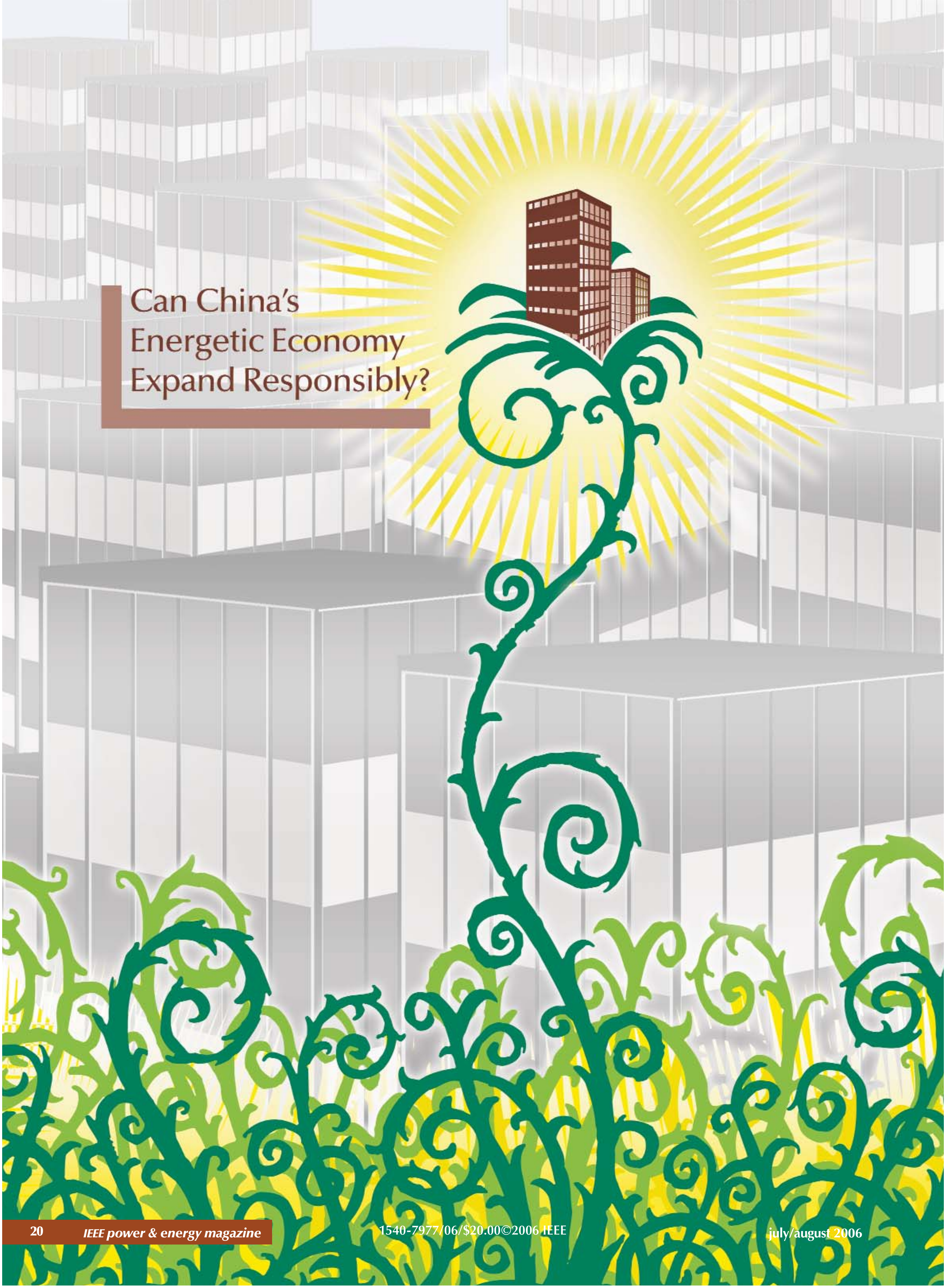
Can China's Energetic Economy Expand Responsibly?



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China's Energy and Environment

by Felix F. Wu, Jin Zhong, and Lizi Zhang

AFTER CENTURIES OF HIBERNATION, CHINA'S ECONOMY HAS FINALLY RISEN. ITS economic boom has benefited its own people and other nations as well. The progress has also led to straining of energy resources and caused distress to the environment. In this regard, only through wise policies and innovative technologies can China live forever prosperously and harmoniously with nations in the world.

The Present

Deng Xiaoping's policy of reform and openness in 1978 has fundamentally and completely transformed China from a backward country to one of the top five economic powers in the world. Based on its gross domestic product (GDP), China's economy has multiplied more than eight times (see Figure 1). This unprecedented economic transformation and sustained growth in history has resulted in significant improvement in the living standards of 1.3 billion people. It also resulted in overwhelming poverty reduction. Specifically, the number of people classified as below the poverty line in rural areas has dropped from 250 million in 1978 to 29 million in 2003. Similarly, China's contribution to world economy has become equally significant. It has emerged as the "world's factory" from which the whole world benefits. At present, it contributes to the growth of the world's economy by 10% and to the growth of world trade by 12%. Moreover, cheap merchandise from China is credited as an important factor in holding down the world's inflation rate in the last ten years.

However, China's economic growth, like that of other countries, is accompanied by undesirable effects. These include the depletion of energy resources and the pollution of the environment.

Energy

Economic growth is mainly fueled by energy. China's energy consumption of 1,386 Mtoe (million tons of oil equivalents) ranks second in the world. However, while its economy has been growing at an average annual rate of 9.7% over the last 20 years, its energy consumption has been growing at the much slower rate of 4.6% (see Figure 1). This means that its efficiency in energy utilization has improved. As depicted in Figure 2, its energy intensity, as defined in terms of energy consumption per dollar of GDP, has gone through a significant 70% reduction. In other words, to produce the same amount of economic output, it is now using only 30% of the energy it consumed before. However, when compared with other developed countries (Table 1), China uses 3.5 times as much energy as the United States, 4.4 times as much as Germany, and 7.2 times as much as Japan for the same economic output. Of course, in making comparisons, one has to keep in mind that the difference is also affected by the composition of each country's economic activities; the developed countries have moved their economies gradually from manufacturing oriented to service oriented, hence to being less energy intensive.

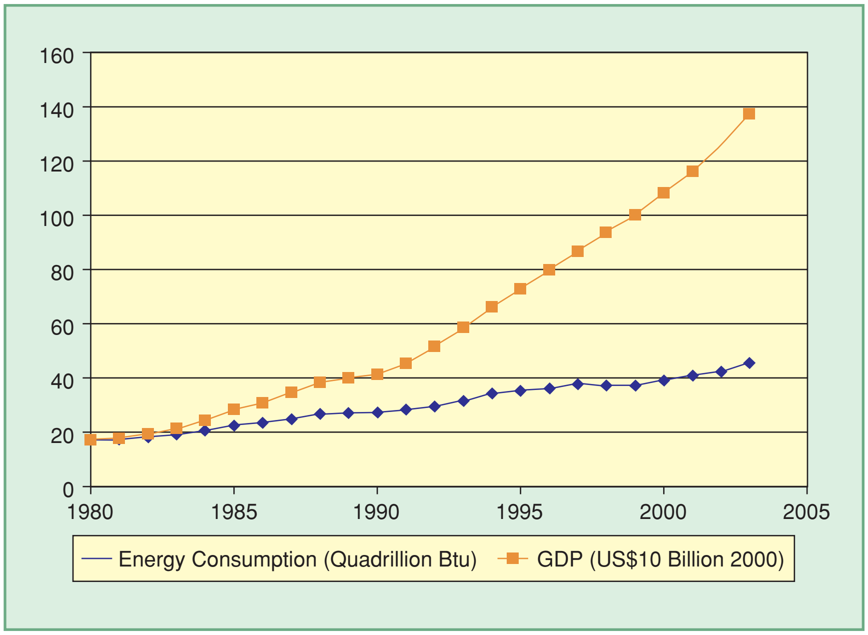

figure 1. GDP and energy consumption (compiled from data at EIA, http://www.eia.doe.gov).

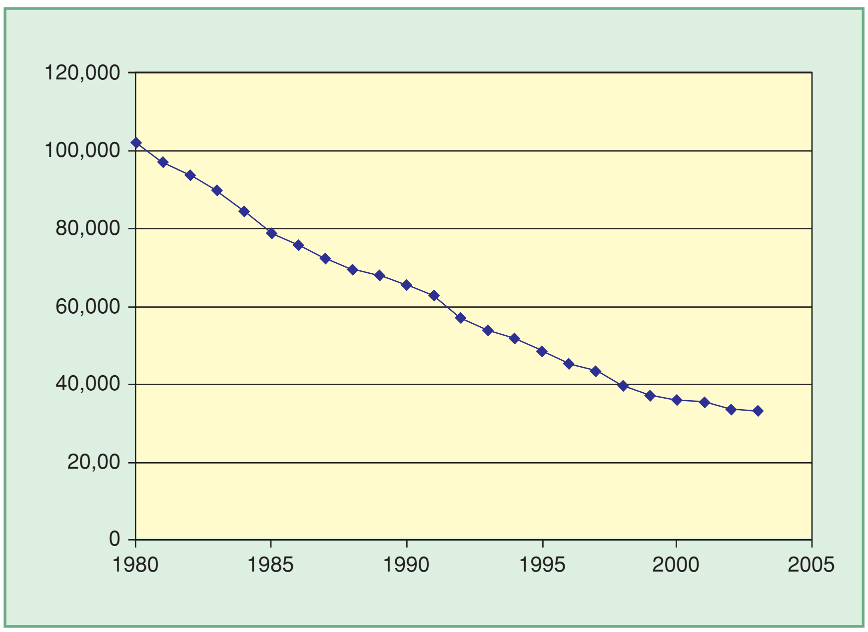

figure 2. Energy intensity in Btu/US$2000 (compiled from data at EIA, http://www.eia.doe.gov).

table 1. Comparison of energy intensity in Btu/US$2,000 (compiled from data at EIA, http://www.eia.doe.gov).

	China	U.S.	Germany	Japan
Energy Intensity	33,174	9,521	7,547	4,605

Table 2 shows the improvement in energy intensity of several countries from 1995–2002. Particularly, Japan and the European Union (EU) are already highly efficient in terms of energy utilization; thus, they show only modest reductions. Compared to India, another developing country, China has improved much more.

China's primary energy depends largely on coal. The country's breakdown of primary energy sources in 2004 included 69% coal, 22.3% oil, 2.5% natural gas, 5.4% hydro, and 0.8% nuclear (Figure 3). The country's large dependence on coal (69%) is above the world's average of 25.5%. Half of the coal requirement is used for generating electricity. The other major consumptions of coal include some energy-intensive industries like steel, petrochemical, cement, etc. Thus, China's GDP is driven too much by the coal-based low energy-efficient industries.

The path taken by the United States, Japan, and other advanced economies has shown that as they climb up the economic ladder from low technology to high technology, they also climb up the energy ladder from coal to oil, natural gas, nuclear, and renewables (C-O-G-N-R) at the same time. Along with the higher status on the energy ladder, they are more efficient, more environmentally friendly, and more sustainable resources.

China's total energy production and consumption since 1980 are shown in Figure 4, along with three separate charts showing the production and consumption in coal, oil, and gas. Note that China is basically self-sufficient in coal and natural gas, respectively. Throughout the 1980s, one-quarter of the oil produced was exported. As a matter of fact, in earlier years (1977–1985), oil accounted for one-third of the new revenues that were used to promote the economic reform. Industry expansion in the early1990s and the subsequent high demand of oil forced the government to give up on the self-sufficiency policy, resulting in China's becoming a net oil-importing country since 1993. Now, it ranks as the second largest oil consumer. Another interesting fact to note: Figure 4(d) shows the rapid increase in the production and consumption of natural gas since 1995, indicating the requirement of the government policy for higher quality fuel. Overall, China produces 94% of the energy it consumes, and the only source of energy it imports is oil. China's 120 million tons of imported oil represent 31% of its total oil consumption (based on 2000 figures). China's oil accounts for only 6% of the world's total oil trade, as compared to the United States's 27%, the EU's 26%, and Japan's 11%.

Environment

Economic development in China starts from the cities. Economic disparity between urban and rural areas is very significant. In some rural areas, life is like that of most underdeveloped countries: the direct burning of biomass (firewood, crop stalks, and straws) is used as the primary source for

table 2. Improvement in energy intensity in tce/US$100 (compiled from data in Wang, 2005).

	1995	2020	% of Reduction	% Annual Reduction
China	1,229	837	31.9	4.56
United States	285	249	12.6	1.8
Japan	94	90	4.4	0.63
EU	160	148	7.5	1.07
India	689	619	10.2	1.46
World	283	262	7.4	1.06

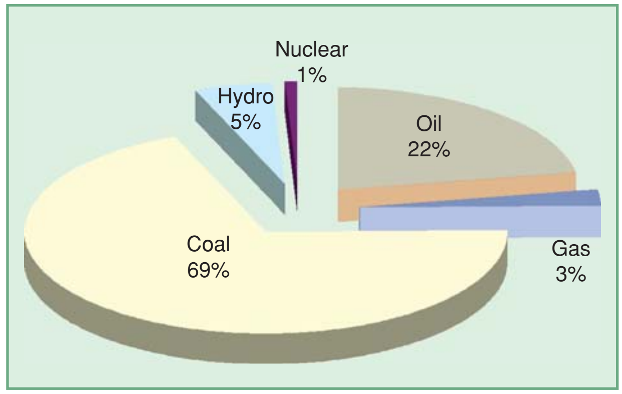

figure 3. Composition of energy resources (compiled from data at http://nyj.ndrc.gov.cn/sjtj/t20051128_51344.htm).

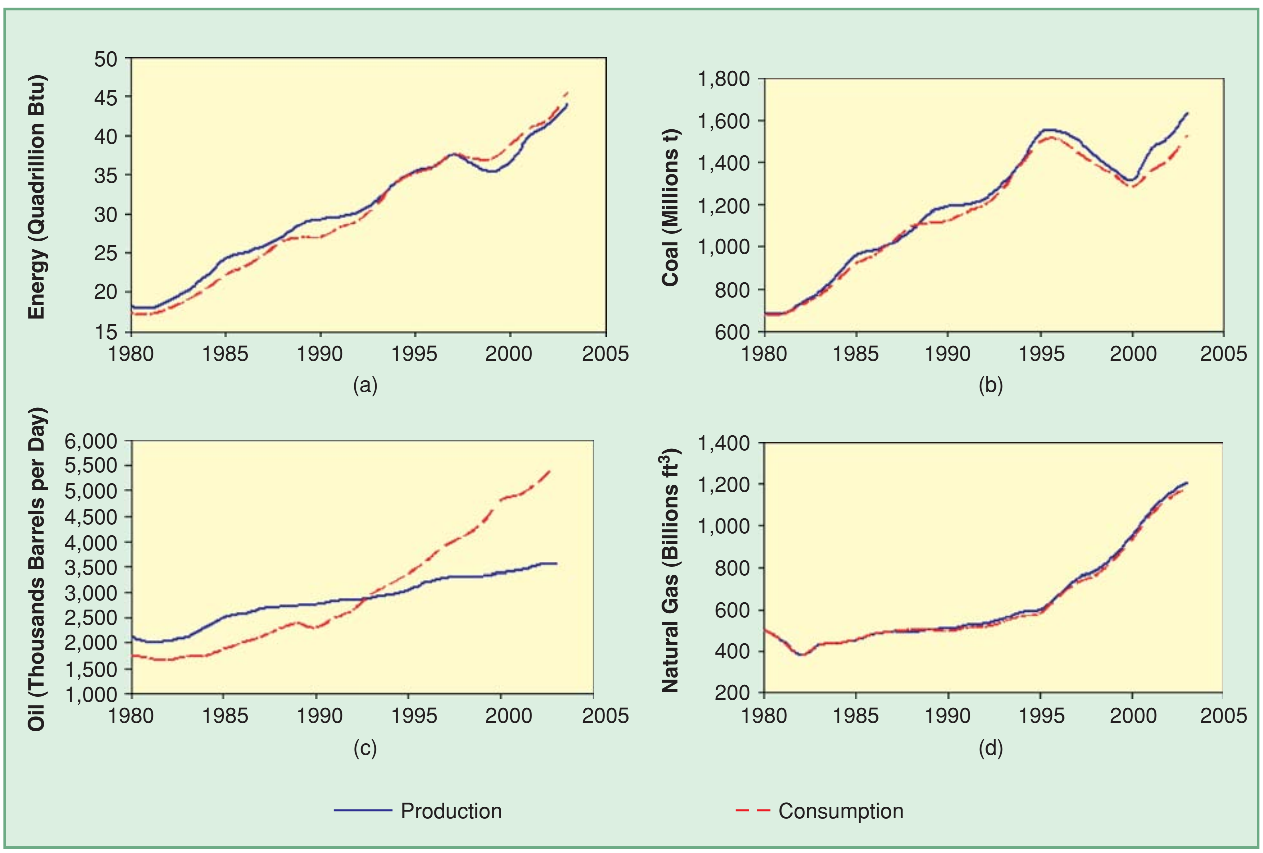

figure 4. Evolution of energy production and consumption (compiled from data at EIA, http://www.eia.doe.gov).

cooking and space heating. Fifty-six percent of rural residents in 2003 relied on such biomass for energy, which is an improvement from 84% in 1980 (Figure 5). However, the direct use of biomass fuel has significant environmental effects in terms of the depletion of forests, degradation of agricultural land, and detrimental health effects resulting from concentrated air pollution. Studies have shown that deaths from chronic respiratory diseases in rural areas due to direct coal and wood burning are on the same level as cigarette smoking.

Rural electrification has been the path taken by developed countries to eliminate such detrimental environmental impact. Electrification has a higher overall efficiency and, by source concentration, it controls pollution more easily. Furthermore, it is estimated that electrification would reduce annual deforestation by 1,300 km^2 (or 9,000,000 m^3) of wood.

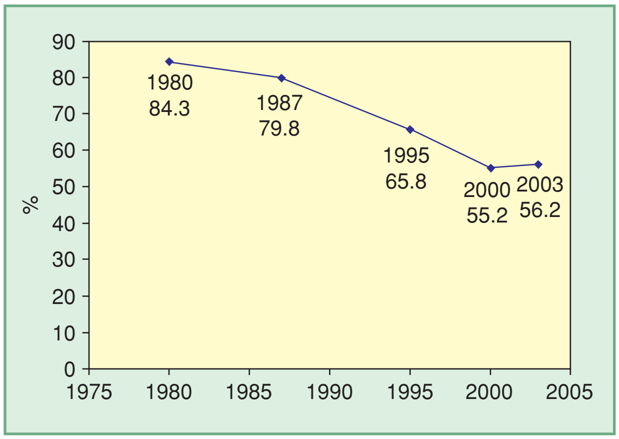

figure 5. Percentage of rural households on biomass fuel (compiled from data in Wang, 2005).

table 3. Energy efficiency (compiled from data in Wang 2005)

	1980	1989	1997	2002
Efficiency	25.9	28	31.2	33.4

China's heavy dependence on coal is the root of its environmental problem. The environmental impacts of coal, from extraction to end use, encompass land disturbance, water usage, groundwater contamination, and air pollution. Coal contributes to 90% of the total sulfur dioxide (SO_2) emission in the atmosphere, 65% of nitrogen oxides (NOx) emission, 70% of particulates, and 80% of carbon dioxide (CO_2) emission in China. Oil also contributes to NOx, particulates, and to SO_2 to a lesser extent. All fossil fuels contribute to CO_2 emission.

Emissions of SO_2, NOx, and solid particulates have detrimental implications for air quality and health. SO_2 and NOx may travel hundreds of miles, causing acid depositions made from sulfur and nitrogen oxides mixed with rain (acid rain) over a large region. Acid rain results in damage to trees and crops and sometimes extends to the acidification of streams and lakes, resulting in the destruction of aquatic ecosystems. It also leads to the corrosion, erosion, and discoloration of buildings and monuments. In China, the affected area by acid rain has expanded to more than 1,000,000 m^2 since the 1990s. Moreover, one-third of China has a pH value of less than 5.6, i.e., high acidity (see Figure 6).

Carbon dioxide is the major cause of greenhouse gases that contribute to global climate change. The other major greenhouse gas is methane. These gases have a long residence time. The accumulation of man-made greenhouse gases due to the burning of fossil fuels has occurred since the industrial revolution, and it is believed to have reached the maximum point of the atmosphere's carrying capacity, trapping radiated heat from the sun, and leading to higher long-term atmospheric temperature. The effect of climate change is long term, and it is global. Notably, the CO_2 emission in China has more than doubled in the last 20 years, as shown in Figure 7. In addition, it ranks second worldwide in CO_2 emission. Figure 8 compares the total emission of China with that of the United States, Japan, and Germany. On a per capita basis, however, China's CO_2 emission is only 14% of that

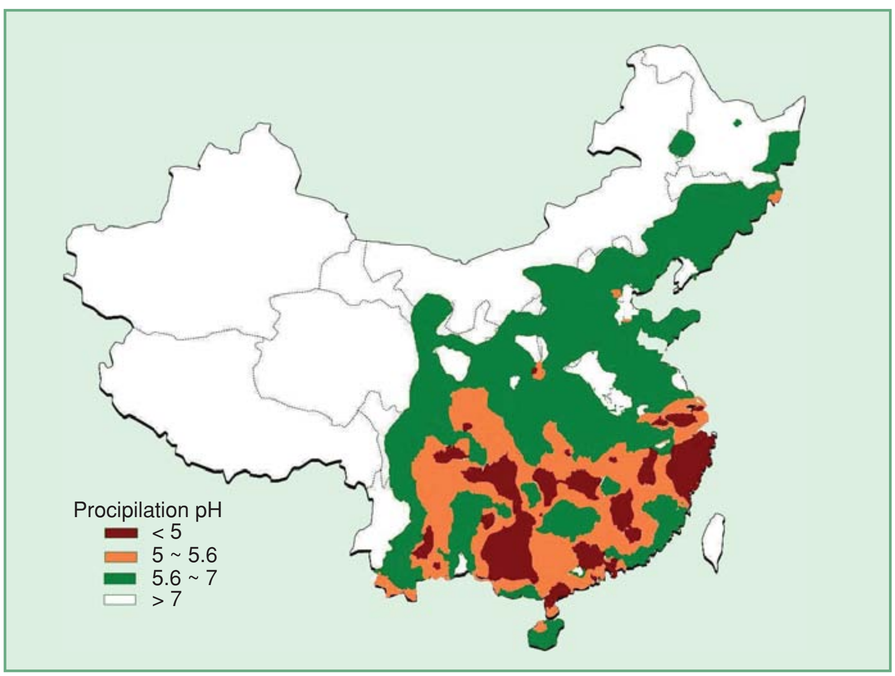

figure 6. Geographical distribution of the pH value of precipitation, 2001 (from http://www.vecc-sepa.org.cn).

table 4. Coal consumption in thermal power plant in gce/kWh (compiled from data in Wang, 2005).

	1990	2000	2003
China	427	392	381
Japan	332	316	312

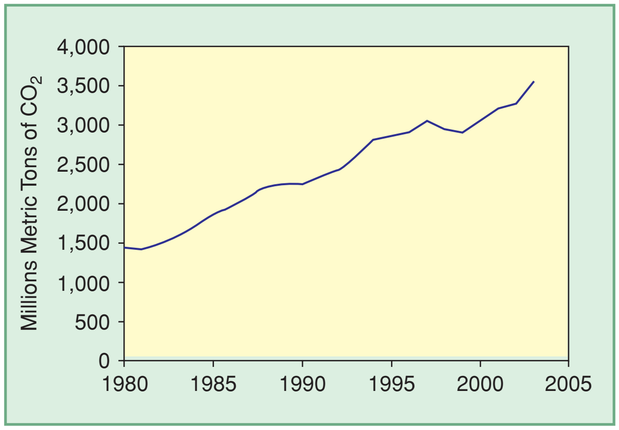

figure 7. CO_2 emission evolution (compiled from data at EIA, http://www.eia.doe.gov).

produced by the United States, 29% of Japan, and 68% of the world average.

In summary, except for oil, China is basically self-sufficient and will remain so in terms of energy supply. It is heavily dependent on coal, and almost every energy and environmental problem China is currently facing, such as large quantity, low efficiency, and high emissions, can be traced back to coal.

Statistics on China fall into two categories. In total values, the numbers are either impressive or scary, whereas on a per capita basis, the numbers suddenly become either modest or forgivable. In Figure 9, we attempt to present a fair picture for comparison. We put the values of population, economy (GDP), energy consumption, and environmental impact (represented by CO_2 emission) of leading economies, including China, the United States, Japan, and Germany, side by side. The numbers are normalized as the percentage of the world total. A quick glance at the chart immediately shows that China still has a huge potential to grow economically, relative to its human resources. Its use of energy and its damage to the environment, relative to its economy, however, is much too high, and they must not allow it to grow any more, as the economy grows. Its disturbance to the environment must be aggressively curbed, and per capita energy consumption and environmental pollution must not be allowed to catch up to the present levels of the developed countries.

Developing countries have been emulating and following the steps of developed countries in their quest for development. They tend to use the cheapest means, including energy, to generate the highest economic gains in the shortest time possible, and they worry about addressing environmental problems created along the way later. China is no exception to this. However, due to its sheer size and condensed time of development, the energy problem and its environmental impacts are enormous. Right now, the cost is just being tallied, but soon, it must be repaid.

By 2020

China's plan for the next 15 years is to continue its economic growth, albeit at a slower rate. The goal is to quadruple its GDP, while, at the same time, only doubling energy consumption. In other words, it has to reduce its energy intensity further by 50% or an average of 3.3% annually. As mentioned earlier (Figure 2), it has an impressive achievement in the reduction of energy intensity in the last two decades. However, the past would be difficult to repeat, especially now that China has moved up in its development. As a country's economy advances, the

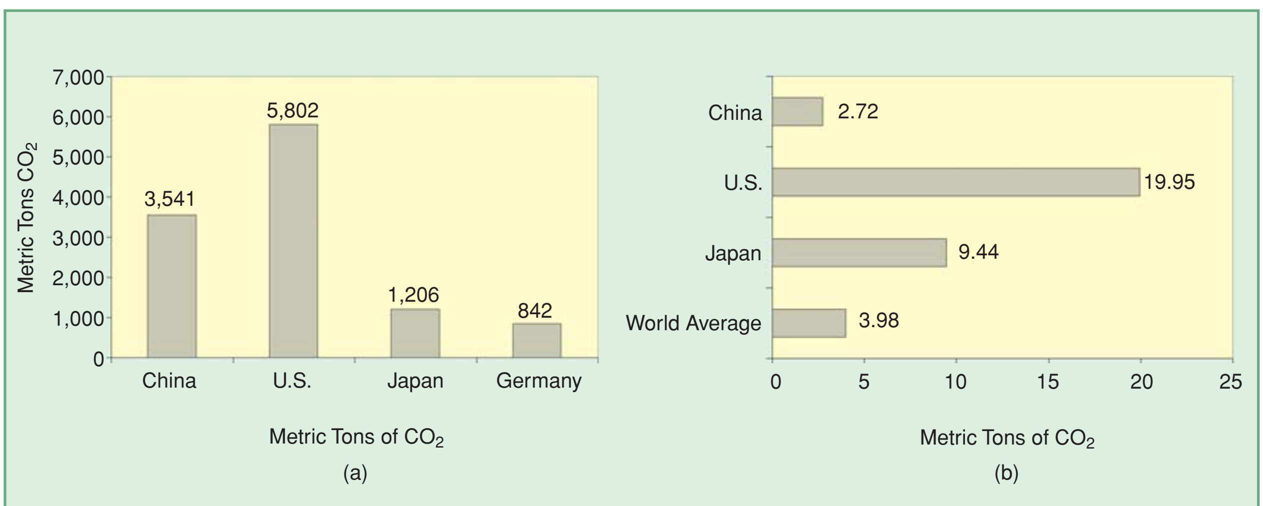

figure 8. CO_2 emission in 2001: (a) total amount and (b) per capita (compiled from data in IEEJ, *Handbook of Energy and Economic Statistics in Japan*, 2004).

harder it is to improve its energy intensity. This is shown in Table 2: the United States and Japan have an average improvement of around 1% annually. As such, achieving another 50% reduction in energy intensity in the next 15 years will not be easy for China.

Furthermore, China will likely face two new issues that will be largely outside of its own control and will make it difficult for the country to be left alone to pursue its continued economic development. The first issue is regarding energy security as China increasingly depends on foreign oil. The second one is the international pressure for China to clean up its environment.

Energy

There will be significant shifts in energy usage in China in the next 15 years. Industries will continue to shift towards being more high-technology oriented and less energy intensive. There will, however, be a bigger shift in the end-use side. Economic development in China has ushered in a growing portion of the middle class population. With the improvement in the standard of living and the influence of Western culture, middle class people are now demanding automobile and residence ownership. Moreover, it is expected that the 100 million-strong middle class will be doubled in the next five years. Thus, use of energy in transportation and construction will increase. As recorded, the total number of vehicles (including buses, trucks, and automobiles) in China has increased rapidly from 5 million in 1990 to 10 million in 1995 to 24 million in 2003. Privately owned automobiles have jumped from 1.1 million in 1995 to 8.4 million in 2003. The total number of vehicles is expected to exceed 60 million by 2020, with a larger share of private automobiles. Gasoline consumption will consequently increase. Vehicles already contribute to 80% of the pollution of big cities like Shanghai and Beijing, and this situation is expected to get even worse.

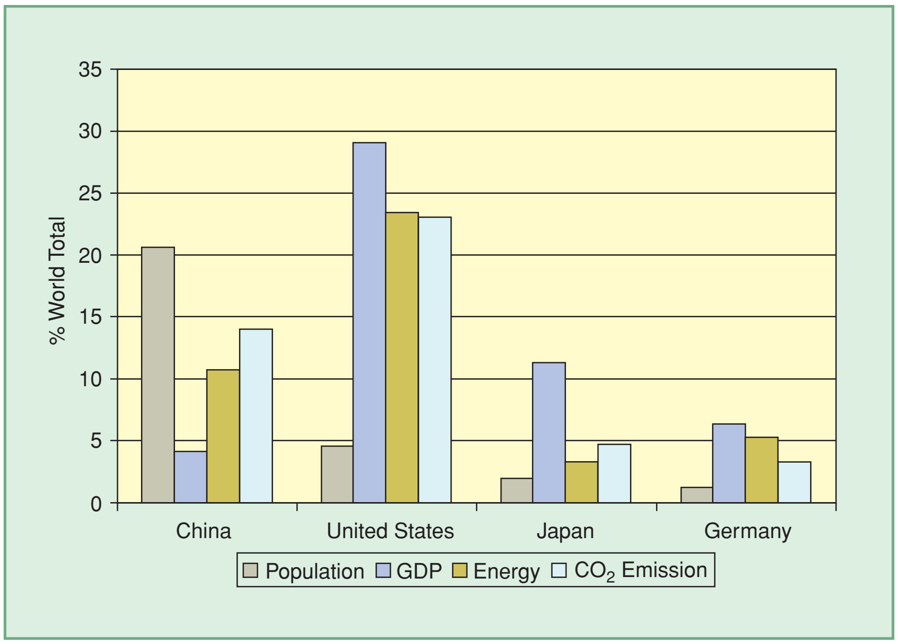

figure 9. Comparison of population, GDP, energy consumption and CO_2 emission as a percentage of the World Total (compiled from data at EIA, http://www.eia.doe.gov).

With the growing number of the middle class and the hundreds of millions of people from rural areas settling in the cities in search of better jobs, the construction of new housing and energy use in buildings will likewise increase. Modern appliances—for example, air conditioning and water heaters—as part of living-standard improvement consume energy. The forecast is that transportation and construction will increase their share of energy demand from 27–43% in 20 years (see Figure 10).

As a fast-developing country, China's share of electricity in energy use will continue to rise at a fast rate. As mentioned earlier, the trend of rural electrification will continue. The currently installed electricity capacity of around 500 GW, ranked second in the world, can be expected to double to 1,000 GW in 2020, requiring the continuous addition of more than 30 GW of capacity annually. The development of this largest and most complex power system will be one of the biggest engineering challenges of the century (See Wu and Fu, 2005). More electrification opens up opportunities to move up the C-O-G-N-R ladder to rely more on natural gas and nuclear energy sources.

Trends in moving up the C-O-G-N-R ladder are already happening in China. As noted earlier (Figure 4), the use of natural gas has surged recently. Since China became an oil-importing country in 1993, the use of oil has increased steadily, and the import percentage has been growing. In 1995, 7.6% of its oil was from imports; this percentage has risen to around 30% now. It is estimated that by 2020, if the current trend continues, China will reach 60% of imported oil consumption, sharing the same percentage with the United States. Thus, being faced with this rising oil demand, Chinese companies are scrambling all over the world to secure oil supply.

Oil price is the single most volatile and key factor influencing the world economy, and oil security is the root of many international conflicts. In the near future, China's oil demand will have a far-reaching impact on the world, and China will face tremendous challenges in its pursuit of economic development due to oil security and price stability.

Environment

Increasing the use of gasoline in vehicles will make local pollution in Chinese cities worse. Overall, oil and gas will not replace coal in any significant proportion in the next 15 years. Therefore, coal consumption will still dominate. Coal consumption in China by 2020, if we double its current rate of 1.5 billion tons, will reach 3 billion tons. The emission of SO_2, NOx and other pollutants will likewise double if no drastic actions are taken.

The emissions of SO_2 and NOx in the year 2000 were 27.2 million tons and 19.9 million tons, respectively. It is estimated that based on environmental sustainability, China has the capacity to absorb 16.2 million tons and 18.8 million tons of SO_2 and NOx, respectively. In other words, this is already 68% over its SO_2 limit and 6% over the NOx limit. Thus, doubling this in 2020, the SO_2 emission will be 235% over its sustainable limit, and NOx will be 111% over its limit. As mentioned previously, the problem of acid rain is already serious, and the country cannot afford doubling this damage. Furthermore, this problem may become a legitimate concern of neighboring countries and later become an international issue.

CO_2 emission and climate change are clearly global issues. The most significant international environmental treaty ever agreed upon and signed was the UNFCCC (United Nations Framework Convention on Climate Change) at the 1992 Earth Summit in Rio de Janeiro. This treaty sets out a framework of action to control and cut down greenhouse gas (GHG) emissions. A protocol was subsequently adopted at a conference held in Kyoto in 1997, which was ratified by the majority of the participants. Under the Kyoto Protocol, participating industrialized countries agreed to reduce their overall emission of greenhouse gases by an average of 5.2% below the 1990 baseline between 2008–2012. China was classified as a developing country and was therefore exempted from the mandatory reduction requirement. In the case of the United States, which ranks first in terms of CO_2 emissions, the Bush administration refused to sign the Kyoto Protocol. As recent public awareness of climate change issues increases, the U.S. government may soon change its course and come to some kind of agreement with the international community. As shown in Figure 8, China ranks only second to the United States in CO_2 emission. However, sometime between 2020–2030, China may surpass the United States in CO_2 emission. In any case, international pressure will definitely mount on China. China cannot expect to continue to pursue its economic development without international intervention on environmental concerns in the next 15 years.

Necessary Steps

China's energy and environmental problems are serious. These problems have been experienced by developed countries, though not on the same scale. The measures taken by these countries to combat energy and environmental problems include the following:

- ✔ enhancement of energy efficiency in production and utilization
- ✔ conservation of energy usage
- ✔ use of cleaner fuel (e.g., natural gas)
- ✔ use of nonfossil energy sources
- ✔ employment of environmentally friendly technologies.

The energy and environmental problems facing China are enormous, and hence more measures must also be taken. The government has adopted an energy and environment policy calling for "conservation first, resource diversification, and environmental friendliness." In addition, several legislations in energy and environment have been enacted in recent years, including the Energy Conservation Act in 1998, the Renewable Energy Act in 2006, and the Emission Control Act in 2006. We will discuss the potential for success of each of these policies in the following section.

Conservation First

As pointed out earlier (Table 1), the energy intensity of China is significantly higher than that of the United States and Japan. The overall energy efficiency, including transmission and utilization, in China has improved from 25.9% in 1980 to 33.4% in 2002 (as shown in Table 3). From these figures, it is believed that there is plenty of room for efficiency improvement and usage conservation. Let us first start with the industrial sector for instance. The industrial sector

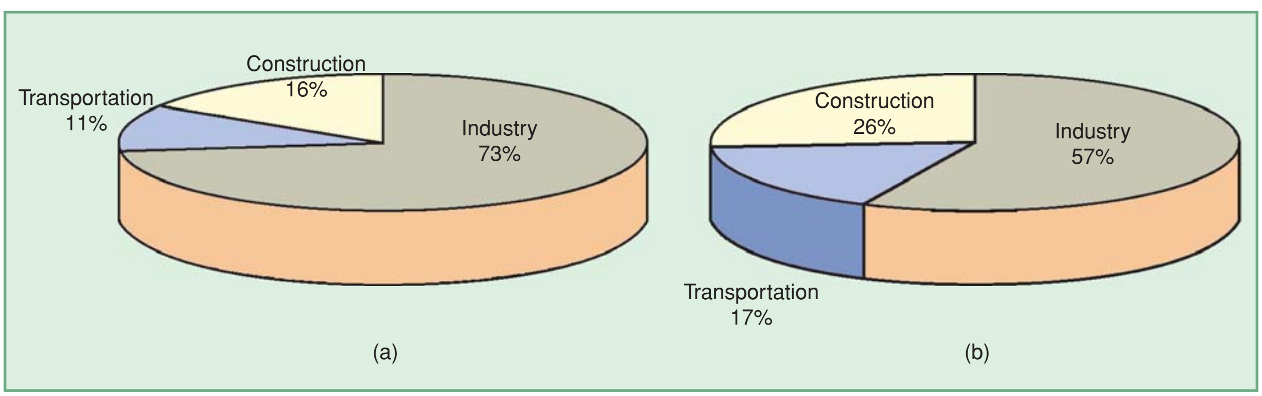

figure 10. Share of energy demand in (a) 2000 and (b) 2020 (compiled from data at http://www.moneychina.cn/d/2005/12/07/1133935635781_ 3.html).

has the largest share of energy usage in China and will continue to do so in the future. It is estimated that among the eight energy-intensive industries, the average energy usage per unit output is 47% higher than the corresponding numbers in developed countries. Therefore, the largest percentage of energy savings could come from industrial improvement in process technology and management. Moreover, in the utility industry, energy conservation could come from efficiency improvement in production and consumer conservation through demand-side management (DSM). In the area of efficiency improvement, for example, the average amount of coal to produce 1 kWh of electricity of Chinese thermal power plants (Table 4) has improved by 11% from 1990–2003, but it is still 15% higher than the comparable rate of 1990 Japanese power plants and 22% higher than 2003 power plants. [The corresponding figure for German power plants is 309 gce/kWh (gram coal equivalent/kilowatthour), which is similar to that of Japan.] Further efficiency improvement seems possible.

Transportation and construction are the two sectors that are taking off. At this stage, appropriate policies and technologies can be adopted to ensure long-term energy savings and environmental benefits. China must not follow the mistakes of some developed countries in wasteful automobiles and housing. The average fuel efficiency in vehicles in China today is 20% lower than that of developed countries. China must tighten fuel efficiency standards and aggressively develop public mass transportation and efficient intelligent transportation systems. China must also embrace the sustainable design option in construction, for example, the practice of remanufacturing. Technology innovation and government policy can play decisive roles in significant improvement in appliance energy efficiency. Energy conservation must reach rural areas to prevent affluent residents from tearing down energy-efficient traditional homes to build Western-style new houses. In effect, it would be a disaster if home energy consumption in rural areas catches up with urban areas.

Resource Diversification

China has limited fossil fuel resources. Its proven oil reserve is 25 trillion tons, gas is 440 trillion cubic meters, and coal is 1,000 trillion tons. The per capita values are only 11%, 4.3%, and 55%, respectively, of the world's average. Proven reserves for developing countries are functions of exploration and are not considered accurate. But, China has been aggressive in its effort in the exploration of oil and coal and has been doing so with the help of the latest technology. Natural gas, on the other hand, is in the early stage of development, and its reserve has the potential to grow. It is estimated that the proven reserve in gas will grow at an annual rate of 10% (compared with 4% in oil). The rate of extraction of natural gas to the amount of proven reserve is 1:62, which compares favorably with the world's average of 1:40. (For oil, the rate of extraction to reserve is 1:15 for China and 1:60 for the world). China has the potential to deploy more natural gas. Natural gas is more environmentally friendly, more efficient, and is the preferred source of fossil energy for developed countries. It does not produce sulfur, has 90% less nitrogen oxides, and emits 40% less carbon. Generating electricity with natural gas with the latest combined-cycle gas turbine (CCGT) power plants can reach twice the efficiency of old fossil plants.

China has a large hydro potential. Hydro is classified into large hydro and small hydro. Large hydro refers to the conventional hydro generation of electricity that is connected to the power grid. Rural hydro power generation (usually in the kilowatt range) for immediate and local consumption that is not linked to the power grid is called *small hydro*. Currently, China's hydro generating capacity is at 100 GW, representing 22% of the total installed capacity of the electric system, but the energy it produces represents only 15% of the total electric energy consumption, which is below the world's average of 18%. The estimated exploitable hydro capacity in China is around 500 GW. In order to reach the goal of 20% electric energy coming from hydro power plants with a total capacity of 200 GW by 2020, China needs to build 7,000 MW capacity of hydro plants annually. That will not be an easy endeavor. Hydro power plants, however, are not without environmental impact. In addition to the safety concern over possible collapse, dams may cause the destruction of natural habitats, inundation of productive land and forests, loss of cultural sites, displacement of people, and so on. The Three Gorges project, for example, along with its numerous benefits, also submerged 70,000 hectares of land, of which 40% were arable land, profoundly disturbing the ecology of the surroundings.

China has nine nuclear power plants with a total capacity of 7 GW. Nuclear is pollution free and does not contribute to global climate change. However, the opposition to the development of nuclear energy comes from concerns over safety, terrorism, and waste disposal. China's nuclear capacity at 1.6% is way below the average of those of developed countries. Thus, China plans to expand its capacity to 40 GW by 2020. However, China does not possess patents for core technology for commercial nuclear power plants, and it only relies on foreign countries for technology. Another issue with nuclear power is that the reserve and production of domestic uranium may not be enough to sustain large deployment.

Renewable energy, such as hydro, solar, and wind, has the least environmental effect. Large hydro plants and conventional biomass energy are renewable energy sources according to their strict definition. However, the new definition of renewable energy sources excludes these two and is limited to the category of small hydro, wind, solar, and electricity generated by biomass and solid wastes. These restricted renewable sources represent 14.5% of the total renewable resources in China, and small hydro is the single largest contributor (78%) to this list. Small hydro potential is estimated at 125 GW. Meanwhile, China has a large wind energy

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potential of 250 GW on shore and an additional 750 GW off shore. The government's plan is to have 100 GW capacity from renewables in 2020, of which 70 GW are from small hydro, 20 GW are from wind, and 10 GW are from biomass. The plan also calls for solar panels to cover 300 million square meters, replacing 40 million tons of coal and providing 2 GW of electricity. Currently, solar is only 65 MW. The viability of renewable energy development is critically dependent on government policies. The government requires generating companies with more than 5,000 MW of installed capacity to have at least 5% of their capacity to be fueled by renewable sources by 2010 and 10% by 2020.

Environmental Friendliness

Conservation and diversification efforts all help to make energy production and consumption more environmentally friendly. Other, more specific, environmentally friendly solutions are either technological in nature or are part of adhering to a policy. Clean coal technologies in coal mining, processing, and power plants will have a major impact on the heavily coal-dependent China. The large-scale adoption of clean coal technologies, such as scrubber, CFBC (circulating fluidized bed combustion), PFBC (pressurized fluidized bed combustion), and flue-gas desulphurization (FGD), can significantly reduce pollution, such as particulates, sulfur dioxides, and nitrogen oxides. Carbon sequestration technology, however, is not commercial yet. Moreover, no cost-effective technologies to reduce carbon emission from coal are available.

The problem is that domestic-made equipment currently in use is generally not very effective, while imported equipment is too expensive. Indeed the experience of deploying emission control devices in developed countries has shown it to be expensive, and on the average, they add 25% to the capital costs to power plants and 20% to the operating costs. Some in developing countries think that they are ill-afforded luxuries. However, such costs have to be weighed against the social costs of environmental effects. For example, according to a study conducted by Tsinghua University, acid rain costs China an annual economic loss of over US$13 billion and health costs from coal amounting to 7% in 1997 will increase to 13% of the GDP by 2020. The costs of clean coal technology are high, but the total costs will be higher if it is not implemented.

The new laws in China have enabled the government to require closing down coal mines that produce coals with sulfur content greater than 3%, installing coal desulphurization devices for those with sulfur content between 1.5% and 3%, and closing down small (<50 MW), inefficient coal power plants. Enforcement of new environmental regulations could slow down the deterioration of the environment, which is desperately needed.

Challenges

To continue its economic development, China's goal for the next 15 years is to quadruple its GDP with only doubling its energy consumption. In relation to its phenomenal success in the last two decades, the goal to continue economic development is possible; but its goal of energy consumption may not be easy. Although difficult, further reduction in energy intensity (ratio of energy consumption per economic output) may be achievable through aggressively adopting available measures developed in the West. This means that it must embrace and improve upon all policies and technologies on energy conservation, efficiency enhancement, resource diversification, pollution control technologies, etc. However, the consequences of China's gulping oil consumption on the world market and its distressing environmental impact on the planet from various sources, in the meantime, may be too much for the world to bear, thus it will become a global concern. Though on a per capita basis, China's energy consumption and environmental pollution may always be far from even close to the Western's current standards. Whether China likes it or not, to continue to enjoy peaceful economic growth in the future, it needs to solve its energy and environmental problems immediately. However, the solutions that have been developed by the developed countries may be too small and too slow for China, as the urgency in dealing with these problems has not been at all that great for them. In particular, China needs bold actions and innovative approaches to develop new technologies to solve its energy and environmental problems and take the lead in solving the world's energy and environmental problems. The challenges, both technological and institutional, are immense, and actions must be taken before it is too late.

Technological

Currently, China does not have its own technologies in critical energy and environment areas; therefore, aggressive development is necessary. Technology development has three levels. The first level is the improvement of cost-effectiveness of available technologies. The second level is

> China needs bold actions and innovative approaches to solve its energy and environmental problems.

pushing the envelope for the existing paradigm of technologies. The third level is the development of technologies that lead to a paradigm shift. To succeed, China needs to implement all these three levels. At present, it has programs that cover the first two levels well. For example, as mentioned earlier, China is developing clean coal technologies in fluidized bed combustion and flue-gas desulphurization, which belong to the first level. China is enthusiastically pursuing second-level technologies such as coal gasification and liquification, and IGCC (integrated gasification combined cycle) research. In the meantime, the Shenhua Group is building the world's first commercial direct coal-liquification plant in inner Mongolia, while "syngas city" is being established in Shandong province.

The development of first-level technologies is immediately needed, while the development of second-level technologies is a necessary step. The solution to the immense energy and environment problems of China, however, relies on the hope of the development of the third-level technologies. China is well equipped to embark on the first two levels of technology development, but the development of third-level technologies remains as the ultimate challenge to scientists and the society at large.

In many new areas of energy and environment, for instance, conservation and renewables which do not depend on a large base of existing technologies, China has the potential to lead the world in developing third-level technologies that would enable it to leapfrog over the West in the path of energy development. Moreover, China's fast track toward electrification offers another opportunity to bring modern material and information technologies to bear on a new paradigm of efficient power systems and electric energy management. Furthermore, transportation and construction are other candidate areas for revolutionary technologies that may break away from the Western paths.

However, China confronts two major challenges in developing the third-level technology. The first is that research and development (R&D) investment in energy and environment is too small. Like other developing countries, the total R&D expenditure in China, as a percentage of its GDP, is low, but it shows signs of improvement. However, the relative weight of energy and environment R&D is small. In 2000, energy R&D was only 6.4% of the total R&D budget. Although there has been an increase recently, it still remains low in relation to the significance of the problems. The second challenge is that innovation in research is weak. The current reward system favors less risky short-term research, thus, at present, R&D in China is dominated to a large extent by the type that is followed in the West. Bold and innovative research is rare.

Institutional

Institutional support is necessary for the success of technology development. Recent government decisions point to major policy change toward development that is more energy and environmentally centered. China's 11th Five-Year Plan (2006–2010) opens a new chapter for China, shifting from the traditional model of development, which is focused on output and consumption, to one that places greater emphasis on the quality of growth, efficiency, and sustainability. It introduces the concept of the "Green GDP" in policy-making. The idea is to deduct ecological and environmental losses from economic gains. The Green GDP will be used officially to gauge progress and to evaluate the performance of government officials. The challenges lie ahead in the definition of the Green GDP and the enforcement of the policy. With such bold vision from the government, if successfully implemented, China has a rare chance to accelerate the development of environmentally friendly energy resources, jump up the ladder of energy development, and surpass that of the West.

The government also intends to strengthen its R&D. In February 2006, China unveiled the "National and Long-Term Science and Development Outline" for an "innovation-based economy." This calls for the transformation of China from being the world's factory to the world's innovation base. The most important component of the plan is to gradually increase the investment in R&D from the present 1.23% of GDP to 2% by 2010 and, consequently, to 2.5% by 2020. By comparison, R&D investment in the United States is 2.7% while it is 3.3% in Japan. It would have a far-reaching impact, in particular, if the R&D policy would be made coherent with the Green GDP initiative, and if the government would put enough focus on energy and environment technologies, in addition to the traditional economy-enhancing areas such as materials and information technologies.

Translating research funding into scientific and technological innovation, however, has always been a challenge to countries that have become newly affluent. Innovation can be nurtured but not manufactured. The foundation that creates sparks to innovation—human resources and research culture—cannot be built overnight. Attempts to pursue advanced research as a national effort seldom succeed. Advanced research in civilian areas, in particular, such as energy and environment, ought to be global. Support for such advanced scientific research and technology development should recognize no national boundaries, only national priorities.

The market economy often breeds innovation and entrepreneurship as the keys to successful technology development. In the energy and environment area, China exerts efforts to push its market economy. Thus, electricity markets have been liberalized in 2005. The first emission-trading demonstration project, sponsored by the State Environmental Protection Agency and the U.S. Environmental Defense Fund, was completed in 2003 in East China between two power companies. Since then, emission trading has been expanding to other provinces. Other government policies, such as regulations, taxes, and market structures, if properly conceived and executed, may also encourage innovation and entrepreneurship.

However, market economies are not self-regulating. They cannot simply be left on autopilot, especially if one wants to ensure that their benefits are shared widely, for instance, in the energy and environmental areas. Managing a market economy is not an easy task. It is a balancing act that must constantly respond to economic changes. This is the challenge that China will have to face.

Education and social attitude are important factors in supporting technology development. China must come to grips with its proper roles and responsibility in leading the world to contribute in energy and environment R&D. The government has taken the lead, but the leadership attitude has to permeate all levels of the society. Educators, scientists, engineers, and business entrepreneurs must all take the challenge to lead the world toward sustainable development in energy and environment.

Conclusions

In the last two decades, China has achieved unprecedented success in its continued economic growth, consequently benefiting its people and the world at large. However, economic success has brought negative effects on energy and the environment. Thus, in a short period of time, China has become the second-largest consumer of petroleum, the largest contributor of sulfur dioxide, and the second-largest contributor of carbon dioxide. Hence, China's energy consumption and environmental impact must be seriously curbed for sustainable development. In addition, technological innovation is necessary to develop new solutions to solve the mounting energy and environmental problems.

In line with this, government has recognized the importance of the environment and has moved to enshrine in policy making the concept of a Green GDP. It now experiments on managed market-based mechanisms with markets, regulations, taxes, tariffs, and so on to achieve a balanced development. Nobel Laureate Joseph Stiglitz, former chief economist at the World Bank, praised the effort with this comment: "While America says that it cannot afford to do anything about (greenhouse gases), China's senior officials have acted more responsibly."

China has the opportunity to leapfrog to renewable resources and sustainable development. The technological as well as the institutional challenges are tremendous, but China's success could be its greatest gift to humankind.

Acknowledgments

The support from the National Key Basic Research Project (2004CB217900), sponsored by the Ministry of Science and Technology of China, and CERG Project (HKU 7190/05E), sponsored by the Research Grant Council of Hong Kong, is gratefully appreciated. Most data cited in the text, unless otherwise noted, are from the article by the Development Research Center of State Council (see "For Further Reading").

For Further Reading

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