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Integrating urban ecosystem sustainability assessment into policy-making: insights from the Gold Coast City

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This paper introduces a policy-making support tool called 'Micro-level Urban-ecosystem Sustainability IndeX (MUSIX)'. The index serves as a sustainability assessment model that monitors six aspects of urban ecosystems – hydrology, ecology, pollution, location, design, and efficiency – based on parcel-scale indicators. This index is applied in a case study investigation in the Gold Coast City, Queensland, Australia. The outcomes reveal that there are major environmental problems caused by increased impervious surfaces from growing urban development in the study area. The findings suggest that increased impervious surfaces are linked to increased surface runoff, car dependency, transport-related pollution, poor public transport accessibility, and unsustainable built environment. This paper presents how the MUSIX outputs can be used to guide policy-making through the evaluation of existing policies.

Keywords: urban ecosystem; sustainability assessment; composite index; parcel-scale spatial analysis; Gold Coast City

Abbreviations

DPSIR:	Driving force-Pressure-State-Impact-Response
FEEM:	Fondazione Eni Enrico Mattei
GCCC:	Gold Coast City Council
MUSIX:	Micro-level Urban-ecosystem Sustainability Index
UNEP:	United Nations Environment Programme
BREEAM:	Building Research Establishment Environmental Assessment Methodology
LEED:	Leadership in Energy and Environmental Design
CASBEE:	Comprehensive Assessment System for Building Environmental Efficiency

1. Introduction

An urban ecosystem is characterized as a combination of artificial and natural ecological systems, where people built their settlements on the remnants of natural ecosystems and form a complex structure that mimics their functions (Guidotti 2010). Sustainable design of the urban ecosystem is based on reshaping the patterns of cities – including urban form, architecture, design of infrastructure and other support systems, social and economic processes – to mimic the processes of natural ecosystems, so that the resulting

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effects will be relatively natural. A sustainable urban ecosystem is defined by Newman and Jennings (2008, 108) as “ecosystems which are ethical, effective (healthy and equitable), zero-waste, self-regulating, resilient, self-renewing, flexible, psychologically-fulfilling and cooperative”. To assess environmental performance, examine ecological limits and provide the long-term protection of environmental quality within an urban ecosystem, sustainability assessment is needed to be integrated into planning process. It aids planners and policy makers in formulating sustainable policies through monitoring environmental problems and their impacts on the natural environment (Yigitcanlar 2010). As outlined by the UNEP (2004), sustainability assessment provides the following benefits:

- Supporting sustainable development: The assessment results (1) highlight the economic, social, environmental opportunities and constraints; (2) organize the policy- and decision-making process by reducing the complexity of each stage, and; (3) help governments to reach proposed sustainability targets;
- Facilitating good governance and institution-building: The integrated assessment (1) promotes the transparency of the policy- and decision-making process; (2) helps build social consensus about its acceptability, and; (3) enhances coordination and collaboration between different government ministries and bodies;
- Saving time and money: The integrated assessment (1) strengthens the intersectoral policy coherence; (2) provides early warning of the potential problems, and; (3) minimizes environmental, social and health impacts, thereby reducing the costs required to remedy them;
- Enhancing participatory planning for sustainable communities: The integrated assessment (1) increases the awareness of governments and citizens on the significance of ecosystem functioning, and; (2) strengthens national commitment to sustainable development.

Although many approaches exist (Hardi *et al.* 1997; Ness *et al.* 2007; Singh *et al.* 2009; Srinivasan *et al.* 2011), the research on employing different assessment tools and methodologies to help policy- and decision-making is still in progress. An example of the methodology for urban ecosystem sustainability assessment, which measures the interaction between human and ecosystem well-being, developed by the International Union for Conservation of Nature and Natural Resources consists of seven stages as follows (Guijt and Moiseev 2001):

- Determine the purpose of the sustainability assessment: In this step, the purpose and objectives of the assessment are clarified;
- Define the system and goals: The geographic area for the assessment is defined. A vision and goals for sustainable development are developed and recorded;
- Clarify dimensions, identify elements, and objectives: The dimensions, which will be used for measuring performance towards sustainable development are developed. Data collection and storage are carried out;
- Choose indicators and performance criteria: All selected indicators are explained in detail and the performance criteria for each indicator are justified;
- Gather data and map indicators: The indicator scores are calculated and the scores are mapped;
- Combine indicators and map the indices: The indicator scores are aggregated into an index through some methodological steps and the scores are mapped in order to explain the findings easily;

- Review results and assess implications: This step involves the analysis of the results, causes, implications, and identification of the priorities for improvement. The results give a snapshot of the current situation and the findings help to determine the policies and actions.

The main objectives of this research are: (1) identify the environmental impacts of development on the urban ecosystem and its components; (2) develop a set of indicators to define the environmental pressures at micro-level spatial unit, and; (3) establish a parcel-scale composite index to evaluate the efficiency of implemented policies. In light of these objectives, the paper introduces a new sustainability assessment tool called ‘Micro-level Urban-ecosystem Sustainability IndeX (MUSIX)’. In recent years, an increasing number of sustainability indicators/indices have been developed to evaluate environmental impacts at the macro-level from national to regional and international scales. However, these studies report multiple barriers in terms of micro-level spatial data availability in the indicator development process, which raised the issue of missing data treatments (Dizdaroglu 2015). As stated by Alberti (2008, 102), the smallest spatial unit produces information that varies from household/building to street/parcel-scales. These parcels then combine to create new functional units as suburbs/neighbourhoods which interact with regional/national-scales. In this context, MUSIX provides a methodological approach for identifying a set of parcel-scale indicators that can be used for monitoring the impacts of development on urban ecosystem components. In the case of Gold Coast City, MUSIX detects the sustainability performance of a residential area referring to six main issues of urban development – i.e., hydrology; ecology; pollution; location; design, and; efficiency. For each category, a set of core indicators is assigned in order to evaluate the progress towards sustainable development. While the indicators of the model provide specific information about the environmental problems in the area (e.g., irregular-shaped lots covered by large impervious surfaces, increased surface runoff, limited access to local services/amenities within walking distance, inadequate public transport services, lack of climate responsive landscape design), the composite index score produces a big picture view of the sustainability performance of the neighbourhood (e.g., loss of natural vegetation, stormwater management issues, auto-dependent pattern of development, transport-related pollution, consumption of non-renewable resources). In the light of the model findings, existing policies are evaluated to guide the preparation and assessment of development and local area plans in conjunction with the Gold Coast Planning Scheme, which establishes regulatory provisions to achieve sustainable development.

The paper is structured as follows. Following this introduction, Section 2 introduces salient characteristics of the case study area, planning policies of the local council, structure of the MUSIX. In light of the model findings, Section 3 presents the interpretation of the model results and evaluation of existing policies. Section 4 concludes the paper with useful insights from the application of the model.

2. Materials and methods

2.1. Case study area: the Gold Coast City

This study is part of a joint Australian Research Council project that aims to develop recommendations for the adaptation of current water sensitive urban design (WSUD) practices to climate change, changing urban form, and future transport systems. The Gold

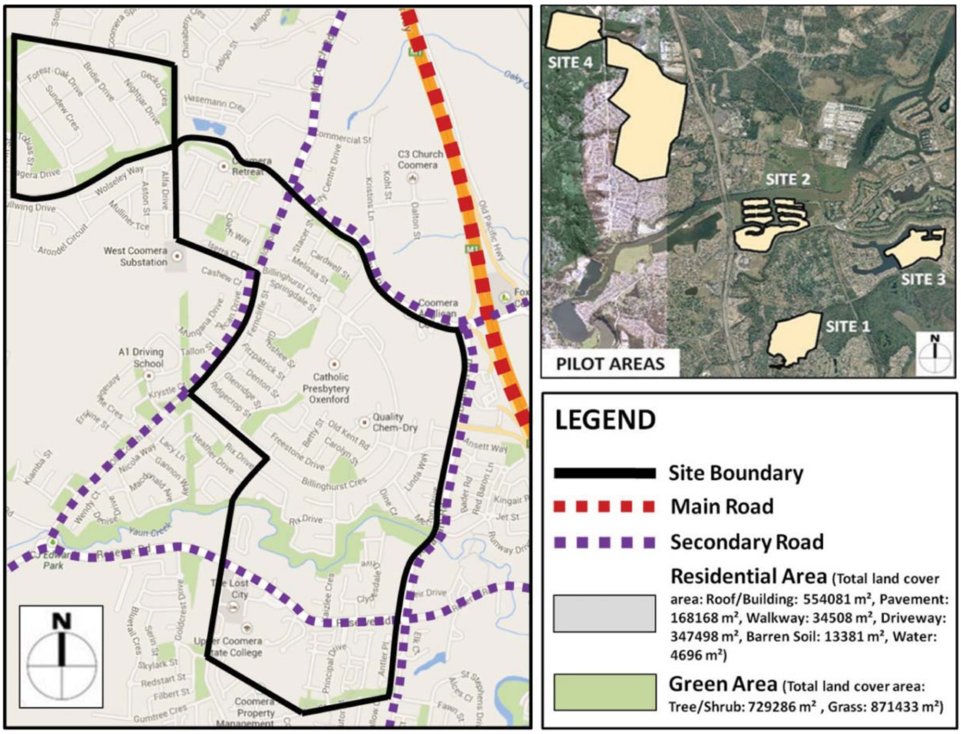

Figure 1. Location of the pilot-test area in the Gold Coast City.

Coast City is chosen as the test bed for this project. The Gold Coast City is located on the Eastern coast of Australia in the South East of the State of Queensland. The city is a tourist attraction and vibrant economic hub covering an area of 1,334 km^2. The city shows a linear development, which includes a high rise coastal strip surrounded with highways, canal estates, and low-density housing developments mixed with entertainment, employment, and retail activities (GCCC 2008). The population of the city is approximately 546,067 and the population density is 4.09 persons per hectare. In order to ensure data and content integrity within the project, four pilot sites, as shown in Figure 1, are selected for the implementation of MUSIX. In this paper, the findings of Site 4 are presented. Site 4 is a high-density residential area located in Upper Coomera, which is one of the rapidly growing suburbs located at the Northern end of the city, with a population of 21,136, including mostly low-income groups (ABS 2015). Wetlands and sugar cane lands are located on the eastern boundary. On the west, the suburb is bounded by Brygon Creek which flows into the Coomera River and Hotham Creek. The suburb has an undulated topography that forms a steep valley to the West. This steeper land is a vegetated land that is threatened by potential future residential development. The suburb includes a popular theme park, Dreamworld, a major shopping centre, and a university campus, as well as being close to the Gold Coast railway line and the Pacific Motorway (GCCC 2012). A general map of the area is shown in Figure 1 (Google Maps 2013). The area consists of detached single and two-storey lot dwellings with backyard gardens. The total size of the pilot area is approximately 272 hectares and the total number of parcels is 1,515.

2.2. *Overview of the existing planning policies*

The Gold Coast City confronts major environmental problems depending on population growth, rapid urbanization, and expanding transport infrastructure. These environmental pressures have significant impacts on coastal environments and water resources. According to the 'Our Living City Report' published by GCCC (2006), some of these pressures include (1) local air pollution emissions from growing economic activity and vehicle use; (2) clearing and habitat destruction; (3) beach erosion due to foreshore development and unnecessary use for recreational purposes; (4) land degradation, particularly canal constructions; (5) increased urban development as well as a growing number of tourists, visitors, and day-trippers, and; (6) increased demand for clean and safe drinking water. The City Council responds to these challenges by developing strategies, plans, and programs that help to protect its ecosystems and support sustainable management of its resources under the Sustainable Planning Act 2009. This Act was introduced by the Queensland Government to assist state and local governments with achieving ecological sustainability in planning. Additionally, the Corporate Plan 2020 sets out key strategies towards city's vision under three themes, (1) the best place to live and visit; (2) prosperity built on a strong diverse economy, and; (3) people contribute to a strong community spirit (GCCC 2015a). This plan is supported by other key documents, such as the Gold Coast Planning Scheme 2003. The planning scheme establishes regulatory provisions to achieve ecological sustainability through the formulation of place codes, development codes, constraint codes, and other assessment criteria that provide guidance for best practice development solutions (GCCC 2008). The Draft City Plan 2015, which is city's new planning scheme in the final stages of the approval process, will replace the Gold Coast Planning Scheme 2003. Key aims include facilitating new housing, providing catalysts for jobs, key infrastructure connections, and protecting the environment from urban sprawl. In addition, this plan will help the city take full advantage of the significant opportunities ahead, including the Gold Coast 2018 Commonwealth Games, revitalization of key centres, such as the CBD (Central Business District) in Southport, and investment in transport infrastructure, such as light rail (GCCC 2015b).

2.3. *The MUSIX model*

The MUSIX model is constructed by the following steps.

2.3.1. *Theoretical framework*

The theoretical framework of the MUSIX is based on developing a sustainable urban ecosystem which aims to integrate human activities into natural systems by carrying out environmental policies to ensure their long-term sustainability. To achieve a sustainable urban ecosystem, MUSIX focuses on two overarching objectives which constitute the main categories of the indicator set, (1) ecological resilience of natural environment by preserving the ecosystem's stability through improving its resistance to tolerate the damage of human activities, and; (2) sustainable design of built environment towards eco-friendly architectural design and urban planning. In light of these objectives, MUSIX incorporates six main goals that aim to achieve a sustainable urban ecosystem, (1) hydrological conservation; (2) ecological protection; (3) environmental quality; (4) sustainable urban design; (5) the use of renewable resources, and; (6) sustainable mobility and accessibility. These sub-categories consist of 14 indicators, presented in Table 1.

Table 1. Theoretical framework for the indicator selection.

Aims	Goals	Categories	Indicators	Contribution to sustainable urban ecosystem by:
Ecological Resilience of Natural Environment	Hydrological conservation	Hydrology	(1) Evapotranspiration – investigates the changes in evapotranspiration rates resulting from impervious surfaces. (2) Surface runoff – investigates the surface runoff rates of different land cover types.	● Managing surface runoff; ● Reducing pollution, flooding, and erosion risks; ● Improving the green infrastructure, and; ● Protecting water and air quality.
	Ecological protection	Ecology	(1) Urban habitat – investigates the environmental quality in the urban development by measuring the green area ratio. (2) Microclimate – investigates the urban heat island effect of impervious surfaces on the microclimate by measuring the albedo of surfaces.	● Preserving existing biodiversity and natural ecosystems; ● Protecting endangered and threatened species; ● Promoting urban green space network, and; ● Reducing urban heat island effect.
	Environmental quality	Pollution	(1) Stormwater pollution – investigates transport related stormwater runoff pollution. (2) Air pollution – investigates transport related air pollution. (3) Noise pollution – investigates transport related noise pollution.	● Preserving community resources; ● Protecting the health of the community, and; ● Creating a more pleasant and better quality of life.
Sustainable Design of Built Environment	Sustainable urban design	Design	(1) Lot design – investigates the implementation of passive solar design principles within the existing parcel plan. (2) Landscape design – investigates the implementation of subtropical landscape design principles within the existing parcel plan.	● Ameliorating microclimate and improve thermal comfort; ● Reducing environmental impact of buildings and paved surfaces; ● Encouraging energy efficiency, and; ● Providing a better visual effect on built environment.
	Use of renewable resources	Efficiency	(1) Energy conservation – investigates the implementation of energy efficient design principles within the existing parcel plan. (2) Water conservation – investigates the implementation of water efficient design principles within the existing parcel plan.	● Providing energy conservation; ● Improving water use efficiency; ● Providing sustainable waste management, and; ● Achieving the long-term management of natural resources.
	Sustainable mobility and accessibility	Location	(1) Proximity to land use destinations – investigates the accessibility of the site to the land-use destinations within walking distance (800 m). (2) Access to public transport stops – investigates the accessibility of the site by public transport. (3) Walkability – investigates the site accessibility by looking at the design of streets and pedestrian ways.	● Minimizing automobile dependency; ● Promoting cycling and public transport; ● Providing mixed-use neighbourhoods that are easily accessible, and; ● Providing a safe and convenient environment for pedestrians.

2.3.2. *Indicator selection and data collection*

The indicator set presented in Table 1 was developed through a comprehensive review of existing indicator initiatives (UNCSD 2001; OECD 2003; EEA 2005; Japan Sustainable Building Consortium 2007; SEDAC 2007; US Green Building Council 2008, 2009). Additionally, an expert panel was established to reach a consensus on the desired indicators. The panel members were composed of academics, researchers, and professionals who are familiar with the characteristics of the local area and existing planning policies. Through a series of workshops, experts provided useful insights into the selection of relevant indicators for the policy formulation process. MUSIX utilized the best environmental data available and indicators were selected through consideration of the local environmental problems within the pilot test-bed Gold Coast City.

2.3.3. *Normalization and calculation of indicators*

Benchmarking normalization was employed to remove the scale effects of different units by standardizing the original indicator units to normalized units. Indicator scores are ranked by applying benchmarks according to the normalized values that are given regarding whether the indicator value is above/below/around that threshold value. These threshold values for each indicator were assigned by reviewing various studies in the literature (see Appendix 1 detailing calculation method and benchmark values used to evaluate performance of each indicator). Similar to the five-point Likert scale used for the FEEM sustainability index (Carraro *et al.* 2009), each indicator is expressed as a value between 1 and 5 indicating different levels of sustainable targets, (1) low (extremely unsustainable situation); (2) medium-low (not sustainable but not as severely as in the previous level); (3) medium (a discrete level of sustainability); (4) medium-high (satisfactory level of sustainability but not on target), and; (5) high (target level of sustainability).

2.3.4. *Multivariate analysis*

A statistical analysis was employed to examine the underlying structure of the data. First, a Kolmogorov−Smirnov test was performed to investigate the distribution of the indicator data-set. As a result of the non-normal distribution of the data-set, the Spearman's rank correlation analysis was conducted to examine the relationship between the indicators with reference to similar studies (e.g., Pinho and Manso Orgaz 2000; Raju, Lucien, and Arondel 2000; Saltelli *et al.* 2004; Dramstad *et al.* 2006; Schulman and Peters 2008; Can *et al.* 2011; Rinner and Hussain 2011). The correlation between the indicator data-sets is presented in Appendix 2. A high correlation was found between 'evapotranspiration (ISR)' and 'surface runoff (SR)' ($r = 0.734$), 'stormwater pollution (SW)' and 'air pollution (AIR)' ($r = 0.648$), and 'proximity to land-use destinations (LUD)' and 'access to public transport (PT) stops' ($r = 0.731$) indicators. A correlation coefficient ratio 0.8 was taken as the benchmark value as suggested (Katz 1999; Lehman *et al.* 2005; Morien 2006; Christmann and Badgett 2009). It needs to be mentioned that this analysis was conducted with normalized indicator values (between 1 and 5) which narrowed the range of data and resulted in a decrease in standard deviations and an increase in the correlation coefficients. Hence, it was expected to see a high correlation between the scores. Additionally, these indicators measure different variables by using different calculation methods. Based on the literature, these correlations can be interpreted as follows:

- large amounts of impervious surfaces (ISR) are associated with increased SR;
- stormwater pollution (SW) is associated with air pollution (AIR), which means transport-related pollutants become washed off during a rainfall from paved surfaces by causing stormwater pollution;
- proximity to LUD is related with access to PT, which means sustainable mobility encourages PT by providing easier access and shorter times to get to the destination.

2.3.5. Spatial analysis

Spatial analysis of the study area was carried out through aerial remote sensing data with the use of ArcGIS software. From visual and digital interpretations of the aerial photo imagery derived from Google Maps, the total area of each land cover type within parcels was measured by using the ArcGIS Analysis tool. The land cover classification was based on nine main types: roof-building; pavement; driveway; cycleway; walkway; tree-shrub; water; turf-grass; and barren soil.

2.3.6. Weighting

For this study, expert opinion weighting was selected due to the spatial scale and scope of the research. MUSIX is developed to measure the local-level environmental performance of an urban area. In this sense, consultation of local experts' opinion helps to reflect the implications of the existing planning policies, local environmental issues and needs of the study area. Second, MUSIX is developed as an assessment tool to serve in the policy-making process. In this sense, the model results are highly benefited from the input from developers, planners, and policy makers that consist of the expert survey participants. The results indicate that experts assigned 'energy conservation' as the most important indicator. The reason for this is the study area is located in a sub-tropical zone which faces high temperature and humidity all year round. In this climate, energy efficiency is critically important to avoid high energy use of air conditioning systems and reduce greenhouse gas emissions. Passive solar design is an advantage in hot and humid climates to minimize energy use. The results indicate that experts assigned 'noise pollution' as the least important indicator. The reason for this is that there is no commercial, transport, or construction noise problems at a level that adversely impacts on the quality of life of residents in the area. However, neighbourhood noise from residential premises, animals, air conditioners, loud music, or alarms might be an issue which cannot be detected during expert surveys. The results also showed that all indicators met the minimum required relevance rate of 3 and above, so that they were confirmed by experts as key components in sustainability assessment.

2.3.7. Aggregation

This step is composed of two different aggregation stages. First, an arithmetic aggregation was conducted. Additive aggregation is basically the arithmetic average of the weighted and normalized indicator scores. The composite index score was calculated by the following equation:

$$\mathrm{MUSIXCI} = \sum_{i=1}^{n} w_i.x_i, \tag{1}$$

where CI is the composite indicator value, n is the number of indicators, w_i is the weight for indicator i, and x_i is the normalized indicator value.

Second, a spatial aggregation was conducted. The study area was divided into 100 metre × 100 metre grid cells and ArcGIS software was used to transfer parcel-scale aggregated composite index scores into grid cell scores. The aggregation of geographical data is widely used in the analysis of urban systems (Dur, Yigitcanlar, and Bunker 2014). However, there are many challenges, such as the modifiable areal unit problem, which is a widely recognized spatial analytical issue that affects the results of such analyses due to the scale or zoning of the space (Paez and Scott 2004). If the areal units are too small the results might not be meaningful, in contrast, if they are too big the results might not be accurate. Therefore, an interim scale is necessary in order to avoid detection issues. In order to investigate the sensitivity of the changes that occurred from different spatial scales, descriptive statistics of aggregated data were performed for 50, 100, and 150 metre grid cell sizes. Eventually, the 100-metre grid cell was selected as the spatial unit based on the acceptable results from the analysis (Dizdaroglu and Yigitcanlar 2014). Each parcel's composite index score is multiplied by its area percentage within the grid cell and then summed into a single composite score for each grid cell. Finally, the composite index score was presented in five comparative sustainability levels: as suggested by Yigitcanlar *et al.* (2007), low (0.00−1.00), medium-low (1.01−2.00), medium (2.01−3.00), medium-high (3.01−4.00), and high (4.01−5.00).

2.3.8. *Sensitivity analysis*

Each composite index is constructed by several subjective steps, which include the calculation method, selection of indicators, choice of aggregation, and weighting procedures that are associated with some uncertainties in the methodology. Therefore, it is necessary to analyse the sensitivity of the index by using alternative methodological assumptions. In this context, as the first part of the sensitivity analysis, alternative techniques were applied in the weighting and aggregation procedures, as follows: (1) equal weighting which provides the measurement of each indicator with the same degree of importance; (2) factor analysis which allows investigating a statistical relationship to determine the importance of each indicator, and; (3) geometric aggregation which allows investigating the correlation among the performance of the indicators. The composite index scores were calculated by using different combinations of alternative methodological techniques, as illustrated in Appendix 3. The calculation based on 'Expert Opinion Weighting and Geometric Aggregation', 'FA Weighting and Geometric Aggregation', and 'Expert Opinion Weighting and Geometric Aggregation' yield lower sustainability results compared to the MUSIX model results. Specifically, FA weighting with geometric aggregation performed negative differences in a couple of grid cells compared to other scenarios. The underlying reason for this difference depends on the fact that geometric aggregation uses multiplication to summarize data; hence, it performs lower scores than arithmetic aggregation. In order to assess the overall impact of these different methodological assumptions on the MUSIX model results, Spearman's rank correlation analysis was performed with reference to a number of similar studies (Groh,

Table 2. Correlation between the MUSIX model results and different methodological assumptions.

Alternative calculation methods	Correlation with the implemented method (expert opinion weighting, linear aggregation)
Equal weighting, linear aggregation	0.995**
FA weighting, linear aggregation	0.988**
Equal weighting, geometric aggregation	0.985**
FA weighting, geometric aggregation	0.975**
Expert opinion weighting, geometric aggregation	0.990**

**Correlation is significant at the 0.05 level (two-tailed).

von Liechtenstein, and Lieser 2008; Groh and Wich 2009; Saisana 2010). Due to the large data-set, the level of significance was set at 0.05 and a two-tailed test was chosen to identify the level of significant differences between the indicator data-set in either direction. The results revealed that the impact of any of these assumptions is negligible overall, as the correlations between the MUSIX model results and the others are greater than 0.9 (Table 2).

As the second part of the sensitivity analysis, the impact of an underlying indicator on overall outcome of the model was assessed through performing exclusion of one indicator at a time. The analysis was conducted via removing one indicator at a time and then recalculating a reduced model score (Table 3). A low correlation between the MUSIX score and reduced model score implies that the model is highly sensitive to the exclusion of that indicator. The analysis revealed that the correlation between the MUSIX score and the reduced model scores are greater than 0.5, which reveals that the model is robust to small changes in the indicator set.

Table 3. Correlation between the MUSIX model score and reduced model scores.

Reduced model	Spearman's correlation
Evapotranspiration removed	0.727**
Surface runoff removed	0.657**
Urban habitat removed	0.607**
Microclimate removed	0.630**
Stormwater pollution removed	0.674**
Air pollution removed	0.808**
Noise pollution removed	0.563**
Proximity to land-use destinations removed	0.696**
Access to public transport stops removed	0.709**
Walkability removed	0.861**
Lot design removed	0.699**
Landscape design removed	0.759**
Energy conservation removed	0.661**
Water conservation removed	0.641**
The MUSIX model	1.000

**Correlation is significant at the 0.05 level (two-tailed).

3. Interpretation of the model results and evaluation of existing policies

Findings of the MUSIX are presented in a clear and accurate manner through ArcGIS maps. Parcel-scale findings are illustrated in Figure 2

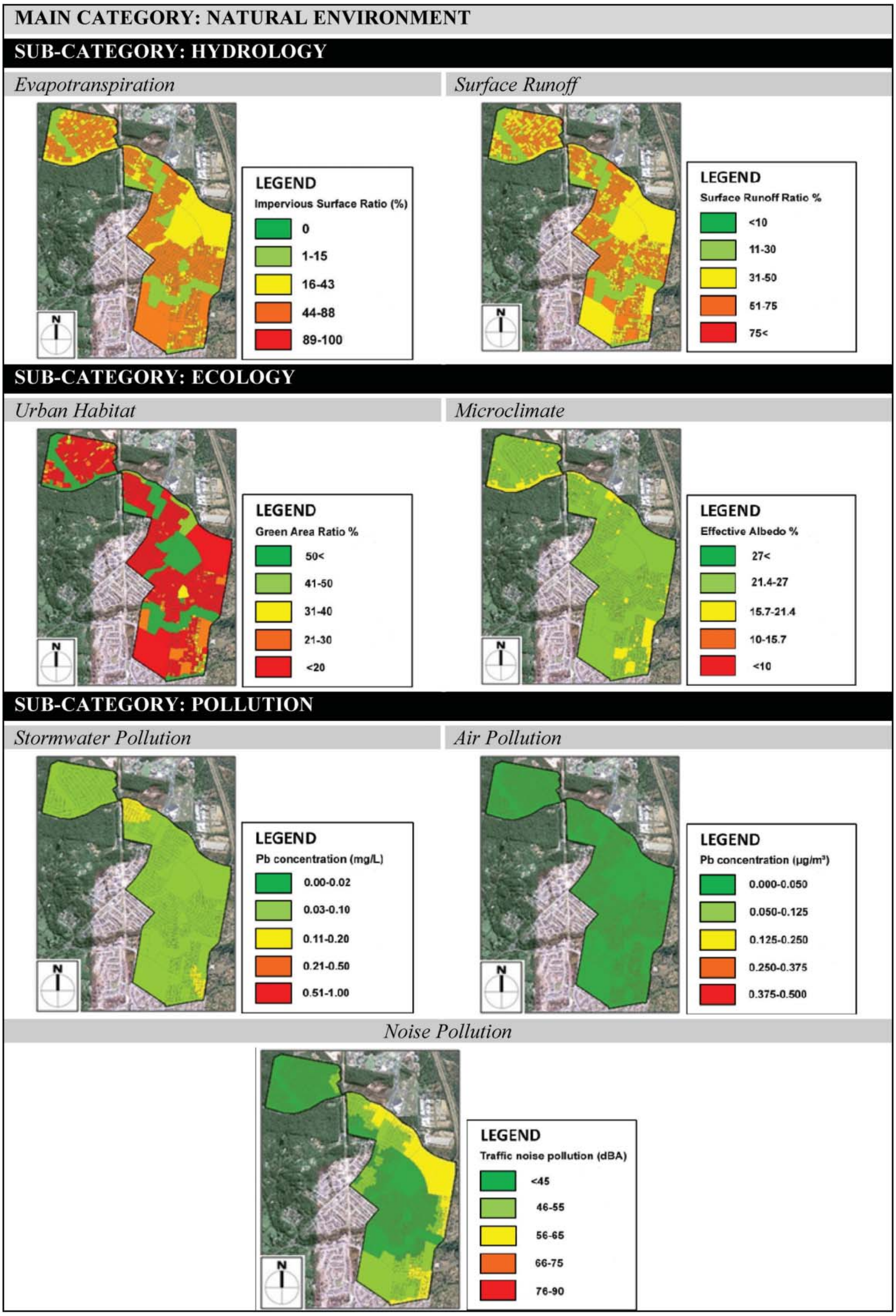

Figure 2. Parcel-level findings of the indicators.

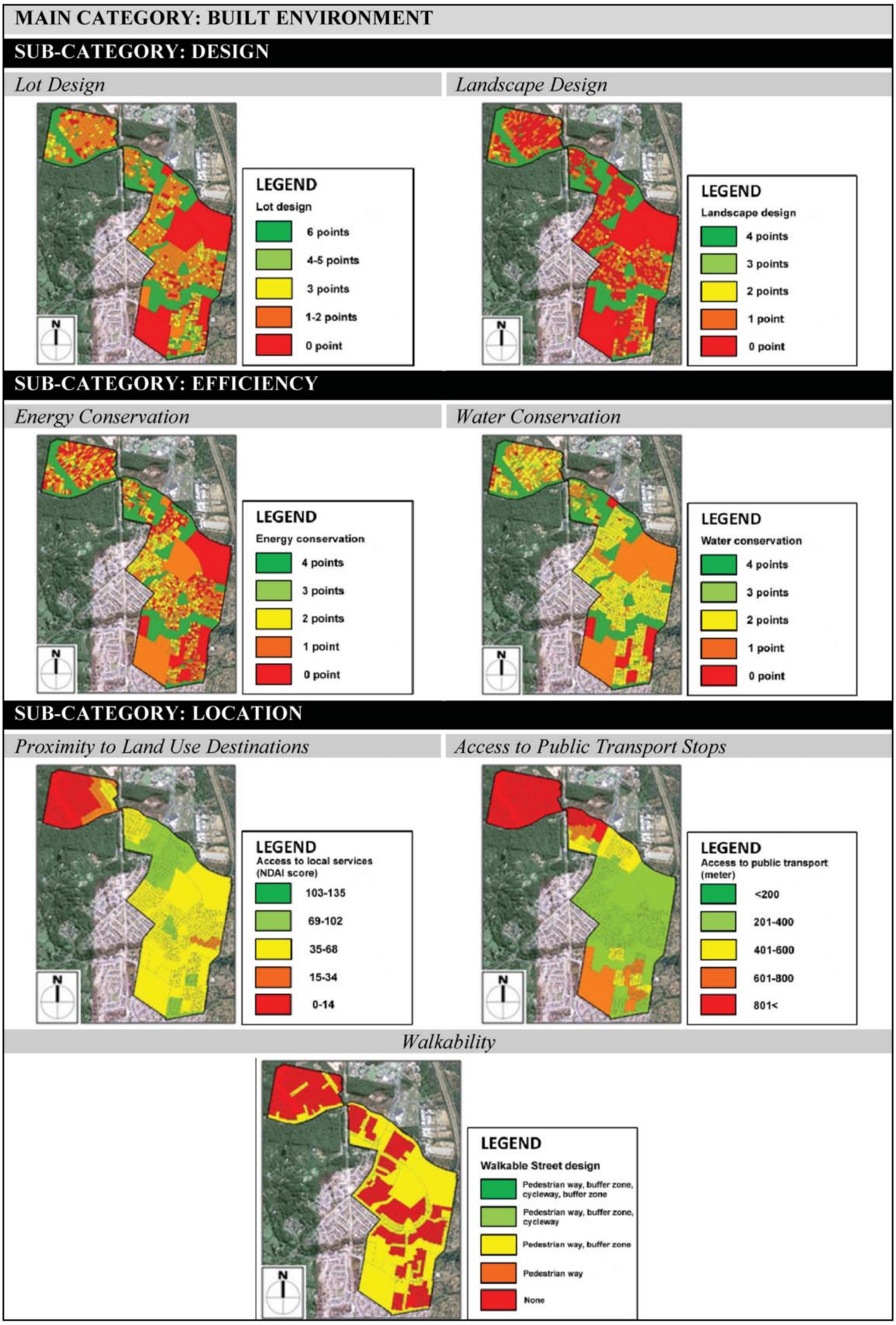

Figure 2. (*Continued*).

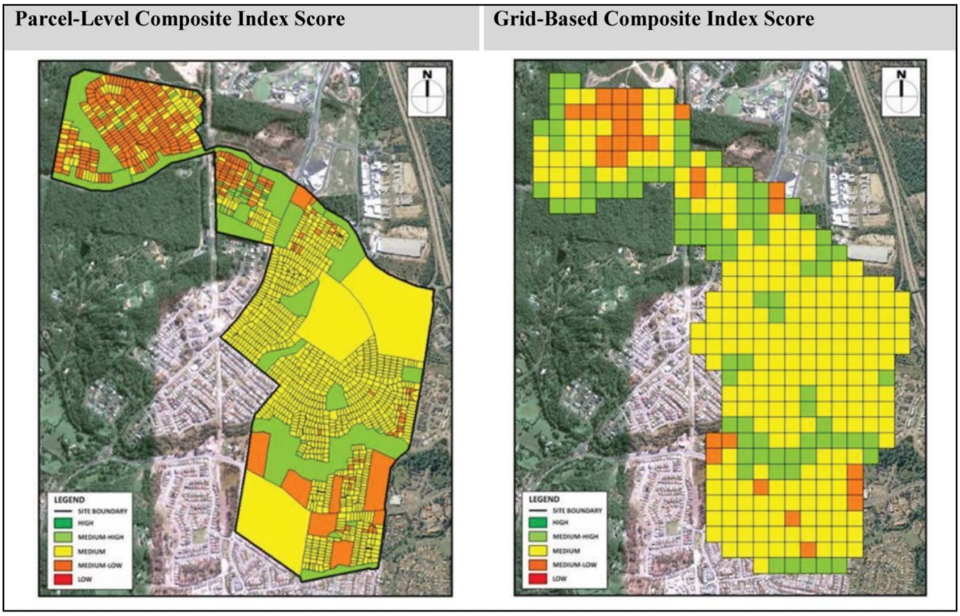

Figure 3. Grid-based composite index scores.

In addition to parcel-scale information, the outcomes of this study are also presented at the grid cell scale to easily integrate parcel-scale model outputs with the different scale assessment tools in the local planning process. Composite index maps of the site are illustrated in Figure 3.

The grid-based composite index score of the area is medium (2.01–3.00). The composite index score shows that the growing residential pressure in the area results in increased impervious surfaces (composite score: 2.16/sustainability performance: medium), which have significant impacts on the site hydrology through excessive SR rates (composite score: 2.34/sustainability performance: medium). In addition, the car-dependent pattern of development in the area contributes to SR by creating more impervious surfaces thereby increases the risk of transporting pollutants into water resources (composite score: 3.90/sustainability performance: medium-high). An increase in the impervious surfaces also affects the ecology of the area by clearing natural vegetation (composite score: 1.23/sustainability performance: medium-low). The development patterns in the area create an environment that discourages pedestrian and bicycle travel (composite score: 1.46/sustainability performance: medium-low). As the area is highly dependent on motor vehicle use, there is limited accessibility by walking – 800m – to land-use destinations (composite score: 2.84/sustainability performance: medium). Lastly, the results indicate that climate responsive design strategies in terms of energy and water efficiency aspects are not common in the area (composite score: 2.57/ sustainability performance: medium).

Evaluation is a key component of the policy-making process. It is a means of determining the appropriateness, effectiveness, and efficiency of government policies and programs, and contributing to policy improvements and innovation (ACT 2010, 3). Evaluation of existing policies provides an understanding of what works, what is being done well, what should be followed or vice versa. By defining their strengths and weaknesses, governments and policy makers can enhance the quality of services they provide. In light of the model findings, evaluation of existing policies can be categorized under the following headings.

3.1. Sustainable stormwater management

The sustainability performance score of 'Site Hydrology' category is medium (composite score is 2.25). Specifically, the large percentage of impervious surfaces (51%) due to high-density development lowers the rate of evapotranspiration (33%) in the area. Moreover, as a result of auto-dependent development, the area is largely covered by paved surfaces (e.g., asphalt, concrete) with increased rates of SR (52%). The results show that the type of development has adverse impacts on waterways, with stormwater pollution posing a major threat to waterway health. To guide stormwater management activities, the City Council prepared a Stormwater Quality Management Plan (GCCC 2015d) which is applicable to all types of land development and re-development. In this plan, the City Council adopted WSUD practices under the city's planning scheme to provide an integrated approach for SR management. Nevertheless, the results indicate that the implementation of these policies is not so successful in the area. Not all of the communities in the area are spending and investing in those strategies which have a range of social, environmental, and economic benefits. It is clear that the City Council should encourage individual landowners and community groups to install sustainable stormwater systems through a variety of regulations, educational, or incentive programs.

3.2. Sustainable ecosystem management

The sustainability performance score of 'Site Ecology' category is medium (composite score is 2.63). As most of the parcels have large amounts of impervious surfaces, the results demonstrate a very low green area ratio (11%) in the area. There are only a few large urban green spaces in the site; which unfortunately, are threatened by development pressure. The microclimate and thermal effect of the site is generally favourable (effective albedo is 24%) as parcels mostly have light-coloured roofs and surfaces related to the climatic conditions. The results show that the area is losing its native vegetation cover from increased impervious surfaces and canal construction. In response, the City Council proposed a Nature Conservation Assistance Program (GCCC 2015f) which provides financial assistance to individual landowners for on-ground restoration projects to protect wildlife habitat on private property. Furthermore, the rehabilitation of endangered and threatened species is protected through the Nature Conservation Strategy (GCCC 2015c). However, the results reveal that the community awareness of environmental issues in the area, as well as the policies to encourage the conservation of biodiversity, need to be enhanced. Additionally, the new developments should be built on previously developed, degraded, or brownfield sites that have no ecological value.

3.3. Environmental quality

The sustainability performance score of 'Site Pollution' category is medium-high (composite score is 4). The pilot site is located in the periphery of the city adjacent to the woodlands, hence the results represent a good picture of stormwater quality (0.09 mg/L), air quality (0.014 $\mu g/m^3$), and noise pollution level (36dBA). To promote environmental quality, the Queensland Government established two pollution prevention policies:

Environmental Protection (Water) Policy 2009 and Environmental Protection (Air) Policy 2008. Furthermore, Environmental Health and City Law Services provided an online lodgement system for reporting noise complaints. However, it has to be mentioned that the rest of the study area is mostly made up of human-made canals and waterfront dwellings that affect water quality. In this context, the natural hydrology of the water systems needs to be protected by reducing the construction of man-made water bodies. The results also show that there is growing stormwater pollution due to the high level of car dependency. Therefore, transport-related air pollution and emissions need to be reduced by promoting green transportation.

3.4. Climate responsive urban design

The sustainability performance score for the 'Site Design' category is medium-low (1.97). Climate responsive site design plays an important role in encouraging energy efficiency in subtropical regions like the study area (Kennedy 2010). The City Council prepared Energy Conservation (Design for Climate) (GCCC 2015e) policy under the city's planning scheme to reduce greenhouse gas emissions arising from energy consumption, in accordance with the Kyoto Protocol and the Cities for Climate Protection program. The policy consists of passive solar design principles such as lot shape, building orientation, solar access, and so on. Unfortunately, most of the parcel layouts do not meet these principles. Due to high-density development, most of the parcels do not have gardens or green spaces; hence, the site presents very poor performance regarding subtropical landscape design (composite score: 1.60/sustainability performance: medium-low). The results show that the study area lacks green spaces. Therefore, eco-friendly landscape design needs to be integrated into the built environment in order to support local biodiversity by using endemic vegetation.

3.5. The use of renewable resources

The sustainability performance score for the 'Site Efficiency' category is medium (2.57). The results show that existing parcel layouts do not meet the principles of energy and water efficient designs, such as encouraging alternative sources, using sustainable roof and paving materials as well as water-saving systems. Most of the parcels do not use sustainable energy sources, such as solar panels. In response, the Australian Greenhouse Office, a Federal Government initiative, offers rebates for installing photovoltaic (PV) cells. The water conservation of the area is generally favourable, as the results indicate a high rate of rainwater tank usage (composite score: 3.00/sustainability performance: medium). Sustainable water initiatives taken by the government has certainly impacted on the behaviour of residents. For instance, the City Council offers free sustainable gardening workshops to promote water efficient gardening through composting, worm farming, plant grouping, and mulching. Moreover, the City Council established a water-saving tips brochure which is designed to make water conservation in homes and gardens.

3.6. Sustainable mobility and accessibility

The sustainability performance score for the 'Site Location' category is medium (2.43). The results indicate that the area has limited accessibility to land-use destinations by walking (Neighbourhood Destination Accessibility Index score: 51). Specifically, the northern part of the site has very limited accessibility to LUD by walking (street design is solely composed of pedestrian way, no cycleway, and buffer zone) as well as access to PT stops (628 meter). As a result of automobile oriented land-use patterns in the area, automobile dependency needs to be reduced by providing different transport modes and mixed-use neighbourhood centres. Moreover, PT needs to be encouraged in the area by providing efficient PT routes and times. In response, the Gold Coast City Transport Strategy 2031 (GCCC 2015g) aims to reduce car dependency by creating an integrated and sustainable transport system. Some of the initiatives in this plan involve: Gold Coast light rail, Council cab services assisting older people and those with disability, oncology patient transport, and car sharing.

4. Conclusion

By developing and testing MUSIX, this research validates that parcel-based spatial analysis can be used as an assessment tool for the local planning scheme to evaluate the sufficiency of existing policies. The model findings provide many advantages in guiding development of policies at local level. First, the model serves as a rating tool for evaluating the existing development by highlighting environmental opportunities and constraints in the area. Second, it serves as a design tool for assisting the environmental quality of future urban areas by setting standards for energy-efficient and climate-responsive residential parcel design. Third, it assists governments and planning institutions to monitor urban ecosystems by providing quantitative information on the impacts of development on the environment (Dizdaroglu and Yigitcanlar 2014). MUSIX also assists different stakeholders by (1) helping master planned communities and developers to rate the sustainability of their development which can also be linked to other sustainability rating systems – such as BREEAM, LEED, Green Star, and CASBEE; (2) assisting local governments to detect environmentally problematic areas in the existing settlements, thereby; this information can be used to improve the future development of infrastructure and services, and; (3) increasing the awareness of individual residents on the environmental issues and the model findings can be used by them to make sustainable improvements in their residential parcels.

On the other hand, MUSIX has limitations. The main limitation of this research was the lack of reliable data during the indicator selection. At the beginning of the study, a comprehensive list of indicators was developed. However, the indicators which are related to socio-economic structure (e.g., household density, income, education, family size, immigration status) were excluded due to problems with individual or household level data collection and privacy issues. As a further research direction, a postdoc research will be carried out to examine the impacts of socio-economic structure of the urban ecosystem on sustainability. The indicators were selected by considering data availability of the Gold Coast area. The same indicator list can be adapted and applied by other local authorities within the greater region. To implement this methodology in different local areas, the indicator-base of the model needs to be customized in relation to the land use and environmental characteristics and parcel-scale data coverage. Furthermore, some challenges occurred during land cover detection through aerial remote sensing data. Because of poor data resolution, weather conditions or shadowing issues, the images were not detectable for some residential areas, hence; some practical and time-efficient solutions were implemented for the success of the study. Lastly, the size of the parcels in the area range from 500 to 2,000 m^2. For any parcels larger than this size, such as schools or retail centres, it needs to be taken into consideration that the parcel-scale might cause loss of detail. In such cases, an alternative approach should be considered.

As an extension of this research, by integrating with the social and economic aspects of sustainability, the model can be further developed to measure the sustainability performance of other local contexts. For instance, at the local level, household surveys provide valuable insights into how the existing environmental policies respond to their own needs and use of resources. Additionally, possible directions for the future design and application of MUSIX could be combined with a new module for evaluating development scenario alternatives. By producing accessible, easily combined parcel-based data, the model findings can support planners and managers in the decision-making process, including the following benefits: (1) providing information to compare during the evaluation of proposed development projects or plans; (2) helping practitioners to choose the most appropriate plan to accomplish sustainability goals; (3) providing collaboration between different government bodies that are needed to ensure the creation of sustainable urban ecosystems.

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Appendix 1. The normalization and calculation of indicators

MAIN CATEGORY: NATURAL ENVIRONMENT

INDICATOR | UNIT | CALCULATION | BENCHMARK VALUES and the REFERENCES

SUB-CATEGORY: HYDROLOGY

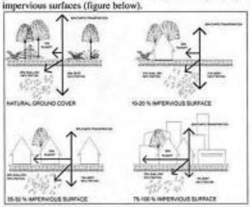
EVAPO-TRANSPIRATION | %

This indicator investigates changes in evapotranspiration resulting from impervious surfaces. The impervious surface ratio was calculated by dividing the total impervious surfaces in a parcel by the total parcel area, as shown below:

$$ISR = \frac{IA_{total} * 100}{A_{Total\ area}}$$

Where: IA_{total} is the total impervious area within parcel, $A_{Total\ area}$ is the total parcel area.

The parameters of this indicator are derived from the U.S. Environmental Protection Agency (1993, p.46) study, which investigates the changes of evapotranspiration rates resulting from increased impervious surfaces (figure below).



Evapotranspiration Rate (%)	Impervious Surface Ratio (%)	Benchmark Value
40	0 (Natural Ground cover)	HIGH
39	1-15	MEDIUM-HIGH
37	16-43	MEDIUM
33	44-88	MEDIUM-LOW
30	89-100	LOW

SURFACE RUNOFF | %

Surface runoff rate for each parcel was calculated based on the 'composite runoff coefficient' formula, which has been used in a number of studies in the literature (Caltrans, 2001; ODOT, 2005; Nicklow *et al.*, 2006; City of Springfield, 2007). The runoff coefficient (C) is defined as the % of rainfall that becomes runoff. Composite runoff coefficient was generated by multiplying each surface type by its coefficient and then dividing the sum of these results by the total parcel area, as shown below:

$$C_{com} = \frac{\sum(C_{individual\ area})(A_{individual\ area})}{A_{total\ area}}$$

Where: $C_{individual\ area}$ is the runoff coefficient of each surface type, $A_{individual\ area}$ is the area of each surface type within parcel, and $A_{total\ area}$ is the total parcel area.

Type of Surfaces	Ranges	Runoff Coefficients	References
Tree cover	0.06-0.20	0.13	Lindeburg (1994)
Grass	0.05-0.35	0.20	ASCE/WEF (1992)
Barren soil	0.35-0.45	0.40	ASCE/WEF (1992)
Driveway/walkway/cycleway	0.75-0.85	0.80	Lindeburg (1994)
Pavement(asphalt, concrete, brick)	0.70-0.95	0.83	ASCE/WEF (1992)
Roof	0.75-0.95	0.85	ASCE/WEF (1992)

Benchmark values derived from Markart *et al.* (2006) were assigned as shown below.

Surface Runoff Ratio (%)	Benchmark Value
<10	HIGH
11-30	MEDIUM-HIGH
31-50	MEDIUM
51-75	MEDIUM-LOW
75<	LOW

SUB-CATEGORY: ECOLOGY

URBAN HABITAT | %

The green area ratio is based on the calculation of the crown area of existing trees and shrubs. Low lying vegetation, such as perennials and grass, was not included. Green area ratio for each parcel was calculated by dividing the total green area in a parcel by the total parcel area, as shown below:

$$GAR = \frac{GA_{Total\ area}}{A_{total\ area}}$$

Where: $GA_{Total\ area}$ is the total green area within parcel, $A_{total\ area}$ is the total parcel area.

Benchmark values derived from Japanese green rating tool CASBEE (2007) were assigned as shown below.

Green Area Ratio (%)	Benchmark Value
50<	HIGH
41-50	MEDIUM-HIGH
31-40	MEDIUM
21-30	MEDIUM-LOW
<20	LOW

MICROCLIMATE | %

The albedo of different surfaces for each parcel was calculated based on the 'effective albedo' formula, which was derived from the study conducted by Taha *et al.* (1988). The effective albedo was generated by multiplying each surface type by its albedo value and then dividing the sum of these results by their total area as shown below:

$$EA = \frac{\sum(A_i * \propto_i)}{\sum A_i}$$

Where: A_i is the area of each surface type within parcel, $\propto_i$ is the albedo value of each surface type.

Type of Surfaces	Ranges	Averages	References
Roads (driveway/cycleway) (asphalt)	0.05-020	0.13	Oke (1978), Akbari et al. (1992)
Water surface (solar altitude between >10°C and >45°C)	0.03-0.22	0.14	German Solar Energy Society (2008)
Barren soil	0.17	0.17	German Solar Energy Society (2008)
Pavement	0.15-0.25	0.20	Akbari et al. (2009)
Building roof	0.10-0.35	0.23	Taha et al. (1988)
Grass	0.25-0.30	0.28	Akbari et al. (1992)
Walkway (concrete)	0.25-0.40	0.33	Akbari et al. (2009)

As stated by Oke (1978, p. 247), the albedo value of urban surfaces are in the 10-27 range. Therefore, five reference levels were equally assigned in this range, as shown below.

Effective Albedo (%)	Benchmark Value
27 <	HIGH
21.4-27	MEDIUM-HIGH
15.7-21.4	MEDIUM
10-15.7	MEDIUM-LOW
<10	LOW

SUB-CATEGORY: POLLUTION

STORMWATER POLLUTION | mg/L

This indicator was calculated based on transport related lead concentrations in the stormwater. This study is part of an ARC Linkage project, which investigates the transport related pollutants build-up and wash-off from road surfaces that are collected from 11 sites in the case area. In the scope of this project, stormwater pollution data were derived from the study conducted by Mahbub (2011). By using transport network forecasts for 2011, a stepwise regression analysis was employed to estimate the wash-off concentration on each road segment by Dur (2012). These values were then interpolated by ArcGIS spatial analysis tool to the whole area.

Benchmark values are derived from water quality standards for drinking, recreational and irrigation advised by National Health and Medical Research Council and the Natural Resource Management Ministerial Council (NHMRC and NRMMC, 2004).

Pb concentration (mg/L)	Benchmark Value
0.00-0.02	HIGH
0.03-0.10	MEDIUM-HIGH
0.11-0.20	MEDIUM
0.21-0.50	MEDIUM-LOW
0.51-1.00	LOW

AIR POLLUTION | μg/m³

This indicator was calculated based on transport related lead concentrations in the air. As in the previous indicator, the same statistical and spatial analyses and disaggregation procedure were applied for this indicator.

Benchmark values are assigned in accordance with the classification and standards of air toxics from the Department of Sustainability, Environment, Water, Population and Communities as shown below (DSEWPC, 2001).

Pb concentration (μg/m³)	Benchmark Value
0.000-0.050	HIGH
0.050-0.125	MEDIUM-HIGH
0.125-0.250	MEDIUM
0.250-0.375	MEDIUM-LOW
0.375-0.5	LOW

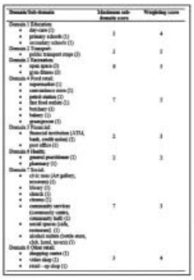
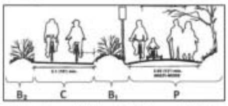
NOISE POLLUTION | dBA

This indicator was calculated based on the road traffic noise in the study area. The method of calculation was adapted from the CORTN (calculation of road traffic noise) developed by the UK Department of Transport (DOT/Welsh Office, 1988). The CORTN model estimates the basic noise level L10 (This is the noise level exceeded for 10 % of the time of the measurement period) both on 1h and 18h reference time. This level is obtained at a reference distance of 10 m from the nearest carriageway edge of a highway. First, virtual receptors are located to the site through ArcGIS software. Additionally, all the relevant road and traffic data (such as traffic volumes, compositions and speeds) need to be provided from local council or the relevant Authority. By using this data, the noise level for each receptor is calculated by using ArcGIS software.

Benchmark values derived from Kloth *et al.* (2008) were assigned as shown below.

Traffic noise pollution (dBA)	Benchmark Value
<45	HIGH
46-55	MEDIUM-HIGH
56-65	MEDIUM
66-75	MEDIUM-LOW
76-90	LOW

Appendix 1. (*Continued*)

<table>
<tr><th colspan="4">MAIN CATEGORY: BUILT ENVIRONMENT</th></tr>
<tr><th>INDICATOR</th><th>UNIT</th><th>CALCULATION</th><th>BENCHMARK VALUES and the REFERENCES</th></tr>
<tr><th colspan="4">SUB-CATEGORY: LOCATION</th></tr>
<tr><td>PROXIMITY TO LAND USE DESTINATIONS</td><td>NDAI score</td><td>This indicator was calculated based on the accessibility of each parcel to land use destinations, which is located within 800 m walking distance by using the ArcGIS Network Analysis tool. Land use destinations (classified on the right-hand side) are defined as the local services provided for the residents to visit regularly for their needs. NDAI score is calculated by the following equation:
$$NDAI = \sum_i S_i . w_i$$
Where i is the LUD category (i=1,2,…,8), S is the score of the LUD category and w is the weight of the LUD category.
</td><td>Benchmark values were adapted from the Neighbourhood Destination Accessibility Index (NDAI) developed by Mavoa <i>et al.</i> (2009). The NDAI is a GIS tool that measures the pedestrian access to eight domains of neighbourhood destinations within given boundaries (Witten <i>et al.</i>, 2011, p. 205). Weightings ranging from 2 to 5 were assigned to each domain based on their relative importance as a catalyst to physical activity. The weighted domain scores were then summed to produce a total neighbourhood destination index score.
<table>
<tr><th>Access to local services (NDAI score)</th><th>Benchmark Value</th></tr>
<tr><td>103-135</td><td>HIGH</td></tr>
<tr><td>69-102</td><td>MEDIUM-HIGH</td></tr>
<tr><td>35-68</td><td>MEDIUM</td></tr>
<tr><td>15-34</td><td>MEDIUM-LOW</td></tr>
<tr><td>0-14</td><td>LOW</td></tr>
</table></td></tr>
<tr><td>ACCESS TO PUBLIC TRANSPORT STOPS</td><td>meter</td><td>The distance to the nearest public transport stop was calculated for each parcel by using the ArcGIS Network Analysis tool.</td><td>Benchmark values were adapted from the Land Use and Public Transport Accessibility Model (LUPTAI) developed by Yigitcanlar <i>et al.</i> (2007) and assigned as shown below.
<table>
<tr><th>Access to public transport (meter)</th><th>Benchmark Value</th></tr>
<tr><td><200</td><td>HIGH</td></tr>
<tr><td>201-400</td><td>MEDIUM-HIGH</td></tr>
<tr><td>401-600</td><td>MEDIUM</td></tr>
<tr><td>601-800</td><td>MEDIUM-LOW</td></tr>
<tr><td>801<</td><td>LOW</td></tr>
</table></td></tr>
<tr><td>WALKABILITY</td><td>points</td><td>Points were assigned based upon achieved criteria for sidewalk design advised by Time-Saver Standards for Urban Design, as shown:


Abbreviations: P (pedestrian way), B_1 (vegetative buffer zone), C (Cycleway), B_2 (buffer zone) (Watson <i>et al.</i>, 2003, p. 541)</td><td>Benchmark values were assigned as shown below.
<table>
<tr><th>Walkability</th><th>Benchmark Value</th></tr>
<tr><td>P + B_1 + C + B_2</td><td>HIGH</td></tr>
<tr><td>P + B_1 + C</td><td>MEDIUM-HIGH</td></tr>
<tr><td>P + B_1</td><td>MEDIUM</td></tr>
<tr><td>P</td><td>MEDIUM-LOW</td></tr>
<tr><td>None</td><td>LOW</td></tr>
</table></td></tr>
<tr><th colspan="4">SUB-CATEGORY: DESIGN</th></tr>
<tr><td>LOT DESIGN</td><td>points</td><td>Points were assigned based upon the principles of passive solar design met by the existing lot plan (derived from King <i>et al.</i>, 1996; DEWHA, 2008).
<table>
<tr><th>Efforts to be evaluated</th><th>Benefits</th><th>Points</th></tr>
<tr><td>Lot shape: Rectangular</td><td>To get best solar access and most suitable for maximising lot yield</td><td>1</td></tr>
<tr><td>Building orientation: Long side E-W orientated</td><td>To maximise the best use of solar energy</td><td>1</td></tr>
<tr><td>Solar access: North facing living areas or outdoor spaces</td><td>To improve energy efficiency by providing access to winter sun</td><td>1</td></tr>
<tr><td>Zero lot line: houses set to south of lots</td><td>To reduce lot size, maximise solar access and outdoor living space</td><td>1</td></tr>
<tr><td>Attached housing: sharing walls with neighbours particularly on the E or W boundaries</td><td>To save energy and reduce greenhouse gas emissions</td><td>1</td></tr>
<tr><td>Location of other buildings: Avoid other buildings carports, sheds) on the northern side of the lot</td><td>To maximise the use of north facing living areas</td><td>1</td></tr>
</table></td><td>Benchmark values were assigned as shown below.
<table>
<tr><th>Lot design</th><th>Benchmark Value</th></tr>
<tr><td>6 points</td><td>HIGH</td></tr>
<tr><td>4-5 points</td><td>MEDIUM-HIGH</td></tr>
<tr><td>3 points</td><td>MEDIUM</td></tr>
<tr><td>1-2 points</td><td>MEDIUM-LOW</td></tr>
<tr><td>0 point</td><td>LOW</td></tr>
</table></td></tr>
<tr><td>LANDSCAPE DESIGN</td><td>points</td><td>Points were assigned based upon the principles of subtropical landscape design met by the existing parcel plan (derived from Kennedy, 2010).
<table>
<tr><th>Efforts to be evaluated</th><th>Points</th></tr>
<tr><td>Southern side: No trees.</td><td>1</td></tr>
<tr><td>Northern side: Trees shading the north of buildings can reduce energy needs in summer by providing cooling. Depending on their height and distance from the building, such trees may need to be deciduous.</td><td>1</td></tr>
<tr><td>Eastern side: Trees shading the eastern sides of buildings cast shadows in the cooler morning hours.</td><td>1</td></tr>
<tr><td>Western and South-western sides: Trees shading the west and south-west of buildings reduce summertime energy demand for cooling by blocking the hot afternoon sun.</td><td>1</td></tr>
</table></td><td>Benchmark values were assigned as shown below.
<table>
<tr><th>Landscape design</th><th>Benchmark Value</th></tr>
<tr><td>4 points</td><td>HIGH</td></tr>
<tr><td>3 points</td><td>MEDIUM-HIGH</td></tr>
<tr><td>2 points</td><td>MEDIUM</td></tr>
<tr><td>1 point</td><td>MEDIUM-LOW</td></tr>
<tr><td>0 point</td><td>LOW</td></tr>
</table></td></tr>
<tr><th colspan="4">SUB-CATEGORY: EFFICIENCY</th></tr>
<tr><td>ENERGY CONSERVATION</td><td>points</td><td>Points were assigned based upon the principles of energy efficient design met by existing parcel plan (derived from Olgyay, 1963; Hyde, 2000)
<table>
<tr><th>Efforts to be evaluated</th><th>Points</th></tr>
<tr><td>Create an outdoor living space such as courtyard, verandas, balconies</td><td>1</td></tr>
<tr><td>Use of renewable energy such as photovoltaic panels, solar water heating</td><td>1</td></tr>
<tr><td>Use of light-coloured roof</td><td>1</td></tr>
<tr><td>Use of light-coloured paving</td><td>1</td></tr>
</table></td><td>Benchmark values were assigned as shown below.
<table>
<tr><th>Energy conservation</th><th>Benchmark Value</th></tr>
<tr><td>4 points</td><td>HIGH</td></tr>
<tr><td>3 points</td><td>MEDIUM-HIGH</td></tr>
<tr><td>2 points</td><td>MEDIUM</td></tr>
<tr><td>1 point</td><td>MEDIUM-LOW</td></tr>
<tr><td>0 point</td><td>LOW</td></tr>
</table></td></tr>
<tr><td>WATER CONSERVATION</td><td>points</td><td>Points were assigned based upon the principles of water efficient design met by existing parcel plan (derived from Olgyay, 1963; Hyde, 2000)
<table>
<tr><th>Efforts to be evaluated</th><th>Points</th></tr>
<tr><td>Use of green roof</td><td>1</td></tr>
<tr><td>Reuse of water (rainwater tank)</td><td>1</td></tr>
<tr><td>No pool or other water features</td><td>1</td></tr>
<tr><td>Estimated Irrigation water use does not exceed the residential water consumption target implemented by the Queensland Water Commission</td><td>1</td></tr>
</table></td><td>Benchmark values were assigned as shown below.
<table>
<tr><th>Water conservation</th><th>Benchmark Value</th></tr>
<tr><td>4 points</td><td>HIGH</td></tr>
<tr><td>3 points</td><td>MEDIUM-HIGH</td></tr>
<tr><td>2 points</td><td>MEDIUM</td></tr>
<tr><td>1 point</td><td>MEDIUM-LOW</td></tr>
<tr><td>0 point</td><td>LOW</td></tr>
</table></td></tr>
</table>

Appendix 2. Spearman correlation coefficients of the indicator set

	ISR	SR	SW	AIR	NOISE	GAR	EA	LUD	PT	WLK	LOTDSG	LNDDSG	ENERGY	WATER
ISR	1.000													
SR	**0.734****	1.000												
SW	0.005	0.062**	1.000											
AIR	0.075**	0.120**	**0.648****	1.000										
NOISE	-0.034	-0.040**	0.290**	0.304**	1.000									
GAR	0.271**	0.327**	0.036	0.023	-0.132**	1.000								
EA	0.070**	0.044**	-0.018	0.013	0.066**	-0.109**	1.000							
LUD	-0.099**	-0.041**	0.137**	0.109**	-0.169**	-0.012	-0.035	1.000						
PT	-0.079**	0.009	0.244**	0.089**	-0.105**	0.064**	-0.051**	**0.731****	1.000					
WLK	-0.075**	-0.062**	0.086**	0.014	-0.059**	0.058**	-0.021	0.177**	0.188**	1.000				
LOTDSG	0.301**	0.256**	-0.117**	-0.053**	-0.093**	0.014	0.070**	-0.114**	-0.161**	0.032	1.000			
LNDDSG	0.460**	0.445**	-0.137**	-0.036	-0.190**	0.427**	0.000	-0.157**	-0.113**	-0.014	0.340**	1.000		
ENERGY	0.282**	0.250**	0.022	0.110**	0.060**	0.016	0.068**	-0.065**	-0.053**	-0.011	0.306**	0.271**	1.000	
WATER	0.241**	0.234**	0.212**	0.216**	0.127**	-0.249**	0.114**	0.150**	0.062**	0.010	0.261**	0.044**	0.216**	1.000

**. Correlation is significant at the 0.05 level (2-tailed), n=2843

Abbreviations: Impervious surface ratio (ISR), surface runoff (SR), stormwater pollution (SW), air pollution (AIR), noise pollution (NOISE), green area ratio (GAR), albedo (EA), land use destinations (LUD), public transport (PT), walkability (WLK), lot design (LOTDSG), landscape design (LNDDSG), energy consumption (ENERGY), and water consumption (WATER). High correlations are highlighted in bold.

Appendix 3. Composite index maps calculated by alternative methodological techniques