人口問題研究 (J. of Population Problems) 53－2 (1997. 6) pp. 43～49

The Effect of Urbanization on Energy Consumption*

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1. Introduction

The following equation has often been used to analyze the relationship between population and environmental issues.[1]

$$E = Pe \qquad (1)$$

The equation (1) is an identity, where E, P and e denote total effect, population and effect per capita, respectively. In this paper, the equation (1) is applied to energy consumption which is clearly related to fossil fuel combustion, because carbon dioxide emissions which are primarily due to fossil fuel combustion are considered the most important cause of global warming for the future.[2] Therefore, in the following discussion, E and e denote total energy consumption and energy consumption per capita, respectively.

After an overview on the relative importance of increases in population and energy consumption per capita in Section 2, the significant relationship between the proportion of the urban population and energy consumption per capita is shown in Section 3. In Section 4, the energy consumption of the country with the largest population, China, is analyzed with special attention being paid to three large cities. Finally the concluding remarks are presented in Section 5.

2. Increases in Population and Energy Consumption per Capita

When the equation (1) is applied to the whole world, the annual increase rate of P was 1.7 percent over the period 1980-1993,[3] while that of e was no more than 0.3 percent over the

* This is a revised version of the paper presented at the symposium, "Population, Urbanization and Global Environment: Experiences from China and Thailand," Diamond Hotel, Tokyo, October 18-19, 1996. This research was funded by the HDP grant from the Environment Agency of Japan for the "Interrelationship between Population Growth in Developing Countries and Global Environment."

1) Françoise Bartiaux and Jean-Pascal van Ypersele, "The Role of Population Growth in Global Warming," IUSSP, *International Population Conference: Montreal 1993*, Vol.4, Liège, IUSSP, 1993, pp.33-54.

2) J. T. Houghton et al. eds., *Climate Change 1995: The Science of Climate Change*, Cambridge, Cambridge University Press, 1996.

3) Throughout Sections 2 and 3, data on total populations and the proportions of the urban populations for the whole world and for each country are taken from the following two statistical reports.

United Nations, *World Urbanization Prospects 1990*, New York, United Nations, 1991.

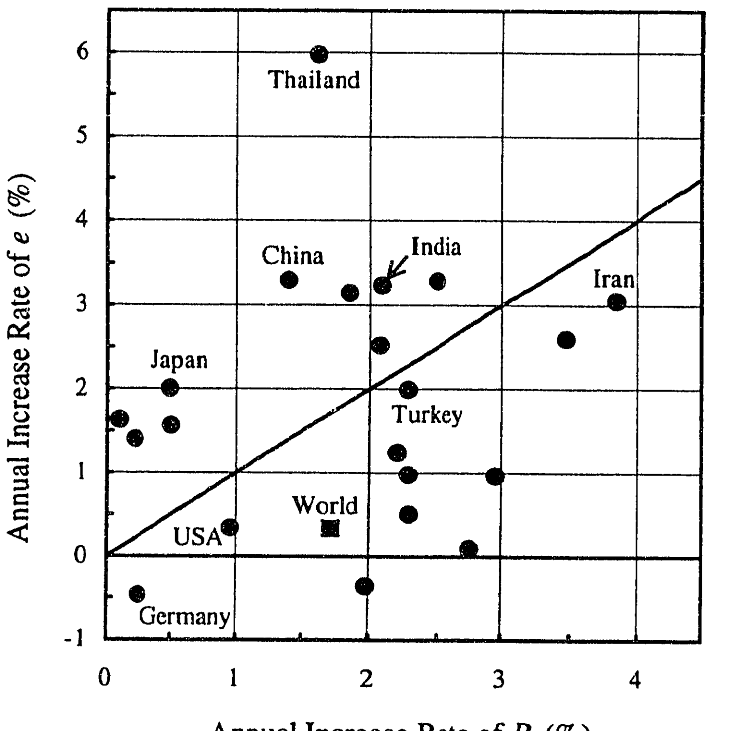
United Nations, *World Urbanization Prospects: The 1994 Revision*, New York, United Nations, 1995.

The latter is the main source and only the data on seven countries for 1980 are taken from the former; these are the USSR, the Federal Republic of Germany, the German Democratic Republic, the Socialist Federal Republic of Yugoslavia, Czechoslovakia, Yemen Arab Republic and People's Democratic Republic of Yemen. Data for 1993 are calculated by the trinomial expressions obtained from the data for 1985, 1990, 1995 and 2000.

same period.[4] When the level of data aggregation is lowered to the country level, however, various differences in the relative importance of these two increase rates emerge.

Figure 1 shows the annual increase rates of P and e over the period 1980-1993 for the twenty-one countries with populations of over fifty million in 1995.[5] The straight line expressing the balance of these two rates divides the countries into two groups almost equal in number.[6] However, it is noteworthy that the annual increase rate of e exceeded that of P in the countries with the largest populations, China and India. Furthermore, the highest annual increase rate of P was 3.8 percent, the rate for the Islamic Republic of Iran, while that

Figure 1 Annual Increase Rates of Population and Energy Consumption per Capita (1980-1993)



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4) Throughout Sections 2 and 3, data on energy consumption for the whole world and for each country are taken from the following statistical reports and include biological fuel consumption.

United Nations, *1990 Energy Statistics Yearbook*, New York, United Nations, 1992.

United Nations, *1993 Energy Statistics Yearbook*, New York, United Nations, 1995.

Data for 1980 and 1993 are taken from the former and the latter, respectively.

5) Though the Russian Federation and Ukraine also had populations of over fifty million in 1995, the data for them are not plotted in Figure 1 because of the lack of data on their energy consumption in 1980. In the same figure, the data for Germany in 1993 are compared with the total of the populations and the average energy consumption per capita for the Federal Republic of Germany and the German Democratic Republic in 1980.

6) Naturally the location of the plotted point of each country in Figure 1 strongly depends on the period observed. According to the following paper, for example, the annual increase rate of energy consumption per capita of the United States over the period 1950-1970 was 1.9 percent, while that of the population over the same period was 1.5 percent.

John P. Holdren, "Population and the Energy Problem," *Population and Environment*, Vol.12, No.3, 1991, pp.231-255.

of e was no less than 6.0 percent, the rate for Thailand.

It is not possible to neglect the importance of the change in energy consumption per capita. The purpose of the next section is to imply that energy consumption per capita is related to a demographic variable in spite of the form of equation (1).

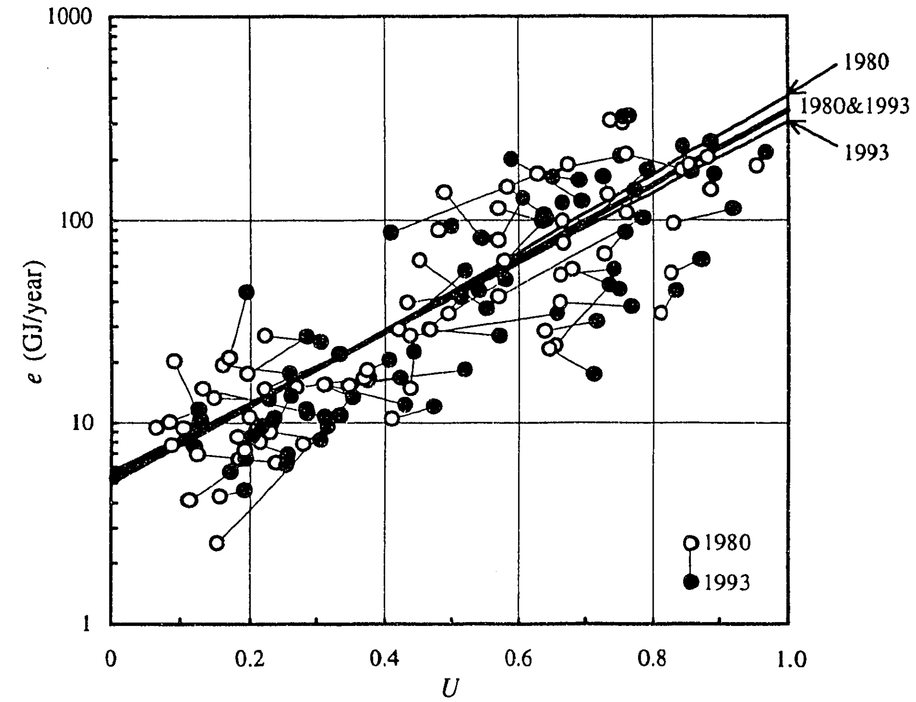
3. The Relationship between Urbanization and Energy Consumption per Capita

Figure 2 shows the relationship between the proportion of the urban population and energy consumption per capita in 1980 and 1993 of the countries with populations of over ten million in 1995.[7] The distribution of the points implies the validity of a regression analysis based on the following equation, where U denotes the proportion of the urban population and a and b are coefficients.

$$\ln e = aU + b \qquad (2)$$

The regression analysis is applied not only to data from 1980 and 1993 alone but also to data from these two years and the result shown in Table 1 is obtained. The method used involves weighted least squares with the populations for each year treated as weights. Energy consumption per capita, e, is measured in gigajoule per year. All the adjusted R squares for

Figure 2 Proportion of the Urban Population and Energy Consumption per Capita (Countries with a Population of over Ten Million in 1995)



7) The number of countries shown in Figure 2 is seventy-five for 1993 and seventy-three for 1980. The nine countries shown only for 1993 are the Russian Federation, Ukraine, Uzbekistan, Kazakhstan, Belarus, Germany, the Federal Republic of Yugoslavia, Czech Republic and Yemen. Those shown only for 1980 are the seven countries listed in footnote 3).

the three cases were over 0.70.

The three regression lines obtained are shown in Figure 2. The similarity between the two regression lines for 1980 and 1993 implies that the cross-sectional relationship between U and e is stable.

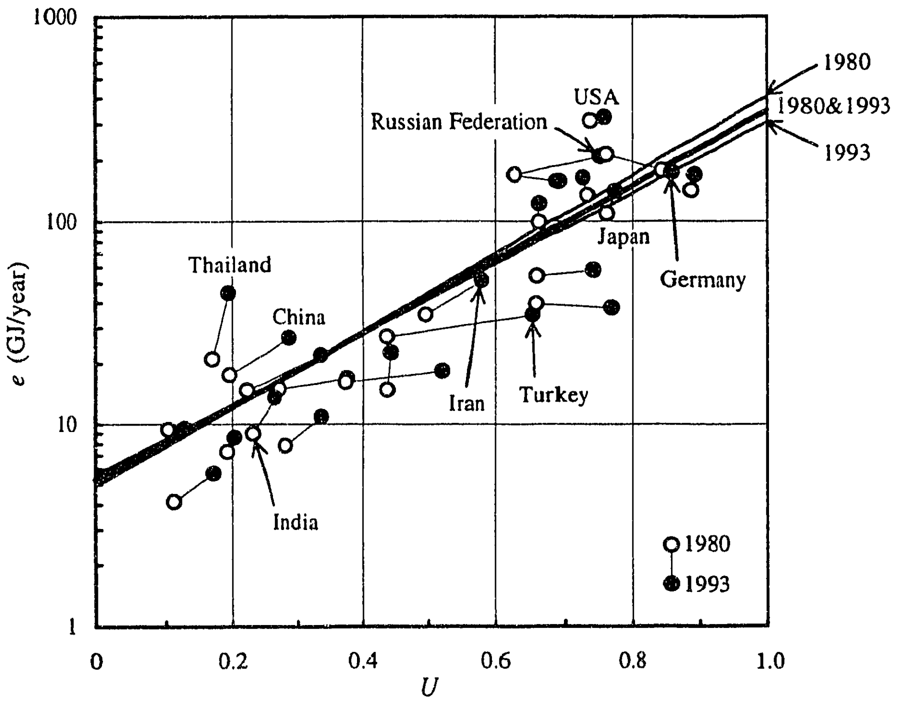
Table 1 Result of Regression Analysis Based on Equation (2)

Explanatory Variable	Year (s)		
	1980	1993	1980&1993
U	4.41	3.99	4.18
Intercept	1.60	1.73	1.67
$\bar{R}^2$	0.775	0.709	0.743

Figure 3 shows the same relationship as in Figure 2, but data on countries with populations of less than fifty million in 1995 are omitted to help distinguish between countries. The regression lines, however, are not altered from Figure 2. It is notable that for some countries the shifts in the plotted points over the period (1980-1993) are not along the regression lines in spite of the cross-sectional correlation between U and the natural logarithm of e. Though urbanization in Thailand is not very remarkable, the change in its e level is extremely rapid as shown also in Figure 1. Though urbanization in Turkey is remarkable, the change in its e level is relatively moderate.

Nevertheless, now we should consider what mechanism leads to the significant correlation between U and the natural logarithm of e. It seems that the level of economic development determines U and e simultaneously. However, it is also likely that U determines e according to the energy consumption per capita of both urban and rural areas, namely, that urbanization is the cause of the increase in e. If the latter mechanism exists, there must be difference in energy consumption per capita between urban and rural areas.

Figure 3 Proportion of the Urban Population and Energy Consumption per Capita (Countries with a Population of over Fifty Million in 1995)



4. The Case of China

Since Beijing, Tianjin and Shanghai are separate administrative divisions of China with status as either provinces or autonomous regions,[8] it is possible to obtain not only data on their populations[9] but also data on their energy consumption.[10] Table 2 shows the populations and energy consumption per capita of these three cities, the rest of China and the whole China for 1990.[11]

Table 2 Population and Energy Consumption per Capita by Region in China (1990)

Region	Population ($\times 10^4$)	Energy Consumption per Capita (GJ/year)
Beijing	1032	76.9
Tianjin	866	70.1
Shanghai	1283	72.5
3 Cities	3181	73.3
China excl. 3 Cities	109936	23.3
Whole China	113117	24.7

Though the total population of the three cities is only 2.8 percent of that of the whole China, it is notable that the average energy consumption per capita for them was 3.1 times as large as that of the rest of China and 3.0 times as large as that of the whole China.[12]

To decompose the growth in energy consumption for the whole China denoted by E, we get the following by modifying the equation (1).

$$E = P_{3C}\, e_{3C} + P_{E3C}\, e_{E3C} \qquad (3)$$

In the equation (3), P_{3C} and e_{3C} denote the population and energy consumption per capita, respectively, of the three cities, namely, Beijing, Tianjin and Shanghai. Similarly P_{E3C} and e_{E3C} denote the population and energy consumption per capita, respectively, of the rest of China excluding the three cities. Table 3 shows the annual increase rates of these four variables over the period 1986-1990 and the contribution of their growth to the growth in E over the same period. In spite of the large size of e_{3C}, the contribution of the growth in

8) Chongqing also has become a separate administrative division in March 1997.

9) Throughout Section 4, the demographic data on administrative divisions in China are taken from the following statistical report, and the population data are measured at the end of each year.
Yao Xinwu and Yin Hua eds., *Basic Data of China's Population*, Beijing, China Population Publishing House, 1994, pp.12-71.

10) Throughout Section 4, the data on the energy consumption of administrative divisions in China are taken from the following statistical reports and do not include biological fuel consumption.
Department of Industry and Traffic Statistics of State Statistical Bureau, *Zhongguo Nengyuan Tongji Nianjian 1989* [*China Energy Statistics Yearbook 1989*], Beijing, China Statistical Publishing House, 1990.
Department of Industry and Traffic Statistics of State Statistical Bureau, *Zhongguo Nengyuan Tongji Nianjian 1991* [*China Energy Statistics Yearbook 1991*], Beijing, China Statistical Publishing House, 1992.
Data for 1986 and 1990 are taken from the former and the latter, respectively.

11) Throughout Section 4, Tibet is not included in "China" because of the lack of data on its energy consumption. The population of Tibet was 2.18 million in 1990.

12) According to the following paper, the average energy consumption per capita of the Bangkok Metropolitan Region was 3.8 times as large as that of the whole Thailand in 1988.
Toshiaki Ichinose, Keisuke Hanaki and Tomonori Matsuo, "International Comparison of Energy Consumption in Urban Area," *Kankyo Kogaku Kenkyu Ronbunshu* [*Proceedings of Environmental Engineering Research*], Vol.30, 1993, pp.371-381 (in Japanese).

P_{3C} is the smallest of the four not just because P_{3C} is much smaller than P_{E3C} but also because the increase rate of P_{3C} is relatively small.[13] Actually the proportion of the total population living in the three cities decreased over the period and their growth is not remarkably noteworthy. Instead the contribution of growth in e_{E3C} was the largest.

Table 3 Increases in Variables in Equation (3) and Their Effects (1986-1990)

Variable	Annual Increase Rate (%)	Contribution to Growth in E (%)
P_{3C}	1.32	2.3
e_{3C}	2.19	3.9
P_{E3C}	1.79	32.4
e_{E3C}	3.32	61.4
E	5.03	

Table 4 Population Growth in Beijing, Tianjin and Shanghai (1986-1990)

City	Natural Increase ($\times 10^4$)	Net Migration ($\times 10^4$)	Total Growth ($\times 10^4$)
Beijing	35	26	61
Tianjin	33	18	51
Shanghai	28	23	51
Total	96	67	163

It is possible to break down the population growth in the three cities into natural increase and net migration by utilizing data on crude birth rates and crude death rates. For each year over the period 1986-1990, the difference between the population growth and the estimated natural increase is regarded as net migration. Table 4 shows the result and implies that 41 percent of population growth in the three cities over the period 1986-1990 was due to net migration, which contributed an estimated 0.9 percent to the growth in energy consumption for the whole China.

5. Concluding Remarks

Prior debates on the relationship between population and environmental issues have had a tendency to focus on population size and to ignore other demographic variables.[14] In this paper, however, it has been shown that urbanization is a useful demographic concept to approach the study of global warming.

It is still difficult, however, to clarify the mechanism by which urbanization relates to energy consumption. The possibility that urbanization is the cause of increases in energy consumption per capita is supported by the Chinese data but has not been proven yet.

The limited data available on the energy consumption of cities which are rapidly increasing in population prevent the study from progressing. Though the data on Beijing, Tianjin and Shanghai are available, their growth rates are not very remarkable. It seems that energy consumption in China is being pushed up by the growth of other existing cities and/or the

13) The annual increase rates of the populations of Beijing, Tianjin and Shanghai over the period 1986-1990 were 1.53, 1.53 and 1.02 percent, respectively.

14) Daniel J. Hogan, "The Impact of Population Growth on the Physical Environment," *European Journal of Population*, Vol.8, No.2, 1992, pp.109-123.

emergence of new cities.

Reliable demographic data on countries in which urbanization is proceeding rapidly are also needed. It is desirable that migration be studied with attention being paid to changes in migrants' life styles and/or occupations, which affect energy consumption.

都市化がエネルギー消費量におよぼす影響

今 井 博 之

環境問題を人口学的観点から論ずる場合，地域全体による環境への影響を人口と１人当たりの影響との積として表すという方法が一般的であるが，本研究ではこの方法を地球温暖化と関係が深いエネルギー消費量に対して適用する．

恒等式（エネルギー消費量）＝（人口）×（１人当たりエネルギー消費量）を世界全体に対して適用すると，1980-1993年において，人口は年率1.7%で増加しているのに対し，１人当たりエネルギー消費量は年率0.3%でしか増加していない．しかしながら，この恒等式を国別にあてはめると，同じ期間について，１人当たりエネルギー消費量は，中国，インドを含む多くの国で人口を上回るペースで増加しており，タイにおいては年率6.0%で急増している．

また，１人当たりエネルギー消費量は各国の都市人口割合と明瞭な関係をもっており，1980年，1993年のそれぞれのクロスセクション・データについて，都市人口割合と１人当たりエネルギー消費量の対数との間に正の相関が現れる．このことは，①経済発展の程度が都市人口割合と１人当たりエネルギー消費量とを同時に規定する，②都市と農村とで１人当たりエネルギー消費量に格差がある，の２つの可能性を示唆するが，②では，都市化は１人当たりエネルギー消費量増加の原因として位置づけられる．

中国の統計では，北京，天津，上海の３つの直轄市がそれぞれ単独の行政区域としてあつかわれてきたため，これら３都市の人口およびエネルギー消費量を３都市を除いた全中国のそれらから区別することができる．1990年時点では，全中国の2.9%の人口をかかえる３都市の１人当たりエネルギー消費量は，３都市を除く全中国の3.1倍であり，都市化が１人当たりエネルギー消費量増加の原因となりうることがわかる．しかし，３都市の人口の割合は1986-1990年でむしろ低下しており，中国における１人当たりエネルギー消費量の増加は，３都市を除いた地域における都市の成長や出現によるものと考えられる．