

Review

Policy Driven Compact Cities: Toward Clarifying the Effect of Compact Cities on Carbon Emissions

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Abstract: Compact cities, characterized by high density and accessibility with fully developed inner-city public transport, are widely discussed and practiced around the world in response to the challenges of sustainable development and global warming. On this basis, we are committed to answering the question of how cities with varying urban growth rates adopt different policy practices, and whether these practices contribute to achieving the goal of building a sustainable, low-carbon city. Specifically, this study assesses the theoretical evidence and practical experiences on the effect of compact city characteristics and policies on urban CO₂ emissions using a focused literature review and representative case studies. The results illustrate that public transportation is often strengthened in compact city policies and the density and spatial configuration of cities has a significant impact on urban carbon emissions. Moreover, there are significant differences within the impact mechanisms of compact cities on carbon emissions between small-medium-sized cities (dealing with aging populations and resource waste) and megacities (dealing with excessive urban sprawl). However, there is still insufficient quantitative evidence on the effectiveness of compact city policies and this review provides insights into future compact city planning toward policy approaches which yield lower carbon emissions.

Keywords: compact city; sustainability; urban planning; carbon emission; global warming



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1. Introduction

With the urgent need for nations worldwide to reduce greenhouse gas (GHG) emissions, various actions have been adopted to address contradictions between economic development and environmental preservation. As cities play an important role in human activity and are therefore linked to carbon emission levels, sustainable urban development is an important social issue requiring our attention.

Previous scholarship has focused on the relationships between various aspects of cities and carbon emissions. Many empirical studies draw different conclusions on the effect of urbanization on carbon emissions. Some hold that urbanization helps decrease carbon emissions in that population density increases the scale effect on the utilization of public facilities [1], while others identified an increase in CO₂ emissions through the process of urbanization due to large scale population and economic activity agglomeration, causing an overall increase in energy consumption [2,3]. Urbanization measured by land-use change is also found to be positively correlated with CO₂ emissions [4]. There are also scholars who draw attention to GDP growth. For example, Fujii et al. tested the Environmental Kuznets Curve (EKC) hypothesis and discovered an inverted U-shape relationship between urban economic development level and CO₂ emissions in transport, residential and industry sectors with a turning point towards decline [5]. The form and spatial structure of the city itself has also been investigated. It was found that larger houses with a more dispersed distribution consumed more energy [6], while a study in Norway found that decentralized

houses consume energy up to fifty percent more than connected houses [7]. A study in Chinese cities also identified a negative effect of residential density improvement on urban carbon emissions [8].

As a spatial form characterized by ‘compactness’, the compact city is widely discussed in contemporary urban policy as a means to address sustainability goals in economic viability, environmental quality and social equity among others [9]. It has been adopted and practiced by policy makers all around the world although the concept still generates debate. Some maintain that compact cities will promote sustainability through higher residential densities which bring equitable accessibility to local businesses and services. This high-density living also nurses urban vitality and increases social interaction [10]. Mixed land use, another key compact city component, changes commuting patterns generated from urban sprawl in which long travel distance is required in daily life by integrating businesses and recreation in residential areas [11]. Energy consumption from households and transport in highly dense areas can be reduced due to concentration [7]. Theoretically, the compact city strategy is helpful toward reducing urban CO₂ emissions and cities like Vancouver (Canada) and Portland (US) are employing compact city policies as a tool to achieve their goal of reducing GHG emissions. In 2012, OECD published ‘Compact City Policies: A comparative assessment’ [9]. This report provides detailed insights of both the concept and practices of OECD countries in applying compact city policies, so significant contribution to the discourse, providing a solid foundation for future studies. A sizable body of literature empirically investigates how various aspects of compact urban form have an impact on economic, social, and environmental urbanism. However, the evidence varies both thematically and geographically across studies [12]. Furthermore, there is currently no specific and detailed review on how the various characteristics of compact urban form have an impact on the urban environment, especially on carbon emissions.

The overall aim of this study is to assess and sort the theoretical evidence and practical experiences on the effect of compact city characteristics and policies on urban CO₂ emissions. To achieve this aim, we identified the key factors relevant to the construction of compact cities based on both literature review and historical precedent, summarizing how these factors impact upon carbon emissions. This study also utilizes case studies from several different policy driven compact cities in both developing and developed nations using restriction tools (setting urban boundaries, density requirements, etc.) and financial tools to implement a sustainable and high-efficiency urban form. The key policies and practices of these cities will be extracted and compared to provide insights for future research of compact city policy.

The contents of this study are organized as follows. Section 2 lays out the methods used to undertake our literature review. Section 3 engages with international precedents and policies for compact cities, with Section 4 detailing the discussion. Section 5 presents our conclusions, limitations, and proposed future work.

2. Literature Review

The methodology used to identify key scholarship relevant to our study is a focused literature search and review using targeted keywords. We utilized the Scopus academic publication database using the primary keyword ‘compact cities’, which returned 375 studies. In order to increase relevance with regard to the relationship between compact cities and carbon emissions, we added the keyword ‘carbon emissions’, which reduced our initial review paper set to 56 studies. Based on the initial review findings that compact cities’ carbon emissions are reported to be heavily associated with population density and land use approaches, we included the keywords of ‘population density’ and ‘mixed land use’ to identify an additional 18 relevant studies for our review. The assessed literature is recent, with the oldest manuscript reviewed from the year 2001, and the majority published after 2010. We sorted and filtered the relevant cross-references and 76 identified academic papers and other literature were reviewed using an integrative review method in order to uncover both theoretical and empirical insights.

2.1. Approach to a Sustainable City Form: Definition and Characteristics

The definition of compact city varies and the term ‘compact city’ dates to 1973, initially proposed by Dantzig and Saaty, highlighting a circular city with a special city form of high-density residential areas, low dependency on automobiles, and a clear boundary from the surrounding area [13]. The spatial features showed mixed land use, diversity, and a clear identity. The concept also highlights social functions including social equity, self-sufficiency of daily life, and independent governance. However, this single-center form has certain limitations, particularly in the event of population growth and effects such as congestion that may occur, as well as unaffordable house prices. Thomas and Cousins proposed a development that is more decentralized with basic characteristics of compactness in scale, accessibility without an automobile, and strengthening of open space and green land [14]. Churchman identified compact city policies as realizing the intensification of urban resources by increasing residential density, mixed land use, and restricting development outside of designated boundaries [15]. Other scholars have also detailed the characteristics of compact cities. For example, Burton points out that high density not only includes high average population and building density, but also high density of building form, which could accommodate such a population. Furthermore, mixed land use should provide various and abundant infrastructure and services both vertically and horizontally [16]. Neuman identified a high ratio of open space and sufficient fiscal capacity to finance the development [17]. The OECD defines compact cities as a spatial form characterized by ‘compactness’ and compact city policies are understood as approaches to achieve a compact city by influencing the ways in which urban space is utilized [9].

There are also some commonly discussed points regarding the important characteristics of urban areas. With regard to urban size, differing from shrinking cities or urban decay, becoming more compact does not always equal minification, irrespective of size or population. In fact, many large metropolises are applying compact city strategies to counter urban sprawl. Urban sprawl has been correlated with increased energy use, pollution, and traffic congestion and a decline in community distinctiveness and cohesiveness [18]. Compact urban development is thought to be a solution to this disordered situation. Development boundaries are usually set in these cases, however small cities such as Toyama in Japan or Anshan in China also adopt compact city strategies in response to an aging society and industrial restructuring issues. These aspects will be discussed in more detail in the following chapters.

Small cities and mega cities usually differ in their city structure regarding the city center. When the compact city concept was first proposed, it was idealized as a single centered circular city with explicit tiers. As a result, the concept is frequently misunderstood as opposed to decentralization, emphasizing a pattern oriented to downtown or central city areas versus a dispersed spatial pattern, with obvious density consequences. It has also been argued that efforts in downtown renewal have failed with the process of decentralization [19].

However, from a more practical point of view, many metropolises have a multi-centric structure. That does not preclude them from being compact. The OECD has stated that the structure of compact city does not presume a specific urban form and different metropolitan areas should pursue different urban structures to form a compact city (monocentric, polycentric, or other approaches). For example, a monocentric compact city may not be realistic in megacities, as it may well cause significant negative externalities (e.g., traffic congestion or air pollution) and offset the benefits of a compact city. Instead, a polycentric compact city may be preferable in this case [9].

Building forms are also important when discussing density issues. To guarantee higher density in metropolitan areas, high-rise buildings are usually promoted, and policies are made to ensure sufficient accommodation and jobs are available in these urban centers. London in Britain sets development plans to guide the construction of tall buildings as a means of promoting regeneration capacity and administering future growth, fostering new dwellings and economic growth, especially in order to make optimal use of public transport

and achieve good connections to services and amenities [20]. Nanjing in China has released policies stating that the approval of construction of low-density houses including villas and cottages will be stopped to increase floor area ratio (FAR), the ratio of floor area to land area, indicative of density [21]. Apart from high-rise buildings, Vancouver in Canada launched the EcoDensity Chapter that allows secondary suites, basement suites, and laneway housing to be built on the bases of existing residences to increase accommodation and overall density. Compactness in building and urban forms varies economically and geographically; flexibility should be aimed for in planning compact city policies.

2.2. Dimensions and Indices

Scholars have synthesized core dimensions of compact urban form. Ahlfeldt and Pietrostefani reviewed 189 studies and found three primary categories of compact city characteristics which are economic density, morphological density, and mixed land use [11]. Kotharkar et al. measured six aspects of compact urban form including density, density distribution, mixed land uses, transportation network, accessibility, and shape [22]. Bibri et al. identified four dimensions of compact city as compactness, high density, land-use mix, and sustainable transport [23]. Dempsey pointed out that the characteristics of compact cities are well-known within the dominant theoretical paradigm of sustainability, including high residential density with mixed land use, efficient public transport system, and low energy consumption [24]. The OECD gives three key characteristics of ‘compactness’, which are: (1) dense and proximate development patterns; (2) urban areas linked by public transport systems; and (3) accessibility to local services and jobs [8]. While some empirical studies use population density, others use land development density and road density to indicate urban compactness [25].

Most studies share the key dimensions with little differences and sometimes overlap with each other. These features all focus on the aspects which could improve urban sustainability. For example, high population and residential density improves energy efficiency and further reduces energy consumption per capita. Mixed land use development and high accessibility reduced travelling distance to workplaces, entertainment, and local services. This approach works together with transit-oriented development which enhances public transport connection to reduce the use of private cars and further mitigate air pollution and GHG emissions. Explicit characteristics of compact urban form clarifies the ‘causes’ in studying compact cities and measurable indicators representing the characteristics that are the foundation for investigating the effect of compact city strategies in reducing CO₂ emissions. This study will follow the definition of the OECD report which was published in 2012, as it provides a clear classification between indicators relating to compactness and indicators relating to compact city policies for the first time [9], to assess density, accessibility, and public transport as three key aspects of compact cities and explore in detail how they are interlinked with compact city policies, and how carbon emissions are affected.

2.2.1. Indicators Related to Compactness

- Density and Proximity

Quantifying compactness usually starts with density, which is the most frequently used index and can be measured in a number of different ways. Population densities including persons per hectare, persons per hectare in built-up areas, and jobs per urban hectare are proposed to measure overall urban densities [16,26]. Gross density and net density are also proposed to distinguish between the number of dwellings on all land use types and residential building sites, excluding roads, parks, and other nonresidential land use [27]. There are also density indicators which closely relate to evaluating the efficiency of urban land use. FAR, or floor space ratio, is commonly used in urban development practices, describing the ratio of total floor space inside buildings to the total floor area of the property [27], measuring the intensity of the use of urban areas.

The regeneration rate is also discussed in compact urban planning at which new development is constructed inside already developed parcels or is replacing old structure

in its place [8]. This together with vacancy rates of housing and office building stock are useful for measuring the intensity of use of existing urban buildings.

Apart from average urban density, the spatial distribution of density also reflects the spatial characteristics of urban form. Spatial metrics, or landscape metrics can be used as a quantitative measure to characterize this. Makido et al. use a 'Compactness Index' which combined the shape and number of settlement patches to represent compactness [28]. Proximity is also used to assess the morphological aspects of compact cities. Different from density, proximity is concerned with how urban activities are dispersed in a metropolitan area. It can usually be measured by average travel distance within a given area. Commuting distance, average distance for shopping, leisure, and logistics are also measured to assess proximity [9].

- Accessibility to local businesses and services

Accessibility to local businesses and services refers to the convenience with which residents reach local services such as groceries, clinics, and restaurants, as well as neighborhood jobs either on foot or by a short ride on public transport [9]. Accessibility is closely related to population or employment density but also to the mixed land-use elements of a compact city. Mixed land use is the approach most widely applied to represent accessibility to local businesses and services [29]. Research has found that mixed uses of land have a significant impact on travel patterns and commuting behavior [30]. The vehicle miles travelled (VMT) can also be lowered via a higher degree of mixed land use [31].

However, developing indicators on mixed land use is challenging. Existing studies show that a clear definition of mixed land use does not exist and there are varying views on what constitutes mixed land use. It can be simply gauged as a binary (0–1) variable such as either non-residential uses exist or not within some defined geographic area [30]. Job-housing balance is another way to indicate the degree of local mixed land use and is used to measure urban sprawl [32,33]. Other indicators are also proposed to measure accessibility, for example the ratio of residential area to non-residential area, the percentage of residents who have access to local services within 500 m, and the number of key facilities per thousand inhabitants [16,34].

- Public transport systems

When a city becomes compact and population density increases, intra-urban mobility can be influenced in several ways. On one hand, on-road trips relying on automobiles become difficult due to congestion caused by increasing traffic which in turn further aggravates pollution and GHG emissions. On the other hand, due to higher accessibility, another important characteristic of compact cities, shorter average distances to reach local services could increase sustainability with the provision of public transport systems, which provide the opportunity to travel at a reasonable cost [35]. Scholars have attempted several ways to measure the availability of inner-city public transport systems. One set of indicators is the percentage of commuters using public transport and the percentage of commuters going to work by foot [36]. Other common indicators focus on the supply of public transport systems, such as total length of public transport lines, number of stations, and station density. From a more micro view, transit accessibility, which denotes the concept of transport system availability, can be understood conceptually as a potential or an activity that anyone could consider using the public transport as a future option [37]. Furthermore, walking access to public transportation stops can be utilized as an indicator; for example, the maximum walking distance for residents to reach transit stops [38]. Another measure of transit accessibility is the spatial coverage, the area which is covered by transit services [39]. Frequency of service could also be considered alongside these indicators.

As shown in Figure 1, the three sets of indicators discussed above cover the main characteristics of compact cities. However, as mentioned in the previous chapter, rather than naturally appearing, a compact city is proposed as an ideal sustainable city form derived consciously from long-term planning and strategic policies. When an evaluation of

indicators relating to compactness are not sufficient to clarify the compact city's formation, policies also need to be classified and evaluated to measure their impact.

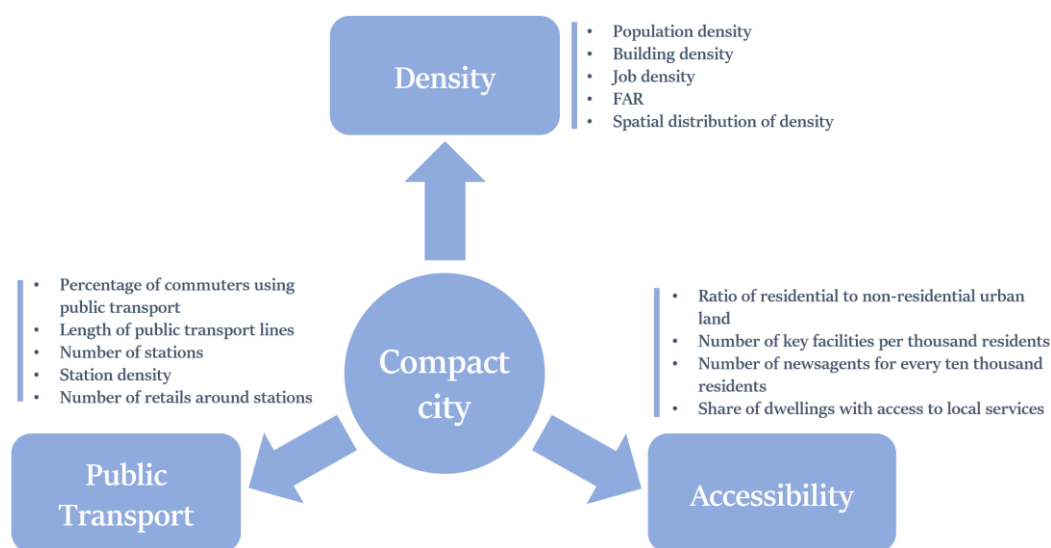


Figure 1. Key indicators measuring compactness.

2.2.2. Indicators Related to Compact City Policies

As is the case with guidelines and ways of implementing compact cities, indicators used to evaluate compact city policies can also be divided into two categories. The first is an indicator used to quantify the thoroughness of compact city policies. For example, the number and variety of policies relating to compactness. The second accounts for the indicators used to quantify the environmental and economic effects of compact city policies.

According to a survey conducted by the OECD in 2010, it was identified that in most OECD countries, the concept of a compact city is an essential part of urban planning policies. In addition to national policies, there are a variety of policies at the metropolitan and local levels including both strategies and instruments. Policy instruments can also be categorized by type of intervention including regulatory, fiscal, partnerships, etc. [8]. Regulatory tools such as urban growth boundary (UGB) and density requirements are commonly used for compact cities to limit urban sprawl and increase the efficiency of urban land use. Financial tools such as incentives or subsidies are used to promote transit-oriented development (TOD). When evaluating the intensity or the degree of compact city penetration, the number, scope, and variety of compact city policies can be considered as indicators.

With regard to the effect of compact city policies, indices are generally associated with the aims of compact urban design and how the indicators can justify and quantify the ability of compact city policies to contribute to the environmental, economic, and social goals of sustainable development [23]. A range of sustainability indicators (SI) to measure urban sustainability have been proposed by international organizations; some are quantitative and explicit, while others tend to be more qualitative and implicit [40]. The Global City Indicators Program (GCIP) run by the World Bank is a decentralized, city-led initiative that aims at building a standard system that measures and monitors city performance and urban quality of life [41]. The OECD points out that while there is a growing discussion on indicators of environmental sustainability, relatively few indicators of social and economic sustainability exist, and have proposed a set of indicators which focus on three aspects including public open space, transport and household energy use, affordability, and public services [9].

Based on the review of previous literature, we found that compact city indicators measure two aspects of the development of compact cities. One is to assess the compactness, to quantify different dimensions generated from key characteristics of compact cities including density, public transport, and accessibility. The other is to evaluate the intensity

and impact of compact city policies on various aspects of city development (environmental, social, economic outcomes, etc.). It should be noted that an ideal compact city does not naturally emerge. It requires detailed guidelines and specific policies to construct. In this research, we focus specifically on the impact on the environment, especially urban carbon emissions. In the next section we focus on studies concerned with the impact of various attributes of compact cities on urban CO₂ emissions.

2.3. Compact City Form and Carbon Emissions

Previous scholarship which has thoroughly and systematically studied the relationship between compact cities and carbon emissions remains scarce. However, there are a number of studies which consider singular aspects relating to compact city development and its impact on urban CO₂ emissions such as density, spatial configuration, and public transport.

- Density and Carbon emissions

To provide evidence for the relationship between compactness and sustainability, scholars often use population density to represent compact or sprawling city forms; however, this is considered insufficient to describe sustainability overall [17]. Scholars considered how urban form itself has an impact on sustainability. The idea of spatial sustainability was proposed to stand for the geometric and configurational layout and arrangement of space, which is an important factor that could influence urban sustainability [42]. Ratti et al. showed that the ratio of passive to non-passive zones plays a key role in the relationship between urban texture and energy consumption and non-passive zones consume approximately double the energy of unobstructed passive zones [43]. A study was undertaken in the Pearl River Delta in China estimating the relationship between urban forms and energy consumption using landscape metrics [44]. Another study in China employed residential density to measure urban spatial form and found that urban spatial form produces a negative effect on urban CO₂ emissions in spite of an increase in CO₂ emissions caused by urbanization [8]. Compactness measured by proximity is also used to study the impact of compact urban form and carbon emissions, and a significant negative effect was found in the north and mid-south of China [45].

- Public transportation and carbon emissions

Transportation emissions accounted for 29% of total US GHG emissions in 2020 [46]. Passenger cars and vans (light commercial vehicles) are responsible for around 12% and 2.5%, respectively, of total European Union (EU) GHG emissions. To meet the goal of achieving net-zero carbon emissions, urban transit needs to shift towards low-carbon mobility where both passenger and cargo transportation emit less GHG than current levels. Wimbadi et al. found that cities are becoming test fields to promote low-carbon mobility transitions in developing new public transport methods. Urban experiments that help pave the way for a low-carbon transport transition have similar goals of creating sustainable urban transport systems through the introduction of low-emissions vehicle (LEV) technologies [47].

Academic literature has uncovered that public transportation systems including mass rapid transit (MRT), light rail transit (LRT), bus rapid transit (BRT), and other variants of public transit offering lower load capacities play a significant role in shifting urban transit, enhancing commuting efficiency and promoting low-emission vehicle technology [48]. Previous research has also found that public transport is one of the solutions to climate change mitigation developed through urban experiments [49,50]. However, this research did not specify which public transport measures were considered and tested in their experiments.

In compact city construction, public transit is considered a priority factor, however it is not the only approach to reducing emissions. The 'Avoid-Shift- Improve' (ASI) approach is used by transport scholars and practitioners. This approach aims to significantly reduce greenhouse gas emissions, energy consumption, and congestion, with the ultimate goal of creating more livable cities. 'Avoid' refers to avoiding or reducing travel or the need to travel, 'Shift' means the shift toward modes with higher level of energy efficiency, while

‘Improve’ stands for improving efficiency through vehicle technology [51]. Precedential studies identify the difficulty of estimating the exact impact of public transport construction alone on overall city carbon emissions.

- Spatial configuration and carbon emissions

Recent research has showed that population growth has an impact on city-level CO₂ emissions but is dependent on the spatial configuration of this population growth [52]. A study of 50 Japanese cities was conducted to determine the correlation between spatial indices of urban form and sectoral CO₂ emissions from the residential and passenger transport sectors. Less complex cities were found to have lower per capita CO₂ emissions, but it was found that denser settlements in the mono-centric form may lead to higher per capita CO₂ emissions [28]. Scholars also built a spatial configuration model to estimate compactness and carbon emissions, where a trade-off was found between high intensification and building energy consumption in engendering compact cities [53]. A study was undertaken on 286 Chinese cities to specify the relationship between polycentric and compact structure and carbon emission reduction. Results showed that although there is not a significant impact of polycentric spatial structure on carbon reduction, a dispersed urban form still generally increases carbon emissions, and a sustainable urban spatial form could help in reducing carbon emissions [54].

Figure 2 shows a flowchart of the pathways identified in the literature identifying how compact city policies influence urban CO₂ emissions. In addition to the possible impacts of the main characteristics of compact cities on carbon emissions mentioned above, previous studies have also paid attention to how the spatial structure of cities affects their industrial structure, and therefore influences the efficiency of energy use which has a significant impact on industrial carbon emissions [55]. Given the background that the majority of cities which have adopted compact city strategies emphasize the strong support and promotion of public transportation, it is necessary to take energy policy into consideration because a reduction in public transport emissions is closely related to the promotion of new energy vehicles (NEV). The rearrangement of the transit system coincides with an update of transportation options, and this plays a fundamental role in evaluating whether the compact city strategy has a positive impact on urban GHG emissions. In the following chapters we discuss some of the world’s precedential compact cities in detail to better understand both successful and challenging aspects.

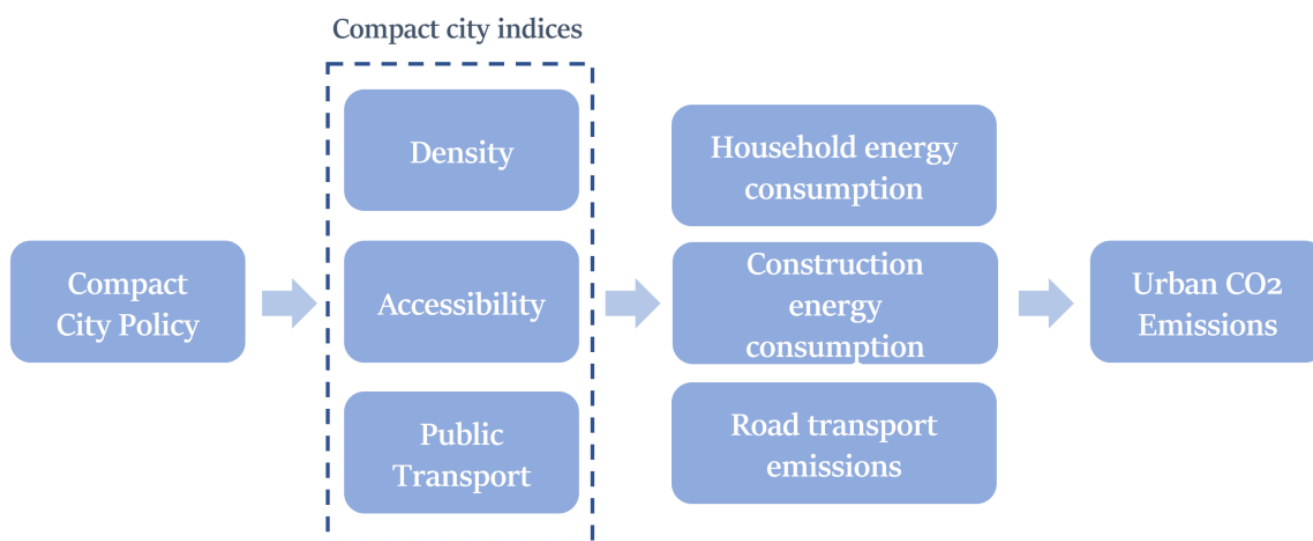


Figure 2. Flow chart of how compact city strategy can influence urban CO₂ emissions.

3. International Precedents and Policies of Compact Cities

In order to achieve a low-carbon urban spatial structure, scholars in the field of urban planning suggest using urban planning methods to undertake a low-carbon reconstruction

of urban space. It has been proposed that the system dynamics model could be used as a decision-making tool in the urban planning process to take carbon emissions and global warming into account in the urban planning process, which will help to reduce carbon emissions and contribute to solving the problem of global warming [56]. This research also identified a relationship between carbon emissions and urban morphology, and advocates for the compact urban space development model. Compact cities can save transportation costs, reduce energy consumption in transportation, and thereby reduce CO₂ emissions [57].

With regard to precedents, many regions have announced compact city strategies as part of their urban planning, and their experience may help in building sustainable cities in the future. Since compact city policies strengthen various aspects of urban development, in this study, we focused on specific policies relating to reducing carbon emissions and achieving sustainable development, targeting the focus of our study. Here, we assess a selection of influential compact cities with a variety of approaches and outcomes based on their specific demographics and needs. To make this study more comprehensive and comparable, we intentionally chose cities from different parts of the world (including Toyama in Asia, Melbourne in Oceania, London in Europe, and Vancouver in America). Furthermore, these four regions have all been practicing compact city strategies for over 10 years, which enables a more thorough analysis and revision of policies and performance of their implementation. Moreover, case selection takes the population into consideration. We chose precedents with both small and large population bases. These case studies aim to identify the empirically important factors of compact city policies.

3.1. Toyama City, Japan

Toyama city has become a global model for compact urban development. Researchers attribute its success to effective governance and dedication [58]. As the capital city of Toyama Prefecture, Toyama, like many other ordinary Japanese cities, was suffering from urban sprawl, an aging society, and declining population in the 2000s. In 2005, with the advancement of urbanization, seven municipalities merged, and the urban area expanded fivefold to 1242 square kilometers, but the population density decreased accordingly [59]. With the declining birthrate and the aging population, the central area of Toyama became empty, and the government faced a worsening financial situation. To address these problems, the Toyama City government issued the Downtown Revitalization Plan and Public Transport Revitalization Plan in 2007 [60,61]. The transition to compact urban development is clearly proposed and policies are introduced to attract residents and businesses to move along transit corridors.

The Downtown Revitalization Plan was carried out in three phases. The first stage was from 2007 to 2012, with the ideal of turning the tide of the decentralizing and deteriorating city center. The most important part of Toyama's success, the LRT system, was also proposed during this stage. The second stage covered the period from 2012 to 2017, enhancing the quality of urban space. In this stage, partnerships with the private sector, nonprofits, academia, and local communities played an important role in developing social capital. The third phase was enforced from 2017 until 2022, further reinforcing the livability of the city center. This phase focused specifically on the relocation of public facilities [58].

The performance of Toyama proved to be stunning. The economic value of the LRT project was enhanced by reducing the construction period to three years instead of the originally estimated nine. The net present value (NPV) of this project also improved by 16.9 billion yen because of the utilization of existing tracks [50]. These efforts resulted in a population shift back into the city center and the utilization of public transportation corridors. It is noted that the behavior of residents, particularly the elderly, was changed due to the LRT system. There is anecdotal evidence that the LRT triggered a mode shift from cars and buses, which will have an impact on reducing urban carbon emissions. In March 2019, Toyama city announced its 3rd 'Toyama City: Environmental Model City Action Plan: CO₂ reduction plan based on compact city strategy' and set the goal of cutting

GHG emissions by 30% by 2030 and 80% by 2050 [62]. Apart from promoting the use of LRT and cycling to cut down on emissions from the transport sector, Toyama city proposed “the promotion of eco-life integrated with compact town development”, in which low-carbon residences deploying renewable energy such as solar power, along with an awareness of ‘eco-life’ are promoted to the public.

3.2. Melbourne, Australia

Melbourne is the second largest urban area in Australia and is the capital and most important economic center in the State of Victoria. Unlike Toyama city which faced a severe aging problem, the factor driving compact city policies in Melbourne arose from the challenges brought by the changes in its industrial structure. Melbourne suffered from industrial decline in the 1980s, with recessions in almost all sectors of the economy. Inner Melbourne was “at risk of becoming a ‘doughnut’ city, with an empty core surrounded by expanding suburban developments” [63]. The region needed to deal with its deteriorating urban centers. Rapid population growth also presented a challenge. The uneven distribution of jobs led to the increased use of automobiles and this kind of commuting pattern had a significant impact on Melbourne’s economic and environmental performance. Office and professional jobs were concentrated in urban centers, while retail services, community services, and industrial jobs were located in the outer fringe [9]. As the metropolitan area continues to grow, more and more people in outer areas will need to commute longer distances to work. Access to the inner-central area will become increasingly congested [64], identifying an urgent need for better planning of transport, residences, and jobs.

Melbourne began its compact city strategy in 2002, when the State of Victoria released ‘Melbourne 2030: Planning for sustainable growth’ [65]. This long-term plan aims at managing sustainable growth in Melbourne and the surrounding regions. The plan pointed out the direction of ‘a more compact city’ for the first time and introduced an urban growth boundary as a tool to contain the sprawling of metropolitan Melbourne. The city planned to build up activity centers as a focus for high-quality development, activity, and living for the whole community and restrict out-of-center development [64]. In 2008, the state government issued ‘Melbourne @ 5 Million’ as a complement to ‘Melbourne 2030’. The plan, in consultation with the Department of Transport, focuses on the construction of a modern integrated transport system in the metropolitan area to achieve sustainability goals [66].

Many steps have been taken by Melbourne towards achieving a low-carbon city and to contain urban sprawl. Policy mandates the intensification of land-use inside the urban growth boundary, with a focus on areas around activity centers and public transport hubs. However, some argued that there was not full and effective implementation of this policy and the growth boundary has been expanded substantially. Woodcock et al. attribute this failure to the government’s fear of electoral backlash if Melbourne’s much-loved urban ‘character’ was transformed [67]. In the latest metropolitan planning strategy, ‘Plan Melbourne 2017–2050’, which was released by the Victorian State government in 2017, the city no longer emphasizes the word ‘compact’. Instead, the concept of the 20-min neighborhood is proposed, which also aligns with the high accessibility characteristic of compact cities [68]. Goals regarding a low-carbon city are also mentioned, such that Melbourne will reduce GHG emissions to net zero by 2050 [69]. However, a conclusive evaluation of the environmental effects of Melbourne’s compact city construction has not been undertaken and the achievement of a low-carbon city is still under development.

3.3. London, Britain

Greater London, with the same extent as the region of London, is an administrative area in England governed by the Greater London Authority. The region covers 1572 km² and had a population of approximately 9 million by mid-2020. The population has been growing since the 1990s. To better accommodate London’s growth within its boundaries and create a better city for people to live in without encroaching on open space, the Greater London Authority published its statutory spatial development strategy, The London Plan,

in 2004 [70]. This was revised and republished in February 2008, and as of March 2021, a new London Plan was issued by the Greater London Authority [20].

The compact city strategy in London starts from The London Plan 2004, in which Objective 1 states that new homes will have to be accommodated within London's existing boundaries without infringing on open spaces. Key policy directions were stated for achieving this objective, emphasizing higher density and intensification commensurate with public transport capacity, resulting in a high-quality compact city. This objective also incorporates Objective 5, 'To improve London's accessibility', in which the development of public transport and transport systems are aimed at tackling congestion and improving sustainability. The London Plan 2004 also set a policy direction to address the issues of climate change and to ensure that the environmental impact of a growing London does not contribute to global warming [70]. To deal with congestion, financial tools such as the London congestion charge are employed to raise funds for the construction of public transport systems. All motorists driving within the London's Congestion Charge zone area will be charged. The congestion charge remains one of the largest in the world and sets a reference point for other cities when considering their own plans [9].

London's compact city strategy has been in place for over a decade and has received criticism from urbanists. Some argue that both the scheme and its implementation have failed to provide the housing residents need, have displaced low-income households, and contributed to spatial social polarization [71]. Others also suggest that although increasing population density generates significant economic returns, risks like congestion and increasing house prices exacerbate inequality within cities [72].

Taking these concerns into account, the Greater London Authority adopted a new London Plan in 2021. In the chapter of 'Design', instead of designing for a compact city as was stated in 2004, a choice was made to strengthen sustainable density which (1) considers and is linked to the provision of future planned levels of infrastructure and, (2) is in proportion to the site's accessibility by walking, cycling, and public transport to jobs and services [19].

3.4. Vancouver, Canada

Greater Vancouver, also known as Metro Vancouver, is the metropolitan area located in south-western British Columbia, Canada, with its major urban center being the city of Vancouver. It covers an area of 2882 km² with a population of approximately 2.6 million. The population experienced significant growth over the past few decades, increasing more than one million people in a generation. Facing continuing growth in the region, a key challenge is to accommodate growth while promoting livability and sustainability [73].

Unlike the above precedents discussed, rather than a single city, Metro Vancouver is a federation of 21 municipalities, one Electoral Area and one Treaty First Nation that collaboratively plans for and delivers regional-scale services. In 2011, a regional growth strategy 'Metro Vancouver 2040: Shaping our Future' was issued by the municipalities, TransLink (the statutory authority responsible transportation network in the Metro Vancouver region), and adjacent regional districts. It gives the collective vision for how the region is planning to accommodate the increasing population and jobs in the next 25 years. It also provides strategies to achieve five goals related to urban development, including the economy, the environment and climate change, housing and community services, and integrating land use and transportation. One of these goals is to create a compact urban area [73].

To achieve this goal, which makes sure growth and development occurs in the right places to increase the efficiency of limited land use and at the same time conserving lands for future generations, Metro Vancouver details three strategies: (1) contain development: setting an Urban Containment Boundary to constrain development within assigned areas to protect important lands and reduce utility costs; (2) grow in the right places: directing residential and employment growth to Urban Centers (designed as priority locations for employment and services, high-density housing, commercial, cultural, recreational, institutional and mixed-use); (3) protect rural landscapes: urban levels of development are

not intended for lands with a rural designation, and to ensure this, sewer services are not extended into these areas. Metro Vancouver also connects creating a compact urban area with achieving regional GHG emission reduction targets for 2020 and 2050. Construction and automobiles contribute to 65% of the regional GHG emissions [46]. A compact urban area promotes lower levels of car use and encourages the development of more energy efficient buildings to further reduce per capita emissions of both GHG and pollutants [73].

To enhance growth in Urban Centers, Metro Vancouver promotes transit-oriented communities, where public transit, cycling, and walking are preferred. This also integrates with Transport 2050 (Translink's new Regional Transportation Strategy) to achieve Goal 5, supporting sustainable transportation choices [74]. Apart from providing convenient, reliable, affordable, safe, and comfortable access for everyone, Transport 2050 also highlights a carbon-free goal in creating future transport. The target is to reduce GHG from light-duty vehicles to 65% of 2010 levels by 2030, and to eliminate transportation GHG emissions altogether by 2050. To achieve this, Translink proposes 4 strategies including: (1) reducing the energy requirements of the transport system; (2) transition to zero-emission vehicles; (3) supporting ready access to low-carbon fuels; (4) account for and reduce upstream and downstream emissions in the transportation system.

Vancouver adopted their compact city strategy focusing on the perspectives of urban land use designation and transit-oriented development and directly link their compact development with reducing GHG emissions. However, the regional GHG emissions in Metro Vancouver area were 14.7 million tonnes in 2019, a modest 1% reduction from the 2010 baseline. Further action is needed for Metro Vancouver to achieve its 2030 target and to become a carbon neutral region by 2050 [75].

Table 1 summarizes the key strategies and policies implemented by the four case study regions.

Table 1. Key strategies and policies for case compact cities from the latest plans.

<div>Compact City</div> <div>Policies</div>		Density		Public Transport		Accessibility		Reducing GHG/Mitigating Climate Change
Toyama [55]	◆	Urban redevelopment projects	◆	LRT development	◆	Welfare facilities	◆	Popularization of low-carbon housing
	◆	Hosting events and festivals to attract residents	◆	Community bus service	◆	Promotion of residences around public transport stations	◆	Raising awareness of eco-life
Melbourne [61]	◆	Increase new housing inside the urban growth boundary	◆	Pedestrian-friendly passages				
	◆	Facilitate well-designed, high-density residential developments in the city center	◆	Completion of the Metro Tunnel project	◆	Creating a 20-min neighborhood	◆	Improve energy performance and efficiency of buildings
			◆	Improve freight efficiency and increase capacity of gateways	◆	Deliver social infrastructure to support strong communities	◆	Facilitate the uptake of renewable energy technologies
			◆	Improve outer-suburban public transport	◆	Deliver local parks and green neighborhoods		

Table 1. Cont.

Compact City \ Policies	Density	Public Transport	Accessibility	Reducing GHG/Mitigating Climate Change
London [19]	<ul style="list-style-type: none">Infrastructure assessment during the planning application process to ensure sustainable density	<ul style="list-style-type: none">Increase capacity of public transport services through financial contributions and cooperation with Transport for London	<ul style="list-style-type: none">Development proposals in proportion to the site's accessibility to jobs and servicesThe delivery of the mayor's strategic target of 80 per cent of all trips by foot, cycle or public transport by 2041	<ul style="list-style-type: none">Detailed energy strategies are required for major development proposals to demonstrate how the zero-carbon target will be metDevelopment proposals referable to the mayor should calculate whole life-cycle carbon emissions
Vancouver [66]	<ul style="list-style-type: none">Urban Containment BoundaryHigher density trip-generating development is to be directed toUrban Centers and Frequent Transit Development Areas	<ul style="list-style-type: none">Frequent Transit Network to increase the proportion of trips by transit, cycling, walking and alternatives to single-occupant vehicle travel	<ul style="list-style-type: none">Provide diverse and affordable housing choicesDevelop healthy and complete communities with access to a range of services and amenities	<ul style="list-style-type: none">Encourage land use and transportation infrastructure that reduce energy consumption and GHG emissions and improve air quality

In summary, we identified that Toyama City was a typical example of implementing a compact development strategy from start to finish, combining compact development and emission reduction in its latest development plan, mapping out a clear path for emission reduction, focusing on (1) increasing the proportion of public transportation use, (2) improving energy efficiency in the city center and housing along the transit route, (3) promoting low-carbon housing and awareness of emission reduction strategies, and (4) promotion of the renewable energy industry. In contrast, Melbourne's compact city strategy, centered on urban growth boundaries, has not worked as well as it should have due to the mismatch between the distribution of employment and housing opportunities provided. In addition, a soaring population lead the government to abandon the compact city strategy and instead emphasize a polycentric structure, with several assigned activity centers characterized by transit-connectedness and high-accessibility. With regard to carbon emissions, although an ambitious target of zero emissions by 2050 has been set, Melbourne's emissions reduction strategy focuses more on improving energy efficiency in buildings and the energy transition than on reducing emissions by planning sustainable urban density and spatial structure. London's compact city strategy aims to accommodate growth while protecting the Green Belt, with a core strategy of better land use, which is also associated with its much-criticized high housing prices. The government seeks to achieve industrial and population agglomeration through high-density mixed-use land that will attract investment to support adequate public facilities and transportation infrastructure. Emission reduction goals are focused on improving energy efficiency in buildings and introducing new energy sources, with limited mention of transportation strategies. Vancouver's compact city policy is relatively comprehensive with urban growth boundary at its core; the regional level compact strategy states a focus on growth in Urban Centers and Frequent Transit Development Areas while preserving agricultural land. There are also community-level compact strategies that create compact communities by emphasizing proximity and accessibility, while emphasizing compact transport development to reduce GHG emissions.

4. Discussion

Based on the literature review and case studies detailed above, here we present a comparative assessment from the perspective of how cities with different urban growth rates adopt different policy practices, and whether these practices contribute to achieving the goal of building a sustainable, low-carbon city.

The cases assessed have different populations and urban growth rates, thus adopting their compact city strategies from different starting points. Basically however, they can be divided into two types: (1) aging society, with low urban growth, building a compact city to avoid waste of resources and restimulate urban prosperity, e.g., Toyama city, and (2) fast growing megacity, with high urban growth, aiming to accommodate increasing population level sustainably, while limiting urban sprawl, e.g., London.

While having the same goal of achieving higher density, these two types of cities place emphasis on different aspects and select different strategies as a result. Cities like Toyama, with a relatively small population size and low urban growth rate, need to focus carefully on their budget when enhancing public transport, ideally choosing lower-cost projects such as buses and light rail instead of subways, which require a longer time for construction at significantly higher cost. On the other hand, generally more financially capable megacities consider capacity as the most important point in designing urban public transport due to the needs of commuting residents. Their primary aim is to alleviate congestion and increase commuting efficiency and to some extent, to achieve environmental goals of mitigating pollution and carbon emissions. Careful planning of transport systems is required in both types of compact cities.

With regard to urban centers, for cities with low urban growth, prosperity in the urban center is essential for attracting people living in the suburbs to move into the city center. Accessibility to local entertainment, medical resources, and public services is also important. While for capital cities with a high, ongoing increase in population, there are no concerns about the concentration of density of residents; instead, affordable and sufficient accommodation in the city center to serve urgent needs is critical for the sustainable development of the compact city. However, open space and green areas in the city center for leisure are also important. This is also supported by the ‘compensatory mechanism hypothesis’ that residents living in high-density areas use far more energy than others for travel by plane, and the commensurate reduction in leisure time travel when residents have access to a private garden [7]. A study in South Korea estimated carbon budgets using the growth and management of urban street trees and demonstrated that urban green management could be a positive measure toward minimizing carbon emissions [76]. This factor is important when considering compact city design, as compact city theory states that a higher density will provide a more sustainable urban form with lower energy consumption per capita. Figure 3 summarizes the two commonly observed patterns of compact cities.

Overall, when it comes to how compact city policies contribute to the reduction of CO₂ emissions, there is insufficient evidence to draw a clear conclusion. One reason for this is that there is still not a comprehensive and effective evaluation system which can quantify compact city performance. Criticisms have been raised by urbanists pointing out that cities like Melbourne and London were not able to follow their compact city strategies or were not able to deliver what they promised under these policies [67,71,72]. Although various aspects such as density, measured by population density and proximity, spatial distribution of density, urban spatial configuration, and polycentricity, etc., have been investigated to clarify the relationship between compact city strategies and carbon emissions, results remain inconclusive. Leveraging and co-effects need to be considered when connecting different aspects of compact city characteristics to their impact on urban CO₂ emissions. This study identified the academic gap that to date there is no systematic and synthetic methodology to analyze how these aspects work together in impacting urban carbon emissions, to give guidance to policy makers as to the priorities in planning a more compact urban form. Further, there is the question of how will the two distinctive types

of compact cities achieve low carbon goals with their divergent approaches in practicing compact city strategies? These are problems that will need to be addressed in future studies.

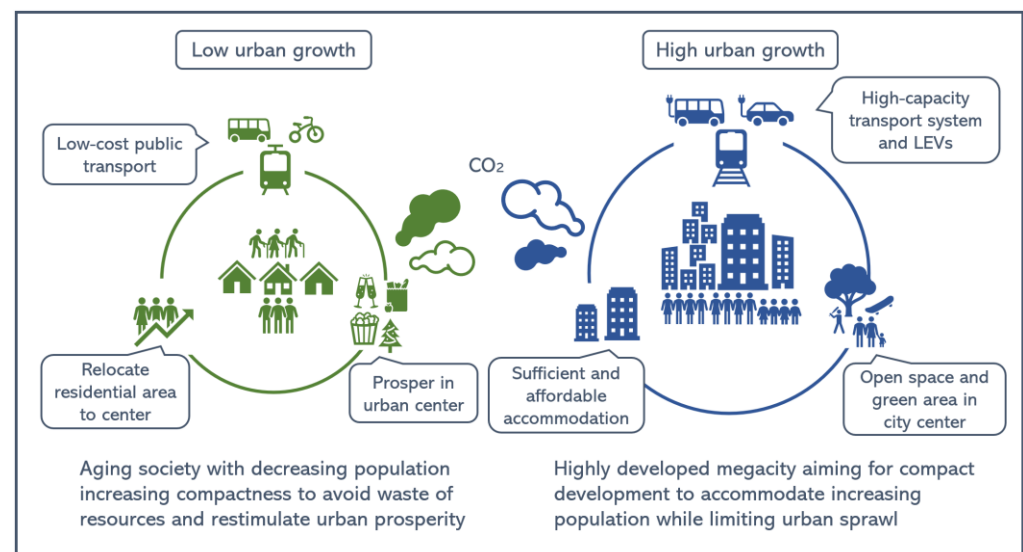


Figure 3. Categories of typical characteristics of cities which adopt a compact city strategy depending on urban growth rate.

This study has certain limitations. This review is based on the author's own experience in guiding the summary of the literature; while undertaken as objectively as possible, it may contain some subjective aspects. The study focused on worldwide compact city practices and their environmental impacts, leveraging studies from the Scopus database in the English language. Literature in other languages were not reviewed and the case studies selected for this paper are all in developed countries with a compact city policy implementation period of more than 10 years. Compact cities in developing countries such as Shenzhen, China are not reviewed due to their relatively short period of compact city policy implementation. It is important to look at these cases in future studies because there are a large proportion of residents commuting with scooters in developing countries, which is a distinctly different pattern than the precedents evaluated here. These differences will no doubt have an impact on the design of road transport in these cities. Additionally, when analyzing the environmental outcomes of compact city strategies, it is ideal to consider the full range of carbon emissions; however, in this study, we did not consider intra-sector carbon emissions. This is also a possible direction for future studies, to identify how compact urban planning impacts upon CO₂ emissions from different sectors including those from residential, transportation, and industrial sectors.

Future research could focus on an investigation of the two identified types of compact cities regarding their carbon reduction capability. In doing so, a determination of which approaches have better CO₂ reduction potential, and which compact city strategies should be prioritized in order to improve sustainability can be made. Ideally, indicators will be able to be modelled to identify generalizable aspects, as well as those applicable to specific cases. Further, scenario-based modelling could be employed to estimate approaches towards a decarbonized society along with spatial models considering the ideal morphological characteristics of compact cities. Moreover, spillover effects and influences on the surrounding areas are critical in questioning whether a compact development strategy is truly sustainable regarding the mitigation of global warming and climate change while maintaining human well-being.

5. Conclusions

This study employed a focused literature review using targeted keywords to sort and summarize previous research on compact city definitions, characteristics, and indicators related to urban form and compact city policies and the relationship between compact city form and urban CO₂ emissions. We found that key indicators relating to compactness including density and spatial configuration have an impact on urban carbon emissions. Public transportation is often strengthened in compact city policies but there is a lack of quantitative evidence on how this affects urban CO₂ emissions overall.

We also investigated key compact city policies using several precedential case studies from different countries. We compared strategies from these cases and identified two types of cities which employ compact city strategies. The first type includes cities with low urban growth, who employ compact city strategies to counter an aging society and population loss. The other type includes megacities with a rapidly increasing population who employ compact city strategies to solve issues which arise from an increased population density. The research gap of the quantification of the carbon reducing capability of compact cities is clarified both theoretically and empirically. Further research is required which focuses on the evaluation of compact city policy implementation performance and its relationship with carbon emissions, as well as the determination of the difference in approach required for the two identified compact city types.

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