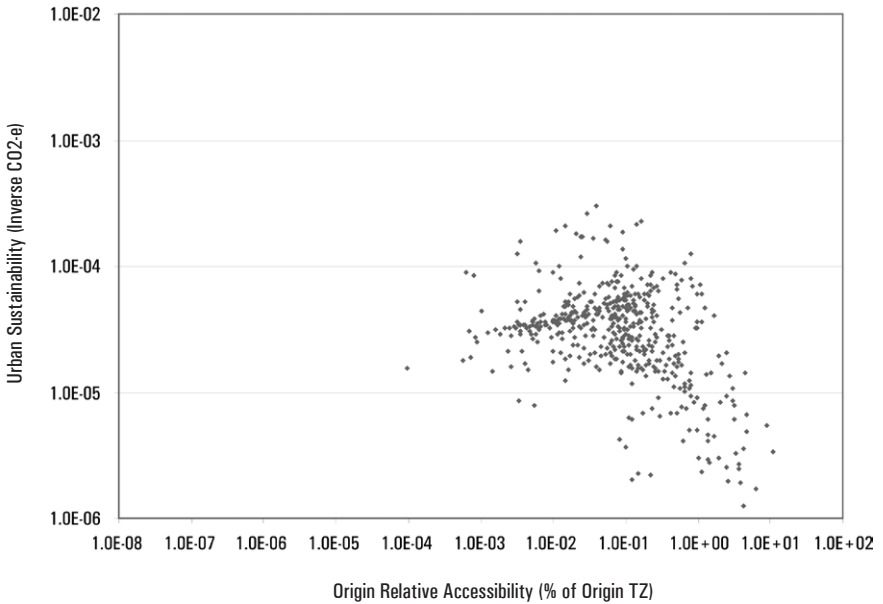
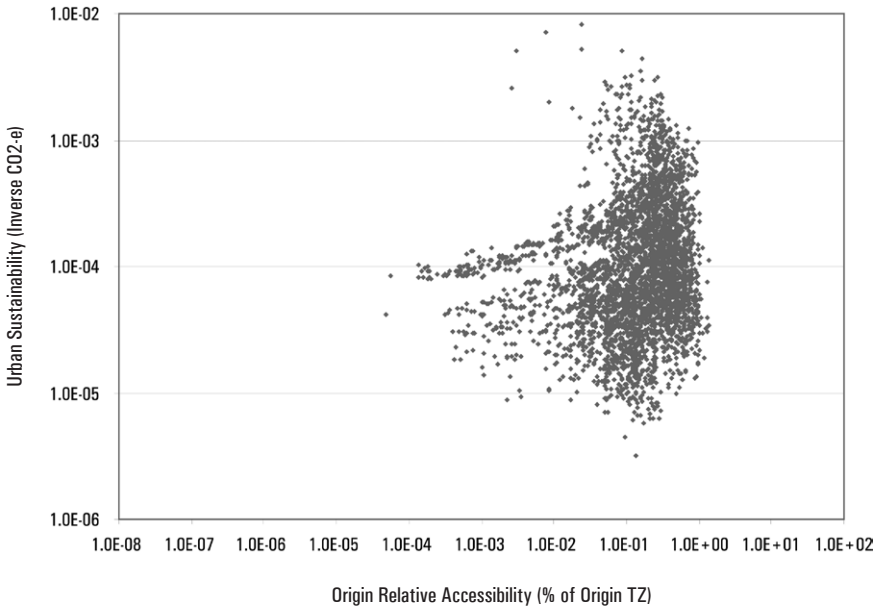


FIGURE 6. Visualizations of Employment Centre Sustainability: Scatter Plots for Penrith. *Source:* Doust, 2008, Figure 6.17, p. 271.

1981 Sustainability Accessibility Metric



2001 Sustainability Accessibility Metric

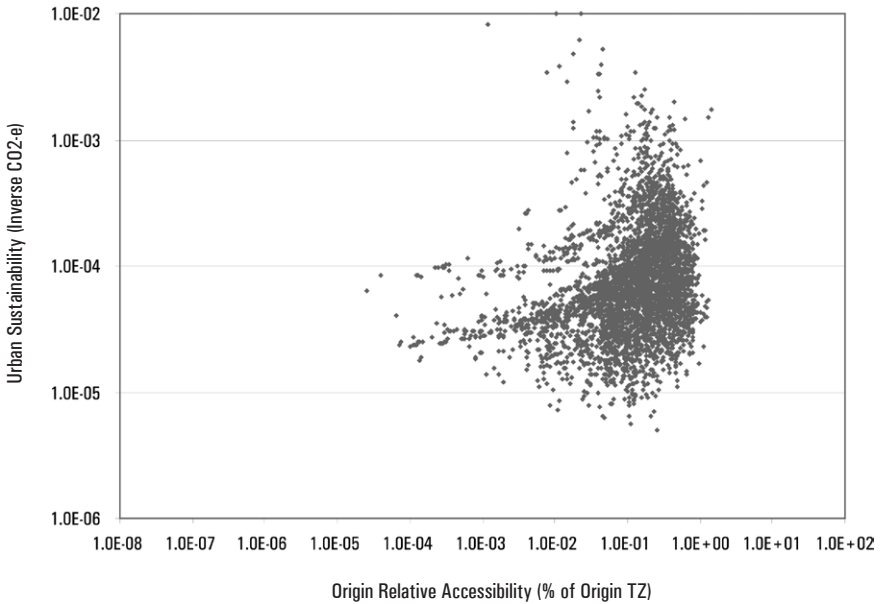


FIGURE 7. Visualizations of Employment Centre Sustainability: Scatter Plots for Sydney CBD. *Source:* Doust, 2008, Figure 6.17, p. 271.

efficiency). Although the interpretations that follow are supported by the data for Sydney, we would expect to find similar findings in other low-density, sprawling cities where data are available for comparative analyses.

Pillar 1 is that of environmental sustainability, or environmental stewardship. The measure trialed through the Sydney case study was the inverse CO₂-e measure based on greenhouse gas emissions. This is a measure of residential zones' environmental sustainability in terms of trips to all places of work in the case study area. It is also a measure of the major employment centre's environmental sustainability in terms of the workforce trips back home from that centre (economic efficiency of labor markets).

Observations made include:

- The metrics showed differences in sustainability performance of the three large datasets of Sydney differentiated as the Inner, Middle and Outer Ring sets from 1981 to 2001. The trends in environmental sustainability have shown that the Outer Ring, where the planning instruments have been focusing on residential growth, is worse than for the Inner and Middle Ring zones. Furthermore, this trend has deteriorated over the period 1981 to 2001.
- The trend for all major employment centres from 1981 to 2001 is one of deterioration in environmental sustainability. In the major employment centres the largest deteriorations were in Penrith, the Sydney CBD, followed by Parramatta, Liverpool and North Sydney. This indicates an opposite trend to that required to halt the growth in total VKT by private transportation by 2021, which is a policy of the New South Wales Government in *Action for Transport* (1998). Planning instruments do not appear to have succeeded in working towards this goal.
- The visualizations for 2001 show that the Sydney CBD and North Sydney remain the better performing centres, with Parramatta, Liverpool and Penrith the least environmentally sustainable. While the planning instruments have produced urban dynamics outcomes whereby local trips are a greater proportion of the Penrith and Liverpool centre's workforce trip patterns, this has not translated into higher environmental sustainability, principally due to the high mode share of the trips by automobile. The corollary is that the planning instruments that have led to the high public transportation share of the Sydney CBD centre work trips are shown to be effective even with a much larger spatial distribution of the workforce away from the centre.

Pillar 2 is that of spatial social equity. The measures proposed in the Sydney case study were the relative accessibility and "raw" accessibility measures in terms of workers accessibility to jobs in the whole case study area, from their place of residence.

Observations made include:

- The *Sydney Region Outline Plan* (NSW Government, 1968) planning instrument has been focusing on establishing a balance of employment to match the residential growth. The trends in raw accessibility have shown that the equity (measured by accessibility to employment) was lower in the Outer Ring in comparison to the Inner Ring and Middle Ring for the whole period from 1981 to 2001.
- The “mean” Outer Ring performance has improved in comparison to the Inner and Middle Rings over the period 1981 to 2001, although the relative improvement in spread is less conclusive. On balance, the planning instruments appear to have improved the Outer Ring accessibility over the period but this is not sufficient to match the higher spatial equity experienced by workers and therefore their families in the Inner and Middle Rings.
- Comparison of the overall case study raw accessibility shows that the spatial equity for the whole area has improved steadily from 1981 to 2001.

Pillar 3 is that of economic efficiency. A measure proposed in the Sydney case study was the raw accessibility measure in terms of employment centre accessibility to workers in the whole case study area, from the travel zones that make up each centre.

Observations made include:

- The raw accessibility-based measures indicated that Liverpool centre is the most economically efficient centre based on accessibility to the workforce, with the Penrith Centre the least accessible to the workforce.
- Liverpool and Penrith have both improved in economic efficiency, as indicated by the “mean” raw accessibility changes from 1981 to 2001. The policy instruments of the study period were aimed at increasing the job opportunities at these outer suburban area centres. Evidence of this was found through urban dynamics metrics, which showed that the workforce was much more localized than in the Sydney CBD, North Sydney or Parramatta (Doust and Black, 2008). The improvement in economic efficiency result shown by this improvement in raw accessibility measure over the study period suggests that the policy instruments have achieved positive Pillar 3 outcomes for the outer suburban Penrith and Liverpool centres. The increase in raw accessibility for the Liverpool centre indicates a much improved pattern of access to the workforce from 1981 to 2001.

Overall Sustainability Performance of the Outer Ring is a summary of the combined assessment of the three sustainability pillars. The summary is from the perspective only of the workers resident in the Outer Ring and the centres of Parramatta, Penrith and Liverpool located in the Outer Ring.

Observations made include:

- Based on the “environmental sustainability-accessibility space” visualization, the sustainability for resident workers is lower than for workers resident in the Inner and Middle Ring zones. The impact of planning instruments has been a neutral change in sustainability in relation to the target trend. However, it has enabled a better performance than the Inner Ring trend.
- Based on the “environmental sustainability-accessibility space” visualization, the sustainability for the Parramatta, Liverpool and Penrith centres is lower than for centres in the Inner Ring zone. The impact of planning instruments has been a neutral change in sustainability in relation to the target trend for the Penrith centre, a drop for the Parramatta centre and a significant improvement for the Liverpool centre. Performance improvements in comparison to the Inner Ring centres of North Sydney and the Sydney CBD are similar, although Liverpool showed a greater improvement. However, the accessibility spread metrics show better performance by the Inner Ring centres.

Overall the strategic instruments, and other planning instruments, shaping a linear extension of residential, commercial and industrial development in new cities along western and south-western transportation corridors, and a new north-western corridor, have not delivered an improvement in sustainability to the level of current community expectations of the early 21st century. However, the outcomes over the twenty-year period for the Outer Ring have generally been an improvement in comparison to the trend in the Inner Ring.

From a sustainability perspective, the New South Wales Government’s “Centres Policy” over the 20 year period 1981 to 2001 shows a mixed result. The first decade showed evidence of decentralization and formation of polycentric centres. These have continued to develop but at a slower pace in the second decade compared with the Sydney CBD and North Sydney – the new “global cities”. These have maintained an overall sustainability advantage over the decentralized centres of Parramatta, Liverpool and Penrith even though there have been some gains by the Liverpool centre over the study period.

CONCLUSIONS

A key to urban sustainability in cities is that environmental sustainability (stewardship), social equity and economic efficiency work together. In the assessment of sustainable performance all three pillars need to achieve complementary outcomes rather than competing outcomes. Urban form, transportation and interactions with communities are central to the question of the long-term sustainability of cities. A holistic, integrated approach to the assessment of the three pillars of sustainability (environmental stewardship, social equity and economic efficiency), and changes over time has been proposed, called the Urban Sustainability Framework (Figure 1).

A particular strength of using the Urban Sustainability Framework and the metrics demonstrated in this paper with particular reference to metropolitan Sydney, Australia, is that they are derived from data sets that have been commonly used by planners for many years. The sustainability framework enables the holistic picture of sustainability to be maintained during the assessment process.

However, a most important aspect of this methodology is that it is analytically based and all visualizations have traceability back through the algorithms to the three source inputs discussed in the paper. This is a particular strength when checking results, making scenario changes, applying different planning instruments and communicating the results to stakeholders and the general community.

Collectively, the Urban Sustainability Framework, sustainability metrics, companion urban dynamics metrics and urban system measures are a practical methodology in assessing urban sustainability performance.

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ENDNOTES

1. http://www.environment.nsw.gov.au/soe/soe2006/chapter2/chp_2.4.html#2.4.24. (accessed 10 Dec 2008)
2. Accessibility to employment (social spatial equity) is a metric of accessibility to employment for workers from their place of residence. This is a measure of social equity for workers in terms of the spatial location. It excludes any measure of the differences in social equity associated with personal characteristics of workers at each place of residence.
3. Accessibility to workforce (economic efficiency) is a metric of accessibility to workers for businesses. This is a measure of economic efficiency for each business in terms of the spatial advantage they have in attracting its workforce. Businesses with high accessibility to workforce are considered to have the greater choice in selection of staff and more opportunity to negotiate wages and salaries, increasing the efficiency of the business.
4. This includes the embedded CO₂-e from car and road construction & maintenance over that route allocated to each vehicle kilometer travelled
5. Where units are (grams of CO₂)⁻¹
6. Hansen measures of potential accessibility

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