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Place-based neighbourhood planning approaches to net zero transport

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ABSTRACT

Integrating place-based neighbourhood planning approaches with transport sector strategies is essential for achieving net zero transport. However, systematic research on the role of different neighbourhood types in reducing transport emissions remains limited, constraining the ability of place-based planning practices to inform the development of integrated strategies. This gap partly stems from the lack of a theoretically informed neighbourhood classification framework applicable to practice. This study addresses the gap by proposing a neighbourhood classification framework and testing its validity in evaluating the influence of different neighbourhood types on climate change costs associated with transport emissions. Using the framework, 10,068 SA1 (statistical area level 1) regions within Greater Melbourne were classified into 14 distinct neighbourhood types. Climate change costs were estimated using data from the 2012–2020 Victorian Integrated Survey of Travel and Activity (VISTA). The results show that mobility-oriented development, transit-oriented development, 20-min neighbourhood, and activity centre neighbourhoods are 6, 3, 1.6, and 1.5 times more effective, respectively, in reducing climate change costs compared to sprawl neighbourhoods. Sprawl neighbourhoods in Greater Melbourne account for an estimated $333 million annually in climate change cost linked to transport emissions. By adopting integrated transport and land use planning, these costs could potentially be reduced to $68 million annually. The findings highlight the importance of targeted, neighbourhood-specific interventions in achieving net zero transport.

1. Introduction

The global cost of climate change is estimated at US$143 billion/year over 2009–19 and is predicted to increase to US$1.79 trillion/year by 2050 (Newman and Noy, 2023). Recognising this threat, over 140 countries, including the USA, European Union, Australia, China and India, have committed to achieving net zero emissions by 2050 (United Nations, 2023). However, the transport sector remains a significant challenge. Despite overall emissions reduction in many countries, transport emissions continue to rise, exposing the inadequacy of past policies focused on ***shifting*** commuters to sustainable transport modes (Bray et al., 2011). The sector currently relies on technological ***improvement*** of travel (electric vehicles, hydrogen fuels, mandatory emissions standards). However, technological improvements alone are estimated to reduce emissions by only 58 % by 2050 (Australian Government, 2021), failing to meet the net zero target (Marsden et al., 2014). Place-based neighbourhood planning, such as transit-oriented development (TOD), offers an alternative by reducing transport emissions through travel ***avoidance***, potentially cutting emissions by up to 65 % (Ashik et al., 2022; Tiwari et al., 2011), bolstering its endorsement by the Intergovernmental Panel on Climate Change (2022). Achieving net zero transport thus requires integrating strategies that involve travel *avoidance*, mode *shift*, and technological *improvements* (Holden et al., 2020). Yet, little research explores how various neighbourhood types influence transport emissions, hindering planning practice (Lynge et al., 2022).

Neighbourhoods, though defined in contested ways (Jenks and Dempsey, 2007; Talen, 2018), are typically considered as geographically distinct urban subareas with unique physical and social characteristics (Martí et al., 2022). They serve as practical units for tailored urban planning and design (Park and Rogers, 2015). Neighbourhood planning involves designing new neighbourhoods or revitalisation of existing ones (Rohe, 2009), through stakeholder deliberation—a process known as place-based planning (Pinnegar, 2012). This approach recognises the

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limitations of top-down strategies in addressing locally perceived challenges (Queensland Government, 2021). Recent studies highlight that achieving net zero transport requires place-based strategies to develop context-specific pathways, as no one-size-fits-all solution exists (Galanakis et al., 2024). A critical first step toward this goal is thus understanding how different neighbourhood types contribute to transport emissions, enabling the development of tailored intervention strategies. However, every neighbourhood possesses unique characteristics, making it difficult to scale up neighbourhood-level intervention strategies (Creutzig et al., 2022), and necessitating a framework 'to distil these in some way that make similarities and differences apparent' among the neighbourhoods (Lupton et al., 2011, p.5).

Over the past century, numerous neighbourhood types have emerged, such as Garden City, Neighbourhood Unit, TOD, and 15/20-Minute Neighbourhood (Rohe, 2009; Sharifi, 2016). From an urban planning perspective, distinctions among these neighbourhood types primarily arise from the standards applied to their urban forms (e.g., cul-de-sac vs. grid street patterns) and functions[1] (e.g., residential vs. mixed land uses) (Arribas-Bel and Fleischmann, 2022). These standards determine travel demand and, consequently, transport emissions (Table 1). In essence, '*avoid*' strategies rooted in neighbourhood planning aim to replace/reduce the need for motorised travel (e.g., enabling walking to destinations, shorter trip length) – i.e., demand-side solutions that extend beyond transport. In contrast, '*shift*' and '*improve*' strategies focus on supply-side solutions (Creutzig et al., 2022; Galanakis et al., 2024). Despite knowledge of how various urban form and function indicators affect transport emissions (Table 1), their combined effects that make up different neighbourhood types remain poorly understood. This gap arises primarily from the absence of a neighbourhood 'grammar'—a systematic framework defining specific standards of urban forms and functions unique to each neighbourhood type, akin to strands of DNA (Arribas-Bel and Fleischmann, 2022).

Table 1
The effects of urban form and function indicators on transport emissions[a].

Indicators of urban form	Effects on transport emission	Citation
Population density	–	Cao and Yang (2017); Hong and Goodchild (2014); Lee and Lee (2014); Ma et al. (2015); Shao et al. (2023)
Employment density	–	Ma et al. (2015)
Job-housing balance	–	Cui et al. (2023); Qin and Han (2013)
Retail density	–	Ma et al. (2015)
Land use mix	–	Cao and Yang (2017); Hong and Goodchild (2014); Ma et al. (2015)
Bus stop density / accessibility	+	Cao and Yang (2017); Hong and Goodchild (2014); Shao et al. (2023)
Metro station density/ accessibility	–	Cao and Yang (2017); Gao et al. (2022); Ma et al. (2015); Song et al. (2016)
LRT accessibility	–	Boarnet et al. (2017a)
Distance to CBD	–	Shao et al. (2023)
	+	Cao and Yang (2017); Yang and Cao (2018)
Distance to town centre	+	Shao et al. (2023)
	–	Ma et al. (2015)
Street connectivity	–	Hong and Goodchild (2014); Song et al. (2016)
	+	Choi and Zhang (2017)
Street density	–	Cao and Yang (2017); Cui et al. (2023)
	No effect	Gao et al. (2022)
Parking availability	+	(Cao and Yang, 2017)

[a] *Articles included in Table 1 were initially identified through a structured search of the Scopus database using the following query:* (TITLE (emission*) AND TITLE (neighbourhood) OR TITLE ("built environment") OR TITLE ("land use") AND TITLE-ABS-KEY (transport) OR TITLE-ABS-KEY (travel) OR TITLE-ABS-KEY (trip) OR TITLE-ABS-KEY (vehicle)) AND PUBYEAR <2025 AND (LIMIT-TO (DOCTYPE, "ar")). This search yielded 129 peer-reviewed articles. These were screened for relevance, and 12 articles were purposively selected to illustrate the range of built environment indicators examined in relation to transport emissions. Particular attention was given to studies that provided empirical evidence on how specific urban form and function indicators (e.g., density, land use mix, access to public transport) influence emissions outcomes.

Place typology, a century-old technique, can help identify neighbourhood types with unique sets of standards for different urban form and function indicators (Chin, 2024; Kamruzzaman et al., 2014a; Lupton et al., 2011), providing a better understanding of urban development patterns (Moon and Quan, 2023), and informing common intervention strategies for each type (Shao et al., 2023; Zemp et al., 2011). This technique has been widely used to classify neighbourhood types and understand their links with, for example, hazard risks (D'amico et al., 2021), urban inequality (Lynge et al., 2022), quality of life (Mittal et al., 2021), cycling behaviour (Zahabi et al., 2016), travel behaviour (Ralph et al., 2016), body fat (Barnett et al., 2022), alcohol use (Rhew et al., 2017), BMI (Hobbs et al., 2018), pedestrian activity (Kim, 2024), and physical activity (Timperio et al., 2017). However, the use of typology to understand the impacts of various neighbourhood types on transport emissions is relatively scarce.

Various typological frameworks have been employed in the literature, varying in spatial scale and/or focus of analysis. At the national level, urban centres are categorized into monocentric, polycentric, sprawl, and linear types (Sapena and Ruiz, 2021). The transect classification framework has been used to categorise metropolitan areas into special districts, urban core, urban centre, general urban, suburban, rural reserve, and rural preserve (Duany, 2002). Railway stations have been classified based on the node-place framework (Bertolini, 1999; Reusser et al., 2008). However, there is no widely accepted classification framework that can be applied at the neighbourhood level, possibly due to divergent views on what constitutes a neighbourhood (Talen, 2018). For example, using neighbourhood size as a reference, concepts like Garden City, Radburn Superblock, TOD, 20-Minute Neighbourhood, and Urban Village have been implemented with areas of 1000 acres, 500 acres, 160 acres, 125 acres, and 100 acres, respectively (Grodach et al., 2019; Haque et al., 2025; Howard, 1985; Park and Rogers, 2015). Due to the absence of an established framework, researchers have used a variety of statistical techniques to derive neighbourhood typologies, employing diverse urban form and function indicators as inputs. These techniques include k-means cluster analysis (Li and Xie, 2018; Lynge et al., 2022; Trudeau, 2013), principal component analysis (Vicino et al., 2011), and factor analysis followed by cluster analysis (Gershoff et al., 2009). While these data driven approaches help explain variations in transport emissions among the generated clusters/classes of neighbourhoods, they fall short in advancing knowledge and practice in at least the following four ways:

a. **A lack of theoretical foundation**: Data driven approaches partition the data based on their best fit to define a class of neighbourhood rather than their theoretical standards. For example, 23 dwellings/ha and 35 dwellings/ha have been identified as the best fits for a transit-oriented development in Australia by Jeffrey et al. (2019) and Kamruzzaman et al. (2014a), respectively. Neither of these standards fully comply with the theoretical standard proposed for a transit-oriented development (e.g., $\geq$ 25 dwellings/ha).
b. **Incomparable findings**: As shown in Table 2, the various types of neighbourhoods generated rarely match between studies, hindering the comparison of their effects across studies and making it difficult to reach conclusions about neighbourhood effects;

[1] Urban form refers to the physical elements (e.g., density, road connectivity, transport network) within a neighbourhood whereas function pertains to the activities in the neighbourhood (e.g., land use mix, amenities). Together, form and function shape the spatial structure of urban areas, and are central to analyses in urban morphology.

Table 2
Neighbourhood typologies identified in existing studies and contexts[a].

Citation	Neighbourhood typologies	Context
Ralph et al. (2016)	Rural, new development, patchwork, established suburbs, urban residential, old urban, mixed-use	USA
Jahanshahi and Jin (2016)	London dominated, medium urban, rural areas	UK
Kleerekoper et al. (2017)	Historical city block and pre-war city block, garden town, residential housing, post-war garden city low-rise, post-war garden city high-rise, high-rise city centre, community neighbourhood, sub-urban expansion	Netherlands
Ghosh and Vale (2009)	Papakainga, low density low rise, eco-neighbourhoods, medium density residential, medium density mixed, medium density mixed nodal, high density medium rise residential, high density medium rise mixed, high density high rise, high density high rise mixed	New Zealand
Abrantes et al. (2019)	Dense and compact areas, consolidated suburban areas, areas of urban sprawl, areas of potential urban sprawl, areas of population growth, rural areas	Portugal
Timperio et al. (2017)	Few land uses, playgrounds and sports facilities, low street connectivity, low traffic exposure; Few land uses, playgrounds and sports facilities, high street connectivity; mixed land use, few playgrounds and sport venues, low intersection density; mixed land use, many playgrounds and sport venues	Melbourne
Pang et al. (2022)	Agriculture, suburban residential, suburban mixed-use residential, peripheral urban core, priority areas for future development, peripheral urban core along the river, historical urban core, other mixed-use areas, extended urban core, mixed-use industrial areas	Geneva
Zahabi et al. (2016)	Downtown, urban, urban-suburb, inner suburb, outer suburb	Montreal
Barnett et al. (2022)	Moderate walkability and high safety, low walkability and high safety, moderate walkability and moderate safety, high walkability and moderate safety, moderate walkability and low safety	Quebec
Kim (2024)	Type 1, Type 2, Type 3, Type 4, Type 5	Seoul

[a] *Articles included in Table 2 were identified through a targeted search of the Scopus database using the following query: (TITLE (typolog*) AND TITLE (neighbourhood) OR TITLE ("built environment") OR TITLE ("land use")) AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE, "ar")). This search returned 94 peer-reviewed articles. These were screened for relevance, and 10 peer-reviewed articles were purposively selected. Selection emphasised capturing geographical diversity and a representative spread of neighbourhood or built environment typologies used in transport and urban studies.*

c. **Misalignment with practice**: The neighbourhood types generated in these studies (e.g., patchwork) do not correspond well with the neighbourhood concepts used in practice (e.g., 20-min neighbourhood), offering limited practical guidance; and
d. **Mutual exclusion of neighbourhood types:** Cluster analysis techniques result in a mutually exclusive manageable number of neighbourhood types (Gershoff et al., 2009). However, in reality, it is possible for a neighbourhood to satisfy the criteria for two different neighbourhood types (e.g., transit-oriented development and 20-min neighbourhood), hindering an understanding of their joint effect.

Based on the above discussion, this paper aims to understand the differential effects of neighbourhood types on climate change costs from transport emissions. The two interrelated objectives of the study are: a) To develop a theoritetically informed neighbourhood classification framework with relevance to practice; and b) To examine how climate change costs from personal travel vary across neighbourhood types to inform integrated strategies for net zero transport.[2]

The paper is structured as follows: Section 2 develops a neighbourhood classification framework based on a synthesis of the literature on neighbourhood planning concepts and their defining urban form and functional characteristics. It also details the data and methods used to operationalise the framework and analyse climate change costs across neighbourhood types. Section 3 presents the findings, while Section 4 discusses their policy and research implications and provides directions for future research.

2. Data and methods

The aim of this study is to investigate the influence of different neighbourhood types on transport emissions, with a particular focus on the associated climate change costs. To address this aim, the study utilised data from Greater Melbourne, Australia (Fig. 1). The analysis focuses exclusively on surface transport emissions, excluding freight due to data limitations. The exclusion of shipping and aviation sectors is based on the assumption that their emission patterns are unlikely to be influenced by neighbourhood types. Additionally, strategies for mitigating emissions from shipping and aviation sectors are acknowledged as needing more time for development (Whitehead et al., 2022).

Delimiting the boundaries of neighbourhoods has proven challenging due to the their definitional inconsistencies (Jenks and Dempsey, 2007). Consequently, researchers have employed various approaches to define neighbourhood boundaries, including geographic boundary (e.g., rivers, roads), administrative boundaries (e.g., postcodes, census tracts), functional boundaries (e.g., catchment areas for important services such as schools), ego-centric boundaries, and social/cognitive boundary (Park and Rogers, 2015; Vachuska, 2024). The pros and cons of these approaches are well-documented in the literature (Jenks and Dempsey, 2007; Martí et al., 2022). Given that this paper focuses on developing a neighbourhood classification framework with relevance to practice, it adopts administrative boundaries. They serve as the key criterion for planning interventions and service delivery catchments and are the most frequently used boundaries in the literature (Martí et al., 2022). Additionally, using administrative boundaries ensures consistency in analysis, facilitates comparability across studies, and enables easy aggregation to other administrative levels (Jenks and Dempsey, 2007).

This study delimits neighbourhoods using SA1[3] (Statistical Area Level 1) boundaries as defined by the Australian Bureau of Statistics (ABS), which are commonly used in Australian neighbourhood-level studies (Thackway et al., 2023; Zhang and Luo, 2024). SA1s have an average population of 400 people, and their aggregated census data is publicly available. In Melbourne, the average size of an SA1 was found to be 217 acres, aligning with typical neighbourhood sizes as discussed earlier. Within the Greater Melbourne area, there are 10,289 SA1s (Fig. 1). To support the analysis, a neighbourhood classification framework is developed to categorise these SA1s into distinct types based on relevant urban form and function indicators and their standards.

2.1. Derivation of neighbourhood types: A framework

One of the objectives of this study is to develop a theoretically

[2] Net zero transport is referred to here as zero emissions at the point of vehicle use. However, we acknowledge that it should ideally be assessed across the entire value chain of vehicles and energy use.

[3] ABS census geographies are classified (from smallest to largest) as: Meshblock (30–60 dwellings), SA1 (200–800 people), SA2 (3000–25,000 people), SA3, SA4 (300,000–500,000 people), Greater Capital City Statistical Area, and State/Territory.

Fig. 1. SA1s in Greater Melbourne classified into different neighbourhood types.

informed, yet policy-relevant, neighbourhood classification framework. To achieve this, seven basic neighbourhood types currently in practice or promoted for future planning in Australia were selected. These types are drawn from various policy/research documents, including Plan Melbourne 2017–2050, Greater Sydney Regional Plan: A Metropolis of Three Cities, South East Queensland Regional Plan 2023, The 30-Year Plan for Greater Adelaide, and Perth and Peel@3.5million. The selected neighbourhood types include transit-oriented development (TOD), mobility-oriented development (MOD), activity centre (AC), 20-min neighbourhood (20MN), transit-adjacent development (TAD), mobility-adjacent development (MAD), and sprawl development.

Fig. 2 presents the proposed classification framework applied in this study, while Table 3 lists the datasets used for its operationalisation. A total of 221 SA1s are excluded from the analysis because they do not meet the criteria for representing neighbourhoods, primarily due to having very low residential populations (<10 persons). These exclusions align with criteria used in previous studies in this context (Shatu and Kamruzzaman, 2021) and reflect a key defining characteristic of

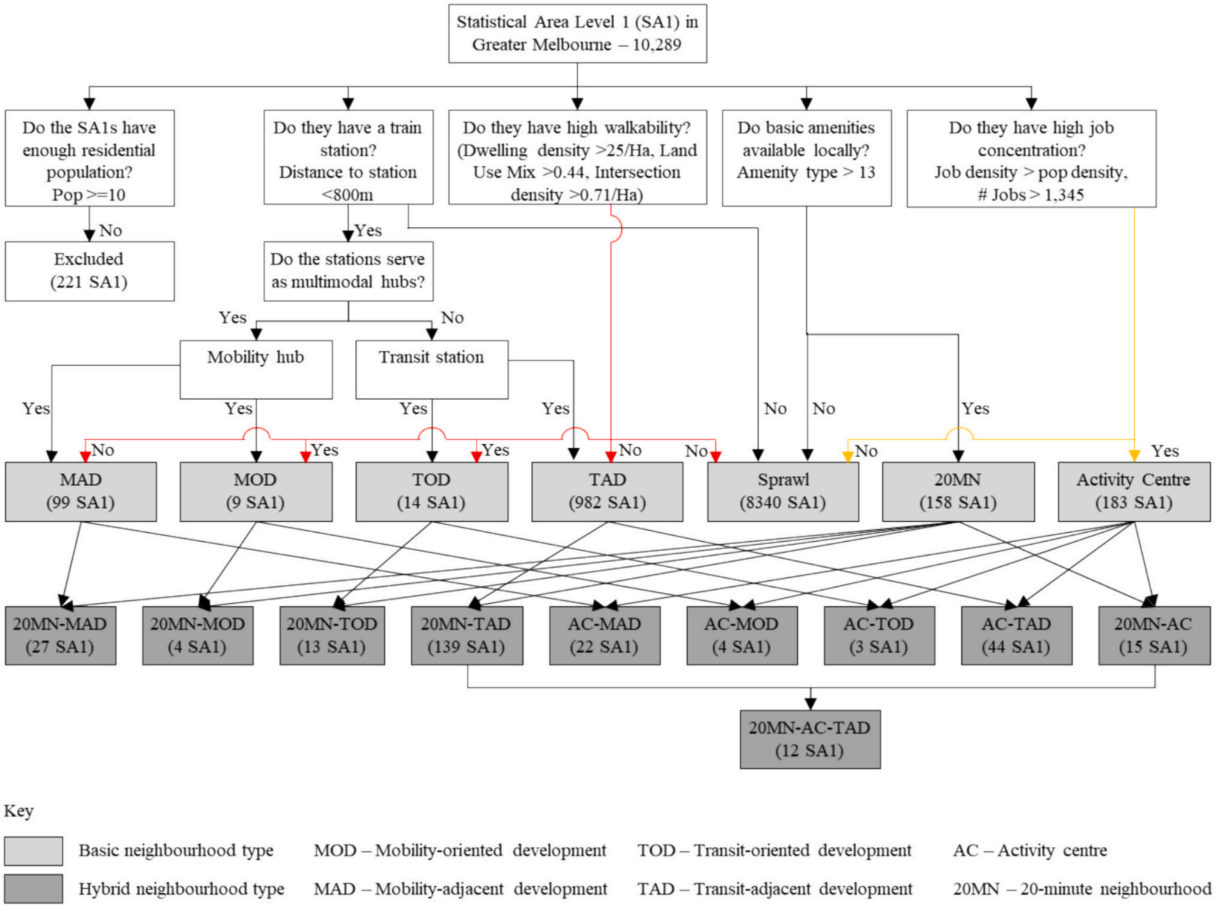

Fig. 2. Proposed neighbourhood classification framework.

Table 3
Data and indicator used to operationalise the neighbourhood classification framework.

Indicator	Data/explanation	Source and year
Population density (person/ha)	Residential population at the SA1 level	Australian Bureau of Statistics (ABS) Census 2016
Land use mix	Each SA1 contains multiple Meshblocks. ABS categorises the Meshblocks into one of ten land use types (e.g. residential).	ABS Census 2016
Intersection density	Derived based on walkable road network – i.e. by excluding road types categorized as motorway, highway, ramp, and tunnel	DATA VIC 2018
Distance to train, bus, and tram stops	Network distance from the centroid of SA1s to train station, bus stops and tram stops	General Transit Feed Specification (GTFS) 2016
Amenity types	Types of amenities located within 800 m from the centroid of SA1s	DATA VIC 2018, AURIN 2018, Open Street Map 2019
Job-population ratio	Employment data is derived based on incoming commuting flow at the SA2 level (statistical area level 2). One SA2 contains multiple SA1s. The number of jobs located within an SA2 was proportionately distributed to the SA1 level based on the size of commercial and industrial land uses.	ABS Census 2016

neighbourhoods: a 'territory becomes a neighbourhood only through occupancy and use by its residents' (Hallman, 1984). Further details on the classification criteria and subsequent steps are provided in the following subsections.

2.1.1. *Transit-oriented development (TOD)*

A transit-oriented development is defined as a neighbourhood characterized by moderate to high residential density, a greater mix of land uses with highly connected street network patterns, and centred on high-frequency public transport services (Cervero and Kockelman, 1997). In this study, TOD neighbourhoods are designated based on four urban form and function indicators: residential density, land use mix (LUM), street connectivity, and access to train stations. Specifically, the following standards are applied: a) located within 800 m of a train station; b) greater than 25 dwellings per hectare; c) greater than 0.71 intersections (three or more way) per hectare; and d) greater than 0.44 land use mix score, applying Simpson's diversity index based on the size of 10 different land uses (residential, commercial, industrial, agricultural, water body, transport, health, educational, recreational). These standards are selected from both the above policy documents and published research studies within this context (Kamruzzaman et al., 2016). The dwelling density, land use mix, and intersection density indicators are commonly referred to as neighbourhood-scale walkability indicators (Huang et al., 2024), consistent with established frameworks such as the 3Ds model (Cervero and Kockelman, 1997)) and recent applications (Rachele et al., 2024). Walkability can be assessed using hundreds of indicators, which vary by both measurement approach (e.g., subjective vs. objective) and spatial scale (e.g., micro, *meso*, and macro levels). This study focuses on macro-level morphological attributes and does not include micro-scale measures such as pavement quality, which fall outside the scope of neighbourhood typology development (Dragović et al., 2023; Fonseca et al., 2025).

2.1.2. Mobility-oriented development (MOD)

The concept of MOD originates from the mobility hub concept, which refers to places where people can seamlessly switch between different modes of sustainable transport (Aydin et al., 2022; Blad et al., 2022). While mobility hub is a relatively new concept, it is increasingly becoming an operational reality in Europe, UK and the USA (comouk, 2021). Australia aims to follow this global trend as part of its efforts to reach net zero transport emissions. Infrastructure Australia (2021) emphasises the needs for an evolution of mobility hub to encourage more journeys to shift from driving to public transport or active transport.

In this study, MODs are defined as walkable neighbourhoods centred on mobility hubs. A train station is considered a mobility hub if provides access to other public transport services, such as buses and trams in this context, within 250 m of the train station (Pimenta et al., 2024). MODs are thus essentially a subset of TODs, expanding beyond the traditional focus only on train stations.

2.1.3. Activity Centre (AC)

Activity centres (ACs) are interpreted in the literature "as areas or neighbourhoods characterized by an outstanding concentration of employment (e.g., number of workplaces)" (Boratinskii and Tikhotskaya, 2021, p.84). In this study, two criteria were applied to designate SA1s as ACs: a) job density is greater than population density, aiming to distinguish them from areas of balanced development; and b) having more than 1345 jobs located within the SA1s, which is one standard deviation away (positively) from the mean number of jobs among all SA1s. The second criterion ensures that there are a sufficient number of jobs available to avoid misrepresenting SA1s as AC based on the first criterion. For example, applying only the first criterion may result in an SA1 as an AC if it has only eleven jobs and ten residents, which would not accurately reflect the nature of an AC.

2.1.4. 20-min neighbourhood (20MN)

The concept of the 20MN emerged just over a decade ago (The Portland Plan, 2012), but it has garnered renewed global policy interest in response to COVID-19-related travel restrictions (Moreno et al., 2021). According to the Plan Melbourne 2017–2050, residents in a 20MN should have access to essential services and amenities within a 20-min round trip from home on foot. This entails locating most basic goods and services within an 800-m radius of residences to facilitate walking access. As per Kamruzzaman (2022), SA1s are designated as 20MN if they exhibit a higher concentration of amenities within an 800-m radius from their centroid. The classification involves considering 18 different types of amenities (aged care, ATM/bank, bar/pub/nightclub, childcare, community centre, dine in places, health facilities including dental, kindergarten, library, maternal & child health centre, neighbourhood parks, place of worship, playground, post office, pharmacy, primary school, secondary school, shopping centre), with SA1s featuring 13 or more amenity types designated as 20MN – i.e., two standard deviation away (positively) from the mean number of amenities among all SA1s.

2.1.5. Transit-adjacent development (TAD)

TADs are situated in close proximity to transit stations. However, unlike TODs, TADs feature suburban street layouts, such as cul-de-sacs; low population densities; and segregated land uses (Duncan, 2011; Renne, 2009). Consequently, distinguishing TADs from TODs poses a challenge, leading to the dilution of TOD research (Halbur, 2007). TADs are often likened to the "evil twin" of TODs; in cases where TOD projects falter, they often transform into TADs. Consequently, suburban developments near train stations cannot be categorized as TODs (Belzer and Autler, 2002). While TODs are an ideal form of development, researchers have long grappled with TADs, often mistakenly identifying them as TODs. For instance, Cervero (2004) noted that approximately 97 % of rail stations in the USA exhibit TAD characteristics, despite being commonly referred to as TODs. Although not specifically planned, research in Australia shows the existence of TAD neighbourhoods (Hale, 2014; Kamruzzaman et al., 2014b). SA1s are designated as TADs if they are located within 800 m of a train station but lack walkability, as defined by criteria discussed above.

2.1.6. Mobility-adjacent development (MAD)

Like TADs, MADs represent the SA1s that are located within 800 m of a mobility hub but lack the walkability.

2.1.7. Sprawl development

Several interpretations of sprawl exist in the literature. Galster et al. (2001) have outlined eight aspects of land-use arrangements: density, continuity, concentration, clustering, centrality, nuclearity, mixed uses, and proximity. Their characterization of sprawl refers to land use characterized by low values on one or more of these dimensions, though specific standards are not provided. In this study, SA1s are designated as sprawl developments if they meet the following criteria: a) located more than 800 m away from a train station; b) not classified as a 20MN; c) not classified as an AC; and d) lack walkability. However, given the contested definitions of urban sprawl, including additional indicators such as transport network quality could help identify sprawl neighbourhoods more comprehensively. Although sprawl as a neighbourhood type is not directly endorsed in the policy documents in Australia, it remains a predominant nature of development. For example, the Plan Melbourne 2017–2050 proposes that 35 % of new housing will be developed in greenfield areas, which often exhibit characteristics of sprawl.

2.1.8. Hybrid neighbourhood

The seven basic neighbourhood types (TOD, MOD, AC, 20MN, TAD, MAD, Sprawl) were cross-examined to identify if any of the selected SA1s falling under a particular category also satisfy the criteria for other categories – e.g., whether an SA1 classified as a 20MN also qualified as an AC. This cross-examination resulted in nine hybrid neighbourhood types: a) 20MN-AC; b) 20MN-TOD; c) 20MN-MOD; d) 20MN-TAD; e) AC-TOD; f) AC-MOD; g) AC-TAD; h) 20MN-MAD; and i) AC-MAD. The SA1s were further cross-examined to identify if they qualified for three basic neighbourhood types (e.g., 20MN-AC-TOD). Only 12 SA1s were found to meet the joint criteria for a 20MN, AC, and TAD in this context.

Taking together the basic and hybrid categories, this study intends to examine the climate change costs from transport emissions across the 17 neighbourhood types. Fig. 3 shows a visual representation of the urban form and function characteristics of six basic types, excluding sprawl.

2.2. Derivation of climate change costs from transport emissions

This study used data from the Victorian Integrated Survey of Travel and Activity (VISTA), covering the 2012 to 2020 survey waves, to derive climate change costs from transport emissions. VISTA is an ongoing survey administered by the Victorian Government, covering Greater Melbourne, Geelong, and selected regional centres. It employs a two-stage clustered random sampling technique, initially selecting a Meshblock within a stratum (local government area), and then randomly selecting 21+ households from each selected Meshblock. Travel diary data are collected from all household members aged 5 and over for a single day, capturing detailed information on the origin and destination of each leg of a trip, as well as the mode of travel, distance, and travel time. Across the 2012–20 period, the survey recorded data from 78,978 individuals in 30,803 households, resulting in a total of 211,012 trips. These trips comprised 247,411 individual trip legs, capturing the complex nature of multimodal travel behaviour.

Fig. 4 presents the distribution of transport modes used across all trip legs, revealing a travel landscape dominated by private vehicle use. Together, Vehicle Driver and Vehicle Passenger account for

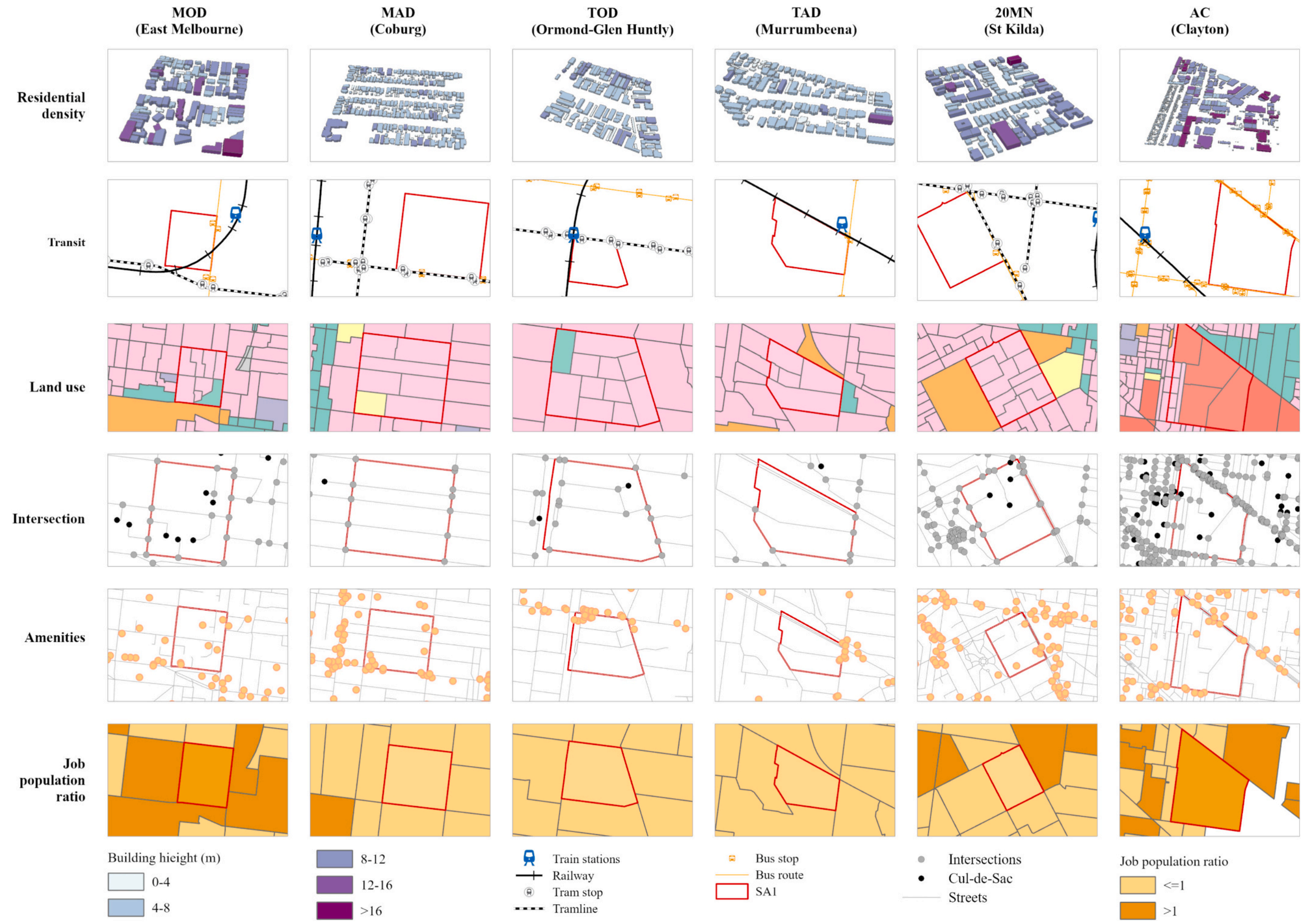

Fig. 3. Urban form and function characteristics of different neighbourhood types.

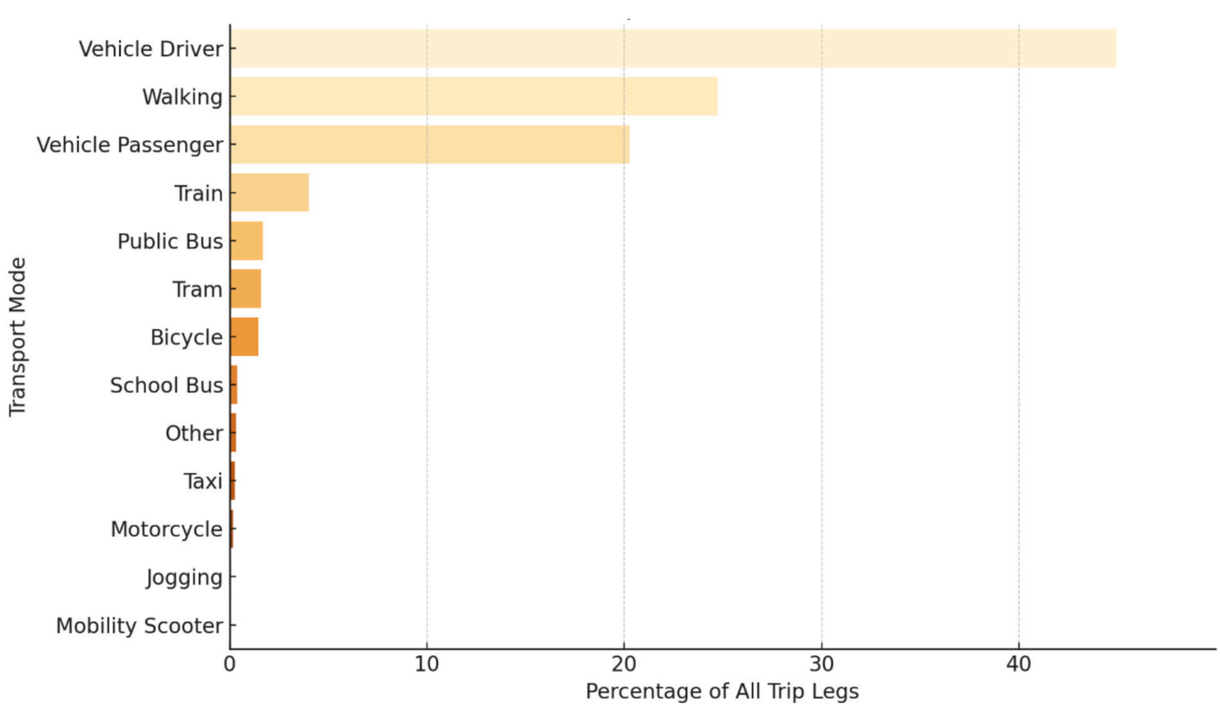

Fig. 4. Mode share across all trip legs in Melbourne.

approximately 65 % of all trip legs, underscoring Melbourne's strong reliance on cars for everyday mobility. Walking is the next most common mode, indicating its important role in short-distance and connecting trips. Public transport modes (train, tram, and bus) contribute smaller shares, while alternative modes such as cycling, taxi, and motorcycle remain marginal. This broad distribution reflects the prevailing car dependence in Melbourne, with limited but present engagement in active and public transport options.

About 92.3 % trips comprise a single leg, while others involve up to 10 distinct legs, as observed in the VISTA dataset (Appendix A). This level of detail is essential for accurate emissions estimation, as each leg may involve a different mode with a unique emissions factor and distance. This disaggregation ensures that emissions are calculated separately for each leg of a trip, avoiding miscalculation that could occur by assigning an entire trip to a single (dominant) mode. For year-on-year changes in mode use, a disaggregated breakdown of transport mode distribution by survey year is provided in Appendix B.

To protect participant anonymity, VISTA provides each respondent's home SA1, rather than their precise Meshblock of residence. An SA1 is a larger spatial unit encompassing multiple Meshblocks and serves as the basis for linking individuals to neighbourhood typologies. Survey participants located outside of Greater Melbourne area were excluded from analysis. In addition, trips made on weekends were also excluded for consistency in findings across the different neighbourhood types. These exclusions resulted in 150,081 trips made by 42,939 individuals residing within 2704 SA1s (Table 4). The climate change costs of these trips were calculated using Eq. 1.

$$CCC_i = \sum M_{mil} D_{mil} \tag{1}$$

where, CCC_i = Climate change cost of trip i (AU$), M_{mil} = Climate change cost per passenger kilometre (pkm) for mode m in leg l of trip i *(AU$/pkm)*, D_{mil} = Travel distance in kilometre using mode m in leg l of trip i *(pkm)*.

Mode-specific climate change cost per passenger kilometre values were obtained from Table 5-2 of the Australian Transport Assessment and Planning Guidelines (2021): PV5 Environmental Parameter Values. Specifically, the "Climate change" values for passenger-kilometre (pkm), expressed in A$ per 1000 pkm was used, which reflect the monetised cost of CO_2-equivalent emissions per mode of travel. These values are calculated using a standardised social cost of carbon (A$60 per tonne CO_2-e) and represent nationally endorsed parameters for transport appraisal in Australia. For each trip leg, the reported distance was multiplied by the appropriate mode-specific value to estimate its climate cost. While this approach does not incorporate household-level vehicle characteristics (e.g., engine type, make or model), it is appropriate for the scale of this study and ensures consistency with national practice for policy-aligned emissions modelling.

The climate change costs of all trips made by an individual were aggregated (summed) to represent their total daily transport-related cost. These person-level costs were then averaged across all individuals residing within each SA1, resulting in an average climate change cost per person per weekday for that SA1. Trips were thus assigned to neighbourhoods based on the home SA1 of the traveller, aligning with research that highlights the strong influence of residential built environments on mode choice and emissions (Leong et al., 2024). This approach is consistent with prior travel behaviour and emissions research, where the built environment around the home is recognised as the primary spatial influence on mode choice, trip frequency, and trip distance (Boarnet et al., 2017b; Nachtigall et al., 2023). This analysis produced SA1-level climate change costs for the 2704 sampled SA1s, drawn from the 10,068 SA1s originally classified into different neighbourhood types using the typology framework. These 2704 SA1s were matched with their corresponding neighbourhood classifications, resulting in representation across 14 out of the 17 typologies (Table 4). Due to very low sample sizes, some types were consolidated: SA1s classified as MOD and 20MN-MOD were merged into a single MOD category, and 20MN-TOD was merged with TOD. This consolidation resulted in 12 neighbourhood types being retained for the emissions analysis. For each neighbourhood type, we calculated a simple average of per-person climate change costs across all included SA1s, with each SA1 contributing equally regardless of its population size or area.

Table 4
Neighbourhood classification of the sampled SA1s.

Neighbourhood type	Number of SA1s classified within Greater Melbourne	Number of SA1s sampled in the VISTA	Number of individuals sampled	Number of trips made by the sampled individuals
MOD	9	1	2	4
TOD	14	4	35	127
MAD	99	28	471	1882
20MN	158	51	620	2387
AC	183	25	382	1389
TAD	982	315	4758	17,233
Sprawl	8340	2222	35,977	124,622
20MN-MOD	4	1	8	26
20MN-TOD	13	1	2	8
20MN-MAD	27	7	93	349
20MN-TAD	139	36	458	1639
AC-MAD	22	–	–	–
AC-MOD	4	–	–	–
AC-TOD	3	–	–	–
AC-TAD	44	7	87	260
20MN-AC	15	2	22	79
20MN-AC-TAD	12	4	24	76
Total	10,068	2704	42,939	150,081

2.3. Analytical approach

Two types of analyses were conducted in this study. First, descriptive statistics were used to examine how climate change costs from transport emissions vary across the neighbourhood types. Second, a multiple linear regression model was estimated to assess the relationship between climate change costs and six urban form and function variables used in the neighbourhood classification: population density, ratio of job density over population density, land use mix, street connectivity, access to train station, and types of amenities. The model also controlled for neighbourhood-level socio-demographic variables, including median age of residents, median mortgage paid per month, median rent paid per week, median family income per week, and median personal income per week. In addition, distance to the Melbourne CBD and to other higher-order centres (metropolitan and major activity centres) was included to capture the influence of urban structure on climate change cost, consistent with factors identified in Table 1 as significant drivers of emissions.

The aim of this analysis is to validate the explanatory power of the variables used in the neighbourhood classification and to understand their individual influence on emissions. Multicollinearity among the factors was checked using the variance inflation factor (VIF). Only variables that were statistically significant ($p < 0.1$) were retained in the final model, with statistically insignificant factors removed through a stepwise elimination process.

Given that the climate change costs were spatially represented at the SA1 level, it is plausible that spatial dependence may exist in the data, particularly if nearby areas share similar built environment or travel behaviour characteristics. To verify the appropriateness of the Ordinary Least Squares (OLS) regression model, we tested the model residuals for spatial autocorrelation using Moran's I. This step was undertaken to assess whether the residuals satisfied the assumption of being independent and identically distributed (i.i.d.), which is fundamental to the validity of OLS inference. The test yielded a statistically insignificant result, indicating no spatial dependence in the unexplained variation.

This finding supports the use of a standard OLS model for this analysis.

3. Results

3.1. Temporal trend of climate change costs from transport emissions

Fig. 5 shows trends in the costs of climate change from transport emissions over the period of 2012–20. While it is commonly understood that people are travelling more now than in previous years, leading to potentially higher emissions and associated climate change costs, the study's analysis of travel survey data spanning an 8-year period reveals little variation in the per-person, per-weekday climate change costs from transport emissions. This finding suggests that, despite potential sample bias due to the time span of the data, findings on the effects of neighbourhood types on climate change costs remain valid. Similar results have been reported in other contexts, indicating that travel behaviour remained relatively stable during the pre-pandemic period (Kamruzzaman et al., 2020; Le Vine and Jones, 2012; Van Dender and Clever, 2013).

To complement this analysis, Appendix B presents the distribution of transport modes used across all trip legs, disaggregated by survey year. This breakdown shows that private vehicle use—particularly as a vehicle driver—remained consistently dominant throughout the period, while walking maintained a stable and significant presence as the second most common mode. Public transport modes (train, tram, and bus) showed only minor year-to-year fluctuations, with no strong upward or downward trends. These findings support the overall conclusion that Melbourne's travel mode mix and emissions-related travel behaviour remained relatively stable over the study period.

3.2. Spatial distribution of climate change costs from transport emissions

To examine the spatial variation in transport-related CO_2 emissions across Greater Melbourne, Fig. 6 maps the average per capita emissions costs at the SA1 level. These values are standardised using z-scores to enable meaningful comparison across neighbourhoods, with five classes representing standard deviation intervals from the metropolitan mean. Dark green areas indicate neighbourhoods with significantly lower-than-average emissions, while dark red areas represent those with emissions costs more than 1.5 standard deviations above the mean. Railway lines are included to contextualise access to public transport infrastructure. The figure highlights marked geographic disparities in emissions intensity across the metropolitan area. To better understand these spatial disparities, the following section examines how emissions levels vary across different types of neighbourhoods.

3.3. Neighbourhood type and climate change costs from transport emissions

Fig. 7 illustrates the levels of climate change costs incurred in different types of neighbourhoods analysed in this study. On average each person's contribution to climate change cost from transport emissions was found to be $0.21 per day. Consistent with common wisdom, sprawl neighbourhoods emerge as the largest contributor to climate change costs ($0.23). On average, each person living in a sprawl neighbourhood within the Greater Melbourne area incurred a $0.23 climate change cost per weekday due to their travel behaviour. In contrast, MOD neighbourhoods exhibit the greatest potential for reducing climate change costs from transport emissions, followed by TOD, 20MN-AC, MAD, 20MN-TAD, 20MN, and AC neighbourhoods. These neighbourhood types are respectively 6, 3, 2.5, 2, 2, 1.6, and 1.5 times more effective in reducing climate change costs from transport emissions compared to sprawl neighbourhoods, costing on average $0.04, $0.08, $0.09, $0.12, $0.12, $0.14, and $0.15 per person per weekday. Fig. 7 also shows that hybrid neighbourhood design combining the characteristics of 20MN and AC are more effective than their basic types. Similarly, 20MN-TAD neighbourhoods are more effective than their basic types (20MN and TAD). These findings open up opportunities to formalise hybrid neighbourhood planning practice.

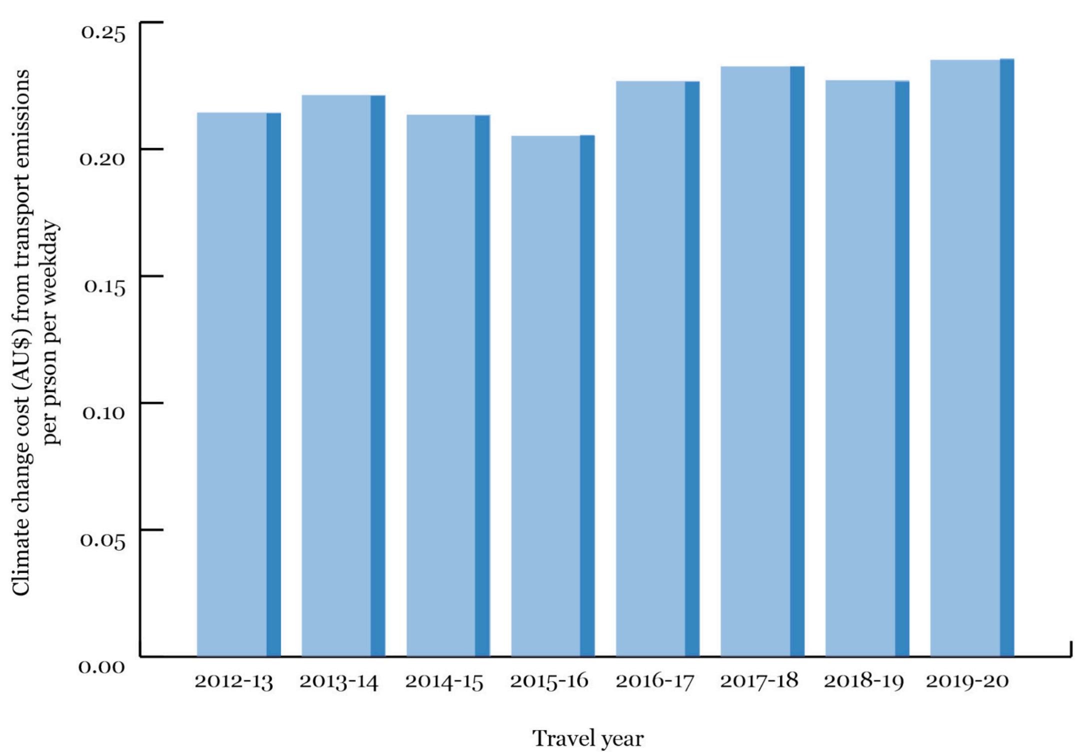

Fig. 5. Trend in climate change cost from transport emissions.

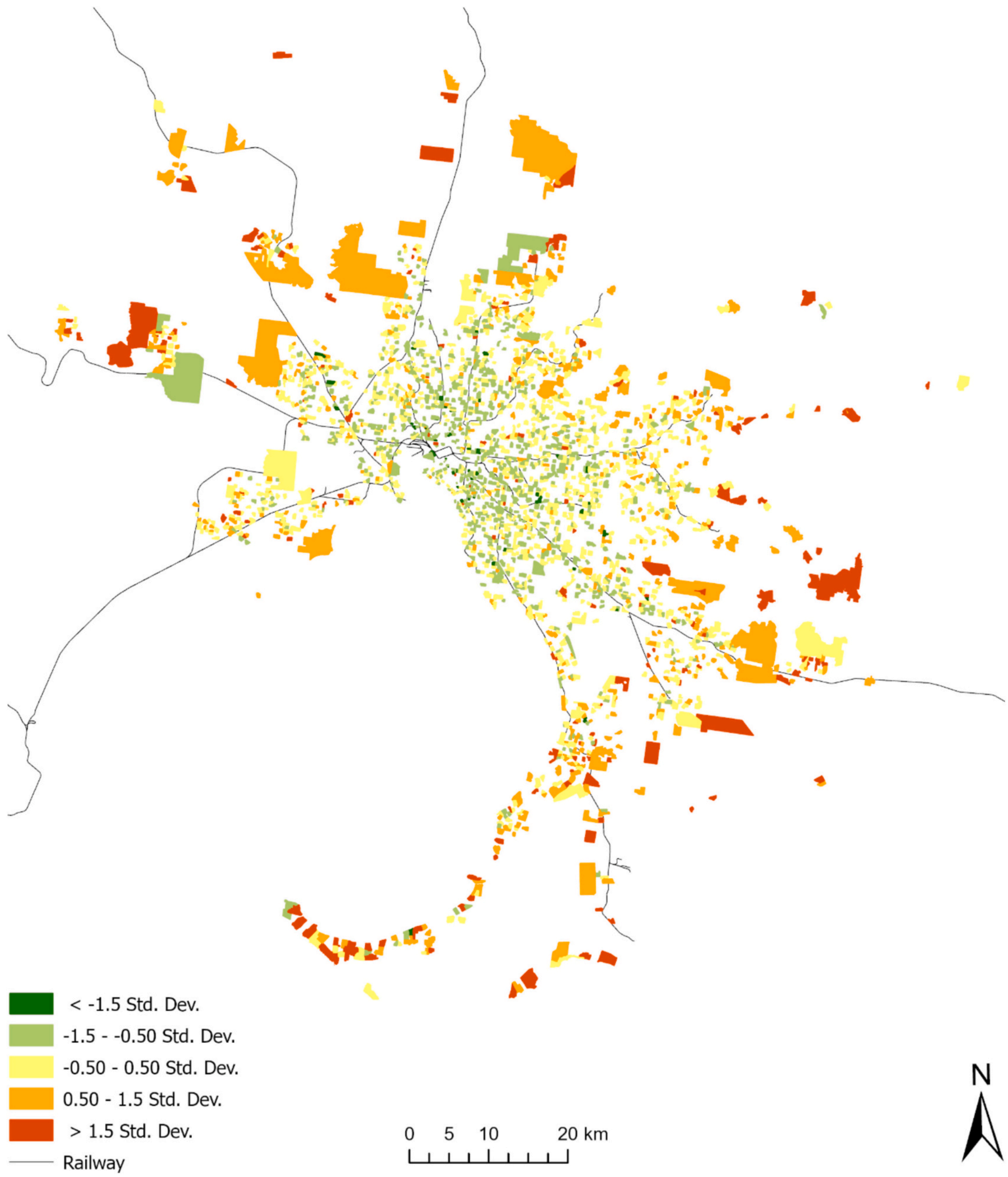

Fig. 6. Spatial distribution (in standard deviation units) of climate change costs from transport emissions among the sampled SA1s.

3.4. *Validity of the neighbourhood classification framework*

The findings presented in Section 3.3 suggest that the different neighbourhood types, as formulated in this study, are associated with varying levels of climate change costs from transport emissions, providing preliminary support for the utility of the neighbourhood classification framework. However, the differences between some neighbourhood types (e.g., AC vs. AC-TAD, 20MN-AC-TA vs. 20MN-MAD) are subtle, raising questions about their distinctiveness. This may reflect the limited explanatory power of the various urban form and function indicators used to differentiate the SA1s into different neighbourhood types. Table 5 reports the statistical significance of the six urban form and function factors (as discussed in Section 2.3) in explaining variations in climate change costs from transport emissions. Four out of the six indicators (population density, street connectivity, access to train stations, and types of amenities) were found to have a statistically significant association with climate change costs. The directions of these associations are consistent with theoretical expectations: higher population density, improved street connectivity, greater accessibility to train stations, and a wider variety of amenities are linked to lower climate change costs, controlling for neighbourhood socio-demographics and urban structure factors. These findings generally support the relevance of the proposed neighbourhood classification framework. Among the significant factors, the distance to the CBD demonstrated the strongest association with climate change costs. Specifically, a 10 km increase in distance from the CBD is associated with an annual increase of approximately $4760 in climate change costs from transport emissions, based on an average SA1 population of 466 people and assuming consistent travel patterns throughout the year.

4. Discussion and conclusions

This study proposes a neighbourhood classification framework to systematically analyse the diversity of neighbourhoods within Greater

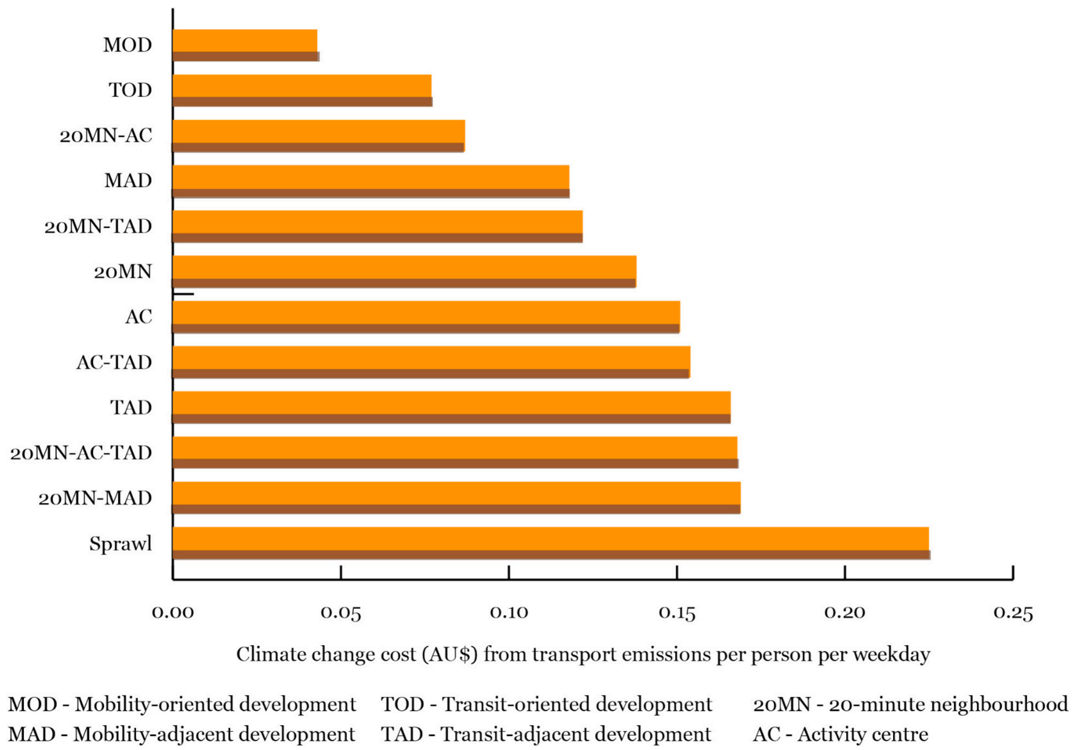

Fig. 7. Patterns of climate change costs from transport emissions across different neighbourhood types.

Table 5
Effects of urban form factors on the cost of climate change from transport emissions.

Explanatory factors	Outcome variable: climate change cost ($) from transport emissions per person per weekday	
	B	Standardised B
Population density (person/ha)	−0.0002**	−0.062
Types of amenities available	−0.0024**	−0.065
Intersection density	−0.0150*	−0.035
Access to train (1: Yes, 0: No)	−0.0127**	−0.035
Distance to CBD (km)	0.0028**	0.405
Distance to Metropolitan Activity Centres	0.0009**	0.070
Distance to Major Activity Centres	0.0027**	0.070
Median total personal income ($/week)	0.0001**	0.153
Median rent ($/week)	−0.0001**	−0.052
Average household size	0.0188**	0.066
Constant	0.0500**	
N		2704
R^2		0.32
F		127.66**

** Coefficients are significant at the 0.05 level.
* Coefficients are significant at the 0.1 level.

Melbourne and their potential influence on transport emissions. By categorizing SA1 regions into distinct neighbourhood types, it provides insights that could inform strategies for reducing transport emissions and associated costs of climate change through place-based, neighbourhood-specific interventions.

In 2016, Greater Melbourne had a population of 4.3 million people, with an estimated daily per capita cost of $0.21 from climate change linked to transport emissions, amounting to approximately $333 million annually. The findings suggest that sprawl neighbourhoods contribute disproportionately to these costs ($0.23 per person per day), consistent with prior research (Lee, 2020). About 83 % of the neighbourhoods (8340 out of the 10,068 SA1s) in Greater Melbourne are classified as sprawl, accommodating 84 % of the population in 2016. These neighbourhoods accounted for $297 million, or 89 %, of the total climate change cost from transport emissions.

Unlike sprawl neighbourhoods, those that integrate transport and land use planning, such as MOD and TOD, demonstrate significant potential for reducing emissions-related costs. Hypothetically, transforming all neighbourhoods in Greater Melbourne into MOD or TOD types could lower annual costs to $68 million or $121 million per year, respectively. However, realising such transformations would require substantial investments in transport infrastructure and land use modifications. This raises a critical question for future research: would the financial and social costs of these investments outweigh the environmental and economic benefits? While the findings support integrated strategies that combine travel *avoidance* and mode *shift* (Holden et al., 2020), the persistence of climate costs incurred even in the most integrated neighbourhood types (TOD and MOD) highlights the need for complementary efficiency *improvement* measures to address the remaining costs (Royal Town Planning Institute, 2021). However, such measures (electric vehicles, fuel efficient vehicles) must be carefully managed to avoid reinforcing current levels of travel demand, which could offset emissions reductions (Creutzig et al., 2022).

The disparity in climate change costs between TODs ($0.08) and TADs ($0.17) reinforces that TADs are essentially the 'evil twin' of TODs (Kamruzzaman et al., 2015), highlighting the critical role of land use planning – specifically, density, diversity, and street connectivity – in mitigating transport emissions. This finding aligns with the widely held view that "transport and development are not two separate things but two facets of the same challenge (i.e. transport is land use planning)" (Planning Institute of Australia, 2007p.1). Yet, such practice is "not well understood by practitioners…and is not yet mainstream practice" in Australia (Transport and Infrastructure Council, 2016p.10). The prevalence of TADs (982 SA1s) and MADs (99 SA1s) in Greater Melbourne, despite access to high-quality transport services, highlights the ongoing challenge of integrating walkable land use patterns.

Notably, the better performance of MADs ($0.12) compared to TADs ($0.17) demonstrates the value of seamless modal transfer options at train stations, even in less walkable contexts (Aydin et al., 2022; Blad et al., 2022). Similarly, the cost differences between MOD ($0.04) and TOD ($0.08) neighbourhoods emphasise the importance of multimodal integration in more walkable contexts. Some hybrid neighbourhood types (e.g., 20MN-AC, 20MN-TAD) appear to outperform their basic types (e.g., 20MN, AC, TAD) in reducing emissions-related costs, suggesting that evolving beyond conventional neighbourhood planning practices could yield additional benefits.

Among the six urban form and function factors considered, land use mix and job-population ratio showed no statistically significant effect on climate change costs, despite evidence of their influence in other contexts (Table 1). However, the statistical insignificance of the land use mix factor is consistent with findings in the Australian context (Mavoa et al., 2018), which suggests that refining the framework, such as reconsidering the inclusion of land use mix, could improve its applicability. Nonetheless, the significant role of 20MN-AC neighbourhoods in reducing climate change costs indicates that factors like job-population ratio may still be impactful when combined with other factors such as local amenities. Although the influence of distance to the CBD factor on transport emissions is debated in the literature (Table 1), this study found it to have the strongest association with climate change costs (Table 5). This underscores the importance of urban structure in determining the sustainability of neighbourhood types, particularly when planning new neighbourhoods. Further research could further explore how the effectiveness of different neighbourhood types, such as MOD, varies with proximity to the CBD.

This study develops a policy-relevant neighbourhood classification framework by identifying urban form and function indicators from globally published literature. To ensure policy relevance, the standards (threshold values) for these indicators were derived from local policy documents and literature, aligning the framework with local context. While this approach enhances policy relevance, a potential limitation is that the framework may be context-sensitive and its application in other settings may require adjustments based on local policy norms. Future research could focus on testing and adapting these thresholds in diverse contexts to improve the framework's global applicability.

Overall, this study highlights the importance of integrating transport and land use planning to mitigate climate change costs from transport emissions. It offers the necessary evidence base as an initial step toward developing place-based strategies tailored to specific neighbourhood type to achieve net zero transport through the neighbourhood planning process. Such effort can enable cities to make significant progress in reducing their environmental footprint.

CRediT authorship contribution statement

Liton Kamruzzaman: Conceptualization, Methodology, Formal analysis, Writing – original draft. **Graham Currie:** Writing – review & editing. **Hai L. Vu:** Writing – review & editing. **Eric J. Miller:** Writing – review & editing. **Roger Vickerman:** Writing – review & editing.

Declaration of competing interest

None.

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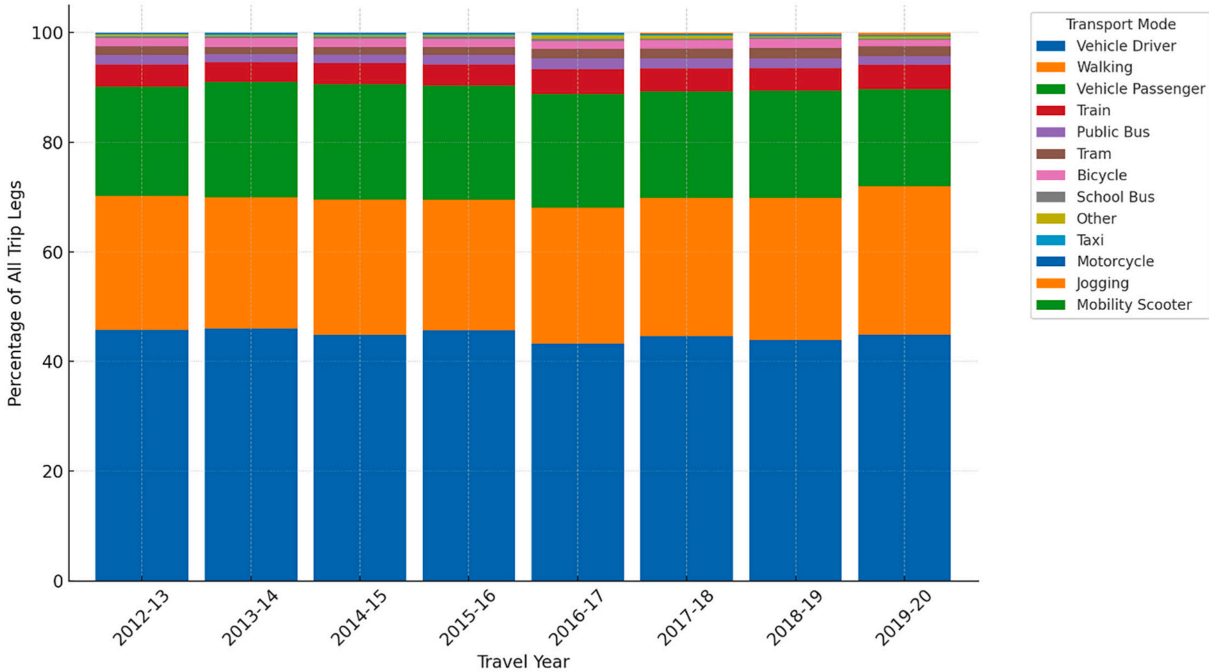
Appendix A. Mode choice distribution (%) across different legs of trips

Travel mode	Trip legs									
	1	2	3	4	5	6	7	8	9	10
Bicycle	1.67	0.01	0.04	0.01	0.01	0.01	–	–	–	–
Jogging	0.10	0.01	0.01	0.01	–	–	–	–	–	–
Mobility scooter	0.01	–	–	–	–	–	–	–	–	–
Motorcycle	0.21	–	0.01	–	–	–	–	–	–	–
Other	0.35	0.02	0.01	0.01	0.01	–	–	–	–	–
Public bus	0.03	1.43	0.26	0.18	0.05	0.03	0.01	0.01	–	–
School bus	0.19	0.24	0.01	0.01	0.01	–	–	–	–	–
Taxi	0.30	0.01	0.01	0.01	0.01	–	–	–	–	–
Train	0.06	3.50	0.68	0.44	0.04	0.01	0.01	–	–	–
Tram	0.01	1.40	0.13	0.26	0.05	0.02	0.01	0.01	0.01	–
Vehicle driver	51.82	0.39	0.43	0.07	0.07	0.01	0.01	0.01	–	–
Vehicle passenger	23.36	0.16	0.22	0.04	0.04	0.01	–	–	–	–
Walking	21.90	0.53	4.78	0.91	0.71	0.13	0.05	0.01	0.01	0.01
Not Applicable	0.00	92.3	93.4	98.1	99.0	99.8	99.9	99.9	100	100
N	211,012									

Note: 'Not Applicable' category denotes the proportion of trips that did not involve a particular leg. For example, 92.3 % of trips are marked as 'Not Applicable' in Leg 2, indicating that only 7.7 % of trips had more than one leg.

Appendix B. Yearly mode share across all trip legs in Melbourne



Data availability

The authors do not have permission to share data.

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