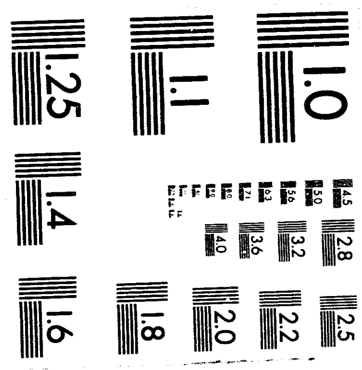
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DESIGNING POLICIES FOR REDUCING FUTURE EMISSIONS OF GREENHOUSE GASES IN THE PEOPLE'S REPUBLIC OF CHINA

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ABSTRACT

The People's Republic of China has recognized the importance of climate change concerns and has signed the Climate Change Convention formulated at the United Nations Conference on Environment and Development. China is now beginning the process of developing an appropriate response strategy for climate change. Several projects have been initiated that deal with various aspects of global climate change. The Asian Development Bank is assisting the Chinese Government in this endeavor by providing technical assistance under an agreement signed in August 1992. The Bank selected a team of international consultants, coordinated by the East-West Center in Hawaii and including Argonne National Laboratory and Japanese scientists, to work closely with Chinese scientists to develop information that would contribute to a national response strategy. The Chinese research team is led by scientists from Tsinghua University and includes specialists from a number of research institutes and government agencies, all under the aegis of the State Science and Technology Commission. This paper presents results from the study concerning the interrelationship between economic growth, energy use, and carbon dioxide emissions in China. The study shows that, despite rapid improvements in energy efficiency and development of nonfossil-fuel energy sources, it will be difficult to prevent a two- to three-fold increase in carbon dioxide emissions between 1990 and 2050.

INTRODUCTION

China was an important player in the development of the Framework Convention on Climate Change and will formulate a national response strategy to honor its commitment as a signatory to the Convention. However, the issue of climate change is a difficult one for China. On the one hand, China is a leading emitter of greenhouse gases and is reliant on coal to fuel the development of its economy and thereby improve the standard of living of its people. On the other hand, China is a country that could be seriously affected by a change in climate; feeding a country of 1.2 billion people is an enormous undertaking and one which could be threatened by a decrease in precipitation, particularly in areas that are already short of water. In addition, the economically developed coastal areas are vulnerable to a modest rise in sea level.

To help resolve these conflicting concerns, China has begun to examine its options for responding to climate change and to study the energy, economic, technological, and social implications of these options. This project is a first step in the process of developing a national response strategy. This particular paper discusses some of the longer term interactions between economic growth, energy supply and consumption, and emissions of carbon dioxide. Other aspects of the topic will be discussed in other papers.

With future increases in population, level of economic and industrial development, and urbanization in China, there will be strong pressure for increased energy consumption, which would tend to increase greenhouse gas emissions. A rational plan for development would seek to sustain economic growth while also protecting natural resources and the environment. The formulation of a plan for management of energy supply and demand should stress the evolution of an energy system with moderate consumption, efficient utilization, and restructuring of industrial and residential consumption patterns. This is preferable to rapid economic growth at the expense of high consumption of resources and deterioration of the environment.

By the middle of the next century, China's goal is to increase per capita GDP so as to achieve the level of a moderately developed industrialized country, with living standards and energy services approximating the 1970s level of western European countries. While this seems a reasonable, and in some ways a modest, goal it will present a tremendous challenge to China. Even with the introduction of advanced technologies and an increase in energy efficiency to the 1990s level of developed countries, the annual per capita primary energy demand will be at least 2,000 kgce. This implies a total national primary energy demand of about 3,000-3,600 Mtce by 2050. And, even with intensified measures to exploit new energy resources such as oil, natural gas, hydroelectric power, nuclear power, and renewable energy, coal will still make up 50% of primary energy supply in 2050. Therefore, it is unavoidable that emissions of carbon dioxide will rise in the future; the challenge is to minimize the increase without unduly impeding social and economic development.

Scenario Definition

Determining a national response strategy for China to respond to the threat of global climate change requires information about how the nation will develop in the future. One would like to know the magnitude of future emissions of each of the greenhouse gases, as well as information on the changing structure of the economy and the status of technological development, in order to determine what control measures might be appropriate, effective, and affordable. There is always a great deal of uncertainty regarding these matters, especially as the time horizon extends beyond the next decade or two. This is particularly the case for a country like China which is industrializing rapidly. An appropriate way to study China's energy future, and the corresponding implications for greenhouse gas emissions, is through scenario analysis, in which a number of possible futures are presented that can be considered to reasonably span the range of likely futures. No attempt is made in this work to identify a most likely future.

For the purposes of this study, several scenarios were developed to the year 2050, the time span covered being sixty years, 1990-2050. Because the rate of economic growth is expected to be high in China — but subject to some uncertainty — it was decided that economic growth should be an important variable. Two scenarios of economic growth were developed, based on current government planning objectives.

In the *high economic growth scenario*, the annual rate of growth of GDP is assumed to be 8.5% from 1990 to 2000, 6.5% from 2000 to 2020, and 4.5% from 2020 to 2050. The average growth rate over the sixty-year period of the study would be 5.8%. GDP would grow from 1.77 trillion yuan in 1990 to about 53 trillion yuan in 2050. Per capita GDP would grow from U.S. $324 in 1990 to U.S. $7,360 in 2050.

In the *low economic growth scenario*, the annual rate of growth of GDP is assumed to be 8.0% from 1990 to 2000, 5.0% from 2000 to 2020, and 3.0% from 2020 to 2050. The average growth rate over the sixty-year period of the study would be 4.5%. GDP would grow from 1.77 trillion yuan in 1990 to about 25 trillion yuan in 2050. Per capita GDP would grow from U.S. $324 in 1990 to U.S. $3,430 in 2050.

Two scenarios of energy system development were similarly constructed to represent alternative levels of energy efficiency improvement and technological innovation.

In the *Business-As-Usual (BAU) scenario*, it was assumed that China would continue its current initiatives to improve the efficiency of its energy system and introduce new technologies, as well as continuing other policies already in place. The elasticity of energy consumption was assumed to be 0.53 from 1990 to 2000, 0.50 from 2000 to 2020, and 0.46 from 2020 to 2050.

In the *Policy Scenario*, it was assumed that China would institute additional measures, beyond those embodied in the *BAU Scenario*, as part of a national climate change policy initiative to further reduce emissions of greenhouse gases. This would be done primarily by increasing the rate of energy efficiency improvements and accelerating the introduction of advanced technologies that emit greenhouse gases at lower rates or do not emit greenhouse gases at all. The elasticity of energy consumption was assumed to be 0.50 from 1990 to 2000, 0.42 from 2000 to 2020, and 0.39 from 2020 to 2050.

By combining these options, four scenarios were constructed at the beginning of the study.

In the *BAU/High Scenario*, total demand for primary energy would grow from 987 Mtce in 1990 to 2,907 Mtce in 2020, and 5,376 Mtce in 2050. The energy intensity of GDP would fall from 0.56 kgce/yuan in 1990 to 0.21 kgce/yuan in 2020 and 0.10 kgce/yuan in 2050.

In the *Policy/High Scenario*, total demand for primary energy would grow from 987 Mtce in 1990 to 2,565 Mtce in 2020, and 4,322 Mtce in 2050. The energy intensity of GDP would fall from 0.56 kgce/yuan in 1990 to 0.18 kgce/yuan in 2020 and 0.08 kgce/yuan in 2050.

In the *BAU/Low Scenario*, total demand for primary energy would grow from 987 Mtce in 1990 to 2,435 Mtce in 2020, and 3,682 Mtce in 2050. The energy intensity of GDP would fall from 0.56 kgce/yuan in 1990 to 0.24 kgce/yuan in 2020 and 0.15 kgce/yuan in 2050.

In the *Policy/Low Scenario,* total demand for primary energy would grow from 987 Mtce in 1990 to 2,218 Mtce in 2020, and 3,157 Mtce in 2050. The energy intensity of GDP would fall from 0.56 kgce/yuan in 1990 to 0.22 kgce/yuan in 2020 and 0.13 kgce/yuan in 2050.

These scenarios of energy and economic development were studied with two computer models operated by the Institute of Nuclear Energy Technology (INET) at Tsinghua University. The Energy Demand Prediction Model makes sectoral predictions of energy end-use demand based on current sectoral composition, rate of economic development and structural change, and intensity of energy consumption. The Energy Technology Selection Model then optimizes the selection of technologies to meet energy demand in each sector for each node of the energy system in accordance with data on cost, performance, and resource availability. Cumulative estimates of total investment, energy supply and consumption, and CO_2 emissions are ultimately produced.

When the analysis of the energy system in China was initiated, it was determined that the energy supply system was limited in its capability to support large-scale growth, even with rapid advancements in all forms of energy supply. The study of the energy supply system determined that, under reasonable assumptions about the rate of expansion of resource use, the level of energy supply in China could not exceed approximately 4,000 Mtce by 2050. This implied that the *BAU/High Scenario* and the *Policy/High Scenario* were probably not feasible. Therefore, further analysis was largely restricted to the two scenarios of lower economic growth.

The following picture of China's social and industrial development was constant for all scenarios:

1) Population - It is assumed that China's basic, long-term policy on family planning and population control, which has led to a dramatic decline in the population growth rate in recent years, will continue to be implemented in the future. The current population of 1,143 million in 1990 is expected to grow to 1,498 million by 2050. However, the average annual growth rate of population will decline from 1.48% in 1990 to 0.10% in 2050.

2) Urbanization - With the progress of industrialization, the growth rate of the urban population will be greater than that of the rural population. Assuming that the per capita GDP of China rises to the level of a moderately developed country by 2050, the urban population of China is expected to grow from 302 million in 1990 to 860 million in 2050. The rural population will decline from 841 million to 638 million. The share of the urban population will rise from 26% in 1990 to 57% in 2050.

3) Industrial Structure - With increasing GDP, the share of each sector in the national total GDP will undergo change, as has been experienced by all nations in the process of development. The share of agriculture will drop, while that of the service sector will increase. Overall, the share

of industry will decline slightly when the growth of the national economy slows. The share of agriculture will fall from 28% in 1990 to less than 10% in 2050, while the share of the service sector will rise from 27% in 1990 to more than 50% in 2050. The share of industry will decline modestly from 44% to about 40%. The share of the transportation sector will remain roughly constant at 5-6%.

Energy Supply

The following assumptions have been made concerning the future supply of energy in China under the *BAU Scenario:*

- Primary energy supply will continue to depend largely on the exploitation and development of domestic energy resources. Imports and exports of natural gas and oil become important after the turn of the century. In 1990, the total primary energy supply was 987 Mtce. The total primary energy supply for China is not expected to exceed 4,000 Mtce by 2050.
- Due to restrictions imposed by limited domestic energy resources, coal will continue to be the major source of energy in the future. In 1990, coal supplied 748 Mtce of primary energy, about 76% of the total. In 2050, the potential for coal supply will reach 2,000-2,200 Mtce, subject to a number of energy, environmental, and transportation constraints. Coal's share of the total energy supply, however, will decline.
- The potential of hydroelectric power will continue to be exploited. By the year 2050, all hydroelectric resources will be utilized, except for those in remote regions such as Tibet. The total capacity for hydropower will be 250,000 - 300,000 MW.
- Nuclear power is expected to play an increasingly important role in easing the pressure on the supply of fossil energy, especially in coastal areas where economic growth is very high and there is a shortage of energy. By 2050, nuclear energy may supply as much as 10% of total energy and 20% of electric power generating capacity.
- By the year 2000, China's crude oil supply will be unable to meet demand, and China will change from an oil-exporting country to an oil-importing country. In 2050, oil production in China is expected to be no more than 200 Mt per year. Demand for liquid fuels, however, will reach 400-600 Mt per year. The shortfall will be made up by imports. At that time, China may be the fourth largest importer of oil after the U.S., Japan, and Western Europe. Coal liquefaction is an option to provide liquid fuels, but it is a technology that requires further development.
- China has large resources of natural gas. At present, however, the level of exploitation is low. In 1990, natural gas provided about 2% of total primary energy (about 20 Mtce). It is expected that both exploration and exploitation will accelerate in the future. By 2050, natural gas supply will reach a peak of about 170 billion cubic meters.
- Renewable energy resources such as wind power, solar energy, commercial biomass, and geothermal energy will continue to be developed and applied, but are not expected to contribute more than 2.3% to China's total energy supply by 2050.
- Directly-burned noncommercial biomass, which at present is the main energy source for domestic use in rural areas, will be gradually replaced by commercial energy sources as the standard of living improves. Directly-burned biomass will then be limited to remote rural regions. In addition, new techniques for the gasification and solidification of biomass will improve conversion efficiency. By 2050, therefore, the amount of biomass burned as fuel is expected to drop from 266 Mtce to about 100 Mtce, and its share of total national energy supply will decline from over 20% to less than 3%.

The above measures are expected to be implemented whether or not the global climate change issue requires special action on China's part. Under the *Policy Scenario*, certain additional energy supply measures are assumed, going beyond those contained in the *BAU Scenario*, as a contribution to a worldwide initiative aimed at reducing greenhouse gas emissions:

- The development and utilization of advanced coal combustion technologies will be accelerated. Increased emphasis will be placed on circulating fluidized-bed combustion, pressurized fluidized-bed combustion, gas/steam cogeneration techniques, and coal gasification combined-cycle systems. Commercialization of these technologies will start early, and application will be widely encouraged.
- Rapid transfer of highly efficient foreign technologi s into China will be explored. There will be extensive international cooperation in the area of renovation of the existing energy system by introducing foreign technologies and foreign investment.
- Use of alternative energy sources will be pursued more energetically. Full utilization of hydroelectric resources, except for remote regions such as Tibet, will be realized twenty years earlier than in the *BAU Scenario* (i.e., by 2030). The use of wind, solar, commercial biomass, and geothermal energy will be increased to a share of about 3.5% of total energy supply by 2050.
- Nuclear power stations will not only be constructed to meet the energy shortfalls in the coastal areas, but also for other regions of China where large-scale development is expected. There will also be some use of nuclear energy for district heating in cities in Northern China.
- The amount of imported natural gas will be increased to ease the energy shortage in the eastern regions and diversify the mix of primary energy supply.

Tables 1 and 2 identify the primary energy supply mix for the *BAU/Low Scenario* and the *Policy/Low Scenario*, respectively.

Energy Consumption

At present, China is one of the highest energy-consuming countries in the world. It is not only higher than most western countries, but also higher than other developing countries with similar GDP. For example, at comparable prices and exchange rates, the intensity of energy consumption per unit GDP in China in 1990 was 2.67 kgce/U.S. $, whereas it was 0.51 in the U.S., 0.24 in Japan, 0.74 in Brazil, and 0.89 in India. The reasons for this discrepancy cannot simply be attributed to low efficiency of energy utilization. Contributing factors include:

1) Exchange Rates - The per capita GDP in developing countries, when calculated at prevailing exchange rates, is generally lower than the real domestic purchasing power. The intensity of energy consumption per GDP would be reduced by a factor of three if calculated according to the index of purchasing power. Both China and India had similar per capita GDP in 1990, but the output of industrial and agricultural products in China was 2-3 times greater than in India.

2) Industrial Structure - China's industry accounts for an extremely high proportion of the GDP mix (44.3%), which is not only higher than that of developing countries, but higher than most developed industrialized nations. The share of energy-intensive manufacturing industries is also very high in China. On the other hand, the service sector is much smaller than in developed and most developing countries. The energy intensity per unit of GDP is much higher in the industrial sector (0.82 kgce/yuan) than in the service sector (0.19 kgce/yuan). The unique structure of China's economy has therefore contributed to the high overall intensity of GDP energy consumption.

3) Technological Efficiency - The specific energy consumption of China's major industrial products is 30-100% higher than that of developed countries, and the efficiency of final energy-consuming facilities is 30-50% lower than the advanced level in developed countries. The efficiency of electric power generation, in particular, is about 25% lower. Thus, there is much room for technological efficiency improvements. However, because of the other factors discussed above, the prospects for efficiency improvement are not as great as would be suggested by the measure of energy consumption per unit GDP.

Figure 1 shows the historical rates of improvement in energy efficiency in China and the rates projected for the future in this study. The technological advancements that will bring about these improvements will be discussed in a separate paper.

By 2050, the economy of China will have reached the level of the 1970s. Even though the advanced energy-use technologies of the developed countries are implemented in China, per capita energy demand will still be greater than 2000 kgce in 2050. In Western Europe in 1975, it was about 1540 kgce. The model runs from this study project that per capita energy consumption will be 2458 kgce and 2108 kgce, under the *BAU* and *Policy Scenarios*, respectively. Because it will be impossible to produce enough oil and natural gas to develop a higher quality fuel mix, even more advanced energy conversion and utilization technologies are needed. The task of energy conservation in China is thus a very hard one.

Carbon Dioxide Emissions

At present, the intensity of CO_2 emissions from energy consumption in China is high: 0.63 kg-C/kgce in 1990. The global average was 0.50 kg-C/kgce, 0.48 kg-C/kgce in OECD countries. As discussed above, a major reason is the high percentage of coal use (76%) in the primary energy mix, as compared with the global average (28%) and the OECD average (22%). The contribution of nonfossil fuels is only 5.1% in China, compared with 12.2% in the world as a whole, and 16% in the OECD — primarily hydro and nuclear power.

By 2050, the contribution of coal to the primary energy mix will have decreased to 58% (*BAU*) or 49% (*Policy*), and the contribution of nonfossil fuels will have increased commensurately. As a consequence, the intensity of CO_2 emissions from energy consumption in China will be near or lower than the current global average. The intensity will be 0.52 kg-C/kgce and 0.46 kg-C/kgce, according to the *BAU* and *Policy Scenarios*, a decrease of 18% and 27% over the 1990 level.

In addition to the consumption of commercial fuels, there is extensive use of biofuels for household purposes in rural areas of China. In 1990, the timber, crop stalks, and other biomass resources used for cooking and heating in rural areas amounted to 266 Mtce, about 21% of total national energy consumption. It is estimated that in China the annual growth and consumption of biomass are approximately balanced, so that there is no net flux of carbon dioxide into or out of the local biosphere. If the consumption of biomass is included in the CO_2 intensity calculation, the value for China reduces to 0.51 kg-C/kgce. The global average reduces to 0.47 kg-C/kgce, and the OECD average remains at 0.48 kg-C/kgce. On this basis, the emission intensities are similar. By the year 2050, biofuels will still comprise about 100 Mtce of energy for rural cooking and heating, about 3% of total energy consumption in that year. The intensity of CO_2 emissions will then be 0.51 kg-C/kgce (*BAU*) or 0.45 kg-C/kgce (*Policy*), slightly less than the value considering only commercial energy.

With improved conversion efficiencies, greater use of efficient end-use technologies, and industrial restructuring, the unit GDP energy consumption intensity will decline over time. In 1990, the unit GDP intensity of energy consumption was 0.56 kgce/yuan. By 2050, it will have declined to 0.15 kgce/yuan (*BAU*) or 0.13 kgce/yuan (*Policy*).

Because of the decrease in the intensity of CO_2 emissions per unit energy consumption, and the decrease of energy consumption per unit of economic output, the GDP intensity of CO_2 emissions will fall from 0.35 kg-C/yuan in 1990 to 0.078 kg-C/yuan (*BAU*) or 0.060 kg-C/yuan (*Policy*) by the year 2050, reductions of 78% and 83%, respectively.

Emissions of CO_2 in China in 1990 were about 626 Mt-C. Without any changes in the industrial structure or any reduction of energy consumption intensity, CO_2 emissions would grow at the same rate as GDP and reach 8,700 Mt-C by the year 2050. However, because of the energy structure and energy intensity changes under the *BAU Scenario*, emissions are projected to grow only to 1,920 Mt-C by 2050, still a threefold increase over current levels. With more rapid commercialization and utilization of new technologies, strengthened energy conservation measures, and a greater emphasis on nonfossil energy and natural gas, the *Policy Scenario* limits CO_2 emissions in the year 2050 to 1,470 Mt-C. Tables 3 and 4 identify the composition of CO_2 emissions by fuel type and year. Figure 2 compares per-capita indexes of the growth of the economy, energy use, and CO_2 emissions projected in this study. Decoupling economic growth from emissions growth will not

Conclusions

This study has demonstrated the tremendous challenges facing China on the issue of carbon dioxide emissions from energy use. Even with great improvements in energy efficiency and switching whenever possible away from fossil fuels, it seems to be impossible to prevent a sizeable increase in carbon dioxide emissions while maintaining a desirable rate of economic development. The possible range for future carbon dioxide emissions is very wide, highlighting the great importance of holding the global climate change issue in mind when planning energy investments. According to the results of the study, about 13 trillion yuan will be invested in the Chinese energy system between 1990 and 2050, investments reaching a peak of 4.5% of GDP in 2000. Even though the *Policy Scenario* requires additional mitigation measures beyond the *BAU Scenario,* energy investments are about 6% lower. That is to say, the additional investments for promotion of energy conservation and alternative energy sources are more than offset by the saved cost for energy production. With additional savings in fuel purchases, the total costs under the *Policy Scenario* are significantly lower than under the *BAU Scenario.* The message is clear. Investment in energy efficiency and alternative energy sources in China makes economic and environmental sense, but will serve to moderate emissions increases, not prevent them.

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	Mtce	(%)	Mtce	(%)	Mtce	(%)	[illegible]	[illegible]
Coal	747.4	75.8	1,054.2	70.7	1,516.6	62.3	2,135.0	58.0
Oil	166.6	16.9	268.3	18.0	426.0	17.5	598.8	16.3
Natural Gas	20.6	2.1	50.0	3.4	145.0	6.0	233.9	6.4
Hydropower	49.9	5.1	107.1	7.2	214.6	8.8	261.7	7.1
Nuclear	0.0	0.0	8.9	0.6	125.3	5.1	366.3	9.9
Renewables	0.0	0.0	2.1	0.1	7.7	0.3	86.0	2.3
Total	984.5	100.0	1,490.6	100.0	2,435.2	100.0	3,681.7	100.0

Table 2 Consumption of primary energy *(Policy/Low Scenario)*.

	1990		2000		2020		2050	
	Mtce	(%)	Mtce	(%)	Mtce	(%)	Mtce	(%)
Coal	747.7	75.8	1.031.8	70.5	1,290.3	58.2	1,555.0	49.3
Oil	166.6	16.9	263.6	18.0	399.0	18.0	521.5	16.5
Natural Gas	20.6	2.1	50.0	3.4	145.0	6.5	240.0	7.6
Hydropower	49.9	5.1	107.1	7.3	226.6	10.2	291.5	9.2
Nuclear	0.0	0.0	8.9	0.6	146.1	6.6	439.5	13.9
Renewables	0.0	0.0	2.6	0.2	11.3	0.5	109.9	3.5
Total	987.0	100.0	1,464.0	100.0	2,218.3	100.0	3,157.4	100.0

Table 3 CO_2 Emissions from energy consumption *(BAU/Low Scenario)*.

	1990		2000		2020		2050	
	Mtce	(%)	Mtce	(%)	Mtce	(%)	Mtce	(%)
Coal	535.0	85.5	753.8	83.1	1,084.4	80.1	1,527.0	79.6
Oil	82.4	13.2	132.3	14.6	210.1	15.5	259.3	15.4
Natural Gas	8.4	1.3	20.5	2.3	59.3	4.4	85.7	5.0
Total	625.8	100.0	906.6	100.0	1,353.8	100.0	1,918.0	100.0

Table 4 CO_2 Emissions from energy consumption *(Policy/Low Scenario)*.

	1990		2000		2020		2050	
	Mtce	(%)	Mtce	(%)	Mtce	(%)	Mtce	(%)
Coal	535.0	85.5	737.8	83.1	922.5	78.3	111.8	75.8
Oil	82.4	13.2	130.0	14.6	196.8	16.7	257.2	17.5
Natural Gas	8.4	1.3	20.5	2.3	59.3	5.0	98.1	6.7
Total	625.8	100.0	888.2	100.0	1,178.6	100.0	1,467.1	100.0

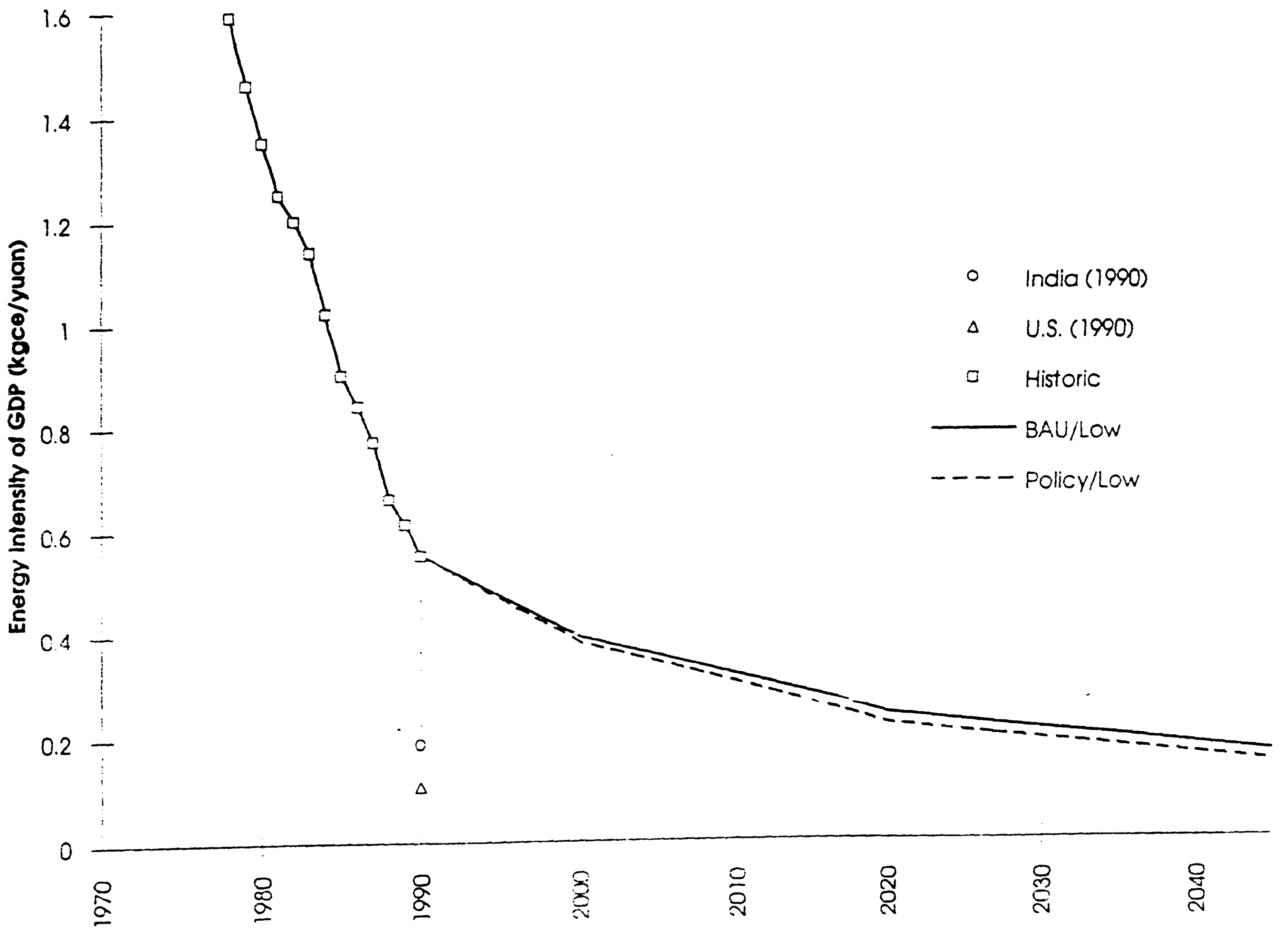

FIGURE 1 Trends in energy intensity.

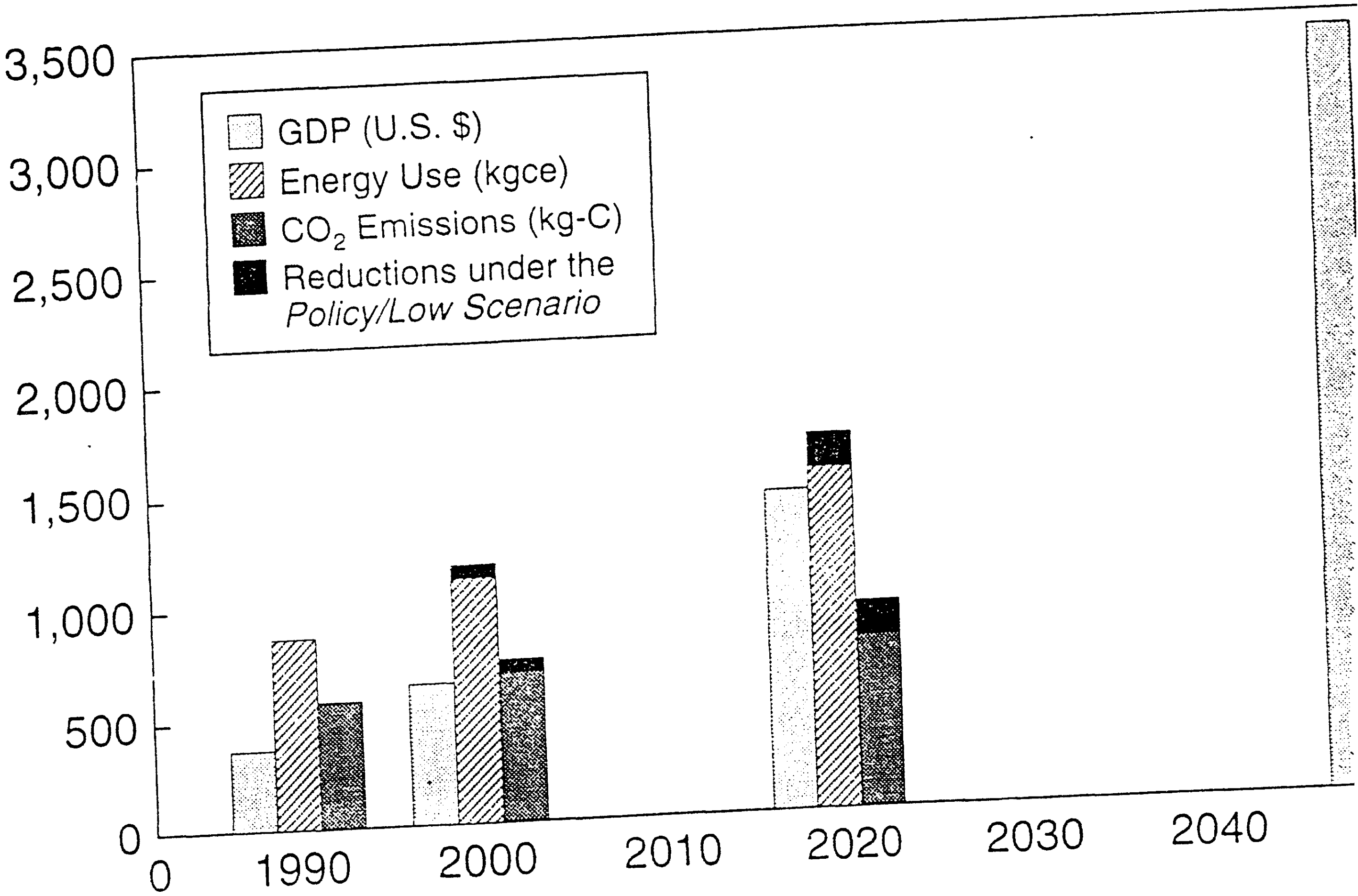

FIGURE 2 Annual, per capita indexes of growth.

KEY WORDS

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EMISSIONS

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