Modelling Shopping Transport Energy Performance to Explore Low Carbon Potentials

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Introduction

Shopping activity is an important part of human life and a crucial component in urban planning, with its property, location and scale having a large impact on travel patterns. Owing to the randomness of shopping performance and the limit to detailed shopping travel survey data, it is difficult to precisely grasp the nature of human behavior in shopping activities. Furthermore the transport energy consumption must be controlled to mitigate the impacts of Climate Change. Besides the progress in technology innovation, the human adaptive capacity plays a significant role in reducing transport energy use.

This paper presents a probabilistic model that can be used to estimate shopping transport energy consumption in the absence of empirical data and analyse the potentials of reducing shopping trips by car. Based on the combination of Huff model and Gravity model, some new metrics were developed to quantify the shopping activities. The property of shopping facilities, spatial distribution, travel distance, travel patterns are the key part of model to determine how much transport energy is consumed. By synthesizing a situation in which all travellers could choose viable travel mode to minimize transport energy use, hence the ratio of original shopping values with possible zero transport energy consumption was proposed as a measure to quantify the adaptive capacity to energy constraints. With the assistance of GIS system, an international comparison between the two cities in New Zealand and China was conducted using this model to investigate the differences and relevant factors that can affect transport energy use.

Terms and definitions

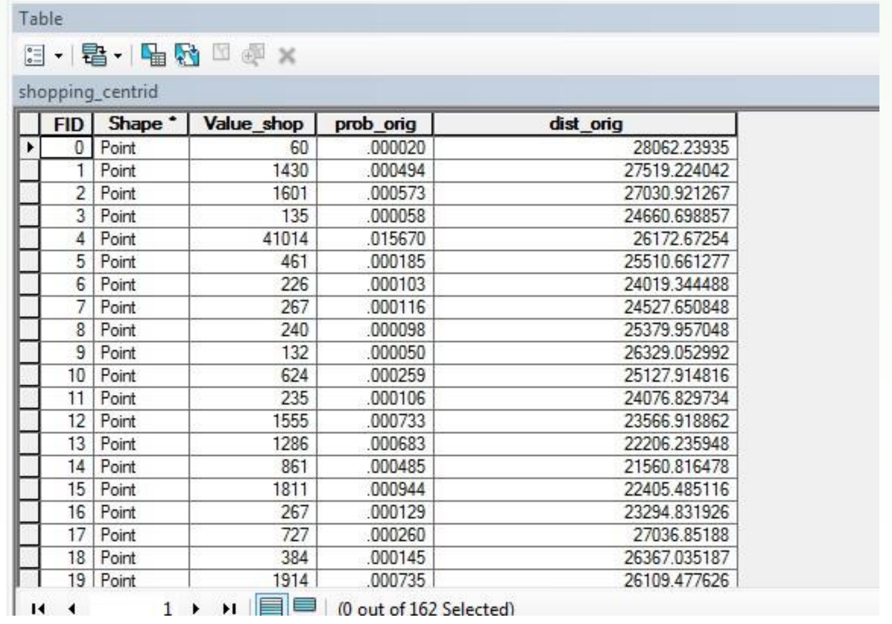
1. **Essentiality classification for shopping**
   - Essential goods(food, drink) value=3 Highly frequent
   - Necessary goods(clothes, household appliance) value=2 Moderately frequent
   - Optional goods(jewel, flower) value=1 Least frequent
2. **Huff Model + Gravity Model**
   - Scale A (m^2)
   - Attractiveness(essentiality) At (1,2,3)
   - Trip momentum $W_{ij}=(A \times At)/d_{ij}^2$
   - Trip probability $P_{ij} = W_{ij}/\sum W_{ij}$
3. **Shopping value**

   A measurement to quantify the level of shopping prosperity in a region

   $$(SV)_i = \sum_{j=1}^{n} (A_j \boldsymbol{At}_j)$$
4. **Local weighted shopping activity value**

   The overall shopping activities people living in a region can access within a city

   $$LSV_i = \sum_{j=1}^{n} (f_{shopping} \times SV_j \times p_{ij})$$



Table

shopping_centrid

FID	Shape *	Value_shop	prob_orig	dist_orig
0	Point	60	.000020	28062.23935
1	Point	1430	.000494	27519.224042
2	Point	1601	.000573	27030.921267
3	Point	135	.000058	24660.698857
4	Point	41014	.015670	26172.67254
5	Point	461	.000185	25510.661277
6	Point	226	.000103	24019.344488
7	Point	267	.000116	24527.650848
8	Point	240	.000098	25379.957048
9	Point	132	.000050	26329.052992
10	Point	624	.000259	25127.914816
11	Point	235	.000106	24076.829734
12	Point	1555	.000733	23566.918862
13	Point	1286	.000683	22206.235948
14	Point	861	.000485	21560.816478
15	Point	1811	.000944	22405.485116
16	Point	267	.000129	23294.831926
17	Point	727	.000260	27036.85188
18	Point	384	.000145	26367.035187
19	Point	1914	.000735	26109.477626

(0 out of 162 Selected)

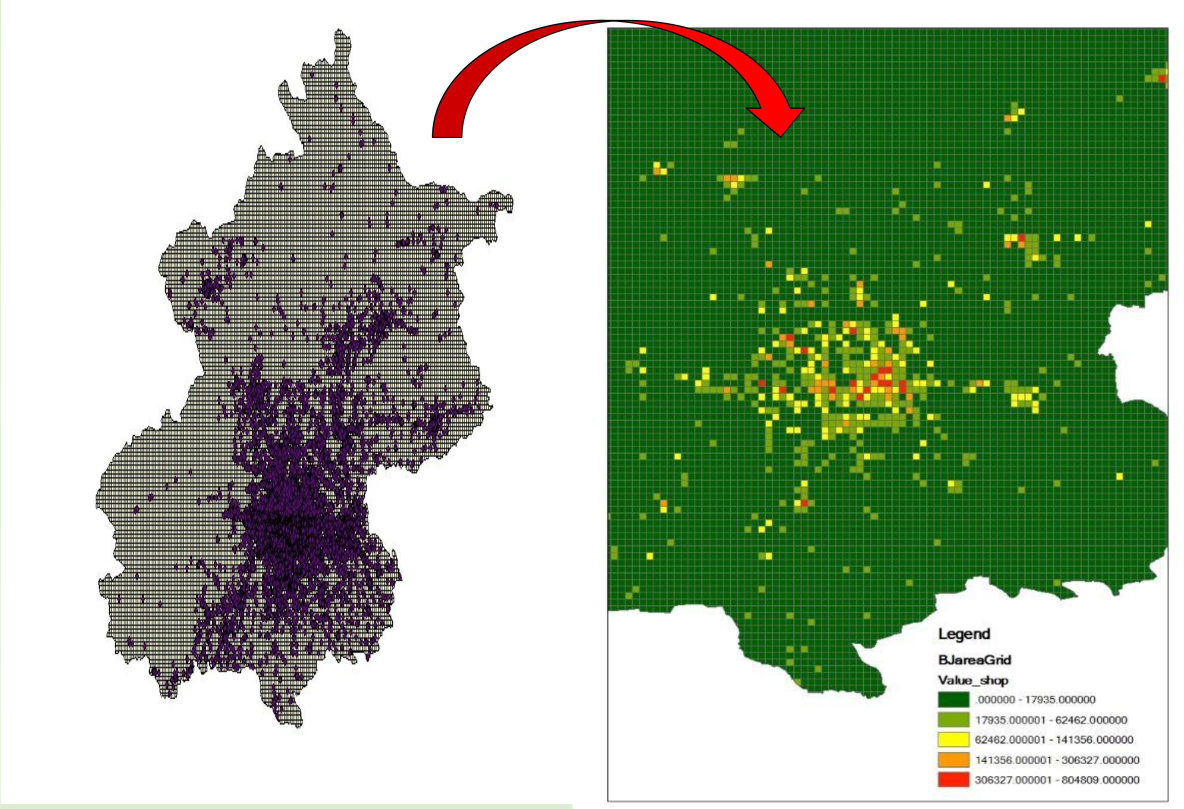
A screenshot of one origin's shopping trip matrix

Methods

1. **Spatial analysis for shopping facilities**

   1.1 Mesh grid simplification for study area (1km×1km square with a centroid)

   1.2 Classification and quantification for shopping facilities



2. Transport energy calculation

2.1 Shopping travel patterns

Trip Mode Split for Shopping (%)	Distance Bins(km)					
	d1(0-1)	d2(1-2)	d3(2-3)	d4(3-5)	d5(5-10)	d6(>10)
Walk	90	40	10	0	0	0
Cycle	5	18	20	16	3	0
Bus	3	5	10	10	15	15
Car	2	47	60	74	82	85
Subway	0	0	0	0	0	0

Distance-based trip mode split in Christchurch, New Zealand (Source: MOT,2015)

Trip Mode Split for Shopping (%)	Distance Bins(km)					
	d1(0-1)	d2(1-2)	d3(2-3)	d4(3-5)	d5(5-10)	d6(>10)
Walk	89	40	4	0	0	0
Cycle	10	26	30	20	10	0
Bus	0.4	10	30	35	32	35
Car	0.6	10	20	25	35	40
Subway	0	14	16	20	23	25

Distance-based trip mode split in Beijing, China (source: Guo,2010)

2.2 Shopping activities simulation

❖ **Study area input:**
- Population
- Origin i
- Destination j
- Transport network (travel distance as impedance)

❖ **Constant input:**
- Model energy intensity: em_{mode}
- Shopping trip frequency: $f_{shopping}$
- Travel mode split: T_d

2.3 Transport Energy calculation

$$E_i^m = \sum_{j=1}^{n} (d_{ij}^m \times em_{mode} \times f_{shopping} \times T_d \times p_{ij})$$

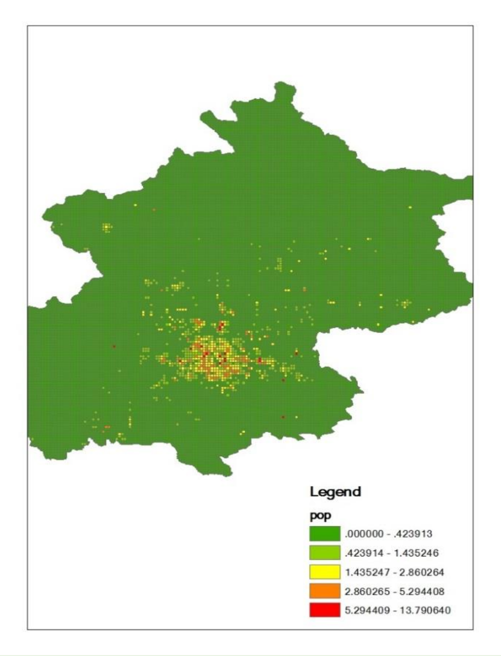
$$\bar{E} = \sum_{i=1}^{n} (E_i^m) \text{ /population}$$

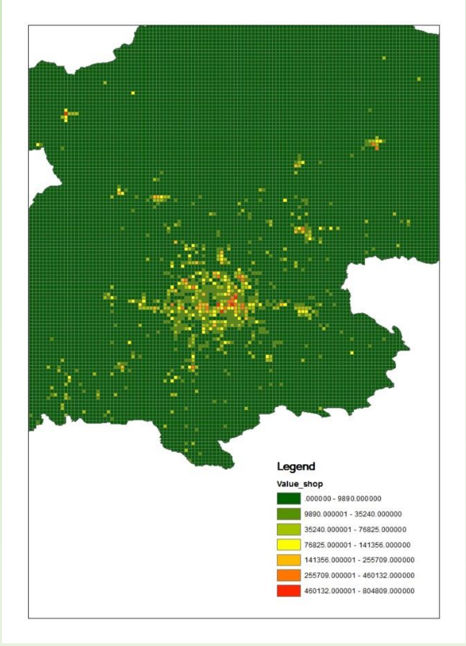
2.4 Adaptive capacity analysis

Recalculate the local weighted shopping activity value of each cell assuming all the car trips within 5km are replaced with walk mode(<=1km) and cycling mode(<=3km or 5km) to see how much shopping value could be accessible with 0 transport energy use.

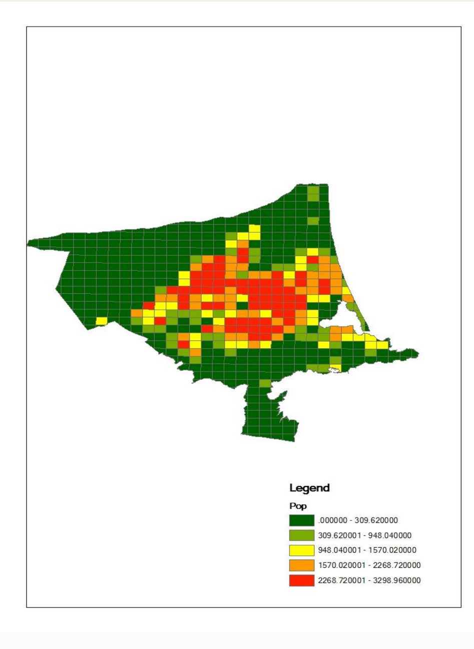
Results

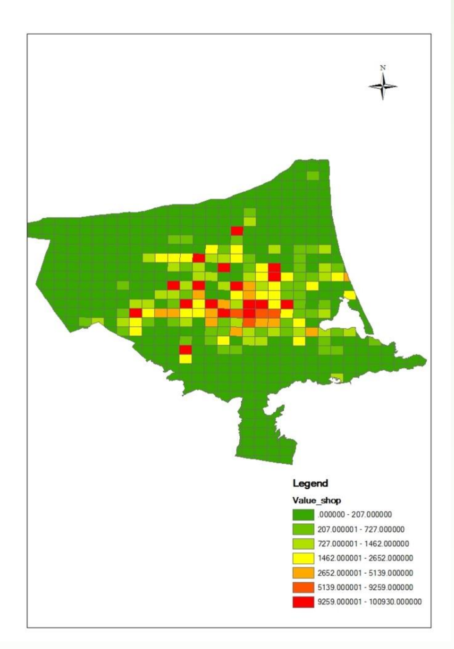
A representative of high density development: Beijing


Population density distribution in Beijing
(Unit: 10,000person/km²)

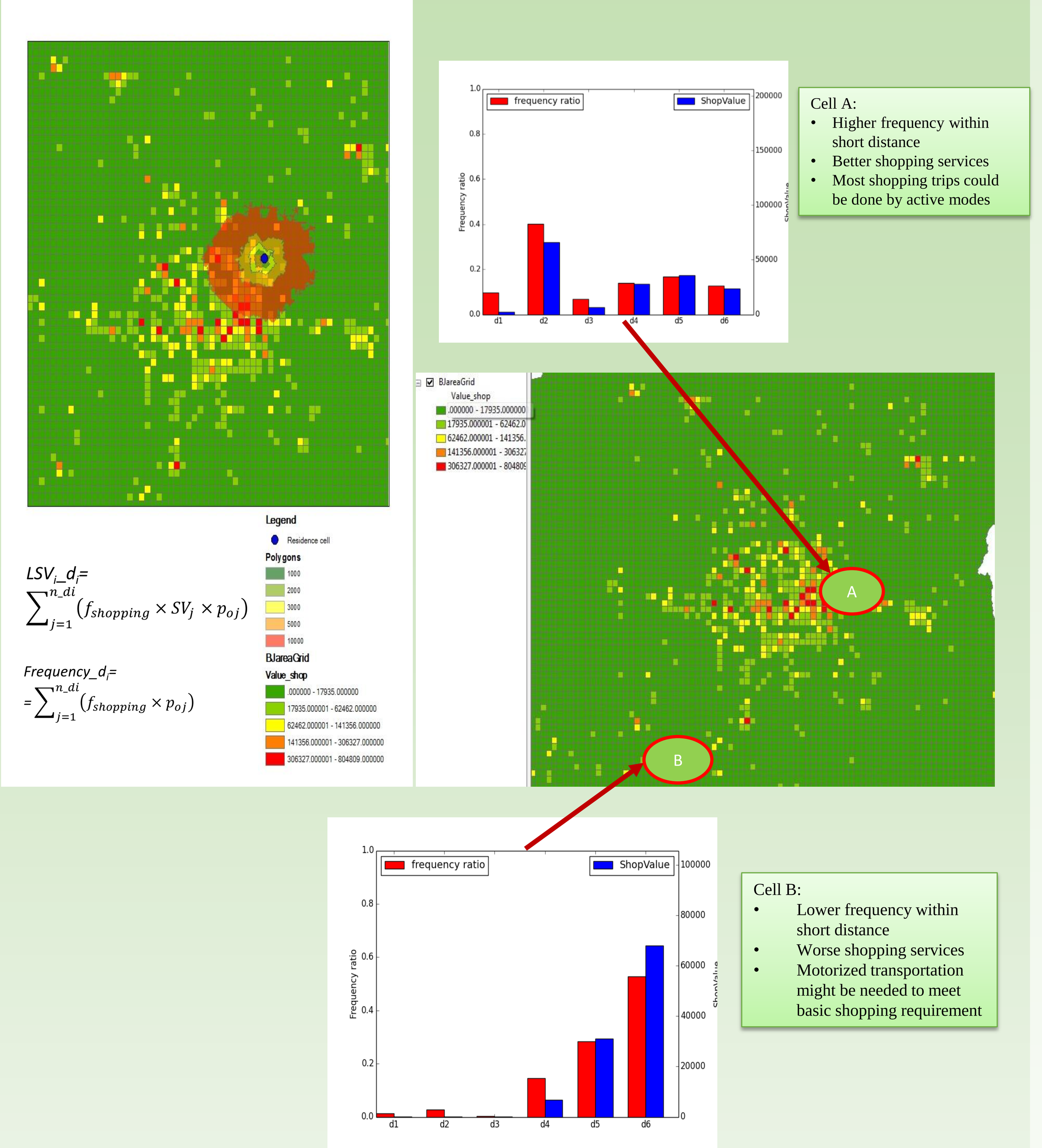

Shopping value distribution in Beijing

A representative of low density development: Christchurch

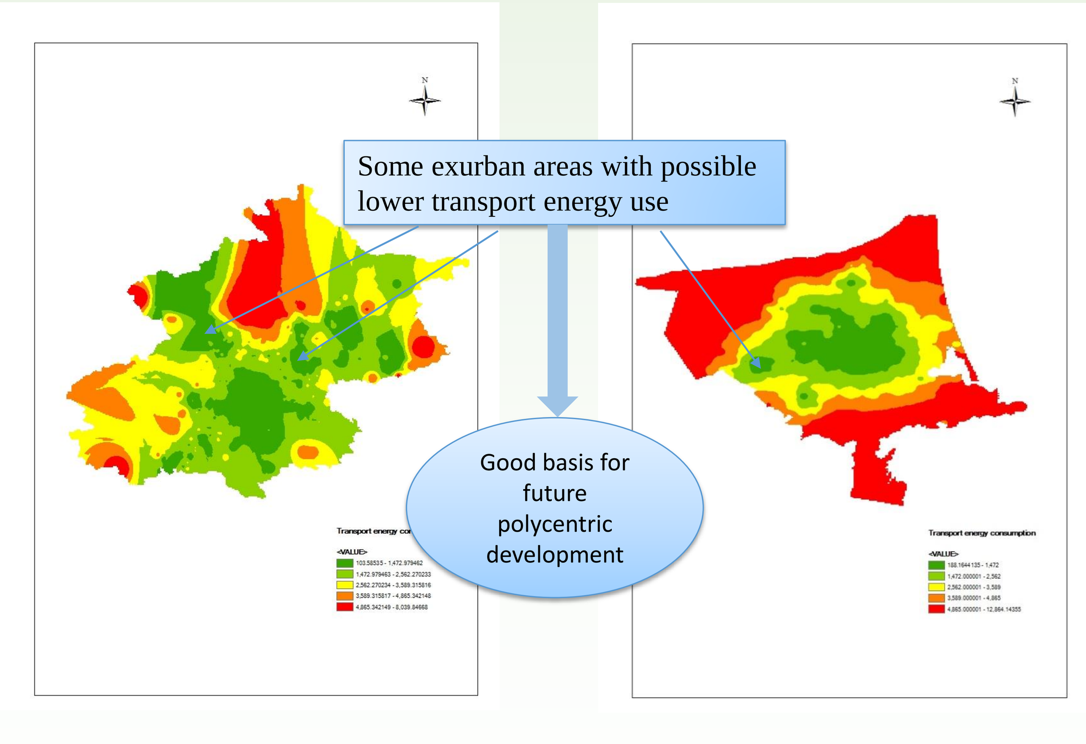

Population density distribution in Christchurch
(Unit: person/km²)


Shopping value distribution in Christchurch

A micro-level analysis on shopping travel patterns of two different cells

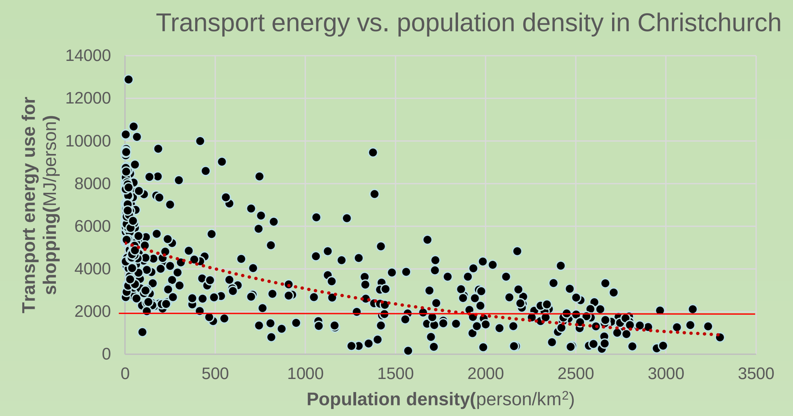


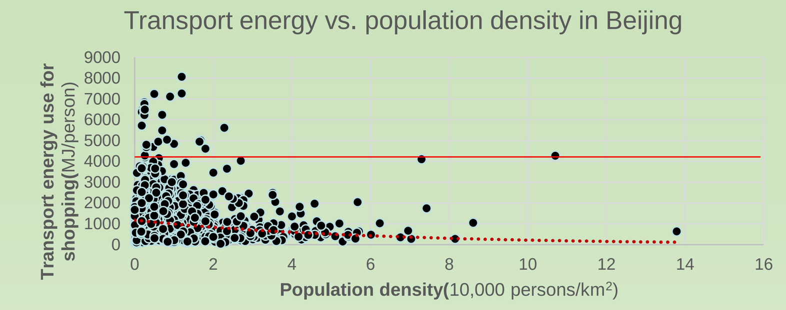
Transport energy consumption comparison



Transport energy consumption distribution map of Beijing

Transport energy consumption distribution map of Christchurch





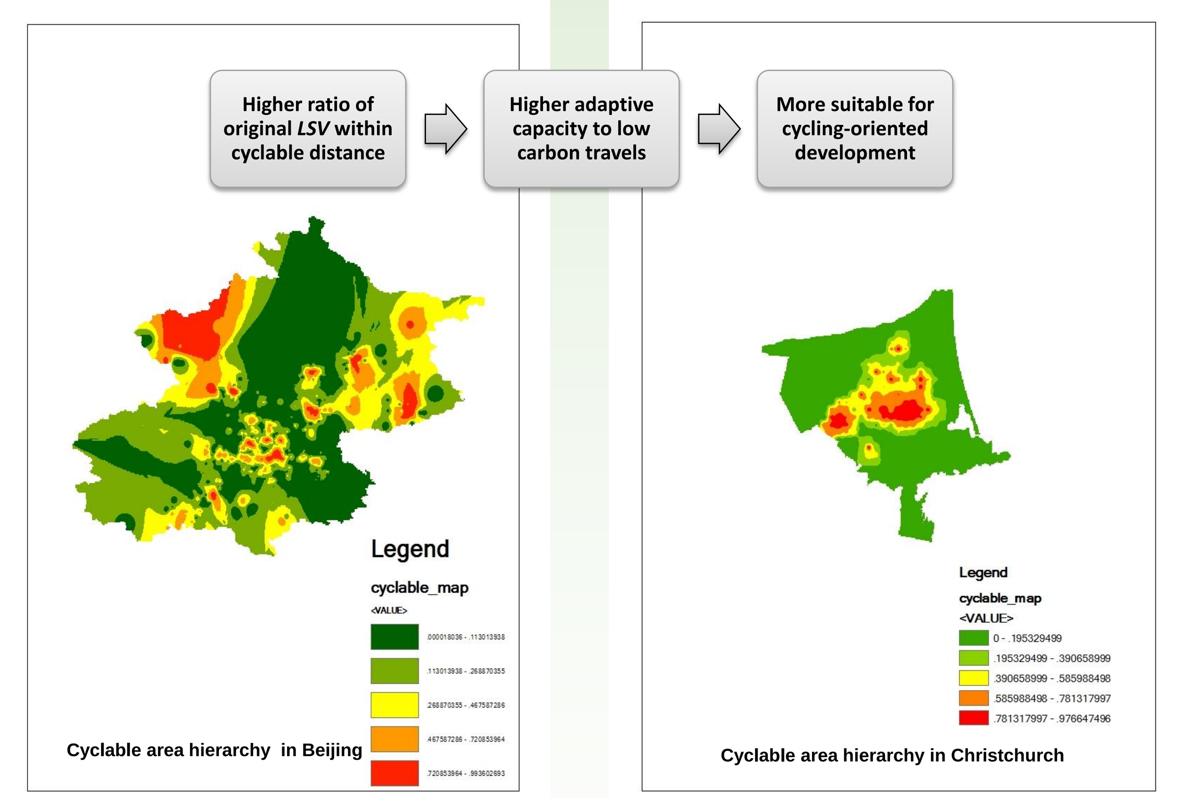
Travel patterns comparison between Christchurch and Beijing

City	Average transport energy use for shopping(MJ/person)	Average weighted VKT for shopping(km/year)	Average trip distance for shopping(km/day)
Beijing	1286.78	301	11.08
Christchurch	4137.80	1121	7.5

The derived VKT data for shopping from travel survey 1170 km/year
Source: NZTA,2006; MOT,2015

Adaptive capacity analysis within 3km

——the ratio of original local weighted shopping value after mode shift in 3km



Cyclable area hierarchy in Beijing

Cyclable area hierarchy in Christchurch

Conclusions

- Proximity to shopping facilities can contribute to more active travel modes
- High density population could reduce transport energy use
- Provide an alternative analytical model when the shopping travel survey is not available
- Provide a site-selection tool for cycling-oriented development