nuclear plants being retained in the public sector) so that conditions and assumptions within the range envisaged in the international studies will generally be found appropriate.

Fuel choice

It is not claimed that the methodology and assumptions of the international cost surveys should be adopted by others for their comparative assessment of nuclear power and its alternatives for baseload electricity generation.

Each government and utility will wish to take into account its own requirements and policies, its national resources, infrastructure, manpower, relevant technical experience, and the impacts of energy supply on the national economy and on the environment. The aim will often be a balanced mix of generating plants, reflecting both financial costs as well as these wider issues.

Macro-economic evaluation of nuclear power development in China

A report on the nuclear electricity programme's prospects in the country's coastal area

by Dadi Zhou, G. Woite, and Chuanwen Hu

The Chinese nuclear power programme for electricity generation is in an early stage.

Two nuclear power stations are under construction. One is the Qinshan nuclear power plant, a 300-megawatt-electric (MWe) unit located in the Zhejiang Province. The plant was domestically designed and most of its equipment was manufactured in China. It is expected to be connected to the electrical grid in 1991. The other nuclear power station is being built at Daya Bay in Guangdong Province. It has two 900-MWe units purchased from foreign suppliers that are scheduled to be put into operation in 1992 and 1993.

Overall, China's nuclear power programme for electricity generation has progressed very slowly in contrast to the successful experience in other areas of nuclear development over the last 30 years. Why is this the case? Many factors have influenced the development of nuclear power, in particular the structure and development of the national economy and energy system.

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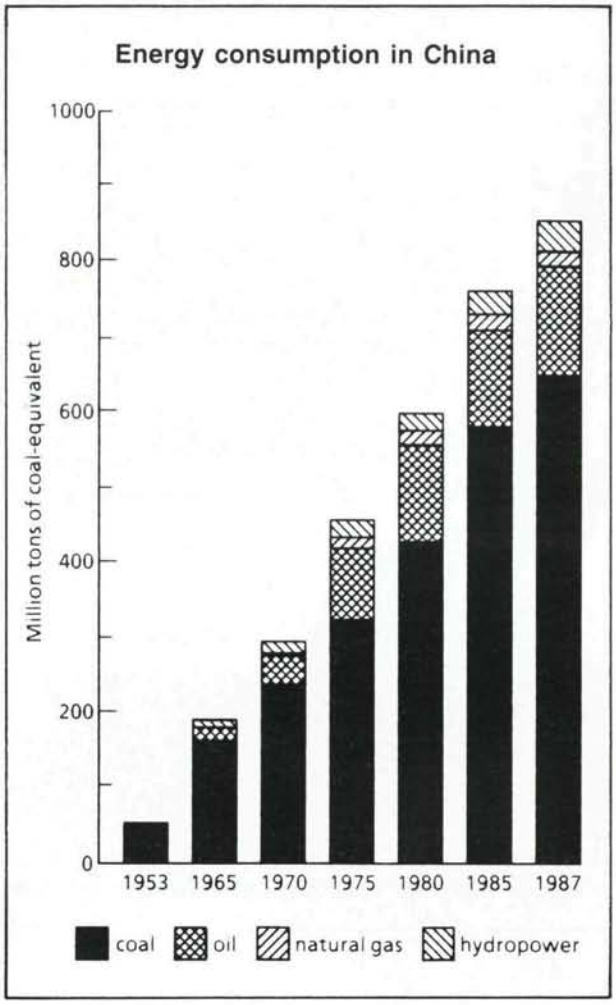
The Chinese energy system: Structure and development

During the 40 years since the foundation of the People's Republic of China, the energy industry has made considerable progress. In 1988, total primary energy production reached 958 million tons of coal-equivalent (tce), 39 times more than in 1949; the average annual growth rate was nearly 10%. *(See accompanying graph.)* During the same period, the output of coal increased from 32.4 million tons to 983 million tons, with an average annual growth rate of 9.1%. Electricity generation increased from 4.3 terawatt-hours (TWh) to 545 TWh, with an average annual growth rate of 13.2%.

Over the past decade, the policy of reform and opening to the outside world has spurred the development of the national economy. Capital investment in industry and agriculture were exceptionally expanded during 1983-87. Investment in the energy sector, however, did not increase correspondingly in this time period, which led to a serious gap between energy demand and supply.

Power shortages. In 1988, the capacity of power-consuming equipment in China totalled 286 gigawatts, which is 2.5 times the capacity of power-generating equipment. Electric power and oil shortages spread over most of the country. Annual power shortages amount to



about 75 × 10^9 kilowatt-hours (kWh). Power shortages have resulted in a serious and abnormal situation for production and livelihood. To make up for them, some small-scale thermal power units with low efficiency and small diesel engines were put into operation in many regions (especially in the fast-growing coastal area).

It is evident that this energy shortage is an important constraint on the national economy. Energy development is a key element of economic development in China.

The Chinese Government pays great attention to this problem and is adopting effective measures to accelerate the development of the energy industry as simultaneous adjustments are made to the industrial structure.

As a main principle, energy development in China is based on domestic energy resources. The country is abundant in coal resources, its main energy source, and has great hydropower potential. Proven reserves of coal are 860 × 10^9 tons, and exploitable hydropower capacity is 380 × 10^6 kW, only 8% of which has been exploited. China is the world's greatest coal producing and consuming country. In 1988, domestic coal consumption reached about 980 million tons.

China's *per capita* commercial energy consumption in 1988 was 800 kilograms of coal-equivalent, only one-third of the world average. Its energy consumption per unit of gross domestic product (GDP) was among the highest in the world. As a result of poor management, ageing equipment, backward technology, and wasteful consumption, the efficiency of energy production and utilization is very low.

China's economy is centrally planned and most of its energy production, distribution, and consumption quotas are stipulated by national planning. Capital investment in the energy industry has been insufficient; it was only 8.6% of the total investment in fixed assets in 1988. Moreover, the limited funds are preferably used for short-term projects so as to meet urgent needs of energy supply. Consequently, projects such as hydropower and nuclear power plants, whose construction requires a long time and entails high capital costs, could not be implemented for lack of funds. This has made the energy structure worse.

Another factor is that the income of energy enterprises does not cover expenditures. The prices of energy products determined by government authorities have been too low for a long time and the taxation of the energy industry is unreasonable. This situation must be changed for sound development of the energy sector.

China's mid-term energy development strategy is summarized as follows:

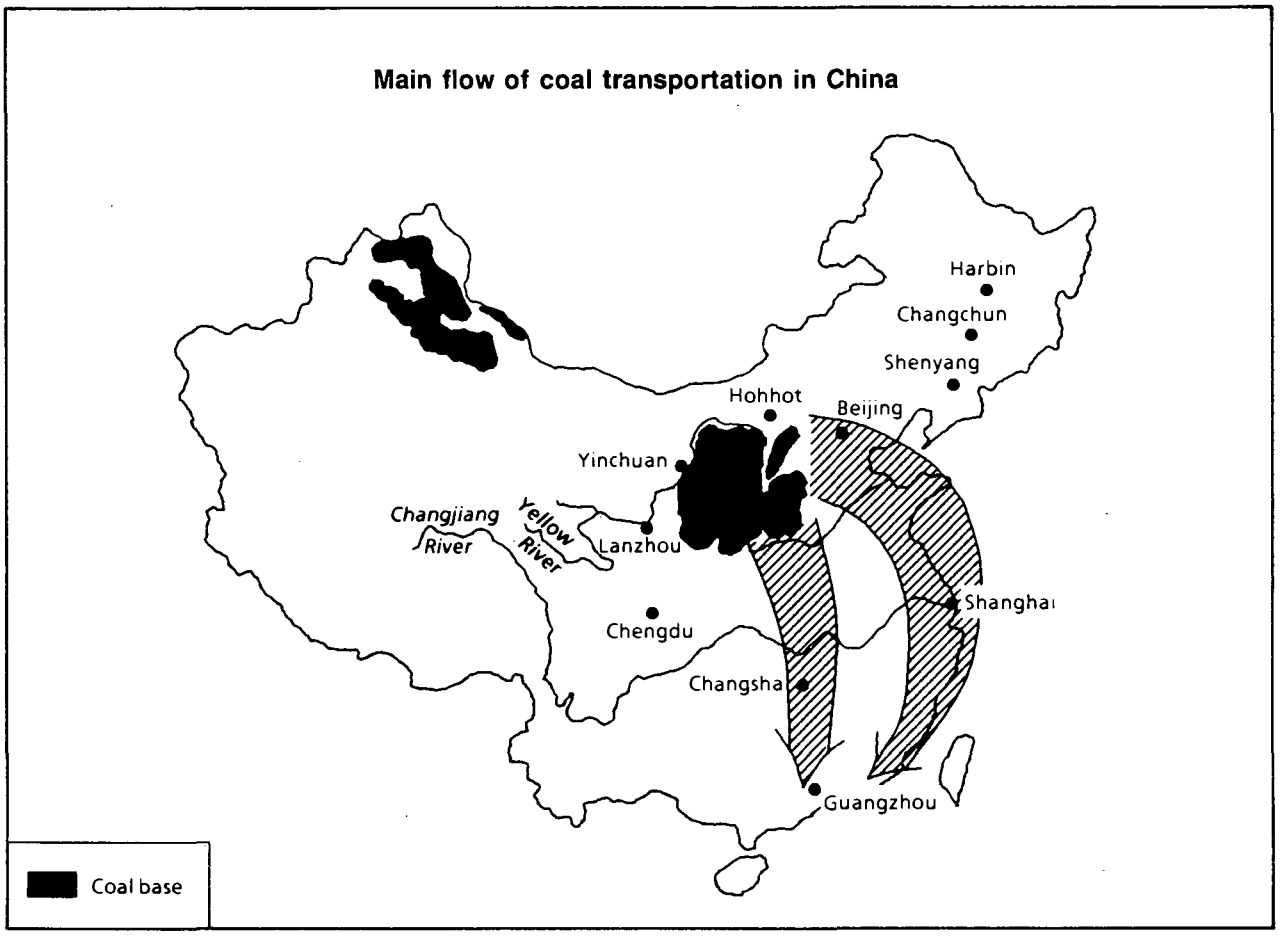
- Pay equal attention to energy development and conservation;
- Improve energy structure, distribution, and management;
- Develop energy industries with electric power as their center and coal as their basis; actively exploit petroleum and natural gas; and make great efforts to develop hydropower and nuclear power.
- Take into consideration all aspects and impacts of technology, economy, and environment for decisions on energy production and utilization.

Issues regarding coal as a main energy source

As the main energy source, coal occupies a very important position in the economic and social development of China. In 1987, coal accounted for 72.6% of the total primary energy production, 76.3% of the total primary energy consumption, over 80% of the thermal power generation, and 90% of the residential energy consumption. Chinese experts expect that the output of raw coal in China will reach about 1.4 × 10^9 tons by the end of this century.

In recent years, disadvantages of coal as the main energy source have gradually become evident. An increase in the production and utilization of coal in large amounts will exert growing pressure on transportation and the environment.

Energy efficiency. The efficiency of energy utilization is about 26% in China. For coal use, it is even lower, only 20%. Average heat efficiency of coal for residential use is only 15%-18%. An important reason for this is that most of the coal-consuming equipment in



China is old and inefficient. Another reason is that open fireplaces are very common in rural areas. Coal fire cannot be switched on and off like gas or electricity, and it is usually kept burning during the day or overnight.

According to statistical data issued by the World Resources Research Institute in 1988, the energy consumption per unit of GDP (in US $) in China is 4.97 times more than in France, 2.1 times more than in the United States, and 1.65 times more than in India.

Transportation. The geographical distribution of China's coal reserves is quite uneven. Just over 80% of existing coal reserves are concentrated in the north and northwest regions. However, about 74% of the coal is consumed in the developed eastern and southern coastal areas of China. A massive coal flow has to be transported through China. *(See map.)* About 60% of the total coal output, or about 600 million tons per year, is transported. It goes mainly by railway, occupying 40% of the gross volume of rail freight, and by ship, occupying about one-third of ship freight in the middle and lower reaches of the Changjiang River and in coastal waters. The transportation distances from the coal base in the north of Shanxi province to Shanghai, Xiamen, and Guangzhou in the coastal area are over 2000, 2800, and 3300 kilometers, respectively.

To ensure energy supply in the coastal areas, first priority is given to coal transport even if other freights are delayed. Insufficient transport capacity has substantially constrained the development of coal-based industries and has affected the reliability of electric power supply, resulting in substantial economic losses. In some coal-producing areas, production quotas are assigned according to transportable volume.

Additional coal capacity. It is estimated that the capacity of coal-fired power stations should be increased by more than 10×10^6 kilowatts annually until the year 2000. Most of the new power stations will be built in the east and south of China. To implement this energy and electricity development, extensive construction of transportation facilities, such as railways, ports, channels, and manufacturing of vehicles and ships, are prerequisites. They should be taken into comprehensive consideration together with social, economic, environmental and population problems, such as financial investment, occupation of farmland, resident migration, and employment.

Environmental considerations. In China, most of the coal is used for direct combustion and most of the coal-consuming facilities are operating without flue gas desulphurization or other purifying systems. Serious

environmental pollution has been caused by massive coal-firing. Air and ground pollution through fly ash and sulphur dioxide have exceeded the standard stipulated by the State in many cities of China.

Regarding sulphur dioxide content in the atmosphere, for instance, 19.4% of the cities monitored by the State have exceeded standards, and in some of them, the atmospheric content of sulphur dioxide has been ranked among the world's highest. Some cities in central China, such as Chongqing, Changsha, and Nanchang, have seriously suffered from acid rain. It greatly has affected the health of the residents and the economic development. The greenhouse effect and climate changes will have a strong impact on the coastal area of China. It is therefore indispensable to gradually reduce the consumption of fossil fuel and to improve the energy structure through the use of non-fossil energy resources.

The energy price system of China

A quantitative analysis method is necessary for the economic evaluation of electric power stations. Cost comparisons between nuclear and coal-fired plants, for example, are based on various prices of all equipment and materials. The energy price system of China, however, is very complex and distinct from other countries. It causes problems in macro-economic and micro-economic analyses, and leads to poor compatibility with international evaluations.

Before carrying out its reform policy in 1980, China had followed an economic model characterized by highly centralized planning. The Government set allocations of investment and production among sectors. The prices of all main production and consumption goods were stipulated by the Government with consideration to social equilibrium in the national economy. The enterprises were working to meet production quotas without profit.

In the 1980s, the economic reform has brought a great change in management. Market adjustment factors are used to supplement centralized planning. The ability of local governments to make decisions about their economy has been enhanced in line with the reduction of the central government's authority. A two-level financial system has been established for the central and local governments, and the economic reform has encouraged enterprises to work for their own profit.

Since 1984, a double price system has been formally introduced in the price management system. For the same product, the state stipulates low prices for planned output, and allows free pricing according to market conditions for output beyond the plan. Even planned output has two or more prices according to quotas of production and consumption.

For coal produced by State-run coal mines, there are three planned prices (pithead prices). The planned low price is set for the base production amount, which is equivalent to the output of 1982. A price 50% higher is set for additional amounts produced according to the current year's planned quota. A third price, 100% higher than the low price, is set for amounts produced beyond the current year's planned quota. An average price for customers is calculated according to the weight of these amounts and thus varies with incremental output.

Based on this price system, most State-run coal mines suffered a deficit and had to be subsidized by the Government. Furthermore the deficit refers to current direct expenditures in the production process, not including exploration costs and capital investment. In other words, prices are lower than the current production cost, and much lower than the long-run marginal production cost of most State-run mines.

The price of coal produced by local State-run mines (provincial or county mines) is determined by the local government. The prices in different regions vary and depend upon local energy resources and the local government's financial subsidy.

The third type of coal production in China is township mining where farmers operate the mines. They produce about one-third of China's coal output. The operation of township mines is guided completely by the market and its price fluctuates according to supply and demand.

Considering the transport costs for long distances and the multiple price system of coal production and transportation, coal prices in the eastern coastal area vary widely. They also rise sharply because of serious energy shortages. Additionally, petroleum production and electricity have multi-price systems.

As mentioned above, current energy prices are quite low and reflect neither their current production cost nor a reasonable profit. The market for unplanned production is not well established. The prices of various energy products are dependent on their status in the mixed economic management system. It is affected by various non-economic factors, including the form of ownership, investment sources, relationship with the State plan, and channels of distribution and circulation. The existing multi-price system implies difficulties not only in the management of energy prices, but also in the evaluation of investment projects.

The energy price system, as well as China's general price system, should be reformed. Several energy price concepts have been proposed for economic analysis. The "shadow price" introduced by the State Planning Commission is for evaluation of investment projects. The "mine-profitable" coal price has been put forward by the Development Center of the State Council of China and the World Bank in a joint research project. The marginal price is taken as a function of the amount of production and consumption as well as a function of time. The unplanned coal price in the eastern coastal area is much higher than the level of international coal prices. It reflects the trend of supply and demand in the local market.

Prospects of nuclear power development

In the past 30 years, China's nuclear industry has made significant progress. A complete nuclear fuel cycle system, including uranium exploration, milling, isotope separation, fuel fabrication, and spent fuel reprocessing has been established on an industrial scale. Professional teams on nuclear science and technology have been established and have accumulated experience in various fields. China has had a sound foundation for the development of nuclear power.

The first nuclear power project in China, the 300-MWe Qinshan plant, was approved by the Government in the early 1970s. Unfortunately, the project was suspended for more than 10 years. The decision makers underestimated the energy demand and the importance of improving the energy structure. The position and role of nuclear power in the country's energy development was not given sufficient attention. There was no adequate long-term planning for nuclear power development. The financial channels for investments in nuclear power plants and in the nuclear equipment manufacturing industry were not defined by the end of 1989 in the national economy planning. The fund allocations among relevant ministries were not co-ordinated for nuclear power development. Because of fund shortages, the start of Qinshan's construction was delayed and the second phase of the Qinshan project, two 600-MWe units, is still pending even though it was approved by the Government in 1987. Firm integration of nuclear power in national energy planning is required to assure domestic financing of nuclear power plants. Other causes for delayed nuclear power projects are the long debates on the most appropriate reactor type and unit size.

Energy and electricity demand. The gross amount of Chinese primary energy demand is projected to be above 1.43×10^9 tce by the year 2000. Electricity generation should reach at least 1200×10^9 kWh, with an installed capacity of 240×10^6 kW. By the year 2015 more than 2×10^9 tce of primary energy will be needed. The coal supply will not be able to meet the demand in all cases.

To increase the electricity supply, hydropower construction is to be accelerated, but economically exploitable hydropower resources are limited. Many proposed hydropower stations will be built in the remote southwestern areas of China. The technology and economics of long-distance transmission of electricity must be taken into account to assess the feasibility of those projects. Large-scale hydropower projects, such as the Three Gorge Station of the Changjiang River, are under debate because of financial and bio-ecological problems. According to China's energy strategy, oil-burning power stations should not be constructed any more.

Nuclear power projections. The idea that nuclear power should become one of the three main power sources (thermal, hydro, and nuclear) for China's electricity supply is presented in the current energy development planning. The near-term goal proposes about 6–8 GWe of installed nuclear power capacity by the end of this century. By the year 2015, nuclear installed capacity is proposed to reach 30-40 GWe, representing an 8%–10% share of total electrical power capacity.

Since nuclear power plants should preferably be built in the coastal area, the local nuclear share will rise to a significant proportion there. It will show that nuclear power can play an important role for mitigating power shortages, transport loads, and air pollution in the area. The economic development in the coastal area of China is faster than in the inland regions. Serious energy and power shortages have encouraged high enthusiasm for the development of nuclear power in the area, and the local governments have the economic advantage of establishing their own development strategy.

To evaluate the feasibility of nuclear power projects in the coastal area, two important problems must be pointed out.

The first one is the comparative economic analysis, based on a rational competitive price system. As mentioned earlier, current coal prices do not reflect the real (long-term marginal) production cost. The investments and operating costs of the complete fuel cycle, including everything from exploration to transporation, should be taken into account for both coal and nuclear energy. Furthermore, as most nuclear power plants in China will be put into operation after the year 2000, the reference price of coal should be projected to 2000 or later to take into consideration this time factor, as well as the gap between supply and demand.

Secondly, the economic and social benefits from the development of nuclear power should be evaluated for the long-term strategy. Particularly in the densely populated coastal areas of China, where development is constrained by energy shortages, nuclear power would be a suitable alternative to meet long-term energy demand.

Important issues. In conclusion, the following issues are important for the prospects of nuclear power in China's coastal area:

- The existence of serious shortages of power and energy resources, which forecasts indicate will persist;
- The importance of a rational competitive price system for meaningful comparative economic analysis of nuclear and conventional fuel cycles;
- A comprehensive assessment of energy technologies, including social, health, and environmental impacts;
- A regional macro-economic evaluation for the densely populated and fast-developing coastal area.Considering these issues, nuclear power's development will be essential for meeting the mid-term and long-term energy demand in the coastal area. It should play an important role in supplementing electricity supply and become a strong pillar of electricity generation for long-term economic development.