Evaluation of Intensive Urban Structure in Sapporo Based on the Ecological Footprint Index

Hokkaido University　○Student Member　Yujiao Guo
Hokkaido University　Regular Member　Kunihiro Kishi

1. INTRODUCTION

In the past century, the resources and the environment have been excessively exploited and destroyed. Environmental problems have seriously plagued humans. And in recent years, Japan faces serious demographic challenges owing to its lower birth rate and the population aging. The problems are most acute in Hokkaido which are no longer a matter of rural areas only. Even in Sapporo City, the population is forecast to decline in the future.

In accordance with the current situation, Sapporo set up a compact city planning which accumulate residential functions and city functions in the surroundings of subway stations based on the current urbanization area. However, to realize the compact city in Sapporo where the population declining in the future, it is essential to aggregate residential areas and city functions, eventually reduce the urbanization area.

2. OBJECTIVE

This research by analyzing the human activities influenced on the environment to evaluate which district is inefficient in the use of environmental resources and has higher environmental burden. Then consider how to aggregate residential areas and city functions to reduce the environmental burden by facing the population declining in the future, finally realize the intensive urban structure in Sapporo city.

3. ECOLOGICAL FOOTPRINT (EF)

The Ecological Footprint (EF) defined as total area of productive land and water area required to produce all the resources consumed and to assimilate all the wastes produced, by a defined population in that area.

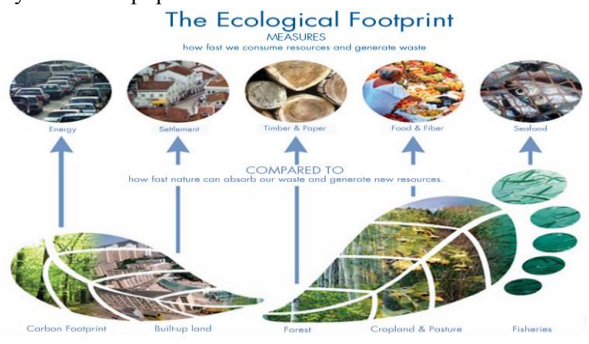

Fig. 1 Image of Ecological Footprint

In other words, the Ecological Footprint measures the ecological assets from the demand side that a given population requires to produce the natural resources it consumes (including plant-based food, livestock and fish products, timber and other forest products, space for urban infrastructure) and to absorb its waste, especially carbon emissions. The image of Ecological Footprint shown as **Fig.1**.

According to the definition, author divided EF into three categories, shown as **Tab. 1**. However, the Ecologically productive land mainly depends on the productivity of land or water area which is scarcely changed by the individuals' behavior. In this paper, the author only focuses on the built-up land and energy land for each district in Sapporo city.

Tab. 1 Classification and explanation of EF in this study

Classification	Explanation
Ecologically Productive Land	Land or water area to provide plant-based food, livestock and fish products, timber and other forest products
Built-up land	Land for urban infrastructure
Energy land	Forest area needed to sequester CO2 emissions

4. METHODOLOGY

4.1 Build-up land (EF_B)

According to the Sapporo city planning the whole city can be divided into three parts: urbanization area, urbanization adjustment area and outside city planning area. In the urbanization adjustment area, development activities and urban facilities are not carried out in principle. In this paper, the build-up land is calculated using the actual area of urbanization area in each district, calculated as follows.

$$\mathrm{EF_B} = \frac{A_u}{POP}$$

A_u: urbanization area

POP:population

4.2 Energy land (EF_{CO2})

Energy land can be considered as four parts: business sector, industry sector, household sector and transportation sector. The total CO2 emissions can be calculated by integrate the CO2 emissions for each sector.

According to the Progress of the Kyoto Protocol Target Achievement Plan, in Japan, the average absorbed amount of cultivated forest is 1.35 t-C/ha and 0.42 t-C/ha for natural forest. In Sapporo, the cultivated forest is 11,375 ha and natural forest is 56384 ha. The average absorbed amount of forest in Sapporo can be calculated accordingly as 2.11 t-CO2/ha. And EF_{CO2} can be calculated as follows.

$$\mathrm{EF_{CO2}} = \frac{E_{co2}/2.11}{POP}$$

E_{co2}: CO2 emissions of all sectors

(1) Business

Business sector means the CO2 emissions released from the energy consumption in offices, office buildings, shops, etc. and donated as E_1, calculated as follows.

$$E_1 = \sum_{i=1}^{n} A_i \times u_i$$

i: Architectural uses

A_i:Building floor area of i

u: CO2 emissions per unit

Japan Sustainable Building Association conducts a nationwide survey of energy consumption of non-residential buildings, and it is announced as "Database of Environment-related non-residential buildings", the calculation of CO2 emissions per unit is based on the value in Hokkaido. For applications that do not have a DECC value, use the value of national value. The example data of CO2 emissions per unit shown as **Tab.2**.

Tab. 2 Business CO2 emissions per unit

Classification	CO2 emissions (t-CO2/m^2 • year)
Regional national facilities	94.2
Business facility	113.5
…	…

(2) Industry

Industry sector means the CO2 emissions released from the energy consumption in agriculture, forestry and fisheries, mining, construction, manufacturing, and donated as E_2, calculated as follows.

$$E_2 = \sum_{i=1}^{n}\sum_{j=1}^{m} C_{ij} \times 44/12$$

C: carbon content of energy consumption

i: Industries of agriculture forestry and fisheries; mining; construction; manufacturing

j: Energy source (coal, coal product, crude oil, light oil…)

This paper uses Hokkaido's annual energy consumption data to estimate the energy consumption for each ward of Sapporo. The specific estimation methods are as follows.

i. Manufacturing:

$$EC_i = EC_H \times V_i / V_H$$

EC_i: Energy consumption of district i

EC_H: Energy consumption of Hokkaido

V_i:Shipment value of manufactured goods of district i

V_H:Shipment value of manufactured goods of Hokkaido

ii. Agriculture, forestry and fisheries; mining; construction:

$$EC_i = EC_H \times N_i / N_H$$

EC_i: Energy consumption of district i

EC_H: Energy consumption of Hokkaido

N_i: Number of employees of ward i

N_H: Number of employees of Hokkaido

(3) Household

Household sector means the CO2 emissions released from the energy consumption at home and donated as E_3, calculated as follows.

$$E_3 = \sum_{i=1}^{2} N_i \times u_i$$

i=1, detached house

i=2, co-residential house

N: number of households

u: CO2 emissions per unit

The data of CO2 emissions per unit shown as **Tab.3**, it is the common values in Hokkaido.

Tab. 3 Household CO2 emissions per unit

Classification	CO2 emissions (t-CO2/household • year)
Detached house	7
Co-residential house	4.66

(4) Transportation

Transportation sector means the CO2 emissions in automobiles, railways and aircraft, due to lack of freight data in this paper only take passenger transportation data into consideration and donated as E_4, calculated as follows. In passenger transportation, the amount of carbon dioxide emitted from each transportation mode can be expressed as the CO2 emissions per unit (person • kilometer) multiplied by the distance and number of people transported. And in this paper, author only focused on the traffic behavior in Sapporo city by the citizens of Sapporo.

$$E_4 = \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{t=1}^{m} a_t \times v_{tij} \times d_{tij}$$

a_t: CO2 emissions per unit of transportation t

v_{ij}: Number of trips from zone i to zone j

d_{ij}: Distance from zone i to zone j (km)

n: Number of zones

t: Transportation mode

When i ≠ j, definition of trip distance by different transportation mode shown as **Fig.2**.

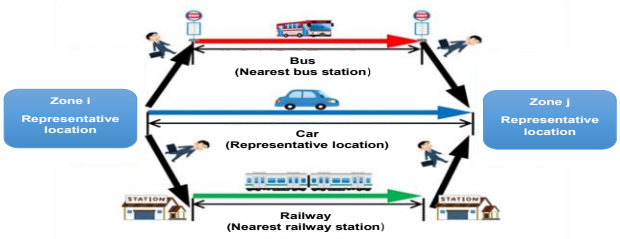

Fig. 2 Definition of trip distance (i≠j)

When i=j, the distance is calculated as the radius of the circle which having the same area of that zone.

The amount of carbon dioxide emissions per unit per unit for passenger transportation shown as **Tab.4**.

Tab. 4 CO2 emissions per unit for passenger transportation

Transportation mode	CO2 emissions (g-CO2/person • km)
Railway	20
Bus	67
Airplane	98
Car	141

From 4th Central Hokkaido PT survey, the OD tables can be prepared for current trip between c-zones (total 206 zones in Sapporo).

5. ANALYSIS

5.1 EF_B

The EF_B calculated according to the method shown in **3.1** and the results are shown in **Fig.3**.

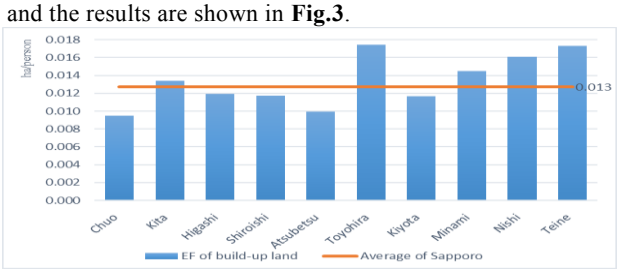

Fig. 3 EF of build-up land

The EF of build-up land directly reflects the utilization rate of urban infrastructure area by human activities in defined regions. From the results, it can be noticed that the EF_B of Chuo ward is the lowest in Sapporo, while in the Toyohira ward, etc. the value is higher than the average in Sapporo. In other words, compared with people living in the Chuo ward, people in other wards occupied more urban areas.

5.2 EF_{CO2}

The EF_{CO2} calculated according to the method shown in **3.2** and the results are shown in **Fig.4**.

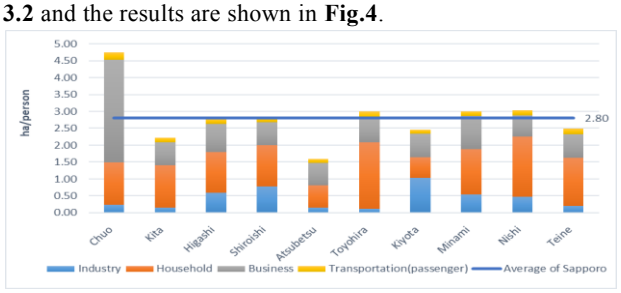

Fig. 4 EF of energy land

By looking at the results, it can be found that the EF_{CO2} of Chuo ward is obviously higher than other wards, and almost as half as the average value of Sapporo. Because the Chuo ward is the central of the Sapporo city where business facilities are concentrated, and it will also attract citizens from other regions to carry out various activities in Chuo ward.

5.3 Passenger Transportation

The EF for the transportation sector is the most vulnerable to personal behavior. In this paper, the author also focuses on the analysis of CO2 generated by passenger transportation in Sapporo.

(1) Average travel distance

Tab. 5 Average travel distance (km)

District	Walk・Bicycle	Car	Bus・Tram	Subway	JR	Total
Chuo	1.24	4.78	4.53	5.33	8.15	4.04
Kita	1.26	4.98	5.57	6.04	8.80	3.99
Higashi	1.22	5.01	4.83	5.50	8.99	3.87
Shiroishi	1.06	5.08	4.39	5.48	7.31	3.87
Atsubetsu	1.20	4.67	4.59	5.54	8.68	3.66
Toyohira	1.28	6.59	6.02	8.19	14.70	5.26
Kiyota	1.12	4.63	4.04	7.09	6.16	3.72
Minami	0.95	5.28	3.34	10.05	12.17	4.64
Nishi	1.44	5.70	4.76	12.17	9.86	4.89
Teine	1.35	5.61	5.66	8.27	13.95	4.63
Sapporo	1.21	5.12	4.80	6.18	8.62	4.12

The average travel distance of various modes of transportation is calculated, shown in **Tab.5**. It can be found that the average travel distance is larger in areas far from the city center and inconvenient for public transportation.

(2) Average CO2 emissions per trip

The average CO2 emissions per trip shown as **Fig.5**.

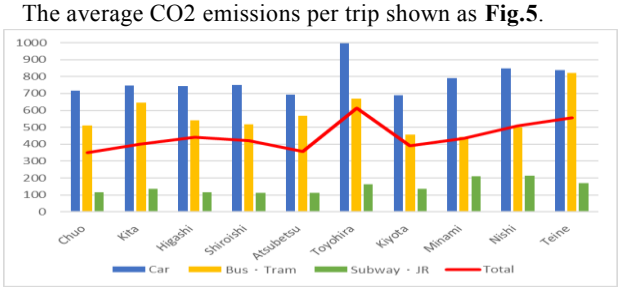

Fig. 5 Average CO2 emissions per trip

Because of the traffic volume in Chuo ward is significantly higher than other wards, the total CO2 emissions of Chuo ward is larger than other wards, but due to the abundant public transportation resources and lower utilization of automatic cars, the average CO2 emissions per trip is the lowest. On the contrary, due to the longer average travel distance and higher automobile utilization rate, the average CO2 emissions in the Minami Ward is the highest.

6. CONCLUSION

6.1 Build-up land

Build-up land is the direct use of urban infrastructure area, reducing the urbanization area can reduce the pressure on the environment, especially for the Toyohira ward etc. which is inefficient in the use of build-up land. In the future, the population declining in the suburbs will be more severe, which will also require the reduction of the urbanization area in suburbs, otherwise, the pressure on the environment will gradually increase as the population decreases. In addition, while intensification of urban residential and functions are being carried out, the regeneration of natural resources is equally important for suburban retreat areas.

6.2 Energy land

Energy land is the virtualized land use according to the CO2 emissions. The denser the human activities, the higher its value. It is impossible to reduce the impact on the environment by simply changing areas of human activities, only way is to reduce the CO2 emissions for each sector. The CO2 emissions of the industry and business sector are not easily changed by personal activities. From personal point of view, there are many ways to reduce the CO2 emissions, like changing the house type from detached house to co-residential house, using public transportation instead of automatic vehicle, moving from the suburbs to the more prosperous areas, etc.

REFERENCE

[1] Report of the 4th Central Hokkaido PT Survey, 2007

[2] Global Footprint Network, https://www.footprintnetwork.org/