

The impacts of TOD on sustainability based on the livability prism model

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Abstract. The universal issue for authorities is to plan land use more effectively and efficiently, and to provide more sustainable mobility in urban areas. The sustainable prism model is proposed to achieve the requirements for sustainable development. Transit-oriented Development (TOD) is a city planning method that coordinates the mass transit system and the land use pattern. This article analyzes the sustainable prism and discusses the effect of TOD on sustainabilities in ecology, economy and equality to provide the city planner insight into the urban development pattern. Generally, TOD can reduce the energy consumption in the transport sector and related infrastructure, contribute to the air quality from the environmental aspect, facilitate employment and attract investment in the economic aspect and improve discrepancy in employment availability and transport burden among different groups from the social equality aspect. However, the noise pollution in the environment, the value capture effect in the economic aspect and the TOD efficiency in the social justice aspect are insufficiently discussed.

Keywords: Transit-oriented Development, Ecology, Economy, Equality, Sustainability.

1. Introduction

Currently, local authorities of metropolia worldwide are facing a series of challenges, including traffic congestion, urban sprawl, social inequality and negative externalities of transport. With the rapid progress of urbanization, it is predicted that approximately 67% of the world's population will live in urban areas by 2050, which urges municipalities to take immediate measures to tackle social inequality [1]. Transit-oriented Development (TOD) has been proposed and acts as an elegant solution to integrated urban design.

TOD is a regional development method firstly proposed by Calthorpe, who suggests traditional auto-based development cannot be sustainable and should be substituted by the urban planning method that prioritises public transport in the first place [2]. The TOD refers to the communities located within approximately 600 meters of the rail transit stations aggregating the function of residential, employment, open space and public service [2]. Before Calthorpe used the exact word TOD, its theory can be traced to 1957. Stein created the concept of neighbourhood unite or superblock, which occupies approximately 500 hectares of land along the arterial of the city. Those neighbourhoods consist of education facilities, land for horticulture and a walking system strictly separated from automobiles [3]. The community united with the walkable element is further developed by the pedestrian pocket theory [4]. Although pedestrian pocket theory determines that a quarter of a mile is a suitable development diameter for

walking from the public transport site to the agglomeration of dwelling, shopping and office, they advocate the balance of public transport usage and private vehicle instead of replacement. Analogously, the California Department of Transportation defines TOD as a community equipped with residential, employment and commercial functions in a large public transport station with mediate or high-density development characteristics and private vehicles are not excluded from it [5]. Maryland Department of Transportation add more attention to the cycle mode and higher density requirement but still does not repel the mode of the automobile. The city-level TOD is promoted by Cervero, which focuses on the mass transit system as the pillar of the city system and the support of the spatial growth form of the urban and regional area [6]. Ohland and Dittmar define TOD in the community or the neighbourhood level as analogous to the Calthorpe, but further, discuss the economic characteristics of TOD [7].

Cervero and Sullivan present the Green TOD theory, which is suggested to have the extra benefit of implementing TOD and green urbanization [8]. Lots of analyses of TOD focus on the effect of diminishing the negative environmental impact of transport and economic growth by practising this concept. However, some scholars have noticed that social justice is undermined in the previous sustainable development practice [9]. For instance, the approach to mitigating climate change can unfairly influence different people [10]. Campbell establishes a conflict model for sustainable development and claims that the three aspects including social justice, ecology and economy have tension at the root (Figure 1) [11]. Economic prosperity and efficient allocation of property is the opposite of social equality. Economic development is also a detriment to the ecological system. Protecting the environment will contradict allocating the existing resource in a social justice way.

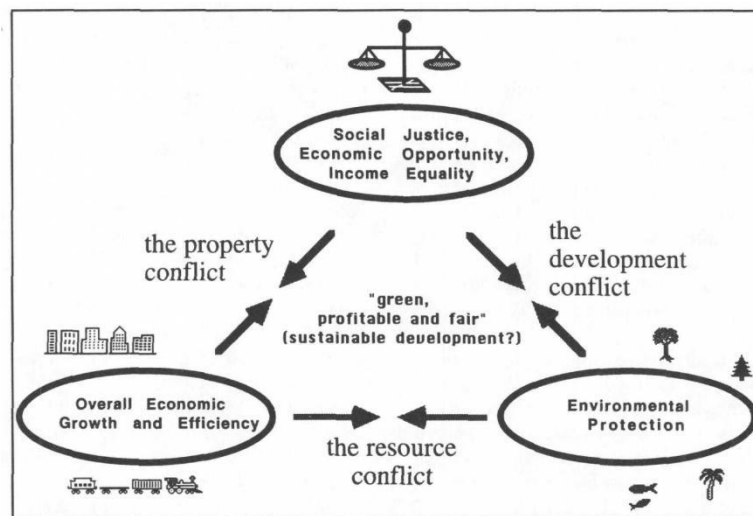


Figure 1. Conflict model of sustainability [11].

Godschalk adds three axes representing three more conflicts to the conflict model of sustainability to form a livability prism (Figure 2) [12]. The development conflict refers to the belief that the entire market economy can provide high-quality life. The green city conflict refers to the controversy over whether natural environment or built environment should be priorities. The gentrification conflict refers to the contradiction of protection of the existing impoverished group in the downtown and urban renewal to increase the attractiveness of the city. Although it might be a Utopia scenario, the gist of the livability prism model is the feasibility of achieving sustainable development in terms of social equality, ecological benefit and economic growth.

This article considers the Godschalk's livability prism model and discusses the effect of TOD on sustainabilities in ecology, economy and equality.

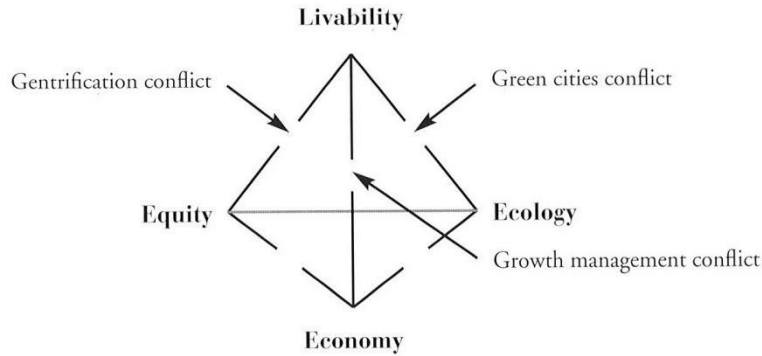


Figure 2. Livability prism model [12].

2. The impact of TOD on ecology

Ecological benefits have been an essential part of urban planning in accordance with sustainable requirements. The existing environmental impact research of TOD consisted of urban heat island (UHI), carbon emission, noise affluence, urban sprawl, traffic congestion and air pollution. The research scale can be split into the whole TOD project or the single element of the TOD project.

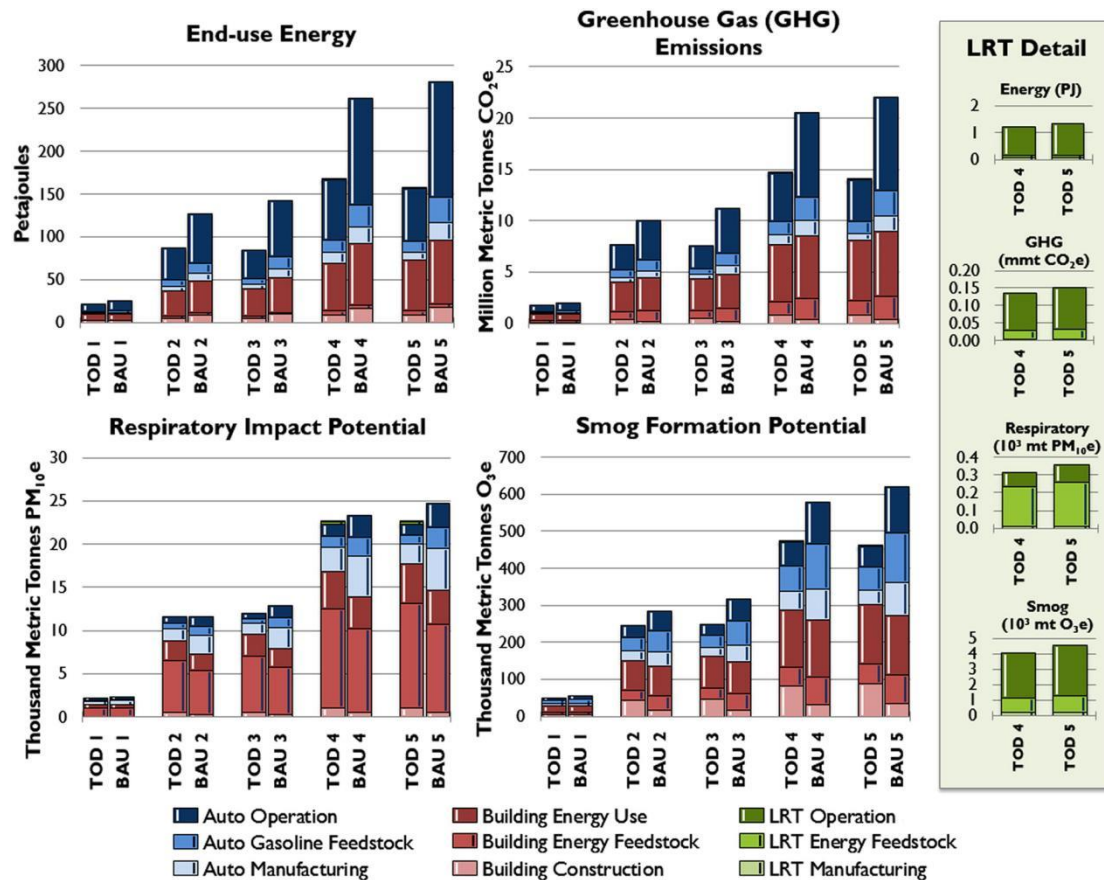


Figure 3. Life cycle environmental impact of TOD [16].

TOD is beneficial to control and decrease greenhouse gases (GHS). Carbon dioxide (CO₂) occupies the largest proportion of greenhouse gases (GHS), rendering global warming most significantly [13]. Although great efforts have been made to mitigate CO₂ emissions globally, its proportion of the transport sector keeps growing, attracting many scholars researching it [14]. Ashik et al. researched the carbon emission difference between aggregated TOD areas and aggregated non-TOD by surveying the household travel distance multiple by the carbon emission by the utilized transport mode [15]. Based on cluster analysis, the research shows that TOD or non-TOD has an independent influence on the CO₂ emission of households and in the TOD cluster the CO₂ emission is significantly lower than non-TOD area. In addition, Kimball et al. apply life cycle analysis to TOD construction [16]. 60-year is assumed as the life cycle to assess the air-related indexes in the construction of the TOD facility and the operation of transport. As figure 3 shows, TOD e to diminish the life cycle energy consumption and the GHS emission of infrastructure by 9-25%. The influence of photochemical smog and the insidious healthy impact on the respiratory system seems increased due to the more amount and sharing of electricity generated by burning coals. However, it is offset by the declined private vehicle utilization. Combining the building influence and transport, overall photochemical smog is reduced by 25%, GHS emission is cut down by 36% and insidious healthy impact respiratory system is improved by 8.4%.

Ao and Yang argued that the self-selection effect of residential building plays a role in transport-related CO₂ emission [17]. The self-selection effect refers to the residents selecting the dwelling site because of the social economic status or attitude about the transport, then forming a specific travel pattern. Existence of the self-selection effect suggest a possibility that the difference in carbon emissions roots in the attitude of certain people instead of the built environment. In this way, the built environment's influence on the transport of carbon emissions can be overrated and further affect the decision-making and planning concept in the transport sector.. There are also some negative externalities of TOD under critique or involve some controversy. For instance, Yildirim and Arefi analysed the noise level within a quarter-mile range of rail transit stations and suggest that the stations in TOD suffer a 9dB higher noise level than the non-TOD stations in Dallas city, America [18]. Lam et al. research more than 200 residential areas in Hong Kong, China. They suggest that the residential areas with the mix of land use character advocated by TOD have a quieter environment than the old neighbourhood [19]. Kong and Dorina suggest the alleviated private vehicle dependence by the encouraged multi-mode transport make TOD area have a lower noise level, but also dependent on the built environment [20]. Even though TOD may be noisier due to the rail transit system, Theebe demonstrate it more acceptable than highway transport noise [21]. The influences of TOD on the UHI has also been widely researched. Kamruzzaman et al. point out the scenario that TOD can decrease the VKT so as to reduce GHS emission and traffic congestion, while TOD areas have a higher intensity and growth rate of the UHI effect [22]. The single TOD feature of the high density of population, employment and dwelling is also considered as the deterioration of the situation of the UHI effect [23].

3. The impact of TOD on economy

Transport refers to the movement of commodities and people, in this way, it is closely related to the economic growth of a certain locality. The improvement of the transport system can affect the economy at various levels. It affects the efficiency of productivity in terms of GDP at the macro level, the economics of agglomeration and the labour market in the mesoscopic and the land supply and the real estate market in the microeconomic [24]. The statistics at the provincial level are examined from 2003-2017 in mainland China to evaluate what role the investment of infrastructure play in economic growth [25]. The result shows that within a certain threshold, transportation investment positively impacts the quality of the economy and can stabilize and sustain economic growth.

TOD is proposed to have positive effect on employment structure. Knowles admit that TOD plays a critical role in assisting Copenhagen, Denmark increases its international compatibility, which attracts an abundance of investment all over the world and provides thousands of opportunity for employment [26]. The effortless mobility to the city centre based on rail transit and the sound urban amenities expand the catchment area of Copenhagen. Apart from attracting inward investment, the labour market is

stimulated to expand in DC. Washington [27]. This research manifests in the TOD area providing 250% more jobs than the non-TOD area. Nevertheless, The TOD impact also can be vague, MARTA rapid transit system does not differ in the overall population and employment situation of the area with the station from non-station area [28]. However, it does change the employment structure which shows the increased portion of civil servants is happening in the proximity of stations and TOD station has a higher employment attractiveness than non-TOD stations.

TOD also has effect on the increment in the value of real estate. Even the published TOD projects plan can have an effect of a 20-70% increment on the value of the vacant land within the TOD area in Washington County, America [29]. The case in Atlanta shows a similar result, the value of real estate increased by 30% from analogous housing in a mile buffer from TOD in the belt line to the buffer of a quarter mile [30]. The effect on rental price is also found by Renne et al., which suggest it in TOD area is higher than in non-TOD area [31]. Su et al. align with Renne et al., and further indicates operation function of the metro station and TOD feature of accessibility of public open space, design of the neighbourhood and availability of multiple modes of transport can exacerbate this correlation [32]. The public-private partnership in TOD practice introduces the capital from the private sector to supplement the huge gap between the demand for sustainable urban infrastructure and the finite governmental budget [33]. It is also necessary for local authorities to implement comprehensive development of the land resources in the proximity of metro stations through TOD to capture the surplus value of TOD to make up for the construction investment and the deficit of operation of the mass-transit system [34]. Hong Kong, China is an instance which applies this method and has realized the sustainable profit for constructing and operating the mass rapid transit system [35].

4. The impact of TOD on equality

TOD can facilitate the alleviation of the social inequality caused by gender differences. The present land-use pattern and transport infrastructure can be deemed as not meeting females' equal development requirement. The urban sprawl caused by traditional automobile-oriented development has a tremendous impact on female labour participation, for the unemployment rate of females is 540% higher than males when they migrate to a suburban area in Delhi [36]. This situation can be the result of antiquated social norms that females take more responsibility for raising the child and household work, therefore they have less time to commute. However, the change in the transport field can contribute to solving the issue. Not only can diversified land-use patterns provide more jobs surrounding the residential position for females, but also the design of the transport system that prioritises public transport and non-motorized transport modes (such as walking and bicycling) can decrease the extra commute time for females since they have lower ownership of the vehicles and availability of driving licence [37]. For this reason, the discrepancy in the availability of employment-related activities and commercial services between males and females has a negative correlation with the TOD level of a region. Furthermore, research suggests that the female group is more dependent on the mass transit system and prone to hunt for a job, prioritizing the distance between dwelling and the corporation even abandoning the employment opportunity, better job or higher salary [36]. Consequently, females are more vulnerable to the performance, known as the level of service (LOS), of public transportation. TOD can fulfil the public transport demand of females and decrease the trip's cost in terms of time and capital. Empirical analysis has been conducted by Lo and Houston that the absolute gender discrepancy in the range of life and the distance between work and residence is decreased by 72% and 74% respectively in the TOD region to the non-TOD region in California State, America [37]. Thus, TOD does improve social equality from the gender aspect.

TOD also can be an approach to mitigating the inadequate equality between different income groups. In the previous development pattern, there is a tendency in Asia that high-income group dwells in the city centre with high accessibility to the public transport system, but rely on the private vehicle-based trip, while low-income groups living in the suburban area but dependent on the mass transit system [38]. Moreover, Zhao and Li suggest that the proportion of the transport fare in the total income of poverty groups is 61% higher than normal income groups, which incurs a further difference in disposable funds.

Hence, both the poverty issue and inequality can be perpetual if the stale city planning method is applied continually. TOD can dwindle the inequality issue in several ways. Chiefly, the diversified and intermixed land-use pattern equilibrates the population dwelling and job demand in the object development area. Zhao and Li approve that low-income groups can gain more benefits than high-income groups from the residential and employment-balanced land-use pattern of TOD, which can be the consequence of the commute time reduced by 127% when the degree of land-use diversity increases by a unit. In addition, high-density and different sizes of residential buildings are constructed in the community surrounding the core public transport nodes by TOD. The dimension per housing unit decreases as the distance to the transport nodes decreases, which can offset the effect of increased value per square meter and provide comparatively low total cost dwelling to the low-income groups [39]. As a consequence, the small unit and high-density residences provide the low-income group with the most convenient access to public transport service at an affordable price, while the medium and high-income families, which are not so dependent on the public transport system, are arranged in the periphery of the communities surrounding public transport nodes where has higher automobile mobility. This design of community embodied the concept of social equality.

Although TOD can bolster social equality theoretically, it is under doubt in several aspects. According to the investigation done by Cox, the government subsidy to the mass transit system can be taken advantage of by the high-income groups which use the public transport approach rather than the policy the original target, the low-income groups [40]. Furthermore, the enormous increased capital input to construct the metro or light rail system will retrench the expenditure for education and health care. However, Milan and Creutzig argue that economic growth is accelerated and overall social wealth is improved by implementing TOD, which will directly transform into social equality in a higher hierarchy [1]. This implied that the construction of TOD facilities might not detract from social equality from another aspect. The efficiency of bolstering social equality by TOD is also challenged to be lower than the subsidising the vulnerable groups directly and invest the care facility and service [38,41]. Apart from that, public housing is a vital approach to placing the poor in the centre area of transit nodes, without it the low-income groups can still be excluded by the society [38,39]. Nevertheless, in the context of China, public housing is scarce due to political reasons and supply-demand contradiction [39]. The further critique also consists that social-economic factors play a more important role than the land-use pattern in the general trip cost of the low-income family [38].

5. Conclusion

This article reviews the origin of TOD and analysis its impact on sustainability from the perspective of environmental protection, economic growth and social justice respectively.

TOD shows its potential in GHS reduction and energy preservation, but the noise influence is under discussion and more imperial research is required to separate TOD impact from the self-selection effect.

From the economic aspect, researchers have demonstrated its stimulation to attract inward investment and facilitate the cluster economy. However, the real estate value increment also needs to be further considered. It might cause the gentrification and displacement of the local residents or the private sector needs to scrutinize the positive externality taken advantage of by the private sector.

In terms of gender equality and social justice among different classes, existing researches elucidate its effect to fulfil the availability demand of females and improve the accessibility of socially vulnerable groups.

However, the effectiveness and efficiency of TOD need to be researched and compared with other social welfare approaches. Those are mainly the result of the development methodology integrated into TOD that implements intensive development of mass transit systems and the surrounding area to increase density, the intermixed land-use pattern to achieve diversity and the transport system design suitable for non-motored travel patterns. To those controversies and research gaps in the implementation of TOD, more empirical analysis needs to be conducted to determine the quantitative and qualitative relationship between TOD and sustainability. However, whether the TOD can successfully address the

sustainable issue provides a new way of thinking and practical reference to get rid of the stale city planning method and develop a city more harmoniously.

References

- [1] Milan B F and Creutzig F 2017 *Cities* 70 122–34
- [2] Calthorpe P 1993 *The Next American Metropolis: Ecology, Community, and the American Dream* (New York: Princeton Architectural Press)
- [3] Stein C S 1951 *Toward new towns for America* (Liverpool: Liverpool University Press)
- [4] Kelbaugh D 1989 *The Pedestrian Pocket Book: A New Suburban Design Strategy* (Michigan: Princeton Architectural Press)
- [5] Ma Q 2003 *Urban Planning Overseas* 5 45–50
- [6] Cervero R 1998 *The Transit Metropolis: A Global Inquiry* (Washington, DC.: Island Press)
- [7] Dittmar H and Ohland G 2004 *The New Transit Town: Best Practices In Transit-Oriented Development* (Washington, DC.: Island Press)
- [8] Cervero R and Sullivan C 2011 *Int. J. Sustain. Dev. World Ecol.* 18 210–8
- [9] Middleton N and O’Keefe P 2001 *Redefining sustainable development* (London: Pluto Press)
- [10] Reckien D, Creutzig F, Fernandez B et al. 2017 *Environ. Urban.* 29 159–82
- [11] Campbell S 1996 *J. Am. Plann. Assoc.* 62 296–312
- [12] Godschalk D R 2004 *J. Am. Plann. Assoc.* 70 5–13
- [13] Dawson B and Spannagle M 2009 *The complete guide to climate change* (New York: Routledge)
- [14] Kamruzzaman M, Hine J and Yigitcanlar T 2015 *Int. J. Environ. Sci. Technol.* 12 3463–78
- [15] Ashik F R, Rahman M H and Kamruzzaman M 2022 *Transport. Res. Part D-Transport. Environ.* 105 103227
- [16] Kimball M, Chester M, Gino C and Reyna J 2013 *J. Plan. Educ. Res.* 33 395–410
- [17] Cao X and Yang W 2017 *Transport. Res. Part D-Transport. Environ.* 52 480–94
- [18] Yildirim Y and Arefi M 2021 *Habitat Int.* 107 102297
- [19] Lam K-C, Ma W, and Chan P K et al. 2013 *Environ. Monit. Assess.* 185 9683–95
- [20] Kong W and Pojani D 2017 *J. Urban Des.* 22 388–410
- [21] Theebe M A 2004 *J. Real Estate Financ. Econ.* 28 209–34
- [22] Kamruzzaman M, Deilami K and Yigitcanlar T 2018 *J. Transp. Geogr.* 66 116–24
- [23] Deilami K, Kamruzzaman M and Hayes J F 2016 *Remote Sens.* 8 716
- [24] Banister D and Thurstain-Goodwin M 2011 *J. Transp. Geogr.* 19 212–23
- [25] Zhou J, Raza A and Sui H 2021 *Appl. Econ.* 53 2615–30
- [26] Knowles R D 2012 *J. Transp. Geogr.* 22 251–61
- [27] Green R T and James D M 2016 *Rail Transit Station Area Development: Small Area Modeling in Washington DC: Small Area Modeling in Washington DC* (New York: Routledge)
- [28] Bollinger C R and Ihlanfeldt K R 1997 *J. Urban Econ.* 42 179–204
- [29] Knaap G J, Ding C and Hopkins L D 2001 *J. Plan. Educ. Res.* 21 32–9
- [30] Immergluck D 2009 *Urban Stud.* (Edinburgh, Scotland) 46 1723–45
- [31] Renne J L, Tolford T, Hamidi S and Ewing R 2016 *Hous. Policy Debate* 26 819–34
- [32] Su S, Zhang J, He S, Zhang H, Hu L and Kang M 2021 *Habitat Int.* 107 102309
- [33] De Jong M, Mu R, Stead D, Ma Y and Xi B 2010 *J. Transp. Geogr.* 18 301–13
- [34] Cervero R and Kang C D 2011 *Transp. Policy* 18 102–16.
- [35] Cervero R and Murakami J 2008 *Rail+ Property Development: A model of sustainable transit finance and urbanism* (UC Berkeley: Center for Future Urban Transport)
- [36] Thynell M 2016 *Soc. Incl.* 4 72–82.
- [37] Lo A W-T and Houston D 2018 *J. Transp. Geogr.* 68 42–54.
- [38] Zhao P and Li S 2016 *Int. J. Sustain. Transp.* 10 947–59.
- [39] Liang Y, Du M, Wang X and Xu X 2020 *Eval. Program Plan.* 80 101811–11.
- [40] Cox J B 2006 *Issues* (South Melbourne) 76 11–6.
- [41] Wey W-M, Zhang H and Chang Y-J 2016 *Habitat Int.* 55 109–23.