# Carbon Footprint of an Australian Coastal Town: An Assessment of Three Planning Scenarios at Neighbourhood Level

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**Abstract:** The highly populated coastal cities and towns in Australia are also most vulnerable places to climate change induced by increased greenhouse gas (GHG) emission through anthropogenic activities. It is estimated that urban areas account for 60-80% of the global energy use and emit more than 70% of global greenhouse gases. Since most future population growth is expected to be in urban areas, one main question regarding urban planning is how new urban communities should be developed in order to minimise resource consumption and carbon emissions. This study develops a spatially explicit model to simulate the carbon footprint of a coastal town called Point Cook in Victoria under three development scenarios: 1) the horizontal (the business as usual (BAU)), 2) the vertical (Le Corbusier's 'Radiant City'), and 3) the mixed. By using selected neighbourhoods in Melbourne as case study areas, this research will develop a spatially explicit model that integrates geographical characteristics, urban form, street-network structure, housing type, population density, energy supply, etc. to evaluate the carbon footprint associated with different development scenarios. Data for model calibration are collected from VicLand (for land use information including transport, vegetation, hydrology, planning, and elevation) and the Australian Bureau of Statistics (for attributes about population and social development)). The findings will provide timely information relevant to the debate about suburban sprawl and low impact development and to decision-making in the design and development of low carbon communities. It is hoped that this research will improve the capacity to achieve national goals in carbon emission reduction in Australia.

**Keywords:** Carbon footprint, Planning scenarios, Urban sustainability, Melbourne

## 1. Introduction

The populated coastal cities and towns are concerned with sea level rise due to climate changes and global warming. In order to limit the increase of future global warming in 2˚C, it is necessary to stabilise the atmospheric concentration of $CO_2$ equivalent in about 450 ppm (Güereca et al., 2013). For that purpose, it is required that all countries implement actions to contribute to the reduction of GHG emissions from 2010 to 2050 (Güereca et al., 2013). To cope with global climate change challenges, regional level carbon cycle assessment and local level carbon footprint measurements are important in decision making for city and regional planning since urban areas account for 75% of global carbon emissions (Grimm et al., 2008; IPCC, 2006). In order to systematically measure the impacts of human activities on the natural environment, many tools and frameworks are developed (Barnosky et al., 2012; Borucke et al., 2013; Steen-Olsen et al., 2012; Wackernagel, 2014) to explore flows of energy, water and other goods and services used to satisfy the needs for water, energy, food, shelters and transportation in a society (Chavez and Ramaswami, 2013; Jha et al., 2013; Ramaswami et al., 2012). Among all these tools and frameworks, the consumer responsibility approach uses footprints as indicators of the total direct and indirect effects of a product or consumption activity (Steen-Olsen, 2012).

## 2. Literature review

Carbon footprint is defined as the amount of $CO_2$-equivalent emissions caused directly and indirectly by an activity (Wiedmann and Minx, 2008). Similar to ecological footprint, carbon footprint can be applied to a person, a product, a population, a company, an organisation, a region or a country. As a newly-emerging field, the qualitative and quantitative research is still under discussion so there is no unified and acknowledged method to calculate the carbon footprint. However, the methods used to assess carbon footprint in most studies in the current literature can be classified into three categories: 1) the input-output (IO) analysis; 2) the life cycle assessment (LCA) approach; and 3) the IPCC method. The IO approach uses an allocation model to attribute consumption of input resources to functional uses such as household, food, clothing, commuting, etc. and calculate carbon emissions from each of the functional uses of input resources in a given time period. Many studies using the IO methods explore carbon emissions at household level (Druckman and Jackson, 2009; Jackson et al., 2006) but this approach can also be applied into different spatial levels (Munksgaard et al., 2005). LCA is a tool to assess the potential environmental impacts and resources used throughout a product's lifecycle, i.e., from raw material acquisition, via production and use phases, to waste management (ISO, 2006). Recently LCA has been widely used to estimate the carbon footprint of products or certain industrial level (Bakhshi and Demonsabert, 2012; Pattara et al., 2012) or carbon footprint of certain sectors at city or regional level such as carbon sequestration by growing tress in urban green space (Strohbach et al, 2012). The IPCC method is based on detailed emission inventory from different accounts such as energy, food, waste, etc. (IPCC, 2006). The IPCC method has been widely used to estimate and track emissions profiles for different countries (Hertwich and Peters, 2009; Sinden, 2009) and for individuals (per capita emissions) (Lenzen et al, 2007).

For broad scale urban and regional planning studies, these methods have been used to provide useful accounts for the total emission of a city or per capita footprint in a city. The results are generally useful to guide national policy making aimed at emission reduction. However, national reduction goals are to be realised through local actions such as urban planning, design and development, which are always taken at much finer (e.g. city suburb or neighbourhood) scales. Additionally, national level carbon footprint accounts ignore spatial heterogeneity, which leads to ecological fallacy in analysis. Therefore, spatially explicit carbon footprint accounting is critical to the realisation of ambitions of carbon-neutral cities and implementation low carbon development. Unfortunately there are few efforts being made in this regard so far, although similar studies have been made in water and land use footprint (Phisher and Bayer, 2014; Norman et al, 2012). This study attempts to fill the gap in the carbon footprint literature by applying a novel approach to account carbon footprint at the suburban neighbourhood scale.

## 3. Project site and methods

### *3.1. Project site – The Point Cook Urban Growth Area*

The Point Cook urban growth area is selected to test its carbon footprint under 3 development scenarios. Only 25 km south-west from Melbourne's Central Business District (CBD), Point Cook is served by the Werribee rail line and Westgate Freeway connecting it with Melbourne CBD and regional Victoria (Figure1). Point Cook is the home of Royal Australian Air Force (RAAF) Base Williams, Point Cook is the birthplace of RAAF , and is the current home of the RAAF Museum in Australia. The wetlands of the Point Cook Coastal Park form part of the Cheetham and Altona Important Bird Area. Coupling the population growth is the rapid housing development. As one of the designated urban growth areas (UGAs) by Melbourne 2030 (Department of Infrastructure, 2002), today the Werribee-Point Cook area is one of the major growth regions in Melbourne's western suburbs. In 2011, the total population of Point Cook was 33,362 people. It is expected to increase by over 30,000 people to 63,461 by 2026, at an average annual growth rate of 4.38%. This is based on an increase of over 10,000 households during the period, with the average number of persons per household falling from 3.09 to 3.05 by 2026 (Forecast.id, 2015).

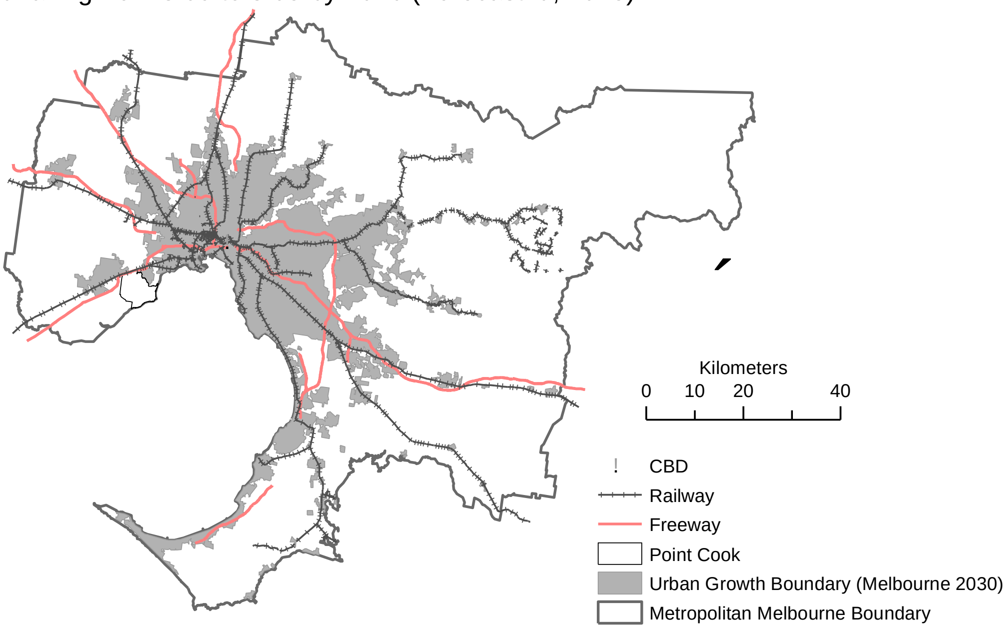


Figure 1: Point Cook is located at the urban growth boundary speculated in Melbourne 2030

### *3.2. Methods*

Time series of remote sensing imageries are collected for digital land use and cover change characterisation. GPS data and other high resolution aerial photos are used for ground truth purposes. Statistical data and demographic data from Australian Bureau of Statistics are collected for the analysis in the later stage coupling the carbon footprint outputs from the GIS-based simulation model. The final stage of the study is to compare the carbon footprint of the 3 different scenarios and assess whether the site is a carbon source or a sink and what the magnitude is. Given the data and tools used in the study, the method itself is innovative as it is the first attempt to analyse the carbon footprint at the neighbourhood level using a spatial explicit approach.

In this study, the carbon footprint is estimated by calculating the balance between the source and sink factors using land use data based on each of the development scenario. Carbon fluxes and emissions of each land use type are mapped using the GIS-based spatial explicit modelling approach. A literature survey reveals that no previous spatially explicit study at suburb scales has been made. Therefore this study is the first attempt to quantify carbon footprint at the neighbourhood scale in a spatially explicit manner.

Based on the assumption that there is no carbon exchange between different land use types, the carbon footprint of a site is calculated as

$$CF = \sum_{i=1}^{n} CF_i \tag{1}$$

Where:

*CF* is the total carbon footprint of the site

*i* is individual land use category; and *n* is the total number of land use categories (*n* = 7 in this study, see below for details)

$CF_i$ is the individual land use type on the site, which is classified into 9 major categories as follows: 1) buildings; 2) agricultural; 3) forest; 4) grassland; 5) water area; 6) wetland; and 7) transport.

Considering the fact that there are different subtypes in each land use category (e.g. different housing densities under the residential category, or different tree densities under the vegetation category), $CF_i$ is calculated as

$$CF_i = \sum_{j=1}^{k} LU_j \times E_j \pm A_j \tag{2}$$

Where:

*j* is individual land use subtype; and *k* is the total number of subtypes in one land use category.

$LU_j$ is the carbon footprint of the area with the *j* subtype of land use. In this study, LU information is adapted from published average carbon flux (see Table 1 for details).

$E_j$ is the equivalence factor for cross site comparisons, which deals with situation where the carbon sequestration or emission rate for the same subtype of land use may be different for different project sites.

$A_i$ is the adjustment factor considering local ad hoc events (such as a local bushfire) that may affect the carbon sequestration or emission of the site.

Integrating Equations (1) and (2), CF is calculated using Equation (3) when Equation (2) is put in Equation (1) as follows

$$CF = \sum_{i=1}^{n} \sum_{j=1}^{k} LU_{ij} \times E_{ij} \pm A_{ij} \tag{3}$$

### *3.3. The three scenarios*

As noted above, if Point Cook grows as projected by 2030, thousands of additional people will require housing over the course of the next two decades. If these people are to be housed in detached single family home then 11,000 homes are required. As we have seen, there is land available for homes set out at an average density of 10 homes per hectare in the current western Melbourne metropolitan area (BAU scenario). To consider the effects of different development scenarios on the carbon footprint of the site, other forms of development are also explored (vertical and mixed scenarios) based on different land use pattern and building densities.

### *Horizontal scenarios (Business As Usual: BAU)*

The horizontal scenario resembles most on-going housing development project in the urban growth frontiers of Melbourne. Under this scenario, to accommodate most of the predicted population increase, Point Cook would simply continue to build low-density suburbs the way it does in the western metropolitan Melbourne region now. The BAU plan for Point Cook growth area is characterised by low to medium density single family housing development with a town centre built in the middle of the site (Figure 2). With over hundreds of years' experience in a sandy and clayey landscape that can be easily remodelled, the western suburb is very good at constructing relatively high-standard suburbia in the quintessential suburban metropolitan Melbourne. The BAU scenario applies a set of design guidelines conceived to ensure that our suburbs are well crafted at the human scale but it doesn't, and nor can it be expected to, substantively challenge suburban orthodoxy. Supporting around 20366 people (2011 census), the current urban footprint of Point Cook is 285,000 hectares. The average density is 10 dwellings per hectare (this is still low compared with the average density in many European cities which is 250 dwellings per hectare, often more).

Under this scenario, the total number of dwelling unit is 18,818, consisted of mainly detached single family houses and limited numbers of townhouses adjacent to the town centre and neighbourhood shopping strips (Table 1).

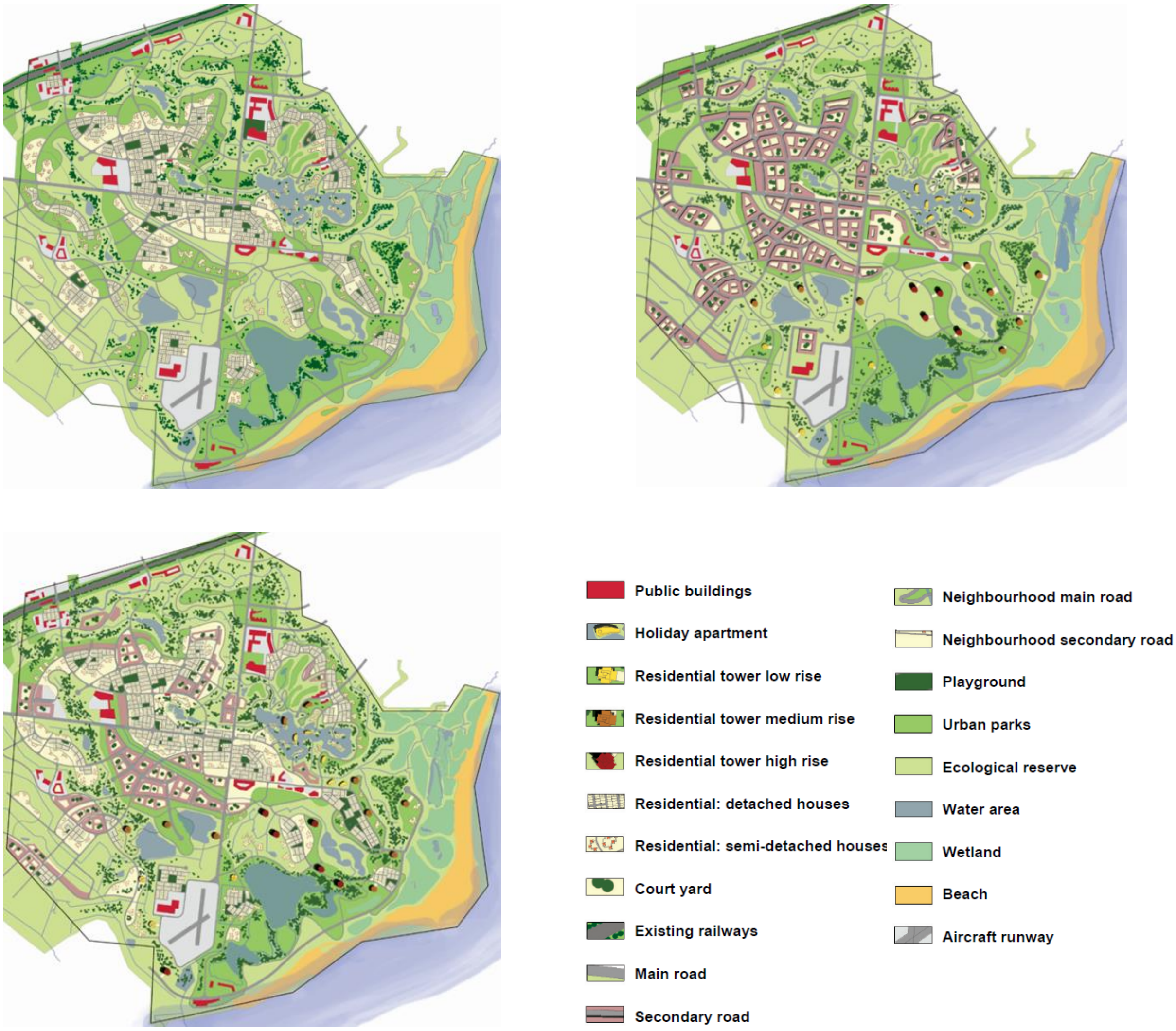


Figure 2. The three scenarios for urban development in Point Cook urban growth area (upper left: BAU scenario; upper right: vertical scenario; and bottom: mixed scenario)

### *Vertical scenario*

The vertical scenario uses a density 10 to 50 times that of conventional suburbia. The theoretical basis for the vertical scenario lies in Le Corbusier's 'Radiant City'. This utopian ideology of urban master plan using the 'Towers in the park' concept was perceived to have certain influence on the urban planning of many contemporary cities including New York City (Schulz, 2015). Though radical, strict and nearly totalitarian in its order, symmetry and standardization, Radiant City proposed principles had an extensive influence on modern urban planning and led to the development of new high-density housing typologies (Merin, 2013). The Radiant City was to emerge from a tabula rasa: it was to be built upon nothing less than the grounds of demolished vernacular European cities. The new city would contain prefabricated and identical high-density skyscrapers, spread across a vast green area and arranged in a Cartesian grid, allowing the city to function as a "living machine (Schulz, 2015)." As mentioned above, the Point Cook growth areas were developed on 'greenfield' land since 1990s thus it provide an ideal opportunity to test the carbon footprint of the vertical scenario using the urban planning concept described in Le Corbusier's 'radiant city' ideology.

The plan under the vertical scenario for Point Cook growth area is characterised by highly density high-rise development with vast landscape reserved as green space or parks (Figure 2). However all commercial, institutional, and social buildings such as town centres, shopping strips, schools, playgrounds, and social housings are maintained the same as in the BAU scenario, in order to compare and highlight the differences in carbon footprint resultant from the different density in residential developments.

Under the vertical scenarios, 19,212 dwelling units are provided through 55 low- to high-rise residential apartment towers (Table 1) on most of the land which would otherwise be used for low density development.

Table 1: Total dwelling units and types under the three scenarios

| Scenario | Detached House (Low Density | Apartment Tower (High Density) | Townhouses (Medium Density) | Total |
|---|---|---|---|---|
| **BAU Scenario** | 15,923 | - | 2,895 | 18,818 |
| **Vertical Scenario** | - | 19,212 | - | 19,212 |
| **Mixed Scenario** | 9,603 | 7,244 | 2,063 | 18,906 |

### *Mixed scenario*

The mixed scenario combines the ideal 'Towers in the Park' concept with the typical existing growth pattern in Australian suburbs. Under this scenario, low, medium, and high rise residential tower are scattered among the low or medium density developments. Some innovative ideas such as Food City (Weller, 2012), which involves increased density suggest that the remaining low-lying land on the site can be utilised for high-tech organic agricultural production (Figure 2). This idea leads to a third, Car Free City, a system of public transport which can be built into greenfield areas and retrofitted through our existing suburbs.

Compared with the BAU scenario and the vertical scenario, the mixed scenario represents the potential for low carbon city development as it provides more flexible housing choices (thus higher level of affordability). It is also a more environmentally friendly approach as well as economically progressive strategy because under this scenario environmental and ecological concerns are considered against other social and cultural issues such as economic desirability and associability of living in an urban area, which are detrimental to urban life. The carbon footprint of this scenario therefore will have profound influence to the planning of future cities and will be most likely to be adopted by the future communities.

The mixed scenario can provide a total of 18,906 dwelling units, including 9,603 detached single family houses of different lot size; 7,244 unit in low- to high-rise apartment towers; and 2,063 units in townhouses (Table 1).

## 4. Results

The plans based on the three development scenarios are digitised in GIS and are used as input data for Equation (3) to simulate the carbon footprint under each scenario. Through literature survey input values for important parameters used in the model are obtained (Table 2). Ancillary data such as remote sensing imagery and GPS readings are used to improve accuracy in digitising site-specific land use types such as industrial and commercial land use, and civic and institutional land use. Model output is analysed in terms of spatial distribution pattern and annual carbon footprint for the entire suburb and for dwelling units.

Table 2: Average carbon sequestration or emission rates for different land use types[a]

| Land Use Type | Carbon Footprint ( ± t $CO_2$-e $ha^{-1}yr^{-1}$)[b] | Reference |
|---|---|---|
| **Buildings**[c] | +24.7 ~ +894.9 | Floyd, 2012; Rothberg, 2011; Alvarez et al, 2014; Kellett et al, 2013 |
| **Agriculture**[d] | -1~ -2.4 | Zhang et al, 2014a |
| **Forest** | -2.5 ~ -45 | Valentini et al., 2000; Zhang et al, 2014a; Zhang et al, 2014b |
| **Water** | - 0.2 ~ -0.4 | IPCC, 2000; Zhang et al, 2014a |
| **Grassland, park, open space** | - 1.0 ~ +0.2 | Parton et al, 1995; Chen et al, 1999; Zhang et al, 2014a |
| **Wetland, riparian lowland** | -0.4 ~ -0.8 | IPCC, 2000 |
| **Transport**[e] | +29.3 ~ +793.5 | IPCC, 2000; Zhang et al, 2014a; Kellett et al, 2013 |

[a] The calculation aassumes no leakage outside the project boundaries and no emissions from carbon stocks in the soil.

[b] The value can be positive and negative where "+" denotes carbon source, and "–" denotes carbon sink.

[c] The building type includes ranging from single family house (24.7 t $CO_2$-e $ha^{-1}yr^{-1}$) to high-rise building (895 t $CO_2$-e $ha^{-1}yr^{-1}$)

[d] $CO_2$ fertilisation effect in agriculture land is considered (at current rates of increase of $CO_2$ in the atmosphere) to be 0.036 t $CO_2$-e $ha^{-1}yr^{-1}$ (van Ginkel et al, 1999).

[e] Carbon footprint of railway transport and airport are not considered due to lack of data.

### *4.1. Spatial pattern of carbon footprint*

The carbon footprint for each scenario is simulated and mapped using ESRI ArcGIS package (version 10.2.2) at original fine resolution (cell size = 20m) and then aggregated to 100m (cell area = 1 hectare). Results show that under all three scenarios, carbon footprint along the freeway is significantly higher than the rest area of the site (Figure 3). It is evident that traffic emissions is highly concentrated and, thus, create more a major carbon source. Therefore, traffic management is a very important part of carbon-budget management. For the rest of the built-up area, carbon footprint under the vertical scenario is highly clustered, while under the BAU scenario, carbon footprint is more evenly distributed, indicating suburban sprawl has increased carbon footprint on these land which would otherwise be a lower carbon source or even carbon sink if remained undeveloped. This pattern is evident when comparing the carbon footprint between the BAU and the vertical scenario (Figure 3). Under the mixed scenario, carbon footprint is higher at limited areas with high density residential towers. The water area and the wetland on the eastern portion of the site is significantly lower than other land on the site in all three scenarios, due to the water area, wetland, and vegetated riparian zones are net carbon sink (Figure 3). Thus vegetation protection is a significant issue if Point Cook is to become a low-carbon community.

The result found in this study is consistent with other researchers' finding regarding the effects of afforestation or reforestation in mitigating carbon emission from anthropogenic activities in Canadian, Chinese and U.S. cities (Liu and Li, 2012; Zheng et al, 2013; Nowak et al, 2013; Pasher et al, 2014). The effect of carbon sequestration by urban forestry could be a useful tool in urban and landscape planning to harness carbon emission in highly intensified urban centres, among other benefits.

### *4.2. Total carbon footprint and average carbon footprint per dwelling unit*

Total carbon footprint for the suburb, number of dwelling units, and carbon footprint per dwelling units under the three scenarios are summarised in Table 3. Based on the simulation results, it is important to note that in terms of carbon emission per dwelling unit, the vertical scenario has the least carbon footprint (490,199 t C), while the BAU scenario has the largest carbon footprint (561,537 t). In terms of average carbon footprint per dwelling unit, the vertical scenario has the least influence, while the BAU scenario again has the largest footprint. Carbon footprint of the vertical scenario and the mixed scenario is 14% and 7% lower than the BAU scenario, respectively. BAU scenario has to be carefully investigated in implementation considering its significant carbon and environmental implications in sustainable urban growth and management.

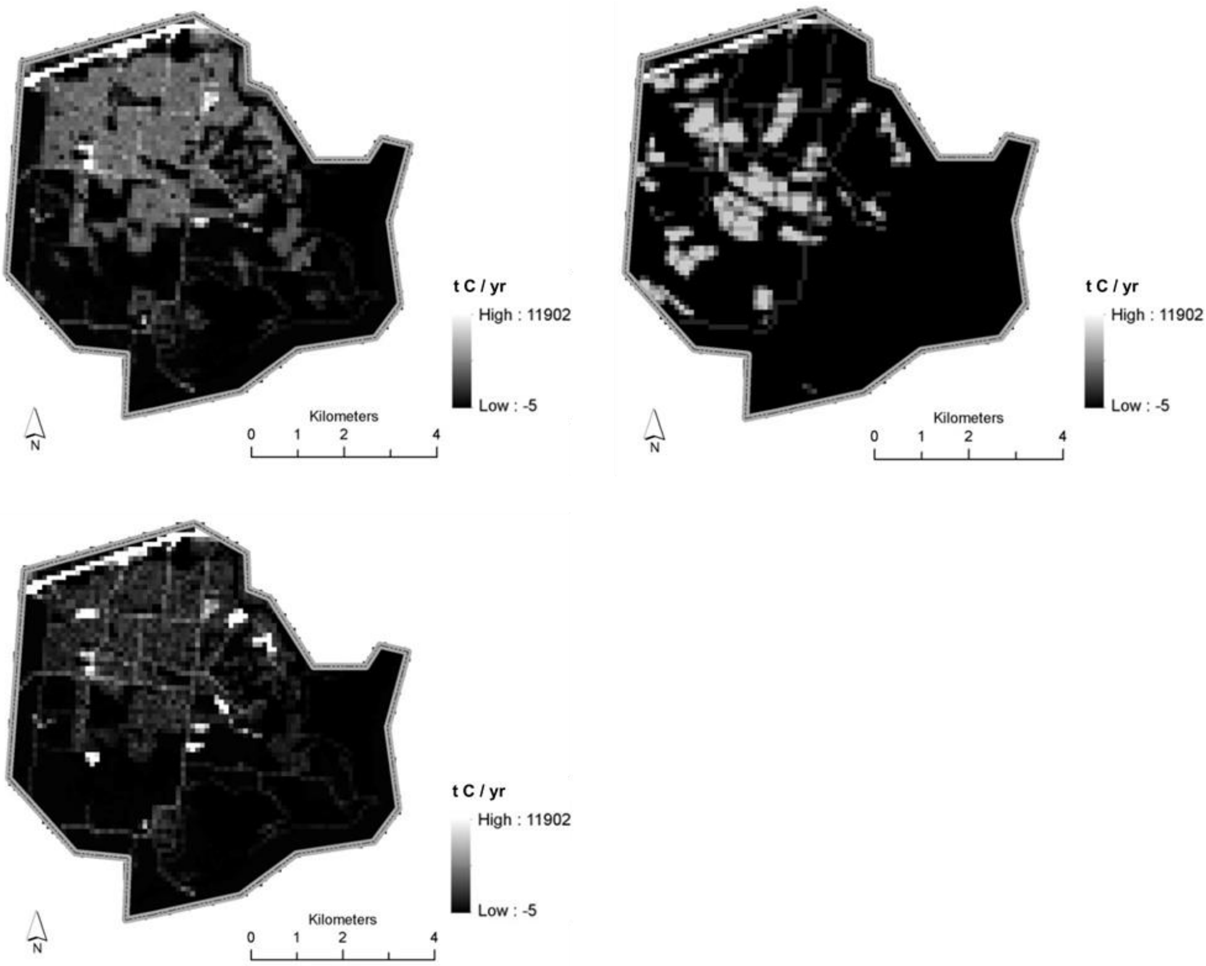


Figure 3. Carbon footprint of three development scenarios for Point Cook urban growth area (Upper left: BAU; upper right: vertical scenario; and bottom: mixed scenario)

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Table 3: Carbon footprint under 3 development scenarios for Point Cook, VIC

| Scenario | Total net carbon footprint *($t\ CO_2$-e $yr^{-1}$)* | Total dwelling units | Average carbon footprint per unit *($t\ CO_2$-e $yr^{-1}$)* | %(BAU) |
|---|---|---|---|---|
| **BAU Scenario** | 561,537 | 18,818 | 29.8 | 100% |
| **Vertical Scenario** | 490,199 | 19,212 | 25.5 | 85.6% |
| **Mixed Scenario** | 523,608 | 18,906 | 27.7 | 92.9% |

As evidenced by this study, vertical scenario in which high density housing development consumes less land thus a larger portion of land on the site can be used for agricultural or other productive land uses has the least carbon footprint. The agricultural and productive land uses can assimilate carbon in the atmosphere. The removal of carbon dioxide from the atmosphere by forests and other vegetation also provides an important carbon sink. Thus development based on land clearing (such as greenfield development) must be carefully considered in order to minimise the carbon footprint of urbanisation. However, the validity of the vertical scenario is yet to be tested on unique sites integrating and balancing the values of the people in the place, design culture, government planning policy, and public affordance.

## 5. Discussion

### *5.1. Development scenarios and the flavour of urban culture*

In Australian cities like Melbourne, which is a quintessential suburban city, the liveability and life style is largely “radicalised” around the low density suburb. Although climate change, global warming and other pressing issues have been affecting citizens’ life style, it is not likely that Australian citizens will soon accept the urban life style similar to those of the Asian cities – where the majority of population live in high rise apartment. Therefore, the priority in the next few decades is to promote and facilitate the mixed scenario. In the 2nd phase, the high density vertical scenario may be considered and tested in some pilot study cities.

Considering its potential in decrease the carbon footprint of cities, the mixed scenario and vertical scenario have been planned or built at small-medium scales around the activity centre in established suburbs or have been planned to be built around new town centres in Melbourne. In the future, this practice could be adopted and used widely in Melbourne’s urban growth frontier given other issues - such as social problems generally associated with high-density residential quarters in areas of relatively low natural and cultural amenity - are sufficiently tackled and well-integrated in design and planning.

### *5.2. Limitations of the study and future work*

The study is based on modelling in a GIS environment. Due to the fact that the simulation study is rested upon geocoded spatial data, the quality of input data has great influence on the outcome of the study. The carbon footprint data are resultant from a literature survey from various sources and at different time frame, which may contribute to errors and increase discrepancy. Therefore data with high quality in terms of both spatial and temporal resolutions are highly desired in this study. In this study, basic land use information is primary data used to drive the model. Details of subclasses within each major land use type will improve the reliability of model output.

Albeit the limitations mentioned above, this research has presented a spatially explicit accounting of carbon footprint at a fine scale in contrast with many carbon footprint studies at national or regional scales, which have been heavily rely on statistical data. These studies at regional or national scale are generally instrumental in leading national level policy making aimed at emission reduction, however, national reduction goals are to be realised through local actions such as urban planning, design and development, which are always taken at much finer scale such as the town and neighbourhood levels in this study. Future efforts should be made to link carbon footprint assessment low carbon city design and planning practice. It would be desirable to incorporate the pre-development carbon footprint assessment in the selection of the best neighbourhood master plan in the planning stage.

## 6. Conclusion

In this study, we measure and analyse the presence of urban carbon sinks and carbon sources under three planning scenarios. We established a model that successfully quantifies the carbon sinks constituted by forest, grassland and wetland and the carbon sources from built-up land. We conclude that carbon emissions in Point Cook under the three planning scenario are highly different in terms of both spatial distribution and quantity. The vertical scenario has least average per dwelling unit carbon footprint, implying that changes in life style, including housing, transport, density, etc. will result in remarkable decrease in carbon footprint. Therefore, from the perspective of urban planning and design, this study provide useful evidence and guidance for the delivery and design of low carbon communities, which is fundamental in the achievement of low carbon living in an increasingly suburbanised Australia.

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