A study on experts' judgement on the future perspective of a country: a case study for China

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The future of the environment in China until the year 2050 has been forecasted through a heuristic approach. A questionnaire survey was given to a group of Japanese experts concerning 47 selected indices, including past data and reference data about other countries. The indices were related to aspects of the economy, population, food, energy, transportation, and the environment. The experts were requested to plot a graph for each index up to 2050 based on their intuition. The lines drawn by 60 experts were compiled along with their comments, and the characteristics of each index were analyzed. Different values for the indices regarding transportation and per capita GDP were forecasted by the experts, while rather similar values were obtained for those referencing population and food consumption. The respective fields of the experts were found to affect their perspectives on the future. Economists tended to show rather optimistic views, expressing a business-as-usual scenario, while engineers predicted limited growth but technological innovation.

Keywords: China, integrated assessment, environmental forecasting, heuristic approach, long-term perspective

1. Introduction

The environment is a complex system where social and natural forces are mutually interacting with each other. Without a systematic analysis, the forecast of environmental issues is impossible. As human activities become diverse and intensive, the complexity of mutual relations in the system increases, and this makes forecasting more difficult. Since there exists no forecasting model which can perfectly reproduce complicated real world phenomena, selecting some areas, fields, or indices out of a whole system of natural and social systems is a realistic approach.

A number of approaches have been carried out to obtain future perspectives on the condition of the environment and development in a region or the whole world [1,2]. These approaches can be roughly classified into two categories. One of them is a top-down approach where one draws some empirical relationships among indices from a macroscopic viewpoint and forecasts the future based on certain premises or scenarios (e.g., [3]). In order to obtain a reliable result by this approach, it is crucial to determine whether an empirical rule obtained in the past can be applied to the future, and whether scenarios drawn will likely be realized. Another is a bottom-up approach based on the accumulation of very detailed data from finely divided areas and different sectors (e.g., [4,5]). Models under this approach are becoming larger and more complicated, and intensive effort is needed to establish a complete data set.

Some factors might cause unexpected changes to some situations that cannot be predicted even by a very sophisticated model. While a rather clear relationship between life expectancy or energy consumption with economic development had been obtained throughout the world, Van Assalt showed a different forecast of populations and life expectancy by integrating people's different preferences into a forecasting model [6]. Policy, culture, people's preferences and other site-specific issues more likely affect motorization, transportation problems, food consumption and supply, and people's lifestyle. Forecasting such situations are difficult by using empirical rules obtained from past experience or detailed numerical data sets. However, it is an important task to provide decision-makers with information on future situations because government policy and other factors can alter future situations [7]. In order to forecast them, some studies integrated the opinions of experts into a forecast model (e.g., [8,9]).

Aiming at the incorporation of experts' judgement into integrated assessment models and obtaining future forecasts in a form understandable to non-experts as a final goal, this study collects experts' perspectives of many different indices of a country, and analyzes their characteristics by index and specialty of the experts. It aims at evaluating the difficulty of forecasting each index, and at identifying differences in perspectives among experts. China was selected as a country for this study because its impact on the global environment and resources is of great concern and it is more familiar to Japanese experts than any other developing country.

2. Forecasting China's future

China has accomplished remarkable economic development since the 1980s. The ninth 5-year plan and the 2010 long-term objective have set the economic growth rate at 8% by 2000 and 7.2% by 2010 and beyond. There is a great concern about the impact on both the regional and global environment by the rapid growth of such a large country. The Chinese government recognized this serious situation, and adopted China's Agenda 21 in March 1994. Aimed at attaining sustainable development, it defines numerical targets until 2000 over a broad field, such as population, food, poverty, health, agriculture, industry, energy, atmosphere, and waste.

China has to solve two kinds of environmental problems simultaneously. One is the local environmental issue presented by industrial pollution [10–12]. This occurs in a short period of time and in spatially small areas. The other is the long-term, global environmental issue presented by global warming [13]. Moreover, energy and food consumption in the country is rapidly increasing, and its impact on the whole world is also of great concern.

The answers to the following questions are crucial for not only China's but also global sustainable development: (i) Will the food supply, energy and natural resources be able to support its entire population?; (ii) Is the regional imbalance of development solvable? And will the insufficiencies of the traffic network infrastructure between coastal ports and inland be improved?; (iii) Will social institutions and laws effectively control the huge country? Macroscopic models by Brown [14], East–West Center et al. [15], and the Japanese Economic Planning Agency [3] forecasted mainly to give the answer to the first question. However, few studies have been carried out for the other two questions, although they will also be crucial issues for China's future. Compared with indices regarding resource consumption or population growth, forecasting indices regarding the above-mentioned issues by numerical models is subject to more uncertain variables. They are likely affected by non-numerical factors such as policy or changes in the cultural and social structure.

Future forecasts of China's environment have been carried out from various points of view [3–5,14–19]. These studies can be categorized into two types of approaches: quantitative approaches which develop numerical models such as an economic model [5,16,17], and heuristic approaches based on interpretation and the intuition of experts [18–20]. The former can quantitatively evaluate the mutual relationship between factors. Among the developing nations, quantitative data sets for China can be rather easily obtained, but their reliability is doubtful. Furthermore, it is difficult for non-experts to understand the model structure and the meaning of the internal variables. The latter approach based on the knowledge and experience of experts

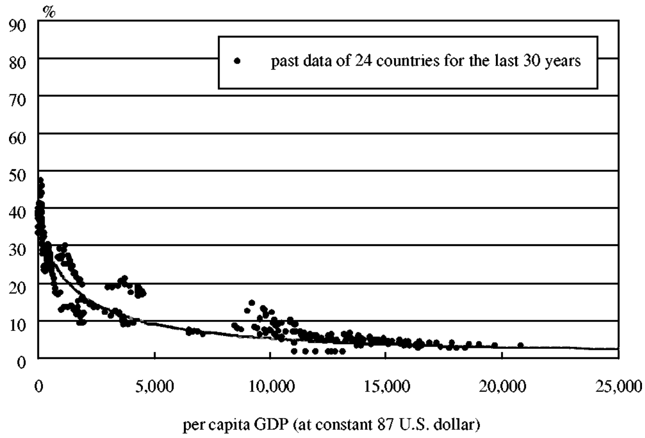

Figure 1. Agricultural share of GDP.

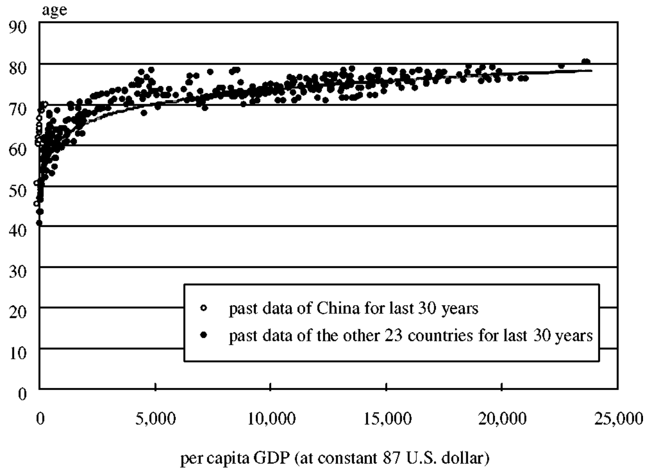

Figure 2. Life expectancy.

is often used to interpret the results obtained by numerical models. Through this approach, interdisciplinary knowledge and various qualitative factors, such as governmental policy or the culture of a region can be taken into account, and a sketch of the future can be drawn (for example, [20]). The relationships between factors are not necessarily formulated or modeled quantitatively. Therefore, conclusions tend to become ambiguous.

Moreover, in both approaches, future situations are often forecasted based on the premise that developing countries will follow similar development patterns as the developed countries, including those Japan has experienced (e.g., [21, 22]). However, China will be able to utilize its latecomer advantages and avoid the pitfalls experienced by developed countries. The fact that factors affecting China could be different from those of former developing countries should also be taken into consideration, but such factors cannot be easily integrated within a numerical model.

3. Objectives of the study

In previous works, the authors obtained some regression curves described in relation to per capita GDP by analysis

Table 1
Outline of the questionnaire survey.

Title	Questionnaire survey for experts about environmental forecast of East Asia–China			
Candidates		Experts on the enviroment and on China in Japan		
(persons)	total	universities	research institutes	private companies
	143	69	32	42
Question form		Draw one line (or two if not possible) as the most probable path to 2050 in a diagram		
Method		Mail survey		
Period		24th March–10th April 1997		
Respondents/mailed		60/143 (43%, including preliminary survey)		

of various indices of the last 30 years for 24 countries, including several Asian countries and some OECD member states [21,22]. Those indices have changed along a similar trend, despite the different background of the countries, such as climate, geographical conditions, and social systems. Curves on agricultural shares as a percentage of GDP and life expectancy are shown in figures 1 and 2. If these curves were applied to the future prediction of a country, the indices could be forecasted without large mathematical models as long as the future economic conditions, i.e., GDP per capita, were obtained. Based on this assumption, the environmental changes of several Asian countries, including China, have been forecasted [21]. Furthermore, a system dynamics model combining some independent factors was developed, and the framework of future environmental situations in East Asian countries was discussed considering the result [22].

However, it is hard for this kind of approach to forecast indices that are likely to be influenced by such factors as government policy, culture, or technological innovation. Motorization, transportation problems, food consumption and supply, and people's lifestyle can be regarded as such indices. It is not clear how much the indices are influenced by these factors. Moreover, it is unknown whether and when changes in policies or technological innovation will occur. The judgement and perspectives of experts are expected to contribute in overcoming this problem. If these experts' views are integrated in the numerical model, forecasting indices will become more meaningful. It could even be utilized to analyze the effectiveness of policies on the indices. The experts' judgement could, therefore, provide useful information urgently needed by decision-makers [23].

On the other hand, integration of the experts' judgement into a model may increase uncertainty of the result of model calculation (e.g., [6,23]). Differences of opinion among experts often significantly affect decision making [24]. Therefore, it is important to identify an adequate way to elicit and utilize the judgement and opinions of experts [9]. Morgan and Keith systematically interviewed leading climate scientists and found great differences between their perspectives on the future of the climate [8].

Integration of experts' judgement, however, has been applied mainly to models forecasting global issues such as climate change and world population. Few studies have attempted to apply this approach for forecasting a wide array of factors within a certain region or a country. The present study investigated the judgement and perspectives of experts in terms of various indices on China's resources and environment. It also discussed the divergence of the perspectives in each index and the relationship between each expert's perspectives and his/her specialty. The study was conducted with the use of a questionnaire survey requesting experts to extrapolate the index curves for China to the year 2050. Each expert drew lines on the graphs based on his/her own knowledge, experience and judgement.

4. Method

One hundred and forty three China experts were selected in Japan, 69 from universities, 42 from public or private research institutes, and 42 from private companies, and mailed a 58 page questionnaire. The participants were given two weeks to reply. The outline of this survey and the number of collected answers are summarized in table 1. The specialties of the experts encompassed a broad range of fields. Among the 143 experts solicited, 60 experts (42%) responded.

Table 2 shows the 47 indices which the experts were asked to forecast. They were selected from indices whose past data are relatively complete, and were classified into six fields (economic development, population, food, energy, traffic, and environment). Some other indices were calculated from the 47 indices for which replies were obtained. For example, the share for the service industries was obtained from agriculture and manufacturing. As a result, 66 indices as a whole were obtained.

Forty seven questions were presented in the same format with a diagram. Relevant past data from 1960 to the present (mid 1990s) was shown in each diagram. Some future indices forecasted by other groups were shown in a footnote as references. If any reference data existed, such as the numerical targets of China's national policy, the present value of some other countries, or the results of simple scenario prediction, they were also shown in the relevant diagrams. Although giving any of the above mentioned reference values could cause an anchoring effect leading to a biased

Table 2
Indices to be investigated in this study.

No.	Index
Economic Growth and Industrial Structure	
Q. 1	GDP growth rate
Q. 2	Per capita GDP
Q. 3	Share of total GDP by industrial sector
Q. 4	Income difference between city and rural
Population and Urbanization	
Q. 5	Total feritility rate
Q. 6	Infant mortality
Q. 7	Mortality rate
Q. 8	Life expectancy at birth
Q. 9	Total population
Q. 10	Urban population
Food	
Q. 11	Per-day food consumption per capita
Q. 12	Per-day animal foodstuff consumption per capita
Q. 13	Total agricultural land
Q. 14	Total harvested land area for crop production
Q. 15	Total irrigated farmland
Q. 16	Fertilizer input per agricultural land
Q. 17	Number of tractors
Q. 18	Crop yields per harvested land area
Energy	
Q. 19	Primary energy consumption per capita
Q. 20	Primary energy consumption per GDP
Q. 21	Income elasticity to primary energy consumption
Q. 22	Crude steel production
Q. 23	Energy demand per steel production
Q. 24	Number of refrigerators for households
Q. 25	Final energy consumption
Q. 26	Share of primary energy supply by energy sources
Q. 27	Share of electricity in final energy consumption
Q. 28	Share of electric power generation by sources
Transportation	
Q. 29	Passenger car ownership
Q. 30	Total number of trucks
Q. 31	Total length of road
Q. 32	Total length of railways
Q. 33	Ton-kilometers of freight transportation
Q. 34	Share of freight transportation by mode of transportation
Q. 35	Passenger-kilometers of passenger transport
Q. 36	Share of passenger transport by mode of transportation
Pollution, materials and desertification	
Q. 37	Total volume of SO_x emissions
Q. 38	Total volume of dust discharged
Q. 39	Ambient SO_x concentration in Chongqing and Shenyang city
Q. 40	Ambient TSP concentration in Shenyang and Tianjin city
Q. 41	Per-day water consumption for residential use
Q. 42	Per-day industrial waste water
Q. 43	Access to water supply in urban area
Q. 44	Access to gas in urban area
Q. 45	Industrial solid wastes
Q. 46	Forest area
Q. 47	Desertification speed

result [23], it was believed to be necessary since the fields of the indices requested to be forecast were so different and all of the experts were not necessarily familiar with all of them.

The following was requested in the questionnaire: (i) draw a line from the present value to 2050 in each diagram; (ii) evaluate yourself, using five grades of expertise regarding the question and your confidence in your forecast; and (iii) comment on your forecast in the free answer column.

The following were described in notes:

- draw one line as the "most probable path" to 2050 in the diagram based on your own knowledge and experiences.
- when it is not possible to draw one line, two lines may represent a maximum and a minimum case.

Every line drawn in the diagrams was digitized and synthesized by computer. The accumulation of plotted lines for life expectancy is shown in figure 4 as an example. The distributions of the forecasted value by every expert in each year were examined for normality, and the result is shown in table 3. Forecasted values of 24 indices (36.4% of the whole) present normal distributions at more than 20 different years (75%) during 2000–2025, while those of 19 (28.8%) do at less than 6 different years (25%). In terms of the forecasted values for 2026–2050, 38 indices (57.6%) present normal distributions at more than 20 different years (75%), while 16 do at less than 6 different years. It is not known whether such values should appear in normal distribution, and some attempts to modify the values taking each expert's specialty into consideration did not succeed in improving the normality. The mean, maximum, minimum, and standard deviation had to be adopted as parameters representing the characteristics of forecasted values since no other appropriate parameters are available. Those of forecasted life expectancy in each year are presented in figure 4. The values of the mean and the deviation of forecasted indices for 2025 and 2050 are shown in table 4.

5. Result of forecasting indices

5.1. Economic growth, industrial structure and urbanization

Most of the experts forecast that China's rapid economic growth is expected to continue up to the middle of the 21st century. These prospects are based on assumptions that the current trend will continue without any big unexpected change. For example, the following events are considered unlikely to occur; (i) the government will become unstable or will collapse, (ii) progress of democratization and decentralization of authority will be hindered, (iii) investment and financial resources for the establishment of infrastructure from overseas will significantly shrink, and (iv) the prices of natural resources or energy will significantly rise. However, many think that the rate of economic growth will gradually decrease from the present 10% to 2 or 3% in the future even if China lives up to the experts' assumptions and continues along its current path of development.

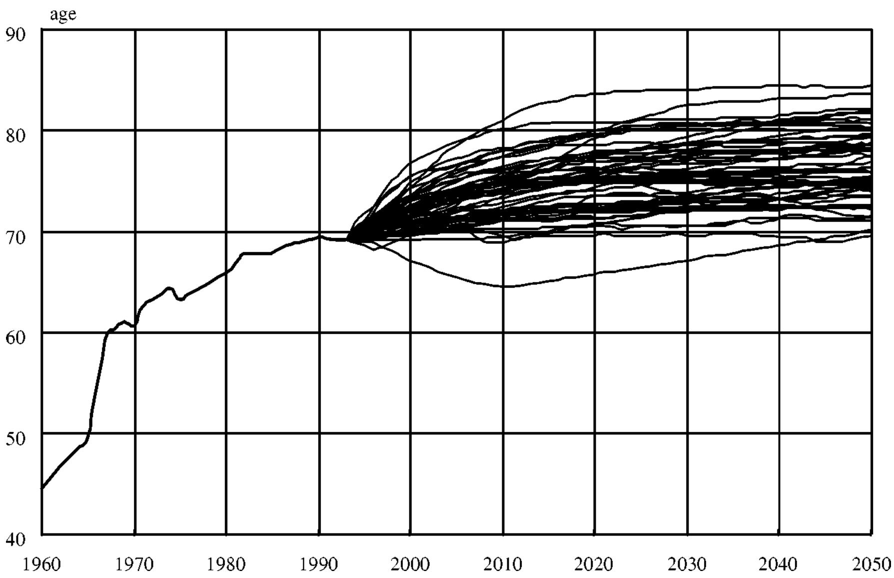

Figure 3. Different perspectives of life expectancy.

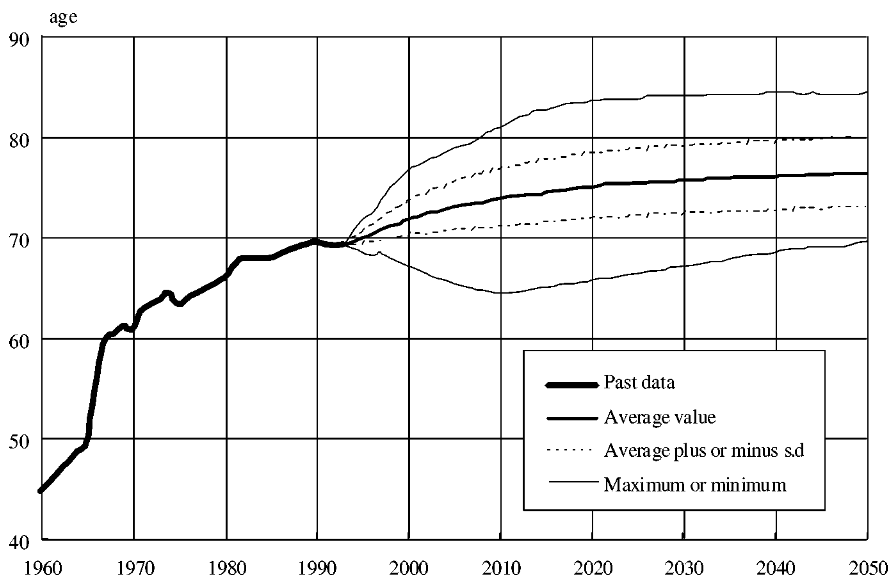

Figure 4. Statistical variables of life expectancy.

Table 3
Normality of forecasted values.

2000–2025 ratio of number of the years when forecasted values presenting normal distribution to the forecasted periods (25 years)	2026–2050 ratio of number of the years when forecasted values presenting normal distribution to the forecasted periods (25 years)				
	0–25%	25–50%	50–75%	75–100%	Total
0–25%	9 (13.6%)	3 (4.5%)	2 (3%)	5 (7.6%)	19 (28.8%)
25–50%	3 (4.5%)	0 (0%)	1 (1.5%)	7 (10.6%)	11 (16.7%)
50–75%	1 (1.5%)	1 (1.5%)	1 (1.5%)	9 (13.6%)	12 (18.2%)
75–100%	3 (4.5%)	1 (1.5%)	3 (4.5%)	17 25.8%	24 (36.4%)
Total	16 (24.2%)	5 (7.6%)	7 (10.6%)	38 (57.6%)	66 (100%)

Table 4
Summary of the results (m: mean, sd: standard deviation).

Parameters	Units	Year 2025 m + sd	2025 m	2025 m − sd	2050 m + sd	2050 m	2050 m − sd
Economy and industrial structure							
GDP growth rate	%	8.19	5.35	2.52	6.54	2.72	−1.09
Per capita GDP	1987 U.S. dollars	2,122	1,571	1,020	6,055	4,045	2,036
Agricultural share in total GDP	%	24.7	21.0	17.3	21.3	15.1	8.8
Industrial share in total GDP	%	42.5	38.1	33.6	42.6	36.9	31.3
Service share in total GDP	%	46.7	40.9	35.2	55.3	48.0	40.7
Income difference between urban and rural area	urban/rural	3.8	3.2	2.6	4.1	2.9	1.7
Population and urbanization							
Total fertility rate	birth/woman	2.1	1.8	1.5	2.3	1.8	1.4
Infant mortality	persons/1,000	23.0	19.5	16.0	19.1	13.5	8.0
Mortality rate	persons/1,000	7.5	6.8	6.2	9.0	7.2	5.4
Life expectancy at birth	age	78.3	75.0	71.8	79.9	76.4	72.9
Total population	millions	1,546	1,471	1,395	1,767	1,552	1,337
Urban population	% of total	51.3	44.9	38.5	73.3	60.9	48.5
Food							
Per-day food consumption per capita	Kcalories per capita	3,692	3,371	3,051	4,181	3,601	3,020
Per-day animal foodstuff consumption per capita	Kcalories per capita	702	610	518	872	718	563
Total agricultural land	million ha	522	483	444	530	460	390
Total harvested land area for crop production	million ha	92.9	88.6	84.2	95.2	88.3	81.5
Total irrigated farmland	million ha	64.1	59.1	54.1	67.4	60.4	53.3
Fertilizer input per agricultural land	kg/ha	237.1	177.5	117.9	330.5	245.2	159.8
Number of tractors	number/1,000 ha of cultivated land	60.4	38.5	16.5	245.7	126.2	6.6
Crop yields per harvested land area	ton/ha	5.8	5.3	4.8	6.4	5.5	4.6
Energy							
Primary energy consumption per capita	TOE per capita	1.81	1.36	0.92	3.47	2.51	1.54
Primary energy consumption per GDP	TOE per 1,000 U.S. dollars	1.15	0.89	0.62	1.03	0.68	0.33
Income elasticity to primary energy consumption	–	0.73	0.56	0.39	0.96	0.67	0.37
Crude steel production	tons/year	203	166	128	350	237	124
Energy demand per steel production	TOE/ton	0.91	0.75	0.58	0.70	0.56	0.41
Number of refrigerators for urban households	sets/million houses	106.2	101.7	97.3	111.5	105.3	99.0
Number of refrigerators for rural households	sets/million houses	73.2	55.2	37.2	99.9	78.4	56.8
Final energy consumption for households and commercial sector	million TOE	369	282	196	670	470	271
Final energy consumption for transportation	million TOE	309	229	149	531	364	197
Final energy consumption for industry	million TOE	942	758	573	1,403	1,017	632
Share of primary energy supply (coal)	%	75.7	67.8	59.9	72.7	58.1	43.4
Share of primary energy supply (oil)	%	27.2	20.9	14.7	29.9	20.7	11.6
Share of primary energy supply (gas)	%	7.5	4.8	2.2	15.3	8.7	2.2
Share of primary energy supply (the other)	%	11.7	6.6	1.4	23.1	12.8	2.4
Share of electricity in final energy consumption	%	17.6	15.9	14.3	22.0	18.9	15.9
Share in electric power generation (coal)	%	74.6	65.2	55.9	72.4	57.3	42.2
Share in electric power generation (oil)	%	13.7	8.6	3.6	16.6	9.7	2.7
Share in electric power generation (hydro)	%	22.2	17.9	13.7	24.0	17.3	10.7
Share in electric power generation (nuclear)	%	11.6	6.6	1.6	20.7	11.8	2.9
Share in electric power generation (gas and the others)	%	3.2	1.6	0.0	9.2	3.9	0.0
Transportation							
Passenger car ownership	number/1,000 people	48.6	13.5	0.0	154.0	58.4	0.0
Total number of trucks	number/1,000 people	44.5	24.1	3.6	89.6	55.7	21.9
Total length of road	10,000 km	247.4	201.6	155.8	381.5	282.6	183.7
Total length of railways	10,000 km	8.5	7.2	5.8	12.1	9.0	5.9
Ton-kilometers of freight transportation	ton-kilometers per capita	7,069	5,844	4,619	10,357	7,974	5,591
Share in freight transportation (Railways)	%	37.0	31.3	25.6	38.3	28.7	19.1
Share in freight transportation (Motor Vehicles)	%	24.2	20.0	15.8	39.1	28.3	17.6
Share in freight transportation (Shipping)	%	54.3	48.7	43.0	55.3	43.0	30.7
Passenger-kilometers of passengers transport	passenger-kilometers per capita	3,247	2,331	1,414	6,534	4,979	3,424
Share in passenger transport (Railways)	%	37.1	31.0	25.0	37.7	26.7	15.7
Share in passenger transport (Motor Vehicles)	%	59.6	53.7	47.9	63.2	51.6	40.0
Share in passenger transport (Shipping)	%	4.6	2.7	0.9	7.0	3.3	−0.5
Share in passenger transport (Aircrafts)	%	16.2	12.6	9.0	25.7	18.5	11.3

Table 4
(Continued.)

Parameters	Units	Year					
		2025			2050		
		m + sd	m	m − sd	m + sd	m	m − sd
Pollution, materials and desertification							
Total volume of SO_x emissions	millions of tons per year	44.8	39.2	33.7	98.5	73.2	48.0
Total volume of dust discharged	millions of tons per year	18.7	17.0	15.3	20.1	16.7	13.4
Ambient SO_x concentration in Chongqing city	mg/m^3	0.35	0.27	0.20	0.30	0.20	0.10
Ambient SO_x concentration in Shenyang city	mg/m^3	0.16	0.12	0.08	0.13	0.09	0.04
Ambient TSP concentration in Shenyang city	mg/m^3	0.51	0.39	0.26	0.48	0.29	0.10
Ambient TSP concentration in Tianjin city	mg/m^3	0.35	0.26	0.16	0.32	0.18	0.04
Per-day water consumption for dairy life	liters per capita	293.8	261.6	229.4	349.2	292.6	236.0
Per-day industrial waste water	liters per capita	48.7	40.0	31.3	50.0	36.1	22.2
Access to water supply in urban area	% of population	97.4	95.7	94.0	98.5	96.4	94.2
Access to gas in urban area	% of population	90.5	85.0	79.6	93.8	87.4	81.1
Industrial solid wastes	100 million tons	10.4	8.9	7.4	13.6	10.2	6.8
Forest area	million ha	132.6	118.0	103.5	134.1	112.8	91.5
Desertification speed	square kilometers per year	2,034	1,357	679	1,919	1,168	417

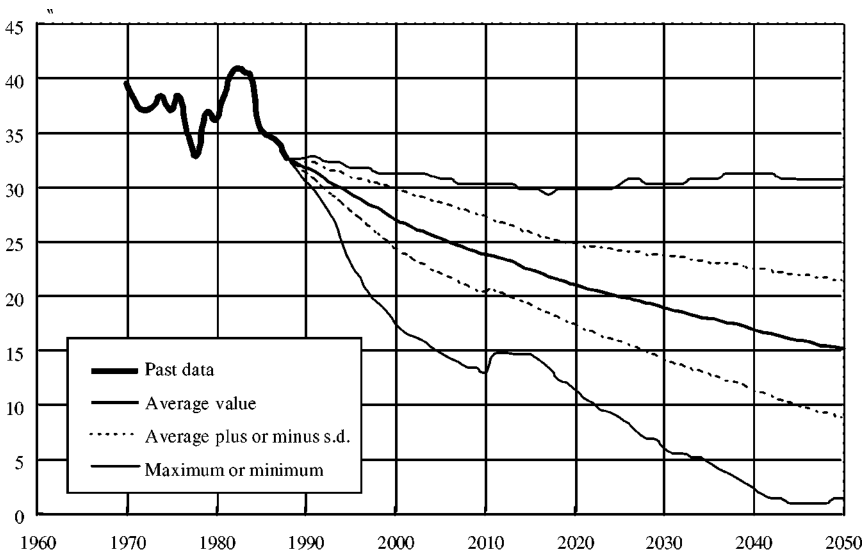

Figure 5. Share of agriculture for the GDP.

The mean value of forecasted per capita GDP in 2020 is USD1,571 (at a constant 1987 U.S. dollar). This represents a similar level to that of Thailand at present. It is expected to reach 4,000 dollars in 2050, a little less than that of the Republic of Korea at present. The values for 2050 forecasted by the experts range from several hundreds dollars to USD8,000.

In this study, experts were requested to forecast GDP growth rate, population, and per capita GDP at the same time despite the fact that one of the three indices can be calculated from the other two. Since this study focuses on characteristics of judgement made by various experts, no adjustment was made among the three. Therefore, the values of the three forecasted by each expert as well as the mean values are not necessarily consistent. Moreover, the exchange rate was not necessarily taken into account although the income is expressed by a constant US dollar value. Some commented that Chinese economic strength would be underestimated when it is measured in US dollars, and that it should be measured by a comparison of purchasing power.

Figure 5 shows the agricultural share of GDP. As most developed countries have experienced, the major industrial sector is expected to shift from agriculture to manufacturing and further to the service industry. However, many view that an agricultural industry in China will be maintained to some extent unlike in Japan because food production will have to be maintained in order to support such a huge population. Some expect certain development of the service industry despite its present underdeveloped state. They think that the government's policy of promoting the service industry and the energy restrictions on heavy manufacturing will accelerate the development of the service industry.

There are different opinions on whether the income gap between city and rural dwellers will increase, while the

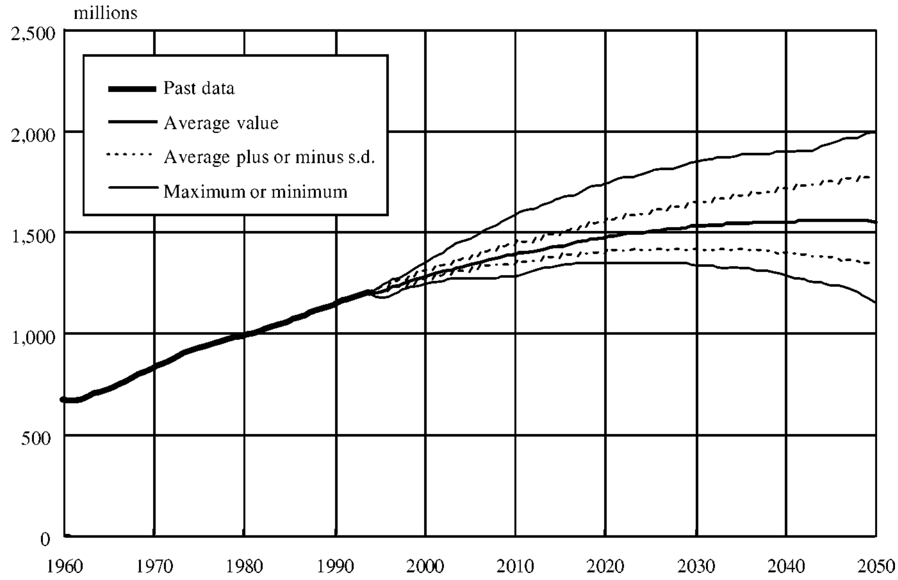

Figure 6. Total population.

mean value of the index shows no particular change in the future from the present. The difference of views arises from the following uncertainties: (i) Will agriculture and farm villages be modernized?; (ii) How effectively will the inland development policy be enforced? Those who do not forecast a wider gap expect that the government will be concerned about social problems due to such a gap and will enforce effective measures to increase income in rural areas.

The forecast for total population shown in figure 6 shows a trend similar to the one predicted by the middle scenario of the United Nations. Many doubt the effectiveness of the "One Child Policy" in the future. They think that the government will ease the policy as the economy grows, particularly in urban areas.

It seems that the present trend of urbanization will continue and reach 60% by 2050. It is suggested that there might be further rapid urbanization as migration to the cities is deregulated. On the other hand, others hold the view that the regulation restricting immigration to urban areas will be further enforced, and that rapid urbanization will be stemmed. Some others think that rural villages will not entirely collapse because the area of the country is too large for the whole rural population to migrate to urban areas.

5.2. Food production and consumption

Food consumption on a calorie basis will reach the present level of South Korea by 2020 and then become stable. It will not reach the present US level until 2050. Some have a concern that food consumption will further increase because Chinese people often leave quite a large part of their meals unconsumed. There is another view that their food consumption will remain at a low level due to worldwide food constraints. Some others predict that total food consumption will further increase while "quality" of diet will not be so much improved as "quantity". They predict that the Chinese will not consume much more animal foodstuffs.

A wider range of views is observed in the forecast of animal foodstuff consumption than that for total food consumption. Figure 7 represents daily consumption of meat on a calorie basis. By 2030, it will exceed the present level of Japan, where the consumption is small despite high income. Some believe the Chinese people's desire to eat meat, especially for pork, is very strong and think that they will spend a lot of money for meat as their incomes increase. Others predict slow growth due to insufficient arable land and limited productivity for meat in the country. There is also a view that the level of consumption probably will not exceed the Japanese level as long as the Chinese retain their Asian lifestyle, in which less meat is consumed than in a western lifestyle.

It is believed that the land area for crops will probably be maintained at the current level. Some areas will be transformed to other land use according to the transition of the economic and social structure. The government's ability to maintain the cropland areas will depend on the effectiveness of its food self-sufficiency policy.

Crop yield will reach 5.5 tons per hectare, the present level of Japan, after 2030 (figure 8). Further yield increases are not expected because of environmental deterioration such as land degradation and a shortage of water, as well as because of a shift from crop growing to livestock raising and horticulture. Some expect that dramatic improvements in biotechnology will further increase productivity. They think that reforming the grain market is necessary since farmers do not have much incentive for intensive farmland use. There is also an expectation of improvement in productivity with the completion and operation of China's South-to-North Water Transfers project which serves to transfer water from the Yangtze river to northern China.

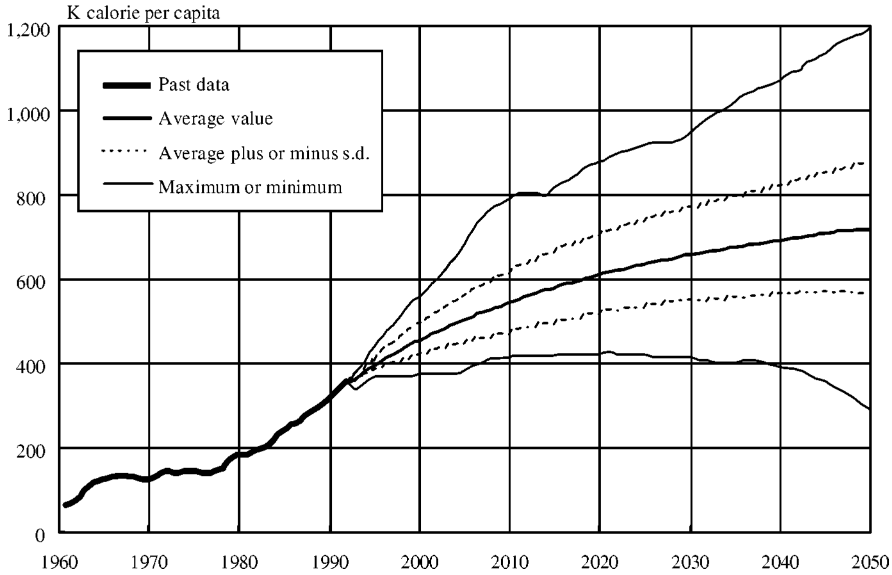

Figure 7. Daily consumption of meat.

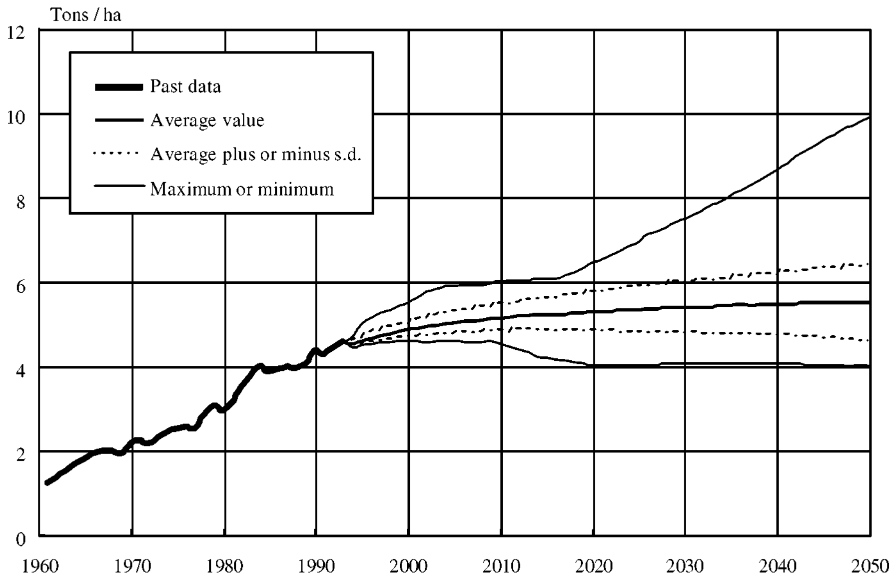

Figure 8. Crop yield.

5.3. Energy

Primary energy consumption per capita is shown in figure 9. It will reach the present level of Brazil by 2050. The forecast for this rapid growth is based on the view that energy-intensive industries (steel, cement, chemicals, etc.) will have to grow in order to supply basic materials needed for supporting the development. In terms of transportation, some predict a quick motorization up to the level of the United States, whose territory is the same size as China's. Others view a different development because the role of railway transportation is expected to become increasingly important.

Primary energy consumption per capita will be decreased to half of the present level by 2050. Some hold the view that energy efficiency will not be significantly improved because the Chinese economy will further depend on energy-intensive industries. Others expect rapid improvement in energy efficiency because of the development of electronics technology and the joint implementation of activities based on the UN Framework Convention on Climate Change. One energy expert suggests that use of non-commercial biomass fuel, which is often excluded from energy statistics, should also be taken into account in the case of developing countries like China. The income elasticity relevant to the amount of primary energy consumption is forecasted to gradually rise and converge at around 0.65. Increasing demand, especially in transportation and residential sectors, will raise the elasticity. However, the insufficient energy supply will hinder its further growth and converge it on a set value.

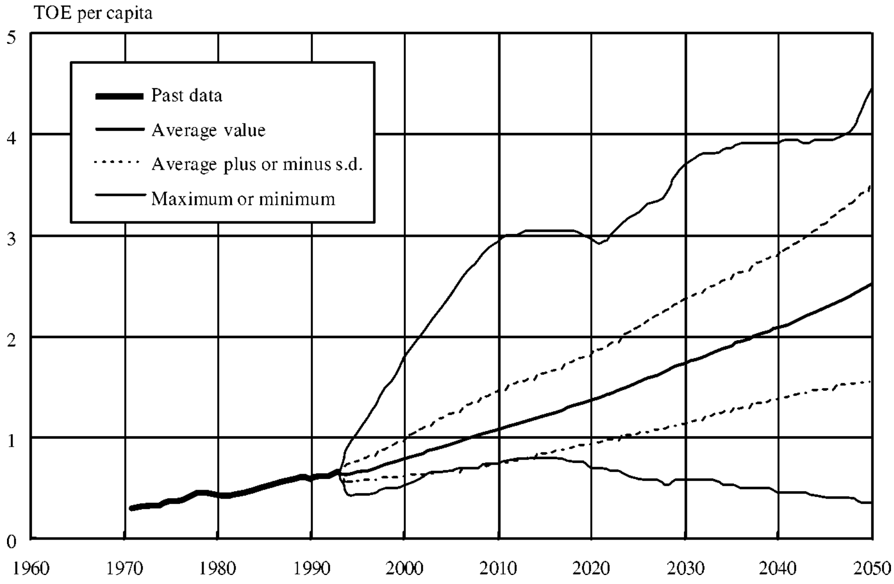

Figure 9. Primary energy consumption per capita.

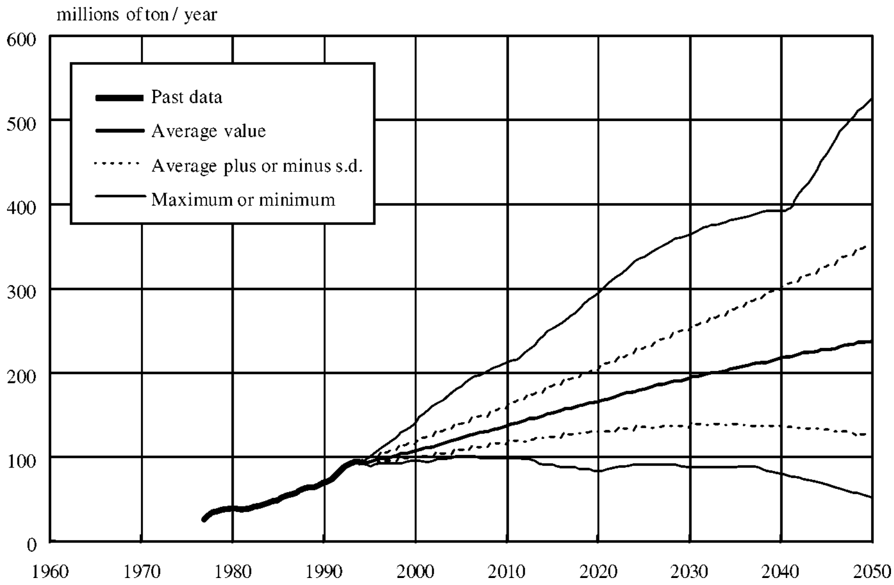

Figure 10. Crude steel production.

5.4. Industrial production

Crude steel production will exceed 230 million tons per year by 2050, nearly twice that of the present (figure 10). China is already the largest steel producer in the world, and will probably be so in the future. Some experts think that the production will increase sharply regardless of domestic demand because it is possible for China to become an iron supply center for other Asian countries. There are other views, especially concerning the long term, which predict that production will not increase because labor costs will rise and China will lose its international competitiveness.

Passenger car ownership will reach 60 cars per 1,000 persons (similar to the present level in South Korea) by 2050 from 0.24 cars per 1,000 persons in 1995 (equivalent to $1/2$ of South Korean level in 1965). However, some doubt such a rapid increase because the development of a road network is not expected to meet the increasing demand of car ownership. Others forecast slower motorization because China has already developed a better railway network than those in other developing countries like Thailand.

5.5. Pollution and others

Air pollution, specifically ambient SO_x concentration in Chongqing city, where it is currently the highest in China, will decrease by 23% to 0.27 mg/m^3 in 2030 (figure 11). Yet many hold the view that rapid improvement cannot be expected due to its dependence on high-sulfur coal and geographical location. Chongqing is surrounded by mountains. Energy conservation, the development of a simplified desulfurizer, and the introduction of cleaner production methods

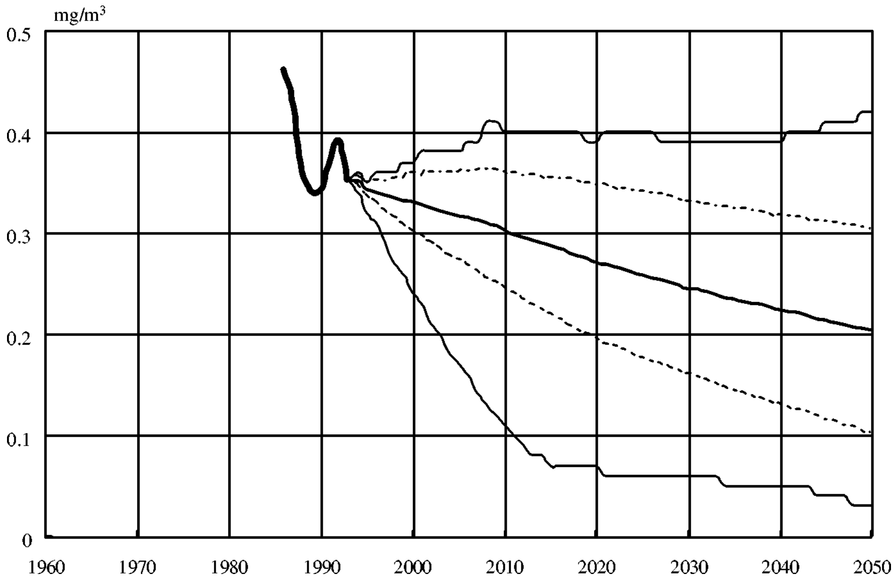

Figure 11. Ambient SO_x concentration in Chongqing city.

are required for further improvement. Some view that effective measures will not be taken before 2020.

Water use will amount to 260 liters per person a day in 2020. This increasing trend will continue, but it will not reach the present level of Japan (350 liters per person a day) before 2050. Many forecasters believe that the government has to take substantial water conservation measures because the actual water supply will not meet the increasing demand. One expert thinks that the wider use of flush toilets will significantly increase demand. Continuous shortages of water will likely occur in some areas.

Industrial solid waste will reach 890 million tons in 2020. While most of the experts predict an increase, some forecast that it will remain at the present level.

1,200 square kilometers of land per year will turn to desert by 2020. The government is trying to slow down the process of desertification to 1,000 square kilometers per year. However, some experts think that desertification is a phenomenon caused by complex combinations of natural, social, and economic factors, and that stopping desertification is technically and economically very difficult. They think that the achievement of this target by the beginning of the 21st century is difficult even though desertification prevention programs have been successful in some areas such as in the Changchiang basin.

6. Investigation of the characteristics of the indices

6.1. Purpose

The difficulty of forecasting future values of indices varies depending on their characteristics. Forecasting indices whose future value will not likely change much is easy. Life expectancy or per-day food consumption per capita are such indices. On the other hand, it is difficult to forecast indices that will likely change to a great extent or are likely to be affected by other factors. Passenger car ownership in China is one of them. Many people think it will rapidly increase, but their estimation of how much of an increase varies. Government traffic policy, development of a road network, and market price of fuel are key factors likely to affect passenger car ownership. This section attempts to categorize indices into several groups depending on the uncertainty of future values and magnitude of the change of each index.

Forecasted values of all 66 indices for the short-term future (2010) and for the long-term (2050) future were analyzed. Their average paths were regarded as the probable paths represented by experts. The deviation of each path of indices, that is the width of the cluster of paths drawn, represents the difference in the opinions of the experts. Indices showing greater deviation seem to be more difficult to forecast than those with a smaller deviation (i.e., narrow width). If a future forecasting model includes such indices, the results of the model simulation will be less certain than that without them.

6.2. Method

Changes in the indices from 2010 to 2050 and their deviation at these years were analyzed. The following non-dimensional variables were defined. The variables in 2010, with parameter i forecasted by expert j, are shown:

$$T_{i,2010} = |\log(X_{i,2010}/X_{i,1995})|,$$
$$U_{i,2010} = \log(100\sigma_{i,2010}/X_{i,2010}),$$

where

$$X_{i,2010} = \left(\sum_{j=1}^{60} x_{i,2010}^{(j)}\right) \Big/ 60,$$

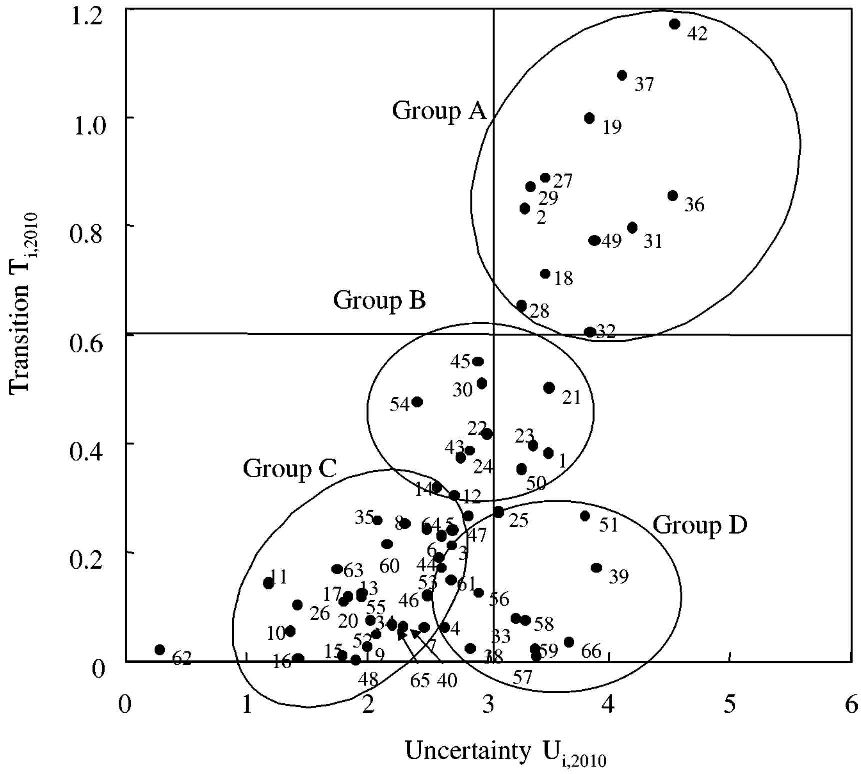

Figure 12. $T_{i,2010}$ and $U_{i,2010}$ in 2010. No. 41 is not shown in the graph, as both its "transition" and "uncertainty" are very large.

$$\sigma_{i,2010} = \left(\sum_{j=1}^{60} \left(x_{i,2010}^{(j)} - X_{i,2010} \right)^2 \right) \Big/ 59.$$

$x_{i,2010}^{(j)}$ is the value of an index i for 2010 forecasted by expert j. $X_{i,2010}$ and $f\sigma_{i,2010}$ are the mean and the standard deviation of $x_{i,2010}^{(j)}$, respectively.

$T_{i,2010}$ represents the magnitude of change of the mean value of index i from 1995 to 2010. Hereafter $T_{i,2010}$ is referred to as "transition". Large transition means that the magnitude of the index would change to a great extent in the next 15 years. They might increase to several times larger than today. Per-day industrial wastewater and total volume of SO_x emissions are such indices. On the other hand, indices such as life expectancy at birth and total population show a small transition, indicating such a big change would unlikely occur for them. Transition could be, therefore, regarded as an indicator representing difficulty of forecasting the index.

However, transition is a difference of mean values during a certain period and does not represent disagreement of experts regarding future value. For example, significant disagreement is not found on life expectancy, and most experts think that it will gradually increase (see figure 4). On the other hand, there are different opinions regarding desertification speed, whose transition is even smaller than life expectancy. Some experts forecast that desertification will be accelerated, but others show opposite views. As a consequence, its transition becomes small. In order to represent another aspect of difficulty of forecast than transition, $U_{i,2010}$, the deviation of the experts' forecasts for index i at 2010, is introduced. Hereafter, $U_{i,2010}$ is referred to as "uncertainty". Uncertainty in this paper simply represents the degree of difference among future perspectives of an index. It is not investigated who is likely to be correct or not among the experts. Uncertainty of desertification speed is larger than that of life expectancy. Therefore, forecasting the former is regarded to be more difficult than the latter.

It should be noted that both transition and uncertainty represent qualitative characteristics of the indices and that their absolute value does not have any substantial bearing.

Transition and uncertainty are shown in figure 12. The indices are categorized into four groups: A, B, C, and D. The indices of each group are shown in table 5. One parameter, No. 41, passenger car ownership, which is assigned to group A is not shown on the graph, because both its transition and uncertainty are too large.

6.3. Results

Indices showing large transition and uncertainty are categorized in group A. In other words, forecasting these indices is difficult at best. This group includes indices related to motorization, such as ownership of passenger cars, trucks, and passenger traffic per capita. Indices related to energy consumption such as new energy sources (gas or biomass), and primary energy consumption for the transportation section also belong to group A. They will likely change to a great extent in the short-term as China's economy develops. This makes a quantitative estimate of the change difficult to forecast. It should be noted that per

Table 5
Classification of indices by $T_{i,2010}$ and $U_{i,2010}$ in 2010.

No.	Group A	No.	Group B
2	Per capita GDP	1	GDP growth rate
18	Fertilizer input per agricultural land	3	Agricultural share in total GDP
19	Number of tractors	5	Service share in total GDP
27	Number of refrigerators for rural households	6	Income difference between urban and rural area
28	Final energy consumption for households and commercial	8	Infant mortality
29	Final energy consumption for transportation	12	Urban population
31	Share of primary energy supply (the other)	14	Per-day animal foodstuff consumption per capita
32	Share of primary energy supply (gas)	21	Primary energy consumption per capita
36	Share in electric power generator (gas and the others)	22	Primary energy consumption per GDP
37	Share in electric power generation (nuclear)	23	Income elasticity to primary energy consumption
41	Passenger car ownership	24	Crude steel production
42	Total number of trucks	25	Energy demand per steel production
49	Passenger-kilometers of passenger transport	30	Final energy consumption for industry
		43	Total length of road
		45	Ton-kilometers of freight transportation
		47	Share in freight transportation (Motor Vehicles)
		50	Share in passenger transport (Aircrafts)
		54	Total value of SO_x emissions
		64	Industrial solid wastes

No.	Group C	No.	Group D
7	Total fertility rate	4	Industrial share in total GDP
9	Mortality rate	33	Share of primary energy supply (oil)
10	Life expectancy at birth	38	Share in electric power generation (hydro)
11	Total population	39	Share in electric power generation (oil)
13	Per-day food consumption per capita	51	Share in passenger transport (Shipping)
15	Total agricultural land	56	Ambient SO_x concentration in Chongqing city
16	Total harvested land area for crop production	57	Ambient SO_x concentration in Shenyang city
17	Total irrigated farmland	58	Ambient TSP concentration in Shenyang city
20	Crop yields per harvested land area	59	Ambient TSP concentration in Tianjin city
26	Number of refrigerators for urban households	66	Desertification speed
34	Share of primary energy supply (coal)		
35	Share of electricity in final energy consumption		
40	Share in electric power generation (coal)		
44	Total length of railways		
46	Share in freight transportation (Railways)		
48	Share in freight transportation (Shipping)		
52	Share in passenger transport (Motor Vehicles)		
53	Share in passenger transport (Railways)		
55	Total volume of dust discharged		
60	Per-day water consumption for dairy life		
61	Per-day industrial waste water		
62	Access to water supply in urban area		
63	Access to gas in urban area		
65	Forest area		

capita GDP also belongs to this group. Since many forecasts are based on the prospect of a growing per capita GDP, this presents a fundamental difficulty for forecasting the future.

Group B contains indices whose magnitude of transition and uncertainty are medium. They are important factors for viewing the transition of social structures, such as the GDP share of agriculture and the service industry, the income gap between urban and rural areas, and the rate of urbanization. Some of the indices related to energy efficiency, such as primary energy consumption, both per capita and per GDP, elasticity of primary energy consumption to GDP, and energy efficiency in steel production. Indices indicating social infrastructures such as the volume of steel production and the total extended distance of a road also belong to group B. The policy of the government and the change of the social structure could alter them. Many of them are influenced by the progress of technology as well as those in group A.

The indices in group C show relatively moderate changes both in transition and uncertainty over the short term. Some of them have already reached their limits. They are the total fertility rate, the mortality rate, life expectancy, total population, total food consumption, the grain yield, and the availability of waterworks and city gas. Some other parameters will not change very much unless effective policy is enforced. They are land use for farmland and forest,

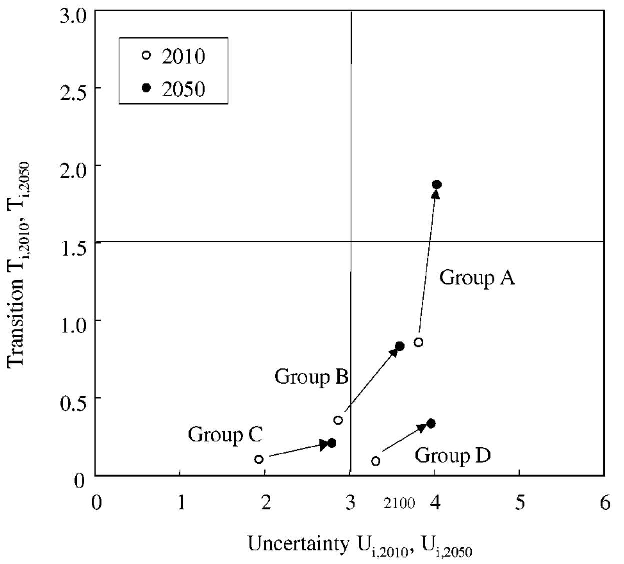

Figure 13. Changes of the transition and the uncertainty toward 2050.

and coal consumption for primary energy. Farm land areas used for grain production, the availability of electricity, and water consumption per capita for living cannot be easily improved in such a huge country. They seem to be rather easily forecasted by a conventional BaU scenario.

The transition of parameters in group D are relatively small, but the uncertainty is large. There are many different views regarding the future of these indices. While some experts think upward change, others think downward. They are air-pollution in some cities, the share of petroleum as a source of energy, the GDP share of industry, and desertification. They would be greatly affected by policy.

Figure 13 shows how the center of gravity of each group classified at 2010 will change by 2050. The center of group A moves upward showing a small horizontal shift. The centers of groups B and D move up and to the right. Group C moves to the right, suggesting no major change in the magnitude, but rather in uncertainty.

7. Perspectives

7.1. Expert's bias

It was reported that the environmental consciousness of Japanese experts varied according to their particular field of study [25]. This section analyzes how the experts' fields affect their judgement. Experts were classified into four groups according to their specialties: economists, sociologists, engineers, and other scientists. Sociologists, political scientists, jurists, and journalists were included in the sociologist group. Physicists, chemists, biologists, and agriculturists were included in the other scientist group.

The forecast tendency of each group was analyzed, using the values of indices belonging to groups A and B at 2030 and 2050 as the medium- and long-term perspectives. The number of experts who forecast larger values than the mean ("+" in table 6) and those forecasting smaller values ("−" in table 6) within each group of experts was examined. When forecasted values were significantly different among the groups, they are also shown in the table as (**) and (*) for the level of significance of 1 and 5%, respectively.

These results indicate that economists forecast further rapid development of economy such as the GDP growth rate and GDP per capita. They also tend to forecast larger increases in indices such as the number of tractors, crude steel production, final energy consumption by the residential sector and the industrial sector, freight traffic per capita, and total SO_x emissions. The view of the economists seems to be similar to the BaU scenario used in ordinary models.

Engineers forecast that the present rapid economic growth will not continue. They forecast smaller increases in production of raw materials and manufacturing (chemical fertilizer, tractors and crude steel). They think that a shortage in these materials will hinder further economic growth. Regarding energy consumption, they also show relatively conservative prospects for the development of new energy sources and nuclear power generation as compared with other groups of experts. However, they hope that SO_x emissions will be reduced by certain technology innovations.

The sociologist group and other scientist group drew a slower development path for the indices of the number of tractors in use, freight traffic per capita, and final energy consumption of the residential sector, and the industrial sector. They forecast increasing environmental loads, such as total SO_x emissions, and industrial solid wastes. They express a grave concern of environmental deterioration. The variation of perspectives of other scientist group is large probably because this group consists of scientists with different backgrounds, while the sociologist group presents a small deviation.

7.2. Perspectives of the three groups

The perspectives of the experts' groups are named as follows, and their characteristics are illustrated using some typical indices;

(i) BaU perspective by economists,

(ii) Environmental Management perspective (EM perspective) by engineers, and

(iii) Environmental Deterioration perspective (ED perspective) by other scientists.

The mean value and standard deviation of GDP per capita, crude steel production, and total SO_x emissions were calculated for each group. They represent living standards, industrialization, and effectiveness of environmental measures and technologies, respectively.

GDP per capita will further increase until 2050 in both the BaU and the EM perspectives (figure 14). The EM perspective shows slower growth than the BaU perspective does. The ED perspective predicts similar growth to that in the BaU perspective up to 2030, but a slower increase after that. Previous research by the authors showed that

Table 6
The different views of experts. [a]

		GDP growth rate			Per capita GDP			Fertilizer input per agricultural land			Number of tractors in use		
		+	−	test	+	−	test	+	−	test	+	−	test
Economists	2030	13	5		13	5		13	5		12	6	**
	2050	17	1	**	12	6		13	5		11	7	**
Sociologists	2030	7	7		8	6		11	3	*	5	9	
	2050	8	6		8	6		11	3	*	3	11	
Engineers	2030	7	8		5	10	*	6	9		3	12	
	2050	9	6		5	10		5	10	*	4	11	
Other scientists	2030	5	8		9	4		4	9	*	3	10	
	2050	7	6		5	8		5	8		1	12	**
Total	2030	32	28		35	25		34	26		23	37	
	2050	41	19		30	30		34	26		19	41	

		Crude steel production			Final energy consumption for households and commercial sectors			Final energy consumption for industry			Share of primary energy supply (the other)		
		+	−	test	+	−	test	+	−	test	+	−	test
Economists	2030	14	4	**	15	3	**	14	4	*	9	9	
	2050	11	7	*	13	5		14	4	*	7	11	
Sociologists	2030	8	6		9	5		11	3		7	7	
	2050	6	8		9	5		11	3	*	8	6	
Engineers	2030	3	12	**	8	7		7	8		3	12	*
	2050	3	12		8	7		6	9		2	13	**
Other scientists	2030	3	10	*	4	9	**	3	10	**	6	7	
	2050	3	10		3	10	**	3	10	**	7	6	
Total	2030	28	32		36	24		35	25		25	35	
	2050	23	37		33	27		34	26		24	36	

		Share in electric power generation (nuclear)			Ton-kilometers of freight transport			Total SO_x emissions			Industrial solid wastes		
		+	−	test	+	−	test	+	−	test	+	−	test
Economists	2030	7	11		17	1	**	11	7		8	10	
	2050	8	10		15	3	**	13	5	*	10	8	
Sociologists	2030	7	7		11	3		8	6		2	12	**
	2050	5	9		7	7		7	7		3	11	*
Engineers	2030	5	10		9	6		4	11	**	5	10	
	2050	2	13	*	8	7		1	14	**	6	9	
Other scientists	2030	5	8		4	9	**	10	3	*	9	4	**
	2050	5	8		3	10	**	10	3	*	8	5	
Total	2030	24	36		41	19		33	27		24	36	
	2050	20	40		33	27		31	29		27	33	

[a] Level of significance of 1% (**) and 5% (*).

significant improvement of the living environment, particularly indices on sanitation, can be expected when GDP per capita exceeds USD5,000 [21]. The BaU perspective alone expects this achievement by 2050.

In terms of crude steel production (figure 15), the BaU perspective expects 280 million tons per year by 2050. The EM and the ED perspectives forecast a growth limit around twice the present level (about 200 million tons).

The ED perspective predicts the smallest increase in GDP per capita, and forecasts the largest amount of SO_x emissions (figure 16). The EM perspective forecasts the smallest amount of emissions reaching 60 million tons per year.

This result may suggest that economists are unlikely to expect any substantial changes that affect the indices. Engineers are more or less likely to expect such changes. Other experts think that environmental conditions will worsen and that the pace of economic development will become slower. Morgan and Henrion suggest that the use of a heuristic model is likely to lead to overestimates if solely recall or imagination is relied upon [23]. Economists study, analyze, interpret past and current issues, and then extrapolate past trends to forecast the future. Engineers work toward improvement of current situations under given conditions considering capacity and limit. They are likely to recall technological innovations for environmental management

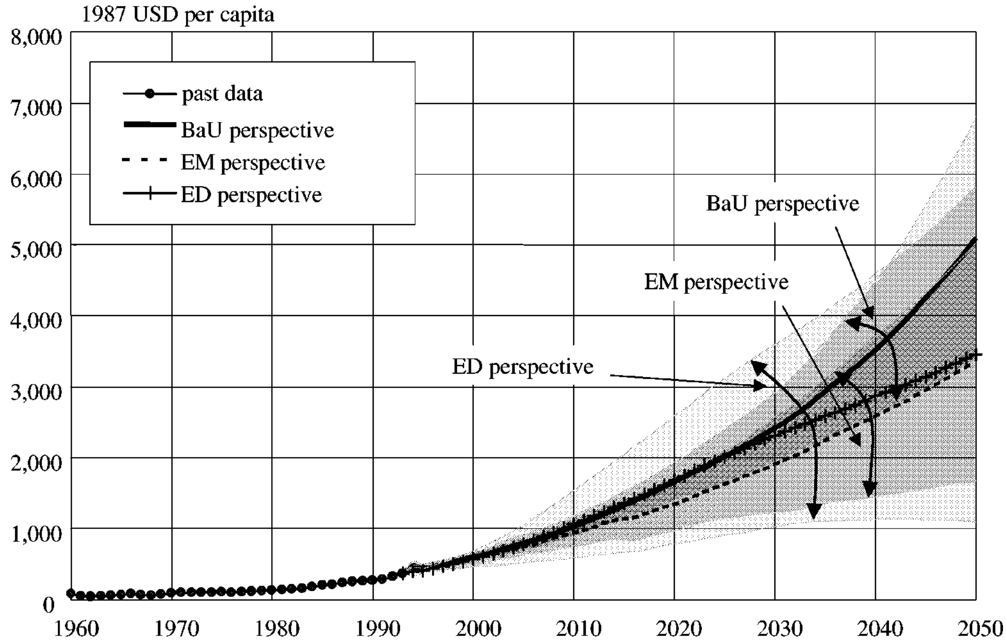

Figure 14. Perspectives of per capita GDP.

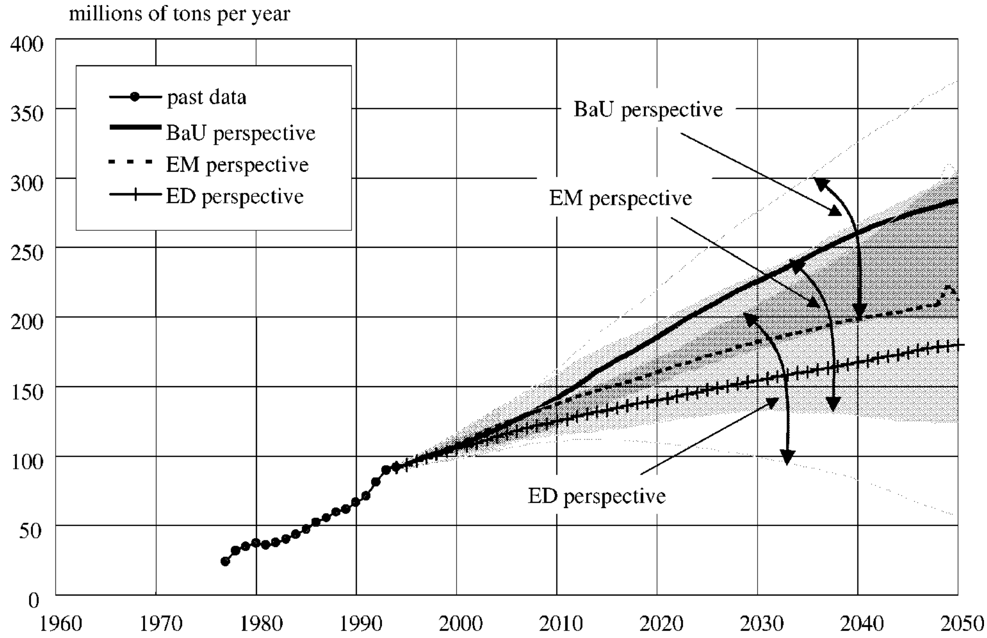

Figure 15. Perspectives of crude steel production.

and expect future improvement. Other scientists are more likely to recall the current worsening environmental situation in China and have a "pessimistic" outlook. These might explain the difference in judgement among experts.

8. Concluding remarks

The results of this study are as follows:

(i) Sixty Japanese specialists drew future paths of 66 economic and environmental indices for China according to their own judgement based on their expertise.

(ii) The indices obtained are classified according to future change and uncertainty. The uncertainty of indices referencing GDP, transportation, and new energy development, which are greatly dependent on policy and selection of technology, is large.

(iii) Forecasts are influenced by the respective specialties of the experts. Economists are likely to forecast BaU perspective. Engineers predict some kinds of limitations to economic growth but expect technological innovation.

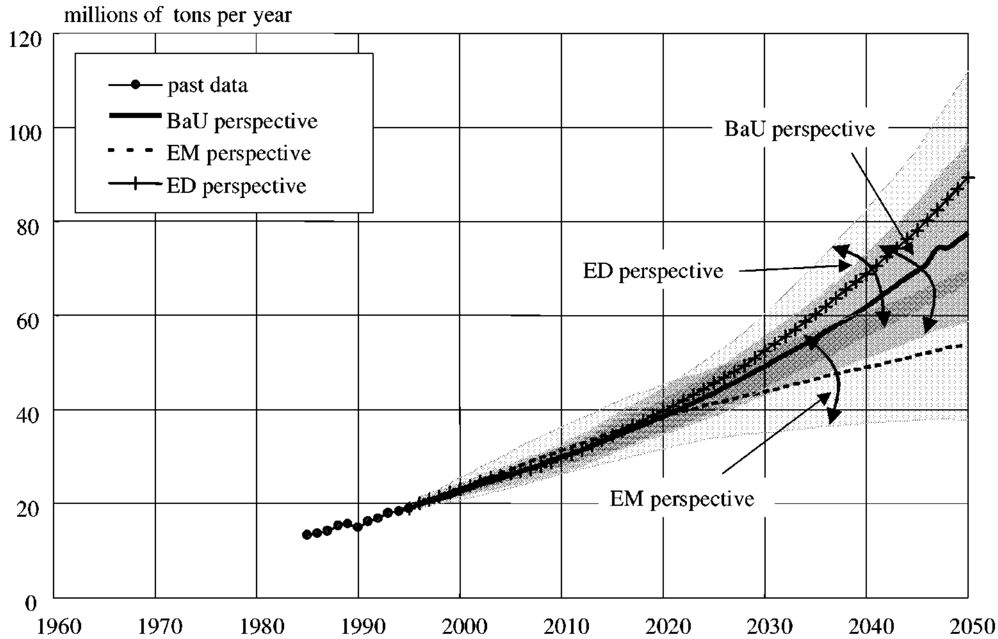

Figure 16. Perspectives of total SO_x emission.

As shown above, the forecast of per capita GDP itself is difficult and many different views exist among experts. Since many models use future values of per capita GDP as a premise, this uncertainty indicates the fundamental difficulty of the forecast. Perspectives of many other indices are not as different as per capita GDP. Although much further study is needed to investigate the characteristics of the indices, it might be possible to forecast "difficult" indices such as per capita GDP by using forecasted values for "easily" predicted ones.

If expert's judgement is integrated into a quantitative model calculation, some issues need to be solved. First, development of a selection method of experts is needed. Because their specialties are found to affect the results, the selection of experts itself would determine the result of the forecast. The necessity of an interface to feed back the result to the experts and for further amendment of their previous forecast, like the Delphi method, should be considered. This process, however, requires a great deal of work. For example, the process of digitizing every line drawn on the graph was extremely labor-intensive. A simple system of data processing or an on-line questionnaire system should be developed for any further detailed study.

Acknowledgement

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References

[1] T. Morita, New trends in policy science, Environmental Research Quarterly 100 (1995) 34–39.

[2] IPCC, Climate Change and Integrated Assessment Models (IAMs) – Bridging the Gaps, *Proceedings of the IPCC Asia-Pacific Workshop on Integrated Assessment Models*, Tokyo, 1997.

[3] D.H. Meadows, D.L.R. Meadows and W.W. Behrens III, *The Limits to Growth* (Universe Book, 1972).

[4] Japan Science and Technology Agency, *Energy Usage and Environmental Forecasting in the Asia-Pacific Region*, 1992 (in Japanese).

[5] AIM Project Team, AIM Interim paper, 1995.

[6] M.B.A. van Asselt, H.H.W. Beusen and H.B.M. Hilderink, Uncertainty in integrated assessment: a social scientific perspective, Environmental Modeling and Assessment 1 (1996) 71–90.

[7] H. Dawlatabadi, Cultural content of integrated assessment and models, in: *Proceedings of the IPCC Asia-Pcific Workshop on Integrated Assessment Models (IAMs)* (1997) pp. 509–515.

[8] M.G. Morgan and D.W. Keith, Subjective judgments by climate experts, Environmental Science & Technology 29 (1995) 468–476.

[9] C. Anastasi et al., Integrated Assessment – Visions for Sustainable Development (Background paper), Paper Represented to the 2nd Poen Meeting of IHDP, 1997.

[10] V. Smil, *China's Environmental Crisis: An Inquiry into the Limits of National Development*, An East Gate Book (Sharpe, New York, 1993).

[11] Q. Geping, ed., *The Knowledge for Environmental Protection* (Hong Qi Press, Beijing, China, 1999) (in Chinese).

[12] H. Imura and T. Katsuhara, eds., *Environmental Issues in China* (Toyokeizai Shinpo-sha, 1995) (in Japanese).

[13] R.T. Watson, M.C. Zinyowera and R.H. Moss, eds., *The Regional Impacts of Climate Change: An Assessment of Vulnerability*, A Special Report of IPCC Working group II (Cambridge University Press, 1997).

[14] L.R. Brown, *Who will feed China?: Wake up call for a small planet* (Norton, New York, NY, 1995).

[15] East–West Center, Argonne National Laboratory and Tsingha University: National Response Strategy for Global Climate Change: People's Republic of China (Final report of the Technical Assistance Project funded by the Office of Environment, Asian Development Bank and implemented by the Department of Science and Technology for Social Development, State Science and Technology Commission of China), 1994.

[16] Y. Matsuoka, T. Kainuma and T. Morita, Scenario analysis of global warming using the Asia-Pacific Integrated Model (AIM), Energy Policy 23 (1995) 257–371.

[17] K. Tsuji, Y. Sekiguchi and R. Makita, Food demand prospects in China and proposals for agricultural development policy, Kaihatsu Enjo Kenkyu, Research Institute of Development Assistance, The Overseas Economic Cooperation Fund 2 (1995) 38–75.

[18] L. Changming et al., *Water Problem Strategy for China's 21st Century* (China Science Press, Beijing, China, 1998) (in Chinese).

[19] L.R. Brown and B. Halweil, China's Water Shortage Could Shake World Food Security, Worldwatch 11 (1998).

[20] Japan Economic Planning Agency, *Some Scenarios on China's 21st Century* (1997) (in Japanese).

[21] S. Kaneko, T. Matsumoto, R. Fujikura and H. Imura, Development and the environment: Forecasting the future of Asia – An empirical analysis using learning curves, Journal of International Development Studies 5 (1996) 17–29 (in Japanese).

[22] S. Kaneko and H. Imura, Long-term perspective on population and food supply and demand in Asia based on empirical equations and BaU scenarios, Journal of Global Environmental Engineering 3 (1997) 99–119.

[23] G.M. Morgan and M. Henrion, *Uncertainty – A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis* (Cambridge Universtiy Press, New York, 1990).

[24] L.B. Lave and H. Dawlatabadi, Climate change: The effects of personal beliefs and scientific uncertainty, Environmental Science & Technology 27 (1993) 1962–72.

[25] M. Naito, T. Morita, H. Ono and N. Sasahara, A questionnaire study of experts on the environmental consciousness of Japanese experts, Environmental Science 4 (1991) 289–294 (in Japanese).