Journal of Global Environment Engineering, Vol. 1, pp. 79–100, 1995

ECONOMIC DEVELOPMENT, ENERGY, AND ENVIRONMENT IN EAST ASIA: A COMPARATIVE STUDY OF JAPAN, SOUTH KOREA, AND CHINA

Hidefumi Imura[1]
Tohru Futawatari[2]
Ryo Fujikura[3]

Abstract

Asian economic development has been more than a miracle. If its current pace is maintained, Asia will be a growth center of the world in the next century. Economic development, however, will inevitably be accompanied by expanded use of energy and other resources, causing environmental degradation and pollutant emissions. Economic development in China in particular will have profound implications not only to the regional but also the global environment, considering its large population and coal-based energy supply structure. Similar observations also apply to ASEAN countries. Thus environmental countermeasures have become pressing and urgent policy objectives for all Asian countries. As Asian economic development occurred in successive waves, the current economic and environmental situation in DAEs (Dynamic Asian Economies) such as South Korea is very similar to that in Japan in the late 1960s to 1970s, and that in China is reminiscent of Japan in the mid-1950s to 1960s. This paper makes a historical comparison of the economic development and environmental conditions in Japan, South Korea, and China. Focusing on the energy demand and the associated emission of carbon dioxide and air pollutants, the paper discusses the environmental implications of the economic development in these countries.

KEYWORDS: *economic development and environment, environmental problems in East Asia, energy and environment, carbon dioxide, air pollution*

1. Introduction

Asian economic development has occurred in successive and overlapping waves. Japan took off in the mid 1950s, followed by the Dynamic Asian Economies (South Korea, Taiwan, Hong Kong, and Singapore) in the 1970s and the ASEAN countries and China in the 1980s (Okita, 1993). Economic development has had two major consequences in Japan: environmental degradation on one hand, and improved financial and technical capabilities to cope with it on the other (Imura, 1993). The same observation would also apply to other Asian nations.

As early as a decade after rapid economic growth started in Japan, air and water pollution became visible and the natural environment was subject to irreversible changes throughout

1 D. Eng., Professor, Inst. of Environmental Systems, Faculty of Eng., Kyushu University, Higashi-ku, Fukuoka, 812 Japan.
2 D. Eng., Research Associate, ibid.
3 D. Sci., Deputy Director, Environmental Cooperation Office, Environment Agency

the country. From the mid-1960s to the 1970s Japan had to devote its maximum effort to regaining clean air and water; countries such as South Korea and China started their fight for environmental protection ten to twenty years later than Japan. As a result, the current economic and environmental situation in these countries is reminiscent of Japan at the time that environmental countermeasures became imperative to achieve economic development.

To a great extent, most of the local pollution problems can be solved by "end-of-the-pipe" control technologies. Nevertheless, technologies can not provide a solution to some critical global problems. Global warming, for example, is caused by the use of fossil fuels, and no radical measures can be found to prevent it. Carbon dioxide (CO_2) emissions in Asian countries have already reached 20% of the world total (Sakai *et al.*, 1992). If economic growth in China, ASEAN and the Dynamic Asian Economies (DAEs) maintains its present pace, their energy consumption and CO_2 emissions will inevitably increase. Constraints on the use of energy therefore will be a critical determining factor in the future economic development in this region.

This paper presents a historical review of the records of economic development and environmental conditions in Japan, South Korea, and China. Based on published reports and available statistical data, the paper compares the changes in socioeconomic conditions, energy consumption structure, and the state of the environment in these countries. It focuses on energy use and the associated emission of carbon dioxide in these countries, reviewing the technical possibilities for saving energy. Finally, in the light of the Japanese experience, it discusses the environmental risks of growth-oriented development policies and the future directions of economic development and environmental action in East Asia.

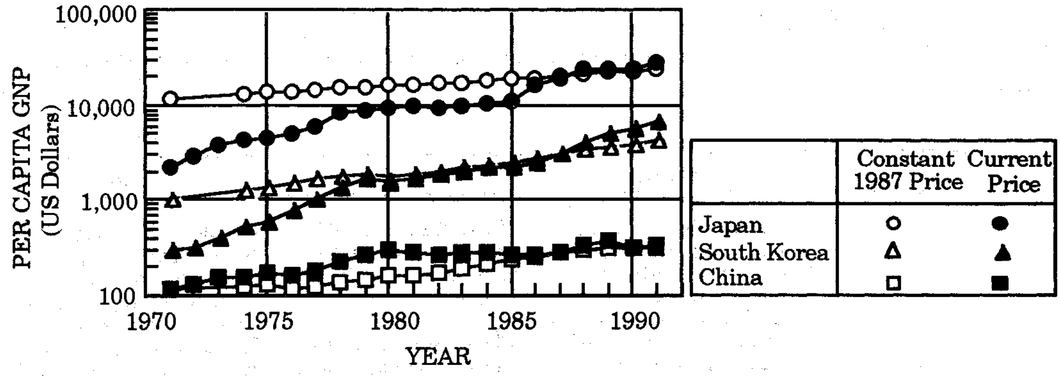
2. Economic Development and Environment in Japan, South Korea, and China

2.1 An Overview

There are conflicting views about economic development and the environment. People in industrialized countries may feel that a slowdown in economic growth should be accepted for environmental protection, whereas people in developing countries may insist on the necessity of growth. Both of these views are persuasive in the context of differing national situations. There is an empirical observation applicable to countries: when per capita annual income reaches a certain level, say about nominal US$2,000 per person, people can basically afford their material needs, and begin to seek a better quality of life. Then they develop an interest in environmental quality and governments must give greater priority to environmental protection.

Figure 1 demonstrates the change in per capita GNP (gross national product) in Japan, South Korea, and China, whereas Table 1 shows indices of their economic development. Table 2 compares the brief history and current situation of environmental actions in the three countries. There are gaps in environmental measures between countries according to the gaps in the stage of their economic development.

Japan reached the above mentioned income level in 1970, and then South Korea in mid 1980s. In terms of the per capita GNP in constant 1987 price, there is a time gap of about fifteen years between Japan and South Korea, and seemingly more than a twenty-year gap between South Korea and China. It is, however, conjectured that the Chinese GNP should be valued at three to four times that in order to translate it into actual purchasing power (SSTCC, 1994). Moreover, inhabitants of large cities such as Shanghai and Beijing have an income three



Data Source: World Tables (World Bank)

Figure 1. Change in per capita GNP.

Table 1. Economic development in Japan, South Korea, and China.

	Japan			South Korea			China		
Year	1971	1980	1991	1971	1980	1991	1971	1980	1991
Per capita GNP (in US dollars, Current Price)	2176	9051	27306	300	1587	6493	120	304	323
Production of Major Basic Materials (million tons)									
Crude Steel	92.4	107.4	105.9	0.5	8.6	21.9	17.8	37.1	71.0
Cement	58.2	86.4	89.0	–	15.6	39.2	25.8	79.9	252.6
Ethylene	3.3	3.9	6.2	–	0.4	1.6	0.0	0.5	1.8
Paper	7.2	10.3	17.0	–	1.4	3.6	2.4	5.4	14.8
Number of Motor Vehicles per 1000 persons	170	324	446	36	13.2	62	0.8	0.9	4.2
Production of Home Electric Appliances per 1000 persons									
Television	132	139	122	3.5	179	370	0.013	2.5	23
Washing machine	25	37	44	–	5	50	–	0.25	5.9
Refrigerator	42	43	45	0.87	17	75	0.006	0.05	4.1

Data Source: World Tables (World Bank); Korea Statistical Yearbook (Korean Statistical Association); Chinese Statistical Yearbook (Chinese Statistics Publishing Company); etc.

to five times as large as those who live in rural areas (Chinese Statistical Yearbook, 1993). In fact, it could be concluded that per capita income in major Chinese cities has almost reached the above level.

As per capita income increases, the demand for mobility also increases. Empirically, when GNP per capita reaches about US$ 4,000, demand for private car ownership rises rapidly. Consequently, if public transportation systems are not properly improved, serious traffic congestion and air pollution caused by automobiles will take place. An example of such problems is Bangkok.

In short, economic growth has brought about environmental problems in Asian countries, and their governments have become aware of the necessity and importance of environmental measures. Some countries, however, are still concerned about the alleged economic impacts of environmental policies, and information about the environmental risks and dangers is not

Table 2. Brief history and current situation of environmental actions in Japan, South Korea, and China.

	Japan	South Korea	China
Major Characteristics of Environmental Problems	-1960s: Time of environmental turmoil: rapid economic growth and industrial pollution, health victims, anti-pollution movement of citizens, reluctant industrial attitudes, etc. -1970s: Systematic implementation of environmental control, industrial structure change triggered by oil crisis, etc. -1980s: Increased demand for the "quality of life," such as urban environ-mental amenities -1990s: Increasing public concerns about global environmental issues, and the public consensus based on the "sustainable development" concept	-1970s: Start of rapid economic growth with little attention paid to the environment -1980s: Systematic start of environmental control measures -1990s: Increased public concerns about pollution incidents. Environmental problems became a subject on the political agenda. Reorientation of the policy of growth necessary, giving priority to environmental protection	-1980s: "Four Modernizations" policy: cooperation with the West and introduction of modern technologies. Rising standard of living and increasing resource consumption and pollutant emissions. Environmental actions led by government initiatives -1990s: Environment became a major constraint to economic development: environmental degradation accelerated; transboundary problems with S. Korea and Japan; environmental measures have become a requisite for acquiring development aid from outside.
Legislative and Institutional Framework at National Level	-1967: Enactment of basic environmental laws ("Basic Law for Pollution Control," "Air Pollution Control Law," "Water Pollution Control Law," etc.) -1971: Establishment of the Environment Agency -1973: Enactment of the "Health Damage Compensation Law" -1987: Amendment of the "Health Damage Compensation Law" -1993: Enactment of "Basic Law for the Environment"	-1977: Enactment of "Environmental Conservation Law" -1990: Enactment of "Basic Law for Environmental Policies" -1990: Enactment of "Atmospheric Environment Conservation Law": strengthening of emission standards, introduction of an emission charge system -1991: Enactment of the "Law on the Cost Allocation and Liability for Environmental Improvement" -1993: Enactment of "Environmental Impact Assessment Law"	-1979: Provisional enforcement of "Environmental Protection Law" -1989: Enactment of "Air Pollution Control Law" -1989: Nation-wide enforcement of "Environmental Protection Law"

Table 2. (continued). Brief history and current situation of environmental actions in Japan, South Korea, and China.

	Japan	South Korea	China
Local Initiatives and Public Awareness	-Since 1950s: Number of local ordinances enacted for pollution control, environmental impact assessment, etc. -Strong public awareness in support of environmental actions	-Local initiatives have been rather week due to the centralized administrative system. Public awareness is being improved with increasing income per capita and environmental initiatives of the government	-Improvement of administrative capabilities of provinces and municipalities under the guidance of the central government -Environmental awareness of the public has not been systematically created, but the situation may change due to aggravating state of the environment and the stronger environmental initiatives of the central and local governments
Economic Instruments	-SOx emission charge based on the "Health Damage Compensation Law" -Financial measures such as public subsidies, low-interest loans, special tax exemption, etc.	-Emission charge based on the "Law on the Cost Allocation and Liability for Environmental Improvement"	-Pollution charge: system amended in 1994
Technological and Financial Situation	-Accumulated knowledge of advanced technologies: "end-of-the-pipe" control technologies, energy conservation, environmental monitoring, etc. -Creation of "eco-business" -Technology transfer to other countries	-Greater investment necessity for installing pollution control technologies, *e.g.*, flue-gas desulfurization -Priority in R&D should be given to environmental technologies.	-Large investment necessity for installing pollution control technologies and improving infrastructures such as sewage system -Replacement of old and inefficient production technologies -Financial problems in purchasing environmental technologies -A number of financial aid and technology transfer projects being implemented or planned

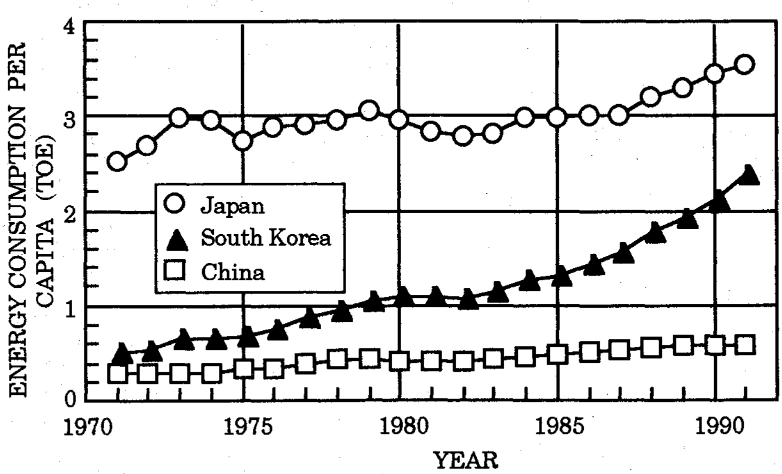
Data Source: Quality of the Environment in Japan (Environment Agency, Government of Japan); Environmental Pollution Control, The Japanese Experience (The United Nations University, 1993); Annual Report on the State of the Environment in Korea (Ministry of Environment, Rep. of Korea); Chinese Environmental Yearbook (Chinese Environmental Science Publishing Company); Report of the Task Force on Japan-Korea and Korea-Japan Environmental Problems (Japan-Korea and Korea-Japan General Industrial Committee, 1994); Report on the Study of Japan-China Environmental Technology Transfer (Japan Productivity Center, 1994) widely shared with the public. Furthermore, many countries suffer from lack of manpower, technology, and administrative capability in implementing environmental policies, although they are rapidly improving relevant legislation, standards, and institutions (Brandon, C., and Ramankutty, R. 1993).

2.2 The Trilemma of Economic Growth, Energy, and Environment

Economic growth and energy demand are closely related to each other. Energy consumption per person increases with economic growth in response to rising industrial production, increasing freight and passenger transport, the wider dissemination of home electric appliances and so forth. Here, energy use is accompanied by emission of air pollutants and CO_2 as long as its major source is fossil fuels. Thus, the economy, energy, and the environment are closely linked to each other. Decoupling of these three factors is very difficult: the trilemma of economy, energy, and environment.

Figure 2 compares the relation between per capita income and energy demand in Japan, South Korea, and China, whereas Table 3 shows the change in energy consumption, carbon dioxide (CO_2) emissions, and emission of sulfur oxides (SO_x) and nitrogen oxides (NO_x). The primary energy consumption per capita in China is considerably smaller than those in Japan and South Korea: its figure in 1991 is comparable to that in South Korea at the beginning of the 1970s, or almost the same as the Japanese in the early 1950s. Nonetheless, due to its large population and coal-dependent energy supply structure, emission of sulfur oxides, nitrogen oxides, suspended particulates, and carbon dioxide in China, which are already enormous in volume, will further increase, giving rise to constraints on its economic growth.

Figure 3 compares the shares of final energy consumption by sectors. In Japan, the percentage of the industrial sector has declined, while that of the transport and commercial/residential sectors has been increasing. In South Korea, the share of the industrial sector has slightly increased. In China, consumption by the industrial sector is remarkably high compared to other countries, and there has been almost no change in its share from 1971 to 1991.



Data Source: Energy and Economic Statistical Data Book '94 (The Energy Data and Modeling Center, 1994)

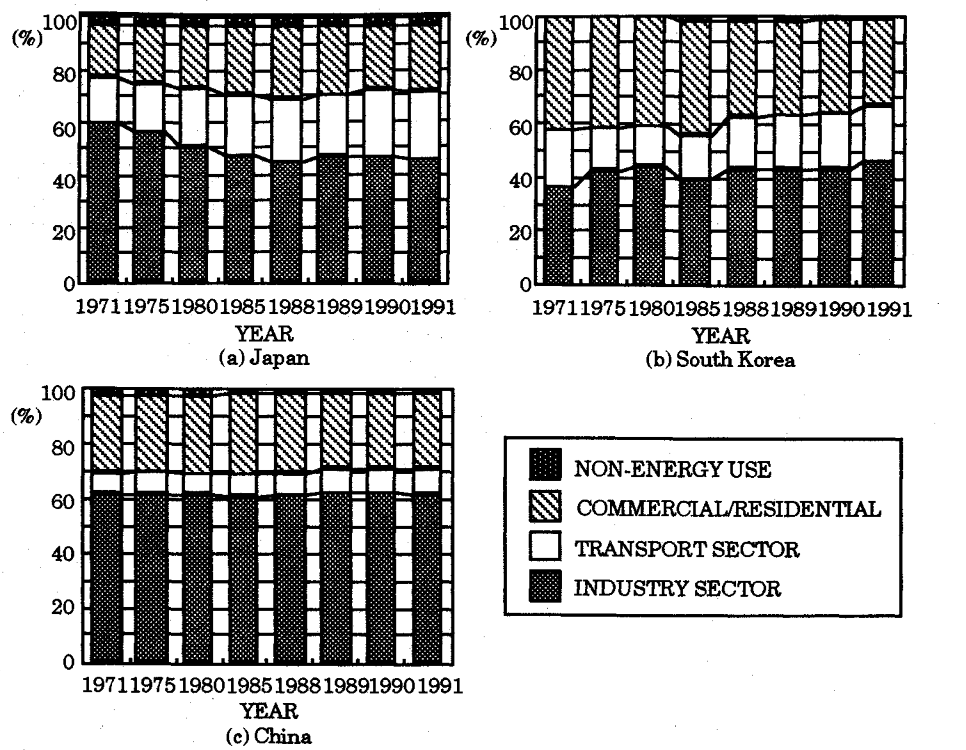
Figure 2. Change in energy consumption per capita

Table 3. Energy consumption and the associated emission of pollutant in Japan, South Korea, and China.

	Japan			South Korea			China		
Year	1971	1980	1991	1971	1980	1991	1971	1980	1991
Primary Energy Demand (Million TOE) (a)	268	346	438	17	41	102	236	412	665
Share / Coal (%)	20.9	17.3	17.6	35.3	31.7	24.5	80.5	74.5	77.9
Oil (%)	74.6	67.9	57.1	64.7	65.9	57.8	16.9	21.6	18.5
Gas (%)	1.1	6.1	10.5	0.0	0.0	2.9	1.3	2.9	2.0
Nuclear (%)	0.7	6.4	12.8	0.0	2.4	14.7	0.0	0.0	0.0
Hydroelectricity (%)	2.6	2.3	1.8	0.0	0.0	0.0	1.3	1.2	1.7
per Capita (TOE/capita)	2.53	2.95	3.54	0.51	1.09	2.36	0.28	0.42	0.58
per GNP (TOE/million US$)	213	184	148	490	613	557	2437	2611	1676
per Land Area (TOE/km^2)	713	920	1164	141	340	847	26	45	72
Final Energy Consumption) (Million TOE) (a)	213	248	305	14	34	79	193	325	496
CO_2 Emission (million tC) (a)	244	291	339	16	39	82	247	424	686
per Capita (tC/capita)	2.30	2.48	2.73	0.49	1.02	1.90	0.29	0.43	0.60
per GNP (tC/million US$)	194	155	114	472	577	450	2548	2683	1731
per Land Area (tC/km^2)	646	770	897	162	394	828	25.8	44.3	71.7
Year	1975 (b)		1987 (b)	1975 (b)	1987 (b)	1991 (c)	1975 (b)	1987 (b)	1992 (d)
SOx Emission (1000 t)	2569		1141	1159	1292	1598	10168	19954	16848
per Capita (t/capita)	0.023		0.009	0.033	0.031	0.037	0.011	0.018	0.014
per GNP (t/million US$)	1.71		0.47	24.1	10.0	8.73	85.4	65.6	34.3
per Land Area (t/km^2)	6.80		3.02	11.7	13.1	16.1	1.06	2.09	1.76
NOx Emission (1000 t)	2329		1935	220	555	878	3727	7371	
per Capita (t/capita)	0.021		0.016	0.006	0.013	0.020	0.004	0.007	
per GNP (t/million US$)	1.55		0.80	4.58	4.30	4.80	31.3	24.2	
per Land Area (t/km^2)	6.17		5.12	2.22	5.60	8.87	0.39	0.77	

Data source:
(a) Energy and Economics Statistical Data Book '94 (The Energy Data and Modeling Center, 1994)
(b) Energy Use and the Environment in Asia, Science and Technology Agency of Japan (1993)
(c) Annual Report on the State of the Environment in Korea (1992)
(d) Chinese Environmental Yearbook (1993)
Note: GNP at constant 1987 price is used.

With respect to per capita GNP in 1991 expressed in US dollars, there are great differences between the nations: US$ 27,300 in Japan, US$ 6,500 in South Korea, and US$ 323 in China. However, for primary energy consumption per capita, differences are smaller: 3.54 TOE (tons of oil equivalent) in Japan, 2.36 TOE in South Korea, and 0.58 TOE in China. The actual purchasing power of a currency and the quality of life in developing countries are undervalued if per capita GNP in US dollars is used as an indicator; energy consumption could more relevantly express the real standard of living in differing countries.



Data source: Energy Balances of OECD and Non-OECD Countries (International Energy Agency, OECD, Paris)

Figure 3. Change in the shares of energy consumption by sectors.

3. Energy and CO_2 Emission Structures in Japan, South Korea, and China

3.1 Comparison of the Energy Consumption in the Industrial Sector

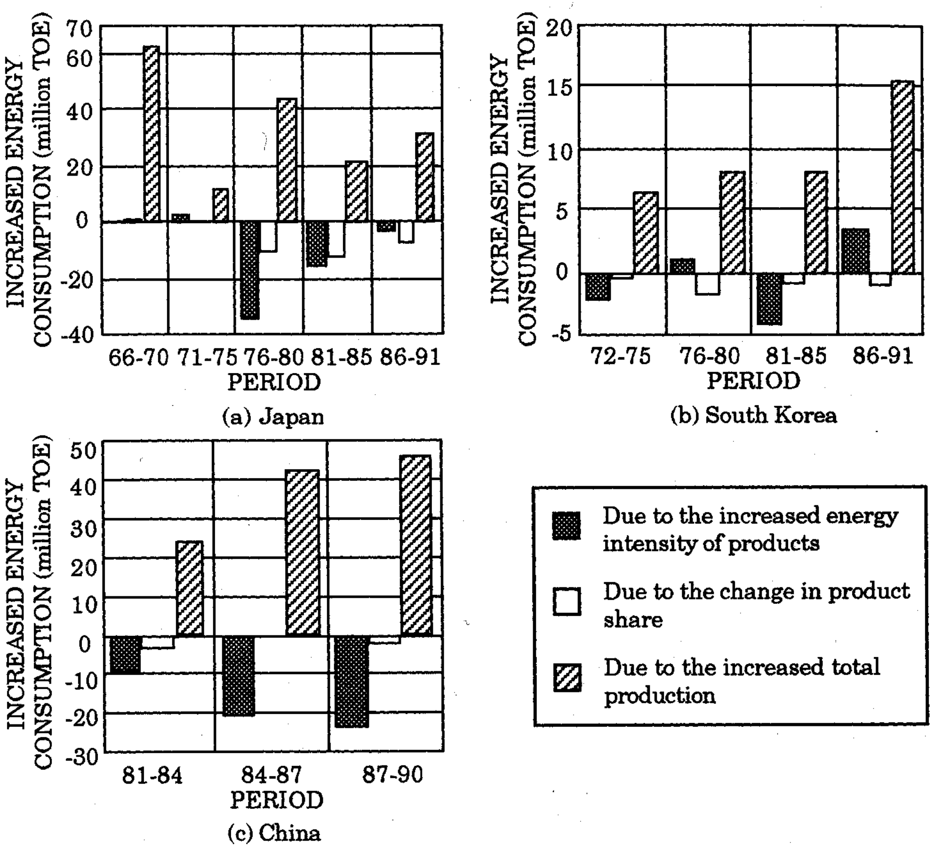
As Fig. 3 shows, the industrial sector shares the largest proportion in the total energy end-use in all three countries. The total energy demand by the industrial sector E can be written as

$$E = \sum_i \frac{E_i}{Z_i} \times \frac{Z_i}{Z} \times Z \tag{1}$$

where E_i and Z_i are the energy demand and the production of the i-th industrial sector, respectively, and Z is the total industrial production. Then the change in E over a certain period of time can be written as

$$\Delta E = \sum_i \Delta\left(\frac{E_i}{Z_i}\right) \times \frac{Z_i}{Z} \times Z + \sum_i \frac{E_i}{Z_i} \times \Delta\left(\frac{Z_i}{Z}\right) \times Z + \sum_i \frac{E_i}{Z_i} \times \frac{Z_i}{Z} \times \Delta Z \tag{2}$$

The first, second, and third term on the right hand side of the above equation express the changes in energy demand due to the change in energy intensity of the i-th product, change in product share (or industrial structure), and the change in total production, respectively.



Note: Analysis was made on the data from Energy Balances of OECD and Non-OECD Countries (International Energy Agency, OECD, Paris) and Chinese Energy Statistical Yearbook (Chinese Statistics Publishing Company). Figures are presented in different scales and different time period between countries.

Figure 4. Changes in energy demand structure.

Figure 4 compares the changes in energy demand in the three countries up until 1991. Here, in the classification of industrial sectors, nine manufacturing sectors are used for Japan and South Korea, whereas five materials producing sectors are considered for China. In Japan, energy consumption increased almost proportionately to production growth until 1975. Then, energy intensity was markedly reduced in 1976-1980, owing to the increased price of oil. This offset largely the energy demand increase due to production expansion. In 1981-1985, the reduction of energy intensity became smaller, while the reduction due to changes in industrial structure came to play an important role.

In South Korea, the total energy demand increase due to production expansion has been remarkable, while energy intensity per production decreased in 1981-1985 but increased again in 1986-1991. This trend in South Korea shows the characteristics of its economic growth, which depended largely upon the production expansion of heavy industries. As in South Korea, Chinese production expansion brought about an increase in energy demand. In China, however, the reduction in energy intensity per production has accelerated, although the change in product share has not been notable.

3.2 Comparison of CO_2 Emission Structure

The relationship between economic production (GDP), primary energy requirement (E_{pr}), fossil fuel consumption (E_{ff}), and CO_2 emission (CO_2) can be expressed by the following equation (Sakai *et al.*, 1992):

$$CO_2 = \frac{CO_2}{E_{\text{ff}}} \times \frac{E_{\text{ff}}}{E_{\text{pr}}} \times \frac{E_{\text{pr}}}{GDP} \times GDP \tag{3}$$

Thus the energy intensity per production can be written as

$$\varepsilon = \xi \times \eta \times \zeta \tag{4}$$

where, $\varepsilon = CO_2/GDP$; $\xi = CO_2/E_{\text{ff}}$; $\eta = E_{\text{ff}}/E_{\text{pr}}$; and $\zeta = E_{\text{pr}}/GDP$.

The reduction in the CO_2 intensity of production ε can be achieved in three ways: the reduction of ξ by changing the share of fossil fuels, i.e., coal, oil and natural gas; the reduction of η by increasing the share of non-fossil fuels such as nuclear, hydroelectric, and renewable energy sources; and the reduction of ζ which can be achieved either by encouraging energy conservation in individual sectors or by changing the share of products.

The changes of the above indices in China, South Korea, and Japan are demonstrated in Fig. 5. The high value of ξ in China can be attributed to its high reliance upon coal. On the other hand, the decreasing value of ξ in Japan was achieved by switching fuel from coal to oil in the 1960s and by the increased use of natural gas in the 1970s and 1980s. The decreasing value of η in Japan and South Korea was mainly due to the expanded use of nuclear energy.

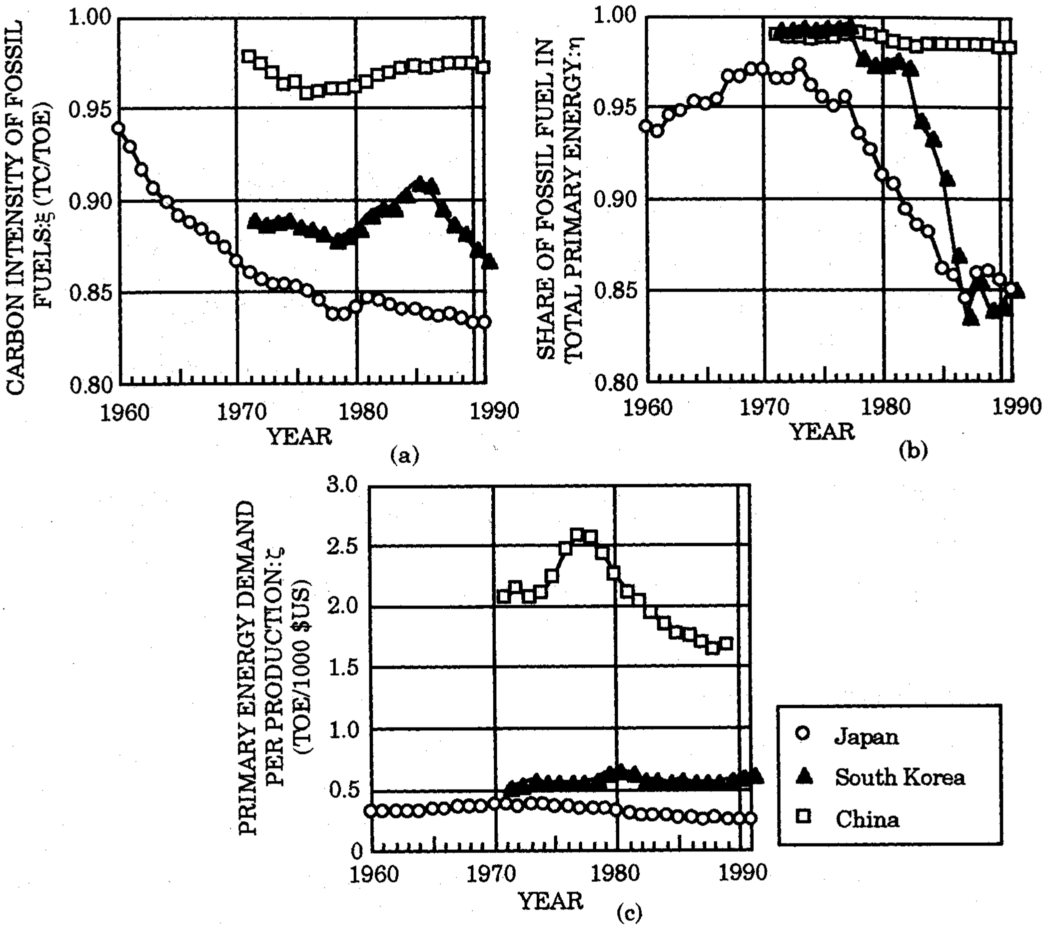
The energy intensity per production ζ has been remarkably reduced in China as shown by Fig. 5-c. This was achieved by the improved energy efficiency of production. Here, it should be noted that the GDP expressed in U. S. dollars are based on market exchange rates. As a whole, the value of ζ is two to five times larger for China than the other two countries, but this difference is much smaller if the figures are based on Purchasing-Power Parity as discussed in 2.1.

4. Energy Demand and CO_2 Emissions in South Korea

4.1 Economic development and environmental policy in South Korea

South Korea is smaller than Japan in the size of its economy, but its intensity of economic activity per land area and its population density are very high. Its total annual emission of SO_x has reached 1.6 million tons (1992), and its SO_x emission per land area is more than four times larger than that in Japan (see Table 3). Its NO_x emission per land area also exceeded the level in Japan, suggesting aggravating ambient air quality in large and industrial cities.

As a result, air pollution levels in terms of ambient atmospheric concentration of SO_2 in big cities such as Seoul and Pusan are comparable to the worst record in Japanese industrial cities such as Kitakyushu (Kitakyushu City, 1993) in the late 1960s, as demonstrated in Fig. 6. In Japan, heavy oil desulfurization technology was applied in the mid 1960s and flue gas desulfurization became wide-spread in the 1970s. In South Korea, the reduction of sulfur content in heavy oil was achieved in the late 1980s and it has almost halved the national total emission of SO_x. Flue gas desulfurization, however, has not been practiced in South Korea

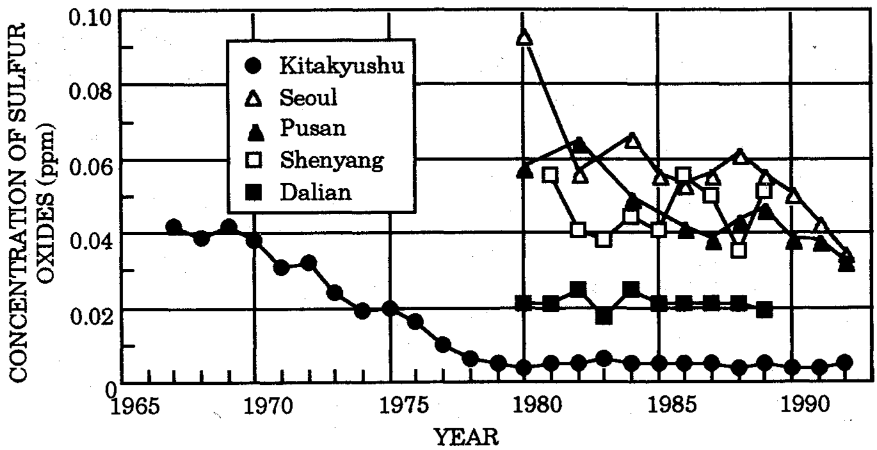


Note: Analysis is made on the data from World Tables (World Bank), Energy Balances of OECD and Non-OECD Countries (International Energy Agency, OECD) and Chinese Energy Statistical Yearbook (Chinese Statistics Publishing Company).

Figure 5. Factors determining the carbon intensity of production.

(Ministry of Environment, Rep. of Korea, 1994) as it requires large investment in plants and equipments .

In Japan, introduction of flue gas desulfurization and denitrification was decided in order to comply with emission standards which were strengthened from the mid-1960s to 1970s. At that time there was strong resistance from industries opposed to environmental regulation, which feared the economic impact. The current situation in South Korea is very similar to that in Japan when it was strengthening environmental control. Here, the question might be raised as to whether the Korean government will decide on stronger environmental policies and whether its industries will accept greater expenditures on environmental countermeasures.



Data Source: Annual Report on Environmental Quality (Kitakyushu City); Annual Report on the State of the Environment in Korea (Ministry of Environment, Rep. of Korea); Chinese Environmental Yearbook (Chinese Environmental Science Publishing Company); etc.

Figure 6. Comparison of the ambient air concentration of SO_2 (annual average) in selected industrial cities in East Asia.

4.2 Industrial Structure and CO_2 Emissions in South Korea

Economic growth in South Korea has been following that of Japan with a fifteen or twenty year gap, the delay apparently becoming smaller in recent years as shown by Fig. 2. However, as demonstrated by Figs. 3 and 4, a gap still exists in the industrial structure and energy efficiency of technologies of the two countries. After the oil crisis, Japan concentrated on the rationalization of its heavy industries, promoting less-energy-intensive industries such as the machinery, information and service industries, while South Korea increasingly relies upon heavy industries such as iron and steel, and ship-building. Such differences in industrial structure and energy consumption between Japan and South Korea may emphasize the characteristics of the latter which is representative of newly industrializing economies. It may also suggest a general rule for the relationship between the stages of economic development and environmental problems.

Kim (1994) carried out an input-output analysis of energy consumption in Korean industries and examined their characteristics. He estimated the CO_2 intensities of goods and services for 65 industrial sectors and analyzed their changes in the last decade. He reported that the recent increase of energy consumption in the industrial sector pushed up the total energy consumption, and suggested the need for immediate measures to control CO_2 emissions in the industrial sector.

According to the Kim's result, CO_2 emission from industrial sectors including primary, secondary, and tertiary industries increased from 26.9 million tC in 1983 to 49.6 million tC in 1992. By and large, production expansion has been the dominant factor which brought about the increase in the emission of CO_2, while the average CO_2 intensity per production was reduced from 0.1262 tC/million Won to 0.1190 tC/million Won. Thus, the growth-oriented economy of South Korea will cause further increases in CO_2 emission, unless its industries adopt more energy-efficient technologies and its economy shifts into less energy-dependent structures.

If the current pace of economic development is maintained, South Korea will join the circle of industrialized countries. Then it must share more stringent environmental obligations. For example, industrialized countries have made National Action Plans to stabilize the carbon dioxide emissions. Environmental performance would be a prerequisite for South Korea to be a fully fledged industrialized nation.

5. Energy Demand and CO_2 Emission in China

5.1 The Huge Pressure on the Environment: Chinese Economic Development, Energy, and the Environment

The primary energy consumption per capita in China in 1991 was almost equal to that of South Korea in the early 1970s and Japan around 1950. There is a large gap between China and the other two countries in this respect, but if the Chinese economy develops at its present pace, the gap will diminish rapidly in a few decades. Here, considering its large population and energy supply structure, heavily dependent upon coal, emissions of air pollutants and CO_2, already enormous, can only increase.

Wu Zong-xin and his research team in Tsinghua University have developed an economic model for analyzing the long-term scenarios of economic development and energy demand and supply in China until 2050 (Wu, 1994; SSTCC, 1994). During this period technology will be further developed, and improved energy-saving technologies will be introduced. In fact over the 1980s the elasticity of energy demand increase to GDP growth in China was relatively small, and it is expected to be smaller in the future. Thanks to these factors, the increase in energy demand and CO_2 emission will slow down. Nevertheless, the basic trend of increasing environmental pressure caused by China's large population and rapid economic growth will not change.

At present, about 17 million tons a year of SO_2 is released into the air in China (Chinese Environmental Yearbook, 1993). If this amount increases in proportion to energy consumption, it will reach about 40 million tons a year in 2020. In comparison, the corresponding figure in Japan was 4.8 million tons a year in the latter half of the 1960s, when air pollution was at its worst; it is now about one million tons a year.

China's natural conditions, especially its spacious land area, ensure a large environmental assimilation capacity. Nonetheless, environmental pressure in industrial areas and big cities where major production facilities and population are concentrated has surpassed the critical level. This can be most directly demonstrated by the air pollution data for large cities as shown in Fig. 6.

5.2 Prospects of Future Energy Demand

In view of its huge population and economic growth potential, energy policy in China affects the world strategy of stabilizing global warming. The above-mentioned Chinese research team led by Wu Zong-xin has presented a scenario analysis of China's social and economic development until 2050, forecasting energy demand and supply and CO_2 emissions. They made basic assumptions regarding the major factors determining future energy demand in China, as summarized below:

(1) Population: The "one-child" policy and other population control measures will be maintained as China's basic national policy in the long term.

Table 4. China's long-term scenario for economic development, and energy demand and supply until 2050 in low growth case.

	1990	2050 BAU	2050 Policy
Population (Billion)	1.134	1.498	
GDP per Capita (US$, 1990 Price)	326	3434	
Primary Energy Demand (Million TOE)	987	3682	3157
Per Capita (TOE)	0.87	2.46	2.11
Primary Energy Supply by Source (%)			
Coal	75.9	56.0	49.3
Oil	16.9	16.3	16.5
Gas	2.1	6.4	7.6
Hydroelectricity	5.1	7.1	9.2
Nuclear	0.0	9.9	13.9
Others	0.0	2.3	3.5
CO_2 Emission (Million tC)	617	1918	1467
Per Capita (tC/capita)	0.54	1.28	0.98
Per GDP (tC/1000 US$)	1.67	0.37	0.28

Data Source: State Science and Technology Commission of China (1994); Wu Zong-xin (1994)

(2) Economic growth: The GDP per person will reach that of today's mid-level industrialized countries such as Spain and Greece by the middle of the 21st century. In order to attain this goal, the annual growth rate of GDP will be maintained at 8-9 % from 1990 to 2000 and then it will gradually slow down. Here, two scenarios are assumed: the "high" and "low" growth scenarios, each assuming 5.8% and 4.5% growth rates over the sixty-year period of the study.

(3) Industrial structure: With economic development, the relative importance of individual industries will be changed. Following a similar path to industrialized countries, the share of agricultural production in the GDP will decrease and that of the service sector will be greater.

(4) Energy technology: Two scenarios are assumed for the energy development, conversion, and end-use technologies as well as for demand control policies: the BAU (business as usual) scenario, and the "Policy" scenario. In the BAU scenario, the energy supply relies on the development and use of domestic energy sources and the increase in energy demand will continue to be restrained according to the policies enforced in the last decade. The Policy scenario is similar to the BAU scenario, but reinforces measures for energy conservation and the development of alternative energy sources such as nuclear power, and further promotes the control of CO_2 emissions.

According to their estimate based on the above scenarios, even in the low growth case, the total primary energy demand in China will be 3,682 Mtce (Million tons of coal equivalent) in the BAU scenario, and 3,157 Mtce in the Policy scenario, as shown in Table 4.

5.3 Technical Possibilities for China: Comparison of Technological Levels in China and Japan

The industrial development in China since the early 1980s has similarities to that in Japan from the mid-1950s to the early 1970s. The average annual growth rate of GNP in China was 9% during 1980-1990, while that in Japan during 1955-1970 was 10%. In both countries, economic development was achieved by the rapid growth of industrial production. The industrial sector's share in total energy end-use (excluding the non-energy use) in China was 68.4% in 1990, while that in Japan was 67.4% in 1970. Thus, energy saving in the industry sector is especially important in China as it was in Japan.

In Japan, production of industrial products such as steel, cement, and paper increased by factors of 5 to 10 over the above period. To achieve this production growth, energy consumption in the industrial sector showed a 6.5 time increase. The elasticity of energy demand increase to GNP growth over 1955-1970 was 1.16. In China, in spite of its rapid GNP growth, the growth rate in energy demand was kept at a relatively low level. The elasticity of energy demand increase to GNP growth was 0.56, contrastingly less than the Japanese value. As a result, the energy intensity of GDP was reduced from 13.36 tce/ten-thousand-Yuan in 1980 to 9.26 tce/ten-thousand-Yuan in 1990. This was largely due to the Chinese government strategy that encouraged energy conservation in individual sectors.

There are large differences in energy intensities in major products between China and industrialized nations. Considering the present technological situation in China, efforts should be made to improve the energy efficiency in energy intensive industries. Overall, the specific energy consumption of major energy intensive products in China is planned to reach the 1980 level in industrial countries. The first priority here should be given to the introduction of technologies already available in industrialized countries. In the longer term, a shift in industrial structure will also be important.

In Japan, energy saving by conventional technologies has already been practiced extensively. The remaining possibility is wider dissemination of special energy-saving technologies requiring longer payback times, i.e., more than 5 years. In this sense, it is more cost-effective to make the same expenditure in China rather than in Japan; this suggests the possibility of a cooperative reduction of CO_2 emissions, or "joint-implementation" which is a mechanism for helping parties to the Framework Convention on Climatic Change meet their net emission limits by financing greenhouse gas reductions in other countries (Bohm, 1994).

In the following, technical possibilities in China for some energy intensive products are examined by comparing Japanese and Chinese technology data:

(1) Iron and steel: Energy consumption for each ton of steel produced in China was 7.32 Gcal/ton-steel in 1990 (SSTCC, 1994). The corresponding values in industrialized countries are considerably lower than this. For Japan, in particular, the value was 6.64 Gcal/ton-steel in 1955, and it was lowered to 5.30 Gcal/ton-steel in 1970, and further to 4.32 Gcal/ton-steel in 1990. The improvement achieved in Japan after the mid-1970s was largely encouraged by the increased international oil price. According to a recent technology assessment report of the Japan Environment Agency (1993), this energy intensity could be further reduced to as low as 3.92 Gcal/ton-steel if various technical measures for energy saving are effected.

The first-stage objective of a Chinese strategy might be to achieve a goal comparable to the 1970 level energy efficiency in Japan. Next comes the second-stage objective to achieve a more ambitious goal such as the present energy efficiency level of Japan.

An impediment to introducing advanced technologies might be the large number of small-scale factories in China. There is a great gap in technological possibilities between new large-scale factories and old small-scale ones. The first priority should be the modernization of larger scale factories, then due attention should be paid to small-scale ones.

(2) Cement: China's cement output (210 Mt) was the largest in the world for 1990. Cement is a basic material indispensable for the construction of buildings, roads, and other social infrastructures. An increase in the use of cement generally shows a very close relationship to macroeconomic indices such as GNP and the total floor space of newly-constructed buildings.

In accordance with the expected GNP growth, China's cement output is estimated to increase to 460 Mt in 2000 (SSTCC, 1994).

Cement output in Japan showed an eight-fold increase from 10.6 Mt in 1955 to 88 Mt in 1980. In the 1980s, however, it showed a slight decline due to the increased oil price. In Japan, the energy intensity of cement clinker was 113.7 kg-coal/t for the fuel and 102.2 kWh/t for electricity in 1990. The corresponding values in 1965, however, were remarkably higher than these values; 203.6 kg-coal/t for the fuel and 120.4 kWh/t for electricity (Kagaku-Kogyo-Nippon-sha, 1991). These Japanese values suggest that the Chinese cement industry has a large energy-saving potential.Substituting the dry process for the old type wet process can reduce the energy intensity of cement clinker by 50%. Then, in the dry process, kilns with suspension preheating (SP) and new-type suspension preheating (NSP) improve energy efficiency.

The energy efficiency of the final cement output can be significantly improved by promoting the use of various waste materials such as blast furnace slag and fly ash, and China uses these waste materials very effectively. This high rate of waste use in the cement industry should be further promoted.

(3) Paper: In 1990, the output of paper and paperboard in Japan was 27.8 Mt, about double the amount in China. The energy intensity of paper in Japan recorded its highest value of 1.0 toe/t (or 1.41 tce/t) in 1976, slightly lower than the 1990 value of 1.55 tce/t for China. However, energy intensity in Japan recorded a remarkable reduction during the 1980s, and its 1990 value was 0.5 toe/t (or 0.704 tce/t), significantly smaller than the corresponding Chinese value.

Paper recycling plays an important role in energy saving in paper making. In 1990, the rate of waste paper use to overall paper production was 23% in China, while in Japan the rate was increased from 41% in 1979 to 50% in 1990.

5.4 Future Energy and Environmental Issues in China

(1) Motorization in China: In view of its large population, motorization based on private car ownership in China poses a fundamental problem to the global environment. The history of motorization in China is relatively short. It is difficult to project future increases in the number of privately owned cars in China by simply extrapolating past data. The Japanese experience, however, shows that motorization can take place very rapidly once it is triggered by increasing public demand for mobility associated with increased income. In Japan, the number of passenger cars increased from a mere 141,000 in 1955 to 8.8 million in 1970 and to 41 million in 1993. This trend was in parallel with the development of the Japanese automobile industry. Construction and improvement of the road systems were also a prerequisite of motorization.

In the long term, with the increasing income per capita, the potential demand for cars will increase very rapidly, especially in some large cities. In this respect, the energy demand scenario for the transport sector set by the above-mentioned Chinese research team (SSTCC, 1994) seems rather optimistic. Fuel economy and environmental standards for both new and used cars would be necessary. For fuel economy, diesel vehicles are more efficient than gasoline vehicles, and the Chinese government is encouraging their use. However, they emit much more air pollutants (nitrogen oxides, hydrocarbons, and particulate matter) than gasoline vehicles, and in Japan cause air pollution in large cities.

With respect to both freight and passenger transport, the improvement of railways should be encouraged, considering their environmental advantages.

(2) Energy End-Use in Commercial/Residential Sectors: In China the industrial sector's share

of total primary energy demand will continue to be the largest; the electricity utility sector will also be a major primary energy consumer. Therefore, it is natural to place emphasis on technological development and technology transfer in these sectors. In the longer term, however, the share of the commercial/residential sectors will gradually increase as was the case in most industrialized countries.

Energy end-use in commercial/residential sectors will increase according to the rising level of per capita income and the standard of living. In view of the large population, energy demand control in these non-industrial sectors will be especially important for China. It should be put into practice by encouraging technological improvement in end-use energy efficiency in cooking and hot water supply, space heating, electric appliances and lighting, using economic instruments such as price incentives, public education, etc.

(3) Environmental problems of urbanization: By the year 2050, it is projected that 60% of the total population in China will live in urbanized areas (SSTCC, 1994). To realize this urbanization scenario, large environmental investment will be required for the provision of houses and social infrastructures such as roads, public transportation, drinking water supply, sewage treatment, and waste disposal.

Moreover, the construction of houses, buildings and various urban infrastructures requires a large amount of basic materials such as iron/steel, cement, and bricks, thereby increasing the energy input in the related industrial sectors. Thus, as an end-user of energy, the role of the construction sector is especially important. Transportation of these materials also requires a large amount of energy. In terms of the primary energy consumption induced by final demand, the share of the construction sector in China was 30.8% for 1990, which was notably high compared with 18.0% in Japan and 16.2% in South Korea (Ikeda and Imura, 1994).

(4) Regional and Other Diversities: In China, income per capita shows a great disparity between urban and rural areas by factor of 3 to 4, and this is closely related to the regional diversity of per capita energy consumption. The average CO_2 emission per capita in China was 0.59 tC in 1987 (Science and Technology Agency of Japan, 1993), but there was a great diversity among regions. In Shanghai and Beijing, it reached about 2.2 tC, almost at the level of industrialized nations such as Japan and France.

In 2050, per capita CO_2 emission will be 1.3 tC or 0.925 tC in the BAU and Policy scenarios, respectively. In interpreting the meaning of these data, consideration of the regional gaps, and of disparities between urban and rural areas would be very important. There are also gaps between national and privatized companies and between large-scale and small-scale firms. In addition to economic effectiveness and efficiency, proper consideration should be given to equity among different parties and economic entities.

6. Directions of Environmental Actions in East Asia

6.1 Lessons From Japanese Experience

Japan has a proven record in environmental pollution control and technology development related to energy use. It has achieved vigorous growth while enforcing strict environmental control measures and achieving improved energy efficiency. The question here is what lessons can the other countries draw from Japanese experience?

Among a number of Asian countries, nations of East Asia, including Japan, South Korea, China, and some others, have many similarities in their social and cultural backgrounds. Economic development in these countries in the last few decades has also exhibited similarities. It is therefore tempting to envisage the formation of an East Asia Model of economic development and environmental measures.

The followings are the lessons from Japanese experience; these may guide the future development of environmental policy in East Asia:

(1) Importance of Preventive Actions: It is widely recognized that prevention is more cost-effective and efficient than curing existing damage. Regrettably, however, ignorance of environmental risks and lack of scientific knowledge and information have caused problems. There has been a number of cases where no effective action was taken until the problem was serious. In Japan, citizens, enterprises, and government have learned a lot from cases such as the environmental damage in Yokkaichi and Minamata, but it was only after many disputes and much confusion that they achieved a common view on the dangers of industrial development and the importance of preventive action.

In Japan the question of causality between pollution and damage, and the responsibility of polluting enterprises was brought to court.In the early 1970s a series of court decisions was handed down determining that enterprises were guilty of illegal actions and that ignorance could not justify negligence. Such court decisions forced Japanese enterprises to put strenuous efforts into pollution control measures. At the same time it was internationally alleged that Japan was exporting without taking sufficient pollution control measures, and the "Polluter Pays" principle was agreed upon in the OECD. It became imperative for Japanese industries to take pollution control measures, and this provided an impetus for them to pioneer advanced environmental technologies.

In terms of economic and environmental conditions, South Korea and China now are faced with the problems Japan used to have. They should not repeat Japan's failures. It will be increasingly difficult for them to enjoy the fruits of economic development without taking environmental measures. They, however, need to make larger expenditure on enforcing environmental regulations and introducing control technologies.

(2) Importance of Public Awareness: The causes and effects of environmental problems are often uncertain and environmental damage is sometimes invisible. Hence it is very important for government, enterprises, and citizens to improve their knowledge and to share scientific information. In Japan the mass media have played an essential role in disseminating information and forcing the government and enterprises to take action.In other words, the mass media created a strong public opinion in favor of environmental protection, which then urged the government to legislate on the problem.

With the rising standard of living, TV and newspapers have spread throughout nations, providing an opportunity to strengthen environmental information and public knowledge. Although countries have different political imperatives, the dissemination of environmental information among the public and the improvement of public awareness should be encouraged.

A large part of CO_2 is generated at factories and power plants where fossil fuels are used as the energy source for the production of goods and services. However, it is the people's consumption needs that induce energy use for the production and distribution of goods and services. Thus, in industrialized countries increasingly greater attention has been paid to the consumption phase of goods and services, rather than to the production phase. Public awareness and attitude towards the protection of the global environment is a key factor in promoting environment-friendly lifestyles.Generally speaking, environmental awareness and public attitudes change according to a nation's economic development and the increase in income per capita. In the long term, the peoples of South Korea and China will pay greater attention to protecting the global environment.

(3) Cost of Environmental Protection: Shortage of funds is often used as an excuse for not taking action. From 1965 to 1975 a total of 6 trillion yen was spent on pollution control and other environmental measures in Japan. With respect to the private sector investment in plant and equipment for pollution control, the highest amount, 970 billion yen or 17% of the total private sector investment of the year, was spent in 1974. Thereafter, the annual environmental investment by the private sector stabilized at about 500 billion yen or 3 to 4 percent of total private sector investment (Imura, 1993). These figures may provide a guideline to the necessary cost of environmental measures.

A characteristic of Japan's environmental problems is that they caused serious health damage to the population; a large number of people was legally designated as victims of health damage. There were more than 10,000 certified victims of air pollution as of 1987, and compensation payments to them amounted to more than 100 billion yen. Then in 1987, the compensation system was revised to reflect improved environmental quality. According to a case study on the Yokkaichi incident, the cost for compensating for health damage was much higher than the cost of technological countermeasures which would have avoided the occurrence of the damage (Study Team of Japan Environment Agency, 1991).

(4) Compatibility Between Economy and Environment: Countries giving priority to development have a tendency to neglect the importance of environmental protection, and may consider the cost of environmental measures as something extra and unnecessary. Such an idea is encouraged by lack of knowledge and understanding of environmental risks. However, in industrialized countries it is widely agreed that the economy and the environment are mutually reinforcing (OECD, 1990). Once environmental control is enforced, it encourages the development of environmental technologies, creating new jobs and business opportunities such as "eco-business." From the macro-economic point of view, it can be concluded that environmental policies in Japan have not deterred economic development, but rather stimulated technological innovation and enabled Japanese industries to survive in the competitive international market (OECD, 1994).

(5) Needs for Developing "Own Technology" and Promoting Eco-Industry: In Japan, environmental policies have had a favorable impact on economic development, stimulating technological innovation. This, however, may not be the case in developing countries which does not have the economic and technological basis to develop their own technologies. Countries will plan to minimize the cost of improving their production facilities. If they have to import most of the necessary environmental technologies, their environmental investment will be an additional cost, without any benefit to development of their own technologies. If this is the case, there is a big difference between those countries and Japan. What is important is for each country to develop appropriate technologies and to create its own environmental industry. The transfer of technology from industrialized countries and the concept of "the best appropriate technology" should be further elaborated in this context.

6.2 Need for Clear Vision and Initiative from Governments

Japan, South Korea, and China have their own political and economic systems. These three countries, however, have one similarity: each of them has a centralized administrative system and the central government has strong control over the country. Such a centralized system has both possibilities and limitations: it was this system that made Japan into an economic giant, while becoming at the same time a constraint on the free activities of the private sector and local development initiatives. In South Korea and China also, centralized political systems greatly facilitated economic development by means of state-operated industries and economic planning. This may be a characteristic of East Asian development that differs from that of Western nations.

China's economic system is rapidly shifting from a centrally-planned economy to a market economy. However, it is well known that the market is not always perfect. It causes distortions and external diseconomies. Profit-oriented business activities have a tendency to use environmental resources as free goods, thereby causing damage to the environment. Proper intervention by government is necessary to guide environmentally sound business activities. Intervention could be done by laws and regulations, by economic instruments, or by dissemination of relevant information.

Furthermore, the role of government will be especially important in the improvement of social infrastructures such as transportation systems. Government should play a central role in the development of new technologies appropriate for the nation, and provide assistance to backward sectors such as smaller-scale firms and factories, including collective and township enterprises.

6.3 Environmental Ethics and Social Responsibilities of Enterprises

Japanese private enterprises caused environmental pollution which gave rise to a number of health victims, and they were the subject of severe criticism from the public. Then they developed a sense of social responsibility, laying stress on a harmonious relationship with society and local populations. In their international activities also, Japanese enterprises have been criticized for having caused environmental problems abroad. In the 1990s, however, they are developing a new code of conduct such as the "Global Environmental Charter" of the Federation of Economic Organizations (or *Keidanren*), in which the role of business in the protection of the global environment is emphasized (Keidanren, 1991). Thus, capitalism in advanced industrial society is being remodeled to be compatible with environmental protection.

On the other hand, Korean industries are enjoying the expansion of production, whereas many state-owned Chinese enterprises have been privatized and are introducing capitalistic management systems. Profit-oriented business attitudes, however, may tend to neglect the environment. In its early stage of industrialization, Japanese industry was criticized for so called "pollution dumping." It is strongly hoped that this failure will not be repeated by other nations. The industries of South Korea and China have to be more aware of their roles in environmental action, and to develop a keen sense of their responsibility for protecting the environment.

6.4 International Division of Work and Technology Transfer

Environmental problems can no longer be considered purely as domestic problems. In today's globalized economy, countries are closely tied together by trade and the flow of capital, and environmental issues have become a main theme in trade negotiations in GATT.

Table 3 clearly shows that there exists a large gap in the intensity of energy, CO_2 and air pollutants (SO_x and NO_x) of production among Japan, Korea, and China. Economic development in China and Korea have been based on the export of energy intensive products and this will further increase their energy demand. On the other hand, countries importing products from countries having larger energy intensity per unit of monetary production may reduce their apparent energy consumption and CO_2 emission, giving rise to environmental costs in other countries. Thus, the gap in energy efficiency of production between countries has significant implication for trade and environment issues (Imura and Moriguchi, 1994).

There has been a trend for Japanese enterprises to move their production facilities to South Korea, China, and other Asian countries, where environmental regulation is less stringent and wage and other production costs are relatively cheaper than in Japan. As a result, the whole region is subject to a trend of polarizing: countries which specialize in production of resource intensive goods and countries which import the finished products for consumption.

Japanese manufacturing industries, especially heavy industries such as steel and petroleum, have been proud of their high productivity and advanced pollution control technologies. They are, however, losing competitiveness with similar industries in South Korea and China. Some people say that Japan should abandon those industries, which cannot compete with newly-industrializing and developing countries. Others have a different view: Japan should retain its production capacities since it has better technology to control pollution and save energy. From the viewpoint of the balanced economic development of the whole region, the former view seems convincing. For the protection of the global environment, the latter view is persuasive. Globally speaking, it is important for Asian countries to share production facilities and environmental technologies properly.

7. Concluding Remarks

Asian economic development is attracting growing attention from the world. East Asian countries including Japan, South Korea, and China are geographically close to one another, and they are expected to tighten their economic links. They have common cultural factors such as Confucianism. In the next century their economic region may become one of the world's most dynamic economic centers.In a few decades, the economic gap between the three countries will diminish and movement of people and goods will become more free.

The industrial development in this region will be dynamic, but it will be accompanied by massive consumption of fossil fuels and by emission of pollutants such as sulfur dioxide and carbon dioxide. If countries continue to give priority to economic development, the trilemma of Economy, Energy, and Environment will grow ever greater. Japan, the front runner in the economic race in the region, must establish a new model for economic development in harmony with the environment. It must achieve economic and social restructuring viz., a changed industrial structure, and reform of its people's lifestyle and, of its mass-production system. Then South Korea will follow Japan.

China and the ASEAN countries must first of all pursue production expansion to meet the increasing consumption demands of the public and to improve infrastructure such as housing and transportation systems. The demand for energy and other resources will inevitably increase, causing large load on the regional and global environment. Sustainable development in Asia will be a policy theme which will be increasingly important for the region.

References

Bohm, P. (1994): *Proceedings of the Tsukuba Workshop of IPCC WG III (Climate Change: Policy Instruments and their Implications)*, pp. 181–198.

Brandon, C. and R. Ramankutty (1993): *Toward an Environmental Strategy for Asia*, A summary of a World Bank Discussion Paper, The World Bank, Washington, D. C.

Chinese Environmental Science Publishing Company (1993): *Chinese Environmental Yearbook (Zhongguo Huanjing Nianjian) 1993*, Beijing.

Chinese Statistics Publishing Company (1993): *Chinese Statistical Yearbook 1993*, Beijing.

Ikeda, H. and H. Imura (1994): Comparative study on the environmental impacts pertinent to infrastructure provision in Japan, China and South Korea, *Environmental Systems Research*, Vol. 22, pp. 154–157.

Imura, H. (1993): *Air Pollution Control Policies and the Changing Attitudes of the Public and Industry: Paradigmatic Changes in Environmental Management in Japan, Environmental Pollution Control — The Japanese Experience*, The United Nations University, pp. 55–85.

Imura, H and Moriguchi, Y (1994): Economic interdependence and eco-balance: Accounting for the flow of environmental loads associated with trade, *Preprints for the Eighth TOYOTA Conference; Toward Global Planning of Sustainable Use of the Earth*, Elsevier. (to be published, 1995)

Japan Environment Agency (1993): *Report by the Committee to Evaluate Counter-Active Technologies Against Global Warming*, Tokyo.

Kagaku-Kogyo-Nippo-sha (1991): *Measures for the Protection of Global Environment — Present Situation and Future Prospects in Major Industries and Local Government*, Tokyo.

Keidanren (1991): *Global Environmental Charter*, May, 1991, Tokyo.

Kim, Joon-Han (1994): CO_2 emissions by industry and the factor analysis of their change in South Korea, Industrial development and environmental problems in East Asia, *IES Report*, No. 1, Institute of Environmental Systems, Kyushu University.

Kitakyushu City (1993): *Annual Report on Environmental Quality.*

Ministry of Environment, Rep. of Korea (1994): *Annual Report on the State of the Environment in Korea.*

OECD (1990): *The Economics of Sustainable Management — A Progress Report*, Paris.

OECD (1994): *OECD Environmental Performance Reviews — Japan*, Paris.

Okita, S. (1993): Steps to the 21st Century, *Japan Times.*

Sakai, T., T. Hamamura, T. Futawatari and H. Imura (1992): Future scenarios of Asian countries with respect to their economic development and CO_2 emissions, *Environmental Systems Research*, Vol. 20, pp. 167–175.

Science and Technology Agency of Japan (1993): *Energy Use and Environmental Prospects in Asia*, Ministry of Finance Publishing Bureau.

SSTCC (State Science and Technology Commission of China) (1994): *National Response Strategy for Global Climate Change: People's Republic of China*, Final Report of the Technical Assistance Project (TA 1690-PRC) funded by the Office of Environment, Asian Development Bank.

Study Team of Japan Environment Agency (1991): *Japanese Experience of Pollution*, Godo Shuppan, Tokyo.

World Bank (1994): *World Tables 1994*, Washington, D. C.

Wu, Zong-xin (1994): Macroscopic assessment of the technical options for the energy system in China, Industrial development and environmental problems in East Asia, *IES Report*, No. 1, Institute of Environmental Systems, Kyushu University.

(Received September 22, 1994; revised version accepted January 20, 1995)