

## Evaluating Compactness of Cities by Energy Consumption Efficiency

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**Abstract:** We present a microeconomic based quantitative analysis scheme to evaluate compactness of cities by the energy consumption efficiency considering 1) the utility theory based on personal consumption behaviors, and 2) a consistency between the level of utility and energy consumption. By representing quality of life by utility, this study develops a CES typed model to estimate the actual and minimum individual energy consumption for present utility. Energy consumption efficiency index is introduced to analyze the compact level of cities. We applied this model to the Kumamoto and Nagasaki region. Higher energy consumption efficiency is found in Nagasaki which has more compact city structure and mass-transit usage. Zones with higher energy consumption efficiency are mainly located in city center and along mass-transit lines in both regions. Such findings suggest that more compact urban structure and higher mass-transit usage can induce greater urban energy consumption efficiency.

**Key Words:** compact city, energy consumption, utility, quality of life, CES

### 1. INTRODUCTION

Since the intensification of the global search for sustainable urban development in the late 1980s, there has been growing support in compact city theories and policies. It is believed this kind of higher density urban form attribute to less car trips and preservation of greens and arable land. Thinh et al. (2002) suggest compact city has two attributes: physical and functional. The physical compactness refers to the spatial configuration of land-use development within the city, the functional compactness to the density and mix of daily activity (Thinh et al. 2002). In seeking to provide empirical suggestions for compact city planning strategy, many studies seek indicators for urban compactness. Measurement and evaluation of compactness of cities are mainly conducted on these two attributes. Thinh creates a database of land-use patterns and evaluates the physical compactness of 116 German Regional Cities (Thinh et al. 2002). While some researchers analyze maps or satellite images like remote sensing images to evaluate the urban signature and compactness (Li et al. 2008; Guindon and Zhang, 2007). Others analyze the compactness measurements based on density and daily activity (Chen et al. 2008).

Our research attempts to analyze the compact city from the view of energy consumption based on two reasons. Firstly, from the physical point, compact urban spatial configuration affects the total amount of energy consumption. Secondly, density and intensity of activities, such as traffic, are major factors influencing energy consumption. Furthermore, growing concerns about urging oil prices and greenhouse gases produced by burning fossil fuels require the urban development to minimize the usage of resources, spatial displacement of environment

and improve energy consumption efficiency (Burgess, 2000; Williams, 1999). The amount of energy consumption is very important and effective index to evaluate the compactness of cities.

Energy consumption is closely related to actual land-use and transportation. Importantly, it affects the quality of life from the individual viewpoint. Aoyama et al. (2006) proposed a micro-economic model to seek a representative consumer's traffic pattern that minimizes energy consumption while keeping the present mobility level. He also investigated the urban structures and transportation policies in order to realize such traffic pattern. It is a good try to solve the energy consumption problem based on the individual mobility through some kind of micro-economic model. However, his research limits to personal mobility. How to estimate the minimum energy consumption without declining quality of life will no doubt be more helpful in urban sustainable development.

Two main aims are included in this study: 1) development an index to evaluate the urban compactness based on energy consumption; 2) estimation the energy consumption on present quality of life. Four sections are included in this paper. In the section 2, we show the development of a model to estimate the minimum energy consumption. In section 3, we apply this model to Kumamoto and Nagasaki regions in Japan, to analyze energy consumption and energy consumption efficiency. The section 4 presents conclusion and discussion.

## 2. METHODOLOGY

### 2.1 Model Framework

The term utility, which had been interpreted in 20th century economics, describes the satisfaction experienced by a person through the consumption or use of a commodity. We use utility to describe quality of life in purely economic terms. Utility is a measurable quantity and is a value function (or scale of preference) to describe consumer behavior. People are assumed to maximize the utility to achieve the present level of quality of life. Maximum utility is achieved by consuming various kinds of goods, like food, clothes, house, trips *et al.*. Consuming goods is also actually a process of energy consumption. The problem in our model is how to estimate the minimum energy consumption at maximum utility and find the corresponding amount of goods.

Some assumptions are needed in order to formulate the model.

1. As transportation sector is a bigger contributor to energy consumption, we classified all goods into two types: mobility goods and composite goods. Mobility goods include car trips and mass transit trips. Composite goods are all other goods except mobility goods. We assume that the representative consumer in zone  $i$  consumes three types of goods: composite goods and trips by car and mass transit. The demands are shown as  $x_{1i}$ ,  $x_{2Ci}$  and  $x_{2Mi}$ , respectively.
2. The mobility level  $x_{2i}$  is a function of the number of trips by car  $x_{2Ci}$ , and trips by mass transit  $x_{2Mi}$ .
3. Utility  $u_i$ , which reflects the level of quality of life, is defined as a function of these three kinds of goods.
4. Representative consumer in zone  $i$  is assumed to maximize his/her utility and mobility by consuming different amount of goods under the income budget constraint.
5. All the income is spent on consuming goods without saving.

We developed our model framework shown as Equation (1). We would like to explore activities that minimize the energy consumption  $E_i$  on the maximum utility level  $u_i^*$ .

$$\begin{aligned} \min_{\{x_{1i}, x_{2Ci}, x_{2Mi}\}} \quad & E = \sum_i E_i = \sum_i (e_1 x_{1i} + e_2 t_{2Ci}(x_{2Ci}, x_{2Mi}) x_{2Ci} + e_3 t_{2Mi}(x_{2Ci}, x_{2Mi}) x_{2Mi}) \\ \text{s.t.} \quad & u_i(x_{1i}, x_{2Ci}, x_{2Mi}) = u_i^*, \forall i \end{aligned} \tag{1}$$

The total energy consumption  $E$  is a multi-objective function of  $E_i$ , which means average individual daily energy consumption in zone  $i$ .  $e_1, e_2, e_3$  are energy consumption unit of each good.  $t_{2Ci}, t_{2Mi}$  are average time of each car trip and mass transit trip, which are functions of car and mass transit trips.

### 2.2 Definition of Utility Function

How to express the utility function is very important. First, we assume that there is a substitutive relation between the number of car trips and mass transit trips. The mobility level can be defined as a function of them. Meanwhile, a substitution relationship also exists between the amount of composite goods and mobility goods. For representing these two kinds of relationships, a nested type CES (Constant Elasticity of Substitution) function is used (Kanemoto et al., 2006). The structure is shown in Figure 1. The actual functional form of utility and mobility is expressed as Equation (2) and (3).

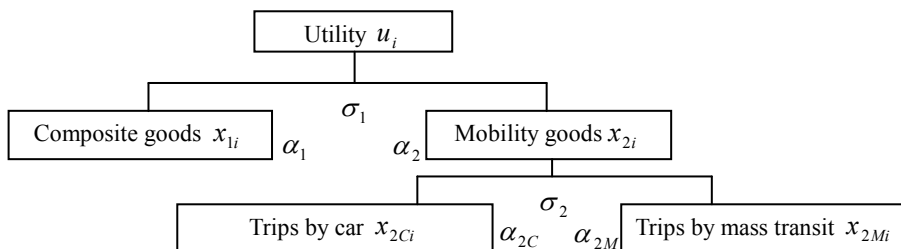


Figure 1 Structure of utility function

$$u_i(x_{1i}, x_{2i}) = \left\{ \alpha_1 x_{1i}^{(\sigma_1-1)/\sigma_1} + \alpha_2 x_{2i}^{(\sigma_1-1)/\sigma_1} \right\}^{\sigma_1/(\sigma_1-1)} \tag{2}$$

$$x_{2i}(x_{2Ci}, x_{2Mi}) = \left\{ \alpha_{2C} x_{2Ci}^{(\sigma_2-1)/\sigma_2} + \alpha_{2M} x_{2Mi}^{(\sigma_2-1)/\sigma_2} \right\}^{\sigma_2/(\sigma_2-1)} \tag{3}$$

Here,  $\sigma_1$  and  $\sigma_2$  are the elasticity of substitution between two goods at the first and second stages. Further,  $\alpha_1$  and  $\alpha_2$  are the share parameters for composite goods and mobility goods, while  $\alpha_{2C}$  and  $\alpha_{2M}$  are those for car trips and mass transit trips, respectively.

### 2.3 Present Utility Level

The following procedure is introduced to calculate the present utility level. At first, maximizing mobility level subject to transportation budget constraint is formulated shown as Equation (4). Revealed mobility level is defined as maximum mobility level, which is determined by the number of trips by car and mass transit.  $x_{2Mi}^*$  are the optimal solutions of the number of trips by mode  $M$  (car or mass transit), and  $x_{2i}^*$  is the revealed mobility level, shown in Equation (5), (6), respectively.

$$\begin{aligned} \max_{x_{2Ci}, x_{2Mi}} : x_{2i} = & \left\{ \alpha_{2C} x_{2Ci}^{(\sigma_2-1)/\sigma_2} + \alpha_{2M} x_{2Mi}^{(\sigma_2-1)/\sigma_2} \right\}^{\sigma_2/(\sigma_2-1)} \\ \text{s.t.} \quad & p_{2Ci} x_{2Ci} + p_{2Mi} x_{2Mi} \leq I_{2i} \end{aligned} \tag{4}$$

$$x_{2Mi}^* = \left( \frac{\alpha_{2M}}{p_{2Mi}} \right) \frac{I_{2i}}{\alpha_{2C}^{\sigma_2} p_{2Ci}^{1-\sigma_2} + \alpha_{2M}^{\sigma_2} p_{2Mi}^{1-\sigma_2}} \tag{5}$$

$$x_{2i}^* = (\alpha_{2C}^{\sigma_2} p_{2Ci}^{1-\sigma_2} + \alpha_{2M}^{\sigma_2} p_{2Mi}^{1-\sigma_2})^{1/(\sigma_2-1)} \cdot I_{2i} \tag{6}$$

Utility maximization problem subject to income constraint is shown in Equation (7). The demand function of the composite goods and revealed mobility are written analytically as the solution of the utility maximization problem as Equation (8).

$$\max : u_i = \{ \alpha_1 x_{1i}^{(\sigma_1-1)/\sigma_1} + \alpha_2 x_{2i}^{(\sigma_1-1)/\sigma_1} \}^{\sigma_1/(\sigma_1-1)} \tag{7}$$

$$s.t. \quad p_{1i} x_{1i} + p_{2i} x_{2i} \leq I_i$$

$$x_{ki}^* = \left( \frac{\alpha_k}{p_{ki}} \right) \frac{I_i}{\alpha_1^{\sigma_1} p_{1i}^{1-\sigma_1} + \alpha_2^{\sigma_1} p_{2i}^{1-\sigma_1}} \tag{8}$$

$p_{1i}, p_{2i}, p_{2Ci}, p_{2Mi}$  are the prices in zone  $i$  for composite goods, mobility goods, car trips and mass transit trips, respectively. Further,  $I_i$  is the individual income and  $I_{2i}$  is the individual transportation budget, each in zone  $i$ .

From Equations (5), (6) and (8), the optimal number of trips in zone  $i$  by car and mass transit can be calculated as Equation (9). Substituting (8), (9) into utility function, the present utility level can be obtained.

$$x_{2Mi}^* = \left( \frac{\alpha_{2M}}{p_{2Mi}} \right)^{\sigma_2} \alpha_2^{\sigma_2} (\alpha_{2C}^{\sigma_2} p_{2Ci}^{1-\sigma_2} + \alpha_{2M}^{\sigma_2} p_{2Mi}^{1-\sigma_2})^{\frac{\sigma_2-\sigma_1}{1-\sigma_2}} \left\{ \alpha_1^{\sigma_1} p_{1i}^{1-\sigma_1} + \alpha_2^{\sigma_1} (\alpha_{2C}^{\sigma_2} p_{2Ci}^{1-\sigma_2} + \alpha_{2M}^{\sigma_2} p_{2Mi}^{1-\sigma_2})^{\frac{1-\sigma_1}{1-\sigma_2}} \right\}^{-1} I_i \tag{9}$$

### 2.4 Energy Consumption Efficiency Index

In order to evaluate the compact level of cities, energy consumption efficiency is introduced. Two kinds of index are analyzed: estimated actual  $UE_i$  and estimated optimal  $UE_i^*$ , which are shown in Equation (10), (11). Weighted index of energy consumption efficiency,  $UE$  and  $UE^*$ , are applied to reflect the regional actual and optimal energy consumption efficiency level, shown in (12) and (13).

$$UE_i = \frac{u_i}{E_i} \tag{10}$$

$$UE_i^* = \frac{u_i^*}{E_i^*} \tag{11}$$

$$UE = (1/P) \cdot \sum_i UE_i \cdot P_i \tag{12}$$

$$UE^* = (1/P) \cdot \sum_i UE_i^* \cdot P_i \tag{13}$$

Here,  $u_i^*$  is the maximum utility, and  $P_i$  is the population, all in zone  $i$ . Further,  $E_i, E_i^*$  are estimated actual and minimum energy consumption in zone  $i$ .

### 3. APPLICATION TO KUMAMOTO AND NAGASAKI METROPOLITAN REGIONS

### 3.1 Study Area

We chose Kumamoto and Nagasaki metropolitan regions for our study. Both regions are located in Kyusyu island in south of Japan. Kumamoto is a little bigger region, with a population of 970,380 in 1997, compared to 726,112 in Nagasaki in 1996. Two cities (Kumamoto and Uto), fourteen towns and one village are in Kumamoto metropolitan region, and the core city is Kumamoto city with a population of 0.67 million and area 267 km<sup>2</sup>. Nagasaki metropolitan region covers three cities (Nagasaki, Isahara, Omura) and four towns. Nagasaki city is the center city with population of 0.44 million and area 241 km<sup>2</sup> (Figure 2).

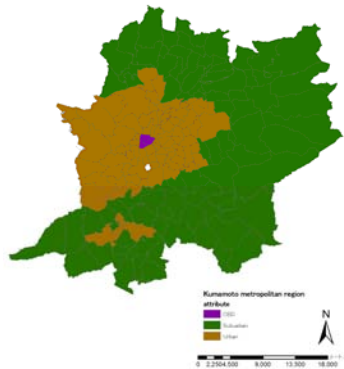


Figure 2.a Kumamoto metropolitan region  
The zone marked by white is Kumamoto Station

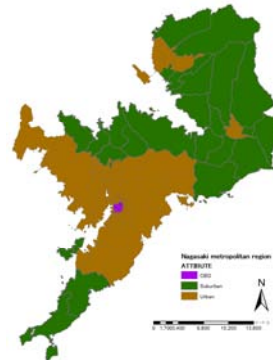


Figure 2.b Nagasaki metropolitan region  
The zone marked by white is Nagasaki Station

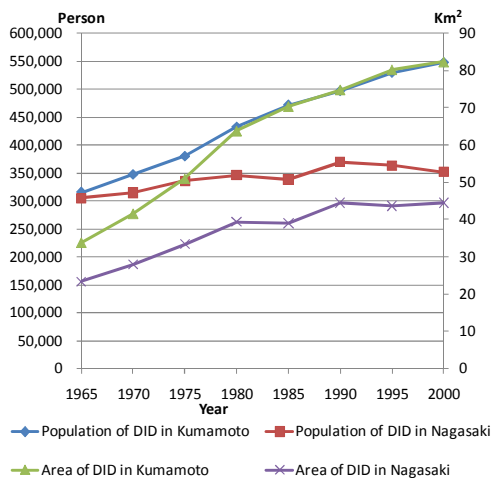


Figure 3.a Population and area of DIDs

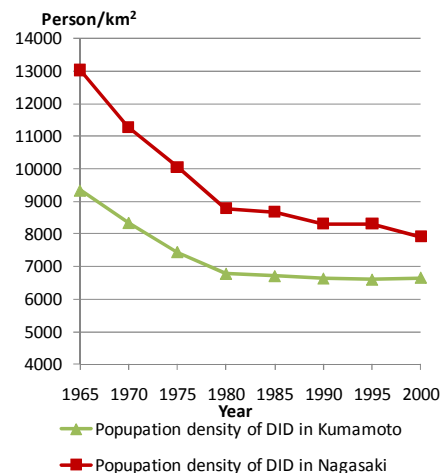


Figure 3.b Population density of DIDs

According to the Japan Statistics Bureau and Statistics Center, a densely populated district (DID), is defined as a district that has a population density over 4,000 inhabitants per square kilometer and a combined population of more than 5,000. With the tendency of urbanization and the flow of population into major urban spheres, it is projected that the population and area of DIDs will continue to grow up, although at a progressively slow pace in developed countries. The phenomenon is also taken place in Kumamoto and Nagasaki regions, where consistently increasing population of DID, the area of DIDs, and yearly decreasing population density of DIDs, are shown in Figure 3. Both regions are proceeding a process of urban growth and urban sprawl. However, compared two regions, Nagasaki regions shows a slow speed of urban sprawl and seems remaining a relatively more compact urban structure than Kumamoto from the viewpoint of smaller DID area and high population density in city center.

### 3.2 Data

We apply this model to Kumamoto and Nagasaki at almost same time period, in 1997 and 1996, when person trip surveys were conducted. The trip data used in this paper are from Kumamoto personal trip survey (PTS) 1997, Nagasaki PTS 1996, supplied by Kumamoto Metropolitan Regional Urban Transport Planning and Consultation Organization, Nagasaki Metropolitan Regional Urban Transport Planning and Consultation Organization. Some basic information of the PTS is shown in Table 1. Residents in Kumamoto are more car-dependence and travel far than the ones in Nagasaki. It can be shown as higher car ownership rate, more average car trips and longer trip length. In Nagasaki, fewer trips are generated each day, and the percentage of trips by mass transit, including railway, light subway, bus, is the relatively higher.

Table 1 Information about related PTS

	Kumamoto (1997)	Nagasaki (1996)
Traffic zones	177 zones	88 zones
Population	970,380	726,112
Car ownership rate(vehicle/1000 person)	569	442
Average trips (one day/person )	2.47	2.38
Average trip length (km/trip)	6.81	2.66
Average car trips (one day/person )	1.44	0.94
Average mass transit trips (one day/person )	0.18	0.33
Other mode trips( one day/person )	0.85	1.11
Mass transit trip share	7.29%	13.87%

In order to estimate the model and investigate the individual energy consumption in each zone, many kinds of data are needed.

- Number of trips by car and mass transit (trips/person·day) are aggregated from original dataset of personal trip survey. We focus on only the trip purpose of commute, business, shopping and returning home trips.
- Average travel time by car and mass transit from zone  $i$  to every other zones is obtained by trip assignment results of road and mass transit networks.
- Generalized cost by car and mass transit consists of two kinds of cost here. One is the time cost, which is the result of multiplying the value of time and trip time. According to statistical report from Japanese Road Bureau, Ministry of Land, Infrastructure and Transport (MLIT), the time value for car trip is 38.11 yen/min·person, and for mass transit trip is 40 yen/min·person. The other kind of cost is the price of each trip. We can get the running fee unit (yen/km·vehicle) data from statistical report by MLIT, considering the fees related to running distance, including oil, tyre, tube, maintenance, vehicle depreciation. We transfer this data to our car trip price  $p_{2Cij}$  as this way:

$$p_{2Ci} \text{ (yen/person·trip)} = \frac{\text{running fee unit (yen/km·vehicle)} \times \text{minimum distance from zone } i \text{ to } j \text{ (km/trip)}}{\text{average number of passengers (persons/vehicle)}}$$

The number of passengers in each car is set to 1.21 according to the report. The price of mass transit trip  $p_{2Mij}$  is determined by the mass transit fare.

- It is difficult to obtain the zonal income data since only the total income in each town and city is available from Kumamoto Prefecture Government and Nagasaki Prefectural

Government. As a positive relationship observed from land price and income level, we distribute the total income among zones according to the zonal price ratio of land confronting major roads and railway, given the land price data by Japanese National Tax Agency.

- The composite goods energy consumption unit  $e_1$  (kcal/yen) is calculated as the result of dividing the all energy each household consumed (kcal/household·month) by the household monthly expenditures except the transport fee, given by Japanese Statistics Bureau of Ministry of Internal Affairs and Communications and EDMC (Handbook of Energy& Economic Statistics in Japan). Car trip and mass transit trip energy consumption unit  $e_2, e_3$  (kcal/trip·min) have relationship not only with the running distance, but also with speed. Here we transfer the trip distance energy consumption unit (kcal/trip·km), which is available from statistical report by MLIT, to trip time energy consumption (kcal/trip·min). Having the data of weighted average speed (km/min) of all trips, the result of  $e_2, e_3$  can be calculated and are listed in Table 2. Similar energy consumption unit for composite good are found in two regions. Nagasaki shows bigger energy unit for car trips and mass transit trips.

Table 2 Energy consumption unit

	Kumamoto(1997)	Nagasaki(1996)
Composite goods $e_1$ (kcal/Yen)	3.64	3.51
Car trip $e_2$ (kcal/trip·min)	197.18	256.59
Mt trip $e_3$ (kcal/ trip·min)	18.16	20.09

### 3.3 Procedure of Estimating Minimum Energy Consumption

We estimate the minimum energy consumption according to the stepwise as shown in Figure 4. The procedure is as follows:

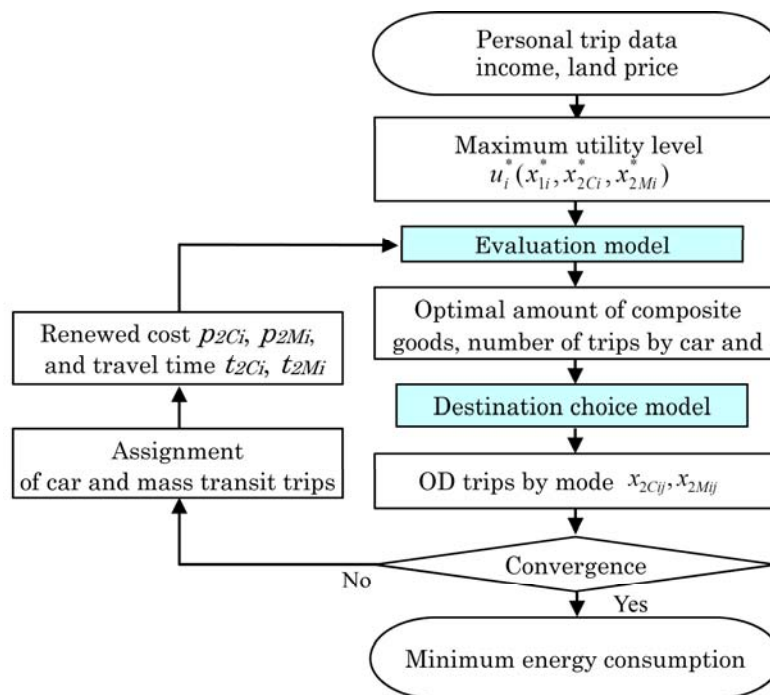


Figure 4 Calculation flow of minimum energy consumption

Step 1: As the numbers of car and mass transit trips by zone can be calculated from mobility

maximization process, so the present utility level can be evaluated by Equation (2).

Step 2: By using the evaluation model, which minimizes energy consumption for present utility level, we can calculate the corresponding amount of three kinds of goods: trips by car  $x_{2Ci}$ , trips by mass transit  $x_{2Mi}$ , and composite goods  $x_{1i}$ .

Step 3: The trips  $x_{2Ci}$  and  $x_{2Mi}$  given by step 2, are distributed to zones to form OD matrixes of mode by using a destination choice model. It will be mentioned later.

Step 4: Compare the OD matrixes with the original ones before the destination choice model. If  $x_{2Ci}$  and  $x_{2Mi}$  converge, stop and calculate the minimum energy consumption; otherwise, proceed to step 5.

Step 5: Assignments of OD matrix of car trips and mass transit trips are done.

Step 6: We solve the model again with a renewed costs,  $p_{2Ci}$ ,  $p_{2Mi}$ , and travel times  $t_{2Ci}$ ,  $t_{2Mi}$ .

Step 7: Return to Step 2.

### 3.4 Results

We compared the results of estimated actual and minimum energy consumption (Table 3). More than 70% of the estimated actual energy is consumed by composite goods. The actual energy share of car trips is over 20% in both regions. However, this value is a little bigger in Kumamoto, 2.37% higher than in Nagasaki. The energy share of mass transit trips in Nagasaki is 1.69%, higher than Kumamoto (2.47% to 0.41%). There is a big reduction in estimated minimum energy consumption, more than 10% cut compared to the actual energy in both regions. It is possible to reduce 5300kcal individual daily energy consumption in Kumamoto by decreasing 81.2% of energy consumption by car trips and increasing mass transit trips four times. In Nagasaki, the goal of cutting 12.8% of energy consumption can be achieved by reducing 87.8% of energy for car trips and increasing energy share in composite goods and mass transit trips by 5.7% and 175% respectively. Big energy share of composite goods (nearly 90%), relative higher energy share of mass transit trips and reduced car trips energy share contribute to minimum energy consumption in both regions. The main attributors to achieve the minimum energy consumption goal are increasing energy share of composite goods and mass transit trips, and decreasing energy share of car trips. Compared the estimated actual and minimum energy consumption, Nagasaki shows a smaller difference than Kumamoto, with a decreasing rate of 12.8% to 14.2% (Table 3).

Table 3 Estimated actual and minimum individual daily energy consumption

	Kumamoto		Nagasaki	
	Estimated actual	Estimated minimum	Estimated actual	Estimated minimum
Total energy consumption (kcal/person-day)	$3.72 \times 10^4$	$3.19 \times 10^4$ (-14.2%)	$2.81 \times 10^4$	$2.45 \times 10^4$ (-12.8%)
Energy for composite goods(kcal/person-day)	$2.72 \times 10^4$	$2.93 \times 10^4$ (7.7%)	$2.08 \times 10^4$	$2.2 \times 10^4$ (5.7%)
Energy for car trips (kcal/person-day)	$9.87 \times 10^3$	$1.85 \times 10^3$ (-81.2%)	$6.79 \times 10^3$	$8.22 \times 10^2$ (-87.8%)
Energy for mass transit trips (kcal/person-day)	$1.52 \times 10^2$	$7.89 \times 10^2$ (419.0%)	$5.92 \times 10^2$	$1.63 \times 10^3$ (175%)
Energy share of composite goods	73.12%	91.74%	73.79%	89.99%
Energy share of car trips	26.48%	5.79%	24.11%	3.36%
Energy share of mass transit trips	0.41%	2.47%	2.10%	6.65%

Note: the figure in () shows the increasing percentage of estimated minimum compared to estimated actual energy consumption

We investigated the energy consumption efficiency at regional and zone levels. Larger the value of index is, more compact the city is. The difference between estimated actual and



optimal energy consumption efficiency,  $\Delta UE^* = UE - UE^*$  (estimated actual energy consumption efficiency minus optimal energy consumption efficiency), is calculated to compare the achievement level of optimal energy consumption efficiency.

From Table 4, individual utility level in Kumamoto is higher than in Nagasaki. It is the same as expected since lower income level in Nagasaki with the average income 6,286 yen/person·day compared to 8,290 yen/person·day in Kumamoto. The actual energy consumption efficiency is higher in Nagasaki region. It is interesting to observe that Nagasaki region shows higher estimated actual energy consumption efficiency, but with lower estimated optimal energy consumption efficiency. The difference between estimated actual and optimal energy consumption efficiency, is bigger in Kumamoto (0.032 compares to 0.028 in Nagasaki). Nagasaki is more compact than Kumamoto with higher estimated actual energy consumption efficiency. This is consistent with results suggested by other evaluation method, such as population density. Higher population density of DIDs means more compact urban structure of Nagasaki mentioned in 3.1. Moreover, Nagasaki region seems to be much easily to reach the goal of optimal energy consumption efficiency than Kumamoto.

Table 4 Estimated actual and optimal energy consumption efficiency

	Kumamoto		Nagasaki	
	Estimated actual	Estimated optimal	Estimated actual	Estimated optimal
Utility	6,966	6,966	5,289	5,289
Total energy consumption (kcal/person·day)	37,276	31,888	28,154	24,496
Energy consumption efficiency	0.187	0.218	0.188	0.216
Difference between estimated actual and optimal efficiency $\Delta UE^*$	-0.032		-0.028	

Figure 5 and Figure 6 show the space distribution of estimated zonal actual energy consumption efficiency, estimated zone optimal energy consumption efficiency, network and population density in the Kumamoto and Nagasaki region. Although a few zones with higher estimated actual energy consumption efficiency are found in suburban or rural area, the energy consumption efficiency decreases with the distance to the city center. Zones along the mass transit lines are higher energy efficient. For zonal estimated optimal energy consumption efficiency results, zones with higher values are mainly concentrated in the city center.

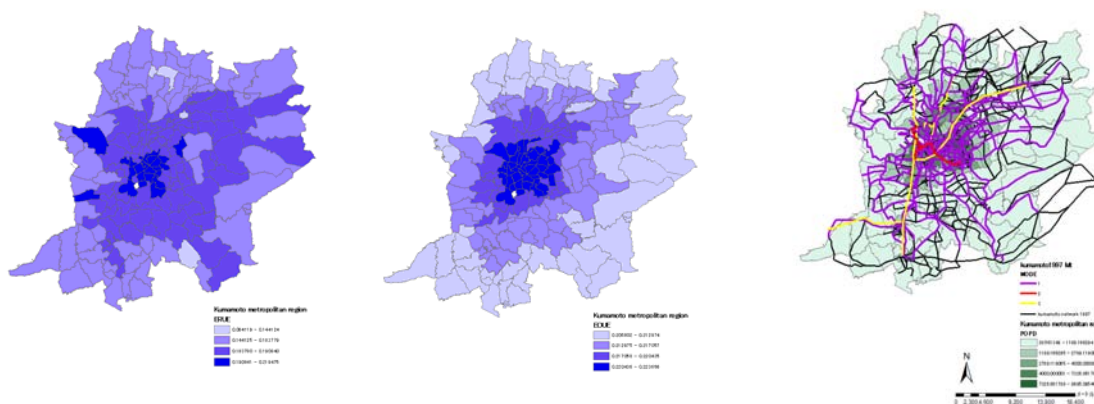


Figure 5 Estimated zone actual energy consumption efficiency; estimated zone optimal energy consumption efficiency, network and population density in Kumamoto in 1997

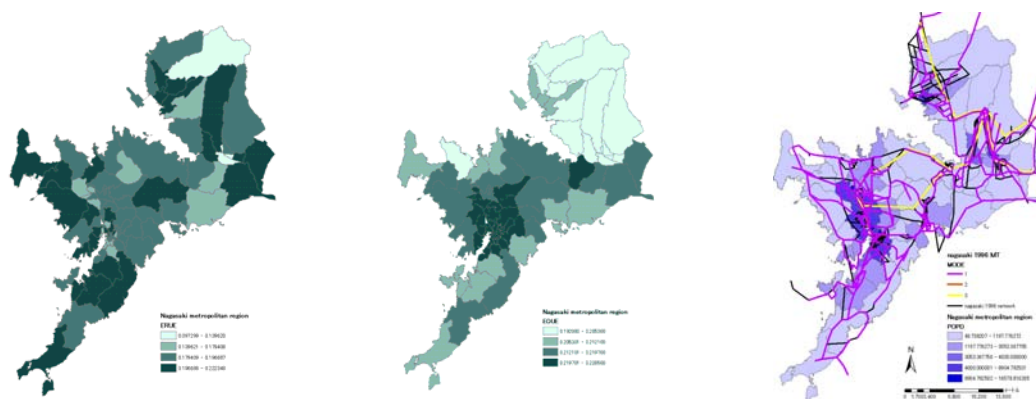


Figure 6 Estimated zone actual energy consumption efficiency; estimated zone optimal energy consumption efficiency, network and population density in Nagasaki in 1996

#### 4. CONCLUSIONS

Representing quality of life by utility, the present level of quality of life can be expressed by the maximum utility. A microeconomic model is developed to estimating the minimum energy consumption on maximum utility represented by consumption of composite goods, trips by car and mass transit. Energy consumption efficiency index is introduced to compare compact level of cities. By applying the model into Kumamoto and Nagasaki metropolitan region, the results proved that greater energy consumption efficiency corresponds to more compact urban structure in Nagasaki. More compact urban structure and higher mass transit usage can induce greater energy consumption efficiency.

The methodology of this paper is important since it gives a research framework to estimate the energy consumption on maximum utility from microeconomic viewpoint. Its result is valuable to give suggestions for policy making in light of reducing the energy consumption while keeping individual quality of life.

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