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Guest Editors: Guangwei Huang and Zhenjiang Shen

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Editorial introduction

Special issue on "Low carbon city in Asian Cities"

Guest Editors:

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Climate change is already beginning to transform life on Earth. Around the globe, rains and droughts are intensifying, glaciers are melting and sea levels are rising. If we don't act now, one-fourth of Earth's species could be headed for extinction by 2050. A path we must take is the Low Carbon City because Greenhouse gases (GHGs), a principal cause of global warming, are emitted in large quantities in cities where population growth and human activities are concentrated. The Kyoto Protocol Target Achievement Plan requires urban governance to promote low-carbon societies. In the case of Japan, about 50% total CO₂ emissions are attributed to socio-economic activities in the cities—residential sector, business sector and transportation sector. These activities in cities can be characterized as diverse and complex. It interacts with urban forms and functions. The dispersed urban forms of most North American cities, which were built recently, encourages automobile dependency and are linked with high levels of mobility, resulting in increase in CO₂ emissions. On the other hand, the dense urban cores of many European, Asian cities enable residents to make between one third and two thirds of all trips by walking and cycling. Nevertheless, it has been seen that the response to the rapid concentration of population in Asian cities is the housing development in suburban areas. This outward expansion of cities has given rise to an urban structure producing a large environmental burden, particularly in terms of traffic problems. Meanwhile, the evolution of transportation has generally led to changes in urban form. The more radical the changes in transport technology have been, the more the alterations on the urban form. One may argue that compact city is a solution to the problem of urban sprawl. However, due to the huge population in Asia, the population densities in large Asian cities such as Taipei, Jarkata and Beijing are already too high even with great expansion to go for more compact. Therefore, within Asia, one of the keys to averting a climate change crisis lies in low carbon transport. China, India and Asia's other emerging economies could promote fuel efficient vehicles, public transport, and sustainable urban planning. Or they could become locked into inefficient vehicles, energy intensive infrastructure, and suburban sprawl. The path they choose will have long-term impacts not just on Asia but on the entire world.

In view of the close interrelationship among urban form, transportation and CO₂ emissions and constrains toward compact city in Asia, the main focus of this special issue was placed on transportation sector, seeking

innovative solutions. Gao and her colleagues' contribution in this special issue proposed a concept of Behavior Zone as a unit for spatial planning and showed that the estimation of CO₂ emission based on Behavior Zones has several advantages as compared to estimation methods based on individual commuting behaviors in Beijing. Another contribution from Pai and Huang studied the travel behavior change of the residents under the influence of Transit Jointed Development (TJD) in Taipei. It concluded that TJD has significant positive effect on the Mass Rapid Transit (MRT) application and helps a lot for driving reduction. Another case study from Shrestha, et al. included in this issue was directed at studying urban accessibility and evaluating different scenarios with regard to the potential towards low carbon transport development in Kathmandu Metropolitan City. This issue also includes a paper dealing with solar power generation in Chinese cities. Zhang et al studied the potential and variance in solar irradiance and PV power generation among Chinese cities and addressed the issue of suitability to develop distributed PV power system in the targeted cities.

The studies collected in the special issue serve as good references for pursuing low carbon development in Asian cities although these works need further refinements in many aspects. In particular, guest editors take the view that authors should also discuss CO₂ emissions from the transport sector in relation to topographic features and meteorological conditions, which are missing in this issue. All submitted manuscripts were peer-reviewed. The guest editors would like to thank the reviewers for their hard work, time and valuable comments and suggestions that make this special issue possible.

Spatial Pattern of Transportation Carbon Emission based on Behavior Zones: Evidence from Beijing, China

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Key words: Low-carbon, traffic behavior, traffic mode, community, behavior zone

Abstract: Reducing daily transportation carbon emission is one of the main tasks for accomplishing low carbon city. Most existing studies have evaluated transportation carbon emission from industrial structure or micro-economic viewpoint, such as the efficiency of public transportation, work and home relationship, and modal choice of personal trips, but studies on the general impact of personal behaviors on transportation carbon emission is inadequate. A main reason of this relies on the lack of an appropriate spatial unit for integrating people's greatly diversified behaviors. This study proposes the concept of 'behavior zone' (BZ) based on homogeneous assumption of behaviors, in order to analyze people's traffic behavior and its carbon emission effect by sub-areas. With a survey analysis of the characteristics of people's daily trips in Beijing's sample residential areas, the critical indices of BZ are identified including housing price, development intensity and population density, and access to public transportation. With these indices, Beijing is classified into five BZ types, where the modal choice behaviors of inhabitants are projected. Then the total environmental impact of daily trips is estimated based on carbon emission levels of various traffic modes. The results provide a plenty of implications for low carbon strategies such as intensity control by floor-area-ratios and household densities, and adjustment of public transportation services.

1. INTRODUCTION

As the result of demographic and economic agglomeration, cities become the centers of carbon emission. In general, industrial production, building construction, and transportation are three largest sectors that contribute to the carbon emission of cities. According to [IPCC \(2007\)](#), the emission by transportation accounts for 31% of the total greenhouse gas emission, and it has been growing in the past decades at a speed higher than any other sectors. Thus it is greatly important to reduce transportation carbon emission for the purpose of low carbon city.

In the past 10 years, most Chinese cities experienced the process of quick motorization. In Beijing, for instance, the total amount of vehicles increased from 1.69 million in 2001 to 4.76 million in 2010, with every 100 families holding 60 private cars. Along with income growth, the figures are anticipated to increase further more. Although motorization has enabled a higher degree of modal choice and increase people's satisfaction, the

negative environmental impact is enormous. [Zheng & Huo \(2010\)](#) showed that in Beijing more than 50% of polluted particles came from burning fossil fuel for energy, especially that of motor exhaust. In 2009, the average one-way commuting time of Beijing's residents is 45 minutes, which has increased by nearly 20% since 2005. Phenomenal over-congestion, traffic jam, out-based consumption, weak self-cleaning power of the environmental system, and heat island effect impose great challenges to the sustainable development of cities ([Lin & Wang, 2012](#)).

So far many studies have been conducted to raise planning and management solutions to the transportation emissions. The impact of spatial structure of cities, traffic modes, and the service level of public transportation are widely accepted as critical factors to be considered. The environmental impacts of transportation emissions have been evaluated by many at a regional or national scale to examine related planning issues. For example, [Newman & Kenworthy \(1989\)](#) compared the density of population and employment, mass public transportation, and road network of 84 countries in the world, and demonstrated the merit and demerit of compact urban forms by assessing the direct and indirect impact of these factors on carbon emission of cities.

Some other literature focused on the personal or household diversity of trips such as commuting distance, modal choice driven by different public policies and urban planning idioms ([Buliung & Kanaroglou, 2006](#); [Krizek, 2003](#); [Ma et al., 2011](#); [Zheng & Huo, 2010](#), [Chai et al., 2011](#)). These studies suggested a base for micro environmental and transportation policies by considering the diversity of people's behavior and preference, which were more close to real world. Many of these studies had adopted sampling survey approach, and with the development of communication technologies and prevalence of mobile service, many incorporated mobile equipment (e.g., GPS or smart phones) to get the trip data of large population to model people's traffic patterns ([Ma, 2012](#); [Martin, 2012](#)). For example, [Chai \(2012\)](#) investigated the moves of respondents across time with questionnaire and GPS tracing facilities in typical residential areas of Beijing, and compared the behavioral patterns of residents in different kinds of communities. However, restricted by sampling method and because of the barrier of user's dependency on hardware, the results of case studies were often criticized concerning the representativeness of samples.

It is commonly agreed that the preference or behavior of people ought to be examined with specific geographical contexts. Because of the existence of uncertain geographic context problem, the way for defining the areal unit of geographic context may significantly affect the behavioral pattern to be analyzed ([Kwan, 2012](#)).

It is thusly essential to select an appropriate spatial scale for analyzing the characteristics of transportation activities in cities. According to the theory of social geography, people living in the same social environment tend to behave identically, and the spatial pattern of social areas yields from mutual interactions and competitions ([Shevky & Williams, 1949](#)). [Shevky & Bell \(1955\)](#) proposed a method for classifying social areas, that is, to identify the community types of each census unit according to the economic status of residents, household attributes, and social segregation index (composition of ethnic minorities). This classification method was adopted by many western researchers. In Chinese cities, the accumulation of social groups in the form of residential blocks or gate communities is quite evident. The social polarization and competition of such social areas constitute the new spatial

structure of cities right now ([Gu et al., 2003](#)).

In this study, we assume that the traffic behavior of people living in certain kind of social areas share common traffic behaviors. Based on this assumption, the different patterns of people and households concerning transportations carbon emissions can be represented by appropriate classification of social areas. The emphasis of this study is to establish appropriate method for identifying the spatial pattern of different traffic behaviors. Taking Beijing as an example, we attempt to estimate the general environmental impact based on the transportation carbon emission levels of different areas.

2. METHOD FOR IDENTIFYING BEHAVIOR ZONE

2.1 Assumption on the Sphere of People's Daily Behavior

We define the social area where people have similar social-economic attributes and behaviors as a 'behavior zone' (BZ). Subject to the constrain of space, it is highly possible that people in different BZs show different traffic patterns, which are revealed by the modal choice and scope of daily trips ([Krizek, 2003](#); [Chai et al., 2011](#)). On the other hand, the behaviors within the same BZ are identical, thus BZ can be regarded as homogeneous spatial unit.

To identify the appropriate boundaries of BZ, we made a hypothesis on the stability of people's traffic behaviors. The stability of any procedure depends on the spatial scale for one to observe a phenomenon. Viewing from a very small scale, the activity of an object is usually instable and shows a random pattern, but when the scale becomes larger enough, its activity looks much more stable and a certain pattern reveals ([Li & Cai, 2005](#)). Assume that the behavior of people also follows the same rule of self-organization. Consequently, if we can discover where the behavior patterns of people turn stable, the boundary of a behavior zone can be found. Fitting the frequency of a person's trips (h) against distance (d) with certain model such as a Gaussian function, the threshold value (d_0) will be identified (*Figure 1*).

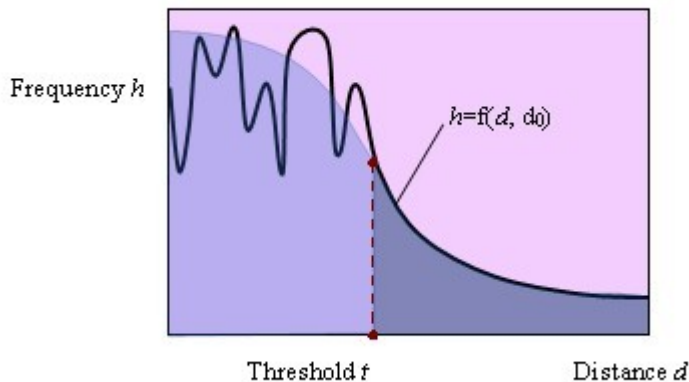


Figure 1 Threshold distance for defining the range of behavior zone

2.2 Critical Factors and Rules for Defining BZ

Based on the afore-mentioned assumption, we designed an experiment

and conducted a survey to investigate the daily trips of residents in Yongtai residential area, which is outside the Northern 5th Ring Road of Beijing. The sample area covers approximately 2 km² and have 19 gated residential blocks formed in different times. In and around the sample area, we selected 24 target places, including market places, supermarkets, convenience stores, shopping centers, parks, sports centers, museums and cinemas, and then investigated people's familiarity with each place.

An interview was implemented in June 2010 toward 100 randomly selected residents. The respondents were asked to answer the frequency of their visits to the 24 predefined places, household attributes including income, age, education, income, work status, housing ownership, family structure and dwelling time in the study area. To ensure that the respondents were familiar with the general environment around their homes and that their perceptions were stable, people who dwelled in this area less than one year were removed. These were mostly young and single inhabitants in rental private houses, whose lifestyles were significantly different from other families. As a result, 94 valid samples remained.

The age and gender of the respondents well followed an average distribution, and about 40% of them had lived in this area for more than five years. 60% reported that they often went out around home and 40% spent most time in the study area at spare time.

It was found that the frequency to a target place is associated with the hierarchy of services provided by the place. Two of the 24 target places, a large vegetable market and a shopping center along main roads surrounding the study area, have significantly larger coverage than other places, thus they were excluded in the following analysis (Ji & Gao, 2012).

Based on the location data of sample points, distance and visiting frequency to target places, we conducted a spatial cluster analysis. As a result, two clusters were specified. After generating Voronoi polygons of the sample points belonging to different clusters, the study area was split into two parts (Figure 2). Then the irregular borders of each part were adjusted to adjacent main roads. This gave the border of two behavior zones.

We observed that the size of BZ is generally larger than single residential block. Adjacent areas with similar attributes and sharing common shopping and public transportation services are closely correlated and quite likely to form a behavior zone. Within BZ, there was no road broader than 30m. In this example, there were several closed work unit compounds (marked by grey polygons in Figure 2). Because the management system was totally different from normal residential areas, these special areas should be separately treated .

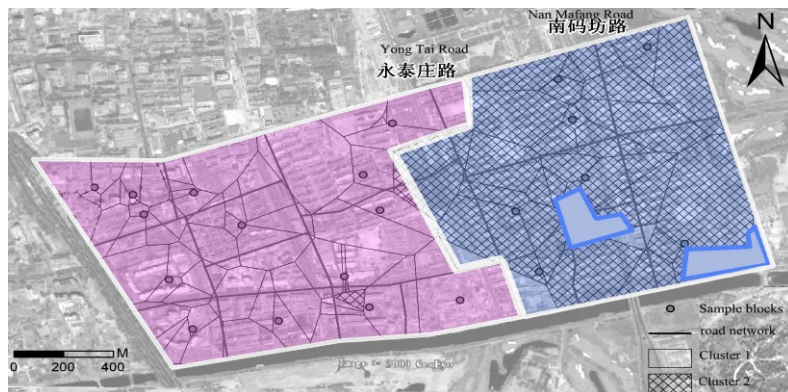


Figure 2 Cluster of behavior zones in Yongtai district in Beijing

Examining the characteristics of residential blocks in same clusters, we found that they are fairly alike in development time, housing price, development intensity (indicated by floor-to-area ratio, or FAR), and the level of property management fee. The attribute of access to public transportation services is also convergent, indicated by the number of bus stops within 800m and distance to nearest subway station (see [Ji & Gao \(2010\)](#) for reference). These results suggested the critical variables and rules for defining BZ (*Table 1*).

Table 1 Average statistics of residential blocks belonging to different behavior zones in Yongtai district

Type	Building age (year)	Housing		Access to public transportation		Monthly management fee (RMB/m ²)
		price (RMB/m ²)	FAR	Bus stops within 800m	Subway stations within 1km	
I	11	17,000	2.1	2.6	0	1.0
II	6	20,000	3.7	0.9	0	2.0

3. CLUSTER ANALYSIS OF BZ IN BEIJING

3.1 Data on Residential Blocks

We collected data of all residential blocks in Beijing, including location, development time, site area and floor-to-area ratio, and average list price of second hand houses, from the largest two real estate information websites, i.e., *Anjuke* (www.anjuke.com) and *Sofang* (www.sofang.com) in 2012. As a matter of fact, the two websites provide broad information service for developers, real estate agencies, and normal people in Beijing. Moreover, all the potential transaction information provided by users has been pooled and published in a regular format. Therefore, the quality of the data is good.

The records of all residential blocks listed on website pages were collected and the accuracy of information was cross-checked with data from two different websites. To focus on the built-up areas of Beijing, we removed residential blocks outside of the six central districts, which is about 1,370 km², having a population of 11.72 million (in 2011). As a result, 7086 residential blocks remained. *Table 2* gives the basic statistics of sample blocks.

Table 2 Basic statistics of sample residential blocks in Beijing

Critical factors	Indices	Ave.	Min	Max
Housing price	Average second-hand housing price in a block (RMB/m ²)	30,365	2,711	63,230
Development intensity	FAR	2.9	0.2	30
Housing quality	Property management fee per month (RMB/m ²)	2.0	0	20
	Building age (years)	13	1	63
Access to public transportation	Number of bus stops (<800m)	5.7	0	39
	Number of subway stations (<1km)	1.5	0	10

3.2 Spatial differentiation of BZ

The following steps were followed to identify BZ in Beijing's six central districts.

First, a cluster analysis was run with the above data. With the *K*-means cluster analysis method, we explored the similarity of different sample blocks. The between-cluster distance with regard to the number of clusters showed that the decline of between-cluster distance significantly slowed down as the whole sample was divided into six or more clusters. Therefore, we divided the sample into five clusters (*Table 3*).

Table 3 Statistics of residential blocks in five clusters

BZ type	Number of sample blocks	Number of bus stops (< 800m)	Number of subway stations (<1km)	FAR	Management fee (RMB /m ² per month)	Housing price (1000 R MB/m ²)	Building age (years)	
1. Luxury villa BZ	149	2.4%	7.9	0.4	1.5	3.7	35.65	8.1
2. Suburban BZ	2284	37.5%	6.9	0.2	1.0	0.9	23.85	13.0
3. Traditional BZ	329	5.4%	25.6	1.8	0.6	0.2	49.57	14.7
4. High-density BZ	1333	21.9%	17.7	0.7	3.7	3.2	32.11	9.6
5. Mature BZ	2001	32.8%	20.9	1.2	1.0	0.5	31.80	17.3
Total sample	6096	100%						

According to characteristics of each cluster, we named them as Luxury villa BZ (cluster 1), suburban BZ (cluster 2), traditional BZ (cluster 3), high-density BZ (cluster 4), and mature BZ (cluster 5). Among them, clusters 2, 4 and 5 are residential blocks of commercial houses, and they account for 37.5%, 21.9% and 32.8% of the sample, respectively. Cluster 1 covers most low-rise detached houses, and cluster 3 traditional courtyard houses.

The sample sites were mapped with their address information as a point layer with ArcGIS. Then, BZs were identified by the following steps. First, Voronoi polygons of the sample points were generated and the cluster attribute of the points were assigned to the Voronoi polygons. Second, adjacent Voronoi polygons with the same cluster attribute were merged. Then, the borders of the polygons were adjusted with the nearest main roads that were broader than 20m. Finally, non-residential sites identified through the land use map of Beijing were removed from the layer gotten from the last step, whereby the polygon layer of BZ was derived.

Besides the five BZ types in *Table 3*, some areas did not have complete data and some were under-construction residential projects or public housing projects where the houses were prohibited to enter market. Excluding them, there are 1076 BZs in total (*Figure 4*).



Figure 4 Distribution of different BZ types in Beijing

4. BZ-BASED ESTIMATION OF TRANSPORTATION CARBON EMISSION

4.1 Traffic Behavior of People in Different Types of BZ

In order to estimate general transportation carbon emission, previous knowledge on the traffic behavior of people, especially on modal choice and trip distance, is necessary. For this purpose we have incorporated the data and result of existing studies.

Previous studies by Yanwei Chai's research team have focused on the traffic behavior of people living in different communities ([Ma et al., 2011](#)). In 2007, a trip diary survey was implemented in 10 typical residential blocks in Beijing. 3481 travel activities of 1120 persons in a weekday were recorded. On average, the investigated people travel 3.1 times a day. The above data were used for obtaining the dominant traffic mode and travel distance of people on weekday.

People's traffic mode data from a questionnaire survey toward Beijing's 6000 residents in Beijing, conducted by Wenzhong Zhang's group in 2009, were also used ([Chen et al., 2012](#)). As this dataset is more up-to-date and based on a larger sample, we used them for adjusting the rate of different travel modes obtained from Chai's survey (*Table 4*).

The result revealed that, the modal choice of people significantly differed across BZ. For 35% of Beijing's residents, bus is the main choice for daily travel. The probability of taking bus is especially high among inner city inhabitants in traditional courtyard housing areas (47%). The residents of luxury villa BZ rarely take buses. Instead, 80% use private cars. It is

noticeable that suburban BZ residents use cars much more often than inner city inhabitants.

Table 4 Traffic modes in different BZs (%)

Mode	Luxury villa BZ	Suburban BZ	Traditional BZ	High-density BZ	Mature BZ	All
Walking	3.0	11.7	7.8	12.1	16.6	13
Bicycle	1.0	9.7	30.2	21.0	21.5	17
Motor bicycle	0.0	2.2	5.9	3.1	0.6	2
Subway	10.0	16.8	4.0	10.2	9.4	12
Auto	80.0	29.3	5.1	15.4	10.8	20
Bus	5.0	30.3	47.0	38.3	38.2	35
Other (taxi)	1.0	0.0	0.0	0.0	3.0	1

The trip diary survey of Chai's group in 2007 mentioned above was used for estimating the average commuting distance of people. As Table 5 shows, commuting distance significantly differed across BZ. For example, in mature zone and traditional zone, people's average commuting distances by bicycle are 2.6 km and 5.1 km, respectively.

Table 5 Average one-way commuting distance by different traffic modes (km)

Traffic mode	Luxury villa BZ	Suburban BZ	Traditional BZ	High-density BZ	Mature BZ
Walking	1.4	1.8	1.0	0.8	1.1
Bicycle	1.3	4.1	5.1	4.3	2.6
Motor bicycle	0.0	2.5	17.9	5.0	10.0
Subway	10.3	20.3	11.7	17.2	16.0
Auto	19.1	14.1	21.0	16.0	10.4
Bus	8.7	11.9	20.4	15.7	9.1
Other (taxi)	7.5	15.0	20.0	24.0	18.7
Average distance	16.8	11.1	10.1	13.8	5.8

4.2 Carbon Emission Parameters of BZ

IPCC (2006) presented carbon estimation methods based on energy use, measured by the emission from traveling by one kilometer per capita, and the estimation results varied across traffic modes and technologies in different countries. In Chinese cities, automobile, bus, subway and train, and motor vehicle are most important traffic modes. Based on survey and experiment, Ni (2009) and Chai et al. (2011) calculated carbon emission parameters for each traffic mode (Table 6).

Table 6 Carbon emission parameters for each traffic mode

Traffic mode	Intensity of carbon emission (per capita g/km)
Auto (incl. car, taxi)	135
Bus (incl. commuting bus provided by work unit)	35
Subway, train	9.1
Motor bicycle	8.0
Others (Walking, bicycle)	0.0

With parameters in *Table 6* and the proportion of different traffic modes in each BZ given in *Table 4*, the carbon emission parameters of BZ was calculated:

$$S_j = \sum_{i=1}^n \gamma_{ij} \times \eta_i \quad (1)$$

where, S_j is carbon emission parameters (g per km/person), γ_{ij} is ratio of the i -th (for $i=1$ to 5) traffic mode in the j -th kind of BZ (refer to *Table 4*). η_i is the standard carbon emission of the i -th traffic mode in *Table 6*.

As a result, the intensity of carbon emission in different BZ was revealed (*Table 7*). The per capita carbon emission of luxury villa BZ was the highest, when the commuting distance increases every 1 kilometer the carbon emission reaches to 110.7g. And the traditional zones seem produce least carbon emission, which is only about 24.2 g per km/person.

Table 7 Carbon emission parameters of each BZ

BZ types	Intensity of carbon emission (per capita g/km)
Luxury villa BZ	110.7
Suburban BZ	51.8
Traditional BZ	24.2
High-density BZ	35.4
Mature BZ	28.9

4.3 Spatial Pattern of the Transportation Carbon Emission in Residential Areas

With the carbon emission parameters obtained in section 4.2, personal daily carbon emission intensity, C_j , was calculated:

$$C_j = \sum_{i=1}^n \gamma_{ij} \times \eta_i \times \beta_i \times R_j \times T_j \quad (2)$$

where, i, j are indicators of traffic mode and BZ type, respectively; γ_{ij} is the rate of traffic mode i in the j -th BZ type (given in *Table 4*); η_i is carbon emission parameters of mode i which is given in *Table 6*, β_{ij} is the average commuting distance of people who take the i -th mode in the j -th BZ type which is given in *Table 5*; R_j is the rate of working people in the j -th BZ type, and T_j is people's average commuting frequency per day in the j -th BZ. The values of R_j and T_j are given by *Table 8*, which are also estimated with Chai group's survey data in 2007.

Table 8 Commuting frequency and commuting population in different BZs in Beijing

	Commuting frequency per day		Proportion of commuting population in total
	Four times*	Twice	
Luxury villa BZ	0%	100%	59.4%
Suburban BZ	3.4%	96.6%	70.0%
Traditional BZ	18.6%	81.4%	62.8%
High-density BZ	2.4%	97.6%	65.0%
Mature BZ	17.4%	82.6%	64.7%

* People getting used to going back home at noon time are assumed to commute four times a day.

Based on the results, the spatial pattern of personal transportation carbon emission intensity was identified. For simplicity, it was classified to five levels split by 1 standard deviation, i.e., relatively low, so-so high, and extremely high. *Figure 5* revealed that in Beijing, carbon emission intensity significantly increased from central to suburban areas. Most areas outside or around the 5th Ring road belong to the high and extremely high levels.

Clearly, travel distance and traffic mode closely relate to carbon emission intensity. Therefore, in order to reduce the carbon emissions of high and extremely high zones, certain kind of planning regulations and behavior induction methods should be applied such as land use adjustment, floor-area-ratios and household densities control, as well as the supply of public transportation facilities to attract more people to use low-carbon traffic modes.



Figure 5 Spatial pattern of Transportation Carbon Emission Intensity (per capita per workday)

5. CONCLUSIONS

This study proposed the concept of ‘behavior zone’ (BZ) as the basic spatial unit for summarizing people’s greatly diversified behaviors. Based on a homogeneity assumption about people’s travel behavior, method for determining BZ was presented and the carbon emission effect of different urban areas were estimated.

The application of BZ provides a new perspective for understanding, analyzing and managing the integral geographical texture of urban areas. Empirical study on Beijing’s residential blocks revealed that housing price, property right type, and management fee of individual blocks could be employed to identify the boundaries of BZ and that residential areas could be divided into five BZ types including luxury villa areas, suburban zone, traditional zone, high-density zone, and mature zone. These generalized rules

for defining BZ are useful in most other cities.

Compared to existing estimation methods based on individual behaviors, the application of BZ has a variety of merits. It helps solve the problem of uncertain geographic context. While individual behaviors commonly exhibit a high degree of uncertainties, BZ can screen out the noise but retain the useful information about urban context. This is quite useful for analyzing the spatial differentiation of urban space and its structure. Moreover, BZ provides a better linkage to area-based spatial policies. As shown in Section 4, with BZ as the basic spatial unit, the transportation carbon emission effects of people's daily commuting activities in each part of the city have been clarified. By studying the intensity (amount) of carbon emissions in various scenarios, evaluating the effect of certain spatial policies, such as public transportation, land use planning, and population relocation, becomes possible.

Limited by available data, the current work is still preliminary. For instance, we only considered residential blocks with market price of houses, but public housing blocks and areas of other land use types were neglected; Due to lack of detailed population data of residential blocks, the total amount of transportation carbon emission was not calculated, even though it should be more meaningful in practice; To facilitate the estimation, many simplified assumptions were also made, such as identical commuting distance and frequency in the same type of BZ. In the future, the current methods should be further improved based on systematic survey on people's travel behaviors.

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The Travel Behaviours Change of the Residents of Transit Jointed Development in Taipei Metropolitan Area

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Abstract: In recent years, there are plenty of researches advocating the concept of Transit Oriented Development. Among the mass transit infrastructure projects driven vigorously by the government, the most important one is the construction of MRT. In Taipei Metropolitan Area, the Transit Jointed Development (TJD) is flourishing while the construction of the MRT system is gradually completed. Up to now, there are 82 sites in Taipei MRT system, among which 35 sites have been completed and opened for lease with totally 75,577,369 square meters floor area for 6,317 households. Thus, can TJD improve the Transit Oriented Development become a very important issue. Therefore, this research selected 9 TJD sites for discovering the travel behaviours of the residents before and after they moved in the TJD housing.

The research findings show that compared with the data before the residents moved in the residences of TJD, their MRT share for commuting increased from 25.92% to 57.11%, and the car share declined from 28.44% to 15.60%. The total distance reduced was 42.68km, averagely 0.1km reduction per household everyday. In terms of the commute days, the total driving days reduced 373 days, averagely 0.86 day reduction per household; and the total MRT commuting days increased 619 days, averagely 1.42 days increase per household. The totally travel time reduction is 1,133 min, averagely 2.6 min reduction per household; and the cost totally reduced NT\$1349, averagely NT\$3 reduction per household.

According to the results, TJD has significant positive effect on improving MRT share and reducing car usage. Besides, the results also show that TJD reduce the work commuting distance, commuting time and cost, and helps the government undertaking the Transit Oriented Development.

1. INTRODUCTION

In recent years, Taipei MRT system has been under sustained development. The total passenger volume of Taipei MRT had exceeded 500,000,000 person-trips until Dec. 29th, 2010. Taipei MRT will formally become a member of Nova/CoMET and conduct technological exchange with the subway systems of international metropolises such as London, New York, Paris and Moscow, which implies Taipei MRT development is tending to mature. As the Taipei MRT system is gradually completed, the TJD is

increasingly important. However, since there is a lack in the studies of TJD in Taiwan currently, this study is going to investigate and analysis the travel change of TJD residents.

In the past decades, in order to cope with the great population in Taipei metropolitan area and the consequent traffic jam and air pollution, government has taken much effort on the MRT system construction in Taipei Metro Area. Meanwhile, the TJD plan has been integrated in the MRT system for financing. As a result, TJD has become one of the common ways to furnish the Transit Oriented Development (TOD) in Taiwan.

So far, there are 82 development sites in Taipei MRT system, among which 35 sites have been completed and open opened for lease with totally 75,577,369 square meters floor area for 6,317 households. However, to what extent can TJD improve the MRT usage is still lack of research. Therefore, taking the TJD sites completed and open for lease as the subjects, the study selects 9 sites for the empirical research in order to understand the travel behaviour change of the TJD residences. Travel behaviours contain the amount of car ownership by the residents, the transportation mode for commute, the car usage frequency and the commute time and cost.

According to the motivation mentioned above, the study first compares the travel behaviours before and after the residents moved into TJD housing. Then, the study discusses the factors that cause the change of travel behaviours, expecting to provide planning suggestions for further TJD development.

2. LITERATURE REVIEW

TJD is the practical implementation of TOD. According to the study of Quade et al. (1996), when the population density of a certain area is doubled, the usage of MRT system will be more than double. From this we can see the ratio of MRT share increases as the population density increases. With such a development orientation, the study is going to understand how the travel behaviours change and what factors result in the change, with the expectation to find out the reasons based on the findings of the previous studies. The effects of TOD and TJD on the commute travel can be seen in Cervero's (2008) research. He takes 900 households in Shanghai and its three subzones (Jiangqiao Town, Meilong & Shenzhuang Town and Sanlin Town) as the subjects, Cervero (2008) observed the change of the accessibility to work from the residence area, the change of the mode for commute and the change of commute time after the residents moved to those sites. The findings are as follows:

(1) The accessibility to work reduces the least after they moved from downtown to the area with subway service.

(2) In the case that transport modes have been changed, the most common change is from non-motorized vehicle to bus, which is followed by the change from bus to subway. Besides, the cars ownership of the residents increase which leads the car commute increases greatly.

(3) The commute time increases when the non-motorized vehicle is changed to motorized one. That's because the residence is farther to the work place after moving, which means the speed superiority of the motorized transport can be balanced by the distance.

CTODRA (2004) investigated the TOD areas in the U.S. In 2000, there were 140,000 citizens (62,000 households) living in the areas within half mile (about 800m) around the subway stations throughout the U.S. That

study covered 27 TOD areas and classified them according to the scale of city (giant, large, middle and small). The results showed that the household types and the building styles in TOD areas have the following features: 1) the households in TOD areas are relatively small; 2) the householders who afford the family in TOD areas are mainly 18-24 years old and the middle-aged are rare, which is more common in small cities; 3) there is no significant difference in the family income, but the extremely poor households in TOD areas obviously decrease as the subway system grows; 4) the larger the city is, the fewer the residents in TOD areas own the houses, which is possibly caused by the house price according to the author; and 5) the amount of cars held and the frequency used by the residents in TOD areas are significantly low.

After investigating the residents who moved into TOD areas (within 400-800m around the station) in San Francisco Bay, Los Angel, San Diego during 2002-2006, Hollie (2006) explored the following questions: 1) what types of the households are in TOD areas; 2) what factors lead people to move to TOD areas, and whether the reasons for moving are all the same among different types of households; and 3) whether those factors affect the application of mass transit. Through the Binary Logit Model Analysis, he arrived at the following results:

The residents in TOD areas of San Francisco Bay pay more attention to the residence cost, those in Los Angel pay more attention to the environmental quality of surroundings, and those in San Diego emphasize on the type and quality of the residence.

The families with different incomes live in different TOD areas. For example, high-income families live around the subway stations, while the low-income families live around the bus stops.

The residents in TOD areas use mass transit for 13-40 times more than others per year.

As the literature reviewed above, the benefits of TJD are summarized into three aspects as follow.

(1) Transportation mode

TJD is closely related to TOD. According to the definition of TJD mentioned above, the TJD is the practical implementation of TOD and thus contributes a lot to the transport. Zhong (1997) indicated that TJD is helpful to improve the finance of MRT construction and promote the usage of mass transit.

(2) Land Use

In the respect of land use, Chang (2007) indicated that TJD integrates the transport, commerce and residence effectively, and exhibits the mixed land use concept of TOD practically. Li and Lai (2007) claimed that the mixed land use can improve the efficiency of land use, reduce the commuting time trip numbers.

Moreover, Chen (2007) put forward some practical ideas on the TJD and land use types. In the business area, it is often positioned as office building, shopping mall, business apartment or multifunctional building. In the residential zone, it is positioned as diversified residences with 2-4 rooms. In some large cases, residences are also accompanied by shopping mall or other facilities to support the daily life.

(3) Real Estate Market

In the respect of real estate market, Chen (2007) pointed out that the price of the residences of TJD tends to be steady and soaring up from the perspective of the law of supply and demand in the real estate market. That's because the MRT network has currently become wider and the value of TJD

in the future is gradually increasing. Moreover, according to Hong and Lin (1999), the distance between residence and the MRT station has significant effect on the residence price. The price decreases as the distance increases. Since the distance between the residence of TJD and the MRT station is 0, the residence price of TJD should be the highest.

3. RESEARCH DESIGN

There are totally 34 TJD sites of both the primary and subsequent networks, they were classified and sampled for the empirical research, based on which the questionnaire and survey are designed. The study classifies the stations into four types according to the transportation feature.

(1) Transfer Station

Transfer Station refers to the junction of two or more MRT or railway lines, for example, Taipei Main Sta., Zhongxiao Fuxing, Zhongxiao Xinsheng, Minquan W. Rd., Guting and Banqiao. The land-use type in those areas were mainly commercial. They feature as the hubs of urban traffic with strong transfer trips. They have the same functions as the interchange stations, but the transfer capability is stronger. Most of them are the cores of urban development.

(2) Terminal Station

Terminal Station refers to the terminal of a MRT line, for example, Yongning, Nanshijiao, Xindian, Daqiaotou, Luzhou, Zhuwei and Danshui. They are located usually near the outskirts with relatively low land use. Those areas focus on residence and the commercial function is in lack. The housing type is different from public housing, since there are more private housing. The traffic condition is relatively poorer in shortage of convenient mass transit, which requires more private vehicles.

(3) Interchange Station

Interchange Station refers to the station with plenty of bus lines nearby which facilitates the interchange. The station with more than 20 bus lines is defined as the interchange station, for example, Gongguan, Dingxi, Dapinglin, Qizhang and Jing'an. The commerce is often flourishing in those areas with the developing power next to the transfer stations. Both the interchange stations and the transfer stations are hubs of traffic, but the former is weaker than the latter in terms of transfer capability. Most of them are the cores of regional development.

(4) Regular Station

The stations without the above features are defined as the regular stations, for example, Yongchun, Houshanpi, Yong'an Market, Xianse Temple and Jiangzicui. The areas are often the residential zones with perfect living functions. They are similar to the interchange stations in terms of development model, but the strength of development is weaker. As for the traffic, the mass transit is more convenient than the terminal stations but inferior to the interchange stations.

Since the study focuses on the correlation between the TJD and the change of travel behaviour, the residential TJD buildings in different developing conditions are chosen for the study on the change of travel behaviour. The sampling principal is as below.

(1) Serving more than 2 years.

Being ignorant of the occupancy rate, the study chooses the TJD buildings that have got the building usage license for more than 2 years as the selecting objects in order to find sufficient household samples.

Moreover, after 2-year experience, the residents can really reveal life-style changes after moving, especially, the cognition for MRT convenience and the need for parking space supply.

(2) Mainly used for residence

Since the study mainly discusses the travel behaviour, the residential TJD buildings were selected as the empirical sites. The land use is based on the building usage license.

(3) With the MRT stations located in New Taipei City

Compared with Taipei city, the MRT system of New Taipei city is under development and the domestic habit of using mass transit is gradually formed. Besides, New Taipei city can support more volume and larger scale of development. Thus it is an object worthy of observation and study. Since the MRT system of New Taipei city is under development, we can further observe what factors affect the usage of MRT significantly.

Based on the above principles, the following TJD buildings are selected: Dingxi, Yong'an Market, Jing'an, Dapinglin, Qizhang, Xindian Dist. Office, Xindian and Jiangzicui. After sample selection, we can find the total number of households in the survey scope is 2,647. According to the findings of field survey, the average occupancy rate is estimated as 70%. The period of survey is from 1st July 2011 to 31st Oct. 2011.

4. ANALYSIS OF THE SURVEY RESULTS

4.1 Sample background Analysis

Totally 2,362 questionnaires were distributed for the study and 471 were returned, which 463 were considered valid. After the preliminary sorting, the Reliability Analysis was conducted on the questionnaires. On the whole, the Cronbach's α was 0.552 which means the questionnaires were reliable.

According to the statistics and analysis on the 436 valid questionnaires, males and females account for 48.85% and 51.15% of the samples respectively. The 18-40 years old householders who afford the family account for 63%, while the 40-50 years old householders account for 37%, which shows most of the respondents are young adults.

In terms of the number of family members and the monthly family income, the households can be classified into small families and normal families. In the study, small families generally have two or more persons, while normal families have three or more persons. According to the monthly family income, the households can be divided into low-income families, middle-income families and high-income families. In the study, the monthly income of the low-income families is less than NT\$50,000, the middle-income families fall in the range from NT\$50,000 to NT\$110,000, and the high-income families, above NT\$110,000. In the respect of the family type, the small family samples take the majority, accounting for 60.32%; the common family samples account for 39.68%.

In the respect of family income, the middle-income family samples take the majority, accounting for 50.23%; the low-income families take the second place, accounting for 28.21%; and the high-income families are the fewest, accounting for 21.56%.

4.2 The Changes of Travel Behaviours

(1) The change of car ownership

In the respect of car ownership before and after the moving, the samples without car increase from 180 to 217; the samples with one car reduce from 203 to 188; and the samples with two or more cars reduce from 53 to 31. The car ownership totally reduces 59 at least after the moving (as in figure 1).

(2) The change of commute mode

Most residents of the TJD buildings used to drive before they moved, accounting for 28.44%. After moving, most residents use MRT, accounting for 57.11%. Compared the different modes before and after the moving, it's found that the MRT usage for commute increases from 25.92% to 57.11%, while the car usage reduces from 28.44% to 15.60% (as in figure 2).

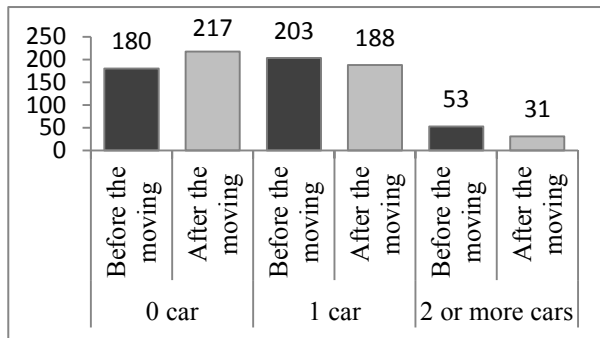


Figure 1. The comparison of the car ownership before and after the moving

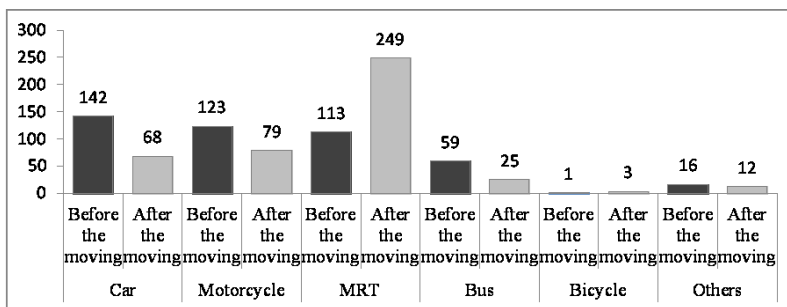


Figure 2. The comparison of vehicles used before and after the moving

Table 1. Styles in the CF2001 template (%)

County/City	Mass transit	Motor-cycle	Car	On foot	Bicycle	Others/taxi	Total proportion
Dept. of Rapid Transit Taipei	23.38	29.72	12.75	28.28	4.50	1.37	100.00
New Taipei	15.02	45.13	14.84	21.12	3.14	0.74	100.00
Taipei	34.10	29.90	16.20	15.40	4.20	0.20	100.00
Statistical Dept. of Ministry of Trans. and Com.							
New Taipei	24.90	44.60	14.50	10.90	4.70	0.30	100.00
The study							
New Taipei	63.84	18.12	15.60	-	0.69	2.75	100.00

(Source: The abstract analysis of the Survey of the Daily Vehicle Application of the Public issued by the Statistical Dept. of Ministry of Transportation and Communications in 2010. The Estimation Model of the Entire Transportation Demand in Metro Area of Taipei issued by Department of Rapid Transit Systems in 2010.)

Compared to Taipei City, the people of New Taipei City had already used the mass transit more frequently than the people of Taipei County and Taipei City before they moved to the TJD buildings (as in table 1). After the moving, the MRT usage increased greatly. Thus we can infer that the

residents of TJD buildings used to be the users of MRT and had formed the habit before they moved. Thus with the greatly improved convenience of MRT, the MRT usage increases significantly after they moved into the TJD buildings.

(3) The change of the frequencies of car and MRT usage for commute

In the respect of the usage frequency for commute, the samples without driving increase from 231 (before the moving) to 292 (after the moving), and the samples without taking MRT reduce from 214 (before the moving) to 82 (after the moving). The samples driving to office more than 4 days per week reduce from 125(before the moving) to 62(after the moving), and those taking MRT more than 4 days per week increase from 120 (before the moving) to 229 (after the moving). As for the commute days, the driving days reduce 373 days, averagely 0.86 day reduction per head, and the MRT usage days increase 619 days, averagely 1.42 days increase per person.

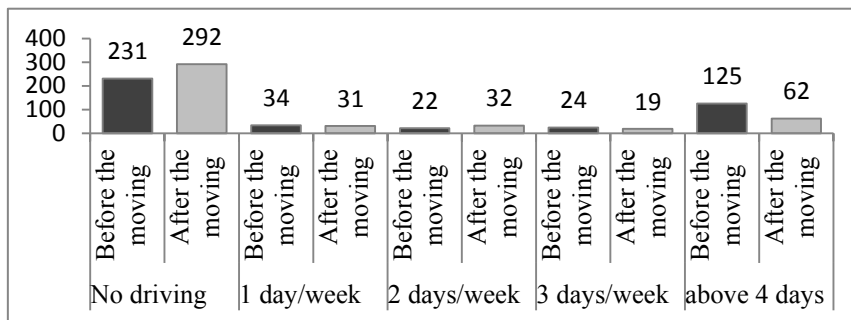


Figure 3. The comparison of the driving frequencies before and after the moving

Table 2. The frequency distribution of the commute time and cost

Commute cost (NTD)	Frequency	Percentage	Commute time (min)	Frequency	Percentage
Above 70	7	1.61%	Above 50	1	0.23%
31 to 70	22	5.05%	21 to 50	35	8.03%
11 to 30	71	16.28%	11 to 20	41	9.40%
0 to 10	44	10.09%	0 to 10	75	17.20%
0	122	27.98%	0	70	16.06%
-10 to 0	49	11.24%	-10 to 0	104	23.85%
-30 to -11	81	18.58%	-11 to -20	61	13.99%
-70 to -31	23	5.28%	-21 to -50	45	10.32%
Under -70	17	3.90%	Under -50	4	0.92%
Sum	436	100.00%		436	100.00%

(4) The changes of commute time and cost

As for the daily commute time and cost, the residents of TJD buildings spend totally 1,133min less on the commute than that before the moving, averagely 2.6 min reduction per person. The commute cost reduces NT\$1,349, averagely NT\$3 reduction per person. The frequency of change on the commute time and cost is listed in Table 2.

4.3 Influential Factor Analysis

(1) The effect of MRT station type on the car occupancy

By using cross-tabulation analysis to discuss the relationship between the car ownership and MRT station type. The result of chi-square test is

significant (chi-square value is 30.696, and P is less than 0.01), which means there is significant relationship between the car ownership and MRT station type. From Table 3, it's found that there are 82 samples own cars around the terminal stations, accounting for 61.7%, which is higher than interchange stations (56.2%) and regular stations (36.3%). It's inferred that the MRT is less convenient for the samples around the terminal stations and the private vehicles are required, so the car ownership is higher.

Table 3. Crosstable of car ownership and MRT station type

		MRT station type			sum
		regular	interchange	terminal	
Car ownership	0	63.7%	43.7%	38.3%	49.8%
	1	32.1%	45.9%	54.1%	43.1%
	2 and above	4.2%	10.3%	7.6%	7.1%
	sum	100.0%	100.0%	100.0%	100.0%

Pearson chi-square value 30.696***

(2) The effect of MRT station type on the driving frequency

As to the driving frequency for commute and the MRT station type. The result of chi-square test is significant (chi-square value is 39.104, and P is less than 0.1), which means the driving frequency for commute is significantly related to the MRT station type. From table 4, it's found that the samples around terminal stations who drive for commute account for 42.1%, which is higher than the samples around interchange stations (37.8%) and regular stations (22%). It's inferred that the MRT is less convenient for the samples around terminal stations and the private vehicles are required, so the driving frequency for commute is relatively higher. Moreover, according to the car occupancy analyzed above, the car occupancy of samples around the terminal stations is the highest, which results in the higher driving frequency.

Table 4. Cross table of driving frequency and MRT station type

		MRT station type			Sum
		regular	interchange	terminal	
Driving frequency for commute	No driving	78.0%	62.2%	57.9%	67.0%
	1 day/week	6.5%	11.9%	3.0%	7.1%
	2 days/week	6.5%	8.1%	7.5%	7.3%
	3 days/week	1.8%	4.4%	7.5%	4.4%
	Above 4 days	7.2%	13.3%	14.1%	14.2%
Sum		100.0%	100.0%	100.0%	100.0%

Pearson chi-square value 39.104***

(3) The effect of MRT station type on the commute mode

As to the commute mode and the MRT station type, the result of chi-square test is significant (chi-square value is 35.153, and P is less than 0.01), which means the commute mode selection is significantly related to the MRT station classification. From Table5, we can see that the samples around the terminal station drive most, accounting for 28.6%; the samples around the regular stations take MRT most, accounting for 61.9%. It's inferred that the car occupancy and the driving frequency of samples around the terminal stations are the highest, while the car occupancy and driving frequency of samples around regular stations are relatively lower, so they have to take other modes for commute.

Table 5. Commute mode and MRT station type

	MRT station type			sum
	regular	interchange	terminal	
Car	7.7%	12.6%	28.6%	15.6%
Motorcycle	22.0%	20.0%	11.3%	18.1%
MRT	61.9%	57.8%	50.4%	57.1%
Bus	6.5%	3.7%	6.8%	5.7%
Bicycle	0.6%	1.5%	0.0%	0.7%
Others	1.2%	4.4%	3.0%	2.8%
sum	100.0%	100.0%	100.0%	100.0%

Pearson chi-square value 35.153***

5. CONCLUSIONS

(1) TJD can improve the application of mass transit and reduce the commute time and cost.

According to the field investigation, it's found that more than a half of the residents choose MRT for commute after they moved in TJD buildings. Based on the 2,647 households in the survey, there is at least an increase of 825 people who turn to use MRT after the moving, which helps a lot to improve the MRT usage. On the other hand, the study also investigates the reduction on commute time and cost after the residents moved in TJD buildings. The daily commute time reduces 2.6 min per head on average and the commute cost reduces NT\$3 per head.

(2) TJD can reduce the car ownership and driving frequency

According to the field investigation, the car ownership of the residents reduces significantly from 58.72% to 50.2% after they moved in TJD buildings, with the reduction of 59 cars owned at least. As for the driving frequency, the residents who used to drive more than 4 days a week reduce from 125 to 62 after the moving.

(3) The MRT convenience of TJD has significant effect on the car ownership and driving frequency.

According to the analysis, the poorer the convenience of MRT is, the higher the car ownership is. In the study, samples around the terminal stations with the poorest MRT convenience own the cars accounting for 61.7%, which is higher than the samples around interchange stations (56.2%) and regular stations (36.3%). The driving frequency of the samples around the terminal stations accounts for 42.1%, which is higher than the interchange stations (37.8%) and regular stations (22%). From here we can see the significant effect of the MRT convenience on the car occupancy and driving frequency.

Due to the limit on funds and manpower, the study only chooses 9 cases as the empirical spots from the 34 TJD cases completed in 2010. Fortunately, the results are ideal. The future studies are expected to conduct more comprehensive surveys on the TJD stations to make the results perfect. Moreover, with the increase of the TJD stations such as 3 Rings & 3 Lines and the Airport Line in Taipei metropolitan area, it's necessary to add more surveys on TJD stations for better planning strategies.

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Paving the Pathway for Low Carbon Development *Urban Accessibility based Planning Support for Low Carbon Transport Development in Kathmandu*

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Abstract: The concept of ‘low carbon development’ (LCD) emerged from the concerns of developing countries on development policy and climate change rather than climate change alone. As the transport sector in most developing countries is unsustainable, ‘low carbon development in transport’ (LCDT) plans should address approaches to reduce emissions from transport, while maintaining or improving transport, as a catalyser of development. LCDT, as such, may pave a pathway towards LCD. Due to the complexity and uncertainty involved in long-term planning tasks, scenario-based planning support systems (PSS) have been regarded as useful tools for exploring future impacts of any kind of plans and policies. Thus, this paper aims at developing an urban accessibility based PSS for evaluating different scenarios of LCDT plans regarding their potential towards low carbon transport development in Kathmandu Metropolitan City (KMC).

This modelling framework combines an accessibility analysis and Activity-Structure-Intensity-Fuel (ASIF) framework in a GIS-based modelling platform. Based on interviews with government officials and documents of the Kathmandu Sustainable Urban Transport (KSUT) project, three plans were identified as qualifying for LCDT plans and were evaluated under high and low population growth scenarios. The evaluation shows that there could be an increase in accessibility along with emissions reduction gains for the current public transport (PT) improvement plan as well as for a plan of expanding the number of trolley buses in the PT vehicle fleet, under assumptions of a low population growth scenario. The trolley bus renewal plan can also lead to emissions reduction, but at the expense of accessibility. However, emissions would still be high against the base year for all the plans in the high population growth scenario. Performing a sensitivity analysis, it was concluded that penetration of trolley bus in the vehicle fleet has a great potential towards LCD. The results show that a shift from private to public transport is necessary in all the LCDT plans to realize a LCD in transport.

1. INTRODUCTION

1.1 Low Carbon Development and Low Carbon Transport as a climate change mitigation strategy

Under the United Nation Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, developed countries are required to support mitigation actions and adaptation to climate change in developing countries. Though climate change needs to be addressed by both developing and developed countries, it is being overlooked mostly in developing countries due to their urgent need to give preferences to development activities (Halsnæs & Verhagen, 2007). Therefore, the notions of ‘low carbon development (LCD) and low carbon development strategy (LCDS)’ have appeared as new concepts in the arena of climate change since 2009. Finally they were adopted into the Copenhagen Accord and Cancun Agreements as ‘low-emission development strategy’ (Tilburg et al., 2011). The 2011 Durban Climate Conference, COP17, has restated the importance and potential of LCDS to take national climate change policy and development policy together in a co-ordinated manner (UNFCCC, 2011).

Many authors, organizations and countries have their own interpretation regarding the definition and the concept on LCD. However, Yuan et al. (2011) have to some extent summarized the various concepts on LCD into a common understanding; three components for LCD are: reducing CO₂ emissions, intensive use of low-carbon energy and ensuring economic growth. Tilburg et al. (2011) define ‘low carbon’ as reducing emissions trajectory below business as usual (BAU), and further argue that LCD explicitly reconciles the mitigation and development priorities of the country. LCD can be pursued in any sector including industry, agriculture, households and transport.

According to the International Energy Agency (IEA), the transport sector accounted for 26% of world’s energy use and 23% of energy-related GHG emissions in 2004 (IPCC, 2007). Moreover, in transport, emissions are rising at the highest rate of all sectors. This has been accounted to rapid economic growth, urbanization and motorization that are happening at an alarming rate in most developing countries. As reported by ADB (2011), rising incomes, urban expansion and dispersion of activities have increased the demand for and dependence on motorized transportation with rates doubling every 5 to 7 years for Asian countries. Though motorization is perceived as a headway towards development, manifested problems as described by Dimitriou (1992), such as air pollution, congestion, accidents, GHG emissions and increased marginalization of urban poor ultimately lead to inhibition of sustainable development (Dimitriou & Gakenheimer, 2011). Thus, following concerns about this dilemma, the concept of sustainable low carbon transport has emerged, which explicitly addresses sustainability priorities, while mitigating GHG emissions (Sakamoto et al., 2010).

The avoid-shift-improve (ASI) strategy of (Dalkmann & Brannigan, 2007) can be taken as a potential strategy for developing cities towards low carbon transport. The ASI strategy has created a new paradigm in the field of transport, which helps nations to deal with unsustainable transport and GHG emissions. Thus, this study has regarded low carbon development in transport (LCDT) plans as a response that can avoid or reduce travel, can encourage shift to more sustainable and environmentally friendly modes or

that can improve the energy and carbon efficiency of modes, while maintaining development and economic growth.

Dalkmann & Brannigan (2007) have further categorized different policy instruments under each strategy (avoid, shift, improve) into five groups namely planning, regulatory, economic, information and technological. In addition, Dhakal (2006) discusses the 'rebound effect', the positive impact of a policy measure alone is often partly offset by its negative impact, e.g. increase in total travel as a result of lower fuel costs from more efficient vehicles. Therefore, to realise substantial reduction in CO₂ emissions, it has been argued that the effectiveness of a package of policy instruments will be greater as compared to a single instrument.

1.2 Development and accessibility

In the past, transport plans were usually geared towards increasing mobility (Geurs & Ritsema van Eck, 2001). But concerns over sustainability, i.e. a balance of economic, social and environmental goals, have led to adoption of the concept of accessibility as a performance indicator for sustainable development (Ha, 2011). Further referring to Amartya Sen's capability approach (Sen, 2002), this study has considered accessibility as an enabler for enhancing the capabilities of people to reach a wide number of opportunities such as employment, education, and thus help to stimulate economic development. Several studies have used the concept of 'accessibility to employment' for assessing and valuing the benefits of proposed land use and transport plans and policies on economic development of people since employment is the source of income (Bertolini et al., 2005; Cervero & Kockelman, 1997). Following the contribution of Sen's capability approach (Sen, 2002), there is an increasing body of literature that advocates the need to broaden the perspective of looking over the development of a country as improvement in all dimensions of human needs such as health, education instead of growth per capita income only (Mazumdar, 2003; Saito, 2003). Hoffman (2006) has further emphasized access to education and equitable access to education as basic foundation for developing other capabilities for human development.

Thus, following a wider horizon of development, this research has considered physical accessibility to education as an enabler for the young generation to develop capabilities and hence contribute in the further economic development of the country.

1.3 Planning Support Systems

The formulation of spatial plans and policies has always been a complex process. Planning support systems (PSS) can be valuable geo-technological tools enabling planners to handle the complexity of planning processes by evaluating alternatives within future scenarios integrating social, economic and environmental aspects (Geertman & Stillwell, 2009; Hickman & Banister, 2007; Pettit, 2005). Albeit, there is consensus on the use of PSS in the appraisal of transport policies and plans for exploring their impact in the long run, a research gap still exists on its use in evaluating the impact of LCDT plans on urban accessibility and hence their contribution in strengthening LCD.

Thus, this research attempts to fill in the aforementioned gap by addressing these two questions: how are urban accessibility and LCDT

related and how to develop a PSS to derive and evaluate accessibility of existing LCDT plans under certain growth scenarios for the case of Kathmandu Metropolitan City (KMC).

2. STUDY AREA

2.1 Kathmandu Metropolitan City at a glance

Kathmandu Metropolitan City (KMC), covering about 50.6 km², is the largest metropolitan area and capital city of Nepal, in South Asia. Among five cities comprising the Kathmandu Valley (figure 1), KMC is the largest urban agglomerate in the country and is home to approximately 20% of the total urban population. According to Central Bureau of Statistics (CBS) the total population of KMC was 671,846 in 2001 (KMC, 2013) whereas it has risen to 975,453 in 2011 (CBS, 2012). Apart from being the capital city, KMC is the headquarter of the Central Development Region, which constitutes three zones, namely, Bagmati, Narayani and Janakpur. The city itself is located in Bagmati Zone and consists of 35 wards.

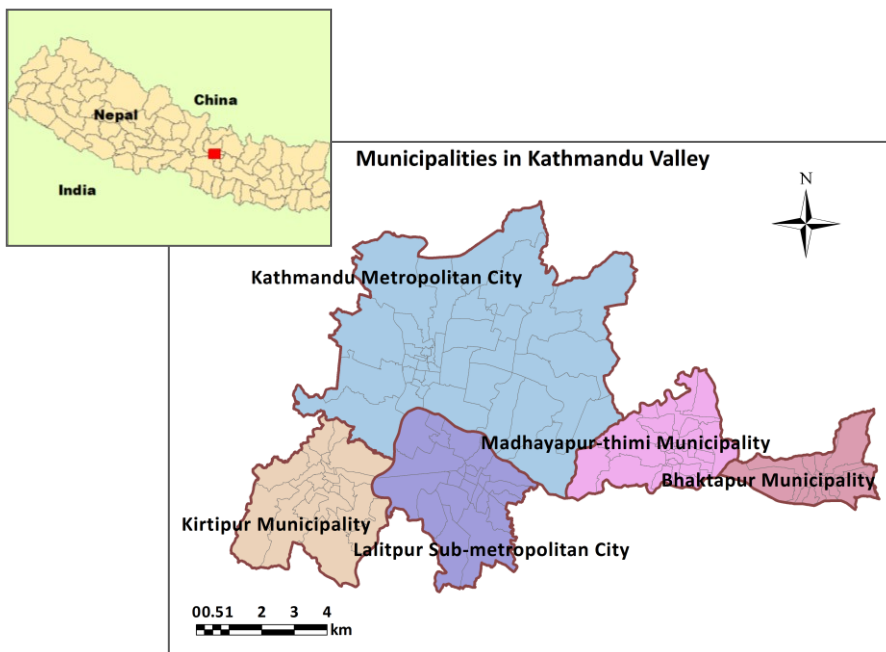


Figure 1. Kathmandu Valley with five municipalities

2.2 Transport challenges in KMC

Urban growth or urbanization is usually associated with environmental problems. Based on interviews with stakeholders from the government sector, academic institutions and private sector working in the field of transport, the following factors, which have a negative impact on one or more dimensions of sustainable transport in KMC, have been listed.

With urbanization, the city is facing an increasing population trend along with substantial growth in vehicle numbers, especially two-wheelers (2W),

exceeding the carrying capacity of existing road infrastructure. Thus, rapid urbanization with increasing travel demand, limited road capacity, and modal shift towards private modes are all contributing to the problems of traffic congestion, delays and increasing travel time per trip, as well as decrease in road safety in the city. Moreover, motorization of the city has always been coupled with the use of poorly maintained vehicles and adulterated, low quality fuels, burdening the environment of the city.

Public transport (PT) in the city has become despicable and holds the stigma of an unreliable, inefficient and uncomfortable system. After the demise of the government owned mass transportation systems such as 'trolley bus' and 'sajha yatayat' in 2008, it is currently being fully owned and operated by more than 150 individual PT entrepreneurs. As a result a large numbers of small occupancy vehicles are always waiting in queues for their turn to start operation, after which they are tempted to maximise fare revenue by loading the passengers from locations other than the designated stops, overruling traffic rules etc. Consequently, unscheduled and unreliable public transport, overloading with large number of passengers and an uncomfortable environment inside the vehicles, haphazard loading and unloading of passengers, issues of road safety have delivered the PT system of the city a bad reputation. Hence, it has remained as a vehicle used by captive users, who do not have alternatives, whereas those who are capable are shifting to private modes, especially two-wheelers, which are easy to use and relatively affordable.

Both slow moving lower occupancy vehicles such as 'tempos' and higher occupancy high-speed vehicles are using the same route, which has been identified as another reason of traffic congestion in addition to increasing numbers of private vehicles, since it has lowered the speed of high-speed vehicles. The present route planning of public vehicles originating and ending in the core city, poor traffic management, absence of strict laws and orders on vehicle fitness and poor driving behaviour are further contributing to the ad hoc transport system.

Furthermore, the current transport system and policies in the city are focussing on mobility of vehicles rather than ease of all people to reach destinations and without a proper pedestrian environment, non-motorized transport is being neglected. Besides, motorized transport is not easily accessible to physically impaired people, women and senior citizens and it has been argued that the lower income groups are spending one third to half of their income on transport. Any kind of planning task requires the coordination from ministerial to departmental levels for its effective implementation. Without good governance, effective implementation of plans and policies are at stake for the city.

2.3 Conceptualizing LCD and LCDT in KMC

Interviews with stakeholders on the concept of LCD and LCDT for the city revealed that the share of Nepal in total global greenhouse gas emissions is only 0.025 percent (Panthi et al., 2010), with per capita emissions also being among the lowest in the world. Therefore, the immediate need of the country is adaptation rather than mitigation of GHG and as such mitigation concerns are often considered as an economic burden. However, there has been realization that mitigation efforts through LCD strategies (LCDS) in line with national priorities and capacities do not

necessarily constitute economic burden, while the nation as a whole can benefit through various co-benefits such as lower energy consumption, reduction in air-pollution, and secondary co-benefits such as relief in traffic congestion and health of people, and improvement in levels of accessibility of the people. Though the development of LCDS is in an initial stage, different sectors have been identified already where potential benefits of GHG emission reduction plans can be obtained, most significantly in the transport sector.

Currently, the transport sector of the city is dependent on imported fossil fuel energy which is increasing with increasing motorization, especially the private vehicles. This has not only burdened the country's economy but also contributed to negative impacts on the environment through local air pollution, health of people as well as accessibility of people through increases in congestion levels due to rapid motorization. Thus, an important pathway of LCD for the city in the transport sector is reduction of its dependency on fossil fuel. This can be done by making the PT system more time efficient, reliable and accessible to all the people as well as making the system energy efficient using alternative fuels. The country also has the potential to introduce a hydropower plant for generating electricity with zero emissions. However, there should be an integrated approach to make this energy source sustainable.

The increase in daily trips and travel demand of people, especially with private vehicles, has been viewed as another reason for unsustainable transport in most of the developing cities. But most of the daily trips in KMC are limited to jobs and education. In such case, strategies and policies of the city could be directed more on how people travel instead of how many trips people undertake. Moreover, transport plans on expansion and widening of roads without proper transport management on increasing personal mobility, is likely to accelerate emissions. So, encouraging mass transit systems and making the PT system of the city reliable, time and cost efficient on the one hand can help in energy and fuel saving, while on the other hand they can encourage people to shift from their private modes. Two schools of thoughts were advocated to deal with the problems of unsustainable transport system in the city. Mass transit systems such as monorail and light rail using electricity as a source of energy are thought to be feasible for solving the current problems of the city, but there is a need of large investment throughout its lifecycle. With no strong policies of the government, sustainability and therefore economic benefits from such system is on the verge. With this argument, the second school of thought of optimizing the current infrastructure system was widely agreed upon, for instance, renewing the trolley bus system with articulated busses and priority lanes, proper route planning and improved traffic management, promoting non-motorized modes, cordon pricing for private vehicles in restricted areas, and improving the current ring road as expressways etc.

Thus, following on the stakeholders' interviews, from the three strategies for LCDT, 'shift' and 'improve' have been addressed as being the most feasible strategies to relieve the associated transport problem of the city. Along with shift to environment friendly modes, improvement on technology and energy efficiency of vehicles is also needed. Though there are policies on vehicle fitness tests, EURO I standards, scrapping of old vehicles, and energy mix, the effective implementation of these is lacking. Moreover, a low cost alternative and clean energy such as electricity need to be promoted, e.g. by financial incentives for such vehicles.

3. LOW CARBON TRANSPORT PLANS FOR KMC

The Kathmandu Sustainable Urban Transport Project (KSUT), supported by the Asian Development Bank under the Sustainable Transport Initiative is an on-going project aimed at improving the quality of urban life in Kathmandu Valley (MoPPW & ADB, 2010) through different measures. For the short term, the measures identified were:- improving public transport, implementing traffic management plans for the central area of the city, promoting non-motorized modes in the historic area of the city and improving air quality within the city at large. Thus, building on the interviews, the KSUT project and following ASI strategy, the next section analyses the LCT plans for the city.

3.1 Improving the public transport system and encouraging modal shift

A combination of policy instruments (planning, regulatory, economic, information and technological) are deemed most effective in improving the ridership of public transport as compared to implementing those policy instruments in isolation. From the KSUT report (ADB & MoPPW, 2010) plans for enhancing the PT system of the city addressing one or more of the mentioned policy instruments are included in this study:

Delineating of primary and secondary routes according to vehicle type: This planning instrument is anticipated to improve the efficiency of PT by optimizing transport capacity according to the demand. This delineation of routes, which in its current situation are being used by both high speed and slow moving vehicles, is expected to overcome the mismatch between vehicle types and use of road space, increase the speed and reduce in congestion. The primary routes are assigned to large buses, with an estimated capacity of 100 passengers including standing passengers. The secondary routes are assigned to minibuses with capacity of 60 including standing passengers. Even though transfers between primary routes and secondary routes pose disadvantages to the user, such inconvenience could be minimized by providing user-friendly terminals and scheduled PT. Moreover, the fare system could be rationalised by establishing a different multi-mode ticket system, e.g. using smart card technology for implementing a sophisticated and complex fare structure for users' benefits.

Dedicated bus lanes with integrated system: The successful cases of BRT could be taken as examples where the performance of the public transport system could be further enhanced by planning dedicated bus lanes or assigning routes as bus only lanes along with technological instruments for implementing integrated system of fare collection and proper scheduling of buses.

Restriction of private modes to the central part of the city: In addition to increasing attractiveness of PT (as a 'pull policy'), regulatory instruments can restrict the use of certain motorized vehicles, types of vehicles used and the standards they should adhere to. Thus, regulatory instruments such as restricting vehicles to the central part of the city and congestion charging help in managing transport demand of central part of the city and encourage people to shift from private modes to public transport on the other ('push policy').

Incentives and tax reduction policies for public transport: Financial incentives for PT users, as an economic instrument, may strengthen patronage of public transport. Tax reduction policies of government on import of public vehicles attract private investors and may promote public private partnerships in development of sustainable low carbon transport.

3.2 Renewal of the trolley bus system

The government owned trolley bus system got shut down completely in 2008. No clear reasons have been forwarded, but according to views of experts, political circumstances, poor organisation as well as weak patronage of the system were the main reasons of the demise of the system. Further reasons for inability to attract passengers were assumed to be low speed of the vehicles and limited and inconvenient routes.

The KSUT project proposes the renewal of the trolley bus system in some of the existing routes as well as expanding it into new routes with improved technology and performance of the system. Hence addressing a shift strategy, a planning instrument such as identifying potential routes, plays a significant role along with technological instrument for improving the efficiency of newly proposed vehicles. Furthermore, economic instruments, such as providing financial incentives including tax reduction in combination with regulatory instruments such as restricting motorized modes other than trolley bus in priority lane, congestion charging etc could be more effective in promoting low emission vehicles.

4. ACCESSIBILITY BASED PSS, A TOOL FOR EVALUATING KMC IN LOW CARBON PERSPECTIVE

To derive scenarios of urban accessibility based on the LCDT plans discussed in the previous section as well as to demonstrate the application of PSS for generating and evaluating those scenarios, the following sections describe the data required, pre-processing of the data, modelling framework and its operationalization platform.

4.1 Data Compilation

The data used in this study were collected from primary and secondary sources. For the primary data, interviews on the concept of LCDT and LCD for KMC, existing transport challenges and transport plans for the city were undertaken with relevant people from the government, the private sector and academia. The secondary data were collected from different government departments, private offices and consultancies in the form of spatial and non-spatial data. Data to be preserved in vector format included the city ward boundary, road network, public vehicles routes and stops, locations of schools and colleges. Processing of road network data and public vehicle routes to render usable topology was done in ArcGIS, bus stops were digitized manually where necessary, referring to the KSUT report (ADB & MoPPW, 2010). As the ward level census data consisted of population according to gender, the population of higher schools and colleges were extracted using the percentage of population between ages 15-29. For this

study, access to schools and colleges was considered as a proxy for broadening the capabilities of the young generation to seek socio-economic opportunities and hence contribute to the future development of the city. Thus, spatial locations of only higher schools and colleges were extracted, resulting into 151 destination points.

The public vehicles considered were minibuses, microbuses, electric tempo and gas tempo whereas the two-wheeler (2W) was taken as representative of the private mode. In the existing situation, the mode share considered were 52.8% for the public transport and 40.7% for the two wheelers (ADB & MoPPW, 2010; Bajracharya, 2010). The network data was prepared to represent intermodal network consisting of two or more modes. The following formula was adopted for developing an intermodal network dataset

Total travel time by public vehicle = walk time to stop + waiting time for vehicle + travel time in vehicle + walk time to destination

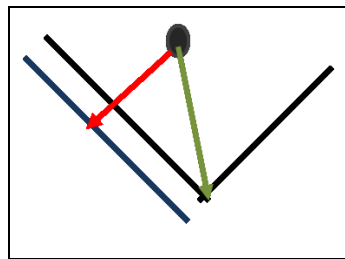


Figure 2. Intermodal connectors for vehicle route and road

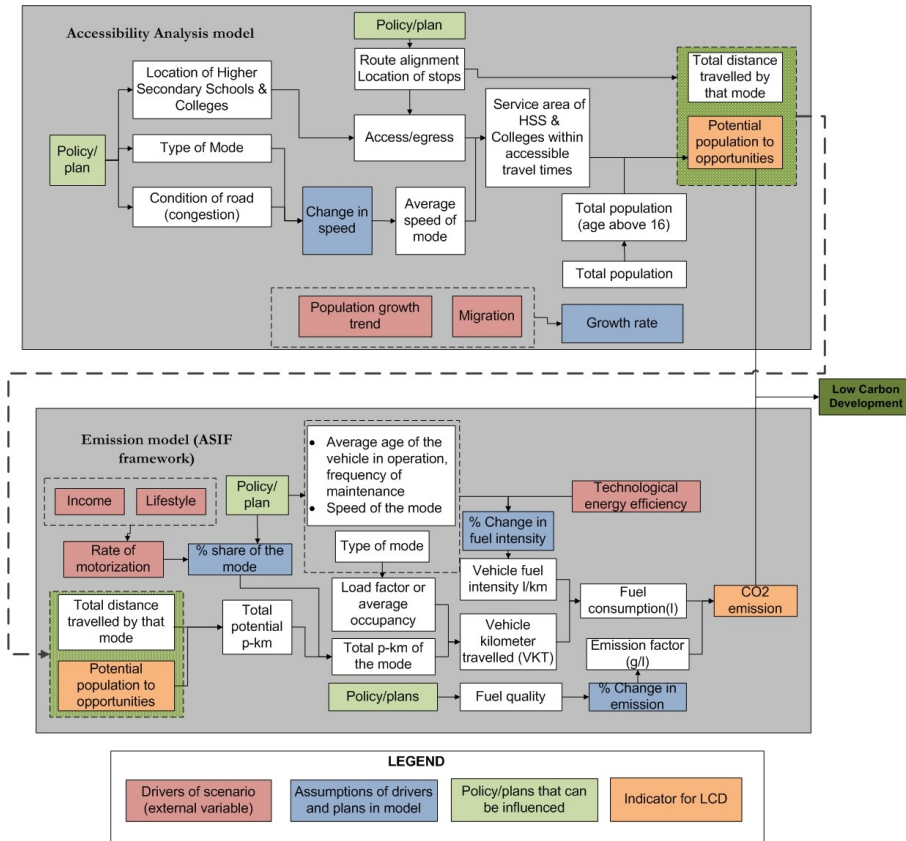
In figure 2, the blue line represents the vehicle route coded with an average speed, whereas the black line represents the road network coded with walking speed. The solid circle represents a bus stop and the red line represents the connector between the bus stop and the vehicle route, which was coded with waiting time. The green line represents the connector between stop and road network. As such, people are allowed to get on the bus and get off to their required point only through stops.

4.2 Modelling framework for developing the Planning Support System

Figure 3 presents the modelling framework for developing the PSS for assessing the impact of all the three LCDT plans on urban accessibility, and hence their contributions towards low carbon transport development in the city. This framework integrates the accessibility analysis with a carbon emission model. The output obtained from the accessibility analysis in terms of potential population and distance travelled by mode under consideration to reach the facilities is used as input into the emission model for estimating carbon emissions.

From the various relevant scenario parameters of population growth, rise in income and changing rate of motorization, population growth was used for constructing growth scenarios for KMC until 2020. The output of the various growth scenarios in terms of this parameter is handled as an input that affects different components of the model and hence changes the number of potential population and the carbon emissions during that service provision. The potential population in this study was defined as those who are provided service with the mode under consideration. Finally, using the

indicators of potential population and the resulting emissions during the service provision, a quantitative assessment of LCDDT plans was undertaken.



For measuring the accessibility, this study has applied a simple contour measure as a location-based activity measure (Geurs & Ritsema van Eck, 2001). The data for KMC lacked information on travel demand, such as origins and destinations of people, individual choice on modes and travel behaviour of people in the city, which would be required for operationalizing the other type of measures. Furthermore, the objective of this study was to demonstrate application of PSS in dealing with accessibility impact of LCDT plans; thus easiness in conceptualization, operationalization and interpretability with undemanding data made the contour measure most suitable for this study. In this approach, computing the number of persons that fell inside the various isochrones was considered as the potential users of the modes, while the interpretation of accessibility for this study was directed as- the higher the number of people serviced by LCDT plans, the higher is the accessibility.

For measuring carbon emission from transport, the Activity-Structure-Intensity-Fuel (ASIF) framework proposed by Schipper et al. (2009) was used which has been presented below.

$$G = A * S_i * I_i * F_{i,j}$$

where, G = Carbon emission from transport

A = total transport activity

S = modal structure

Figure 3. Modelling framework for developing PSS

I = modal energy intensity

F = carbon content of fuels

Due to the lack of intensive transport activity and behavioural data, the population that can access high schools and colleges within the pre-set travel time isochrones were seen as the potential users of the mode. Thus, calculating the distance travelled to those locations by different mode and the serviced potential population as the output from the accessibility analysis, total transport activity in passenger-km (p-km) was calculated as well. Based on the mode share, passenger-km were estimated for each mode, which was then assigned to vehicles km travelled (VKT) according to the known occupancy factor of that mode. With VKT and the fuel intensity (l/km) of the mode, total fuel consumed was calculated which was further converted into CO₂ emission (tons) according to emission factors (g CO₂/l)

5. OPERATIONALIZATION OF THE MODELLING FRAMEWORK IN A GIS-BASED PLATFORM

The contour measure of location-based accessibility was operationalized in the model builder platform as shown in figure 4 using ArcGIS network analyst. The current transport system as well as the future transport system was represented with distinct sets of network data. These network data when used as an input would result into a number of potential users of each transport mode and the distance travelled by the mode, which serve as an input for the emission model as activity in p-km.

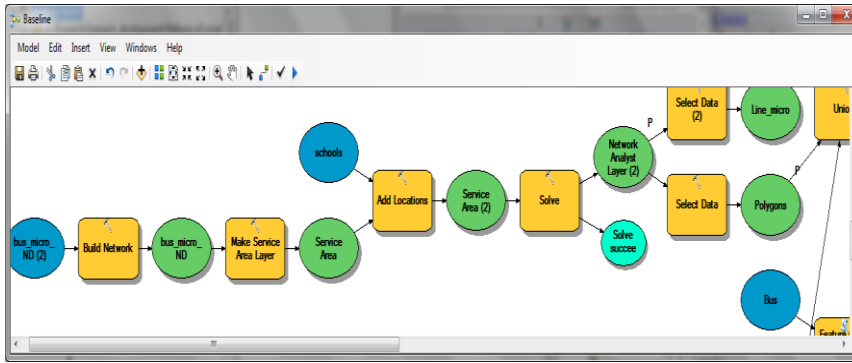


Figure 4. Applying contour measure of accessibility for each mode in ArcGIS model builder

The ASIF framework was also operationalized in the open modelling platform of Scenario 360 in CommunityViz (Placeways, 2013). For each type of mode under consideration a user interface was created, which facilitates the user to change the slider bar to make assumption for mode share, average occupancy, fuel intensity and emission factor as shown in figure 5.

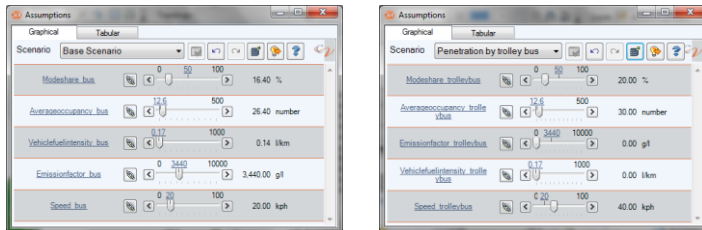


Figure 5. User interface for making assumptions

The indicator charts for number of potential population served and the emissions produced as shown in figure 6 allows on the fly visualization of these changes. Further, alerts were added to this PSS, shown in red in the indicator chart, to show the effectiveness of the plans against the baseline.

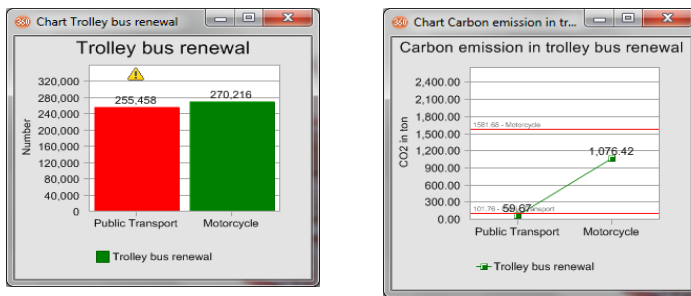


Figure 6. Indicator chart for the number of potential population (left), emission produced during that service provision (right)

6. APPLICATION OF PSS FOR THE CASE OF KMC

6.1 Definition of growth scenarios

To investigate the effects of the chosen LCDT plans and policies on the accessibility of people to opportunities and related carbon emissions

produced during that service, different growth scenarios were constructed, each assuming varying population growth rates. Since the definition of accessibility in this research was operationalized as how many more people would be served by the new plans and systems, uncertainties on future growth of population would yield different results. The study has therefore considered two growth rates of 4.76% (CBS, 2012) and 7.9% (Pradhan, 2004) representing a low growth scenario and high growth scenario respectively. These growth rates respectively represent the growth rate of Kathmandu district for the year 2011 and with projected population for 2001. Thus, with the combination of low and high population growth scenario and selected policies/plans, eight scenarios were constructed (Figure 7).

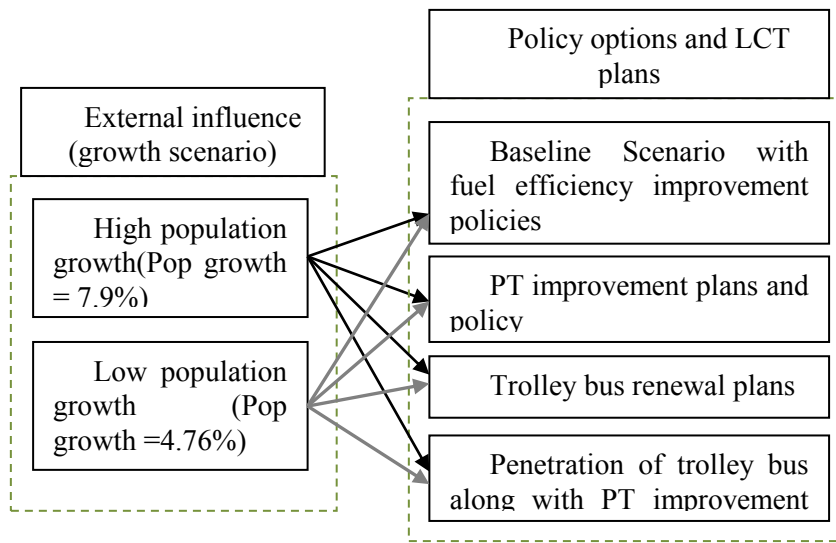


Figure 7. Combination of growth scenarios and alternative LCDT plans

6.2 Interpretation of baseline scenario and alternative LCDT plans for KMC

The chosen LCDT plans are: Increased public transport patronage, trolley bus renewal plans and penetration of trolley bus along with PT improvement plans. The following sections describe the interpretations of baseline scenario and these LCDT plans.

6.2.1 Baseline scenario with fuel efficiency improvement policies

For the baseline scenario until 2020, assuming GDP growth of 5%, it is estimated that the growth in traffic will be 8.75% per annum from 2010-2015 for public transport, car and motorcycles; from 2016-2020 it will then be 8.5%, 7.5% and 5.0% per annum respectively (ADB & MoPPW, 2010). This shows that the growth of two-wheelers will decrease compared to public transport and car after 2015 onwards.

Even though the number of two-wheelers in total number of vehicles would be less as compared to cars as private vehicle in 2020, assuming that their popularity would still continue to remain among youths and without any initiation in enhancing public transport patronage, strong enforcement of laws and order and strong policies, current travel demand share of 52.8% by public transport and 40.7% for two wheelers will still continue in the

future. The present mode share among public transport:- small occupancy vehicles (micro bus and tempo) with 47% and 13% respectively and high occupancy vehicles (minibuses, buses) with 31% was also assumed to be same for the baseline scenario.

The fuel efficiency estimated by Dhakal (2006) for 2004 and MoPPW & ADB (2010) for 2010 has shown little variation. However, due to the improvement of vehicle technology worldwide and increase in capacity of people to afford more efficient vehicles subjected to rising income along with enforcement of some of the policies on fuel efficiency, improvement of 20% was assumed in fuel efficiency for baseline scenario in 2020.

6.2.2 Increased public transport patronage

The main elements of this alternative are the delineation of primary and secondary routes, and dedicated lanes for primary routes. With such improvement, average waiting time is expected to be 3 min in each stop (MoPPW & ADB, 2010) as compared to average 10 min in the existing condition (peak hour assumption). In contrast to average speed of 20 kilometres per hour (kph) in the current situation for all types of vehicles, the average speed of vehicles is expected to be 25 kph given as a conservative estimate in the KSUT report whereas due to the dedicated bus lanes and proper traffic management, the speed of the large buses in the primary routes is assumed to increase to 40 kph (Dhakal, 2003). In order to make public transport more attractive, by managing demand and supply, the average occupancy of vehicles is assumed to decrease by 15% to create comfortable environment inside the vehicle. Hence, with these assumptions, the mode share for public transport in 2020 is estimated to be increased by 20% following the KSUT report (ADB & MoPPW, 2010). This increase will be compensated by simultaneous decrease in mode shares of 2W. Due to delineation of route, there will be need of interchange of vehicles from primary to secondary. However, such interchanges will be made convenient by providing user-friendly terminals, scheduled arrival and departure of vehicle as well as convenient interchange spots.

6.2.3 Renewal of trolley bus system

For the renewal of the trolley bus system alternative, a few primary routes of previous plans have been identified as potential routes for trolley bus by the KSUT project. Thus, in these routes, the trolley bus system is assumed to be in operation with dedicated lanes. The plan further addresses import of new trolley buses that are technologically more efficient than the older ones resulting in an average speed of 40 kph.

Since trolley buses are operated with electricity, they are regarded as clean vehicles and the CO₂ emissions of the system are calculated based on the grid emission factor. Assuming that the electricity will be made available from the hydropower plant as a potential source of energy, the system could be run with zero emission. However, this needs strong coordination between concerned authorities. As such, with the coordination of Nepal Electricity Authority, the trolley bus system will be operated with electricity making this system sustainable. With strong regulatory and economic instruments of financial incentive and taxes, this system will be able to attract passengers.

6.2.4 Penetration of trolley bus system along with PT improvement plans

This alternative considers penetration of trolley bus system along with PT improvement plans, i.e. a combination of the two previously discussed options. Based on the number of trolley buses, it is estimated that it will be able to meet 20% of travel demand in 2020 as a conservative estimate from the KSUT report. Thus, 20% of modal split of large buses on primary routes will be shared by trolley bus. The remaining assumptions on average occupancy, fuel efficiency, emission factors will be as those of PT improvement plans.

7. RESULTS AND DISCUSSIONS

7.1 Accessibility impact of alternative LCDT plans

With 151 locations of high schools and colleges distributed in the city and overlapping of routes for all PT, most of the areas of the city are accessible within 30 minutes of travel time by PT in the baseline scenario (figure 8), while in the same baseline scenario improvement on the accessibility by 2W is shown to be less and is mostly concentrated on the south eastern part and periphery of the city (figure 8). The implementation of LCDT plans (PT improvement plan and penetration of trolley buses along with PT improvement plan) would not hamper the accessibility of people (figure 9). Instead some of the areas in periphery of the city would benefit from this plan. Due to reduced congestion, the average speed of 2W would also be improved resulting in an increase in the accessibility of south eastern part of the city. In the case of the alternative scenario with trolley bus renewal plan, large buses on a few of the primary routes would be replaced by trolley buses as these are zero emission vehicles having similar performance in terms of speed as that of the large conventional busses. The result of this alternative scenario (figure 10) shows some decrease in service area mostly in the south eastern part of the city for PT, whereas for 2W, given the increase in speed against the baseline, there would be an increase in service area.

Though the results show variation in the accessibility due to the LCDT plans, the larger part of the city is reachable from at least one of the facilities by using either of the modes - public or private. This is due to the large number of facilities dispersed around the city. The network model prepared for this analysis considered traffic with constant average speed for every road segment, while no congestion factor was applied, which might possibly overestimate the speeds in city centre whereas underestimates it in other areas of the city. In reality the frequency of public vehicles in the city is irregular; so the average waiting time of 10 minutes was assumed for the baseline whereas 3 min was assumed for the new system referring to the KSUT project. With these assumptions and in the absence of a calibration and validation of the model for the case study area, there is high probability of deviation of the accessibility result from reality. Despite these limitations, having the analysis done in relative terms, i.e. comparing each scenario with the baseline scenario, the results are argued to be valid.

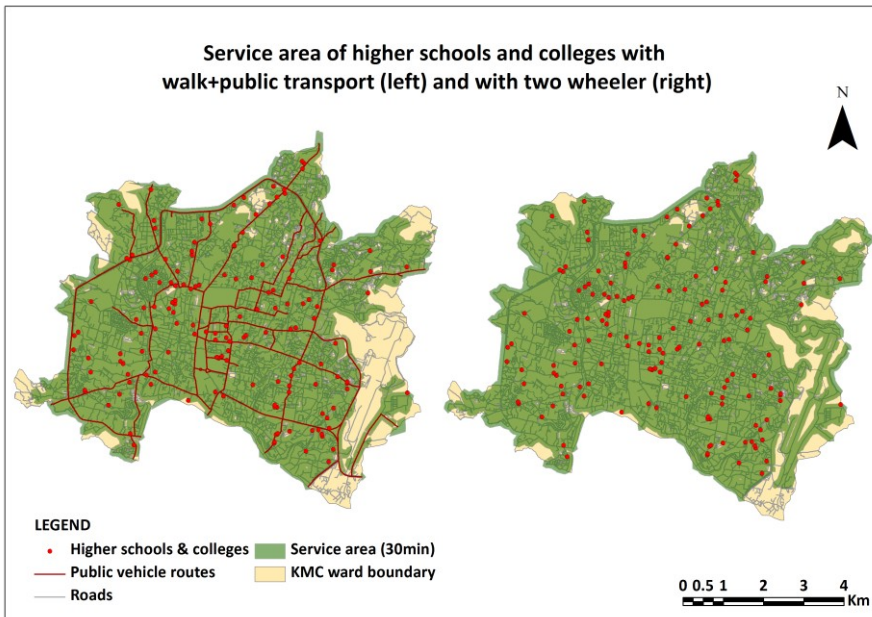


Figure 8. Service area by public transport + walk and 2W within 30 min from facilities (higher schools & colleges) for baseline scenario in 2020

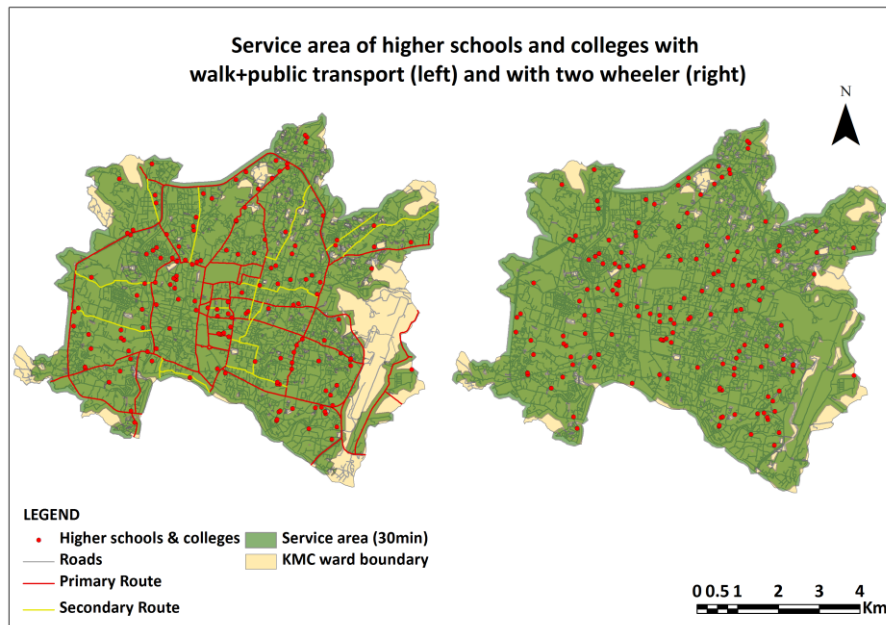


Figure 9. Service area by public transport + walk and 2W within 30 min from facilities (higher schools & colleges) for alternative scenarios with PT improvement plan and penetration of trolley bus along with PT improvement in 2020

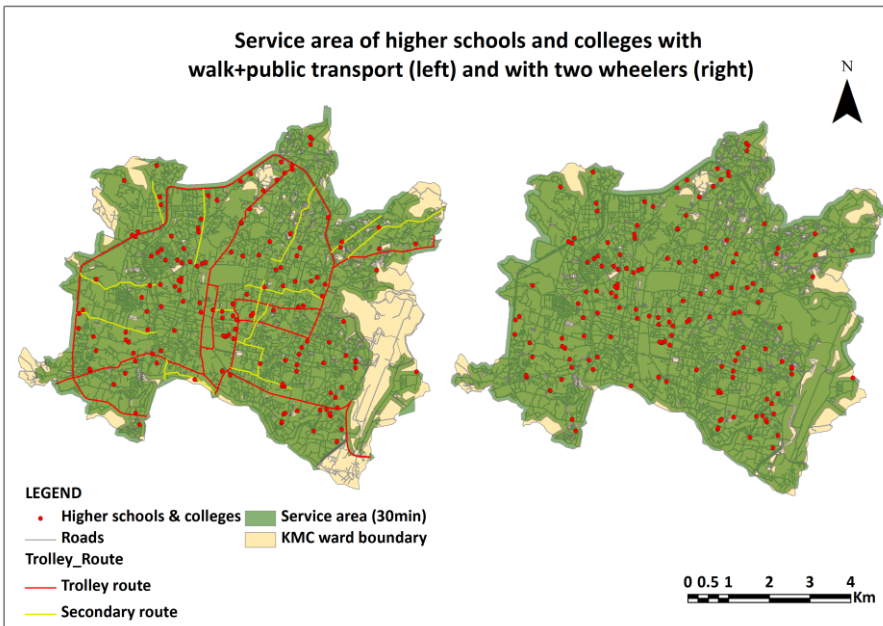


Figure 10. Service area by public transport + walk and 2W within 30 min from facilities (higher schools & colleges) for alternative scenarios with trolley bus renewal plan in 2020

In both the high and low population growth scenarios, both alternatives with PT improvement plans and penetration of trolley bus system along with PT improvement plans could increase accessibility against the baseline shown in figure 11. But there would be a decrease in accessibility due to the alternative with trolley bus renewal plan, which would be due to absence of a few primary routes. Having some congestion relief, the average speed of 2W would be increased resulting in an increase in the level of accessibility.

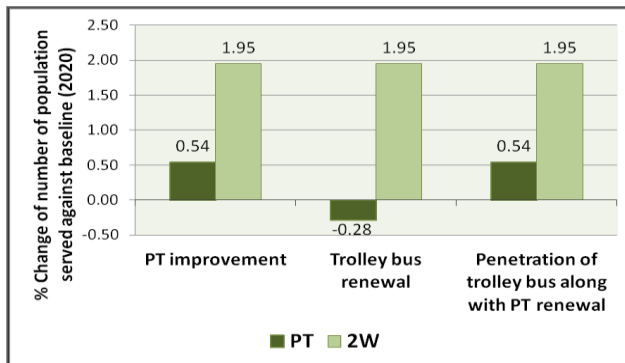


Figure 11. Percentage change against baseline (2020) for number of people served by LCDT plans for each mode.

7.2 Emissions for growth scenarios and alternative LCDT plans

The baseline scenario with only improvement in fuel efficiency clearly shows a non-desirable future as depicted in figure12. Under the high population growth scenario there would be an increase in total emission with all the alternative LCDT plans implemented against the base year. Even

though there would be an increase in accessibility in the high population growth scenario, the assumptions on modal shift would not be sufficient to reduce the emissions in absolute terms, unlike in the low population growth scenario.

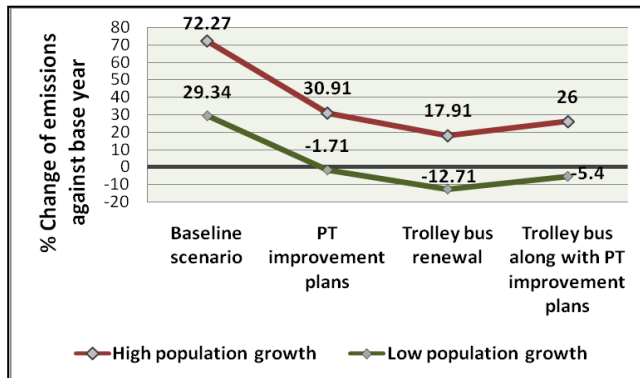


Figure 12. Percentage change in total emission against the base year for alternative scenario of LCT plans under high and low population growth scenario in 2020

More accessibility means more people would be able to take part in activities, which increases travel demand. The increase in modal share of private vehicles, the need for people to interchange between routes due to delineation of primary and secondary routes, as well as the construction of additional few primary and secondary routes, would all contribute to the increase in emissions against the baseline in alternative scenario with the PT improvement plans shown in figure 13. But under the same circumstances, penetration of trolley bus system on primary routes as a zero emission vehicles and meeting 20% of ridership of large buses would halve the emissions. On the other hand the reduction in emissions against the baseline in the alternative scenario with the trolley bus renewal plan would be at the expense of lower accessibility. Since an increase in modal share for public transport was assumed to be compensated by subsequent decrease in two wheelers, there will be a reduction in emissions and the total emissions reduction gain can be seen in all the alternative scenarios with LCDT plans shown in figure 13, the highest during trolley bus renewal.

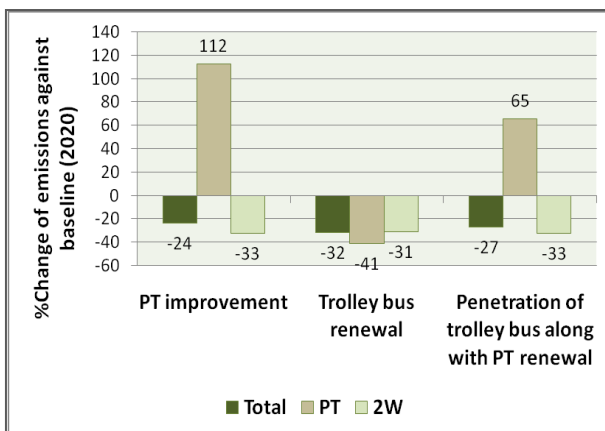


Figure 13. Percentage change of emissions against baseline in alternative scenarios with LCDT plans under both high and low population growth scenarios in 2020

7.3 Sensitivity analysis

The sensitivity analysis was performed varying the critical parameters in the model which were average speed and mode share. One of the effects of the LCDT plans would be on improvement in average speed of vehicles resulting into change in the accessibility of people. Thus, the analysis was done by lowering speed on primary routes from 40kph to 25kph in PT improvement plans since primary routes form large part of public vehicle routes. As shown in figure 14 within this limit in change in speed the LCDT plans would still result in higher accessibility against the baseline and there would still be reduction gain as depicted in figure 15.

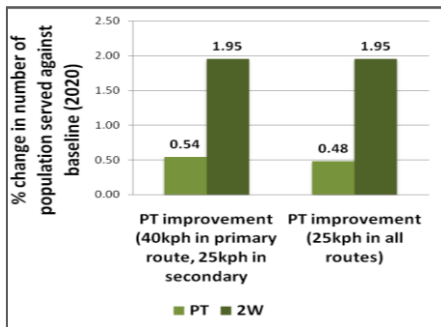


Figure 14. Percentage change in number of people served in 2020 against baseline with consideration of different speed for alternative scenario with PT improvement plans

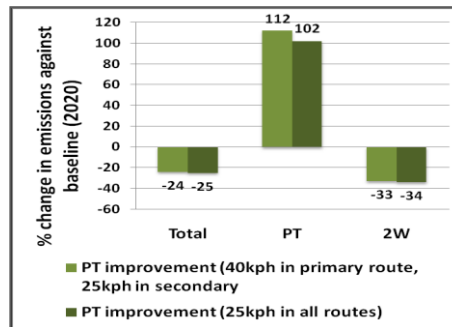


Figure 15. Percentage change in emission in 2020 against the baseline with consideration of different speed for alternative scenario with PT improvement plans

There are many factors that influence the choice of mode by individuals such as cost, travel time, security, convenience, comfort etc. Bajracharya (2010) shows that people in Kathmandu give first preference to reliability and punctuality secondly to comfort and least to the fare. So, if the new system is able to increase its attractiveness in terms of reliability, comfort, convenience at lower or the same cost as of the old system then there could be some modal shift. Ultimately, it depends on people's attitude and the degree of modal shift remains uncertain. Therefore, a sensitivity analysis was performed to see the performance of alternative scenarios with those LCDT plans under varying mode share. As shown in figure 16 with a 5% increase in the mode share of PT due to subsequent shift from the 2W, it would lead to an emission reduction gain against the baseline for the alternative scenario of penetration of trolley bus along with PT improvement plans even when there is only 5% share in ridership by trolley bus. But in the alternative scenario with PT improvement plans, only 5% shift from private would not be able to lead to emission reduction gains since PT would contribute to the emissions along with 2W.

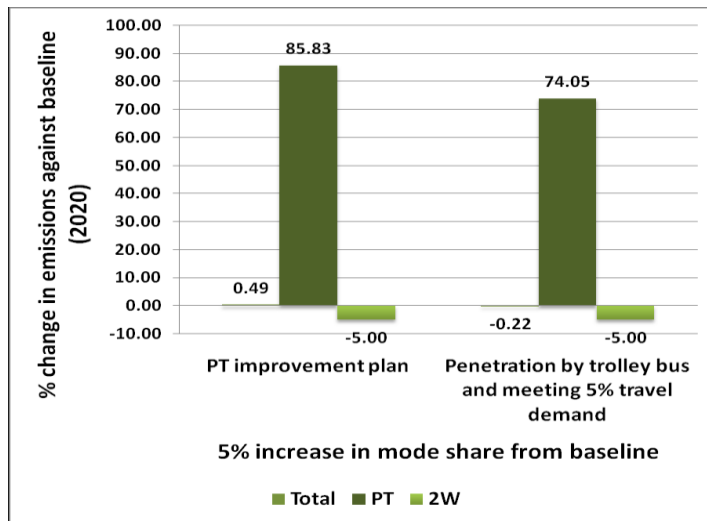


Figure 16. Percentage change in emissions in total and for each mode against the baseline with 5% increase in mode share for alternative scenarios of two LCT plans

8. CONCLUSION

Concerns pertaining to the need of developing countries to address both development policy and climate change have captured the attention of both policy makers and academicians. The concept of low carbon development (LCD) follows a development-first approach and aims to enhance development while minimizing carbon emissions.

The transport plans considered in the study include modal shift and energy efficiency. Defining accessibility as an enabler for widening human capability to reach to number of opportunities, we argue that to realise LCD for the city, LCDT plans should improve accessibility while at the same time minimize CO₂ emissions. Nevertheless, increase in accessibility means providing more opportunities to people to participate, which increase the travel demand and hence increase emissions. The result from scenario analysis of LCDT plans in figure 13 shows a decrease in CO₂ emissions against the baseline for all the three alternative plans considered in the study due to the subsequent decrease in mode share of 2W, with the trolley bus renewal alternative showing the highest amount of reduction in CO₂ emissions. However, the decrease in emissions with the trolley bus renewal plans will be at the expense of accessibility.

Thus, making low carbon modes appealing and user friendly through spatial organization and route reorganization would not be sufficient for minimizing emissions. Therefore, behavioural change and shift from private to public modes is necessary to realize substantial emissions reduction gain as depicted with the result of scenario analysis on LCDT plans and sensitivity analysis (figure 13 and figure 16 respectively). Ultimately, the final choice on mode depends on people's preferences, attitudes and behaviour. So, for realizing substantial shift, the package of policies that address 'push and pull' could be more effective for the case of KMC

The use of models in developing different energy consumption and CO₂ emissions scenario is increasing widely (Cai et al., 2007; Dhakal, 2003). However, the methodological development for evaluating the impact of LCDT plans and their contribution towards LCD of the city is scanty.

Moreover, the development of PSS integrating accessibility analysis and emission modelling, as a concrete tool in evaluating the LCDT plans for their impact on LCD of the city, is virtually not available. Addressing this research gap, this study has been able to develop such tool and demonstrated its application for KMC. Nonetheless, some limitations exist because of data constraints. The approach has been limited with demand side data on origin and destination of people in the city, mode choice of people, value given by people to land use and transport component, which will help to operationalize other measures of accessibility. Thus, for further research future PSS should incorporate a stated preference survey design to know people's attitudes on the current and future transport system.

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Development Feasibility of Distributed Photovoltaic Power System in Residential Area of Chinese Cities

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Key words: Distributed, Photovoltaic, Household electricity, Residential area, City, China, Feasibility, Urbanization,

Abstract: China has stepped into the accelerating phase of urbanization since the early 1980s, which has boosted the electricity consumption and CO₂ emission of the urban area. Most existing studies discussed related issues on national or regional scale from the perspective of the energy sector, but little research has focused on the scale of urban level and topics in urban development. This paper intends to utilize the approach of spatial analysis and spatial statistics to identify the potential and feasibility of Chinese cities in developing distributed photovoltaic power system (D-PVPS) for meeting household electricity demand. The result shows that most Chinese cities are feasible to develop the D-PVPS which can totally cover the present household electricity consumption in residential area, based on the estimation carried out in this paper. Some of the rest cities are also suitable to develop the D-PVPS in the visible future when photoelectric ratio enhances. Finally, policy implications and suggestions are raised to promote the much broader D-PVPS application in Chinese cities under the background of future urbanization.

1. INTRODUCTION

This work intends to discuss the implementation feasibility of distributed photovoltaic power system (D-PVPS) for meeting household electricity demand in 285 prefecture-level cities of China. Accordingly, urban household electricity consumption conditions and photovoltaic (PV) power potential of the studied cities are firstly analysed. Combined with the discussion about corresponding techniques, application paradigms and policies, in-depth analysis is taken to raise suggestions for promoting D-PVPS application of Chinese cities.

With 30 years' fast and stable development, China has become the second largest economy, meanwhile, it also becomes the largest primary energy consumer and contributes to the 20% of global greenhouse gas emission in 2009 (Liu, Geng et al., 2012), which undermines the sustainability of China's future development. As one of the influential factors, the accelerated urbanization process has contributed much to the sharp energy consumption increase of China in the past 30 years (Jiang and Lin, 2012; Liu, 2009; O'Neill, Ren et al., 2012; Dong and Yuan, 2011;

Zhang and Lin, 2012). In 2011, the urbanization ratio of China has firstly reached 51.3%, however, predicted by the UN (2012), the accelerating phase of Chinese future urbanization will generally finish around 2035-2045 (urbanization ratio reaches 70%). Consequently, in the future, the on-going urbanization process will continue to influence the structure and gross amount of energy supply and demand in Chinese urban area (Dai, Masui et al., 2012).

As the hotspot of Chinese future urban energy sector, household electricity consumption is the key (Baeumler, Ijjasz-Vasquez et al., 2012). Firstly, household electricity demand has already and will be continued to sharply increase, as mass population will further migrate and accumulate around urbanized area, which will pull up the gross amount of power demand (Liu, 2009; Yu, Pagani et al., 2012). In the second point, with the more comprehensive utilization of electronic appliances and the increasing living conditions, the average household electricity consumption level per capita will be enhanced (Dai et al., 2012; Murata, Kondou et al., 2008). From the other aspect, the present dominant position of urban gases and gasoline in urban household energy structure will be gradually replaced by electricity, under the trend of comprehensive application of electric vehicle, electrification in cooking and heating, and the exhaust of fossil fuels etc. in the future (Murata, Kondou et al., 2008; Pachauri and Jiang, 2008).

Another trend in Chinese energy sector is the rapid development of renewable energy, especially in solar power generation (Jackson, 2011; Zhang, Chang et al., 2012). In the last 10 years, Chinese cumulated PV power capacity has dramatically increased from 42MWp in 2002 to 3300MWp by the end of 2011 (Xu, Charlie et al., 2012), which can demonstrate the resolution of China in promoting renewable energy. But, at present, the newly installed PV capacity is mainly large scale photovoltaic power plants (LS-PV), while the D-PVPS is relatively underdeveloped compared with the Europe and Japan (Wissing and Jülich, 2012; Xu, Charlie et al., 2012; Yamada and Ikki, 2012). As the largest solar module producer and exporter, when facing the depression of global economy, spurring the demand of PV products inside domestic market is a potential approach to maintain and optimize the development of Chinese PV industry (Jäger-Waldau, 2012; Zhao, Zhang et al., 2011). The “Golden Sun Project” of China is exactly one of the initiatives since 2009.

Because of the advantages in less land occupation by utilizing rooftop, synchronicity between power load and generation during daytime, none grid-transmit loss etc., D-PVPS is more suitable to develop in urban area, which could be comprehensively utilized by hospitals, universities, shopping mall, office building and residential area. (Eltawil and Zhao, 2010; Parida, Iniyani et al., 2011) Besides, the development of smart grid and electric vehicle will also promote the development of D-PVPS in the future (Asmus, 2010; Thornton and Monroy, 2011). As a developing country, the urban infrastructure of China is incomplete. Developing D-PVPS as part of the next generation urban infrastructure is also an important consideration during Chinese future urbanization (Bobker, 2006), which could help to wisely utilize the fiscal investment of Chinese local governments and avoid repeating construction of infrastructure.

From the above background, it can be identified that China is suffering from energy issues, but the more intractable challenges from the aspect of urban household energy sector will become apparent, if China would successfully cut down energy density by increasing efficiencies in industrial sectors. Especially, for urban household electricity issues, China has to not

only cope with the current and emergent difficulties, but make strategic plan and investment in the long run towards the potential opportunities and challenges during its future urbanization. Accordingly, the study on the feasibility of distributed and renewable power system in Chinese cities is of great importance. However, the systematic studies on this topic is limited, and the existing related studies are not from the perspective of urbanization or urban planning either.

In China, residential area is a type of land use where housing is dominated. As the price of household electricity is much lower than commercial and industrial use among Chinese cities, residential area has relatively less positivity to invest and develop the D-PVPS. Besides, in China, most urban residential areas are collective apartments, where the rooftop is shared among multiple households. In consequence, it is more difficult to initiate D-PVPS in residential area compared with commercial and industrial land use, as it needs efforts to reach a consensus among stakeholders. Accordingly, to promote D-PVPS in the residential area of Chinese cities, local governments should be the sponsors, financiers, coordinators and sometimes direct investors, and more attractive policies and fiscal subsidies should be introduced as well.

However, for local city governments, whether it is feasible to develop residential D-PVPS needs systematic analysis about their local conditions and potential benefits. Specifically, based on the collected data, this paper intends to focus on the discussion of these conditions and benefits, and try to raise suggestions for the local governments of the study cities.

The remainder of this paper is organized as follows. In the next section, we introduce the methodology and study cities. Respectively, Section 3 and 4 discuss household electricity consumption and solar power potential of the study cities. Section 5 will discuss the feasibility of developing residential D-PVPS of the study cities in detail. The paper ends with a brief conclusion of our study and practical suggestions for decision makers.

2. METHODOLOGY AND STUDY CITIES

2.1 Methodology

Developing D-PVPS is a strategic investment for Chinese urbanization and low-carbon development in the future, which has fundamental social meanings in the long run. At present, the levelized generation cost of solar power is much higher than the power generated from the source of fuels, hydropower or even wind. Besides, the cost of D-PVPS is higher than LS-PV as well. Most pioneering countries in D-PVPS, including Germany, Spain, Japan and the US etc., have propelled high subsidies of feed-in tariff to encourage the accumulation of social capital towards the sector of D-PVPS, because of the high return rate of the investment. Comparatively, Chinese present D-PVPS subsidy is initial installation oriented, but the related governmental departments are regulating new policies to extend the development of feed-in tariff subsidy in D-PVPS. In the other aspect, with the development of technologies in PV industry, the future cost of D-PVPS will be significantly diminished, which will appeal more investors and further boost the development of D-PVPS.

Even at present conditions, with the subsidies from Chinese central government, developing D-PVPS in most Chinese cities is already cost-

effective or even profitable. In this regard, the D-PVPS investment and maintaining cost will be gradually reclaimed by the electricity generated in the first 20-25 years of its life-cycle, as the solar panel efficiency will drop dramatically afterwards. Therefore, most Chinese cities are already feasible for developing D-PVPS economically. However, the judgement whether a city is suitable to extensively promote residential D-PVPS inside its municipal territory from the perspectives of renewable energy and infrastructure is also needed. In this study, the cities where the potential PV power generated through D-PVPS meet the urban household electricity consumption are identified as the suitable cities to develop the D-PVPS. Accordingly, issues about household power conditions, solar power potential, residential rooftop area needed and suitable point-in-time to develop the D-PVPS of the study cities are analysed by following the below steps (Figure.1).

Firstly, this paper intends to compare and analyse household electricity consumption conditions of the study cities, and specifically both gross amount and consumption level per capita are calculated. Further, spatial statistics method (Getis-Ord G_i^*) is utilized to analyse the spatial patterns of the cities in terms of household electricity consumption. In the second step, the potential of photovoltaic power generation of each city is estimated based on the “annual average solar irradiance estimation data”. On the basis of the former two steps, this paper intend to analyse feasibility of the study cities in developing D-PVPS, and, based on the analysis, related suggestions are raised to decision makers for making a smart strategic arrangement in residential D-PVPS application.

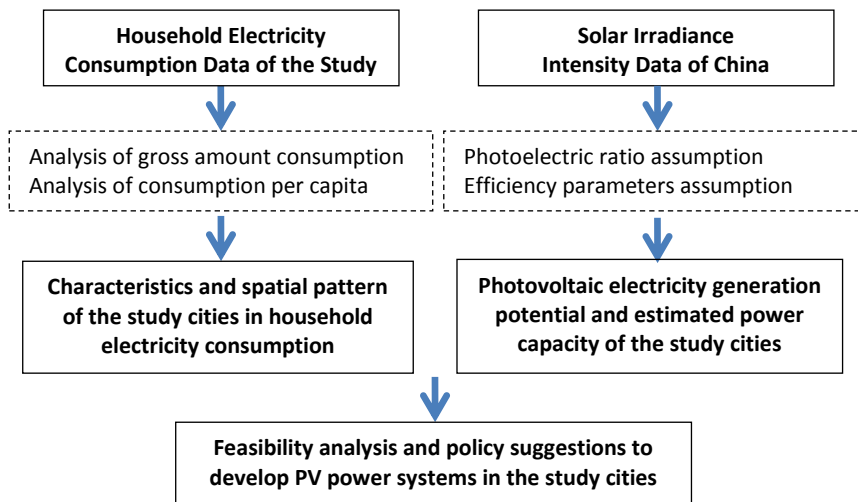


Figure 1. Framework and main procedures of this study

Specifically, suitability of the cities to develop the D-PVPS is firstly identified by making a balance calculation between household electricity consumption and potential solar power generated per unit of residential area, which considers the potential available rooftop area that can be installed with PV panels inside the residential area. Further, the suitable point-in-time to develop the D-PVPS for the study cities are discussed as well, which is based on the discussion about the development of future photoelectric transferring ratio in the visible future and in the relatively longer future as well.

2.2 Study cities

This study is carried out by analysing 285 prefecture level cities of China (Figure.2). Most Chinese prefecture level cities are distributed in the east and the middle region of China, which covers almost half territory of the country (for lacking of data, cities in Taiwan province, Hong Kong SAR and Macao SAR are not included). These prefecture level cities will be responsible for accommodating the newly immigrated urban population from the rural area during Chinese future urbanization process.

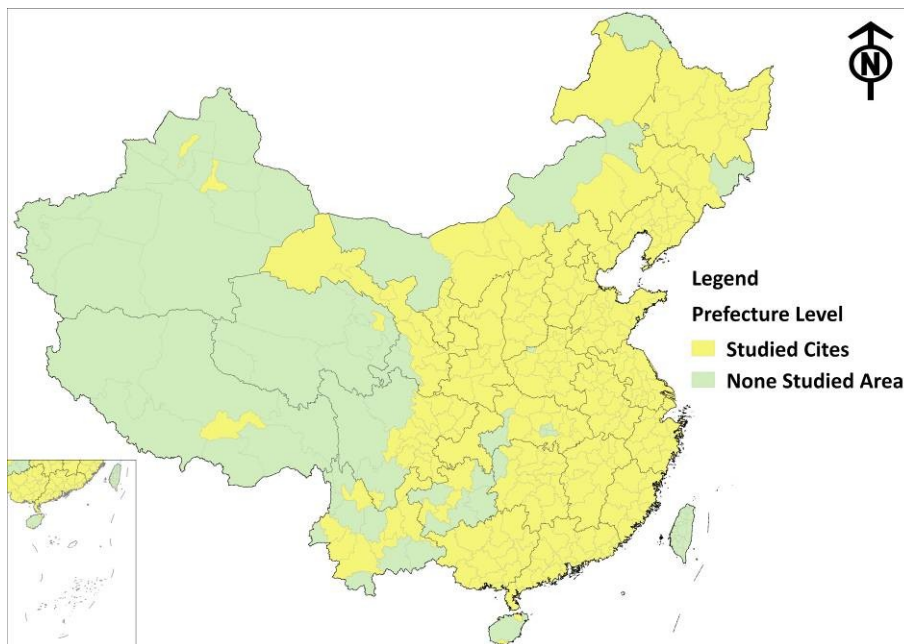


Figure 2. Spatial distribution of the studies cities

3. HOUSEHOD ELECTRICITY CONSUMPTION

3.1 Gross amount of household electricity consumption

Based on the data of “China city statistical yearbook 2011 (Data in 2010)”, it can be identified that the variance of annual urban household electricity consumption among Chinese cities is significant. For the top two largest household electricity consumption cities, the total amount is 5000 times larger than the smallest household electricity consumer of Chinese cities. Figure.3 shows the spatial distribution of different cities in annual total urban household electricity consumption. In general, the cities located in the eastern part of China consume more household electricity compared with the western and central part of the country.

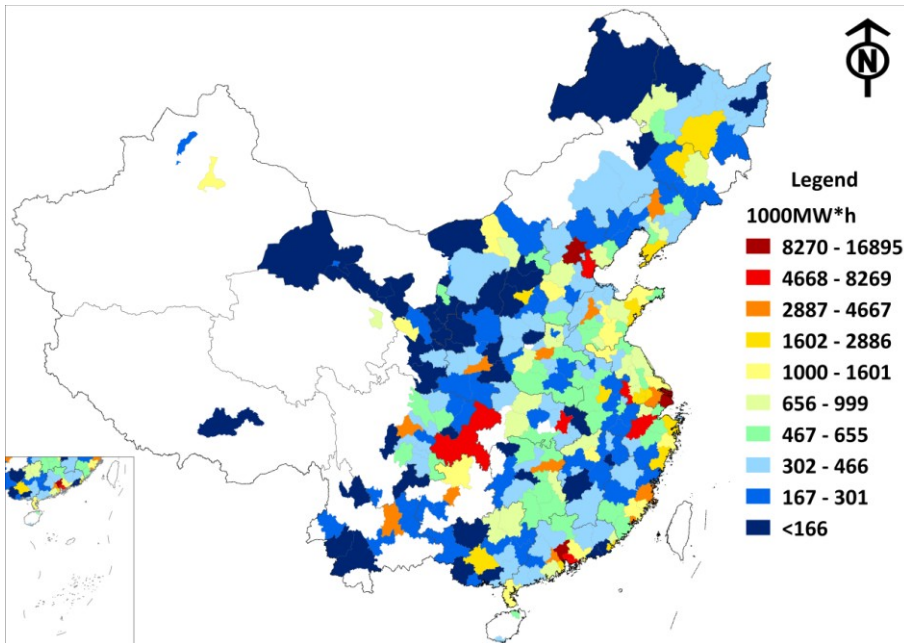


Figure 3. Annual urban household electricity consumption of the study cities

Further, this paper also analysed the local autocorrelationship through the Getis-Ordi G^* statistical analysis, which is used to identify statistically significant spatial clusters of high values (hot spots) and low values (cold spots). The hot spots in this analysis means the cities and its surrounding neighbour cities (within a radius of 300km) have the gross amount of household electricity consumption that is significantly higher than the average level of all the study cities, while the cold spots means the cities and its neighbours have relatively lower value compared with the global average (Prasannakumar, Vijith et al., 2011). From the analysis, the hot spots Jing-Jin-Ji , Pearl River delta, Yangtze River Delta are obvious, and the clusters are significant at a confidence level of 99%, while there are no cold spots identified during this analysis (Figure.4).

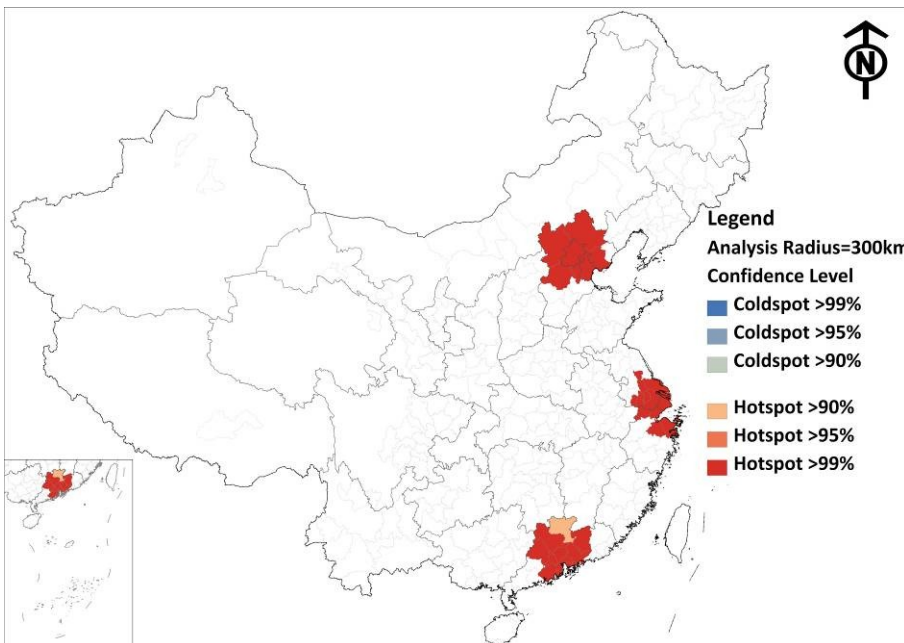


Figure 4. Hot and cold spots analysis of study cities in household electricity consumption

3.2 Household electricity consumption per capita

In another aspect, the value of annual household electricity consumption per capita is also analysed, and the result is shown as follows. Most cities have a relatively lower household electricity consumption density, which is under the amount of 500kw*h per capita, while the value of some other cities are over 1000kw*h per capita (Figure.5).

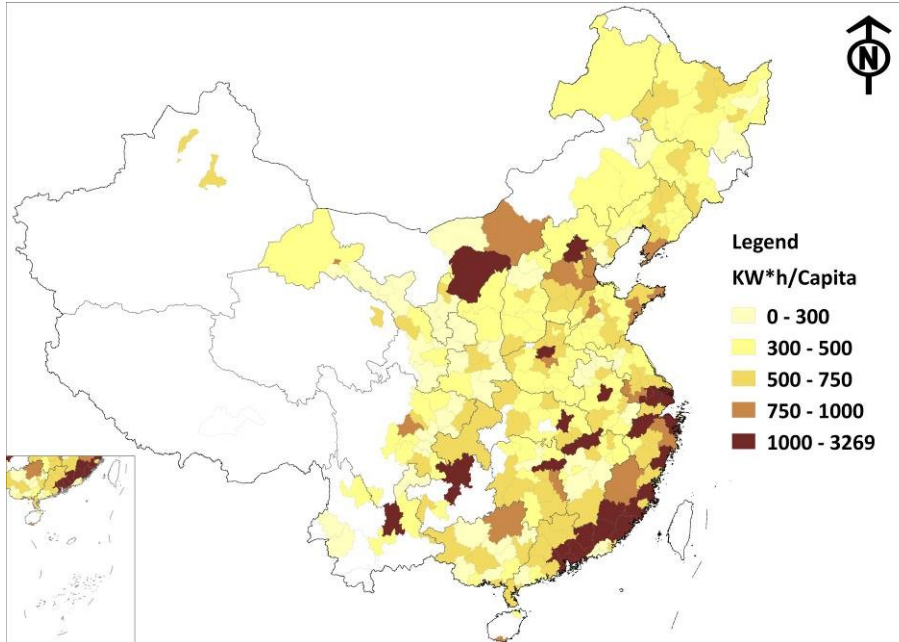


Figure 5. Annul household electricity consumption per capita of the study cities

Similarly, the spatial pattern of household electricity consumption per capita of Chinese cities is also highly clustered. The hot spot is concentrated along southeast coastal area, including part of Jiangshu, Shanghai, Zhejiang, Fujian and Guangdong provinces, while the cold spot is around western region, including part of Gansu, Ningxia, Shanxi and Sichuan Provinces (Figure.6).

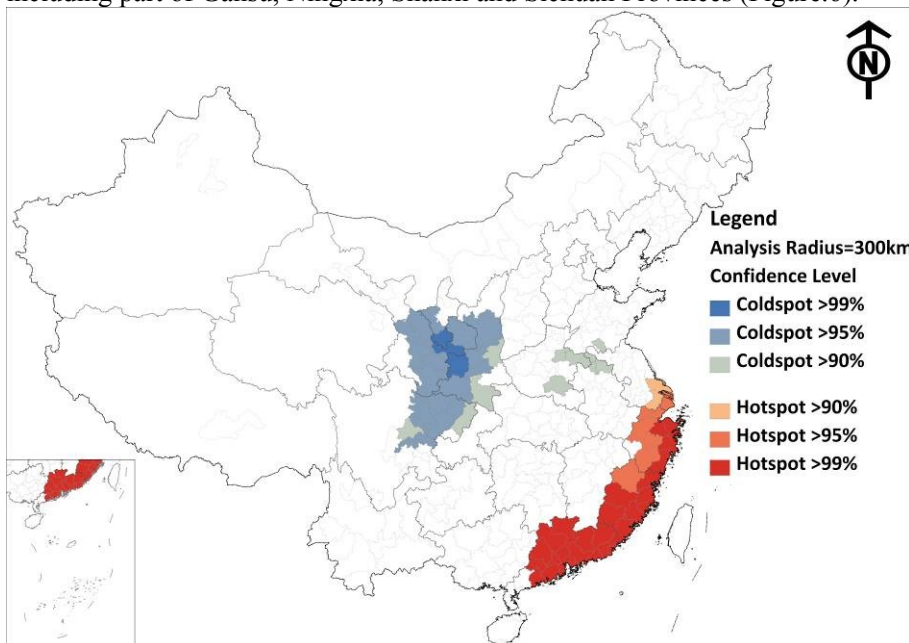


Figure 6. Hot and cold spot analysis of household electricity consumption per capita

4. SOLAR POWER CAPACITY ESTIMATION

From the above analysis, it can be concluded that the quantitative variance of annual urban household electricity consumption among study cities is extremely obvious, which indicates the huge gap in city size, economic development etc. of Chinese cities. The spatial cluster pattern analysis further supports this perspective.

Comparatively, the variance of annual urban household electricity consumption per capita is small, and the spatial cluster pattern of this aspect is potentially correlated with both economic development and climate conditions of the study cities.

Accordingly, the spatial distribution pattern of urban household electricity consumption of the study cities is more related to economic conditions. However, the solar power capacity of the study cities is more connected to natural factors. The following sub-sections will discuss this topic in details.

4.1 Data

One of the most determinative factors to judge the feasibility of photovoltaic system application is the solar irradiance that arrives at the earth's surface. In this paper, "annual average solar irradiance estimation dataset" in the national database of "Data Sharing Infrastructure of Earth System Science, China (DSIESS)" is utilized to evaluate the PV power potential of the study cities.

This dataset is processed and interpolated based on the solar irradiance observational time-series data from 1950-1980 from almost 600 weather stations distributed nationally. Estimation approach is based on the multiple stepwise regression method raised by [Tian, Zhu et al. \(2005\)](#) and [Zhu, Tian et al. \(2005\)](#), which considered 6 primary influencing parameters, and that is:

- X₁— annual sunshine duration (0.1 hour),
- X₂— percentage of possible sunshine (%),
- X₃— annual average cloud cover (%),
- X₄— absolute humidity (100Pa),
- X₅— elevation (0.1m),
- X₆— altitude (degree).

Consequently, the regression equation is as follows:

$$Q=170292+20.73189*x_1-0.19171*x_1*x_6+0.07212*x_5*x_6, (1)$$

With the equation above, the estimated spatial data is shown in Figure.7. Nationally, the western part and middle part of China are inherited with higher solar energy, while northeast, southwest and east part of the country has lower irradiance potential comparatively.

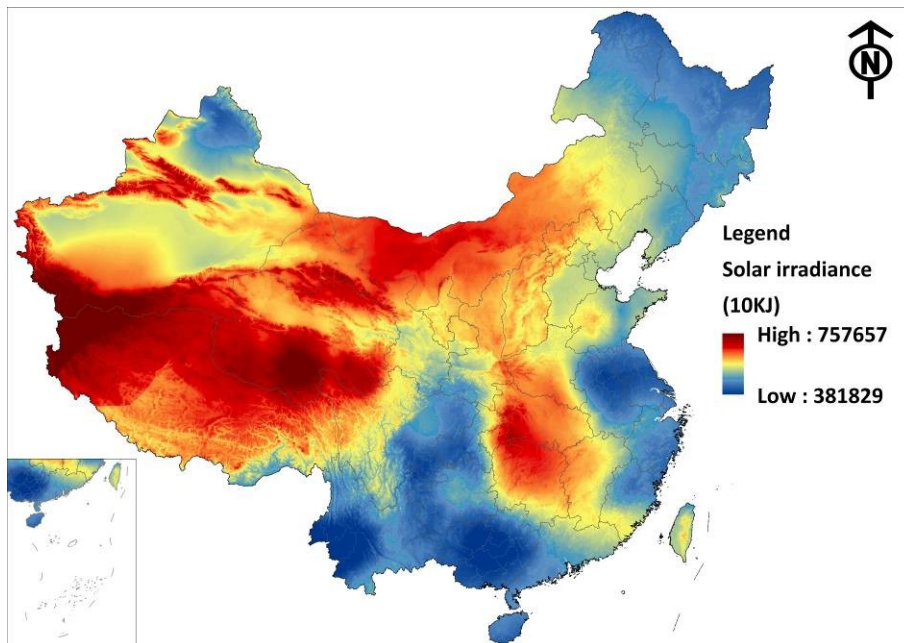


Figure 7. Solar irradiance spatial distribution of China

4.2 Solar power potential calculation of the study cities

Except for the dominant influencing factor---solar energy irradiance, the exact amount of the harvested electricity at the end-use point could be various depending on the specific PV system applied, the efficiency of solar cell, auxiliary techniques, management schemas and other related climate parameters etc.

(1) Solar cell efficiency

At present, the dominant and commercialized products are mono-crystalline and poly-crystalline silicon solar cell in the market. The average transferring ratio of solar panels from solar energy to electricity is between 10-18%, which is predicted to be improved to approximately 30% and with lower cost in the visible future (El Chaar, Lamont et al., 2011). Considering Chinese current condition and to make a more founded and conservative estimation, the transferring ratio is chosen at 10% in this paper for most analysis.

(2) PV system

Except for the efficiency during photoelectric conversion, another main character that will significantly influence the electricity output is the type of PV system, as the specific system components and system design will determine the efficiency and energy loss during the process of energy type transferring and power transmit.

The most two typical systems at present are stand-alone system and grid connected system, while retrofits based on the above two paradigms are various. Based on related study and monitoring of practical projects, the general efficiency of the above two systems is around 65%-85% (Drif, Pérez et al., 2007; Rehman and El-Amin, 2012)

(3) Management Schemas and ambient conditions

Even it is less important, The management manner of PV system such as depth of battery discharge, automatic adjustment of PV panel tilt angle and orientation, and ambient conditions of the PV module such as temperature, dust and dirt on the panel, air humidity etc., will influence the performance of solar panel not to be working at the peak watt.

(4) Equation to estimate the potential power generation capacity

Accordingly, to cast relatively a more applicable analysis and based on the consideration of the above aspects, more conservative calculation is employed in this paper, and based on the related studies (Meral and Dinçer, 2011; Vardimon, 2011), the employed equation in this paper is as follows.

$$\text{Capacity}_{\text{Solar Power}} = \text{Capacity}_{\text{Solar Irradiance}} * \eta_1 * \eta_2 * \eta_3 * \eta_4, (2)$$

$\text{Capacity}_{\text{Solar Power}}$ — solar electricity generation capacity of each study city

$\text{Capacity}_{\text{Solar Irradiance}}$ —average annual solar irradiance in each study city

η_1 —efficiency of the PV module (depends on type of cell, connection manner of the panel, loss during power transmitting etc.)

η_2 —type of PV system (depends on the efficiency of charge controller, inverter, battery, loss during power transmitting etc.)

η_3 —ambient conditions (temperature of the solar panel, dust or dirt on the panel, air humidity and wind speed etc.)

η_4 — other factorings influencing total efficiency

Based on the equation above, the annual average solar power generation capacity per square meter in the study cities is calculated and the result is illustrated in Figure.8. In the calculation, the photoelectric ratio $\eta_1=10\%$ is taken, which is relatively low value, while the sum of $\eta_2 * \eta_3 * \eta_4$ is fixed at 50%, which is also a conservative parametric value (Leloux, Narvarte et al., 2012; Meral et al., 2011).

From the result, it can be summarized that the solar power capacity of Chines cities is generally between 60-90 kw*h/(a*m²). The cities that have high solar power generation capacity potential are mostly distributed in the provinces that located in the western and middle part of China, such as Gansu, Inner Mongolia, Henan, Hubei, Hunan etc., while the cities with less capacity of solar power generation are mostly located in the northeastern, southwestern and eastern coastal part of China.

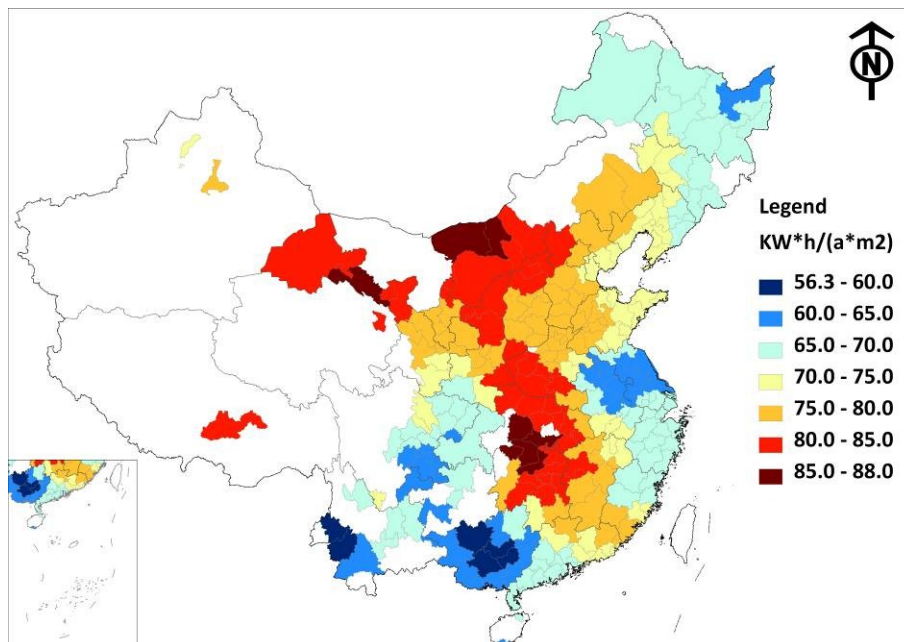


Figure 8. Estimation of annual average solar power capacity of the study cities

5. FEASIBILITY ANALYSIS

5.1 Suitability to develop the D-PVPS

Distributed PV power supply system is the most suitable and feasible solar power application approach for urban area at present and in the visible future. Especially, Building attached PV (BAPV) and Building integrated PV (BIPV) systems have already been comprehensively applied, which can utilize the roofs or facades of the building to arrange solar modules.

The main purpose of this paper is to analyse the suitability to development D-PVPS of the study cities by discussing the roof area needed to arrange PV modules in the residential area. For residential land use in China, the average roof area or building density is around 30% of the whole residential area, based on the “Code of urban Residential Areas Planning & Design GB 50180-93, revised 2002”, which mainly considers natural lighting of each household in the winter.

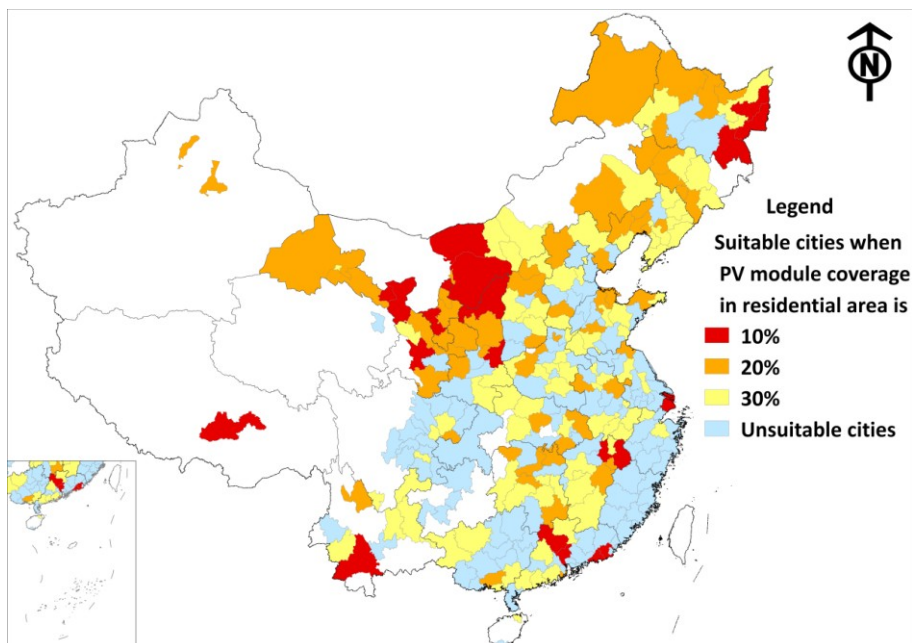


Figure 9. Suitable cities when PV module covers a certain area of rooftop in residential areas

As the amount of electricity consumption per residential area is fixed, the suitability can be estimated by calculating how much roof area is needed to meet the power consumption demand in residential areas. In this paper, we assumed three levels to compare, and that is 10%, 20% and 30% of the urban residential area, and the suitability estimation result is as shown in Figure.9.

From the result, we can judge that nearly half of the study cities are not suitable to develop the D-PVPS, while the other cities can make a balance between household power consumption and PV power supply in the residential area.

For the different percentage of roof area needed, the related energy policies and governmental promotion activity should be different. For those cities that only need 10% of the residential area’s surface to install PV module, it is encouraged to develop stand-alone PV system, which will take residential area as the basic unit to modify the local community-level grid and establish power storage systems, as these cities have relatively more

stable and sufficient power supply. Besides, the financial support from the government should be subsidy for the cost of PV system installation.

In the other aspect, for the cities need more roof area to arrange PV modules to meet the demand of household power consumption, it is more feasible and cost-effective to restructure the whole city grid or regional grid to support and meet the technical requirement of grid connect PV system from specific buildings. Besides, financially, the government should develop the concept of smart grid and offer attractive on-grid tariff to encourage people to build grid connect PV system.

5.2 Point-in-time to develop the D-PVPS

Considering the photoelectric transferring ratio change in the future, the suitability of the study cities to develop the D-PVPS will also change with the development of techniques, and that means, for some cities, the cost-effective time to dominantly promote PV system will be different. Therefore, if assume the area to install the PV module is fixed (10% coverage of the residential area), common and commercialized photoelectric transferring ratio will change to 20%, 30% sooner (El Chaar et al., 2011), or even reaches 40%, 50% in the future, which has been approximately achieved under the laboratory conditions (Green, Emery et al., 2012; Razykov, Ferekides et al., 2011). Accordingly, the suitability calculation based on the future photoelectric ratio development is as follows (Figure.10).

Two thirds of the study cities will be suitable to develop the D-PVPS when the photoelectric ratio reaches 30%, which are mainly located in the northeast, western and central part of the country, and this can be achieved in the visible future. If the photoelectric ratio can reach 40-50% when the existing laboratory techniques are commercialized with lower cost in the long future, most of the cities will be feasible to develop the D-PVPS. However, this is relatively unpredictable at present.

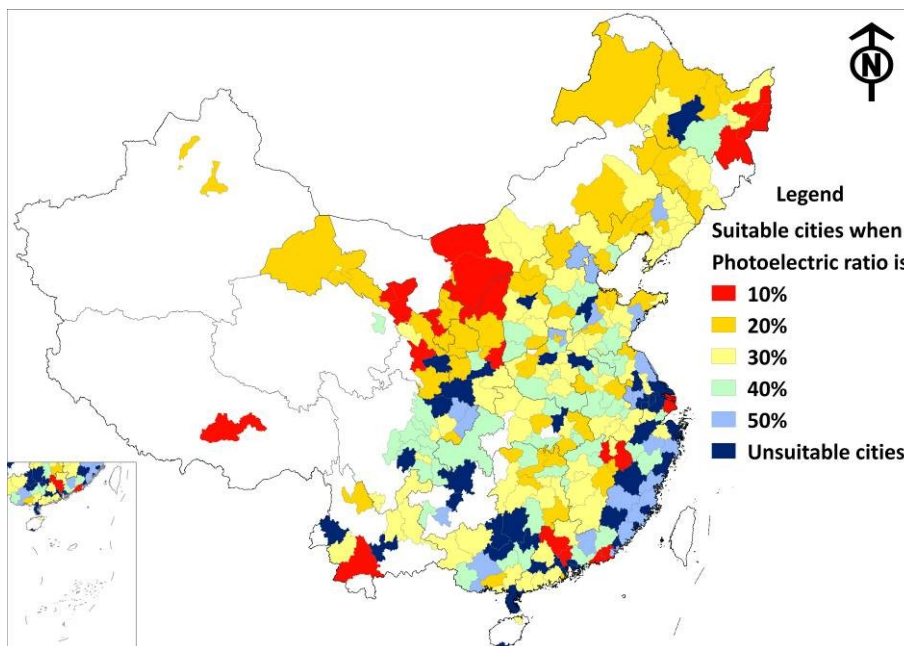


Figure 10. Suitable cities when photoelectric ratio of solar module increases in the future.

6. CONCLUSION AND POLICY IMPLICATION

Compared with the most existing studies, the contribution of this paper is to study the urban PV power issues at a more detailed spatial scale and from the perspective of urban studies. However, for the future development of Chinese residential D-PVPS, there are still more preparations to be finished. Especially, there are 4 important aspects, and that is the modification of regional and city-level grid to facilitate the development of on-grid D-PVPS, encouraging on-grid tariff subsidies to absorb more investment from multiple social and private sectors, experiment of advanced techniques and pilot projects exhibition to offer technical experience, electrification in urban energy structure to optimize household electricity portfolio etc. .

For the future studies, there are still many aspects to be improved. Firstly, in this study, the balance calculation of household electricity consumption and potential solar power generated is based on the current condition of study cities. In the future, studies should consider the future increment of household electricity demand, therefore the study will be more applicable to the reality. Secondly, the estimation of the present study has considered the city as a unified space, which means the residential area in the specific study city has a similar floor area ratio or building density. But in reality, the urban form and inner spatial pattern of study cities are various. Therefore, to enhance the accuracy of the estimation in the future, the compactness of the city and the general residential area pattern should be considered etc.

Furthermore, because most of the study cities are suitable to develop the D-PVPS in the visible future, it is necessary to conduct cost-effective evaluation to the study cities based on the household electricity consumption and the utilization of the D-PVPS by discussing spatial characteristics of urban form. Thus spatial-temporal approach regarding the cost-effective analysis is helpful to consider the development scheme of the D-PVPS in urban areas. Besides, there is still improvability in photoelectric ratio for present solar modules that will have substantial influences on the development of D-PVPS in those cities.

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