Sustainability assessment using ecological footprint for the establishment of a sound material-cycle society
– Focusing on Resident Lifestyles in Shanghai, China –

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ABSTRACT

The authors have undertaken detailed research on the lifestyle of residents of Shanghai, the most developed region in China. Results show a relation between their lifestyles and their ecological footprint (EF). Results are summarized as follows. 1) In EFs related to resident lifestyles, that of energy consumption for transportation is the greatest. Its standard deviation is high. 2) EF of energy consumption for transportation is positively correlated to annual household income. The EF of domestic energy consumption is correlated with living arrangements and the number of people per household. 3) Recent expansion of the wealthy population and trends toward nuclear family households in Shanghai have contributed to increased environmental loads there.

BACKGROUND AND OBJECTIVE

Finding countermeasures for global heating and increasing waste materials are urgent social issues. Some people propose the establishment of a recycling-oriented society as a solution. Various approaches to promotion of a recycling-oriented society have been attempted. Emissions of greenhouse gases and recycling ratios have been used as indexes for evaluation. However accumulation of research results by these means is insufficient. Other investigators have specifically examined the EF index, which comprehensively evaluates myriad environmental loads derived from human activity such as the consumption of natural resources as land area (footprint) [1)]. Because it can evaluate environmental balance and overshoot (ecological red figure[2)]), EF is expected to be a valuable index for the evaluation of the movement toward a recycling-oriented society when one compares it to the environmental capacity of a nation and district. It provides us with an intuitive understanding and a shared vision of environmental issues. Therefore it must assume an important role as a communication tool in promoting our project of "Practical research and education of waste management in Asia–Pacific countries through partnership between academia and government."

This project evaluated sustainability making use of EF to promote a recycling-oriented society covering China, which has shown great economic growth during fiscal (Japanese) 2010–2012. For fiscal 2010, the problems and challenges hindering the promotion of a recycling-oriented society on a macro scale were highlighted, with examination of EF and environmental balance in each district (province). Then in fiscal 2011, the authors' efforts shed light on the time series change of EF in each district and reported a relation between economic growth and environmental loading, introducing the concept of decoupling. Finally as study in fiscal 2012 assessed the lifestyles of Shanghai residents and strove to ascertain the effects of lifestyles of individuals on EF. Research linking "Construction of recycling-oriented society" with "People's life for that construction" is

forthcoming.

METHODS

1. Location of Research

This project has examined Asia–Pacific countries, where environmental issues have surfaced along with economic growth. Among other countries, China is typical, with economically developed districts existing side by side with developing ones. It is exemplary of Asia–Pacific countries in its exposure of regional gaps. Up to fiscal 2011, the authors conducted evaluation of environmental sustainability in China as a country and as its districts (provinces). During fiscal 2012, the relation between lifestyle and environmental loading was investigated for Shanghai, a district of remarkable economic growth.

2. Outline of Questionnaire Survey

Questionnaire surveys of lifestyles were administered to Shanghai residents. An outline of the questionnaire is shown in Table 1. This survey has been designed to provide EFs described later. Therefore, the EFs of each resident were evaluated. Incidentally, the numbers of samples were not uniform among generations because of the nature of the Web survey. This point must be kept in mind when interpreting the results of analysis.

Table 1 Outline of lifestyle survey

Survey of lifestyles of Shanghai Residents	
Date	12–21 December, 2012
Subjects	Residents of Shanghai in their twenties to those over sixty
Method	Survey by questionnaire on Web
Answers collected	400 answers (352 valid answers excluding those found to be erratic for evaluation of EF) Answers from residents: twenties, 135; thirties, 126; forties, 54; fifties, 22; over sixty, 15.
Main survey items	1. About subjects themselves: age, sex, number of people in household, annual household income 2. Lifestyle: food, consumption of energy and natural resources, cars for transportation, others

3. Method used to Evaluate EF

The lifestyle ecological footprint (LEF) is defined herein as the ecological footprint related to the environmental load of the residents' life. It comprises four component EFs listed below. Our evaluation of EFs is related only with EFs originating from environmental loads associated with the life of residents and excludes EF by industries and businesses. However, the latter is an important component of total EF. Components of EF in this study are the following.

Food EF: EF attributable to consumption of foods and articles of taste
Paper EF: EF attributable to consumption of paper products
House EF: EF attributable to consumption of energy in the household
Transportation EF: EF attributable to consumption of energy by transportation (private car and motor cycle)

These EFs were calculated using Equation 1 proposed by Wackernagel et al. [1)]

$$EF_p = \sum_{l=1}^{n} \frac{C_l}{P_l} \quad (1)$$

EF_p: Per person EF (ha per person)
C_l: Per person consumption by consumer product l, (t per person)
P_l: Per area production of consumer product l, (t/ha)
l: Index to the consumer product being considered

Consumption of natural resources and energy data were collected in this survey.

Table 2 Outline of lifestyle EF

Items		Data cited mainly	Literature
Food EF	(i) Area of grass farm to produce beef, mutton and dairy products (ii) Area of farmland to harvest grain	Consumption of grain, vegetables, fruits and other food; land productivity to produce these foods	3)
Paper EF	(iii) Area of forest logged for production of lumber	Consumption of paper products and accumulation of lumber in forests of each production district	4), 5)
House EF	(iv) Area of forest to absorb CO_2 in house emitted by family members	Consumption of electricity and gas, their conversion factors to CO_2, absorption rate of forests	6), 7)
Transportation EF	(v) Area of forest to absorb CO_2 emitted by vehicles for transportation	Consumption of electricity and gas for transportation, their conversion factors to CO_2, absorption rate of forest	6), 7)

RESULTS AND CONCLUSIONS

Table 3 presents EFs of respective items. Figure 1 and 2 show the relation between EF of each item and properties of individuals and families. Analysis reveals the features listed below.

1) The average LEF of Shanghai residents is 0.61 ha, of which the transportation EF is 0.3 ha, the largest component, and occupies the greatest ratio of about 50% of LEF. Furthermore, the standard deviation of transportation EF is as great as 0.43 ha, varying widely among people.
2) Three EFs aside from House EF show strong positive correlation with annual household income at a significance level of 1%. That correlation is remarkable in terms of transportation EF. The transportation EF of family with annual income of more than 160 thousand yuan is about 3.7 times greater than that of family with annual income of less than 80 thousand yuan.
3) House EF decreases concomitantly with increased number of family members. House EF of families with more than three members, for example, is less than half of that of a single-member household.
4) House EF F of a single-family home is some 1.8 times greater than that of collective housing. This derives from differences in the energy efficiency of a home. More people live in collective housing in Shanghai. Therefore, the House EF there is suppressed.
5) Recent expansion of the wealthy population (increased income) and trends toward nuclear family (decreased number of family members) in Shanghai have contributed to increased environmental loading there, which might continue into the future.

Table 3 EF of each item

	Food EF	Paper EF	House EF	Transportation EF	LEF (sum)
Average (ha)	0.072	0.0076	0.20	0.32	0.61
Standard deviation (ha)	0.020	0.0081	0.16	0.43	0.48

valid answers: 352

REFERENCES

1) Wackernagel, M. and W. Rees, Our ecological footprint Reducing Human Impact on the earth, New Society Publishers, (1996).
2) Global footprint network, Ecological footprint and biocapacity 2007, National Footprint Accounts 2010.
3) National Bureau of Statistics of China, China Statistical Yearbook: http://www.stats.gov.cn/, final browsing at 2012.01.
4) China Technical Association of Paper Industry ed., Almanac of China Paper Industry 2010, China Light Industry Publishing.
5) Ministry of Land, Infrastructure, Transport and Tourism: "Research Report of Review on Consumption of Natural Resource for Promotion of a Society with Reduced Load on Natural Cycle of Matter."
6) Japan Environmental Management Association for Industry (Incorporated), Database for Common Original Unit of Equivalent CO_2.
7) Japan Environmental Management Association for Industry (Incorporated), Database for Heating Value of Fuel by Carbon Footprint (CFP) Program.

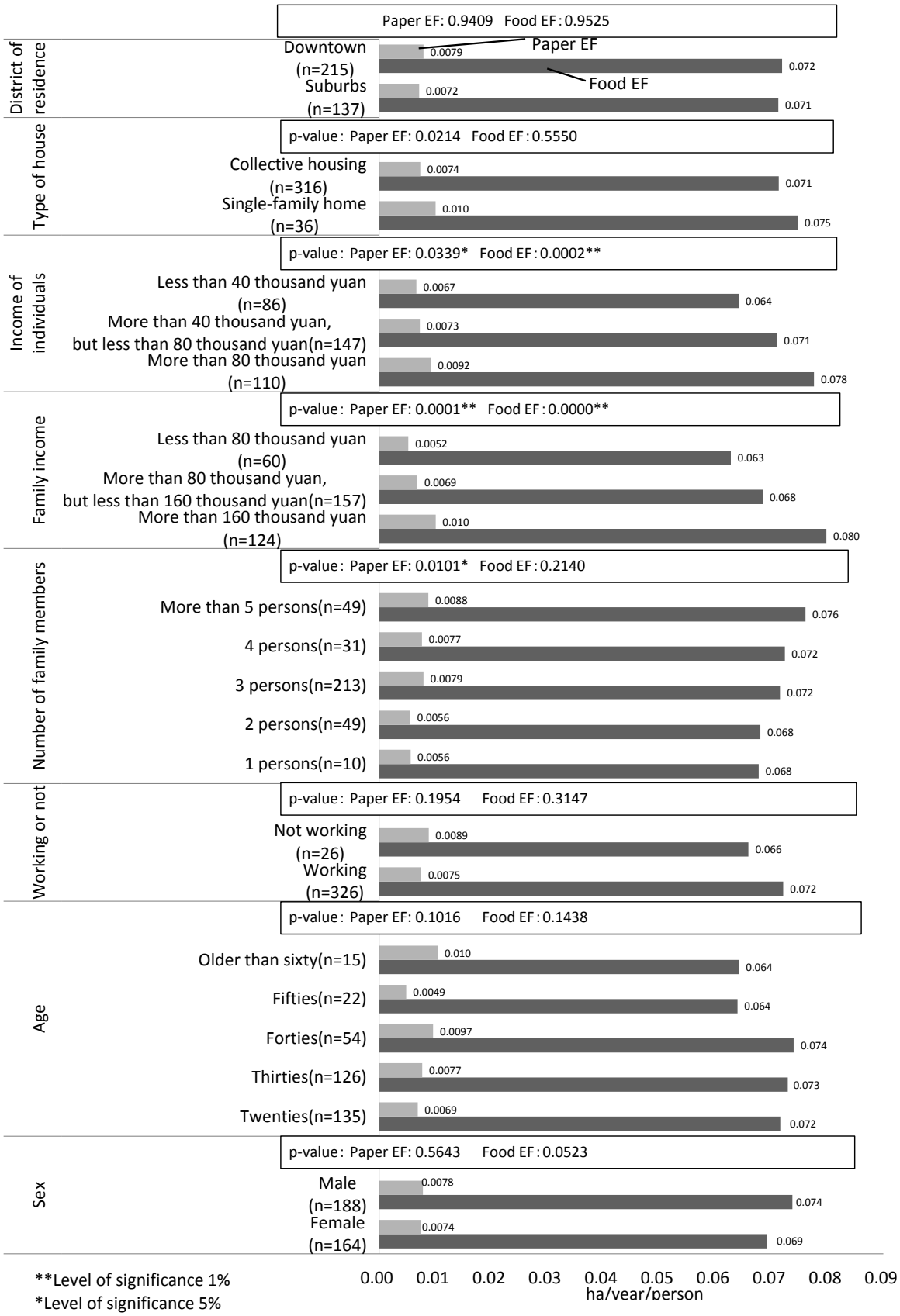

Figure 1 Relation between EFs and household and private property (Paper EF, Food EF)

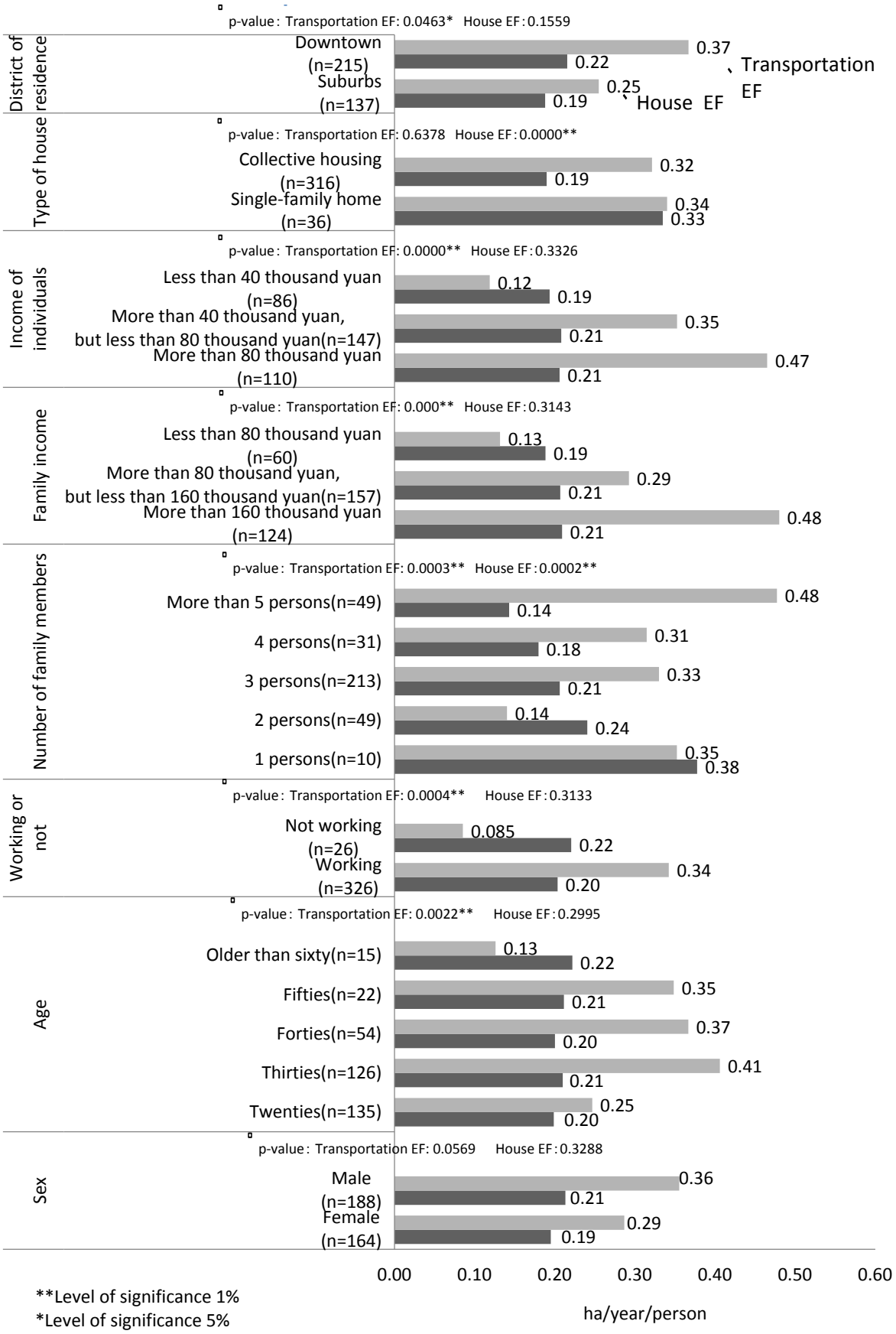

Figure 2 Relation between EFs and household and private property (Transportation EF, House EF)

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Ecological Footprint (EF)

- The EF was developed by William Rees and Mathis Wackernagel at the University of British Columbia in 1992.
- The EF can synthetically indicate different environmental loads such as CO_2 emissions, food consumption, etc., based on land consumption areas (footprint).

Human activities

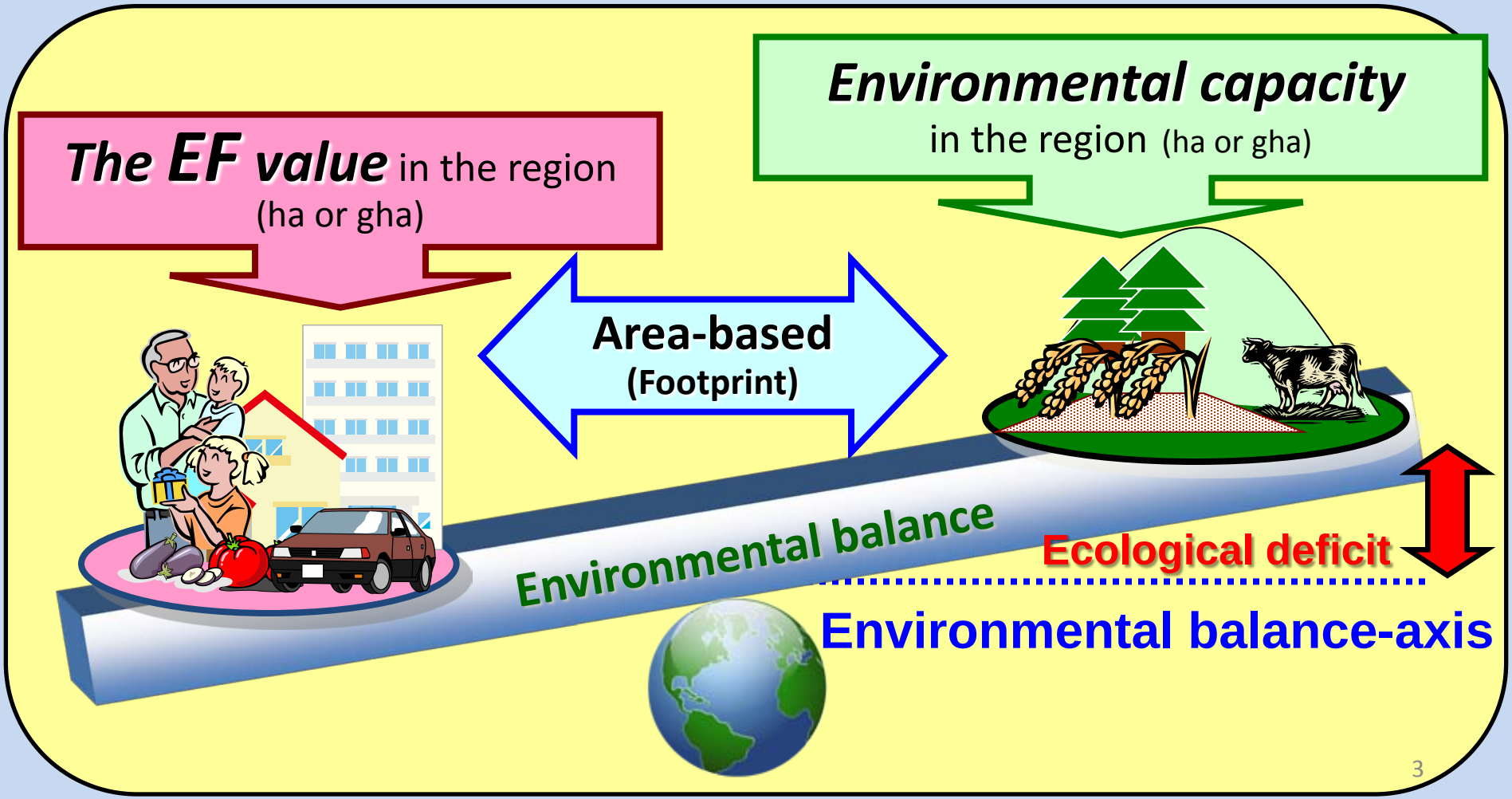
Source : Okayama city website

Resource consumption

Land consumption areas
(Area-based: Footprint)

Ecological Footprint (EF)

This indicator can show the relation between environmental loading and environmental capacity (forests, farmlands, etc.) . It also enables us to estimate the environmental balance.

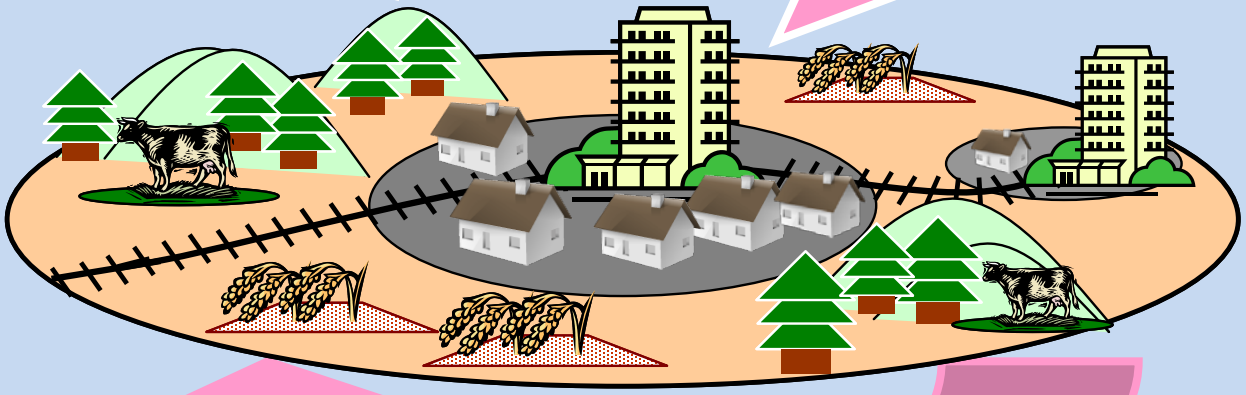


Ecological Footprint (EF)

The EF is a useful tool to assess the environmental balance for the establishment of a sound material-cycle society.

Sink areas
(Nature absorbs environmental loads in rural areas)

Source areas
(CO_2 emission, food consumption and so on in urban areas)



Sound Material-Cycle Society

Progress of Our Project

Fiscal 2010

Evaluation of sustainability in promotion of a sound material-cycle society in China and in each district (province)

The regional ecological footprint and the interregional gaps in China were calculated.

Fiscal 2011

Time series evaluation of sustainability in China and in each district (province)

A time-series sustainability assessment (between 1995 and 2010) of China was performed, which focused on various regions throughout the country with different characteristics based on the decoupling concept using the ecological footprint.

→ Macro-scale evaluation of sustainability in promotion of a “recycling-oriented society”

Objective of Our Research

Fiscal 2012

Evaluation of sustainability at the level of an individual life

The association between the lifestyle of Shanghai residents and the ecological footprint was clarified based on the questionnaire survey.

→ Research linking “Construction of a sound material-cycle society” with “People’s life in relation to it”

Flow of Research

(i) Survey of lifestyles of Shanghai residents

(ii) Consumption of natural resources (food and paper) and energy

(iii) Calculation of the lifestyle footprint (LEF)

Analysis of relation between EF and properties of individuals and households

(i) Survey of lifestyles of Shanghai residents

Survey of consumption of natural resources and energy attributable to individual lifestyles in Shanghai residents

Survey of lifestyles of Shanghai Residents	
Date	12–21 December, 2012
Subjects	Residents of Shanghai in their twenties to those over sixty
Method	Survey by questionnaire on Web
Answers collected	400 answers (352 valid answers excluding those found to be erratic for evaluation of EF) Answers from residents: twenties, 135; thirties, 126; forties, 54; fifties, 22; over sixty, 15.
Main survey items	1. About subjects themselves: age, sex, number of people in household, annual household income 2. Lifestyle: food, consumption of energy and natural resources, cars for transportation, others

What is the ecological footprint (EF) ?

Consumption per resident

Productivity of land (conversion to area)

EF (environmental load)

- Farmland
- Grassland
- Forest
- Land of reduced productivity
- Energy
- Land of CO_2 absorption
- Ocean and freshwater areas

Consumption of natural resources and energy by residents is converted to area, making use of productivity of land and CO_2 absorption rates of forests.

Lifestyle Ecological Footprint (LEF)

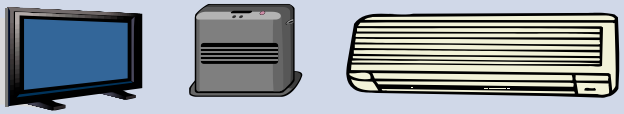
The lifestyle ecological footprint (LEF) is defined herein as the ecological footprint related to the environmental load of the residents' life.

Our evaluation of EFs is related only with EFs originating from environmental loads associated with the life of residents and excludes EF by industries and businesses.

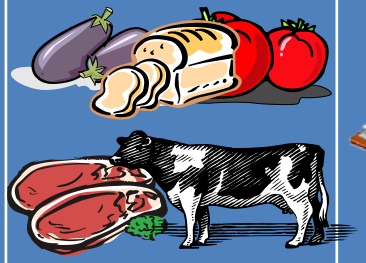
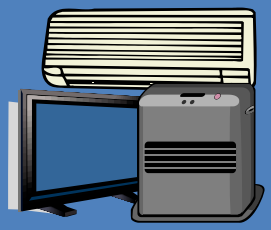
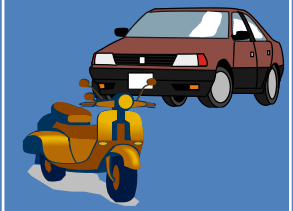
It comprises four component EFs listed below.

Food EF: EF attributable to consumption of foods.
Paper EF: EF attributable to consumption of paper products
House EF: EF attributable to consumption of energy in the household
Transportation EF: EF attributable to consumption of energy by transportation (private car and motor cycle)

Lifestyle Ecological Footprint (LEF)

Items		Data cited mainly
Food EF	(i) Area of grass farm to produce beef, mutton and dairy products (ii) Area of farmland to harvest grain 	Consumption of grain, vegetables, fruits and other food; land productivity to produce these foods
Paper EF	(iii) Area of forest logged for production of lumber 	Consumption of paper products and accumulation of lumber in forests of each production district
House EF	(iv) Area of forest to absorb CO_2 emitted by home appliances 	Consumption of electricity and gas, their conversion factors to CO_2, absorption rate of forests
Transportation EF	(v) Area of forest to absorb CO_2 emitted by vehicles for transportation 	Consumption of electricity and gas for transportation, their conversion factors to CO_2, absorption rate of forest

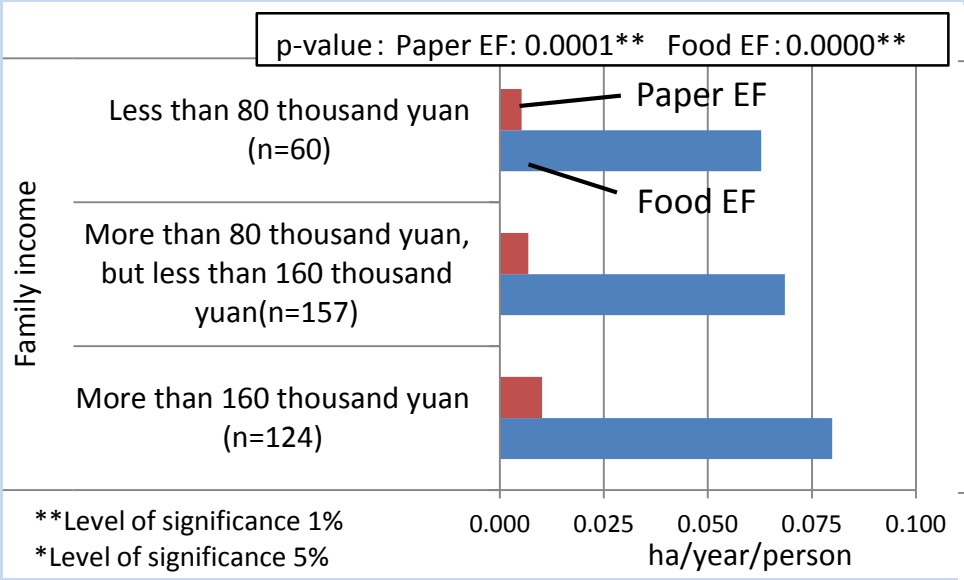
RESULTS

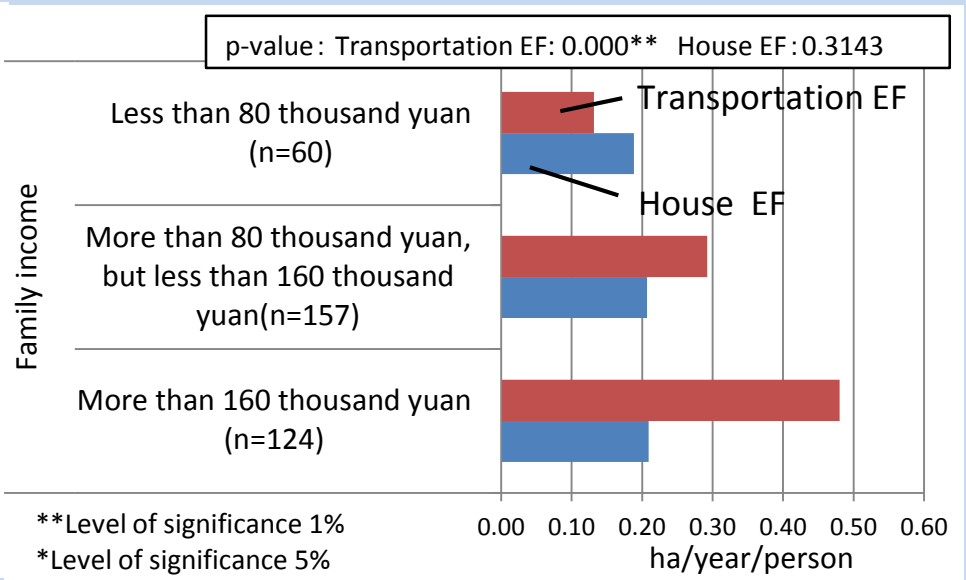
	Food EF 	Paper EF 	House EF 	Transportation EF 	LEF (sum)
Average (ha/person)	0.072	0.0076	0.20	0.32	0.61
Standard deviation (ha/person)	0.020	0.0081	0.16	0.43	0.48

① The average LEF of Shanghai residents is 0.61 ha, of which the transportation EF is 0.3 ha, the largest component, and occupies the greatest ratio of about 50% of LEF.

② The standard deviation of transportation EF is as great as 0.43 ha.

RESULTS

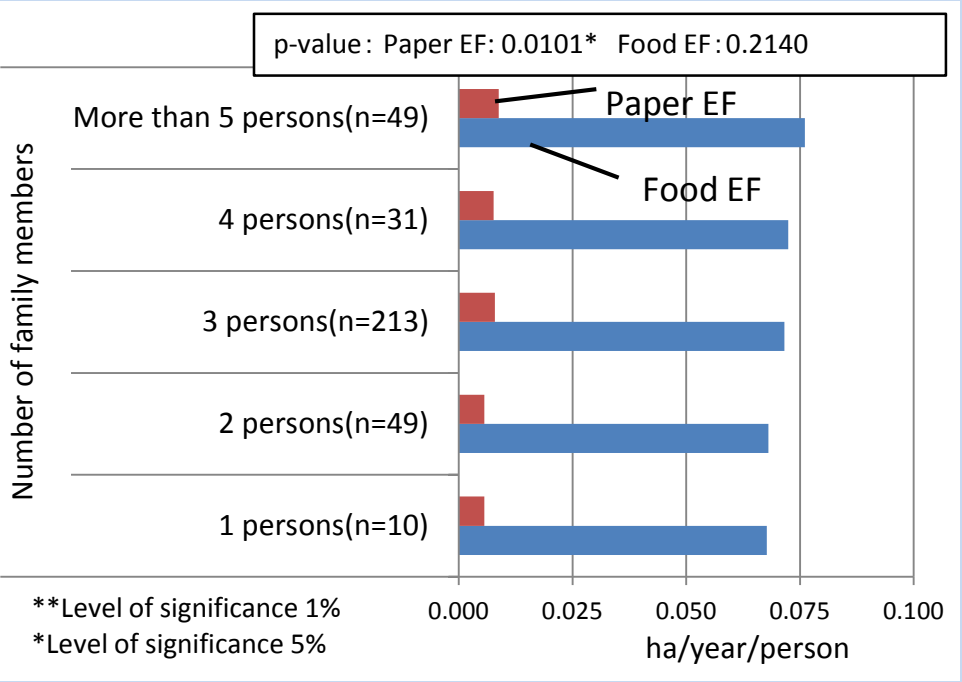


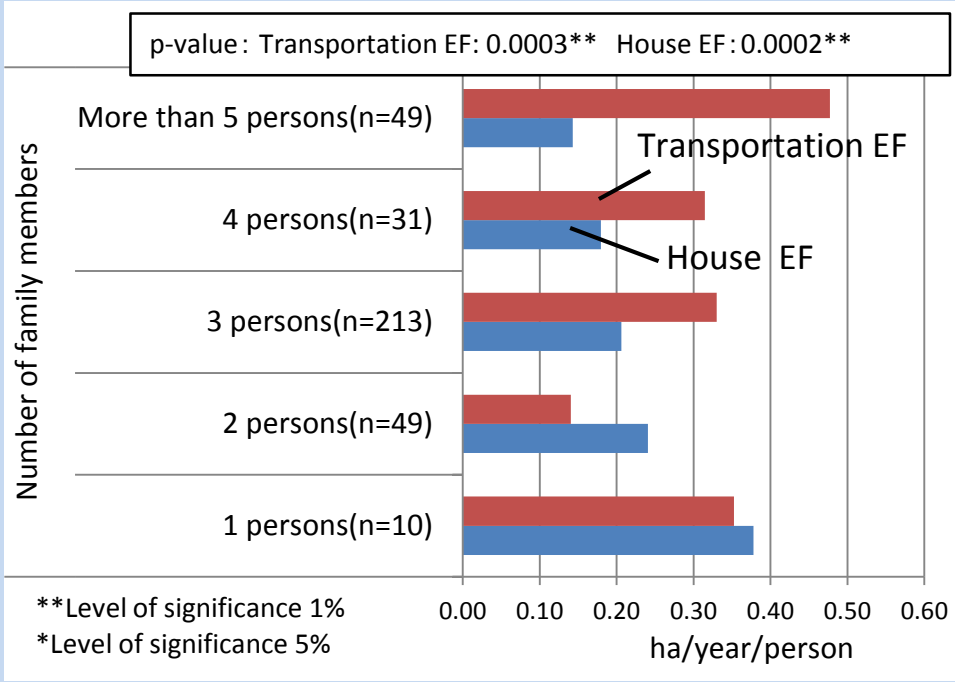


① Three EFs aside from House EF show strong positive correlation with annual family income.

② That correlation is remarkable in terms of transportation EF. The transportation EF of family with annual income of more than 160 thousand yuan is about 3.7 times greater than that of family with annual income of less than 80 thousand yuan.

RESULTS

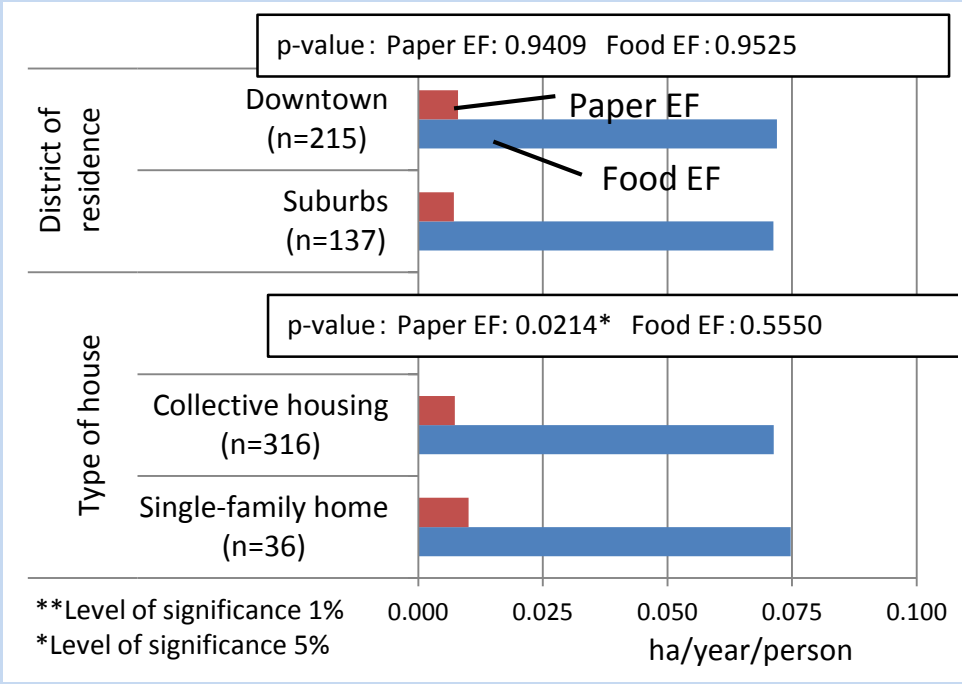


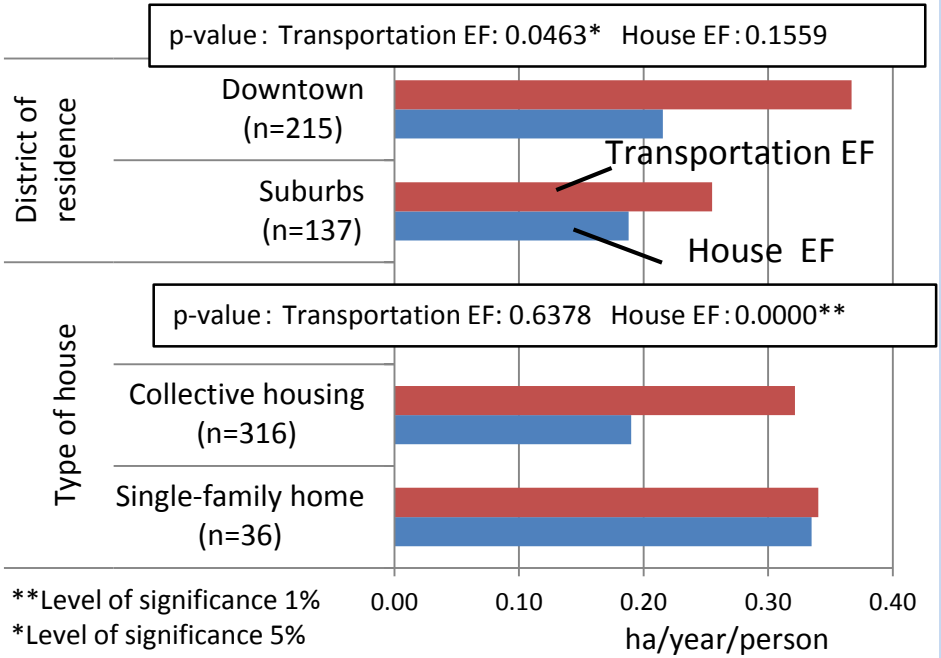


① House EF decreases concomitantly with increased number of family members.

② House EF of families with more than four members is less than half of that of a single-member household.

RESULTS





① House EF of a single-family home is some 1.8 times greater than that of collective housing. This derives from differences in the energy efficiency of a home.

② More people live in collective housing in Shanghai. Therefore, the House EF there is suppressed.

Summary

(i) Of the lifestyle-related EFs, transportation EF is the largest. Its standard deviation is large as well.
(ii) The transportation EF is positively correlated with household income.
(iii) House EF is apparently related to the type of house and the number of family members.

→ Recent expansion of wealthy population and trends toward a nuclear family in city of Shanghai affects greatly to the increase of environmental load.

Future plans

Factor analysis of transportation EF, which is the largest of LEF

(i) Property of individuals and households, (ii) ownership and use of cars, (iii) status of road infrastructure, (iv) status of public transportation

→ Clarify the relation between urban development and transportation behavior(environmental load).