Report No. 12687-CHA

China
Investment Strategies for China's Coal and Electricity Delivery System

March 8, 1995

Transport Operations Division
China and Mongolia Department
East Asia and Pacific Regional Office

Economic Research Center
State Planning Commission
People's Republic of China

Document of the World Bank

Currency Equivalents

Currency Unit = Yuan (Y) = 100 fen

Exchange Rate

1980	1990	1992	1993	1994
US$1 = Y 1.5	US$1 = Y 4.7	US$1 = Y 5.5	US$1 = Y 5.8	US$1 = Y 8.7

Fiscal Year

January - December

Weights and Measures

dwt	=	deadweight ton	kV	=	kilovolt
g	=	gram	kw	=	kilowatt
km	=	kilometer	MW	=	megawatt (10^3 kw)
GW	=	gigawatt (10^6 kw)	std ton	=	standard ton (5,500 kcal per kg)
kwh	=	kilowatt hour			
kcal	=	kilocalorie	tkm	=	ton-kilometer
kg	=	kilogram	TWh	=	terawatt-hour (10^9 kwh)

Abbreviations

AC	—	Alternating Current
CIECC	—	China International Engineering Consulting Corporation
COSCO	—	China Ocean Shipping Company
CTS	—	Coal Transport Study
DC	—	direct current
EI	—	Economic Institute
ERC	—	Economic Research Center
ERI	—	Energy Research Institute
FYP	—	five-year plan
GDP	—	gross domestic product
GIS	—	Geographic Information System
GNP	—	gross national product
ICT	—	Institute for Comprehensive Transportation
MOC	—	Ministry of Communications
MOCL	—	Ministry of Coal
MOEP	—	Ministry of Electric Power
MOR	—	Ministry of Railways
NIC	—	National Investment Company
PCBC	—	People's Construction Bank of China
SDBC	-	State Development Bank of China
SPC	—	State Planning Commission
TSP	—	total suspended particulates
UNDP	—	United Nations Development Programme

Five-Year Plans

5FYP	=	1976-80
6FYP	=	1981-85
7FYP	=	1986-90
8FYP	=	1991-95
9FYP	=	1996-2000
10FYP	=	2001-2005

China

Investment Strategies for China's Coal and Electricity Delivery System

China

Investment Strategies for China's Coal and Electricity Delivery System

TABLE OF CONTENTS

Page No.

MAPS

CONTRIBUTIONS

This report is a joint effort of the State Planning Commission's (SPC's) Economic Research Center and the Bank's study team following ten missions by Bank staff and foreign experts to Beijing and a nine-month training mission and two shorter missions by the Chinese to Washington, D.C. (see Annex 1). It builds on the model development and testing in Phase I of the Coal Transport Study (1989-91), and incorporates new material from Phase II (July-October 1993). Financing was received from the Japanese Policy and Human Resources Development Fund and the United Nations Development Programme.

The Coal Transport Study (CTS) team of the Economic Research Center ERC) was organized into two groups: the Modeling Group and the Policy Group. The Modeling Group members included Shi Qingqi (Study Director), Sun Xufei (Modeling Leader, Phase I and II; Deputy Team Leader, Phase II), Zhang Chuntai (Deputy Leader, Training Phase; Computing Leader, Phase I), Zhou Dadi (Leader, Training Team), Cao Wei, and Xie Zhijun. Part-time members included Rong Qiang, Wang Xuesheng, and Gao Shenhuai. The Policy Group consisted of Xu Zhen (Deputy Director, ERC) and Liu Liru (Director, ICT). Two special panels were set up to assist the Modeling and Policy Groups. The CTS Technical Panel consisted of Zhou Fengqi (Director, ERI), Shi Qingqi, Zou Yuan, Lin Fatang, and Yu Xiaodong (all of EI). The CTS Consulting Panel was made up of Xu Zhen, Yang Zhenjia, Liang Xiufeng, and Zhou Fengqi, and Liu Liru. Other invaluable support was provided by Gan Ziyu and Gui Shiyong (Vice Chairmen of SPC), Wei Liqun (General Secretary of the SPC), Huang Fanzhang (Vice Director of ERC), Zhou Cai Yu (Director, Economic Institute), and Wu Youding (Ministry of Railways, Chief Engineer, Railway Investment Study).

The World Bank team members comprised Chen Juemin (RMC), Peter Cook (CTS Training Director), Zhou Dadi (who later joined the CTS Team), Terry Friesz, Michael Kuby (CTS Technical Leader), Susan Neuman, Xianliang Wang, Thawat Watanatada (Task Manager), and Huikang Xu (RMC).

The report was written primarily by Michael Kuby (CTS Technical Leader) and Thawat Watanatada (Task Manager) and was based on the results of the analysis. Other written contributions came from Zhou Dadi, Xie Zhijun, Cao Wei, and Sun Xufei. Also, Yves Albouy, Sadhan Chattopadhya, and Kathleen Stephenson of the World Bank contributed background materials on electricity, coal production, and coal utilization, respectively. Zafar Khan of the World Bank made valuable suggestions relating to financing. A supplemental report describing the CTS Analysis System was written primarily by Zhang Chuntai and Michael Kuby, with contributions from Susan Neuman and Xie Zhijun. Rebecca Kary assisted with editing and formatting the report. Maps were made by Eric Khandagle, Denise Bergeron, Jodie Cabezas, Jose Clavecillas, Jeff Lecksell, and Yung Koo of the Bank's Cartography Division, and by Barbara Trapido of Arizona State University. Alice Moy and Tess Ortega were invaluable dealing with administrative matters, and Bavani Krishnamurthi helped to check and produce the final version of the report.

The Transport Operations Division Chief is Richard Scurfield, the Lead Economist is Eliana Cardoso, and the Director is Nicholas Hope. Clell Harral was instrumental in conceiving the study and getting the original financing. Over the last several years, the study was supported by Bernard Montfort and Daud Ahmad as Division Chiefs, Paul Stott as Acting Chief, Shahid Yusuf as Lead Economist, Shahid Javed Burki as Director, and Zafer Ecevit as

Acting Director. Pieter Bottelier, as Chief of the Resident Mission in China, provided support to the various missions.

In China, the CTS has been reviewed in three conferences. The first, in December 1991, was chaired by Guo Hongtao, Chairman, Central Advisory Commission, along with Sun Shangqing, Vice President, Development Research Center, State Council, and Gui Shiyong, Vice Chairman, State Planning Commission, among others (see Annex 19). A second conference was held in October 1993 to introduce the latest results, and was chaired by Wei Liqun, General Secretary of SPC, and attended by Xu Zhen, Huang Fanzhang, Ling Zoo, and Meng Guang, Deputy Directors of Economic Research Center, Tu Zuming, Director of Energy Department of SPC, and Lan Shiliang, Director of the (Long-term) Planning Department of SPC, among others (see Annex 20). A third conference in October 1994 included an award ceremony for the Franz Edelman Prize Finalists and a discussion of implementation issues for the recommended strategies. It was attended by Gui Shiyong, former Vice Chairman of the SPC and Deputy President of the Administrative Institute of China, She Jianming, Vice Chairman of the SPC, Wu Jingru, Director of the Electricity Bureau of the State Development Bank, and Li Qun, Director of the Policy Bureau of the State Development Bank, among others (see Annex 22).

In the Bank, the CTS inception report was reviewed in November, 1989 by Clell Harral and Yves Albouy, both formerly with the China and Mongolia Country Department, and Terry Friesz (consultant). The draft CTS Phase I Final Report was reviewed in July 1991 by Kathleen Stephenson (AS3IE), Fernando Montes-Negret (AS3CO), Renato Schulz (ASTIN), Hernan Levy (EA2TP), and Gavan McDonell (University of New South Wales, Australia). The white cover report was reviewed in April 1993 by Hernan Levy (EA2TP), Robert Taylor (EA2IE), Shigeru Kataoka (EA2IE), Shahid Yusuf (EA2TP), and Robert Burns (SA2IN). The yellow cover report was reviewed in March 1994 by Eliana Cardoso (EA2DR), Zafer Ecevit (EA2DR), Phil Anderson (TWUTD), Lou Thompson (TWUTD), Richard Scurfield, Hernan Levy, and Toshiro Tsutsumi (EA2TP), Jeffrey Hammer (EAPVP), Vinod Thomas (EAPVP), Robert Taylor (EA2IE), Shigeru Kataoka (EA2IE), Richard Newfarmer (EA2IE), Robert Burns (SA2IN), and C. Hugh Bannister (Intelligent Energy Systems Pty. Ltd., Australia). Comments from several reviewers were adapted for use within the report.

Training of Chinese team members was coordinated by Peter Cook. Participants included David Bernstein, Enrique Fernandez, Terry Friesz, David Hirshfeld, Jerome Kreuser, Michael Kuby, Susan Neuman, Karen Polenske, Samuel Ratick, Edgar Sibley, Howard Simkowitz, and Scott Sitzer (U.S. Department of Energy).

Awards for the Coal Transport Study

In addition to the Robert McNamara Fellowship won by a CTS team member, the study has been recognized in other ways. It has been awarded a Finalist's Award as one of the six finalists in the 23rd Annual Franz Edelman Competition in Management Science Achievement by the College on the Practice of Management Science of the Institute for Management Science. This is the highest international honor for management science projects that have been implemented and that have produced verifiable benefits for a client organization (the SPC). The study also won the 1993 Applied Geography Citation Award given by the Association of American Geographers. Details about the Edelman competition and past winners are contained in Annex 21. This is the first time a project by China has been selected as a finalist. It is a confirmation to the Bank and the Chinese about the efficacy and appropriateness of the large-scale modeling effort they have undertaken. It also symbolizes greater openness on the part of China. Renewed impetus for continuing and expanding the study may be one result of the recognition.

EXECUTIVE SUMMARY

i. This report develops and analyzes investment strategies and associated policies for China's coal and electricity delivery system, while also taking into account the air pollution effects of the different strategies. Financed primarily by the Japan Policy and Human Resources Development (PHRD) Fund, the Coal Transport Study (CTS) was a joint effort by the World Bank and the Economic Research Center (ERC)—the policy research arm of the State Planning Commission (SPC), China's long-term economic planning agency. This report is based mainly on Phase II of the CTS, conducted from July to October 1993.

ii. The study's original objective focused on coal transport, but because of the interrelationships of investments in the coal, transport, and electricity sectors, the objective gradually expanded to cover the entire coal-electricity delivery system. The study has produced two tangible fruits: an analysis system to assist the SPC with decision-making for the coal-electricity delivery system, and a set of policy analyses and recommendations proposed for the Chinese Government. Methodologically, the CTS developed a cost-minimizing, multisectoral, national-scale network model, similar to those used in western industrial countries, but well-grounded in China's real production-transport-consumption situation and the real options for its future expansion. The computer analysis is complemented by historical and policy analysis of: the causes of the problems; the Government and market forces acting on these sectors; and the policy changes needed to stimulate the recommended investments.

iii. The main conclusion of this study is that if economic growth during the rest of the 1990s continues in the forecast 8–9 percent range, delivery of enough coal and electricity should be possible to satisfy projected demands, despite prevalent rail and port bottlenecks. By rationalizing railway coal flows and by supplementing the railway system with coal washing, long-distance electricity transmission, shipping, hydropower, coal imports, and energy conservation, the kind of debilitating energy shortages experienced in the late 1980s can probably be avoided. However, if economic growth continues in the double-digit range, severe shortages could result from insufficient long-distance energy-moving capacity. Either way, the environmental impact of the increased coal usage will be extreme. The overall outlook has been improved by the Government's recent actions to free most coal prices, raise electricity prices and railway tariffs, decentralize many investment decisions, and accelerate the construction of several important coal-hauling railways. However, to achieve the necessary volume and efficiency of energy delivery and utilization, the Government should continue to remove institutional barriers and subsidies, and develop and enforce market-based mechanisms for reducing air pollution.

Background

iv. *Shortages.* China is the only country in the world to produce or consume more than 1 billion tons of coal in a year, a milestone which they passed in 1990 and which is expected to double by 2010. China is also more dependent on coal than any other country, relying on it for 73 percent of commercial energy requirements. The upsurge of economic activity since 1979 has put substantial pressure on China's energy and transport systems. Since the mid-1980s, China's economic growth has been periodically hampered by shortages of either coal, electricity, or both, due to a shortage of power-generating capacity and the inability to transport enough coal from where it is produced to where it is needed.

v. Currently, coal shortages in most areas have abated and are now estimated at only 3 percent of demand. However, there remains a shortfall of peak electricity of about 20 percent. Also, coal, which accounts for 42 percent of rail freight tonnage, continues to saturate the capacities of most of the major coal-carrying railways. Bottleneck links on the railway network, where traffic in at least one direction reaches 95 percent of capacity or more, leapt from 7 percent of the network in 1985 to 37 percent in 1989. As a result, rationing is used to control access to congested railway corridors. Underlying the railway congestion are underinvestment in transportation infrastructure and fast-growing transport demand.

vi. *Demand.* Coal transport demand is derived from the need to satisfy demands for anthracite, coking, and industrial steam coal, as well as steam coal for electricity. Coal flows are the product of the tradeoffs between coal origins, coal types, transport modes, and other sources of electric power (and their respective prices). Coal and electricity demands have been rising with total and per capita gross national product (GNP), though not as fast. From 1980 to 1990 the GNP grew at an annual rate of around 9 percent, and has since increased to around 13 percent. Coal production grew by 5.3 percent during the 1980s, while electricity production grew by 7.6 percent, both proportionately less than the growth rate of GNP.

vii. During the 1980s, coal prices were partially decontrolled, and electricity prices raised; coal prices are now market-determined and consumer electricity prices now provide for full recovery of investment and interest. From 1980 to 1992, coal prices increased by a total of 122 percent, and real electricity prices by 75 percent. Real freight railway tariffs have been raised by 91 percent since 1990 and now approximate long-run marginal costs.

viii. Chinese experts expect that the low elasticity of coal production relative to GNP will continue, but that electricity demand will return to keeping pace with GNP. The slow growth of electricity production during the 1980s reflects suppressed rather than slacking demand because China's power sector was being planned to satisfy 6 percent growth. As growth surpassed the 6 percent level, the power sector was not able to rapidly readjust. On the other hand, the moderation of coal demand growth for nonelectricity uses is thought to be real because there is less evidence of shortages. This phenomenon is thought to be caused by increased coal prices, structural change in the economy, technical progress, the production of higher quality (and therefore higher value) goods with little additional energy consumption, increased road transport, and the gradual replacement of wasteful residential coal use by more efficient heating and cooking methods.

ix. The official GNP growth target for public infrastructure planning purposes was 6 percent until 1992 when the forecast was raised to 8 to 9 percent growth, more in line with past growth. In this study, future GNP growth was forecast at 9 percent, but low (7.5 percent) and high (10.5 percent) growth rates were also tested. The following table at the top of the next page summarizes the assumptions of the low, medium, and high energy demand forecasts used in this study.

x. *Geography.* Coal was once a widely available resource in China, having traditionally been mined in over half the counties in China. However, in the major industrial provinces of East, Northeast, and Southeast China, economically recoverable reserves are rapidly being depleted. The eastern half of the country must rely increasingly on supplies from surplus-producing areas in the energy base of North and Northwest China, centered in Shanxi and its neighboring provinces: Henan, Shaanxi, Ningxia, and eastern Nei Mongol. In all, this region contains 80 percent of the nation's economically recoverable coal reserves. The great distances between the locations of supply and demand add to the already great pressure on the transport system. As a result, at the peak of the

Forecasted Demands for 2000 vs. Historical Data

	1991	Forecast for 2000 Low	Medium	High
Electricity demand (billion kwh)	678	1,258	1,444	1,661
Nonelectricity coal consumption (million tons of standard coal)	786	885	906	926
Approx. total coal production required (million tons of standard coal—5,500 kcal per kg)	1,087	1,510	1,640	1,780

1988-89 shortages, market prices for coal in Shanghai were reportedly seven times higher than in Shanxi. Thus, the centerpiece of Chinas's strategy is to increase the already large coal production and transport capacity from Shanxi and the nearby provinces of Henan, Shaanxi, Ningxia, and Nei Mongol to the rest of the country.

xi. *Opportunities in the Coal-Electricity Supply Chain.* Although additional railway capacity is one of the most important ways to solve transport bottlenecks, other options can reduce the demand for coal transport, such as coal washing, minemouth power plants, long-distance transmission of electricity, and substitution of nuclear power and hydropower, especially from water-rich Southwest China. These alternative investment strategies can be considered the "demand side" of the transport equation because they reduce the number of tons that need to be transported and/or the distance over which the coal must be transported. For the energy equation, however, these strategies can be considered the supply side because they are different ways of satisfying the same final energy demand. Most of these options involve significant outlays of capital. Some options can be developed significantly faster than railways. The coal washing and hydropower options also have significant air pollution benefits. Hence, in developing long-term strategic plans, the Government must evaluate these measures on an economic basis while taking into account timing and environmental factors.

The Analysis Method

xii. To perform its coordinating role in the overlapping transport, energy, and environment sectors, the main analytical task facing the Chinese Government is to integrate the strategic guidance provided to the different sectors. These three sectors have not always been well coordinated and have suffered from underinvestment because of (a) the rigid institutional decision-making framework; (b) the outdated methods and tools used for policy analysis; and (c) the difficult transition to the new market-based economy. Government organizations and enterprises urgently need modern systematic tools suitable to China's real situation to assist with policy analysis, decision-making, and information supply. In Phase I of the CTS, completed in December, 1991, a decision support system to assist the Government in this multisectoral analysis was developed and tested. The mixed-integer programming model minimizes the total discounted cost of delivering coal and electricity subject to demand and capacity constraints and optional budget and environmental constraints. At the heart of the model are multimodal transport and electricity transmission networks. Forecasts of demands for electricity and nonelectricity coal for the years 1995, 2000, and 2005 are inputs to the model, along with such inputs as costs, capacities, new project options, technological factors, and discount rates. The main outputs are how much of which investments to build where and when; optimal distribution patterns for coal and electricity; and performance measures such as costs, pollution levels, shortages, transport bottlenecks, and shadow prices. The analysis system is designed to complement, not replace, other analytical tools used for more refined economic or logistical analysis in the individual sectors.

Main Conclusions and Recommendations by Sector

xiii. *Impact of Growth.* If the economy grows at up to 9 percent per year, the analysis results suggest that it should be possible, within existing constraints, to satisfy nearly all the coal and electricity demands by 2000. This can be achieved without creating major shortages and without importing coal except in a few problem regions, assuming that additional energy delivery strategies are carried out in anticipation of that growth. However, if growth exceeds 9 percent by one or two percentage points, the planned railway network would likely be overwhelmed, despite railway services being priced approximately at long-run marginal costs. GNP growth significantly higher than 9 percent is not unrealistic given that during 1991-93 the economy grew at about 11 percent per year. In that case, even accelerated construction of substitute measures, such as long-distance transmission and coal washing, would likely not be able to alleviate the pressure on the railways. Unless extraordinary measures are taken to accelerate railway planning, financing, and construction beyond the current pace—which is already breathtaking—China is likely to experience more severe railway congestion, with combined shortages of coal and electricity exceeding 125 million tons per year. Even a policy of unlimited coal imports to coastal regions would still leave a significant amount of coal and electricity demand unsatisfied in the interior regions. Assuming greater than 10 percent growth, energy shortages that would occur above and beyond a 9 percent growth situation are estimated at US$7 billion for the year 2000 alone. This shortfall, expressed in 1993 prices at official exchange rates, is about three-fourths of 1 percent of the projected Chinese GNP. (Economic losses noted here are valued in terms of replacement by coal imports.)

xiv. *Railways.* Rail flows are predominantly from mines in the west to cities and ports in the east and northeast, and from north to central. In any conceivable future scenario, all existing and planned railway capacity for coal being shipped out of the energy base would be utilized. If growth exceeds 10 percent, more investment must be channeled to the railways. The study results were used as a basis to support the Government's recent decision to accelerate the construction of the second west–east line out of the energy base from Shenmu to the new port being built at Huanghua.

xv. China in recent years has concentrated their railway investment more on adding incremental capacity to existing lines than on building new lines, and as a result has one of the highest densities of traffic per km of track in the world. As planned, China should continue expanding the capacity of existing lines by multiple-tracking, diesel traction, electrification, additional sidings and conversion to heavier axle loads. Such improvements generally offer lower investment cost per unit of capacity and relatively faster completion than new construction. This manner of capacity expansion, however, is not sufficient to provide the needed additional throughput capacity to solve the problem of energy base bottlenecks: brand new lines are desperately needed. Of course, these new lines should also take advantage of the low unit cost offered by unit train and heavy axle load technologies.

xvi. The study made two specific recommendations about new lines in addition to the Shenmu-Huanghua line, both of which have since been acted on by the Chinese Government: a new line from Shenmu to Xian (now under construction), and a third west-east line from Shexian to Handan to Jinan (now planned). Heavy haul technology, which the MOR is implementing to reduce the unit capital cost of capacity expansion, is an important part of the railway strategy. It is not expected to have an effect, however, until after 2000, except on the Datong-Qinhuangdao and Shenmu Huanghua mine-to-port lines. Because railway projects take a long time to plan and construct, many provincial governments are taking matters into their own hands by rapidly developing local coal and electricity projects to satisfy their immediate demand for electricity.

xvii. Systemwide coordination is another key to MOR's investment strategy. The MOR must consider interdependencies between different links and modes in planning the expansion of its network. For instance, bottlenecks leading out of the energy base may possibly cause underutilization of the new port capacity being built at Huanghua, or on the existing Beijing-Qinhuangdao line. Similarly, bottlenecks on railways and ports en route to northeast China may cause underutilization of railway projects in the interior of the northeast.

xviii. The efficiency of the railway system depends not only on decisions made by MOR, but on the responses by railway users. Five policy reforms that would promote market efficiency are (1) higher prices; (2) less allocation of capacity; (3) more services offered; (4) more competition; and (5) better and more available information. First and foremeost, the MOR must set prices high enough that shippers will have the incentive to use railways efficiently. Since rail tariffs have already approached long-run marginal costs, congestion pricing on bottleneck links should be investigated for bringing in additional revenues to supply new capital investment, as well as for rationalizing demand for railway transport. The efficiency of coal distribution can be improved by shipping coal with higher calorific value over greater distances. The estimated economic savings from Shanxi would be about US$25 million annually compared with allocating coal without regard to calorific value. Congestion pricing should also have the effect of encouraging shippers to differentiate between types of coal. Congestion pricing should also encourage users to consume more coal locally without using the railway system, which would contribute to a more efficient coal distribution pattern. However, the inflationary impact must also be considered in investigating the use of congestion pricing. Congestion pricing is not uncommon internationally: railways in the United States typically charge higher rates in the congested Northeast corridor.

xix. The second area of policy reform should be to reduce the administrative allocation of railway capacity. Currently, 60 percent of capacity is allocated by planning instead of by market bidding. A case in point is that reallocation of railway capacity from passengers to coal appears to have only limited potential to solve logistical problems without creating substantial unsatisfied passenger demands. The third policy issue is service. The MOR is moving toward offering not just "raw capacity" but "quality capacity" for container transport and dedicated passenger transport. Coal shippers may also be willing to pay more for fast and reliable service, which could perhaps be provided by auctioning off segments of capacity to long-distance, railbased transport services companies that could offer rapid unit train services. This measure would also introduce more competition, the fourth area for policy reform. Price and entry deregulation in the rail-water transport market would also foster competition. Fifth, more and better information is needed at the annual coal ordering conference for coal buyers to consider rail and water prices and services, as well as coal quality.

xx. *Waterways.* An important strategy for relieving pressure on the railway system is to shift more coal flows onto the coastal and inland waterways. Setting up high-efficiency rail-port transport corridors out of the coal base would create a powerful incentive for major power and steel plants to locate along the eastern and southern sea lanes. In the medium demand case for 2000, nearly 140 million tons of coal (not including exports) would be shipped an average of almost 1,500 km along the coast, which represents a doubling of the tonnage, 20 percent longer distance, and more than doubling the fleet size compared with 1990. The inland waterways also play a key role, carrying 22 million tons shipped an average of 660 km, which requires a 75 percent increase in the barge fleet by 2000.

xxi. Constraints, however, will continue to limit the scope for the waterway option, particularly railway bottlenecks *en route* to the loading ports along the northern coast and not enough port capacity, especially at receiving ports. Shanghai will need at least 25 million tons of new unloading capacity, while numerous other ports south of Shanghai and on the Yangtze River will need up to 10 million tons of new capacity. Because of the shortage of loading and unloading capacity, coal is at present sometimes transshipped at general cargo ports lacking the specialized bulk equipment necessary for efficient handling.

xxii. Most harbors at receiving ports are only deep enough to accommodate 9-meter draught, 20,000 dwt vessels or 9-meter shallow-draught 35,000 dwt vessels. Of the main ports on the southern coast, only Ningbo can accommodate 12-meter 50,000 dwt ships. Xiamen is now being deepened to 12-meters (in a Bank-financed project), while the harbors of Wenzhou and Fuzhou are only now being deepened to the minimal depth of 9 meters. None can match the 14-meter depth of Qinhuangdao, China's major loading port. Options to deepen harbors and to develop a Panamax-class or supercollier fleet must take into account the physical conditions at each port. While Chinese 9-meter ships are small compared to world standards, they are competitive with railways over long distances, and, in some cases, they are the only possible direct supply route to some oceanside or riverside factories and power plants that are not connected to the railway system.

xxiii. The recent removal of all price subsidies to railways for purchasing materials and energy supplies, and the potential use of market mechanisms (for example, congestion pricing) instead of rationing to allocate scarce railway and port capacity, should help rationalize shipping patterns. Because of the number of add-on charges involved in securing port and ship access, ports are effectively charging congestion pricing already. The recommended central Government role in the waterway sector is to work with the local port authorities to evaluate, and, if economically justified, to provide deeper harbors for multicommodity ports, to remove distortions from the pricing system, and to decentralize more of the shipping industry. Entry deregulation would encourage price competition, investment in capacity, and improvements in vessel technologies, information systems, and service in general. Waterways are not likely to fulfill their full potential as a provider of coal transport unless the issues related to tariff structure, harbor depths, average ship size, and limited mine-to-port railway capacity are addressed.

xxiv. *Coal Production.* The analysis results confirm the continuation of the current trend to shift more coal production to the North China energy base (an increase from 43 percent of the nation's total in 1989 to around 52 percent in 2000). The results also suggest that coastal regions maintain their absolute levels of coal production. This westward shift represents a savings of more than US$1 billion in coal mine investment costs through 2000 relative to the alternative of maintaining the existing shares of coal production across regions, which could happen if railway capacity from the energy base is not expanded adequately. Imports appear to be economically feasible, but are logistically and financially feasible mainly in coastal cities. These regional shifts and import increases occur during a time when subsidies to producers and consumers are being phased out, coal mines are experiencing competitive price pressures on their products and inflationary pressures on their inputs, mines are generally losing money, and millions of mine workers may become unemployed.

xxv. *Coal Washing*. The results suggest that steam coal washing should be increased from the current level of 7 percent to roughly 16 to 19 percent, and to nearly double that if ash and sulfur reduction at end use points is a policy goal. This appears to be a robust finding because steam coal washing never dipped below that level in any scenario analyzed, including those in which washing costs were raised. The benefits of steam coal washing include reducing transport costs for long-distance flows, lessening local bottleneck effects, achieving environmental goals, and reducing ash disposal and boiler maintenance costs. The net present value (NPV) of economic savings in transport, ash disposal, and boiler maintenance costs (net of washing and incremental mining costs) is estimated at US$3.8 billion over 15 years (in 1993 prices). Based partly on the strength of these results, the Government recently announced guidelines asking large, state-owned mines which export coal to other provinces to wash their steam coal before shipping.

xxvi. The success of this policy will depend on four main factors. First, market-determined prices for coal and rational prices for railway transport services will make the benefits of steam coal washing more transparent and spread more equitably among the parties in the supply-transport-user chain. Second, strong enforcement of environmental regulations on air pollution has been the key to establishing demand for washed coal, as demonstrated in Organisation for Economic Co-operation and Development (OECD) countries. In China, environmental measures and enforcement have historically been weak. Third, the proper legal framework is necessary for willing buyers and sellers to enter into longterm contracts that will guarantee a reliable market for the washery's products and a reliable supply for boilers designed to burn washed coal. Fourth, as long as the macroeconomy remains overheated, users cannot afford to be as choosy about the quality of their coal.

xxvii. *Power Generation*. Because there are only a limited number of inexpensive hydropower sites near load centers, hydropower's share of total capacity, currently 24 percent, may even fall slightly, though in certain regions it can economically generate the majority of the electricity. Thermal power is likely to be China's least-cost alternative for generating most of the electricity in most regions. Because of the many different services provided by a dam, the above conclusions reflect only the competition between thermal and hydropower on an energy cost basis.

xxviii. *Transmission*. Electricity transmission from the regions that have a surplus of new coal or hydropower capacity should be increased. North China has the opportunity to economically increase its share of electricity generation from less than 18 percent in 1989 to nearly 20 percent by 2000 prior to completion of the Three Gorges power plant. Nationally, three major sets of flows stand out consistently in a variety of scenarios: (a) from the coal base to the Beijing-Tianjin-Tangshan area, East China, Central China, and even South China; (b) from eastern Inner Mongolia to the Northeast; and (c) from the hydropower base in Guangxi and Guizhou provinces to Guangdong. Construction of six 500 kV long-distance intergrid transmission lines is estimated to save China roughly US$1.5 billion in combined transport and energy operating costs through 2000, compared with the alternative strategies that would have to be pursued otherwise. This study's results have been used to support China's recent decision to move forward with several transmission projects. Skyrocketing power demand, railway bottlenecks, and shorter construction lead times are helping to overcome years of disinterest in transmission stemming from institutional, technological, financial, and economic barriers.

xxix. In recent years, several provinces were starting to move forward with transmission projects with other provinces in a decentralized fashion. To help ensure smooth coordination of the regional and provincial grids, a regulation was passed in early 1994 that all transmission lines are to be managed by the central Government, while the market will control the power plants. By 2000, China will tie the regional grids together into one national grid. Long-term contracting to ensure reliable supply, demand, and financing between the local, provincial, and central Government parties involved is the key to this kind of interregional arrangement.

xxx. *Environmental Tradeoffs.* Although evaluating the cost-effectiveness of environmental protection measures was not the primary purpose of this study, it was important to capture the fact that some strategies for coal and electricity delivery are less environmentally harmful than others. For instance, using higher quality coal, washing more coal, and substituting hydropower for thermal power in many cases can pay for themselves in terms of reduced costs and reduced pressure on the railway system in addition to reducing pollution. In fact, increasing steam coal washing up to a threshold of nearly 20 percent is a win-win proposition in terms of reducing both cost and pollution. For these reasons, the environmental benefits were measured in terms of how much they reduce the ash and sulfur content of delivered coal.

xxxi. The analysis shows that the absolute amount of ash and sulfur under 9 percent GNP growth would be about one-third higher than in 1990, despite the recommended increase in washing steam coal. This is a critically important finding for a country that already bears the dubious distinction of some of the world's worst urban air pollution from sulfur dioxide and total suspended particulates. To achieve progress on the environmental side, the Chinese Government will have to structure its environmental policies to force firms to internalize the social costs of pollution while giving them as much latitude as possible on the means of response. Pollution taxes may be the most economically effective measure, followed by tradeable pollution permits. In the US, tradeable emissions allowances for sulfur introduced in the 1990s were priced by the market four times lower than the government's conservative estimate, saving some $10 billion per year. Vigorous enforcement of either measure is probably more important than which is ultimately adopted.

xxxii. The level of taxation or the amount of credits should be high enough to force polluters to pay for the environmental damage they cause, yet the level must also consider what is economically feasible. As a partial answer to the question of feasibility, the analysis found that reductions of 10 percent in the ash and sulfur content of the coal to each province can be achieved for only 3 percent more in cost by using better coal, washing more coal, and substituting more hydropower for thermal power. Further reductions of 20 to 30 percent (which would be needed to keep absolute ash and sulfur levels from worsening) would be more expensive, costing 10 to 20 percent more. This increase would be a result of the mounting costs for scrubbers, hydropower, and the need for energy conservation. Because numerous pre- and post-combustion mitigation measures were not included in the analysis, these cost figures can be thought of as conservative upper bounds, achieved by choosing from only a partial menu of technological strategies. The real costs should turn out to be lower.

xxxiii. *Energy Conservation.* Energy conservation has great potential to simultaneously reduce energy shortages, relieve pressure on railways, and protect the environment. Conservation investments were not one of the options included in the analysis system used for this study. A *post hoc* analysis, however, suggests some tentative conclusions. Energy shortages in the model are demands that either could not be satisfied for less than the cost of imported coal (Y 300 per ton in 1990, equivalent to US$47 in 1993 prices) or could not be satisfied at any cost for logistical reasons. Given that the amortized cost of many energy conservation investments is less than Y 300 per ton per year, the results suggest that energy conservation investments could reduce coal demand by as much as 100 million tons given double-digit GNP growth, and up to 30 million tons given growth of up to 9 percent. To realize these goals, energy efficiency improvement must increase by at least 7 percent per year, compared with the present rate of 3.6 percent per year. These conclusions were confirmed strongly by some preliminary analysis using an enhanced model (developed in the McNamara Fellowship program) that incorporates data on energy conservation options and their investment costs, efficiency improvements, and potential savings. . The continuation of reforms that expose energy users to market discipline, that free up coal and electricity prices, and that open China to technology imports should provide ample incentives for conservation. Congestion pricing of rail transport and ports, along with enforced pollution taxation, would further bolster these incentives.

Region-by-Region Summary

xxxiv. *Northeast China.* This study identifies problem regions where fast economic growth or other conditions could exacerbate shortages. It recommends further investigation into energy supply options for each region. Principal among these is the Northeast, where either high demand or reduced allocation of transport capacity could lead to unsatisfied demand. The Northeast must supplement its own supply with coal from the energy base, but is obstructed by two sets of bottlenecks: from the energy base to the Beijing area, and then past the Great Wall to Northeast China. Three largely decentralized strategies include washing coal shipped in from the energy base; increased mining of high-cost local coal; and construction of, and subsequent transmission of electricity from, minemouth power plants on the eastern Inner Mongolia brown coal reserves. Imports are not a practical solution with the exception of the coastal port of Dalian.

xxxv. *Central China.* Central China—especially around the cities of Wuhan, Changsha, and Nanchang—is the next most problematic area. Its coal deficit and highly-congested railway network are somewhat offset by its central location, which gives it many supply options. Some possible supplementary strategies include (a) constructing a new railway south from Shenmu toward Wuhan or other railway expansion projects; (b) producing more coal locally; (c) producing more local hydropower until the Three Gorges project can be finished; (d) redistributing coal by inland waterway; (e) transmitting electricity from surrounding regions, especially from minemouth thermal plants in southeast Shanxi via the Henan grid; and (f) intensifying energy conservation efforts. All of these options could be made more attractive with congestion pricing for bottlenecked railway links.

xxxvi. *South and East China.* The southern and eastern coastal regions must rely mainly on medium-quality local coal and on coastal shipments of high-quality coal from the energy base. Imports of high-quality coal and investments in energy conservation would help keep shortages and sulfur content under control in most eastern and southern cities. Also, because of the distance involved and the bottlenecks that intervene, these two regions are best positioned to benefit economically from purchasing washed steam coal. The environmental benefits should be considered as an additional advantage.

xxxvii. However, in eastern China, possible coal supply problems face cities, such as in Anhui and the interior parts of Shandong, that are without the coastal or inland waterway alternative. Construction of a railway from Handan to Jinan would be one way to address Shandong's problem. A strategy which has just been approved, on a test commercial-scale basis, is a new coal slurry pipeline from Shanxi to Shandong. East China is particularly vulnerable to electricity shortages in high-demand conditions. The electricity balance of the region can be helped tremendously by building transmission capacity from mine-mouth plants in southern Shanxi to cities in Shandong and Jiangsu.

xxxviii. Southeastern China does not have the inland waterway option that eastern China has, but its industrial development has historically been more confined to the coastal areas. Guangdong's electricity balance might be supplemented by transmission of thermal power from as far away as southern Shanxi, or from hydropower plants in Guangxi. Other options for Guangdong's electricity situation might be new power plants using imported oil or coal, or new nuclear plants if they can be built economically.

xxxix. *Southwest China.* In the Southwest, isolation contributes to its lack of flexibility. The Southwest is largely self-reliant in coal and electricity, and can expect coal shortages in the neighborhood of 10 percent in conditions of rapid growth. For coal, its ample reserves are generally high in sulfur. For electricity, the massive Three Gorges project is now under construction here. The Southwest may continue to rely on its vast hydropower potential, but as more and more projects are developed, capital costs become a concern. A related option is to keep more of the power generated at Southwestern hydropower plants within the region instead of transmitting it to Central and Southeast China, or for Sichuan to receive power transmitted from Shaanxi to the north. In the medium term, prior to completion of the Three Gorges power project, authorities may deal with the lack of flexibility by planning and building more railways and by promoting energy conservation.

xl. *Northwest China.* Coal and hydropower resources are abundant in this area. In the future, this region can remain mostly self-supporting while continuing to supply some surplus coal to northern Sichuan and central China. This region can also export thermal electricity to the central China grid and hydropower to the North China grid.

Past and Future Policy Implications

xli. *Past Policy Impacts of the Study.* The CTS was reviewed at a high-level conference for Government officials in December 1991. Following that meeting and the upgrading of the GNP forecast in June of 1992, Government planning agencies requested additional analyses of higher growth rates. The results of these analyses provided a basis for the National People's Congress to adopt the 8 to 9 percent annual GNP growth rate for public infrastructure planning,rather than 9 to 10 percent. Nonetheless this represents a significant increase from the 6 percent or so growth rate adopted during the 1980s. Subsequently, Phase II of the study identified strategies and projects that might make it feasible to satisfy growth in the 8 or 9 percent range. These latest CTS results were reviewed at another high-level Chinese conference in October 1993. In April 1994, the model was used to analyze three different demand cases for the 9FYP, the results and conclusions of which have been used for planning purposes. Most recently, a conference was held in October 1994 to discuss the reforms that would encourage the implementation of the CTS recommendations.

xlii. Some of these recommendations are consistent with long-standing Government strategy of the last 5 to 10 years. Other recommendations have supported recent policy shifts of the last two to three years. Still other recommendations are strategies upon which the Government either has not acted, is still considering, or is going more slowly. By showing the dire consequences of 9 percent GNP growth on infrastructure planned for a target of 6 percent growth, and by recommending strategies for overcoming them, the CTS provided a basis for the recent Government decisions to, among others: (a) accelerate railway construction on the Shenmu-Huanghu, Shenmu-Xian, and Handan-Jinan lines; (b) urge steam coal washing for state-owned plants; and (c) open the door for intergrid electricity transmission. Pursuing these three strategies alone could save China as much as US$7.1 billion (in 1993 U.S. dollars, discounted at 12 percent) over the next 15 years, as compared with the more expensive strategies that would be necessary and greater shortages that would likely result if such strategies were not considered.

xliii. *Policy Issues to Be Addressed in the Future.* China is in the midst of an impressive transition from a centrally-controlled economy to a dynamic, market-driven one, which necessitates a change from central to indicative or guidance planning. Guidance planning requires a multisectoral and systematic method of frequently and rapidly updating public investment priorities, testing plans, identifying potential shortages, and generating new energy supply strategies. The CTS decision support system should be used to investigate public sector investment strategies that will consistently be cost-effective under a variety of future circumstances. This investment evaluation must be complemented by analysis of policy measures and market mechanisms for sending undistorted economic signals to the decentralized sector to induce them to rationalize their energy and transport decisions. Even after the transition phase, the centrally-guided infrastructure investments, such as railways and electricity grid and, to a lesser extent, ports and dams, will still need to be coordinated with each other and with developments in the decentralized sector. This role of indicative planning is similar to the kind of issues analyzed by comprehensive network-type models in OECD countries.

xliv. In the near future, it is most important for the Government to analyze additional railway and waterway measures, especially heavy haul rail technology, port improvements, transport congestion pricing, and power transmission. The Government needs to continue comparing these measures with hydropower, and with decentralized strategies involving coal mining, coal washing, thermal power generation, shipping, and others. The results may be published to allow decentralized enterprises to make well-informed transport and energy investment decisions based on a clear, long-term supply-demand-transport picture. With slight modifications to the analysis system, it could facilitate annual coal distribution planning. With additional model development, the analysis system could also be used to study oil and gas alternatives, energy conservation, carbon dioxide, and other environmental mitigation options.

1. Demand and Shortages of Coal and Electricity

Progress in Transport and Energy Development

1.1 China has made remarkable progress in developing its transport and energy systems over the past four decades. From 1952 to 1993, the length of the railway network increased from 22,900 route-km to 53,800 route-km and the length of the highway network from 126,700 route-km to 1,083,500 route-km. Railway traffic (in tkm) grew at an average annual rate of 7.7 percent (see Table 3.1, Annex 3). During the same period, annual coal output increased at an average rate of 7.8 percent, crude oil production increased at 16.8 percent, and electricity output increased at 12.6 percent. China now ranks third in the world in total volume of freight traffic, fourth in total volume of commercial energy produced, and first in total coal production. Coal accounts for 73 percent of China's commercial energy needs, with oil (20 percent), hydropower (5 percent), and natural gas (2 percent) making up the balance. These figures do not include biomass, which, if commercially traded, would add another third to the national total energy accounts (see Annex Figure 2.1). Industry consumes 70 percent of commercial energy, followed by households (14 percent), services (10 percent), and agriculture (5 percent).

Coal and Electricity Shortages

1.2 Despite the recent progress since 1980, China's economic growth has been severely constrained by shortages of coal and electricity, particularly in 1984-85 and 1987-88. Transport services, coal, and electricity all were heavily rationed during this period. While shortages are not some thing for which the Chinese Government (or, for that matter, any government) keeps an accurate accounting, it is estimated that coal shortages in 1987-88 were at least 30-50 million tons (3 to 5 percent of total production) and electricity shortages at least 70-100 billion kwh (15 to 18 percent of total production). The effects of shortages can be seen in high prices for coal in the free market, idleness of power plants, and increasing coal imports.

1.3 Transport capacity shortfalls reached a low point in 1987-88. At that time, many orders for freight cars went unfilled, industrial plants in coastal cities were idle up to 30 percent of the time because of the lack of raw materials, and some shippers were forced to truck coal over distances of 1,000 km due to the lack of railway freight wagons and lack of line capacity. Some industries were forced to "work three days and shut down four days" due to lack of coal, according to one high-level official.

1.4 As a result of the scarcity of coal at a time when the economy was overheating, market prices for coal rose sharply during 1986-89. Market prices in areas like Shanghai and Jiangsu approached or exceeded international levels. In coal-producing Shanxi Province, average market prices of coal rose from Y 55 per ton in 1986 to Y 125 per ton in early 1989, while minemouth prices in Xuzhou rose at a faster rate, from Y 90 per ton to Y 220 per ton. The gap in market prices between Shanxi and provincial producers suggests that coal shortages were caused by transport bottlenecks rather than by production shortfalls. Bottlenecks and shortages, and the high market prices associated with them, dropped from these high levels in 1990 because of the economic slowdown.

1.5 Since 1992, as the economy heated up again, transport bottlenecks and electricity shortages have reappeared, but coal shortages have not reached the crisis proportions seen earlier. Chinese power officials currently estimate that there is a shortfall between peak demand and supply of 20 percent, which has caused weekly blackouts in residential areas and caused industries to schedule round-the-clock work shifts. Central and local authorities establish quotas for allocating electricity and ration new connections. The electricity shortages today are caused more by lack of generating capacity than a lack of coal.

1.6 Prices of coal, electricity, and railway services have all risen dramatically in recent years. From 1980 to 1992, real coal prices (adjusted for inflation) have risen a cumulative total of more than 120 percent, while real electricity prices have risen about 75 percent. More than 75 percent of all coal is now sold at market prices. By the end of 1994, real coal prices were fully market-determined, and consumer electricity prices had risen to include complete cost recovery. The Ministry of Railways (MOR) now purchases all materials and energy at market prices, and real railway tariffs have been raised by 86 percent from 1990 to 1992, approximating long-run marginal costs. The effect of raising these prices so substantially should be greater efficiency of end use in all three sectors.

1.7 After the coal market was opened up, prices of coal at the minemouth in the energy base actually fell instead of rising, despite the nearly nationwide shortage of electricity. This anomaly was caused by most major railway lines leading out from the energy base being heavily congested, thus preventing energy base coal mines from selling all their production. It would not be accurate, however, to say that coal shortages have been eliminated: rather, there are surpluses in the upstream energy-producing areas, and sporadic shortages in the downstream areas. Downstream shortages were evidenced by the fact that coal stockpiles were drawn down by 32 million tons in 1993.

Intensity of Energy and Transport Use

1.8 It is widely believed that China's transport and energy intensities in terms of freight traffic and energy use per unit of economic output were several times higher than those of countries like India and Brazil (see Annex Table 3.2). While this comparison is problematic due to uncertainties of GNP measurement in China, there is little doubt that their freight and energy intensities are higher than those of many developed countries. One reason is that China relies heavily on coal as a source of energy. Most other kinds of fuel are easier to transport and can be used more efficiently. Coal accounts for almost 73 percent of commercial energy production—much larger than the shares for most other countries (see Annex Table 3.3).

1.9 Besides the heavy reliance on coal, China's freight and energy intensities can be attributed to several other factors: the small service sector; the large heavy industry sector; the lack of preprocessing of raw materials; and the low energy efficiency of outdated end-use technology; and cold weather in the northern areas. With the phasing out of the allocated system, underpricing of energy is no longer a major problem, but it will take many years to replace the existing inefficient energy-using equipment that was built during times of low allocated prices. In addition, freight tends to be hauled over longer distances than necessary, partly because of the vertical integration of Chinese industry and partly because of the heavy reliance on rationing in the distribution of coal and raw materials.

Investment in Transport and Energy

1.10 China's transport and energy systems have expanded significantly since the onset of reforms in 1979, but this expansion has been outstripped by the explosive growth of demand. Since 1955, investment in transportation, although having grown almost 15-fold, has seriously lagged behind GNP, which has increased almost 17-fold, and behind total traffic volume, which has grown almost 24-fold (see Annex Figure 2.2). Government-sponsored transport investment, only 1.3 percent of GNP during 1980-89, increased to 1.9 percent in 1992, but is still below that of other major countries, such as Japan, the Republic of Korea, Brazil, India, and the former Soviet Union, where transport investment ranges from 2 to 4 percent (see Annex Table 3.4). In short, the two reasons for China's transport shortages are explosive growth of demand on one side and underinvestment in transportation on the other.

1.11 Energy infrastructure investment was 3.3 percent of GNP in 1992, and has been shifting steadily away from coal and toward electricity (see Annex Figure 2.3). Coal's share of the energy investment pie fell from over 42 percent in 1953 to 27 percent in 1985 and to 18 percent in 1990, while electricity's share rose from 42 percent in 1953 to 53 percent in 1985, and accelerated to 60 percent in 1990. Despite this boost, China remains underinvested in the capital-intensive electricity subsector, in part because electricity's share of total commercial energy requirements grew from 20 to 25 percent between 1979 and 1990. This trend can be expected to continue. (The electricity share in the United States is 36 percent.) Overall investment in the coal production, coal transport, and electricity sectors for the 8FYP, 9FYP, and 10FYP is estimated to be at least US$200 billion (in 1990 prices, not including rail transport for other commodities or local distribution of power).

Trends in Coal and Electricity Demand

1.12 The demand for coal and electricity in China has grown rapidly since 1980; growth is expected to remain strong through the 10FYP. From 1980 to 1990, coal and electricity consumption grew by 5.3 and 7.6 percent per year, respectively. Both of these figures are lower than the average GNP growth rate of 8.9 percent over the same period. The GNP elasticity for coal demand (computed as the percent change of coal consumption divided by the percent change in GNP) was 0.6 from 1980 to 1990. If the coal used for electricity is separated out, final coal demand grew at only 4.9 percent, which translates to a GNP elasticity of demand of 0.55. The elasticity of electricity consumption with respect to GNP was 0.85 for the 1980s, which is exceptionally low for any country over a sustained period, especially an industrializing one such as China. The elasticity for coal is expected to continue falling in the future, but the elasticity for electricity is considered unreasonably low.

1.13 The resulting lower-than-planned elasticities reflected suppressed demand as well as gains in energy efficiency. Consumption is limited by a lack of available capacity. New power plant construction during the 1980s was planned for an elasticity greater than 1.0, but GNP growth consistently surpassed the planned rate by several percentage points. For the 1980s, China planned for 6 percent GNP growth, but grew at 9 percent. The electricity sector could not speed up construction to keep pace because it was a planned sector requiring large investments and long lead times. The supply of electricity was constantly forced to play "catch-up" during this period. Further evidence that the electricity elasticities reflect suppressed demand lies in the fact that they moved in the opposite direction of GNP growth (and unmeasured shortages). From 1981 to 1985, when GNP growth averaged 10 percent, the GNP elasticity of electricity demand was 0.64. From 1986 to 1990, during which time GNP growth averaged a much slower 7.7 percent, the elasticity was 1.16, and averaged 1.59 during the slowdown of 1989-90.

1.14 Suppressed demand or not, the relatively slow-growing electricity, coal and railway capacity must have, in some sense, satisfied enough demand for the GNP to grow at nearly 9 percent, or, by definition, the economy would not have grown so fast. Can hypergrowth continue without increasing the investments in these three sectors? While a definitive answer is not possible, evidence suggests that it cannot, as argued below.

1.15 First, what little slack there was in the coal and electricity delivery system has been mostly squeezed out: more railway segments are at capacity, more factories are running round-the-clock, and more baseload thermal plants are running at higher capacity utilization factors and postponing maintenance. Second, there has been some relatively simple, low investment measures to increase the capacities in related sectors. In coal mining, the percentage of coal mined by township mines, with their very low investment cost and technological level, increased by 98 percent from 1983 to 1989, while state mines (planned for 6 percent growth) increased only 26 percent. For railways, some minor improvements to yards and signalling and such have been able to increase throughput. Third, there has been even more structural change in the Chinese economy than anticipated, meaning that the unanticipated portion of the GNP growth may have come largely from high value-added industry and services, which are less energy intensive. Fourth, energy conservation has made great strides in recent years, in part because of the rationing, price reforms, and openness to outside technology and management. The reforms have made enterprises focus on profits, and have forced them to reduce waste. While the latter two trends can continue, the former two are problematic. There may not be as much scope for these adaptions in the future as there was in the past. Also, many adaptions were costly, risky, or short-sighted. For instance, oil power plants using imported oil in coastal regions is costly; putting off power plant maintenance is risky; while township mines are short-sighted in the sense that they end up leaving a much higher percentage of the minable reserves in the ground rendered unobtainable because of the unscientific way they exploit the deposit.

Coal and Electricity Demand Assumptions for this Study

1.16 The analytical model used as the basis for this study (see paragraphs 3.14-3.18) is primarily a supply-side cost-minimizing model for investment planning and network optimization. Demands for coal and electricity are exogenous inputs that drive the production and distribution activities on the supply side. While not an equilibrium model per se, the sensitivity of the recommendations to these assumptions may be incorporated by using low, medium, and high demand projections (see Annex 5).

1.17 Demands for three kinds of nonelectricity coal (anthracite, coking and steam) are specified in tons for 49 zones in 1995, 2000, and 2005. Coal demand for the electricity sector is not exogenously specified, but is an indirect result of the demand for electricity, in kwh, at 38 zones, which pulls electricity from hydropower, nuclear or thermal power plants. The thermal plants in turn pull coal to those plants from mines, through washeries, and across the transport network. Needless to say, transport demand in this study is also a derived demand: the actual coal flows are an endogenous result of the tradeoffs between types of power, coal origins, coal types, transport modes, and so on.

1.18 Electricity demand in 2000 ranges from 1,258 to 1,444 to 1,661 billion kwh in the low, medium, and high forecasts. Nonelectricity coal demand in 2000 ranges from 885 to 906 to 926 million tons of standard coal in the low, medium, and high forecasts. However, since most readers do not normally separate out nonelectricity coal, a more meaningful estimate of demand would be the model's total national coal production in 2000 plus coal shortages plus electricity shortages converted to equivalent amounts of coal. This works out to about to about 1.51 billion tons in the low scenario, 1.64 billion in the medium scenario, and 1.78 billion tons in the high scenario. However, it should be kept in mind that these latter figures are model outputs, not inputs; more or less electricity demand could have been satisfied by hydropower or nuclear power.

1.19 The SPC energy demand forecasts used in this study are based more on GNP forecasts and GNP elasticity of demand than on price elasticity of demand; demand curves simply cannot be estimated with any degree of certainty for each time period, region, or coal type in China.

However, price assumptions do enter into the crucial GNP elasticity assumption, along with several other factors. First, the SPC forecasts assumed that all coal prices would be completely market-determined and all electricity prices raised to near their long-run marginal costs (they were) by the end of 1994. Second, the potential for technical improvements in energy efficiency in factories and steel plants is included, but mostly in terms of routine replacement of old equipment rather than installation of highly advanced equipment. Third, the forecast anticipates structural change in the economy. In particular, the expanding tertiary sector is less energy intensive than primary and secondary sectors, though more reliant on electricity on a percentage basis. Fourth, a wealth effect can be seen in the increased energy use and increased preference for electricity by households in modern residences. Fifth, the growth of road transport and the development of China's oil-producing capacity will contribute to substitution away from coal.

1.20 In the early stages of this study, the official Government target for economic growth was 6 percent, but during 1992, after Deng Xiaoping's much publicized trip to Guangzhou, the Government raised the target to 8 to 9 percent. The medium demand forecast assumes approximately 9 percent annual GNP growth through 2000, while the high and low forecasts are for 10.5 and 7.5 percent, respectively.

1.21 The future GNP elasticity for electricity demand is assumed to be 1.0. This assumed elasticity is higher than the historical rate for the 1980s, which did not represent satisfying all demand, as argued in paragraph 1.13. Anything less than 1.0 is atypical of industrializing countries. The coal demand forecast (not including power plant demand) assumes an elasticity of around 0.20, which is less than the 0.55 elasticity of the 1980s. The elasticity of total coal demand works out to about 0.45, which is also lower than that experienced in the 1980s (0.60). Both, however, are in line with the long and short term downward trends (see Annex Figure 2.4). As the Chinese economy develops, a continued shift away from coal and toward oil, gas, and electricity (of which nearly 75 percent comes from coal) is expected to continue. In the first and second FYPs, coal accounted for nearly 95 percent of commercial energy, which fell to around 70 percent in the 5FYP. While China increased its dependence on coal to 76 percent in the 7FYP, this was considered to be supply-driven rather than demand-driven, and it has fallen since then to 74.2 percent. In fact, the GNP elasticity for coal consumption for 1990-92 was a low 0.16, despite an increase of 50 million tons of coal used by power plants over those two years. While this elasticity is probably an aberration due to overreporting of coal production before 1990 and underreporting of it afterwards, it is still astonishingly low.

1.22 For comparison purposes, the CTS's low demand forecast of 1.51 billions tons of coal to be produced in 2000 is similar to what the National People's Congress officially endorses. On the other hand, the Bank's Industry and Energy Operations Division, China and Mongolia Department, is forecasting 1.7 billion tons, which lies between the CTS's medium and high scenarios. Their forecast assumes a 0.4 elasticity for nonelectricity coal, 0.5 for all coal, 0.9 for electricity, and 9.6 percent GDP growth. With this much uncertainty about future energy demand, it becomes important to look at the entire range of demand scenarios.

2. Overview of the Coal-Electricity Supply Chain: Problems and Opportunities

2.1 The process of getting coal out of the ground, beneficiating it, transporting it, and burning it to produce thermal, kinetic, or electrical energy, the latter of which can be transmitted to other places, can be thought of as links in a chain. This supply chain terminates with the final consumption of coal and electricity by end users, and with the emission of ash and sulfur pollutants into the atmosphere. Measures for alleviating coal shortages and reducing pollution are available at all links in the chain. (Tables and figures accompanying this chapter can be found in Annexes 2 and 3.)

Coal Production

2.2 China is the largest coal producer in the world, with total raw coal production of 1.116 billion tons in 1992 (see Annex Table 3.5). China's current coal shortage certainly is not due to any lack of coal reserves. China's approximately 800 billion tons of economically recoverable coal reserves are the largest in the world—approximately one third of the world's total (see Annex Table 3.6). The majority of the reserves are high-quality bituminous coal, with a carbon content of about 60 percent, used for coking or steam coal, depending mainly on calorific value, sulfur, ash, moisture, and volatility (see Annex Tables 3.7 and 3.8). There are also sizable anthracite reserves, with a carbon content generally over 80 percent, used mainly for residential purposes and the chemical industry. There is also some lignite, or brown coal, in the Northeast and Inner Mongolia, with a carbon content of around 30 to 40 percent, which is mainly burned in minemouth power plants because of its low weight-to-energy ratio.

2.3 Coal is mined in over half the Chinese counties. In many areas, coal is obtained from mines close to the market or within the same region. However, in major industrial centers in East, Northeast, and Southeast China, regional and local production cannot satisfy demand, and economically recoverable reserves are rapidly being used up. These three regions currently mine a combined total of 30.3 percent of coal, but have only 10.9 percent of the remaining reserves, which occur in increasingly less economic locations, depths, seam thicknesses, and amounts. The coal deficit in the East grew by 153 percent between 1982 and 1989.

2.4 These large consuming regions in the eastern half of the country rely increasingly on supplies from surplus producing areas in North China, placing pressure on the transport network. Shanxi is the main province able to produce a surplus for shipment outside its borders; it now accounts for more than a quarter of national production (see Map IBRD 26594). Shanxi and the nearby provinces of Inner Mongolia, Ningxia, and Shaanxi all have large reserves of high-quality, low-cost coal. A centerpiece of China's energy and transport strategy is to continue to increase the already large production from this region (see Annex Tables 3.9 and 3.10).

2.5 However, an important ancillary strategy for relieving shortages is to continue or accelerate mining in select eastern areas in order to buy time or fill gaps while the transport capacity out of North China is expanded to reach all parts of China. The tradeoff in cost is that production from the limited eastern coal reserves is increasingly expensive and of poorer quality.

2.6 In 1990, the central Government operated about 600 mostly mechanized underground mines, which generated 45 percent of total production. The remaining 55 percent of total production came from over 60,000 mines operated by provincial or county governments (hereafter referred to as local mines) and by townships or villages (hereafter referred to as township mines) (see Annex Figure 2.5). A few provincial mines use modern mining methods, but many local and township mines work shallow seams or outcrops with labor-intensive pick-and-shovel operations. Encouraged by price and investment reforms, local and township mines can provide the local work force with income and local energy users with coal without relying on the overcommitted railway system, and with minimal investment and short construction lead times.

2.7 The Government could decide to continue encouraging local and township mine growth so as to increase production rapidly and free up investment for other sectors, but there are several negative side effects: dangerous working conditions; poor coal quality; environmental degradation; and, often, wasting of reserves because the unscientific way they exploit the reserves often leaves large quantities of coal further below unaccessible by future mining. These local and township mines generally supply local markets and transport their coal by truck. A strategy involving greater production from such mines would have to include provision of railway spurs to larger local mines and/or collection of coal by truck from smaller mines.

Coal Beneficiation

2.8 Methods for improving the quality of the run-of-mine coal are not routinely practiced, but they are often technologically simple and can play a valuable role in eliminating coal shortages. The steam coal supplied to many users, particularly small users, can be poor—containing stones, 20 to 30 percent ash by weight, and a high percentage of coal fines (small particles). The sulfur content in the North China energy base averages around 1 percent, which is generally low by world standards, but which ranges up to 4 percent and higher in Sichuan and Guizhou.

2.9 Mechanical coal washing is a more expensive method that removes some of the gangue (rock and dirt mine waste), ash, and pyritic sulfur (not chemically bonded to the coal) by a coal-specific combination of crushers, screens, jigs, flotation tanks, and even centrifuges. The net result is a cleaner-burning coal that yields more energy and less pollution per ton. Although coal washing offers environmental and transport benefits, plus lower disposal and boiler maintenance costs, some carbon is also lost in the process. In power plants, washed coal can be more efficient than raw coal if the boiler is designed for it. About 18 percent of coal (but 37 percent of state-produced coal) was washed in China in 1991 (see Annex Table 3.11), compared with more than 50 percent in most Western countries. All coking coal (127 million tons) and some anthracite for the chemical fertilizer industry (10 million tons) are washed by necessity. Only 69 million tons (7 percent) of steam coal were washed in the 71 existing plants. However, almost none of the plants used for washing steam coal were designed for that purpose; they are mostly plants designed for washing anthracite and coking coal that are no longer needed for those purposes.

2.10 Coal fines can be lost either by being sucked up the flue or falling through the bottom grate of industrial boilers. Coal screening is an inexpensive but effective method for separating lump coal from coal fines, so that the fine coal can be distributed to power plant boilers that are designed to use pulverized coal, or so that it can be made into honeycomb briquettes. About 19 percent of coal is screened.

Coal Allocation and Pricing

2.11 The dual price system for coal, featuring large differences between low state-determined in-plan prices on the one hand and higher open market or negotiated prices on the other (see Annex Tables 3.12 to 3.14), is now extinct. Since the dual price system was introduced in the mid-1980s (replacing the preceding fully-controlled system), in-plan prices have increased in real terms (20 percent in 1991). Perhaps more importantly, the percentage sold in-plan was cut in half in January 1993, and now accounts for less than one quarter of all coal. As of the end of 1994, the rest was sold at free market prices, with the possible exception of a few consumer categories. For instance, the MOR now buys all of its coal at market prices and its electricity at nonsubsidized prices. In East China, coal prices are now close to or above international price levels, while in the Northeast, some producers of low-quality coal are unable to sell their entire production. Although the dual price system was phased out in 1994, its aftereffects in the form of inefficient boilers, power plants, buildings, and so forth, will linger on for many years.

2.12 The allocation of coal between sellers and buyers continues to be organized through an annual conference involving producers, large consumers, and central Government agencies. This conference serves the function of a not very efficient commodities market, with the interjection of the transport providers into the mix. The quantity and quality of coal to be supplied are negotiated between participants who have had longstanding supply relationships. Central authorities arrange for the transport of allocated coal. Sometimes, coal supplies are not well matched to consumer requirements because of inflexibility and inadequate responsiveness to changing market needs in the coal and transport allocation system (see Chapter 6, Policy Issues to be Addressed in the Future). By the end of 1994, mines in the coal-rich regions of Northwest, Northeast, and Southwest china had been mostly freed of state distribution plans, with the exception of coal for some power plants for which the price is still controlled by state or local governments.

Coal Transport

2.13 Railways are the predominant mode of transport for moving coal in China (see Annex Table 3.15). There are no major navigable rivers emanating from the North China energy base. However, at least part of the journey to Northeast and Southeast China can be made by water, either by coastal shipping, the Grand Canal, or by the Yangtze River. About 626 million tons of coal were shipped by rail in 1990, and of this, 139 million tons were transshipped to state-owned water transportation (see Annex Figure 2.6). However, if locally-owned shipping is included, 210 million tons moved by water. Trucks carried an estimated 161 million tons. Trucks are used to deliver coal to users near the mines, to collect coal from scattered mines and deliver it to railheads, and to distribute coal in cities. The remaining coal was consumed locally without being transported, and was consumed at minemouth power plants. The railways handled 341 billion tkm, state-owned water carriers 182 billion tkm, and roads only 10 billion tkm. Since the 1950s, railway investment as a percentage of total transport investment has fallen (Annex Figure 2.7).

2.14 Because of the increasing reliance on northern and western coal, the average transport distance for railways has increased from 530 to 545 km from 1988 to 1990. The average waterway distance (state-owned) has increased from 1,175 km to 1,310 km in just 2 years. Trucking is inefficient for long-distance transport of bulk coal, thus averaging just 63 km per trip. However, there were reports of trucks moving coal as far as 1,000 km during the worst coal shortages.

2.15 Coal represents about 42 percent of the total tonnage of freight handled by the railways. China's density of freight traffic on the railways is much higher than that of the United States and India and nearly on par with that of the former Soviet Union (see Annex Table 3.16). In 1993, freight traffic in China averaged nearly 22 million net tkm per route-km, which represents a fairly high level of operating efficiency and asset utilization. Still, there is room for improvement.

2.16 The effective strategies for increasing railway capacity from the energy base can be divided into two categories: building more line capacity, or increasing the throughput of existing assets. A number of new lines are being constructed, most notably a west-east railway from Shenmu in Shaanxi Province to Huanghua, a major new port south of Tianjin, and a third north-south corridor from Beijing to Guangzhou. The MOR is also considering adding a new dedicated passenger line from Beijing to Shanghai to the existing double-track, mixed freight-passenger line. This will separate freight and passenger traffic between the two lines and thereby boost the combined throughput capacity of both lines.

2.17 There is a spectrum of investments for increasing throughputs on existing lines (see Map IBRD 26857). New marshalling yards, longer and more frequent sidings, and better signaling and management can incrementally increase capacity. For larger increases in capacity, there are some possibly very cost effective strategies such as the use of unit trains, or replacing existing rails and wagons with those designed for heavy hauls. Unit trains, marshalled as a single unit that continually loops from origin to destination and back again, is being used on the Datong-Qinhuangdao line and is planned for the Shenmu-Huanghua line. For heavy haul technology, the MOR recently decided to increase maximum freight car axle loads on 10 to 20 percent of its freight cars from 21 to 25 tons per car over the next 10 years. This step, which can increase net tonnage throughput capacity of a line by up to 30 percent, could offer significant help on capacity-constrained lines. However, the effects of existing, less efficient, rail technology can be expected to last through 2000. Finally, the options for expanding the capacity of existing lines by the largest amount are multi-tracking or electrification.

2.18 China has the potential to expand greatly the coal transport capacity on coastal waterways between the northern and southern seaports. Extra distance added by the waterway leg of the trip is not an issue for many coastal cities in East China (see Annex Table 3.17). As an example, distances from Shanxi Province to Shanghai are nearly the same by combined rail-water routes as by the shortest rail-only routes. China has 15 major ports. Qinhuangdao alone loaded 54 million tons in 1991, nearly 70 percent of the coastal coal shipping. Some port capacity currently goes unused because of railway bottlenecks leading to the ports or because of the mismatched capacity of receiving ports.

2.19 Many investment strategies exist for expanding water transport of coal in China. Modern port facilities are not only more efficient, but they decrease the turnaround time of ships in ports. The use of self-unloading ships can reduce the cost of building handling facilities at a user's dock, especially if the annual volume is low. Pusher-barge system, in which barges can be used on the open seas or on the inland waterways (or both, without transshipment) have the advantage that the pusher units are separable from the barges, thus maximizing their at-sea utilization.

2.20 Generally speaking, larger vessels are significantly cheaper per ton than smaller vessels. In this study, per unit investment costs fall from Y 6,000 per dwt for 9-meter ships to Y 4,300 for 12-meter ships and to Y 3,000 for 14-meter ships. With the exception of Qinhuangdao, China's ports are not deep enough to accommodate 14-meter (100,000 dwt) post-Panamax supercolliers. Likewise, their fleet of ships consists mainly of domestically-produced shallow draft vessels 9-meter (35,000 dwt) or smaller. For many years, small ships and shallow ports have jointly constrained the Chinese shipping industry from changing to larger ships like in the international coal trade. However, a new generation of 50,000 dwt shallow draft ships is under development for 2000 and beyond. Potential exists for long-distance transport of coal from a single, deep-water northern port (e.g., Qinhuangdao) to a single, deep-water southern port (e.g., Gaolan, near Shenzhen), which could serve as a terminus for routes by 100,000 dwt ships and as a hub for a fleet of smaller vessels making deliveries to users. However, the high cost and environmental impacts of port construction and dredging, and the total lack of large 14-meter domestic supercolliers, have placed this option on the Government's back burner, perhaps until the Hong Kong takeover is complete.

2.21 Slurry pipelines are a promising technology for long-distance bulk transportation, but they are untested in China. Arid conditions in the north central area limit the potential for coal slurry pipelines, as do their relatively small capacities. A coal slurry pipeline is being built by a Sino-foreign joint venture from Yuxian in Shanxi province to Weifang in Shandong province. Some of the proposed pipeline projects plan to ship washed coal.

Coal Consumption and Conservation

2.22 In 1991, 1.104 billion tons of coal were consumed, of which industries accounted for 78 percent (see Annex Figure 2.1). Power plants used 27 percent of all coal, steel plants used 8 percent, and other industries used 43 percent. Of the remainder, residential buildings used 15 percent, commercial buildings used 1 percent, transport used 2 percent, agriculture used 2 percent, and building construction and others used 3 percent. An estimated 3 to 4 percent (30 to 40 million tons) was lost during handling and transport. Less than 2 percent, or 20 million tons, was exported.

2.23 Many strategies could slow the rate of growth of coal consumption even more than the current projection. Several Bank reports suggested many promising avenues for energy conservation through technological advancement; operating changes; district heating; co-generation; larger-scale industrial plants; substitution of other energy sources (for example, oil, gas, solar, wind, hydro, nuclear, and biomass) where appropriate; and more emphasis on high value-added industries and services.[1] Reform of coal prices will encourage some of these activities. Another important strategy on the coal consumption side is to accelerate the trend to channel more industrial growth toward the coal producing areas. Several factors are working against this, such as the existence of industrial linkages in existing industrial areas, and a less developed technical work force in the coal regions.

2.24 Some Chinese experts think that over the last 10 years, about 70 percent of energy conservation has been contributed by adjustment of industrial structures and enhancement of energy management. The latter includes employing more engineers responsible for energy efficiency in enterprises, and setting up special offices in charge of energy conservation in state, provincial, and local governments. The remaining 30 percent of energy conservation in China came from introducing new technology, changing processes, using new materials, and replacing outdated equipment or facilities with advanced ones. Most such projects are designed to achieve multiple benefits. Expansion of production capacity, improvement of product quality, and environmental protection are generally combined with energy conservation measures. Some sample surveys show that the investment required per unit capacity of energy saving continually increases year to year, but up to now, a marginal production curve or function for energy conservation has not been estimated for China.

2.25 Officially, 1.23 million tons of coal were imported in 1992, mainly to the seaports of Dalian, Shanghai, and Guangzhou. As the economy is opened and reformed, coal imports can play an important role in balancing supply and demand in coastal areas with little investment or lead time.

Coal for Electricity

2.26 Since 1949, China has become the fourth largest producer of electricity in the world, with a total output of 754 TWh in 1992. Power in the country is distributed through nine major grids (see Map IBRD 26595). In 1992, total installed capacity was 166 GW; about 76 percent of this was thermal and 24 percent was hydropower. A miniscule percentage of the thermal capacity is fired by oil or natural gas. From the 1950s to the 1970s, the thermal share of total electricity sector investment fell while that of hydropower rose, until the 1980s when the trend was reversed sharply (Annex Figure 2.8). Industry is by far the largest user of electricity, accounting for 77 percent of consumption in 1992. Approximately 96 percent of the nation's villages and 80 percent of rural families now have access to electricity.

2.27 The electricity sector's 8 percent share of final net energy consumption is one of the lowest in the world, but is likely to go much higher as the service and residential sectors use more (see Annex Table 3.18). One prominent investment strategy is to develop more minemouth thermal power plants, thus avoiding the transport bottlenecks. At present, about 40 percent of all thermal power plants are located at minemouths (within 50 km distance). However, with a few exceptions, most electricity transmission is intra-provincial; the self-sufficiency of most provinces in terms of electricity production is evident in Map 26596. Mine-mouth power development is limited by the availability of water in the Yellow River Basin where coal reserves are concentrated. Also, to compensate for transmission losses of high-voltage transmission lines, mine-mouth power generation requires about 5 to 10 percent more coal mining and power-generating capacity.

2.28 China has developed only 9 percent of its hydroelectric generating potential, estimated at 1,900 TWh per year. Developing more of this hydropower potential would reduce demand for coal transport, but hydropower and the associated transmission lines can be capital-intensive. Most of the potential is located in the Southwest (70 percent), about 1,500 km from the major coastal cities. Hydropower also has positive and negative externalities. On the positive side are the air pollution reduction, irrigation, flood control, and possibly navigation and recreation benefits. On the negative side are the loss of agricultural land and the need for relocation and resettlement of villages. There are several enormous hydropower projects in the 8FYP and 9FYP, including the Three Gorges reservoir and power station on the Yangtze River between Wuhan and Chongqing, approved by the State Council in 1992.

2.29 Local energy resources are also relied on to meet local needs, especially in isolated areas. In 1989, mini-hydro, small thermal, and diesel generating sets had a total installed capacity of 18.7 GW and generated 60.4 TWh. In addition, China commissioned its first nonmilitary nuclear power plant (300 MW) in the Shanghai area in 1992. In Guangdong, the Daya Bay nuclear plant (2x900 MW) will send 70 percent of its power to nearby Hong Kong. Known uranium reserves could sustain seven times more nuclear power production for 30 years, and contingency plans include several additional plants.

2.30 Since the start of economic reforms in 1979, China has made significant progress in modernizing its power generation and transmission technology. Between 1979 and 1989, fuel consumption in new thermal units was reduced to about 400 g of standard coal per kwh, or about 36 to 37 percent efficiency. The oldest, smallest still-operating plants use 60 percent more coal to produce the same amount of electricity as the large (600 MW) efficient coal-fired units (600 MW)—and they produce at least 60 percent more pollution. But only 12 percent of thermal plants are in units of 300 MW or more, and the national average conversion efficiency is only 31.8 percent in 1992. China can now also build and operate 500kV direct current (DC) transmission lines for distances of 800-1,500 km.

2.31 A dual price system for electricity was introduced in the mid-1980s, and was overhauled and simplified in 1993. Three principles govern the current system.

First, higher prices can be charged for electricity from new power plants, as the investment for the new plants (most of whose inputs were purchased from the free market) is comparatively high. Second, the price is composed of three parts: operating cost, return on investment, and profit to the investors. There is thus an element of cost-plus pricing in the system, but the situation is complicated by a variety of surcharges and miscellaneous fees and discounts relating to fuel prices, transport, etc. on a plant-by-plant basis. Third, the price is negotiable between the local and central governments. All told, average consumer prices in regions such as East China now provide for complete recovery of investment and interest. Given the national shortage of electricity, fear of inflation is the main reason behind the delay.

2.32 Different rates continue to be charged depending on whether the power comes from old or new plants, and whether the consumer is a longstanding or new customer. The main difference continues to be between plants built with grant financing before 1985 and plants financed through loans that must be repaid, built since 1985. Loan-financed plants also include the semi-autonomous plants built by Huaneng Inc., an independent, state-owned firm that seeks out foreign financing. Grant-financed plants now use an improved mechanism for automatically adjusting prices to reflect changes in fuel costs. In some places, if large users need more electricity, they are asked to pay an advance payment to help fund the construction of new generating capacity. This advance payment can be as high as Y 1,500 per kw of capacity, and may have to be paid as much as two years before they get any electricity. Consumer pricing for electricity remains complex, nontransparent, and inequitable.

Environmental Impact of Coal

2.33 Air pollution is a serious problem in China. Much of it is caused by burning coal (see Annex Table 3.19), especially on the part of small-scale users with inadequate emissions control technologies. Ambient air concentrations of total suspended particulates (TSP) and sulfur dioxide (SO_2) in Chinese cities are among the highest in the world (see Annex Table 3.20), and are worsening rapidly. They can cause serious respiratory health problems. Acid rain, principally a result of SO_2, damages crops, forests, and aquatic ecosystems. China's contribution to global carbon dioxide (CO_2) buildup, largely due to burning coal, is estimated at 11 percent of the world total. The environmental impacts of coal use are not limited to air pollution. Other impacts include mine runoff and land degradation from strip mining, and disposal of coal ash from boilers and stoves.

2.34 Particulates are considered to present a more serious environmental problem than SO_2-caused acid rain, mainly because most of China's coal has a low average sulfur content (about 1.5 percent) and high ash content (20 to 30 percent). Most types of TSP control equipment (except for fabric filters) are available in some parts of China, but removal efficiencies can be low. Sulfur scrubbers are not currently in use in China, mainly because of their high capital costs, which can add up to one third of the investment costs of a power plant.

2.35 Emissions standards for power plants in China are low compared with the industrialized world. For comparison, the standards imposed on the new Yangzhou thermal plant (4x600 MW) funded by the World Bank are 520 tons of SO_2 per day, compared with 70 tons per day (tpd) for a similar plant in the United States, 19 tpd in the United Kingdom and Germany, and 100-500 tpd for the recommended World Bank standard (100 tpd for highly polluted areas, 500 tpd for unpolluted areas). The particulate limits are similarly lax: 348 mg/m^3 for the Yangzhou plant, versus 50 mg/m^3 in the United States, United Kingdom, and Germany, and 100-150 mg/m^3 for the Bank's recommendation, depending on whether the site is urban (100) or rural (150).

2.36 In addition to these standards, China also has pollution charges on the books, but it is not clear how much they (or the various standards) are enforced. Monitoring emissions is difficult, and up until the recent introduction of the profit motive to factory managers, there was little incentive to comply. They also have ambient air quality standards (see Annex Table 3.21), though how the responsibility for achieving them is distributed is not clear. The multitude of standards and taxes on the books, in combination with the poor air quality, raises questions about their enforcement.

3. Planning and Investment for China's Transport and Energy Sectors

3.1 China is currently reforming its planning and investment system. The Government is decentralizing decision-making and reorienting the economy toward the market in a step-by-step fashion. This chapter describes the Government's role in planning and financing the energy and transport sectors and the problems it faces, and then briefly describes the modeling tool developed as part of this study for assisting the Government in its planning and investment tasks. Greater detail on the planning and investment system can be found in Annex 4. The model is described in a general fashion in Annex 5, and in diagrams in Annex 6.

The Planning System

3.2 The SPC is China's main Government agency for long-term economic planning in China. The SPC draws up the FYPs that outline the development strategy, targets, and key construction projects. Administratively, the SPC serves directly under the State Council (China's Cabinet), which manages the economy on behalf of the National People's Congress. In 1992, to provide a better linkage between the FYP and the yearly plan, the Government adopted a two-year rolling plan with tentative targets for the following year. The State Economic and Trade Commission, newly carved from the SPC, is responsible for day-to-day implementation of the plans. Environmental protection is supervised by the National Environmental Protection Agency, which is situated one level below the SPC or ministry level, but functions like a ministry.

3.3 Ministries are also directly under the State Council. The four main ministries responsible for the coal-electricity delivery system are the Ministry of Railways (MOR); the Ministry of Communications (MOC), which plans and builds highways, waterways, and ports; the Ministry of Coal (MOCL); and the Ministry of Electric Power (MOEP). They prepare blueprints for the long-term development of their industries, and develop investment projects in accordance with the blueprints. However, the two energy ministries no longer directly manage enterprises or construct projects; they are charged with overall sector coordination and policy guidance, and with planning of state-owned energy projects. State corporations under MOEP and MOCL construct and operate these energy projects.

3.4 In 1992, the Chinese Government further decentralized project management and planning. Those construction projects whose funds, materials, and marketing can be handled by a local or provincial government can now be organized, sponsored, engineered, and administered at that level. For some projects that involve several ministries and/or provinces—such as an integrated project of coal mining, rail transport, and thermal power generation—different parts would be handled by the State Coal Mining Corporation, MOEP, and MOR, with the SPC acting as the overall coordinator.

The Financing System

3.5 China's financial sector is in transition from one that allocates credit directly to one that relies increasingly on markets to ensure that savings flow to high return investments. This is substantial progress given that prior to 1987, state investment funds were given as grants and did not have to be repaid separately from the return of profits to the state treasury. The financial sector that emerged from the early and middle stages of reform (1979-1991) was composed of one central bank (The People's Bank of China, or PBC), four specialized banks (industry and commerce, agriculture, construction, and foreign exchange), two comprehensive banks (multi-sector lending), seven newer commercial banks (mainly regional in scope), and tens of thousands of urban and rural credit cooperatives.

3.6 The situation regarding infrastructure financing, however, has changed dramatically with the introduction of the three policy banks, viz., the State Development Bank of China (SDBC), the Agricultural Bank of China, and the Export-Import Bank of China beginning in April, 1994. (see "China: Financial Sector Reforms: Current Status and Issues", Report No. 13492-CHA). Prior to this, the four specialized banks lent money to two classes of projects: first, those that offered high financial rates of return and were bankable; and second, those that did not satisfy commercial lending criteria but were deemed to be of high national priority for policy reasons. Power and transport projects often fell into this category because of their large scale and long payback periods. The purpose of the three policy banks is to disentangle the "directed credit" or policy loans from commercial lending by creating separate institutions for each. For infrastructure in the coal and electricity delivery system, the SDBC is taking over responsibility for policy lending from the People's Construction Bank of China (PCBC). Thus, the PCBC will now be able to function more on commercial lines, while the SDBC will not be profit-oriented and will lend at subsidized rates.

3.7 The SDBC supposedly will have autonomy in deciding which projects to finance from a list provided by the SPC. The SDBC will appraise projects not only for financial viability but also technical quality (to be contracted out) and adherence to state industrial policies. At its startup, the SDBC had 350 projects in its lending pipeline, which does indicate a close relationship with the SPC, at least at first. The SDBC's staff is largely composed of nonbanking staff absorbed from the SPC's Investment Department and from the former SPC-controlled investment companies. Overall, about Y 40 billion per year of investment is controlled by the SPC through SDBC.

3.8 Since the early 1980s, the central Government has been a diminishing source of investment funds. The new approach is to fund a project from various sources, such as (a) the sponsoring ministry or corporation; (b) foreign capital; (c) bank loans; (d) the SDBC (or PCBC); (e) local governments; (f) local agencies; (g) private corporations; and (h) shares of stock. While provinces and cities can plan and build large projects independently of the central Government, the 10 to 30 percent that they typically get as directed credit can be crucial for the project's financial success. The share of central Government financing in the power sector, for instance, has fallen sharply, from 91 percent in 1980 to 30 percent in 1992, while provincial and local governments now provide 40 percent or more.

Problems in the Planning and Financing System

3.9 Inefficiency in the transport and energy sectors are common problems for the Government to try to overcome. Various institutional factors lead to inefficient choice of scale and technology, particularly in the use of energy and raw materials. Generally, larger mines, ports and power plants are more efficient. If a local government invests in production capacity in another province, they lose employment and tax base. Marketing is not advanced in China, which, together with the lack of adequate transportation and telecommunications infrastructure, makes it difficult to generate demand for a product outside the local area. Local governments often do not have the financial resources to build larger-scale projects, or they wish to avoid the Y 30 million cut-off level for requiring clearance by the SPC. Annual budgetary negotiations create a bias toward capital cost minimization without considering operating savings of more efficient technologies.

3.10 Intersectoral and interregional coordination is also a problem. A central problem in this study is investment in power plants, steel plants, and other coal users in locations where enough coal or the right type of coal cannot be delivered because of bottlenecks. However, other examples of poor coordination can be found. Price distortions can create biases, such as artificially low electricity prices favoring electric traction over diesel for railways even for low density corridors. Railway construction has not always been optimally coordinated with port construction. One example is the Datong-Qinhuangdao railway, which was not completed in time for the opening of the new berths at Qinhuangdao. To supply the new shipping capacity with coal, a short spur from the then-endpoint of the railway was built to connect with the Beijing-Qinhuangdao railway. This spur became obsolete upon completion of the DaQing line. Another example is the use of unrealistically low growth rates for planning purposes, which has led to underinvestment in infrastructure.

3.11 In the financing system, the underinvestment in infrastructure is endemic. More capital must be attracted and efficiently used. Adequate investment over the long run will hinge on continued reform of the new market institutions and opening of the system to additional sources of capital, both domestic and foreign.

The Changing Role of the State Planning Commission and its Analytical Needs

3.12 Before the 1980s, the central Government controlled all individual projects through the SPC. During the 1980s, they controlled mainly large projects over Y 30 million. Now, townships can plan and finance some of their own investment projects, and the plans SPC makes are no longer mandatory even for state-owned industries. As the long-term economic planning agency of the Government, one of SPC's main tasks has historically been to distribute state-controlled investment funds between regions and industries in a balanced way.

3.13 In early 1994, the State Council redefined the functions of the SPC in the new socialist market economy. The nine-point plan can be encapsulated as four major functions:

(a) strategic functions such as researching and developing strategies, directions, targets, national industrial policy, and 10-year, 5-year, and annual guidance plans;

(b) macroeconomic adjustment functions such as helping to adjust the supply and demand for capital and monitoring total price levels (the National Price Management Bureau is now part of the SPC);

(c) coordination functions such as helping to establish a national, cross-region market system for important commodities, information dissemination, and helping different sectors to work together; and

(d) fund allocation functions such as reviewing, approving, and guiding key construction projects.

The key theme behind all these functions is that their role has changed from controlling the economy to steering it. Its old role was at the core of the central planning mechanism, while the new role represents a transition toward "indicative planning." Indicative planning involves guiding decentralized enterprises and local governments and advising the central Government on the implications of its policies.

3.14 The SPC consists of a national agency plus provincial planning agencies for each of China's 30 provinces. Planning of the coal and electricity delivery system is done by several departments, including Energy, Transport, Long-Term Planning, Investment, and Science and Technology. The national-level SPC has a policy research arm that provides analytical support to the planning side. The ERC is an umbrella institute that coordinates the activities of several institutes, including the Economic Institute (EI), the Energy Research Institute (ERI), and the Institute for Comprehensive Transportation (ICT). These three institutes contributed researchers for this study, under the supervision of the ERC itself.

3.15 The SPC's new policy and planning role emphasizes working through the market economy. Thus, they have a strong need for a systematic market information system, including forecasting and modeling, in order to guide market performance and steer away from chaotic, uncoordinated public infrastructure development. According to Mr. Wei Liqun, General Secretary of the SPC, they have come to recognize that planning in the past has sometimes been unreasonable. There is a growing realization of the need to analyze multiple alternatives quickly. And, to facilitate the functioning of free markets, they need to open the planning process to different fields of society, including local officials, sectoral experts, and international investors. And, to the extent that the SPC continues to fund state-owned companies and allocate state funds that can make or break a jointly-financed investment project, the SPC should try to do so in such a way as to meet infrastructure needs, coordinate different provinces and industries, promote efficiency, and protect the environment.

3.16 China's economy has been increasingly dynamic in recent years. The GNP forecast has been raised and may soon be raised again. Policies and priorities are being frequently updated as the planning and investment system is reformed. The SPC has recognized these realities by adopting two-year rolling plans. A computer-based decision support system with a rapid response time is one of the ways the SPC is trying to adjust to changing conditions and policies and their own newly-defined role.

The CTS Network Optimization Model

3.17 Because China's transport infrastructure problems of the mid to late 1980s spanned the entire country, the original idea was to develop a decision support tool to help coordinate the expansion of the transport network (see Annexes 5 and 6 and the Supplementary Volume for greater detail). However, in studying the problem it became clear that in addition to increasing the transport capacity, investments such as coal washing and hydropower may, in some circumstances, reduce the demand for coal transportation in a cost-effective and environmentally beneficial way. The close substitutability between rail transport of coal and minemouth power plants coupled with long-distance transmission lines make it necessary to evaluate these different options in a systematic and integrated fashion.

3.18 The analysis tool combines features from major energy transport models in the United States, but has been tailored to the SPC's needs. The CTS model can be considered a Decision Support System because it *supports* SPC policymakers in making *decisions* by providing a fast and comprehensive way to study energy delivery *as a system* rather than as separate parts. It treats the energy delivery system as links of a chain, beginning with coal supply, and continuing through washing, transport, utilization, conversion to electricity, transmission, utilization of electricity, and impact on the environment (see figures in Annex 6). In the model, these activities take place at 48 coal supply nodes, 49 coal demand nodes, 58 electricity supply nodes, and 38 electricity demand nodes, which are linked by 286 railway arcs (177 of which have investment projects), 31 ports, 3 potential slurry pipelines, and 99 transmission lines. Given any forecast of GNP growth and energy demand elasticity for 1995, 2000, and 2005, the model will try to satisfy those demands for the lowest cost possible. The model features a Geographic Information System (GIS) that facilitates the visualization of data and results.

3.19 The model's primary use is to identify logistical trouble spots and broad investment directions by sector and region. The methodology allows the dominance of complex options over one another to be evaluated in a rough but relatively comprehensive way before proceeding to a more refined economic analysis. Thus, the CTS model is designed to complement, not replace, other more detailed models for planning particular sectors of the coal-electricity delivery system, such as rail and electricity planning models. Policymakers can answer "what-if" questions and analyze tradeoffs between economic goals, energy supply goals, and environmental goals.

3.20 Methodologically, this kind of comprehensive national modeling is rare among the Bank's borrowing countries today. But in this case, it is necessary because the coal-transport-electricity-environment system is so large and complex, so interconnected, and has so many alternatives to be analyzed. Coal mining outside the energy base, coal washing, hydropower, shipping, and minemouth power are important "relief valves" for the pressure on the railway system. In addition, some of these investments are faster to implement or have greater environmental benefits than others. Interrelationships among different links of the transport system and more generally among the different links of the supply chain, require an intersectoral planning tool that will compare and coordinate investment projects from MOR, MOC, MOCL, and MOEP on a level playing field.

3.21 Even if the analysis system is never used to referee this competition for funds, the systems thinking behind the model and the consistent data base developed for it may be useful for policymaking. And if it is used, there are several modes for doing so. Using only the planned set of energy and transport options, the potential performance in terms of meeting various growth rates or environmental goals can be assessed. Alternatively, the tool can be used on the leading edge of the planning process to generate new project ideas.

4. Analysis of Investment Strategies

Overview

The Task Ahead

4.1 With rapid economic growth and reform, industries and consumers alike demand more energy and transport. In mid-1992, the Chinese Government increased the GNP growth forecast for the rest of the decade from around 6 percent to around 9 percent. In addition, the coal forecast for 2000 has been raised from 1.4 billion to at least 1.5 billion tons, and the electricity forecast from 1.1 trillion to at least 1.3 trillion kwh. To meet its own forecasts, China plans to produce about 400 million tons more coal than is currently produced—or about 60 million additional tons each year—though the study's analysis actually suggests that the increase needs to be closer to 500 million tons. Of the 400 to 500 million additional tons, around 300 million is needed for new thermal power plants. Without enough coal for electricity, economic growth could fall short of 9 percent. All this needs to be accomplished in a seven-year time frame. This chapter outlines a coordinated strategy for achieving these goals.

Key Modeling Assumptions

4.2 The conclusions are based on 13 scenarios analyzed with the CTS Analysis System in 1993 (see Annexes 7-10), and to a lesser extent on 16 scenarios run in 1992 (see Annexes 11-12). GNP growth of 9 percent was the main forecast studied, but runs with 7.5 and 10.5 percent were also analyzed (see Chapter 1). The analysis is based on 1990 costs, not prices, and all Chinese currency figures are reported here in 1990 yuan. The discount rate is assumed to be 12 percent. One of the key analysis assumptions is that there is no coal imported from other countries except in selected scenarios—an assumption that is consistent with China's past practice. Another key assumption relates to the shortages, which are necessary because demand in the medium term may not be fully satisfiable at a reasonable cost. The cost of shortages is the economic loss from unsatisfied demand, but it also defines the buyers' willingness to pay in that it acts as an upper bound for the delivered cost of any supply chain. The approach adopted for this study is to base the shortage cost on the cost of substitutes for coal or electricity supply (see Annex 13). The basic idea is that the economic loss or willingness to pay, which are nearly impossible to quantify in a semi-market economy like China's, should in any case not be higher than the cost of an available substitute form of energy, such as imports. In this study, the cost of imported coal delivered to coastal ports was estimated at Y 300 per ton. Electricity shortage costs, based on converting imported coal into electricity, range from 20 to 70 fen per kwh, according to an increasing step function that varies from zone to zone.

4.3 The model was provided with investment options exceeding what is planned in the 8FYP and 9FYP (see Annexes 14-17). For some standardized sectors, like thermal power plants and coal washing, potential new capacity was virtually unlimited. For site-specific sectors, new options were far more limited, but still exceed planned capacities. Mining options are about 100 percent greater than the planned capacity, hydropower options are about 50 percent greater, and transmission options are about 800 percent greater. Railway options include a few lines that were not originally in the FYPs or that were listed at a lower priority, some of which have since been inserted into the plans (see paragraph 4.10). The list of possible projects is limited by what can be accomplished realistically in seven years.

4.4 The model was calibrated to approximate certain aggregate targets, such as total coal and electricity production, negligible shortages in the energy base, and a reasonable split between rail and water transport and between hydro and thermal power. In addition, results were checked thoroughly by SPC and Bank experts (see Annex 8).

Prospects for Energy Shortages

Nine Percent GNP Growth

4.5 If the economy grows at about 9 percent per year, the analysis results suggest that it should be possible within existing constraints to satisfy nearly all the coal and electricity demands without importing coal, except in a few problem regions (see Annex Figures 10.1 to 10.4). The combined shortfall of coal and electricity (converting electricity shortages to their coal equivalents) are estimated at around 2 percent of demand. The economic losses due to these shortages (valued at the cost of importing coal) is estimated at US$3 billion (in 1993 prices) for the single year of 2000. These conclusions are based on the assumption that additional energy delivery strategies are carried out in anticipation of that growth. Electricity transmission and coal washing are important components of the delivery strategy recommended by the model, and these only recently garnered serious consideration by planners and enterprises in China. The CTS's conclusions would be less optimistic in the absence of such alternatives. Also, enough capital must be available to build all the projects. A 10 percent reduction in the capital budget could nearly double the combined coal-electricity shortages (Case 92-10).

Impact of Different Growth Assumptions

4.6 With lower growth (7.5 percent in Case 93-13), shortages could be virtually eliminated, but higher growth (10.5 percent in Cases 93-9 to 93-12) would likely overwhelm the railway network. Combined shortages of coal and electricity in 2000 if growth tops 10.5 percent would likely exceed 125 million tons. In the worst case scenario, shortages in 2000 are nearly 8 percent of demand, with an economic cost to the economy of US$10 billion, or about 1 percent of China's projected GNP. If demand surpasses the 1.6 billion tons of coal needed for the medium-demand scenario, the railway projects currently planned for 2000 would probably not be able to handle it, even when supplemented by several railway projects that have been recently accelerated in the MOR's plan (see Railway Investment Program, paragraph 4.9). Furthermore, accelerated implementation of nonrailway projects, such as long-distance transmission and coal washing, will not be able to alleviate the paralyzing pressure on the railways. Coal imports can help somewhat in the coastal cities, but domestic coal that would be replaced by imports still cannot be moved easily to interior cities (see Imports, paragraph 4.33). For 10.5 percent growth, the number of projects being planned or studied does not seem to be enough.

4.7 Transport and infrastructure development need to adjust much more quickly to rising demands. The Government should open up the infrastructure sectors to market forces as much as possible to enable them to be more responsive to changing situations. However, in the rush to reverse the historical underinvestment in long-distance energy transport as quickly as possible, there is a risk that railways, mines, ports, and the entire electricity sector will run into some coordination problems. Therefore, beyond simply setting up market mechanisms, the central Government should have a role in rationalizing network investments. Their role, however, should be a guiding rather than controlling one, in cooperation with provincial and industry authorities.

Transportation Sector Policy Implications

Network Bottlenecks

4.8 The major issue for future coal delivery is how to move enough coal out of the three key provinces in the energy base region—Shanxi, Shaanxi, and western Nei Mongol. In all 28 scenarios conducted for this study—even an extremely low (6 percent GNP) demand case (Case 92-3), and an increased transport capacity case (Case 92-5)—*all* the railway lines leading out of these three provinces operate at full capacity (see Annex Figures 10.5 and 10.6). The maximum amount, about 390 million tons per year, is exported from this region in every scenario. From each case, the strong conclusion is that transport bottlenecks from these three provinces must be solved because the rest of China will rely increasingly on them for coal in the future.

Railway Investment Program

4.9 Nearly all the railway expansion projects within and leading out of the energy base region are economically justified and will play important roles in 3-West coal transport (see Annex Figure 10.7). The study results were used as a basis to support the Government's recent decision to accelerate the construction of a major new west-east unit train corridor from the just-developing mining area of Shenmu to the new port at Huanghua via Shuoxian. However, there is some question about whether it is feasible to complete the port and the last section of the railway by 2000. For this reason, the 9 percent GNP growth base case was run both without it (Case 93-1) and with it (Case 93-2). The results indicate that completing it by 2000 would reduce shortages in 2000 by 7 million tons. Under 9 percent growth, accelerating this project is justified, but not at 7.5 percent growth. Several years ago, the State Council asked MOR to accelerate its railway construction program and complete all the lines planned for 1995 one year early.

4.10 To accommodate 9 percent GNP growth, several major additional railway projects were included in the analysis that were not originally in the 8FYP or 9FYP when we began this analysis. The three most important suggestions for railway expansion for reducing energy shortages beyond 2000 were the following:

(a) Shexian-Handan-Jinan, a new west-east line from the southern part of the energy base to Shandong Province, is now in the railway plan for 2005;

(b) Shenmu-Yanan-Xian-Baofeng, a new north-south line from the far western part of the energy base, has been completed as far as Yanan; the construction of the Yanan-Xian section and the planning of the Xian-Baofeng section should be speeded up so as to open a new channel out of the energy base; and

(c) a dedicated passenger line between Beijing and Shanghai, now being actively studied, would free up capacity for coal and other commodities on the existing Beijing-Shanghai line.

New lines in other regions also play important roles in handling the energy base coal once it exits the energy base, and also coal from other regions (see Annex Figure 10.7). An important caveat concerning these investment recommendations is that the analysis includes only one commodity, coal, albeit the most important one on most lines. The model looks at a prorated capacity for coal, depending on the intercommodity allocation, and an equally prorated share of the total investment cost. For this reason, the model can answer questions about whether a new investment is justified in terms of its coal traffic, but the results should be interpreted in conjunction with a multicommodity railway investment model like the Railway Investment Study (RIS) model. Ideally, before adopting a final railway investment program, the planned capacities could be plugged back into the CTS model to explore whether they will likely be adequate under various circumstances.

4.11 In recent years, China has concentrated their railway investment more on adding incremental capacity to existing lines than on building new lines, and as a result has one of the highest densities of traffic per km of track in the world. As planned, China should continue expanding the capacity of existing lines by multiple-tracking, diesel and electric traction, and additional sidings. Especially important for coal is heavy haul technology, which is being implemented by MOR with Bank assistance to increase railway line capacity at a lower per-unit investment cost. However, the benefits of increasing axle loads from 21 tons to 25 tons per car will not be felt until after 2000. Increasing existing capacity incrementally, however, is not enough to provide the needed additional throughput capacity to solve the problem of energy base bottlenecks; thus, our emphasis on new line construction. Of course, these new lines should also take advantage of the low unit cost offered by modern traction systems, unit trains, and heavy axle load technologies.

4.12 With all the planned energy base railways plus the possible ones mentioned above expected to be utilized to their maximum capacity by 2000 or 2005, a natural question to ask is whether even more energy base railways would be economically justified. The answer is yes, but to do so by 2000 is unrealistic. This study has included practically all the railway projects planned as of early 1993, except for some spurs, local railways, and railways that are primarily for other commodities. This suggests that railway *planning* has not kept up with railway demand. Just as railways are a bottleneck for the energy system, planning is a bottleneck for the railway system. Many more options should be on the table at any given time than can be inserted into the plans.

4.13 The analysis points out the strong interdependencies among the various links of the railway and port network (see Figures 10.8 and 10.9 in Annex 10). Several existing and planned railway and port projects will likely be grossly underutilized because of upstream and downstream bottlenecks, although some of these may be mainly justified by noncoal freight and passenger traffic. An example of less than full utilization is the new coal port of Huanghua, which is in danger of being seriously undersupplied by as much as 25 million tons of unutilized capacity in the 9 percent GNP case (93-2) for 2000 because of expected bottlenecks on the rail segment coming out of Shenmu. The large capacity Beijing-Qinhuangdao line may be only about half used because of bottlenecks leading into Beijing and local consumption in Beijing. Likewise, bottlenecks at the ports and railways en route to northeast China may cause underutilization of the interior railway capacity allocated to coal. Finally, in most of the early model runs analyzed in 1991-92, the railway capacity on lines south and east of Jinan were underutilized, which argued strongly for addition of a new railway line from Handan to Jinan. This line was then added to the model, and has since been approved for construction by 2000.

4.14 Another possible way to increase coal flows without making investments is to raise the ratio of coal traffic to total traffic on each link. In the CTS network model, this ratio is specified exogenously for each link between 20 and 90 percent (see Annex 15). It is difficult to say whether coal flows or passenger flows are more important for maintaining economic growth, since coal provides energy but passengers represent skills and information. Passenger traffic is generally considered to be higher value than freight traffic, and the demand for it is increasing even faster than for freight. Used selectively, the policy of substituting coal trains for passenger trains might help to equalize the throughput on parallel railway links where one is a bottleneck. However, the potential for solving China's coal transport problems in this way is limited because passenger transport demand already exceeds supply on most lines. Furthermore, to successfully increase the throughput of a coal transport corridor, traffic would have to be reallocated by a much larger percentage on some segments than on others in order to increase coal capacity by the same absolute amount on all segments along the corridor. (Scenarios 92-4 and 92-5 illustrate the futility of changing all lines by the same percentage amount but different absolute amount.) The real issue is not whether to give up passenger traffic capacity for coal transport, but how much additional capacity to provide for both.

Coal Distribution

4.15 The cost minimization that takes place in the CTS model replicates the behavior of coal buyers seeking the least-cost source and shipping route for the right kind of coal. Figure 10.10 in Annex 10 shows the optimal railway coal flows by link in the 9 percent GNP case in 2000. Figure 10.11 shows the corresponding interregional coal flows and the waterway flows. The predominant pattern is nearly 300 million tons of coal shipped from the North China energy base to other regions, supplemented by consumption of coal produced within the same multiprovince region. This pattern is quite pronounced: no other region besides North China ships more than 10-15 million tons of coal to any other region.

4.16 Rail flows are predominantly from mines in the west to cities and ports in the east and northeast, and from north to central. Energy base coal by rail is largely intercepted by the middle regions of China (Henan, Hebei, Shandong, and Hubei) before South and East China are reached. Despite getting more coal by rail than the south and east, Central and Northeast China can expect shortages because of their lack of alternative routings by waterways. The south and east rely almost exclusively on water-borne flows and locally-produced coal, which for the most part can be kept successfully off the southern China rail network. Waterway flows are dominated by a huge flow from Qinhuangdao to Shanghai, and lesser flows from Huanghua and other ports to Guangdong, Dalian, and Hangzhou. See Chapter 5 for a more detailed discussion of the individual regions.

4.17 The coal distribution results are generally consistent with the current direction of coal distribution policy in China. However, the analysis suggests two areas for improvement:

(a) Calorific content of coal should be taken into account when deciding on origin-destination pairings and routes. Annex Figure 10.12 shows that coal with a greater energy content is shipped over longer, more expensive routes. It is estimated that the transport cost savings from optimizing flows of steam coal from the northern energy base according to their heat content are around Y 115 million per year in the year 2000 (in 1990 prices).

(b) The model results indicate that as much coal as possible should be consumed in the local area in which it was produced (see Annex Figure 10.11). Long-distance railway throughput can be aided by supplying as much coal from local sources as possible.

Congestion pricing of railway bottleneck corridors would provide an incentive for buyers and sellers to take these steps.

4.18 Generally, there are three parties involved in coal distribution: sellers, buyers, and transport providers. In China, buyers and sellers are becoming increasingly autonomous from the central Government, even for state-owned plants. However, because of the transport capacity shortages, the MOR (rail), the MOC (ports), and China Ocean Shipping Company (COSCO) (ships) have needed to be third parties during any negotiations. To facilitate this process, the Government organizes an annual coal ordering conference to bring all three parties together. This is not so different from OECD countries, where carriers are typically included in long-term contracts between buyers and sellers. However, it is imperative that the quality of coal be included in the negotiations, and that an information system be developed to aid in this process. Contracts in the United States clearly spell out the latitude for coal type variance and the means of testing.

Rail Tariffs

4.19 Railway tariffs for freight were raised by about 140 percent from 1990 to 1993, compared with the GNP deflator at 28 percent. Railway freight tariffs now approximate long-run marginal costs. And yet scarce railway assets are not used to their maximum efficiency. Rail lines are at capacity but the coal is still unwashed, low in heat content, or weighted down with water. These are partly the result of historically low rail rates.

4.20 If the MOR were to charge congestion prices above long-run marginal costs, it should encourage shippers to improve the quality of their coal and switch to attractive waterway options. Congestion pricing should also provide an internal incentive, and the revenue that the MOR needs, to increase its capacity on bottleneck links by implementing heavy haul technology for rails and wagons, building lighter-weight wagons, and operating more unit trains. Congestion pricing is not uncommon internationally: railways in the United States typically charge higher rates in the congested Northeast corridor.

Other Policy Reforms

4.21 Rail prices should be relied on more heavily to allocate resources. Currently, about 60 percent of China's railway capacity is allocated administratively to key users, be they centrally or provincially owned or foreign joint ventures. Because railway transport demand far exceeds supply at present tariff levels, the mandatory traffic allocation system tends to encourage wasteful uses of scarce transport capacity. Reducing this percentage gradually over time would apply competitive pressure to wasteful customers.

4.22 For other commodities, China is moving towards providing more high-value transport services—for example, fast and reliable container transport and dedicated passenger transport—which furnishes not only "raw capacity", but "quality capacity." As a result, rail passengers and container shippers appreciate more and are willing to pay more for the services, thus boosting the value of the railway system to the economy. One way to pursue this in the coal transport market would be to auction off a segment of railway capacity to independent service companies who would provide rapid and reliable coal transport along some rail or rail-water corridors. This earmarked track capacity could be leased to the highest bidders on a competitive basis. This would inject some service and price competition into the mostly monopolized world of coal transport.

Water Transport

4.23 Waterways are an important part of the strategy for handling China's massive north to south coal movements. For medium GNP growth, nearly 140 million tons of coal (not including nearly 25 million tons of exports) would be shipped in 2000 from north to south, nearly double the amount in 1990 (compare Figure 10.11 for 2000 with Figure 2.6 for 1990). The modal split in terms of tonnage handled remains close to the 1989 shares of 81-19 (rail-water).

4.24 Because they haul coal over long distances, waterways play an extremely important role in terms of the nation's total tkm. The tkm modal split is nearly 50-50, compared with 63-37 (rail-water) in 1989. The average distance for coastal shipping can be increased from the 1989 average of about 1,250 km to nearly 1,500 km. For comparison, the current figure of 1,250 km is less than the 1,275 km distance from Qinhuangdao to Shanghai, and half as long as the 2,660 km from Qinhuangdao to Guangzhou. In the model results, all coal shipped by water is shipped at least as far south as Shanghai, except for coal shipped to ports in the Northeast and on inland waterways. The increased distance represents the removal of over 200 billion tkm from the railway system, roughly equivalent to over seven times the coal traffic carried by the Beijing-Shanghai railway in 1989.

4.25 To achieve these gains, ports and ships require significant investment between 1990 and 2000. In addition to projects underway at Qinhuangdao and Huanghua, receiving ports in the south and east-central regions require substantial new capacity. Shanghai will need at least 25 million tons of new port capacity, while Wenzhou, Ningbo, Xiamen, and Yuxikou need at least 5 million tons each, and many other ports need up to 5 million tons each. Port bottlenecks in the medium and high demand scenarios are shown in Figures 10.8 and 10.9. Currently, some coal is transhipped at general cargo or container terminals, rather than in specialized bulk facilities that are far more efficient. The use of port facilities built for handling other commodities indicates the desperate need for more coal-handling capacity.

4.26 The shipping fleet, which has acquisition lead times of one year to five years, needs to be expanded in both number of ships and the size and types of ships. A range between 2.4 million and 3.6 million dwt of new fleet capacity will be needed by 2000. These totals do not include another 200,000 to 300,000 dwt of inland waterway barge capacity. In comparison, the current coal shipping fleet is estimated at some 300,000 dwt of barge capacity, 2.3 million tons of 9-meter general class ships, and 100,000 tons of 12-meter vessels. The future needs for vessel capacity, however, are uncertain because water transport must handle the overflow from the coal-saturated railway system. Thus, investment in new ships varies by as much as 50 percent from one scenario to the next (see Annex Table 9.5). The lowest level of shipping is forecast for the 7.5 percent GNP growth scenario (Case 93-13), in which shipping is curtailed more than proportionately. The highest levels of shipping occurs in a scenario (Case 93-12) in which growth was assumed to exceed 10 percent and the shortage cost was raised to Y 350 per ton. With users assumed to be willing to shoulder a higher delivered cost, higher-cost coal and higher-cost routings come into play; it is mainly the waterways rather than the railways that have the flexibility to expand. Yet it is also true that shipping is held in check by the inability to get coal through to the ports. Assuming that the railway to the new port at Huanghua can be completed by 2000 (Cases 93-2 and 93-10), shipping investment jumps 20 to 30-percent. Even so, the port is only 60 percent utilized, due to railway bottlenecks en route.

4.27 Because of the economics of ship size, the use of larger ships is generally desirable, but the potential for this is quite limited in China due to the geographic conditions at most ports. The advantage of larger ships is represented in this study by the per unit investment costs, which fall from Y 6,000 per dwt for 9-meter ships to Y 4,300 per dwt for 12-meter ships and to Y 3,000 per dwt for 14-meter ships. At present, however, 9-meter, 20,000 dwt ships make up the main part of the bulk shipping fleet. The largest domestically-produced ships in widespread use are 9-meter shallow draft ships rated at 35,000 dwt. An even bigger 9-meter 50,000 dwt design is under development for production after 2000, but such a ship would still be smaller than the ships used for coal transport in the rest of the world, which range from as small as 35,000 dwt as used on the US Great Lakes, to 60,000 dwt Panamax ships, to supercolliers as large a 200,000 dwt used over long distances between two very deep ports. With the exception of Ningbo, which can handle 12-meter draught ships, ports on China's southern coast are generally 9-meters deep or less. None can match the twelve to fourteen meter harbor depth at Qinhuangdao, China's main northern loading port.

4.28 The decision support system was used to analyze several port deepening projects. Several southern ports are not even nine meters deep. The model results support the Government's current plan to deepen Wenzhou and Fuzhou harbors to a depth of 9 meters, and Xiamen's harbor to a depth of 12 meters. An option was considered to invest in creating a port at Gaolan, near Shenzhen, which has some naturally 14-meter deep water. Under this proposal, it could handle ships of 100,000 dwt or larger, with a hub-and-spokes operation using 9-meter general class ships for short-distance deliveries to Guangzhou and Shantou. The analysis results, however, do not seem to favor this option, mainly because of the relatively high investment, maintenance, and environmental costs. A similar conclusion was reached regarding the option to dredge part of Shanghai's harbor to 14 meters. Further investigation of these options is required, however, to obtain a definitive conclusion, which depends on the scale of the operation, the changing composition of the fleet, transport pricing, subsequent improvements to other ports, and other commodities.

4.29 Intermodal competition in China is still biased toward railways. For many origin-destination pairs, rail and water costs are similar, but rail is priced lower. There are numerous cost add-ons for combined rail-water routes. In addition to a port's transfer charge, ports charge pollution fees, construction fees, and policy fees. On rail-water trips, the state energy-transportation fund has to be paid twice—once each for each mode—and intermediaries add to the rate charged. These add-ons effectively impose a congestion surcharge onto port fees, which should encourage longer-distance shipping (see below). When all the legs of a journey are added together, typical shipping costs (in 1990 prices) for an all-rail route from Datong to Shanghai and a rail-water route via Qinhuangdao are both around Y 20 per ton.

4.30 However, even with the pricing biases, water transport is much cheaper than rail over the longest distances. From Datong to Guangzhou, the cheapest all-rail rate is Y 36 per ton, compared with Y 26 for a rail-water trip via Qinhuangdao (in 1990 prices). With the pricing and ship sizes as they are, coastal shipping has three main niches. First, it captures the overflow from congested railways. Second, it offers the lowest costs for the long hauls. Third, some of the users who receive their coal by water do so because they have no rail spur but do have waterfront access to navigable channels.

4.31 While inland waterway traffic is only about one-sixth the tonnage of coastal flows, and averages less than 600 km, they are nevertheless an important lifeline to the Central and Eastern regions—one that can potentially be expanded rapidly. In the medium demand case with Huanghua Port finished (93-2), about 22 million tons of coal moves down (and occasionally up) the Yangtze River. The Grand Canal, running from Xuzhou to Nanjing, does not appear to be cost-competitive, or does not have access to a high quality coal supply. The major recipients of inland waterway traffic are cities and power and steel complexes along the lower reaches of the Yangtze River—but Shanghai mostly should rely on coastal shipping. The major rail-to-inland waterway transshipment ports, from upstream to downstream, are Zhicheng, Wuhan, Yuxikou, and Nanjing. All require new capacity by 2000, especially Yuxikou. Since these analyses were finished, the Government has announced the plan to build a fifth major Yangtze River port between Wuhan and Zhicheng, where the Beijing-Guangzhou railway will cross the river. Because the railway bridge will be a bottleneck, a new port of 5 million ton capacity per year will be constructed to handle some of the coal flows destined for the south central region.

4.32 Further decentralization of port and shipping operations may hasten the ability of waterways to respond to China's energy transport problems. Currently, most coastal shipping operations are centrally-owned, though a fair number of local shipping companies ply the inland waterways, and some power plant companies, including the huge Huaneng Group, are beginning to operate their own ships. Most ports are owned by the municipal governments, but the central Government (the MOC) approves their long-run plans. Qinhuangdao is the only port wholly owned by the central Government, while Xiamen and Tianjin are wholly decentralized. Greater decentralization of the shipping sector is recommended. Decentralization could not only help relieve railway congestion by investing in fleet and port capacity, but it could also spur faster adoption of appropriate vessel sizes and technologies, develop superior information systems for keeping track of coal movements and coal qualities, provide better and faster service, and offer some additional inter-modal competition to the state- and local-owned shipping companies and the MOR.

Imports

4.33 Coal importation is an important strategy, but it was not permitted until recently. While imports are economically feasible, they may not be logistically or financially feasible. Currently, provinces are free to import as much coal as desired, as long as they have the foreign exchange to pay for it. At the moment, coal is being imported to reduce shortages and satisfy special coal type requirements, but as the reforms become entrenched, importing will be determined by an economic comparison with domestic coal. Railway system congestion will likely prevent most interior cities from receiving imports. Especially well-situated are power plants and other big coal users with ship berths along the coast that can receive coal from self-unloading foreign vessels. In addition, it is mainly the coastal provinces that have the foreign exchange reserves necessary for imports. Because of railway bottlenecks, it is difficult for coal imports to penetrate the interior of China. Imports could perhaps be extended up the inland waterway system using oceangoing barges.

Slurry Pipelines

4.34 Slurry pipelines have been discussed for many years, and appear to be cost effective in scenarios with high demand. One pipeline, from Shanxi to Shandong with a capacity of 15 million tons per year, has been given the go-ahead as of January 1994. Slurry pipelines face several barriers. First, planning officials, especially at the provincial level, generally prefer the flexibility of a multicommodity railroad to a coal-only pipeline. This is different from the United States, where railway rights-of-way are the main barrier to pipeline construction. Second, technologically, electricity authorities are concerned about dewatering and reliability. A test line from Changzhi to Jiaozuo may help to alleviate fears, work out technical problems, and determine costs. Water availability in the energy base region may limit slurry's niche to particular bottleneck areas outside the energy base.

Nontransport Sector Policy Implications

Coal Production

4.35 The study's analysis confirms the current trend of shifting coal production to the North and West as much as possible, from around 43 percent in 1989 to an estimated 52 percent in 2000. Only the lack of railway capacity is keeping it from being even higher. To achieve a 52 percent share by 2000, the energy base area captures over 61 percent of new coal mine capacity to be built during the 1990s. Given that coal mine investment costs are about 13 to 18 percent less in the energy base than in the coastal areas, the westward shift of production represents a savings of up to Y 4–6 billion in coal mine investment costs through 2000 relative to the alternative of maintaining the existing shares of coal production across regions, which could result from the lack of railway capacity to transport coal out of the energy base.

4.36 The shift of coal production to the energy base puts more pressure on the railway system. To move the additional 400 million tons of coal needed by 2000, the average distance of railway movements is estimated to increase from around 520 km in 1989 to 640-670 km in 2000 (Annex Table 9.5). However, the coastal-industrial provinces must stabilize or slightly increase their absolute levels of coal production to bridge the gap until the time when North and Northwest China can be relied on even more heavily. Coal in the coastal regions is too expensive to contribute much additional coal if GNP growth exceeds 10.5 percent, and in fact should be cut back substantially if GNP growth is 7.5 percent. The coastal share of national coal production should drop from around 27 percent in 1989 to around 22 percent in 2000, if the energy base railway capacity is adequate.

Steam Coal Washing

4.37 *Analysis and Recommendations.* One of the most robust conclusions of the study is that steam coal washing should be greatly increased from less than 7 percent in 1990 to roughly 16 to 19 percent in 2000 (Annex Table 9.2). Network analysis makes a compelling case for the quadruple benefits of coal washing: (a) reducing transport costs for long-distance flows; (b) lessening local bottleneck effects; (c) reducing ash disposal and boiler maintenance costs; and (d) achieving environmental goals. Steam coal washing is justified economically even without valuing the environmental benefits for a minimum of 16 percent of all steam coal. For at least 200 million tons of steam coal, the environmental benefits of washing are essentially free; it is a win-win situation. This conclusion holds true in all scenarios, no matter whether demand is high or low, or whether transport capacity or costs are increased or decreased.

4.38 Somewhere between 16 and 19 percent, a threshold is crossed, and the additional coal washing is no longer justified purely on a cost reduction basis; it becomes a win-pay situation—unless environmental externalities are included in the cost equation. To reduce ash and sulfur content of coal 10 to 30 percent further, washing as much as 36 percent of steam coal could be justified (see Annex Table 9.2 and Annex Table 12.2).

4.39 The break-even distance for washing steam coal depends mainly on the unit transport cost and the ash content of the coal. Imposing congestion surcharges on railway rates would have the effect of decreasing the break-even distance even further. In some regions, however, a small amount of steam coal washing can be justified mainly by its effect on reducing bottlenecks, not by line-haul cost savings over long distances. This can be seen in the provinces of Liaoning, Hebei, and Anhui, all of which ship washed steam coal over distances much shorter than 1,000 km (see Annex Figure 10.13).

4.40 Overall, it is estimated that the new steam coal washing investment saves around Y 17.5 billion (in 1990 prices, discounted at 12 percent), as compared with the alternative measures that China would have to pursue if no new steam coal washing plants were allowed (see Annex 18).

4.41 *Key Assumptions.* All scenarios assume an operating cost of Y 2 per ton and an initial investment cost of Y 30 per ton for steam coal, in 1990 currency (and, for coking coal, Y 4 per ton and Y 50 per ton, respectively). As a test of the model's sensitivity to these costs, washing investment costs were raised 15 percent (in Case 93-5), with the result that the steam coal washing rate fell by only one-tenth of 1 percent. In addition to transport and environmental benefits, users of washed steam coal also benefit from increased combustion efficiency due to reduced ash disposal and boiler maintenance. Another Bank report conservatively estimated the savings at about Y 2.50 per ton.[2] These benefits have been represented in the model by reducing the carbon loss rate and increasing the heat content of washed coal. Steam coal washing is conservatively assumed to produce only one marketable product: crushed washed steam coal. The rest is considered to be waste. Coking coal washing is assumed to produce a marketable low kcal middlings byproduct that can be burned only in minemouth power plants in addition to clean coking coal and waste.

4.42 *Current Status and Pricing.* The recommendation that steam coal washing be increased to 16 to 19 percent is a major departure from the current level of

0 to 7 percent. Coal washing has been stalled for many years, and virtually no plants in China have been designed and built expressly for washing steam coal. Special cases appear to account for most of the approximately 60 million tons washed, which explains why estimates of current washing rates range from 0 to 7 percent. For instance, excess coking coal washing capacity in Anhui is now used to wash low quality coking coal for power plants. In Chongqing, some anthracite is washed for use as steam coal in power plants that are required by municipal law to limit their average sulfur content to 2.5 percent. In the Northeast, some high ash bituminous steam coal is washed because the power plant boilers do not accept coal with greater than 30 percent ash. Also, about 15 million tons of steam coal produced for export in a China-United States joint venture is washed. SPC experts have indicated that domestic sources of funds could reasonably be expected to raise the percentage of coal washing to 16 percent by 2000.

4.43 Under central planning, producers were allowed to charge at least a 10 percent differential for washed steam coal, and upwards of 20 percent for washed coking coal. While the price of in-plan raw coal was generally below long-run marginal costs, the washing price differentials were enough to cover the incremental washing costs, debt service, and a small profit. The problem was not too low a price, but not enough incentives to convince coal consumers to pay the higher price on a free market basis. Proper pricing of washed coal also requires setting suitably low prices for the byproducts of washeries—middlings, coal fines, and sludge—which are problematic for users due to the difficulty of handling, high ash or water content, low kcal content, or all three. Potential buyers include regular or advanced power plants, briquette makers, or the building materials industry. It will undoubtedly take some time for the Chinese coal market to properly price the products, let alone the byproducts, of coal washing, given that the market does not differentiate well between grades of raw coal. The idea of discriminating between a variety of coal choices will require a change in the mindset of coal users accustomed to a take it or leave it system of coal allocation. With the economy overheating, users often must take what they can get. It is estimated that tens of millions of tons of coal wastes, gangue, or poor quality coal were mixed into the washed coal at mines, ports, or railway stations, and customers had no choice but to pay the higher price for the lower quality coal.

4.44 *New Guidelines.* A recent nonmandatory proposal formulated by CIECC calls for all new large (greater than 2.4 million tons per year) Government-owned coal mines to be asked to build washing plants. This new policy is targeted at the large-scale mines because they can benefit the most; because their automated machinery generally creates a very high percentage of gangue; because large state mines have access to the long-distance railway capacity; and because locally-owned mines could never afford the capital equipment. The new policy urging coal washing is somewhat of a blunt policy instrument, because it is not dependent on distance and coal quality. However, coupled with coal, rail, and electricity price reform, it is believed to be an attempt to jump-start the industry and to break the cycle whereby producers claim there is not enough demand for washed coal while consumers complain of the lack of a reliable supply. In the medium term, this new policy may have the effect of creating an oversupply. In the long run, it would be more efficient to provide an economic framework which will send a strong stimulus to consumers to demand washed coal.

4.45 *Implementation Issues.* While the benefits of steam coal washing may be obvious, proper incentives for change are missing. Incentives must make the benefits of washing transparent to and shared by all actors in the supply-transport-consumption chain. Also, once they mutually agree to produce and consume washed coal, standard, well-recognized procedures for preparing and enforcing long-term contracts between these different actors is critical to eliminate any transaction risk. The incentives and disincentives for internalizing each of the four categories of benefits (environmental, transport cost, transport capacity, and boiler operation) are addressed below, in turn.

4.46 In most countries, steam coal is washed as an inexpensive way to meet environmental regulations on sulfur and ash pollution. The environmental benefit is greatest for small boilers and stoves, which often may have poor, if any, emissions control equipment. Adopting a "polluter pays" policy—whether based on pollution taxes or tradeable permits (see Environment, paragraph 4.63)—would be the single strongest incentive to producers to wash steam coal willingly. The need to enforce whatever regulatory mechanism is adopted is a key for China, where many environmental rules, including some pollution taxes, are already on the books. For instance, it has been reported that some power plants in Chongqing refuse to buy the aforementioned washed anthracite coal because the 2.5 percent sulfur regulation is not enforced.

4.47 Of the two transport benefits of washing steam coal, only line-haul cost reduction exerts a transparent incentive to wash coal, and this would be strengthened by congestion pricing of rail bottlenecks. The transport capacity-saving benefits are not seen or felt by the coal producers or consumers. In buying higher-priced washed coal, users inadvertently free up extra railway capacity, which will benefit other railway customers, but not themselves. As things now stand, with administrative allocation of railway capacity, factory managers may think to themselves, "Why wash coal when the MOR has allocated enough capacity to us to transport all the raw coal we need?" If coal users had to sign a long-term contract with the railways that included a separate, itemized railway capacity fee, there could be a stronger incentive to wash coal.

4.48 Most existing boilers in China were designed for raw coal with lower calorific value than washed coal. Therefore, existing factories and power plants may not fully achieve the increased combustion efficiency benefits and may not be willing to pay very much more for washed coal. New boilers, which can be designed to take better advantage of a higher kcal coal feed, may represent a better marketing opportunity for coal washeries. Use of new boiler technologies will promote greater use of washed coal.

4.49 In summary, the potential benefits from increased washing of steam coal are great. Enactment and enforcement of some kind of polluter-pays laws will provide the strongest incentive for users to care about what kind of coal they burn. This in turn will drive the supply and distribution sectors. Freeing coal and electricity prices to seek their own levels, and pricing railway services to include congestion surcharges, will help to make the benefits of coal washing more transparent. Establishing a legal framework for long-term contracting will lower the risk entailed by buyers and sellers who commit capital to producing or burning washed coal. If all these things are put in place, the new Government policy urging coal washing for large mines may help to jumpstart the process.

Hydropower and Nuclear Power

4.50 The study's analysis of the hydropower sector (Annex Table 9.3) is consistent with the high end of the range in the FYPs, which call for 63-69 GW of total capacity to be built by 2000. In the event of 10 percent or higher GNP growth, or strong efforts to reduce pollution, hydropower construction should top 70 GW. However, hydropower's share of capacity, currently 24.4 percent, might drop slightly to around 22 percent with 9 percent GNP growth, or even to 21 percent, given double-digit growth. The time lag in constructing a hydropower plant is a discouraging factor, as is the lack of inexpensive hydropower.

4.51 Nuclear power does not appear to be cost-effective in the study's analysis, based on 1990 investment cost estimates (Y 6,000 per kw for domestic construction, Y 10,000 per kw for imported technology). Bringing down the investment costs for a new generation of nuclear plants might help improve this situation. This alternative could be analyzed with the CTS model, if future cost estimates were available.

4.52 The conclusions about hydropower above ignore the other benefits of dams, such as flood control and irrigation. Similarly, the conclusions about both hydropower and nuclear power ignore the issue of carbon dioxide reductions, which might have put them both in a more favorable light. Whereas coal washing or switching to higher quality coals can reduce ash and sulfur but no carbon dioxide, hydropower and nuclear power completely eliminate all three.

Minemouth Power and Electricity Transmission

4.53 *Analysis and Recommendations.* The analysis endorses an increase in minemouth power generation with transmission to areas suffering from transport bottlenecks. North China's share of generated electricity could be economically increased from 17.8 percent in 1989 to roughly 20 percent in 2000. There are five reasons for the recent strong interest in power transmission. First and foremost, bottlenecks on the railway system make it impossible for railways to satisfy the demand. Second, the lead time for building new transmission lines is much shorter than for railways. Even though short-distance railways are presumably competitive with transmission, the issue of lead time has become of paramount importance to urban officials. Third, transmission can be cheaper than railways in mountainous regions, where towers and wire are much easier to build than railways. Fourth, the environmental impact of coal combustion can be shifted away from the highly populated urban areas. Fifth, the local governments administering the coal base have taken the initiative, realizing that the more power plants they build, the more profit they can make.

4.54 The first set of major intergrid flows are from Shanxi Province to points east, southeast, and south. In particular, these include four main directions: (a) from the north of Shanxi to the Beijing-Tianjin-Tangshan grid; (b) from the middle of Shanxi to Shandong province via the middle of Hebei province; (c) from southeast Shanxi to Jiangsu province and Shanghai; and (d) from southern Shanxi to the Huazhong grid (Hubei, Henan, and Jiangxi provinces. Other major flows include (e) from the eastern part of Nei Monggoi (Tongliao, Yuanbaoshan, and Yimin River) to the Northeast provinces; (f) from the hydropower plants in Guizhou and Guangxi provinces to Guangdong province; and (g) from thermal plants in Shaanxi to Huazhong and northern Sichuan province (see Annex Figures 10.14 and 10.15). What is particularly noticeable in Annex Table 9.4 is that the electricity flows from Shanxi and from hydropower plants in Guizhou and Guangxi are fairly stable across all scenarios, while the flows from Nei Mongol and to the Huadong and Central regions are sensitive to demand forecast. This result suggests that transmission from Shanxi and Guizhou-Guangxi will be a good investment under most circumstances. On the other hand, Nei Mongol seems to be the marginal supplier, responding positively to increased electricity demand, and negatively to increased electricity shortage costs and increased available railway capacity.

4.55 Overall, it is estimated that the seven recommended new 500-kV intergrid transmission lines could save China around Y 7 billion in discounted costs (in 1990 prices), as compared with not building such transmission lines, as a result of which urban power authorities would have to turn to other alternatives (see Annex 18). Each 500-kV line substitutes for about 10 million tons per year of railway traffic. Construction of these lines, which provide an alternative way to move energy long-distances from the energy base, may partly account for the underutilization of port capacity at Huanghua and Liangyungang in the model results, as compared to the port forecasts.

4.56 *Current Status.* Numerous actual proposals are under consideration for substantially increasing long-distance transmission. In South China, hydropower projects are being considered in Yunnan, Guangxi, and Guizhou in the 2,000 to 4,000 MW range, which would provide 50 percent or more of their output to Guangdong, up to 1,500 km away. In North China, at least 5,000 MW of minemouth thermal power is being planned for transmission to the Beijing-Tianjin area alone. Some of the planned transmission lines would run from (a) Western Mongolia to Beijing; (b) Eastern Mongolia to Northeast China; (c) Datong to Tianjin; (d) Changzhi to Jiangsu; (e) from mid-Shanxi to Shandong; (f) Shaanxi to Sichuan; and (g) Guangxi, Guizhou, and Yunnan to Guangzhou. The CTS analysis may have been a contributing factor in supports of these plans, in that at least some capacity is built on all of these planned lines by the year 2000 in the 9 percent GNP base case. The analysis also recommends (h) Datong to Beijing; (i) Taiyuan to Shijiazhuang and Jinan; (j) Changzhi to Zhangzhou, Wuhan, Guangzhou, and Huaiyin in Jiangsu; and (k) Yimin River to Harbin and Shenyang (for lignite-generated power).

4.57 *Implementation Issues.* In past decades, many structural (interprovincial or intersectoral) and technological barriers have delayed and discouraged long-distance power transmission and favored load center generation fed by railway transport of coal. First, one of the risks in developing transmission projects is that there will not be any spare electricity to transmit as expected. This has happened before with a long-distance line from Wuhan to Shanghai, and has scared many load center officials away from taking such a risk. Interestingly, this phenomenon can be detected in the model results. Transmission to the Central and Huadong regions is surprisingly *less* in the high demand scenarios than in medium demand scenarios. This counterintuitive result can be explained by the fact that faster growth would cause more electricity to be intercepted by cities in the north, leaving less available for intergrid transfers. If the shortage in the origin region still exists when the plant and line are finished, an incentive will exist to sell 100 percent of the power to the local area rather than suffer the line losses and sell only 90-some percent of the power in the destination region. This risk is real, but can be handled with long-term legal contracts. Enforceable agreements and an adequate legal framework will be necessary for load center provinces to have enough trust to enter into such arrangements. However, this risk is minimal for thermal power plants in the energy base, where electricity shortages are not expected.

4.58 A second implementation issue is ownership. As described in Chapter 3, the new model for infrastructure funding in China, especially for power plants, is the pie chart. Local, provincial, and central Governments, banks, and foreign partners each contribute a certain percentage of the funding, with rights to a certain portion of the electrical load. However, this method of project financing is problematic when it comes to transmission lines, which must function as part of an integrated electrical grid with complex functions dealing with load sharing and power outages. China's five big regional grids and nine provincial grids are directly or indirectly under the control of the MOEP. The problems posed by tying new lines owned by pairs of provinces into the centrally-controlled grids prompted the Government in early 1994 to decide that all transmission lines, with a few exceptions, are to be owned and controlled by the central Government. Details regarding how coastal provinces will go about co-financing such lines remain unclear at this time.

4.59 Third, several incentives have for many years encouraged provincial and electricity ministry authorities to build plants in the load center provinces. Provincial officials favor local power plants that create employment, taxes, and technology spillovers to the local area. (The penchant for self-sufficiency in electricity production is evident in Map IBRD 26596). Electricity sector officials have historically preferred load center power plants because the investment for transportation is paid by the

MOR, whereas with a minemouth plant, the electricity sector must absorb the investment cost for transportation. Finally, railways are more attractive to provincial officials than transmission lines (or slurry pipelines, for that matter) because they can haul other goods as well.

4.60 Fourth, there have been technological barriers as well. The DC line technology needed for distances over 1,000 km is new to China. However, one 500-kV DC line is already in operation from a Yangtze River hydropower station in Hubei to Shanghai. While it has encountered some technical problems, others are still being planned. The study's analysis includes a 1,400 km 500-kV line from Changzhi to Guangdong, which is at the upper end of the feasible length. Another technical difficulty lies in the fact that, while most of the regional grids use the same frequency and voltage, electricity shortages have destabilized the frequencies, making it difficult to phase them together. In the short term, one option is to connect the load center grids with single minemouth or hydropower plants in the supply region, rather than connecting the entire supply region grid to the entire load center grid. The single plant in the supply region would function as a remote part of the demand region's grid. However, as the shortages disappear, the stability of the grids will improve, and the long-distance lines now being planned as will eventually become key links in a national grid.

Energy Conservation

4.61 This study did not explicitly and independently consider energy conservation investments (see "China Energy Conservation Study," World Bank Report No. CHA-10813), but instead interpreted the shortage cost in terms of the comprehensive cost of energy conservation in a post hoc analysis. The study estimates that energy conservation could play a major role in satisfying coal and electricity demands in 2000, given double-digit GNP growth. In fact, a rough estimate of the potential for energy conservation is in the neighborhood of 100 million tons. This estimate is based on the amount of demand that cannot be satisfied at a delivered cost of Y 300 per ton. It is argued here that if the shortage cost in the model (Y 300 per ton) is greater than the amortized conservation investment cost, the shortages can be interpreted as energy conservation potential. Assuming a discount rate of 12 percent and a 10-year lifetime for conservation investments, an annual amortized cost of Y 300 per ton is the equivalent of a financial investment cost of Y 1,700. Since the shortages represent coal that cannot be delivered for under Y 300 per ton, investing in energy conservation at a cost of Y 1,700 per ton is justified. In comparison, SPC experts report that a wide range of conservation investments exist for as low as Y 700 per ton. Of course, once those Y 700 per ton conservation investment opportunities are exhausted, the marginal cost would rise, and there is no guarantee that all 100 million tons' worth of energy could be saved by investments of less than Y 1,700 per ton.

4.62 Analysis with an expanded CTS model seems to confirm the above conclusions (see "Studying the Policy of Improving Energy Use Efficiency to Relieve Energy Shortages," Robert S. McNamara Fellowship Program, September 1994). This research should be considered preliminary because it was an individual effort rather than an official Government-supported team effort. Real data on the costs, efficiency, and energy-saving potential of investments in improved coal and electricity devices were collected and added to the energy supply and delivery options in the official CTS model. The preliminary analysis concludes that a combination of investments in energy production and energy conservation can satisfy energy requirements more economically, with fewer shortages and less pollution, than a system based on energy production investments only. Improving energy efficiency (beyond what is assumed in the demand forecast) will lower systemwide costs by 5 to 10 percent compared with the CTS results without conservation variables. However, energy conservation would require more upfront capital investments. Half of the required investment could come from shifting investments from the production sectors, but the other half would have to come from some other source besides coal and electricity supply funds.

Environment

4.63 As China's coal production continues to break its own record year after year, environmental conditions will worsen. Unconstrained by Government policy, the national total of sulfur in the coal (potentially emitted) can be expected to increase from around 14 million tons per year, the 1990 total, to nearly 20 million tons by 2000 (see Annex Figure 10.16). Particulate pollution, a result of the ash content of coal, poses a more severe health problem than acid rain. The total national ash content will increase from approximately 250 million tons in 1990 to about 300 million tons in 2000 (see Annex Figure 10.17).

4.64 To avoid this kind of catastrophic situation, the Chinese Government should consider incentive-based regulatory mechanisms that make enterprises or individuals pay for the environmental damage they cause. Pollution taxes or tradeable emissions permits are preferable to more blunt mechanisms such as emissions standards or mandated use of the "best available technology." The incentive-based measures will generally achieve the same goals at a lower cost by internalizing the costs and enabling those energy users who can reduce pollution more efficiently to do so, thus lessening the negative impact on the entire economy. Taxes and permits also raise revenues for the Government in a less distortionary way than most taxes. Compared with pollution standards, taxes or permits have the advantage of discouraging firms to get rid of all their pollution, not just the pollution above a certain level. Taxes, permits, and standards all require effective monitoring of emissions. One way around this is to charge presumptive taxes, placing the burden on the enterprise to prove that they are polluting less than presumed. Another, much simpler method, is to charge taxes on polluting inputs, but this method does not send as clear a signal to firms and is therefore less efficient. In addition, with tradeable permits, a second information system is needed to keep track of who owns them.

4.65 Evidence from the United States suggests that such programs can succeed in cutting the costs of cleaner air.[3] The 1990 Clean Air Act established a Government auction of tradeable allowances that give the holder the right to emit a ton of SO_2 per year. When the bill was being debated, the industry warned that the cost could be as high as US$1,500 per ton. The government estimated the cost more conservatively at US$600 per ton. But when the auction was held, the market set a much lower price of US$150. The cleanup is expected to total 22 million tons in 2000—considerably more than the 16 million tons required under law. Compared with the government's estimate, the annual savings are almost $10 billion.

4.66 Much information is needed to go ahead with any of these proposals. To impose a pollution tax, the social cost of a unit of pollution must be estimated. For tradeable permits or standards, the amount of permits must be decided on. For any of them, it is useful to have some data on what level of pollution control is economically feasible. The results of this study can provide partial answers to some of these information needs.

4.67 Finding optimal environmental strategies was not the driving force behind this study. But since it is a *coal* transport study, it is important to show quantitatively, in some fashion, the fact that some investment strategies, such as coal washing and hydropower, have more environmental benefits than others. Estimating the social costs of pollution was clearly beyond the scope of this study. Instead, this study adopted the simple, concrete measurement of the level of ash and sulfur content in the delivered coal. The methodology for analyzing the environment is explained further in Annex 5.

4.68 The model was used to estimate how much it would cost to reduce by 10, 20, and 30 percent the ash and sulfur content of the delivered coal to each province. The results suggest that it is economically feasible to impose some kind of polluter-pays principle in China. Annex Figure 10.18 shows the accelerating tradeoff curve between the conflicting goals of cost and ash-sulfur control, and demonstrates that the conflict is not as great as is generally believed, at least for small improvements. The first 10 percent of ash and sulfur reductions can be achieved with a relatively small cost increase of about 3 percent. The cheapest strategy for doing so by 2000 involves building an extra 1-2 GW of new hydropower capacity above and beyond the base case scenario, increasing scrubbers from none to almost 1 million ton of capacity, and increasing steam coal washing from 200 million to 350 million tons, the latter spread liberally over many provinces (see Annex Table 9.6 and Annex Figure 10.13). Ash and sulfur reductions beyond that point are increasingly expensive to achieve, mainly because it necessitates increased use of scrubbers, hydropower, coal washing, and nuclear power, and because it might cause increased shortages. The second 10 percent of reductions will drive costs up by another 7 to 8 percent, while the third 10 percent reduction adds almost 10 percent. For reference purposes, in order to keep China's total ash and sulfur at 1990 levels despite the growth of total coal production would require about 25 percent less ash and sulfur than in the cost-minimizing solution. (For coal washing alone to keep pollution levels constant, about 35 percent of coal would have to be washed.)

4.69 This analysis has its advantages. First, by applying the ash and sulfur constraints at the provincial level, the model realistically represents the way that pollution taxes or tradeable permits allow some users to pollute a lot while others who can afford to do so make deep cuts. The results show the tradeoffs between noncommensurate economic and environmental goals and allows the policymakers to apply their own valuations, rather than forcing them to accept a given estimate of the externalities.

4.70 However, the model overestimates the cost of meeting the environmental goals, since the model lacks several potentially inexpensive ways of reducing ash or sulfur emissions. Other than including scrubbers, the model only analyzes measures that reduce the ash and sulfur going into the boilers and stoves. The unmodeled alternatives include energy conservation, fabric filters, electrostatic precipitators, coal briquettes, fluidized bed combustion, coal gasification, taller stacks, and coal screening. The tradeoff curve thus represents an upper bound on the true costs. A more refined analysis is needed to see how much less expensive it might be to reduce ash and sulfur emissions at the end of the smokestack.

4.71 In particular, the most important missing alternative is energy conservation, which can reduce energy demand (and therefore, in a sense, satisfy it) with no pollution and no railway transport, and, which is likely to cost less on an amortized basis than the shortage cost (Y 300 per ton, in 1990 prices). Given that the model willingly pays the Y 300 shortage cost for over 128 million tons in the 20 percent ash and sulfur reduction scenario (Case 93-4), there appears to be a large scope for energy conservation investment under a tradeable permit system, or equivalent taxation system, that forces at least a 20 percent reduction.

4.72 From another perspective, a value of this tradeoff analysis is to demonstrate to World Bank and SPC policy makers that if investment strategies that are not necessarily the absolute cheapest are researched, alternatives that are only slightly more expensive but have major positive impacts on the environment may be found. Hydropower, steam coal washing, and energy conservation, in the right time, place, and amount, can accomplish environmental and energy supply goals simultaneously. Also important is that there is a significant overlap in the strategies used for meeting high demands and those for meeting environmental goals.

5. Regional Analysis

Northeast China

5.1 The Northeast region of China suffered severe coal shortages in 1988-89, and the shortages returned in 1992-93. Severe coal shortages for this area can be expected in conditions of rapid growth, environmental controls, or restricted transport capacity, or some combination of the three. Northeast China has substantial coal mining capacity of its own, but not enough to satisfy all its needs. It has significant reserves of coking coal, but the current energy supply policy is that the Northeast should not use its coking coal for power generation. Therefore, the Northeast must supplement its own supply potential by drawing coal from "inside the gate," that is, from south of the Great Wall. Three main routes "through the gate" will all be saturated by 2000: the Qinhuangdao-Shenyang line; the Jining-Tongliao line; or by ship from Qinhuangdao to the ports at Dalian, Yingkou, and Dandong. Furthermore, the strategy of increasing railway capacity on these three routes cannot by itself solve the problem of shortages in the Northeast because bottlenecks from the energy base area will prevent coal from reaching the Qinhuangdao and Jining. Nor can coal imports solve the problem, since they are feasible only for the coastal port of Dalian—not for most interior cities—because of congestion within the Northeast itself.

5.2 Expansion of the Hailar-Harbin railway and use of heavy haul technology through the gate are foremost among the recommendations. In addition, several non-railway strategies are recommended. First, the model suggests that a fair amount of the steam coal from Shanxi Province to the Northeast be washed prior to shipment, thus maximizing the energy inflow on the three capacitated routes. Second, coal production in the Northeast may have to be increased in absolute amount, despite the high cost of developing the remaining reserves in this region. Third, Hailar and Tongliao have abundant and cheap reserves of brown coal, which should be developed and burned in new minemouth power plants. The resulting power should be transmitted to Harbin, Shenyang, and Changchun by new transmission lines. However, these measures will likely not be enough if the economy grows faster than 10 percent per year. Nearly 30 percent of the country's shortages may occur in the Northeast, with electricity shortages of around 10 percent of demand. Energy conservation should be pursued vigorously in this region.

Central China

5.3 Conditions are ripe for shortages of coal and electricity in the Central region, especially in the "Double Hu" region of Hunan and Hubei Provinces, home to cities like Wuhan, Changsha, and Nanchang. Prior to the completion of the Three Gorges project, local sources of coal will fall short of demand, and the transport network will continue to be congested. However, because this region is centrally located, it has many energy supply options from other regions, and with the exception of the Wuhan area, shortages in most scenarios are not severe.

5.4 A combination of strategies is needed to keep shortages to a minimum. First, a new railway from Shenmu in the coal base to Xiangfan, near Wuhan, would help accommodate growth after 2000. Second, coal production in Henan Province, officially part of the Central region, should be increased. Production near Zhengzhou, Yima, Pingdingshan, and Xinxiang should be stepped up. Third, Henan, Shaanxi, and southern Shanxi provinces have the opportunity to transmit a great deal of mine-mouth electricity to Hubei and Hunan. Fourth, if Sichuan hydropower plants are built up quickly. Sichuan can supply electricity to the Central region in the interim before the Three Gorges is finished. Once completed, the Three Gorges can transmit a great deal of electricity to Sichuan province.

Eastern China

5.5 Although the Yangtze delta area suffered severe coal shortages in 1987-88, it is anticipated to be in less danger of coal shortages than Northeast China. More than half its coal supply comes from self-supply, and the vast majority of the remainder comes from the energy base region by water transport, an option that was much less available during 1987-88 before the completion of Qinhuangdao port and the DaQing rail line serving it. Landlocked eastern cities, such as Jinan and Hefei, are in greatest danger. In recognition of this, construction of the Handan-Jinan railway, which is in MOR's long-term plan, should be speeded up.

5.6 This region, however, is quite susceptible to electricity shortages. Electricity transmission from Changzhi to Shanghai can play a major role, as can other lines from the energy base to the interior cities of Jinan and Xuzhou. In part because of the transmission options included in the analysis, no new nuclear power capacity needs to be built in Shanghai, even in the high-demand and high shortage cost scenarios.

5.7 This area seems particularly vulnerable to shortages under stricter environmental regulations because of its poor coal quality. Coal imports will be able to help the coastal cities in this region, and the three slurry pipelines on the drawing boards, one of which has been approved, are targeted here. In addition, some oil-burning power plants are being built along the coast to take advantage of currently cheap imported oil, and two gas-fired plants (in Jiangsu and Guangdong) are being planned. Gas has the advantages of little to no SO_2 or TSP pollution, short construction time, and lower investment cost than nuclear. However, domestic gas reserves are minimal and aimed mainly at household use, and LNG imports by water are exceedingly hazardous. Currently, oil and gas make up less than 2 percent of thermal power plant capacity.

Southeastern Coastal China

5.8 The southeastern coastal area shares some of the logistical problems faced by East China, but its industrial development is more concentrated along the coast. Because of the long distance from the energy base and the intervening needs of the central region, East China receives only a small part of its coal by rail. Instead, it relies mainly on water shipments and locally-produced coal. A new proposal for delivering coal to this region (not reflected in the study's analysis) is to ship coal from Guizhou province by rail to Nanning, and then by inland waterway to Guangzhou by river. Some of the coal headed to Guangzhou, Xiamen, Fuzhou, and Haikou should be washed prior to shipment.

5.9 For Guangzhou, the major new dam and hydropower plant at Longtan, and electricity transmission from Changzhi to Guangzhou (technically feasible by 500 kV DC line), can significantly improve the electricity balance of the southeastern area. No new nuclear power capacity would be built in Guangzhou other than what is already under construction.

Southwest Energy Base

5.10 The Southwest energy base, particularly Sichuan and Guizhou Provinces, is mostly used for self-supply in the Southwest region. The region is somewhat isolated from the rest of China in terms of transport and energy. Hardly any coal is exported to other regions in most scenarios, as demand in Chengdu, Chongqing, Kunming, and Guiyang soaks up nearly all the locally-produced coal. Sichuan should export some hydropower to the Central region, and Guiyang should import some coal from Guangxi. Isolation contributes to the region's being structurally prone to substantial future coal shortages. While some regions, like East China, have large shortages in some scenarios, but none in others, the Southwest area can expect shortages approaching 10 percent of demand in all high-demand or environmental control cases, as well as in some others. Despite the fact that, in most scenarios, this region generates about 20 GW—more than 60 percent of its electricity—from hydro, it simply lacks much flexibility to adapt once the reasonably affordable hydropower projects are gone.

5.11 To handle growth of 10 percent or more, the Southwest will have to rely mainly on energy conservation and on hydropower plants in Sichuan, such as the Three Gorges. Further proof of its self-reliance is that it is not expected to have any surplus electricity to transmit to other regions in 2000 (pre-Three Gorges), even under 9 percent GNP growth conditions. Some lignite reserves near the Sichuan-Yunnan border could be exploited, but at a high cost to the environment. A proposed oil pipeline from Xinjiang to Sichuan is also under consideration. Otherwise, they will probably have to rely on expensive hydropower options.

Northwest China

5.12 The northwest provinces of Xinjiang, Qinghai, Gansu, and Ningxia are blessed with abundant coal and hydro resources. In the present and future, this region can continue to be mostly self-sufficient in coal, and can ship some of its surplus to nearby regions, although long distances and intervening opportunities (Shanxi) limit the scope for exports. Some coal can be supplied to northern Sichuan Province and the middle region of China. Likewise, some thermal power can be transmitted to the Huazhong grid in central China, and some hydropower from the upper Yellow River can be shipped to the Huabei (north central) grid.

6. Past and Future Policy Implications

Policy Recommendations and Impacts of this Study

6.1 The analysis system and some preliminary results were introduced to SPC leaders, planners, and researchers in a major conference in December 1991, which was covered by Chinese television (see Annex 19). Following this conference, SPC experts worked closely with the modeling team to improve the realism of the results, thus building confidence in the tool within the planning community and among Chinese policy makers.

6.2 Then, after Deng Xiaoping's much publicized tour of Guangdong in 1992 and the subsequent decision to accelerate economic growth, three of the SPC's planning bureaus (Energy, Transportation, and Long-Term Planning) asked the CTS team to analyze whether and how China could supply the additional energy. Within a week, the analysis system was able to answer the SPC's questions related to the logistical problems and the potential for shortages related to faster growth. On the basis of these results and other evidence, the National People's Congress adopted a relatively high but sustainable growth rate of 8 to 9 percent.

6.3 Following this, the CTS has been used to identify new investment options for surpassing 8 to 9 percent growth rates. After studying the logistics, CTS team members and Chinese experts made suggestions for new energy and transport project ideas. These were input into the analysis system, which then showed how the new projects could nearly satisfy the energy demands of 9 percent GNP growth. These results were presented at a joint Chinese-World Bank conference in Beijing in October 1993, and were received by senior Government officials as helpful and realistic (see Annex 20). Overall, the amount of new investment required is about Y 650 billion or US$140 billion (both in 1990 prices) for the 8FYP and 9FYP, and around US$100 billion more for the 10FYP. These figures include coal production, coal transport (not including other commodities' share of transport investment), and electricity (not including local distribution).

6.4 Some of the recommendations of the study are consistent with national policy and trends over the last 5 to 10 years, and some are consistent with (and may have influenced) some recent dramatic policy shifts, while others go beyond even the recent moves. There is a lot of gray area in trying to sort the recommendations into these three categories, but it is useful nonetheless for the purposes of highlighting where China has come from, where it is now, and where it should be going. Among the policy recommendations in this first category, that is, those that confirm the trends and policy directions of the last 5 to 10 years, are the following:

(a) the shift of coal mining to the northern energy base;

(b) increased use of long-distance water transport, construction of mine-to-port railways, such as the DaQing line, and domestic production of larger ships;

(c) continued development of hydropower, including in remote areas;

(d) increased efforts at energy conservation; and

(e) no heavy investment in the short term in more than a few commercial nuclear power plants.

6.5 The second category of study recommendations have confirmed several major recent trends and policy changes, which were announced concurrently to the last stages of this study, that is, in 1992-93. The CTS results may have been one of many factors that contributed to these policies and trends:

(a) The Y 30 billion complex consisting of the Shenmu coal field, connecting railway, and the Huanghua port has been approved, and financing it has become a national priority. The CTS team's analysis confirmed the urgency of this action, though it was originally thought impossible to finish it by 2000.

(b) New railway lines from Handan to Jinan have been inserted into the plans, and the line from Shenmu to Xian has begun construction. Without the Handan-Jinan line, the coal supply to Shandong's port of Qingdao will dry up. Even with these railways, the model finds it necessary to supplement them with new transmission lines to Jinan and Harbin. Similarly, the Shenmu-Xian line could become a major coal carrier as soon as it can be completed. When the CTS analysis began in 1991, these lines were not considered necessary to include in the 8FYP or 9FYP.

(c) All new state-owned coal mines that ship coal to other provinces are now encouraged to build coal-washing facilities. SPC planners think that 15 percent or more of steam coal could realistically be washed by 2000, a share which is slightly less than recommended in the nonenvironmental scenarios.

(d) The Government recently announced that a national electrical grid will be created. Long-distance intergrid transmission is a key element of this study's recommended strategy.

(e) The coastal areas have been opened up to coal imports; if the users can pay with foreign exchange, they can gain their own access. In this study, between 30 million and 140 million tons of coal imports were found to be cheaper than domestically-supplied coal in 2000, depending on the future assumptions about GNP, the environment, and other factors. Thus, imports can prevent many shortages, although other tentative findings strongly suggest that energy conservation is an even better way to prevent shortages.

(f) The first commercial-scale slurry pipeline was approved in China in December 1993. In the CTS analysis, slurry pipelines were always chosen in the high-demand scenarios in which they were considered.

6.6 While post-1990 planning of the coal-electricity delivery system has made some dramatic steps in the right direction, a number of recommendations from this study have not yet been officially acted on. These constitute the third category of recommendations. Some of them are believed to be under active consideration by the Government. The following recommendations should be accelerated in the 8FYP and 9FYP:

(a) Coal should be distributed according to its heat content. High kcal coal should be shipped over the longest distances to get the most out of the railway and port capacity. Congestion pricing and improved information systems are instruments that should hasten this development.

(b) While the long-term concept of a national grid has been announced, very few long-distance transmission lines have been actually inserted into the plans. Because they are easier to plan and faster to construct than railways, transmission lines can play a key role in preventing massive shortages in the short term. Some of the more promising suggestions from the analysis include those from Hailar to Shenyang and Harbin; from Datong to Beijing and Tianjin; from Taiyuan to Shijiazhuang and Jinan; from Zhengzhou to Wuhan; and from Changzhi to Zhengzhou, Huaiyin in Jiangsu, and Guangzhou.

(c) Steam coal washing can play an important role in regions other than the northern and southwest coal bases. In some provinces near the coast, such as Liaoning, Anhui, and

Hebei, steam coal washing can economically increase the energy throughput on highly congested lines, despite the short shipping distances. And, if tighter environmental regulations are announced, steam coal washing could be part of the least-cost strategy for compliance in many regions.

(d) To avoid worsening particulate and sulfur pollution that is already among the worst in the world, the Government should move quickly to make polluters pay for their environmental damage in one way or another. The analysis results provide support for the economic feasibility of this type of policy. Strategies such as steam coal washing, conservation, and hydropower can benefit the environment, reduce bottlenecks, and in many cases pay for themselves.

(e) The potential for energy conservation appears to be substantial, although the study's analysis on this strategy is preliminary. Reforming the economy, liberating energy prices, and establishing the State Economic and Trade Commission's Y 400 million energy conservation grant fund are important steps in this direction, but more is needed.

6.7 As a rough estimate of the total economic impact of the most important recommendations, a scenario was run without four of the main strategies:

(a) without accelerated construction of three railway and port projects;

(b) without new steam coal washing;

(c) without the proposed intergrid transmission lines (including not only the seven 500 kV intergrid lines, but also the shorter distance AC intergrid lines); and

(d) without coal imports.

The cost difference between this scenario without these options and the base case with these options, was about Y 32 billion, or US$ 7.1 billion (in discounted 1990 prices) for the 15 year time period. Shortages in 2000 were almost 50 percent higher in the "without" scenario.

Implications for the World Bank

6.8 The substantive conclusions of the study have also helped support the Bank's lending programs to China, in which railway and power sector lending in 1995 is expected to approach a total of US$1.5 billion. All of the power sector projects in the Bank's lending program were selected as part of the least cost strategy in the medium demand scenarios. Similarly, the results support increased funding for railways which is part of the Railways VII loan package.

6.9 By recommending least-cost strategies, the modeling effort feeds into a policy dialogue with the Chinese Government to identify and remove institutional barriers and price distortions that may stand in the way of the free market adopting these optimal solutions. For instance, coal washing has long been held back by a host of problems. Coal price reform, long-term contracting, environmental regulation and taxation of pollution all would encourage enterprises to produce and buy washed coal. These kinds of implementation issues were the subject of the latest Bank-cosponsored CTS conference in Beijing in October 1994 (see Annex 22). The meeting focused mainly, though not exclusively, on coal mining, coal washing, electricity generation and transmission, and energy conservation, for which investment decisions are at least partly in the hands of decentralized enterprises.

6.10 On the technical assistance level, this study has effectively transferred these modern management and analysis capabilities to researchers in China. There is potential within the Bank to apply this methodology in other large coal-using client countries, such as India and Poland.

Policy Issues to Be Addressed in the Future

6.11 The energy supply problems that led to this study will continue to threaten China's dynamic growth. Keeping up with economic growth will remain a continuing challenge, one that requires constant evaluation of problems and projects. In particular, more railway and shipping project options need to be first formulated, then analyzed, in a network setting. Planning is constrained when all the options on the drawing board for transporting coal out of the energy base are still inadequate to do the job. MOR and MOC would benefit greatly by ideas formulated in this fashion.

6.12 Particulate pollution and acid rain from increased coal use will inevitably worsen in the 1990s, and China can expect growing pressure from abroad to reduce its greenhouse gas emissions. It is important for the SPC to pursue the dual goals of fueling economic growth and protecting the environment at the least possible cost. Analyses have shown that, up to a point, these two goals can go hand-in-hand rather than in opposition to each other. The CTS analysis system can help the SPC determine where that point (e.g., washing some 15 percent of steam coal) lies.

6.13 New initiatives for solving China's dynamic energy and transport situation are being added to or considered for the CTS analysis system, including the following:

(a) Energy conservation options are vitally important because they can satisfy demand growth without adding any more pollution (other than in their manufacture). In 1994, the World Bank, through its Robert McNamara Fellowship program, funded a CTS team member from the Energy Research Institute to add energy conservation options to the model (see para. 4.62). Analysis of carbon dioxide was also added, which, among other things, distinguishes between coal washing and energy conservation. The former only reduces ash and sulfur, while the latter not only eliminates them but eliminates CO2 as well. Given that the preliminary analysis showed that energy conservation can reduce costs, shortages, and pollution simultaneously, and that it is indispensable for reducing CO_2 emissions, we recommend that the energy conservation and CO_2 modules be added to the Government's official version of the CTS model, along with an updated energy conservation database.

(b) Other energy sources, such as oil, are rising in importance; oil-fired power plants using imported petroleum have begun to compete with coal-fired plants in some coastal locations. Suggestions have been made to add oil and gas to the analysis system. Already, the CTS has been adapted to help the Institute for Comprehensive Transportation to develop an "Energy Transportation Plan for the Year 2050."

(c) The current method for matching coal producers and consumers with each other and with transport providers at the annual coal ordering conference is both slow and inflexible. New long-term contracts between suppliers and users should not necessarily duplicate the origin-destination patterns of the old arrangements. At the October 1993 CTS Report Conference, several senior SPC officials suggested that the analysis system be adapted for facilitating the smooth functioning of the coal/transport market.

(d) More of the unmodeled pollution control alternatives could be added to the system so as to gain a better understanding of how economically feasible are different levels of pollution control.

The Role of Intersectoral Modeling in the Market Economy

6.14 All the past and future uses of the analysis system are still relevant as China evolves from a centrally planned to a socialist market economy. An intersectoral modeling tool such as this need not and should not be used to control investment decisions from the center. It is certainly not so in the United States, which just finished a complete revision of its energy models. The U.S. Department of Energy publishes many reports each year based on the national energy models. Utilities, railroads, barge companies, and coal producers may thus inform their decision-making with a comprehensive picture of demand, supply, competition, trends, emerging technologies, and good options.

6.15 A good example of how an intersectoral model at the national level can contribute in a market economy is its use for environmental policymaking. When the U.S. Clean Air Act of 1990 was passed, the models were used to find the best way to meet the regulations in different regions. Private corporations could refer to the model results to find out whether it is better to scrub or switch in their region, that is, to install pollution control equipment or to switch coal types (or wash coal). Another example is when a tax was proposed on barge fuel, the effect on the competition between regions and between kinds of energy was studied using the models. This information is published annually in dozens of reports.

6.16 The study recommends that the analysis system be used, as in Australia or France, for indicative planning. A country in transition, such as China, falls halfway between a full market economy as in the United States and a centrally planned economy as in China in the past. Under indicative planning, there would be several roles for the CTS analysis system. First, it could suggest directions for investment to local governments and private ventures. Second, it could help guide state-controlled investment, which, while only a fraction of the total for most projects, remains crucial to their successful completion. For instance, in the United States, models are used to guide investment in the federal highway program, harbor dredging, or other cost-sharing schemes. Third, it could analyze the impact of policies under consideration by the central Government.

6.17 Already, the CTS results have reinforced the need for reforms, such as restructuring the distribution pattern for coal, opening the country up to more imports, modifying the tariff structure on rail and water transport, and forming interprovincial partnerships for transmission and coal washing projects.

6.18 In China's transition economy, there is often a blurred distinction between the public and private sectors. With such a broad scope, it is inevitable that some of the activities modeled in this study are (or are becoming) private sector decisions by shippers, carriers, or users, such as where to build township coal mines, whether to ship coal by water, and what type of coal to buy. Others, such as railroad investment and environmental policy remain firmly in the public sector. In between lie those activities that, while in the private sector in some free market countries, look to remain in the public sector in China for some time, such as electricity grid investment and management. The central Government should concentrate their planning efforts on those parts of the economy where a continued Government intervention or regulation is necessary to supplement market mechanisms. In particular, natural monopolies such as railways and power distribution need to be regulated, while externalities such as social costs due to environmental pollution need to be forcibly internalized by the Government. If the Government moves also to free prices, reform the legal system, and remove institutional barriers and subsidies, the market should send the proper signals to firms regarding whether to wash coal, transmit electricity, ship by water, and other options.

6.19 Even though decentralized or semi-autonomous decisions are beyond the newly-defined jurisdiction of Government planning, it is still essential to include them in the model, in order for the Government to predict decentralized responses to central decisions, to build a new railway line, for example. The CTS modeling approach assumes that the decentralized sector is cost-minimizing, subject to regulatory and other constraints. Of course, once the scope of the model extends beyond the jurisdiction of the modeler, it is more useful for gaining strategic insights than for prescriptive planning. A successful example comes from Australia, where the MENSA energy systems model is used by federal and state resource agencies. None of the agencies has overriding directive powers in the areas of infrastructure development for which they have responsibility. Rather, their studies, which are often widely disseminated, serve to focus debate and act as a de facto indicative planning mechanism.

Action Plan for Future Use of the Coal Transport Study

6.20 A series of actions by the Government will be needed for the CTS analysis system to fulfill its future role as a planning tool in a fast-growing, increasingly market-oriented economy. These actions should be carried out in a manner that will reinforce the reforms currently under way in the planning and investment process. The recommended actions include the following:

(a) Continuing supervision of the CTS under the umbrella of the ERC, with direct participation of energy planners from ERI and transport planners from ICT.
(b) Rolling the model over to the next five-year planning period, that is, to 2010.
(c) Providing additional investment options, especially in the railway sector, where heavy-axle investments should be compared to extra tracking and electrification packages.
(d) Taking an active role in guiding the CTS team regarding policy scenarios and assumptions that are important to high-level officials.
(e) Continuing building support for the CTS among ministry and provincial officials by holding conferences to check data and assumptions, and to disseminate results.
(f) Publishing the findings periodically, perhaps in an annual series to be distributed at such conferences and elsewhere.
(g) Using the CTS analysis system as technical input for coordinating the scale and timing of investments by different ministries.
(h) Preparing recommendations to the State Council, to provinces, and to the private sector concerning investments and policies for coal production, preparation, transportation, and distribution, power generation and transmission, and environmental protection.

Mr. Gui Shiyong, Vice Chairman of the SPC, has stated in a letter to the Institute of Management Sciences, that "the CTS, using scientific methods, systematically described the deeper problems and contradictions in the system, ... that it is of great value for the adjustment of planning and decision-making, ...that it has had an important influence on China's economy and should be used more widely, ...that it represents the first time that model results of this kind have been used at this level in China, ... [and that he] support[s] further applications of the CTS, including making economic forecasts for 2010." His full statement regarding how the SPC views the CTS model and what the model has already accomplished for them is included in Annex 21.

NOTES

1. "China: Efficiency and Environmental Impact of Coal Use" (Report No. 8915-CHA, 1991) and "China: Energy

Conservation study" (Report No. 10813-CHA).

2. "China: Efficiency and Environmental Impact of Coal Use," 1991.

3. Martha M. Hamilton, "Selling Pollution Rights Cuts the Cost of Cleaner Air," The Washington Post, August 24, 1994, p. F1, F3.

Annexes

ORGANIZATION OF THE COAL TRANSPORT STUDY

1. The Bank's counterpart for the CTS is the Economic Research Center (ERC) of the SPC of China. The SPC is China's highest economic planning agency. The ERC is the long-range research arm of the SPC, and oversees a number of more specialized research agencies that participated in the CTS. Among these are the Economic Institute (EI), which served as the original host organization for the CTS, the Institute for Comprehensive Transportation (ICT), and the Energy Research Institute (ERI).

2. The Bank was responsible for providing technical assistance to the ERC including arranging for foreign experts to serve as technical advisors to CTS team and organizing a nine-month training program in the United States for five core team members. The Bank also worked jointly with the ERC in preparing detailed work plans and major reports.

3. The Study Director on the Chinese side is Madame Shi-Qing Qi (EI). The core modeling team members who underwent U.S. training were Mr. Sun Xufei, Phase 2 Modeling Leader (Huaneng Co.); Mr. Zhang Chuntai, Phase 1 Modeling Leader (EI); Mr. Cao Wei (ICT); and Ms. Xie Zhijun (ERI). Mr. Zhou Dadi (ERI) served as a Bank consultant and was also part of the training program.

4. In addition to this group, there was a supporting Policy Team and Technical Team, and a Consulting Panel made up of leaders. Members of these teams participated in part of the training program consisting of planning sessions, presentations, and a number of site visits to U.S. coal, port, and railway facilities. The Policy Team consisted of Messrs. Xu Zhen and Yang Zhenjia (Deputy Directors, ERC); Mr. Liang Xiufeng (EI); Ms. Liu Liru (Director, ICT). The Technical Team consisted of Mr. Zhou Fengqi (Director, ERI); Mme Shi; Mr. Zou Yuan, Mr. Lin Fatang, and Mr. Yu Xiaodong (all of EI). The Consulting Panel was made up of Messrs. Xu, Yang, Liang, Zhou, and Madame Liu.

Training Program

5. The training program provided the modeling team members with customized applied courses in economics, benefit-cost analysis, network modeling, data base management, software engineering. The training program also enabled the CTS team to develop a preliminary version of the requisite CTS model, which subsequently was refined, calibrated, and tested. Starting on February 5, 1990, the CTS training program presented a series of five short courses and a software development workshop as follows:

Course	Lecturers
Applied Economics	(Huenneman, Fernandez, and Polenske)
Systems Modeling	(Friesz and Kuby)
Benefit-Cost Analysis	(Huenneman)
Database Management	(Sibley, Simkowitz, and Hirshfeld)
Coal Transport Modeling	(Kuby, Ratick, and representatives from U.S. Department of Energy and Brookhaven Laboratory)
Software Development Workshop	(Kuby, Bernstein, and Cook)

6. The first four courses were presented during the period February-April 1990 in conjunction with training for the China Railway Investment Study (RIS) team, while the fifth was presented from mid-April to end July 1990 and the software development workshop carried through to the end of the training period. The course lecturers were supplemented by a number of invited experts who presented specialized topics of interest to the training team.

FIGURES ON TRANSPORT AND ENERGY

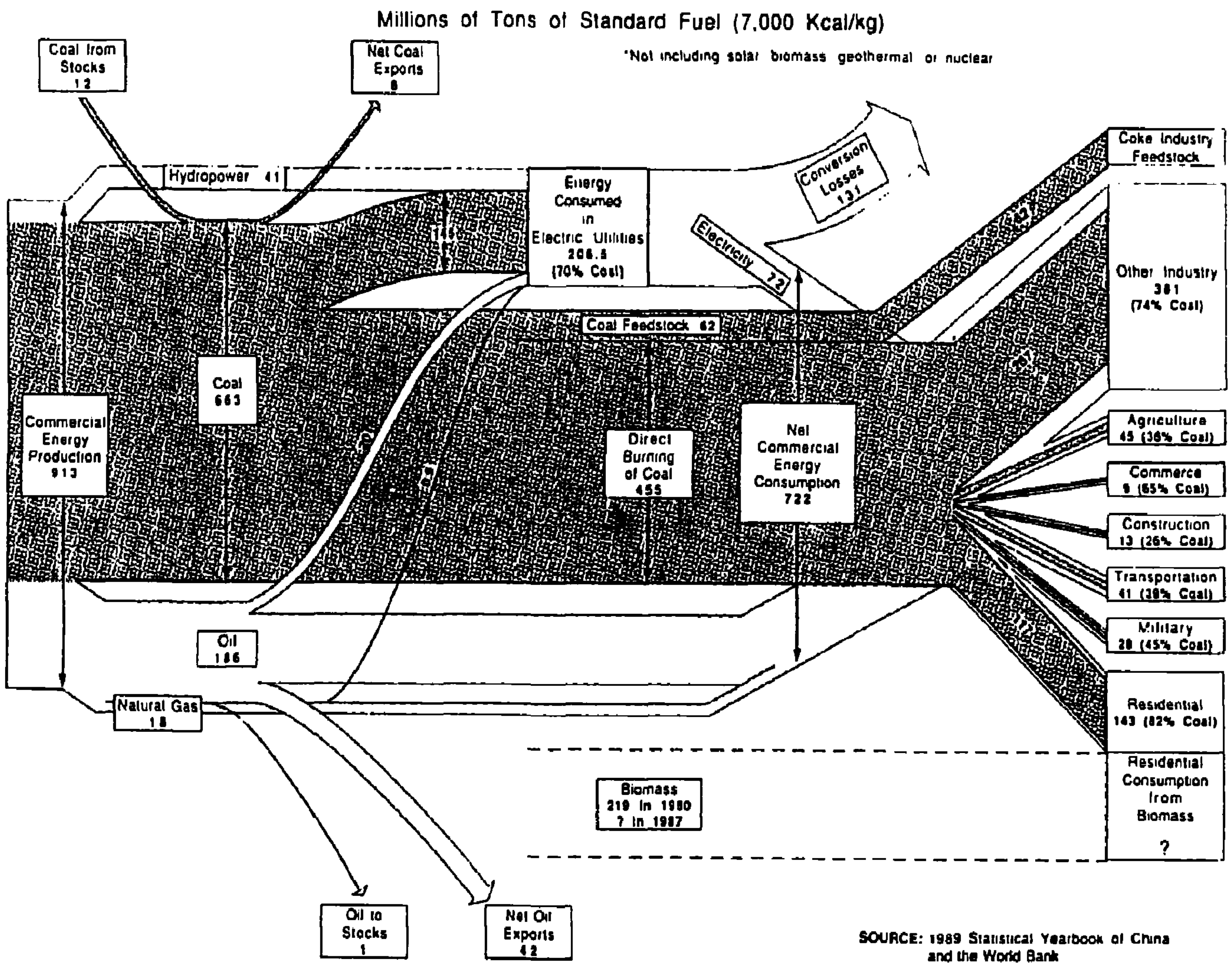
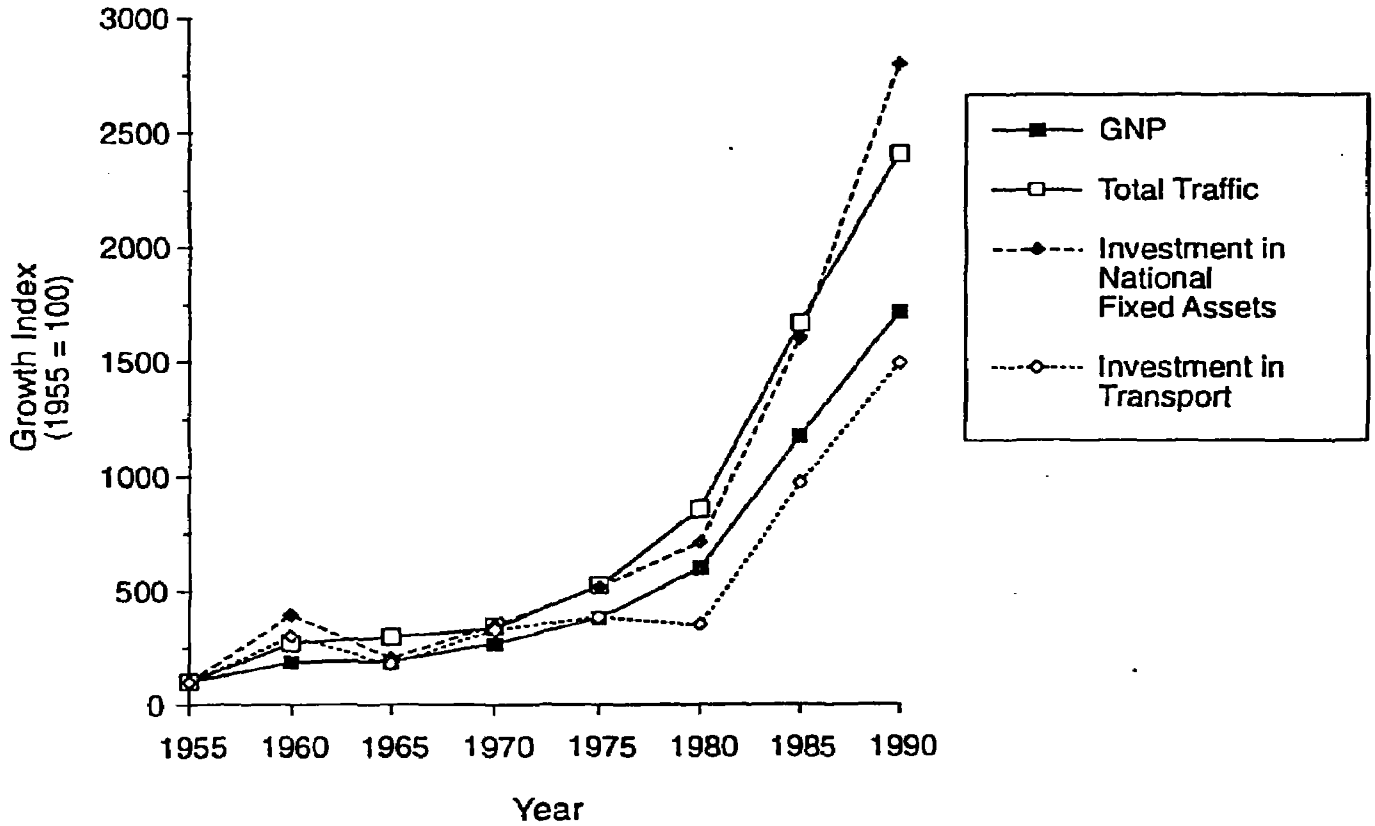


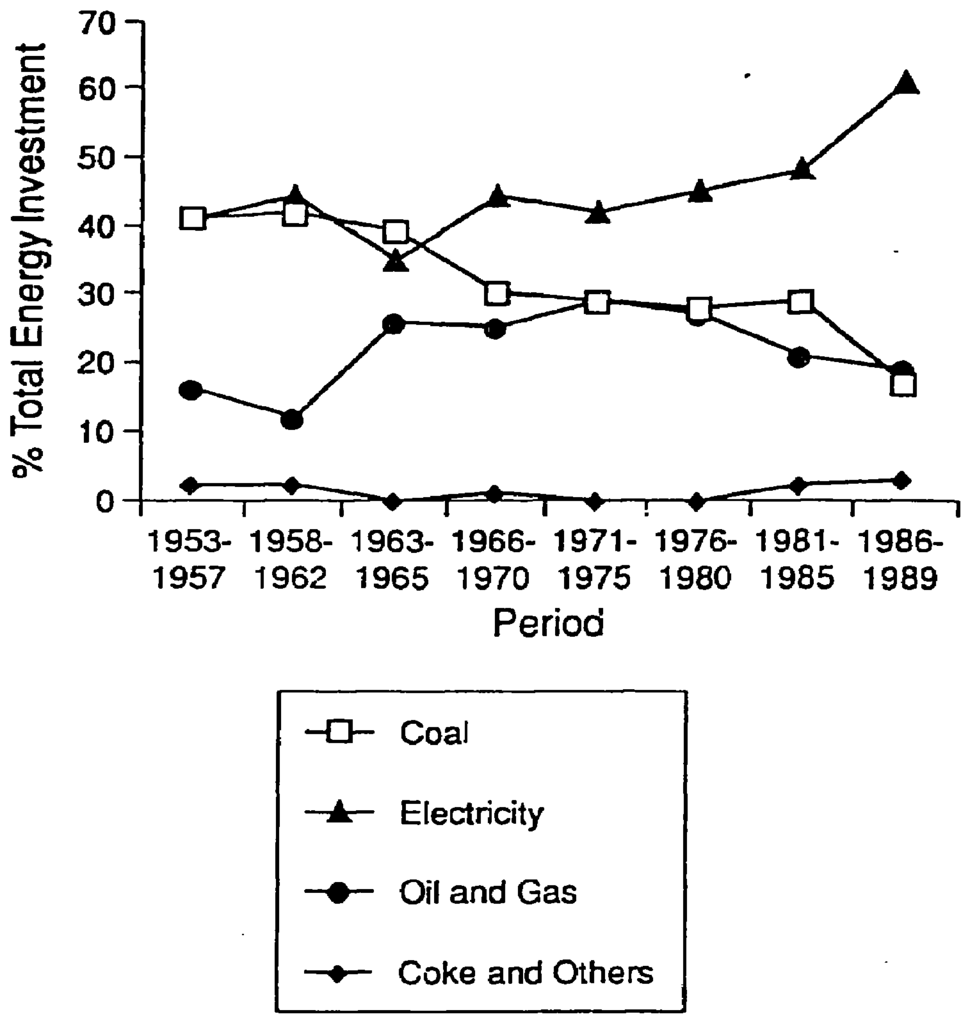
Figure 2.1: Total Commercial Energy Flow in China

Figure 2.2: Investment in Transportation Relative to GNP and Traffic



Source: State Planning Commission

Figure 2.3: Investment Structure of the Energy Sector, by Type of Energy



Source: State Planning Commission

Figure 2.4: Coal Consumption and Production Trends

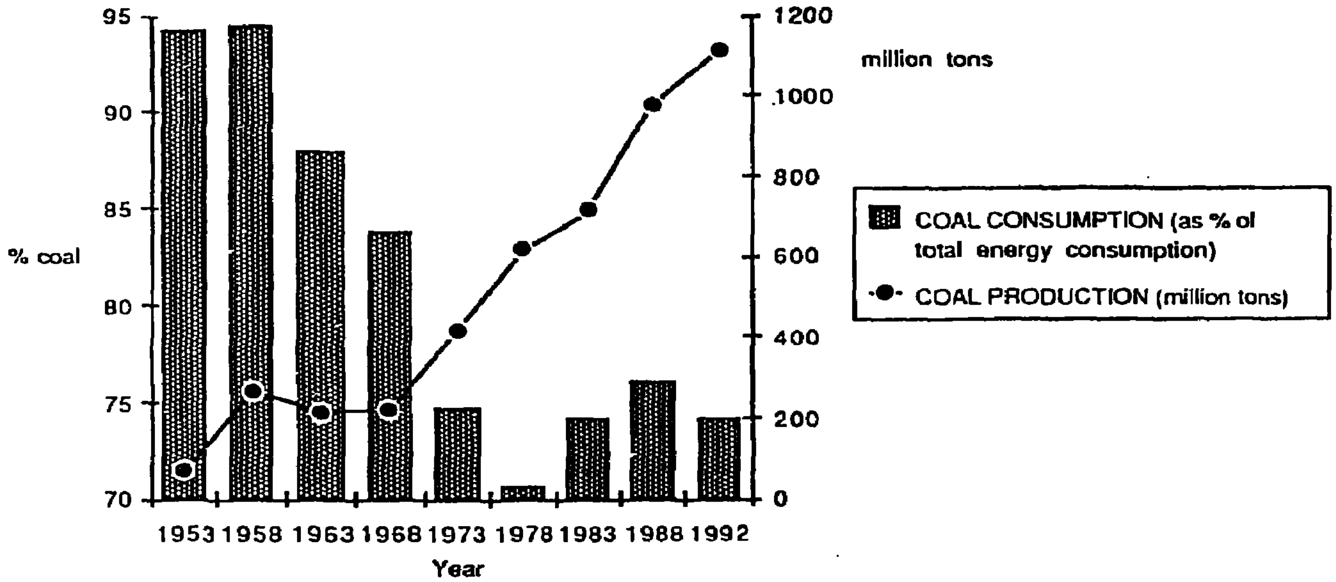
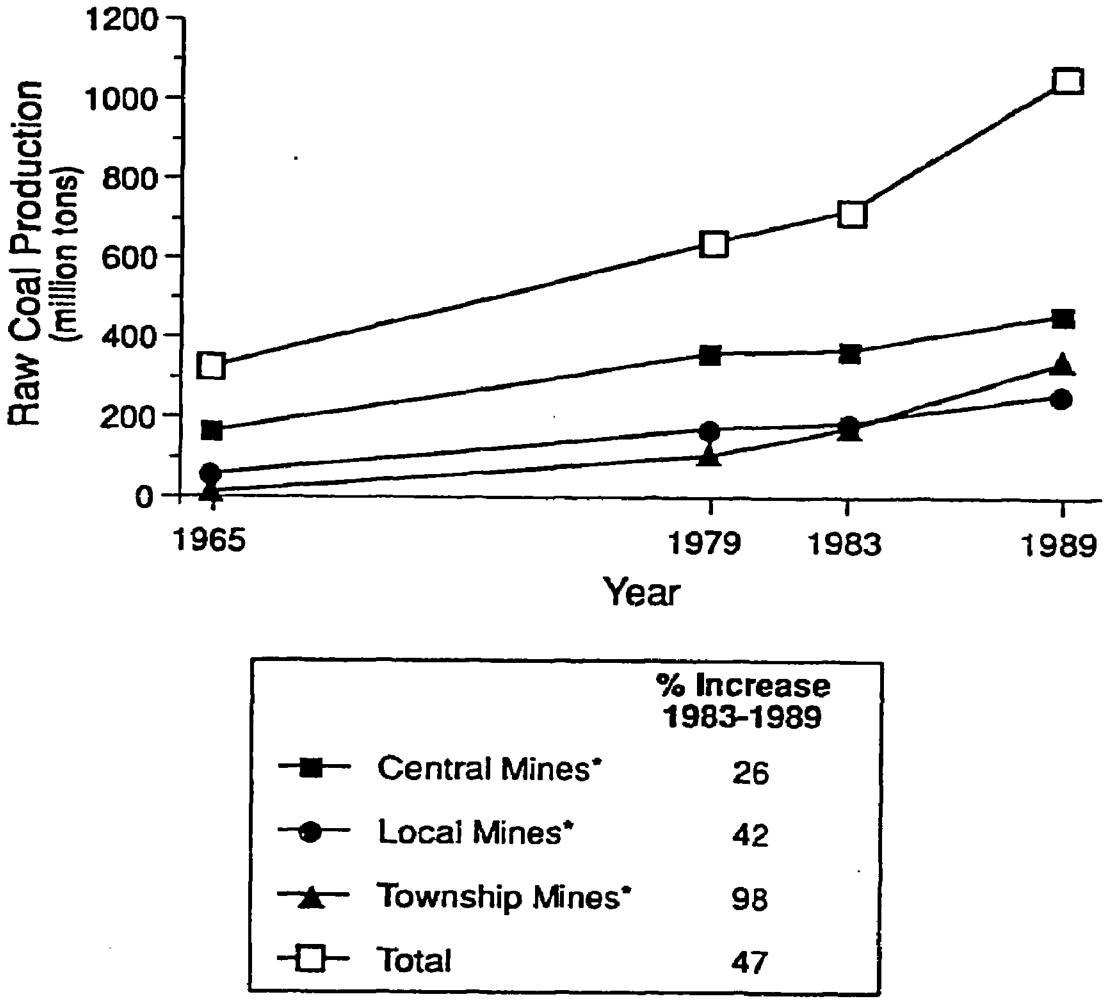


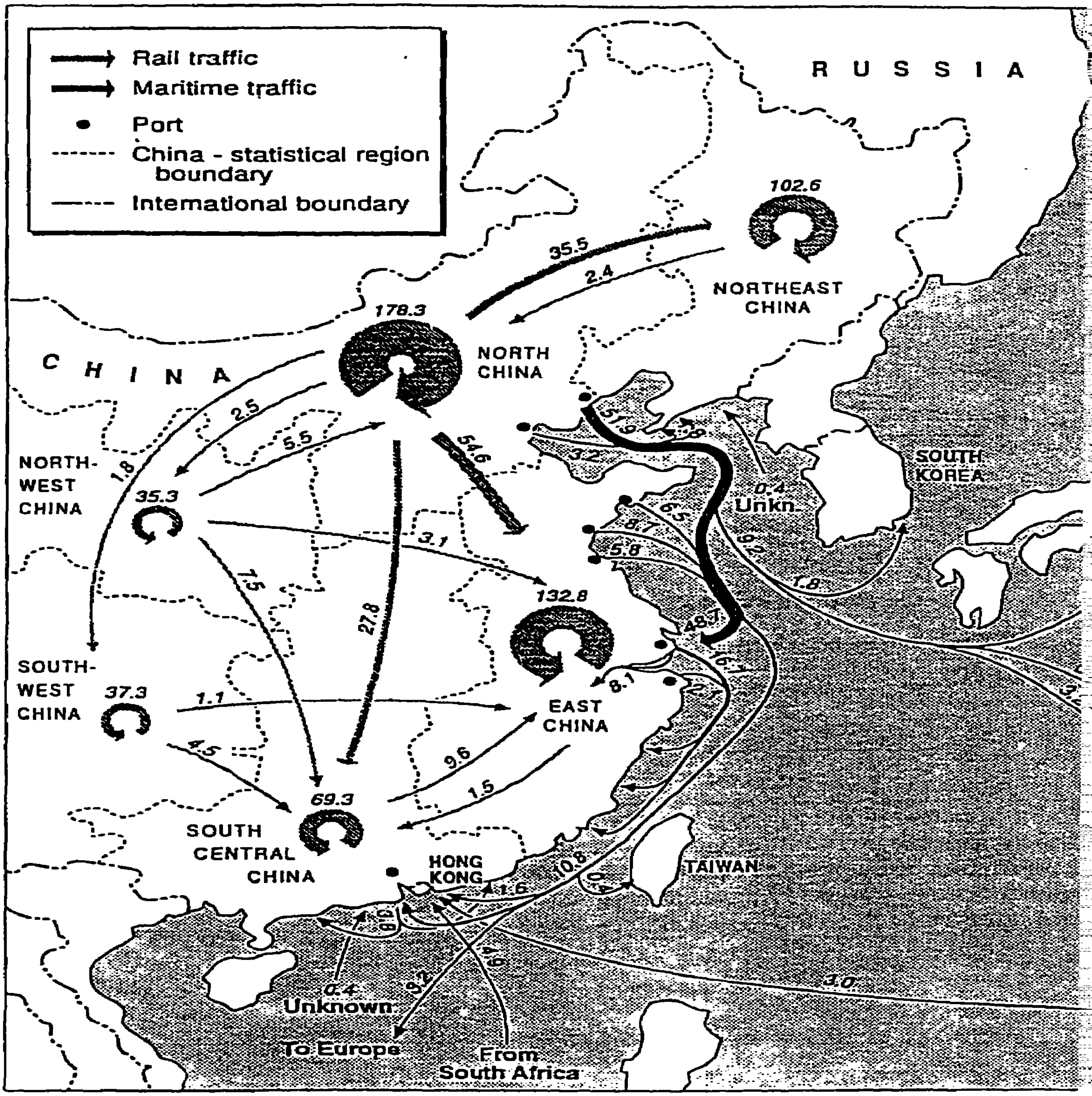
Figure 2.5: Raw Coal Production, by Type of Administration, 1965-89



* Central mines refer to mines from which output is distributed by the central government (*tongpei meikuang*), local mines are operated by provinces, prefectures, or counties, and township mines (formerly referred to as commune and brigade mines) are operated by rural collectives (*xiangjen meikuang*).

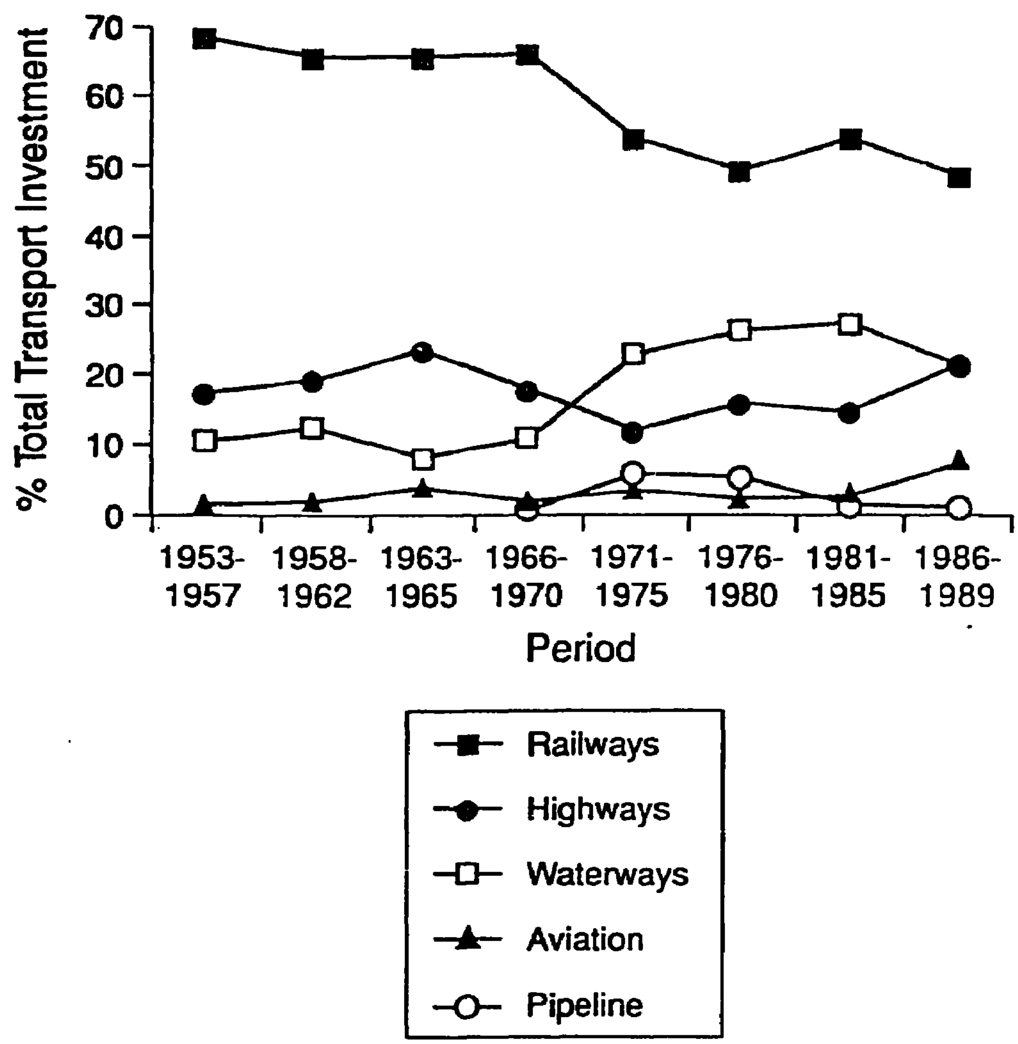
Source: MOCI.

Figure 2.6: Major Interregional Coal Flows, 1989-90
(Millions of Metric Tons)



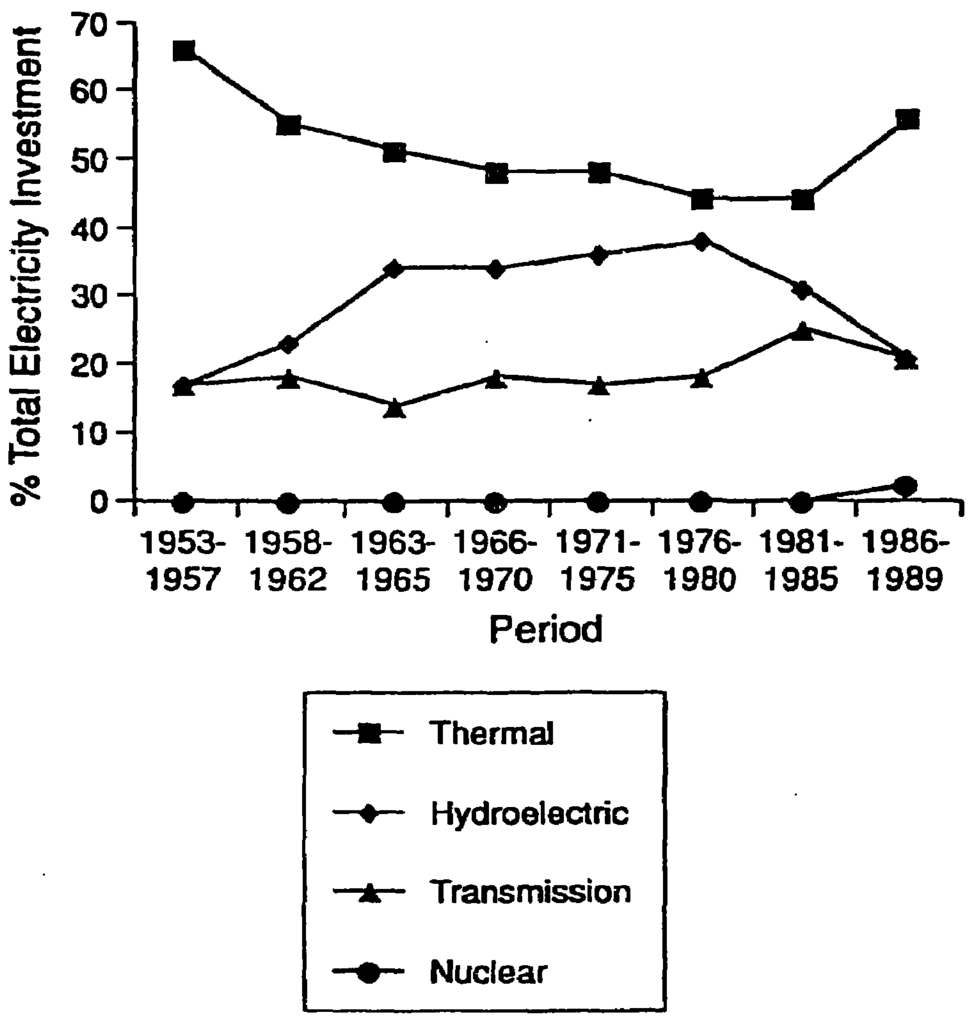
Sources: U.S. Energy Information Administration, China State Planning Commission, and Intern
* Imports/exports are for 1989; Chinese flows are for 1990. Most flows under 1 million metric tc

Figure 2.7: Investment Structure of the Transportation Sector, by Mode



Source: State Planning Commission

Figure 2.8: Investment Structure of the Electricity Sector



Source: State Planning Commission

BACKGROUND ON TRANSPORT AND ENERGY: ASSORTED TABLES

Table 3.1: China: Freight Traffic by Mode
(billion ton-km)

	Rail	Road	Domestic water-way /a	Pipe-lines	Civil avia-tion	Total	Ocean shipping
1952	60.2	1.4	11.8	-	0.002	73.4	2.8
Modal split (%)	82.0	2.0	16.0	-	-	100.0	-
1977	456.9	25.1	102.1	38.7	0.076	622.9	174.1
Modal split (%)	73.4	4.0	16.4	6.2	-	100.0	-
1979	559.9	74.5	139.3	47.6	0.123	821.4	317.1
Modal split (%)	68.2	9.1	17.0	5.8	0	100.0	
1989	1,039.4	337.5	349.8	62.9	0.690	1,790.2	768.9
Modal split (%)	58.1	18.9	19.5	3.5	-	100.0	-
1992	1,157.6	375.5	422.2	61.7	1.342	2,018.4	903.4
Modal split (%)	57.4	18.6	20.9	3.1	-	100.0	-
Growth rate % p.a.							
1952-77	8.4	12.1	9.0	-	15.7	8.9	18.0
1982-92	6.6	14.7	9.5	2.1	21.1	8.1	9.1
1952-92	7.7	15.0	9.4	-	-	8.6	-

/a Excludes ocean-going transport.

Source: Statistical Yearbook of China—1993, p. 467-8

Table 3.2: International Trends in Commercial Energy Intensity (TCPER/GDP) /a

Country	1979/80	1984/85	1987/88
China	1.50	1.20	1.10
Canada	0.85	0.77	0.74
Japan	0.36	0.29	0.28
United States	0.71	0.58	0.56
India	0.61	0.64	0.64
Korea	0.67	0.61	0.60
Poland	0.96	N.A.	0.95
Soviet Union	1.04	N.A.	1.04

/a Measured as total commercial primary energy requirements per US$1,000 of GDP. Ratios for countries other than China come from OECD and ADB publications. All are computed using both 1980 prices and U.S. dollar exchange rates. Energy is measured in toe (tons of oil equivalent). These ratios generally do not include noncommercial energy.

N.A. = not available.

Source: Two publications by IEA/OECD: *Energy in Non-OECD Countries, Selected Issues, 1988* and *Energy Policies and Programs of IEA Countries, 1987 Review*; and *ADB Energy Indicators*, 1989.

Table 3.3: International Comparison of Reliance on Coal
(percent share)

China	73.0
Europe	19.0
India	53.0
Japan	18.5
Korea	34.7
United Kingdom	31.4
Soviet Union	30.0
United States	24.0

Source: IEA, *Coal Information 1989*, *ADB Energy Indicators, 1989* and *Statistical Yearbook of China, 1994.*

Table 3.4: International Comparison of Transport Investment as a Percentage of GNP

Country	Period	Transport investment in GNP
Japan	1964-73	3.5-3.8
Korea	1979-81	2.00
Brazil	1979-81	2.36
India	1975	2.37
China	1981-92	1.34

Source: Final report.

Table 3.5: Coal Supply and Demand Balance Sheet
(million tons)

	1985	1986	1987	1988	1989	1992
1. Coal Supply, of which	874	896	930	982	1,056	1,117
a. Production	872	894	928	980	1,054	1,116
b. Import	2	2	2	2	2	1
2. Coal Demand, of which	823	870	941	1,010	1,048	1,162
c. Intermediate use	254	279	312	341	375	491
electricity use	164	180	203	228	252	335
d. Final use	527	545	579	616	620	607
industries use	297	311	338	361	372	388
e. Coal washing lost	35	36	37	37	38	44
f. Export	7	10	13	16	15	20
3. End-of-year stockpile	141	154	138	107	146	101
4. Change in stockpile a/	+39	+13	-16	-31	+37	-3
5. Statistical discrepancy b/	+12	+13	+5	+3	-29	+57

a/ The national stockpile includes government coal reserves, minemouth stockpiles, and users' own stockpiles.

b/ The statistical discrepancy may include some of the losses during handling and transportation.

Source: Official government sources.

Table 3.6: Comparison of Coal Reserves— Soviet Union, United States, and China
(billion tons)

	World Energy Council	British Petroleum
World total	1,791	1,174
Of which: Soviet Union	265	264
United States	268	268
China	805	184 /a
of which lignite	132	15
Soviet Union, United States, and China as % of world total	75	61

/a Includes all deposits up to a depth of 900 m and a minimum seam thickness of 70 cm. Although broadly comparable, the definition of reserves in China differs from international standards.

Source: *Annual Energy Review 1990*, p. 279, U.S. Department of Energy, May 1991.

Table 3.7: Coal Production by Type of Coal, 1987 and 1991
(million tons and percent)

	1987	%	1991	%
Anthracite	192	21	214	20
Bituminous coal:	703	76	825	76
Prime coking coal	(93)	(10)	(96)	9
Blending coking/steam coal	(362)	(39)	(412)	38
Other steam coal	(248)	(27)	(306)	28
Lignite	33	3	45	4
Total	928	100	1,084	100

Source: ERC.

Table 3.8: Sulfur Content of Chinese Coal Reserves

Sulfur content (percent)	Percent of total reserves
<1	65-70
1-2	15-20
>2	10-20

Source: China General Coal Utilization Corporation, Working Paper No. 1.

Table 3.9: Coal Output and Reserves, by Region, 1989
(percent)

Region	Raw coal output	Proven reserve available for mining
North China	37.2	53.3
Northeast China	14.3	2.4
East China	13.7	5.5
South Central China	14.9	3.0
Southwest China	12.1	8.9
Northwest China	7.8	26.9

Source: China General Coal Utilization Corporation, Working Paper No. 1.

Table 3.10: Interregional Coal Flows: 1980 and 1990 /a
(million tons)

Region	Net coal movement into (-) or out of (+) a region 1980	1990	% Change
Northeast	-13.4	-17.3	29
North	+59.5	+157.8	265
East	-29.2	-109.9	376
Central South	-12.2	-27.7	227
Southwest	+2.4	-12.5	-520
Northwest	+5.3	+9.8	184

/a Overseas shipments not included.

Sources: China Coal Industry Yearbook, 1983 and 1990.

Table 3.11: Steam Coal Washing

Year	Million Tons
1984	31.12
1985	35.79
1989	58.08
1990	64.11
1991	68.51

Source: Energy Research Institute

Table 3.12: Plan vs. Market Prices for Steam Coal, 1989

	Plan	Negotiated
Beijing	55-70	140-150
Shenyang	45-70	80-180
Jiangsu	65-80	220-280
Shanxi	34-50	110-140

Source: Stephenson (1990), *op. cit.*

Table 3.13: Evolution of Coal Prices on the Free Market, 1986-90 /a
(yuan per ton)

	1986	1987	1988	1989	1990 (est.)
FOB Shanxi	50	80	100-120	110-140	100
FOB Xuzhou	90	100	180	220	175
FOB Shandong	-	-	100	200	175

/a These are indicative prices for steam coal. Shanxi is the main producing province in North China. Xuzhou is a mining area in the northern part of Jiangsu province, a major coal consumer in East China, which also imports coal from North China. Shandong is a coastal province in North China and is both a producer and consumer.

Source: State Planning Commission.

Table 3.14: Increases in Plan Coal Prices

Period	Increase in Y/ton	Increase in percent
1958	2.64	20
1965	2.01	11
1979	5.07	28
1985	4.39	17
1990	10.00	16

Table 3.15: Coal Traffic by Railway and Waterway

Mode	Period	Coal (million tons)	Coal (billion ton-km)	Average distance (km)	Daily wagons loaded
Railways	1988	565	300	530	26,513
	1989	609	316	519	28,479
	1990	626	341	545	29,300
Waterways*	1988	124	146	1,175	
	1989	146	182	1,247	
	1990	139	182	1,310	

Table 3.16: Indicators of Railway Asset Utilization: A Comparison between China, the Soviet Union, the United States, India, and Brazil

Indicator	China (1993)	USSR (1987)	USA/a (1987)	India /c (1987-88)	Brazil (1987)
Freight ton-km/route-km (mil)	22.2	26.2	6.5	3.6	8.00
Passenger-km/route-km (mil)	6.5	2.8	0.1	4.4	0.05
Freight ton-km/freight car owned (mil)	3.1	2.2	0.8/b	0.5	1.70
Freight tonnage/car loaded	56.1	53.6	66.6	20.1	55.0
Freight cars per train	40-50 (est.)	50-75 (est.)	71	n.a.	35
Freight car turnaround time (days)	4.2	6.6	18.8	11.6	12.0
Freight car turnaround distance (km)/d	993	1,610	2,125	1,274	750
Freight hauling distance (km)	761	945	1,106	776	460
Freight ton-km/locomotive owned (millions)	80.8	68.5	70.6	24.3	25.0
Freight train-km/route-km/day/d	35.5	42.9	6.1	10.6	6.4
Freight train speed (inc. stops) (km/h)	30.0	31.8	n.a.	22.7	30.0
Freight train gross trailing weight (tons)	2,519	3,085	4,300	2,050	2,200
Freight tonnage per train	1,300 to 1,500 (est.)	1,800 (est.)	2,390	1,053	1,200

/a Class I Railroads only.
/b Includes cars owned by car companies and shippers.
/c 90.58 percent of all freight ton-kilometers are carried on broad-gauge rails, so most above estimates are for broad gauge only. See *Indian Railways Yearbook, 1987-88*, p. 23.
/d Data pertains to 1990.

Sources: China: Ministry of Railways and mission estimates.
USSR: Narodnoe khozyaistvo SSSR v 1987 g. (*The USSR National Economy in 1987*), pp. 21, 307-308, 312, 315. Various estimates from Hunter and Kaple, 1984 and Szyrmyr and Dunn, 1985.
India: *Economic Survey, 1988-89*, pp. 27, 35-36, S-30; *Indian Railways Yearbook 1987-88*, pp. viii, 40, 70, 78-79 and 80-81.
USA: *Railroad Facts*, 1988, pp.9, 31, 32, 35, 36, 43, 46. The World Bank, *Railroad Database*, June 1989.
Brazil: Official Government sources.

Table 3.17: Combined Rail-Water Routes from Shanxi to East China (km)

	Rail	Water	Total distance
1. Datong to Shanghai	1,840		1,840
Datong-Qinhuangdao-Shanghai	620	1,350	1,970
2. Taiyuan to Shanghai	1,500		1,500
Taiyuan-Qingdao-Shanghai	920	750	1,670
3. Taiyuan-Nanjing	1,190		1,190
Taiyuan-Wuhan-Nanjing	1,180	800	1,980

Table 3.18: Share of Electricity in Total and Industrial Final Net Consumption of Energy in Selected Countries /a (percent)

	1980 commercial energy		1985 commercial energy		1988 commercial energy	
	Total	Industry	Total	Industry	Total	Industry
Developing Countries						
China	6.1	7.7	6.5	8.4	7.7	N.A.
Argentina	10.1	18.6	11.3	18.7	11.4	20.9
Brazil	15.5	21.0	20.1	29.5	20.3	28.8
Mexico	7.6	11.3	8.7	10.8	9.8	12.9
India	11.2	12.6	13.5	14.4	14.9	N.A.
S. Korea	8.1	12.5	10.1	15.7	11.2	16.8
Developed Countries						
United States	13.2	14.2	15.1	16.6	15.5	16.8
Canada	16.9	20.2	21.0	24.7	22.5	25.0
Japan	17.8	22.2	20.2	25.3	20.5	26.3
France	12.6	15.2	15.9	18.6	17.2	21.0
Germany, F.R.	13.7	18.2	15.3	20.9	16.0	22.8
Italy	12.9	18.6	14.1	20.9	14.9	21.7
United Kingdom	14.6	16.5	14.9	17.5	15.3	18.7

N.A. = not available.

/a Final net consumption refers to energy consumed by end users, net of conversion, transmission, and other losses. These figures are not the percentage of total energy production that is used for generating electricity, but rather the percentage of final energy consumption that is electricity.

Source: OECD (1989) *World Energy Statistics and Balances, 1971-1987.*
OECD (1990) *World Energy Statistics and Balances, 1985-1988.*
OECD (1987) *Energy Balances of Developing Countries 1970-1985.*
OECD (1988) *Energy Balances of Developing Countries 1985-1986.*
OECD (1990) *Energy Balances of Developing Countries 1987-1988.*
All figures were originally reported in mtoe.

Table 3.19: Estimated Annual Emissions from Coal Use, by Sector
(million tons)

Sources	TSP 1985	TSP 1988	SO_2 1985	SO_2 1988	CO_2 1988
Industrial boilers and plants	7.7	9.3	6.3	9.7	300
Electric power boilers	7.0	8.0	3.5	5.7	153
Residential/commercial	1.2	2.4	2.9	4.6	129
Railroads	1.0	1.0	0.5	0.5	15
Total Coal-Related Emissions	16.9	20.7	13.2	20.5	597
Total Emissions	23	N.A.	15	N.A.	N.A.

N.A. = not available.

Note: 1985 data come from Wage Hanchen and Zhao Dianwu, "Air Pollution Control and Energy Use in China" in *Proceedings of the Chinese-American Symposium on Energy Markets and the Future of Energy Demand*, Berkeley: Lawrence Berkeley Laboratory, USC, November 1988.

Table 3.20: Ambient Concentrations in Major Chinese and Foreign Cities

City /a	TSP ($\mu g/m^3$) Annual average /b	TSP ($\mu g/m^3$) Maximum reading /c	SO_2 ($\mu g/m^3$) Annual average /b	SO_2 ($\mu g/m^3$) Maximum reading /c
Beijing	321-504	965	73-249	566
Chongqing	620	710	300-400	N.A.
Guangzhou	118-325	640	7-143	342
Shanghai	192-360	854	13-115	238
Shenyang	304-598	1,546	78-213	623
Taiyuan	1,070	N.A.	250	N.A.
Xian	495-708	1,310	124-170	317
Bangkok	198-243	386-741	18	48
Delhi	291-453	831-1,062	28-68	97-197
New York City	44-62	87-121	65	116
Tokyo	52	143	25-34	58-68
Warsaw	58-67	213-248	33-46	180-205

N.A. = not available.

/a Data for Chinese cities are for 1988. Data for foreign cities are for 1982-85.

/b For those cities where there were data from more than one monitoring station, a range is given.

/c The 98th percentile of daily values; it represents the level below which fall 98 percent of daily measurements in a year and the threshold, above which lies 2 percent of the measurements (7 days of the year). It provides information on the most polluted days of the year. Ranges represent more than one monitoring station.

Source: World Resources Institute, *World Resources, 1988/89*. Monitoring data were submitted by national governments to the Global Environmental Monitoring System (GEMS), maintained by WHO and the UN Environmental Program. Emission levels can be affected by seasonal patterns in emissions and meteorological conditions. As a result, annual means and 98th percentiles are most meaningful if they include measurements taken during all seasons of the year. Since the analysis did not always include seasonal data, it should be treated with caution. Also, data provided by NEPA and various local EPBs.

Table 3.21: Ambient Air Quality Standards

	Period	Class I	Class II	Class III
		($\mu g/m^3$ = micrograms per cubic meter)		
TSP	Daily average	150	300	500
	Max. at any time	300	1,000	1,500
TSP	(< 10 microns)			
	Daily average	50	150	250
	Max. at any time	150	500	700
SO_2	Annual average	20	60	100
	Daily average	50	150	250
	Max. at any time	150	500	700

Source: National Environmental Protection Agency (NEPA), China.

Planning and Investment for Coal, Transport, and Electricity

Overview

1. China is currently reforming the planning and investment system. They are decentralizing their decision-making and reorienting the economy toward the market in a step-by-step fashion.

2. Investment planning in China is carried out in two parallel processes: (a) formulation of aggregate plans for capital investment; and (b) planning and management of individual projects. The state government continues to coordinate the gross allocation of investment funds between different sectors and provinces, and to macromanage the economy to balance consumption, savings, and investment. Before the 1980s, the central government controlled all individual projects. During the 1980s, they controlled mainly the large projects. Now, even townships can plan and finance some of their own investment projects. Often, the state government is but one of several partners.

3. Government in China comprises the central level and three to four lower levels: (a) provinces, autonomous regions, or major municipalities (Beijing, Tianjin, Shanghai only) (b) counties, and (c) townships. However, sixteen major cities (e.g., Chengdu, Guangzhou, Shenyang) are now "directly managed" by the SPC rather than the province in which they are located.

Organizations and their Functions

4. Figure 4.1 shows the administrative control system for economic planning of the transport and energy sectors. The State Council, at the top of the economic planning hierarchy, is responsible for the five-year plans (FYP) for social and economic development and for obtaining approval of these plans from the National People's Congress. The FYP outlines the development strategy, targets, and key capital construction projects to be pursued over the period. The State Planning Commission (SPC) assists the State Council in preparing the FYPs. The newly-formed State Economic and Trade Commission (SETC) has taken over the responsibility of day-to-day implementation of the FYPs from the SPC. Formerly known as the State Economic Commission, the SETC was merged into the SPC in 1988 and then separated back out in 1992, with additional responsibilities relating to trade and reinvestment. Finally, there are ministries in charge of finance and planning for energy and transportation. Environmental protection is supervised by the National Environmental Protection Agency, which is situated one level below the SPC and ministry level, but functions like a ministry.

5. Paralleling the SPC and ministries at the lower levels, each province has its own provincial planning commission (PPC) and departments of finance, energy and transportation (Figure 4.1).

6. The SPC (the World Bank's counterpart agency in this study) is the long-term planning agency of the central government in charge of new investments. There are several planning departments in charge of finance, energy, and transport planning (which, by the way, have used the preliminary results of this study). The SPC's Long-Term Planning Bureau prepares FYPs and ten year strategic plans. The SPC's National Economic Comprehensive Planning Bureau translates the FYPs into yearly plans that set macroeconomic targets such as money supply and financial budgets and quotas for new investment and equipment replacement among the ministries and provinces. To provide a better linkage between the FYP and the yearly plan, a 2-year rolling plan was adopted in 1992, with tentative planning targets for the following

year. The SPC coordinates the ministries, the state corporations, the provinces, and those cities whose plans are directly managed by the SPC.

7. In addition, the SPC approves all "key" capital construction projects costing more than Y 30 million to build (Y 50 million for transport projects). The projects exceeding Y 200 million must also be cleared by the State Council. Projects costing less than Y 30 million (or Y 50 million for transport projects) are approved by the ministries, provinces, and directly-managed cities according to their responsibilities and the investment quotas set by the SPC.

Planning Process

8. Each ministry and province in China has its own institutions for planning and programming, surveying, engineering design, and research and development, as shown in Figure 4.2. These institutions draw up a blueprint of long-term development for their particular industry or region and prepare investment projects in accordance with the blueprint. The Ministry of Railways (MOR) is in charge of both planning and building the railway network. The Ministry of Communications (MOC) plans and builds the highway network, waterways, and ports at the national level. The Ministry of Energy (MOE) was broken up in May, 1993 into a Ministry of Coal (MOCL) and a Ministry of Electric Power (MOEP) and the existing China National Petroleum Corporation. These two ministries are no longer involved in enterprise management or project construction; they are charged with overall sector coordination and policy guidance, and for planning state-owned energy projects. Various state corporations under MOEP and MOCL construct, finance and supervise these energy projects. Provincial governments are in charge of planning and constructing provincially-run energy projects, coordinated by MOEP and MOCL, and highway and waterway systems, coordinated by MOC.

9. In 1992, the Chinese government further decentralized project management and planning. Those construction projects whose funds, materials, and marketing can be handled by a local or provincial governments can now be be organized, sponsored, engineered, and administered at that level. For some projects that involve several ministries and/or provinces, such as an integrated project of coal mining, rail transport, and thermal power generation, different parts would be handled by the State Coal Mining Corporation (SCMC), MOEP, and MOR, with the SPC acting as the overall coordinator.

10. Those projects that do need support from upper level governments must follow a seven step planning process: (a) the sponsoring ministry or province carries out forecasting and programming of its investment projects; (b) the sponsor discusses its projects with the SPC (or PPC) and identifies priorities; (c) the sponsor submits a preliminary project proposal to the SPC (or PPC); (d) CIECC (or provincial equivalent) appraises the proposal and the SPC (or PPC) approves it; (e) the sponsor submits to the SPC (or PPC) a feasibility study (for joint ventures) or specification (for domestic projects) containing detailed information about marketing conditions, financing, material goods supply, technology, production capacity, economic costs and benefits, and condition of infrastructure; (f) CIECC (or provincial equivalent) appraises the study or the specification and SPC or the State Council (or PPC) approves it; and (g) SPC (or PPC) inserts the project into the yearly plan for execution.

Financing

11. Since the national economy is facing a long-term shortage of capital resources, the number of projects that can be undertaken will depend on how much money is available and can be borrowed. Thus, projects must be carefully chosen on the basis of economic priority so that savings may flow to high return investments.

12. The transition of China's financial sector from one that allocates credit directly to one that relies increasingly on markets can be divided into three periods. In the first phase (1979 to 1986), the government began to break up the monobank system. The People's Bank of China (or PBC) was refocused on controlling the money supply, bank reserves, and other traditional central bank roles. PBC's commercial lending was spun off to the Industrial and Commerce Bank of China (ICBC), which joined three other specialized banks including the People's Construction Bank of China (or PCBC, mainly for infrastructure lending); the Bank of China (mainly for foreign exchange transactions); and the Agricultural Bank of China.

13. During the second phase (1987 to 1991), two comprehensive multisector banks (the Bank of Communications (BOCOM) and the China Insurance Trust Investment Company (CITIC) Industrial Bank) were created, and the specialization barriers between banks began to be eliminated. The third phase (since 1991) was characterized by further market development and transformation, including the establishment of stock exchanges in Shanghai and Shenzhen. In addition to these institutions, there are now seven commercial banks (mainly regional in scope) and some 65,000 near-bank institutions (urban and rural credit cooperatives). Finally, there has been a proliferation of nonbank financial institutions, including almost 400 trade and investment corporations, 90 security companies, 40 finance and financial leasing companies, three insurance companies, and 100 branches of international banks.

14. The specialized banks served two functions until 1994. On the one hand, they engaged in business banking using a growing amount of discretionary funds which they may lend to projects which get the highest rates of return. However, they also acted as an implementation arm of central Government policy. Within the last year, the Government has initiated a new reform to deal with the latter group of so-called "policy loans" or "directed credit."

15. Policy loans generally meet two criteria: they are mandatory for the banks to finance, and they may not satisfy the bank's commercial lending criteria. Five types of loans fall into this category. First (and of primary concern here) are infrastructure investment loans that are essentially financially viable but are large scale and have long payback periods, such as power and transport projects in the FYPs. The other four categories include loans for: technological renovation of fixed assets based on the FYPs; rural development and food security programs; subsidized social sectors such as health and education; and subsidized working capital to priority enterprises. The latter includes strategic industries of national importance, export-oriented industries, and state-owned enterprises of major regional or national importance that are structurally loss-making (including coal mines).

16. In an effort to enable the specialized banks to function like commercial banks, the lending for policy purposes is being separated out from the four specialized banks and shifted to three policy banks. The first policy bank to open its doors was the State Development Bank of China (SDBC) in April 1994, followed shortly thereafter by the Export-Import Bank of China and the Agricultural Development Bank of China. The focus here will be on the SDBC because it is responsible for transport and energy policy loans. The SDBC is not profit-oriented, and would lend at subsidized rates. Funding for the SDBC in 1994 came from three sources: (a) allocation of Y 5 billion from the state budget; (b) inflows of Y 2 billion from earlier SPC-funded projects; and (c) domestic bond issues of Y 65 billion.

17. A short history of some now-defunct institutions may help the reader to understand the roots of the SDBC and also to appreciate how far financial sector reform has had to come. Before 1987, state investment funds were given as grants and did not have to be repaid. The funds were derived from taxes and from the profits of state-owned enterprises—a system which

blurred the lines between the Government, the finance sector, and the enterprises themselves. After 1987, the Government established a state investment fund with these monies, from which low-interest loans were extended by specialized banks such as the PCBC. To manage this fund, the Government in 1988 set up six National Investment Companies (NICs) under direct control of the SPC. The NICs would then choose the projects and find the partners for the SPC. The NICs no longer exist, their staff having been absorbed into the new SDBC, along with staff from the SPC's Investment Department. One potential problem facing the new SDBC is that much of the staff comes from a nonbanking background.

18. The SDBC will appraise projects not only for financial viability but also technical quality (to be contracted out) and adherence to state industrial policies. The exact process for choosing projects under the new system is not clear. Before the new SDBC, the China International Engineering Consulting Corporation (CIECC)—also under the SPC—would appraise projects. The project would then have been forwarded to the SPC and State Council for approval, which would have passed it on to the PCBC for financing. Occasionally a project already approved by the NICs and the CIECC was struck down because of the PCBC's appraisal, but for the most part the PCBC implemented the central government's investment strategy.

19. The SDBC supposedly will have autonomy in deciding which projects to finance from a list provided by the SPC. At its startup, the SDBC had 350 projects in its lending pipeline, which does indicate a tight relationship with the SPC, at least at first. Prior to the formation of the SDBC, about Y 40 billion per year of investment was controlled by the SPC.

20. In any case, the SDBC is not the sole funding source for transport and energy investment funds, which since early 1980s has come from various sources. The new flexible "method" for financing is cost-sharing, symbolized by a pie chart showing the ownership shares of different entities. A typical example might be funded by any number of sources, including: (a) the sponsoring ministry or corporation; (b) foreign capital; (c) bank loans; (d) the SDBC (or PCBC); (e) local governments; (f) local agencies; (g) private corporations; and (h) shares of stock.

21. While provinces and cities can plan and build large projects independently of the central government, the 10 to 30 percent that they typically get from the central Government can be crucial for the project's financial success. The share of central Government financing in the power sector, for instance, has fallen sharply, from 91 percent in 1980 to 30 percent in 1992, while provinces and local governments now provide 40 percent. About 70 percent of total investment is now allocated through the banking system, with about Y 40 billion per year being controlled by the SPC.

22. Whereas the SPC oversees most new investment in China, the State Economic and Trade Commission (SETC) oversees equipment renewal, rehabilitation, and innovation. However, the SETC has fewer funds at their disposal, because most of the depreciation fees are retained by local governments and enterprises. All large-scale equipment replacement projects must be approved by the SETC or its local branches, though the planning process is much more streamlined than for new investments. The SETC also can fund demonstration projects for new technologies, and they have a Y 400 million fund for energy conservation grants.

The Now Nearly Extinct Dual Price System

23. The dual price system for coal, featuring large differences between low state-determined "in-plan" prices on the one hand and higher "open market" or "negotiated" prices on the other, is now virtually extinct. Since the dual price system was introduced in the mid-1980s (replacing the preceding fully-controlled system), in-plan prices have increased in real terms (20 percent in 1991). Perhaps more importantly,

the percentage sold in-plan was cut in half in January 1993, and now accounts for less than one quarter of all coal. The rest is to be sold at free market prices by the end of 1994, with the possible exception of a few consumer categories. For instance, the MOR now buys all of its coal and electricity at market prices. In East China, coal prices are now close to or above international price levels, while in the Northeast, some producers of low-quality coal are unable to sell their entire production.

24. Under the dual system, in-plan coal was priced well below incremental production costs or border prices. Usually, ownership was the dominant factor in determining whether an enterprise's inputs or outputs are sold in or out of the plan. For coal producers, most of the coal produced by state-owned mines was until recently allocated under the plan, although production in excess of quota can be sold with a 50 percent surcharge. Township mines sold most of their coal at market prices, with province-owned mines selling under both systems. For coal consumers, all the enterprises owned by the townships and part of those owned by the local governments were supplied by out-of-plan resources. All the enterprises owned by the central Government could access the in-plan resources, although in most cases, the in-plan supply to the centrally-owned enterprises were not enough to meet their requirements.

25. Central and local governments still control most coal reserves of high quality, as well as the main transportation, such as railways, major ports, and large ships. The township mines can access only the remaining coal reserves and shorter distance transportation modes. Because the ability to sell in the market is dependent upon securing access to transport, the local and township mines in recent years have had little choice but to sell their excess production beyond local needs to the state mining bureaus at in-plan prices. For all these reasons, the in-plan and out-of-plan systems were nowhere near independent of each other.

Analytical Support

26. The State Council, SPC, ministries, and provinces have their own research centers and institutions to provide analytical support. For the SPC, the Economic Research Center (ERC) is an umbrella institute which coordinates the activities of several institutes, including the Economic Institute (EI), the Energy Research Institute (ERI), and the Institute for Comprehensive Transportation (ICT), all of which provided researchers for this study. Analytical results provided by these institutes and by others are one consideration among many used by the decision makers, and not necessarily the dominant factor. Past experience and established patterns tend to be the factors most heavily relied upon in decision making, and models tend to be used as a supporting reference.

Existing Constraints and Outlook for the 1990s

27. The task for SPC is to achieve some balance in the distribution of investment resources among different industries and regions, recognizing demand and supply realities and the availability of foreign and domestic financing sources. Most ministries and provinces each year ask for an increase in their investment quotas from the central government, citing rising transport and energy demand. Naturally, some of the projects put forward for state approval are more affordable and more badly needed than others. There is a tendency for some project sponsors to underestimate project costs in order to improve the chance of getting the project approved, or to provide insufficient allowance for price increases. To identify high-priority projects, the ministries and provinces discuss their proposals in a continuing dialogue with the SPC, often submitting projects for approval several times. A major improvement in the investment planning process since the beginning of economic reforms in 1979 has been the introduction of economic benefits as a key criterion for project selection.

28. Reform of the investment and banking systems is proceeding step-by-step. Inevitably, difficulties and distortions arise when reforms in different sectors are not coordinated. The banking system still does not control the total volume of investment, nor is it free to choose which projects to finance. Profit rates for infrastructure projects tend to be lower than for free market consumer goods because of price distortions, ownership problems, special privileges for Special Economic Zones and joint ventures, and subsidized housing, medicine and insurance. The Chinese rationale for step-by-step reform is that, until these distortions are eliminated, a totally free banking system would tend to underinvest in infrastructure. In mid-1993, some free market measures in banking were rescinded.

Reasons for Inefficient Scale of Projects

29. Institutional factors encourage local government investments to be small scale, resulting in inefficiencies, particularly in the use of energy and raw materials. If a local government invests in production capacity in another province, they lose that tax base. Local governments, in pursuit of high employment, try to produce as many of their needs as possible in local plants, and also try to keep the processing plants for locally-produced raw materials in their jurisdiction. Also, marketing is not advanced in China, making it difficult to generate demand for a product outside of the local area.

30. Local governments often do not have the financial resources to build larger scale projects. In some cases, the slow and cumbersome system of state investment approval also encourages inefficient small-scale projects. Enterprises and local governments find it easier to invest in smaller plants costing below the Y 30 million cut-off level for requiring clearance or financial contribution by the SPC. The design of provincial and county coal mines and coal washing plants are often not optimized in order to stay within a certain threshold of scale and cost.

Other Problems

31. The administrative nature of the planning and investment allocation system continues to emphasize supply targets rather than efficiency, profitability, quality, and technical innovation. Annual budgetary negotiations create a bias towards capital cost minimization without considering operating savings; this tends to discourage upgrading investments or acquisition of more efficient technologies.

32. Price distortions can lead to undesirable side effects. Distortions in the prices of inputs to rail transport, especially the low price of electricity, may result in nonoptimal choice of railway technology (e.g., electric traction instead of diesel traction). The low prices of coal also discourages investment in coal mining.

33. Uneven and inflexible foreign exchange allocation often hampers imports of intermediate or final technologies which could foster more rapid modernization of domestic equipment in a number of industries—including coal, cement, and fertilizer. The lack of foreign exchange may force enterprises to use local materials and equipment which have low initial costs but sometimes do not last long enough to be economical.

Figure 4.1: Administrative Control System for Energy and Transportation

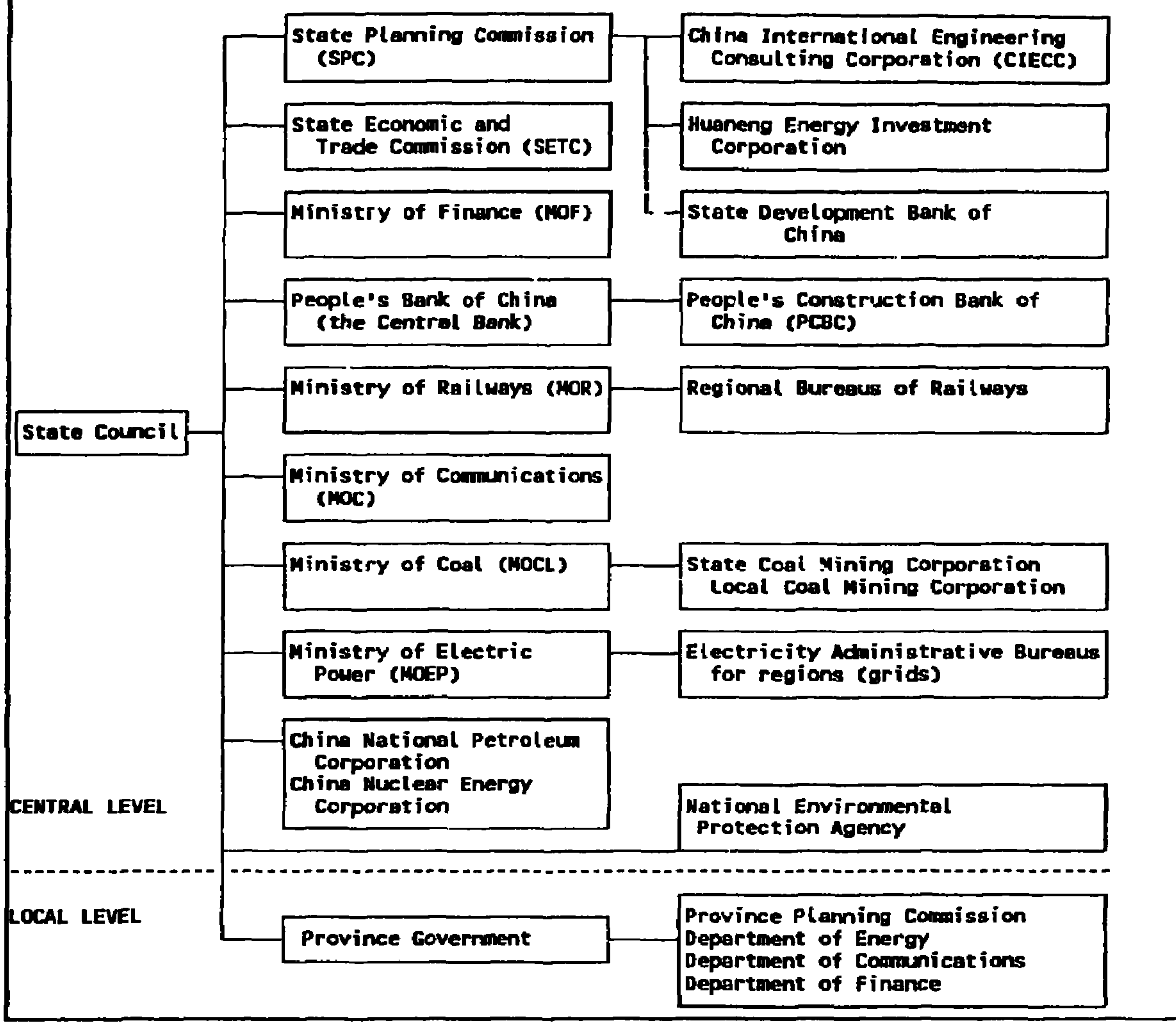
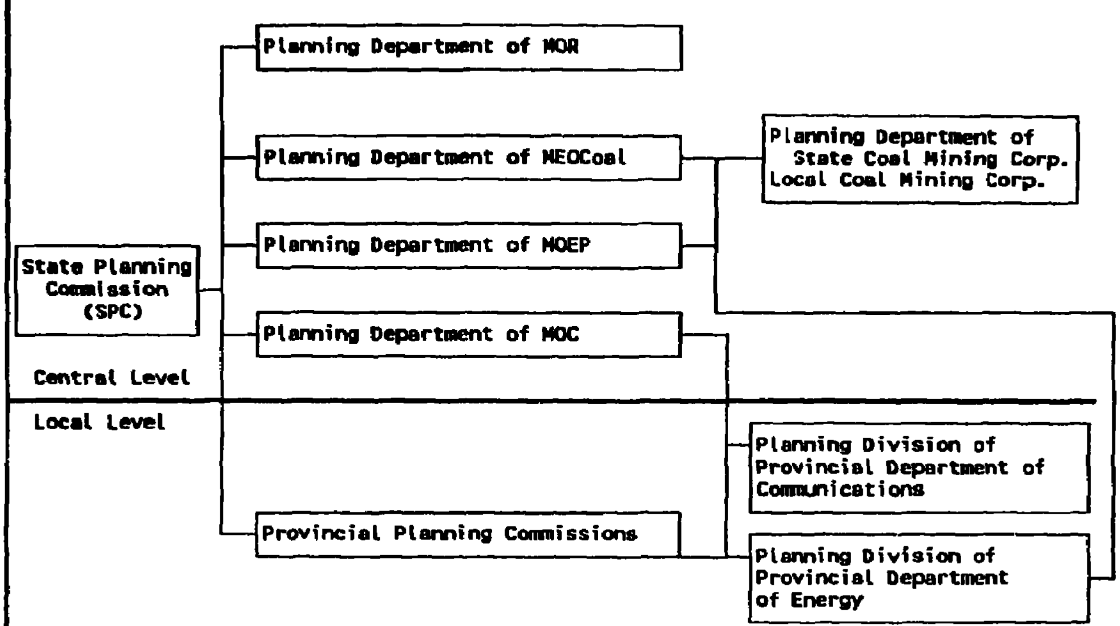


Figure 4.2: Planning System for Energy and Transportation



THE CTS ANALYSIS SYSTEM

1. This annex provides an overview of the CTS analysis system, a summary of strengths and limitations of the model, and a theoretical analysis of supply and demand in linear programming models. The technical aspects of the analysis system, such as the model formulation, data base structures, and software system, are described in Volume II.

Model Overview

Purpose and Scope

2. In studying China's coal and electricity shortages, it became clear that in addition to increasing the transport capacity, investments such as coal washing and hydropower may, in some circumstances, reduce the demand for coal transportation in a cost-effective and environmentally beneficial way. Likewise, there is a close substitutability between rail transport of coal and minemouth power plants coupled with long distance transmission lines. Therefore, it is necessary to evaluate these different options in a systematic and integrated fashion.

3. The CTS analysis system was designed as a strategic-level *Decision Support System* (DSS) to help the SPC in this task. It is a tool to *support* SPC policymakers in making *decisions* by providing a fast and comprehensive way to study energy delivery *as a system* rather than as separate parts. Its primary use is to identify investment priorities by sector, corridor, or region. A fully automated software system allows the user to easily create new scenarios modifying key assumptions. With this DSS, policymakers can answer "what-if" questions and analyze tradeoffs between economic goals, energy supply goals, and environmental goals. It can analyze the effect of hypothetical rail or port projects, cost differentials, import restrictions, budget constraints, environmental goals, or other policy variables on such outcomes as bottlenecks, flows, shortages, costs, capital budgets, and environmental impacts.

4. The task of simultaneously optimizing all of these interrelated energy and transport activities is not doable without a large model. And yet, the CTS model is designed to complement other more detailed models for planning particular sectors of the coal-electricity delivery system, such as rail planning models or electricity system programming models.

Methodology

5. The CTS model is a mixed-integer (linear) program that minimizes the total cost of delivering coal and electricity subject to capacity constraints and optional budget and environmental constraints. It combines features from the major coal and electricity planning models used in the United States, but has been tailored to the SPC's needs. The cost function includes operating costs and annualized investment costs for transportation, mining, and the other sectors, as well as a penalty cost for coal and electricity shortages. Given any forecast of GNP growth and energy demand elasticity for 1995, 2000, and 2005, the model will try to satisfy those demands for the lowest cost possible.

6. The CTS analysis system models all of these activities simultaneously by treating the energy delivery system as links of a chain (see Figure 6.1, Annex 6). The nontransport activities are represented as a generalized network, which is well-suited for modeling energy systems in which the output of one process is the input to another. The chain begins with coal mining by three

levels of technology and four broad types of coal. Anthracite and low ash steam coal can be transported in raw form, coking coal must be washed, and high ash steam coal has the option to be washed. Coal washing is modeled as a flow that converts one ton of raw coal to a lesser amount of better coal. The raw or beneficiated output is then transported over a multimodal transport network to demand nodes, where shortages occur if not enough is delivered. All users of each type of coal, that is, anthracite, coking, and steam coal, are aggregated together at each node.

7. Next (in the second half of Figure 6.1, Annex 6), coal competes with hydro and nuclear power. Thermal power generation is modeled as an activity where the tons of coal in kilocalories are converted to a lesser amount of kilowatt-hours of electricity. Electricity from all sources then flows over a transmission network, with some losses, to electricity demand nodes, where shortages can occur in any of five end-user sectors, each with a different willingness to pay. Demand drives the model, pulling coal and electricity across this entire system. Finally, ash and sulfur content of the delivered coal (from both sides of Figure 6.1) are tallied after accounting for optional coal washing and scrubbers.

Inputs and Outputs

8. The CTS model uses four kinds of inputs. Project data define which investment options are to be considered. Technical data specify capacities, wash-out rates, electricity loss factors, and electricity conversion factors. Economic data set investment and operating costs. Policy assumptions are demands and shortage costs, and, if desired, environmental or importation restrictions, or budget constraints. The model's primary outputs are (a) optimal type, location, scale, and timing of new investment projects; (b) optimal coal and electricity distribution patterns; (c) optimal use of existing mining, washing, transport, generating, and transmission capacity; and (d) predicted locations of bottlenecks and shortages, and data on systemwide costs and amounts of ash and sulfur in the delivered coal.

Level of Detail

9. Temporally, the model covers three time periods: currently these are the final years of the 8th, 9th, or 10th five-year plans (1995, 2000, 2005). Demand must be met in each time period. Investments made in any time period carry over into later time periods, while some preexisting capacity is retired each period.

10. Spatially, the Chinese economy is divided into 48 coal supply nodes, 49 coal demand nodes, 58 electricity supply nodes, and 38 electricity demand nodes. The transport network is represented by 286 railway arcs (177 of which have investment projects), 31 ports, 3 potential slurry pipelines, and 99 transmission lines (see Figures 6.2-6.4, Annex 6).

11. Technologically, there are four basic types of coal (low and high ash steam, anthracite, coking), but within each type, the ash, sulfur, and kilocalories per ton are uniquely specified for each zone. Four classes of coal users (steam coal for electricity, steam coal for industry, anthracite, coking) and five types of electricity users (rural, urban, light and heavy industry, and agriculture) are the driving forces in the model. There are four types of power plants (baseload thermal, middlings thermal, hydro, and nuclear), with the hydro plants being uniquely defined based on local conditions. Four types of transmission lines (220 kV AC, 330 kV AC, 500 kV AC, and 500 kV DC) are used to transmit electricity both within and between grids.

Environmental Analysis

12. The CTS model facilitates multicriteria analysis by allowing constraints to be placed upon the total tonnage of ash and/or sulfur content of the delivered coal to each province in each of the time periods. The analyst can disable these constraints, in

which case they simply count the totals. Alternatively, the analyst can force reductions of any given percent or to any given target (or a range of percents or targets) in order to find out how much more it would cost to do so and what is the least cost way of doing so. In this fashion, the user can trace out a Pareto efficient fronteir between the conflicting goals of minimizing cost and minimizing delivered ash and sulfur content (see Figure 10.12, Annex 10). The solutions found in this way have the property that, given the options available in the model (see Limitations, below), there are no other solutions that are *both* lower cost *and* lower in ash and sulfur content. This type of analysis recognizes the difficulty of putting an economic value/cost on ash and sulfur content, and instead leaves it up to the reader to determine which point on the tradeoff curve is best, considering also various factors not included in the analysis.

User Friendliness

13. The analysis system runs on a 486 IBM-compatible computer and is completely menu-driven. It is automated so that SPC planners can easily generate data inputs for scenarios with modified assumptions about costs, demands, capacities, routes, imports and exports, interest rates, shortage costs, or environmental policies. It automatically processes the results and outputs them in summary tables and maps (see Figure 6.5, Annex 6).

Strengths and Limitations

14. Models have been defined as "simplified representations of reality." There are four ways in which any model simplifies the system under study. First, the model simplifies reality by limiting the choices available for investment and routing decisions. Second, the model simplifies relationships by linearizing a nonlinear relationship or ignoring a feedback loop. Third, some activities must be left out of the model that really are related to the system, and there is always the danger that something that has been left out cannot be adequately treated by scenarios. Fourth, for those activities that are not left out of the model, complexities are ignored and details are suppressed. The way that the CTS model simplifies China's reality in each of these four ways determines its strengths and weaknesses.

Strengths

15. The strength of the analysis system is its use as a spatially-based strategic-level planning tool. The fact that the mining, washing, transportation, and consumption of coal are optimized simultaneously with the generation, transmission, and consumption of electricity, and that all of this is done in a spatially disaggregated way in the context of environmental concerns over a fifteen year time horizon is certainly the main strength of the modeling system. However, in modeling, a broader scope does not always mean a better model, because realistic detail and performance are usually sacrificed by including so much. So why is the broad scope considered to be a strength of the CTS model? Because logistically and economically, these investment activities are so closely interconnected that there are too many tradeoffs for them to be realistically compared outside of such a model. Take coal washing vs new transport infrastructure vs new minemouth power plants and long-distance transmission lines. All of these investments can help alleviate the shortage of electricity in an urban area. But their comparative economics depend on coal type, distance, budget availability, their contributions to sulfur and ash pollution, and losses in washing, generation, and transmission, etc. Perhaps for a given origin and destination, their economics can be compared without a network optimization model, but in China there is a multitude of origin, destination, route, and coal type combinations to choose from.

16. Given that the comparative economics dictates a broadly-defined strategic network model, the next question

is, how can this be accomplished without sacrificing too much realism? In the CTS, the level of detail is pitched to allow for spatial disaggregation of supply, demand, and transportation, while still including related economic activities and multiple time periods. By not disaggregating these activities to the level of individual plants, mines, and rail spurs, enough "room" is left within the model to allow the electricity sector and three time periods to be modeled.

17. The use of path variables is both a strength and a weakness. If one can live with a limitation on the number of transport routing options (see weaknesses), the use of path variables eliminates the need for mass balance constraints at every transportation junction point, which would have had to have been by coal type, and would have made the number of constraints much too large to be included. With path variables, it is possible to uniquely specify the heat, sulfur, and ash of each kind of coal at every origin. Plus, the use of path variables enables the policy makers to determine the source(s) of each user's coal.

18. Another strength of the model is that mixed-integer programming is straightforward, well-known, and understood by planners and economists in China and at the World Bank. There are no heuristics used here with unknown performance levels. Also, the model solution is the result of a single run of a single model, so there are no questions about suboptimality that are often raised by decomposing a model into several parts or by using a family of linked models. Certain problems dictate the use of these other techniques, but for every heuristic used, the "black box" gets more and more opaque. In this case it must be considered a plus that such a complex problem has been made amenable to such a straightforward solution methodology.

Limitations

19. The first and foremost limitation is the limited choice set, and the most limiting case of this is the use of the path variable methodology. While path variables are the best way that multiple modes and coal types could have been handled in a large network, the use of paths is limiting precisely because the number of paths is limited. The number of logistically-possible paths from just a single origin to a single city can be enormous. Despite the use of a least-cost path generator, it is inevitable that some valuable path options will not be included. This has the tendency to force as much coal as possible on this smaller set of cheapest paths, which is not a bad result in and of itself. However, when arcs become capacitated, coal has to flow on whichever remaining paths do not use the congested arcs.

20. A similar limitation of this sort is caused by the use of transport packages. Although a necessary simplification in terms of model tractability, it limits the flexibility of the model to freely optimize investment spending in the transport sector. For instance, if the first phase of an infrastructure package is economically justified but the second is not, the model is forced to make an all-or-nothing choice on both investments together. In summary, the model results are really only as good as the paths and packages that are included as inputs.

21. The second type of methodological simplification is caused by linearity. Many economic phenomena tend to be highly nonlinear. Some examples from this model would include: congestion costs which increase exponentially as links approach their capacities; shortage costs per ton or kWh which also tend to increase at an increasing rate; economies of scale which tend to produce flattening total cost functions; environmental impacts which tend to increase suddenly as thresholds are surpassed; and demand which is a nonlinear function of price. In the CTS, congestion costs are avoided by imposing "brick wall" capacities on arcs; shortage costs are linearized based on the international price of coal; economies of utilization (not of scale) are approximated by a total cost function with a fixed-charge intercept and flatter slope; and environmental impacts are

ignored in favor of ash and sulfur contents which are more quantifiable units. (Demand, a more complex and central matter, is discussed in detail in the third section of this Annex.) These are all standard linearization techniques, but they must be recognized as approximations. In the future, it is possible to enhance the model by using a step function for coal shortage costs, and thus eliminate the shortage upper bounds.

22. The third type of limitation is caused by drawing an artificial line around the system and, by necessity, having to designate some activities as being part of the system's environment rather than part of the system itself. Despite the model's already broad scope, the CTS model is still quite limited by the fact that many energy and environmental activities could not have been included as endogenous variables. Most limiting is the omission of technologies that reduce ash emissions, because it leaves the model with only indirect methods of reducing ash (e.g., changing coal types, substituting hydropower, washing coal), which is inconsistent with the way sulfur is treated in the model. The social costs of pollution are also well beyond the scope of this model. It must be recognized that reducing ash and sulfur content of the delivered coal is *not* the true ultimate goal of environmental policy in China. Likewise, leaving out ash disposal and boiler maintenance activities makes it harder to evaluate the benefits of steam coal washing. Energy conservation, so valuable for reducing shortages and cleaning the environment, must also be modeled exogenously, though it is being added to the model (along with CO2 constraints) in a spinoff research project funded by a World Bank McNamara Fellowship.

23. The fourth type of limitation is oversimplifying or ignoring complex matters. Oversimplification is primarily visible in the electricity sector of the CTS model. For instance, the CTS model does not explicitly use load curves for electricity demand. Instead, the CTS satisfies total demand for kWh (the area under the load curve) and peak demand for kW (the highest point on the load curve). Some accuracy is inevitably lost in this approximation. A second major approximation by the CTS is that peak demands are pooled for the entire grid instead of being satisfied at each node. This implicitly assumes that electricity management within a grid does not need to be planned at the national level. Another example, outside of the electricity sector, is that the CTS model ignores other coal characteristics besides heat, sulfur, and ash.

Demand in the CTS Linear Programming Model

Exogenously-Specified Demands, No Explicit Prices

24. From the outset, it must be acknowledged that the CTS model is primarily a supply-side model. It is not an equilibrium model that solves for the welfare-maximizing supplies, demand and prices. The strategies that come out of the model are, of course, price sensitive, and obviously, prices have to be determined by an equilibrium argument. This model is not designed for determining prices. In fact, the model deals only with economic costs, not prices. However, price assumptions can be (and have been) made in forecasting demands.

25. In the CTS's linear programming methodology, demands for coal and electricity are exogenous inputs that drive the production and distribution activities on the supply side. Demands for three kinds of nonelectricity coal (anthracite, coking and steam) must be specified for each of 49 zones in 1995, 2000, and 2005. Coal demand is for tons of standard coal (5,500 kcal per kg), which can be satisfied by less than one ton of better quality coal or more than one ton of lesser quality coal. Likewise, demand for electricity, in kwh, is specified at 38 demand zones in each time period, but is subdivided into separate demands for the agricultural, urban, rural, light industry, and heavy industry components, each of which is separately

forecasted. Coal demand for the electricity sector is not exogenously specified, but is an indirect result of the demand for electricity, which pulls electricity from hydropower, nuclear or thermal power plants. The thermal plants in turn pull coal to those plants from mines, through washeries, and across the transport network. Transport demand in this study is thus a derived demand: the actual coal flows are an endogenous result of competition between types of power, coal origins, coal types, transport modes, etc.

Low, Medium, and High Demand Scenarios

26. Obviously, there is a great deal of uncertainty surrounding any forecast of future coal and electricity demand, especially as prices are deregulated and as one looks further and further into the future. The major way of dealing with this uncertainty in this model is to run separate scenarios with low, medium, and high demand forecasts. Ideally, an even more theoretically appealing way to use this kind of model would be to iterate between a general equilibrium model and production-distribution models like the CTS. The procedure would be to get price and demand forecasts for coal, electricity, oil and gas from the equilibrium model; pass them to the CTS model or similar oil and gas models; solve the various production-distribution models; pass delivered cost and shortage information back to the equilibrium model; convert delivered cost to price in some fashion; restimate prices and demands; and iterate until consistent solutions are reached. This approach is being taken in the US Department of Energy's new National Energy Modeling System.

27. In the absence of such an equilibrium model, the next best thing is to run the CTS model with a range of different demand assumptions. As the demand forecast is raised from low to medium to high over three different scenarios, the average delivered cost of energy is driven up as the model mines more expensive coal in the coastal regions, washes more coal, substitutes more expensive hyrdopower for coal, ships more coal by water, takes more round-about routes, and otherwise attempts to satisfy that demand at the lowest cost. This process continues up until the marginal delivered cost reaches the shortage cost specified for the coal type, zone, time period, and user type (in the case of electricity). After that, further increases in the demand forecast would lead only to higher shortages.

Usefulness of a Cost-Minimizing Model for China's Emerging Market Economy

28. Models such as these are useful for decision support for a whole variety of decisions that the SPC may be grappling with, both policy decisions and investment decisions. In this multisectoral physical system, there is a complex set of logistical interrelationships that cannot be understood in any other way. That is not to say that the many minds that together make up the market will not eventually allocate resources efficiently. But the methodology affords an opportunity to evaluate various complex options more completely than the current transition market economy can evaluate them. **The methodology allows the dominance of complex options over one another to be evaluated in a rough way before proceeding to a more refined economic analysis.** Furthermore, externalities such as environmental effects may not be comprehended by the system of prices in China for many years, if ever.

29. In China's socialist market economy, much economic decision making has been decentralized. Just because a variable is in the model does not mean that the government has to centrally control it. Of course, many of these decisions are internal to firms. **The variables are included in the model so the relationships and tradeoffs can be analyzed.** With the model, the key Chinese decisonmakers at least have a better sense of where profit-maximizing (cost-minimizing) firms might build thermal plants and where they might build hydro than if

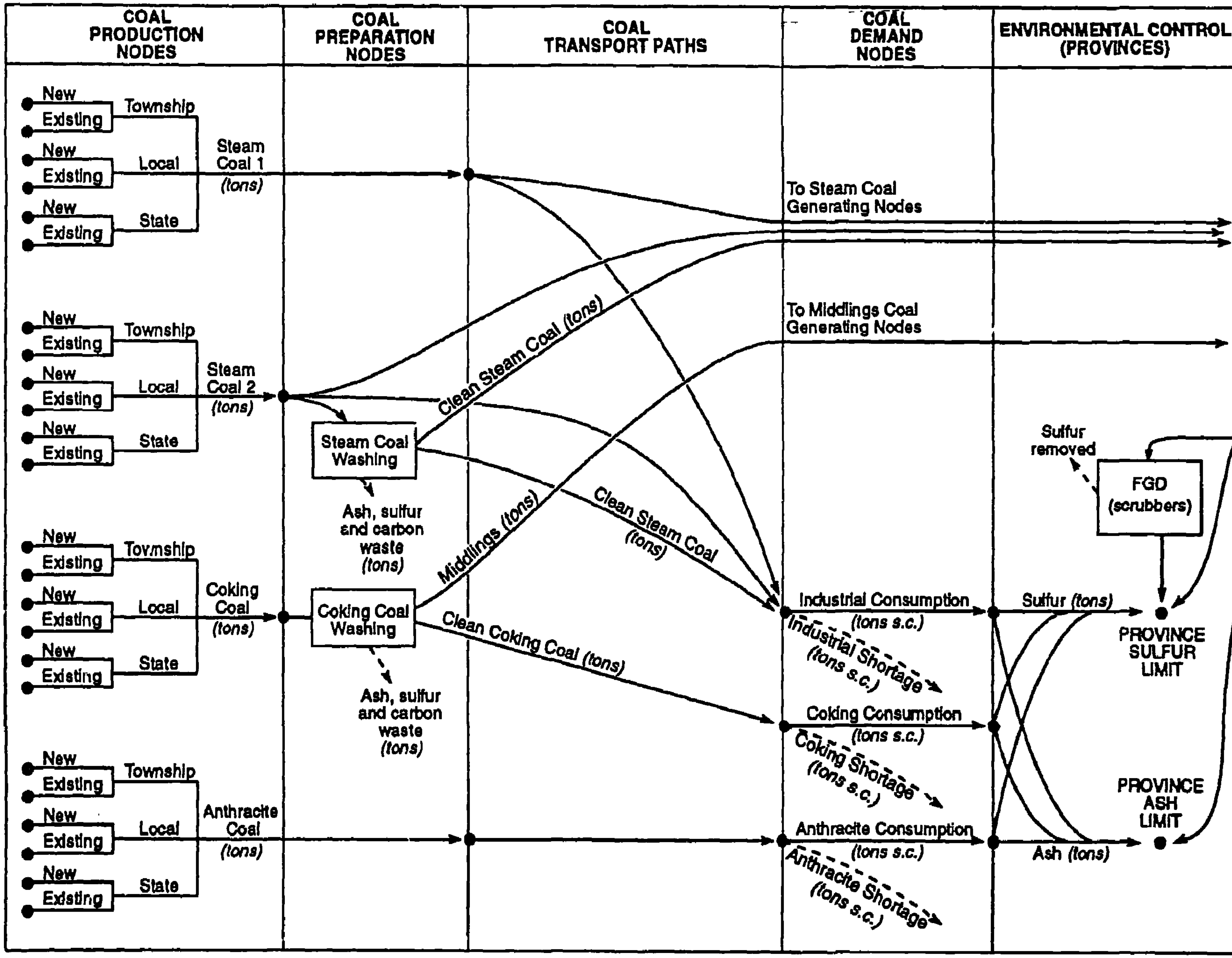
those essentially decentralized decisions had been left out of the model.

30. A cost-minimizing model need not distract attention away from the actual market policy instruments the government is likely to be able to use. In fact, it can do exactly the opposite. For instance, despite the fact that most industrial coal users already pay at least the long-run marginal costs for transport, and therefore the market signal that would encourage firms to wash coal are present, steam coal washing has not taken off in China. There is no well-developed market for washed coal yet. We cannot yet rely too much on China's not-fully developed markets. In the US, 50% of coal is washed, and even a larger percentage in Europe. The main reason why market forces have not yet caused an increase in coal washing is that the transaction costs (institutional barriers) for washing might be too high and the environmental policies for internalizing social costs of pollution are not in place. Therefore, these model results add fuel to the policy dialogue regarding lowering those transaction costs, removing those institutional barriers, and internalizing externalities. To cite another example, Mr. Gui Shiyong, Vice Chairman of the SPC (in a letter to the management science prize commission) wrote that the "CTS proposed for the first time that it is reasonable to import coal in the coastal areas to alleviate the coal shortage. Presently, some provinces like Guangdong have followed this proposal." This is a *pro*-reform impact of the model.

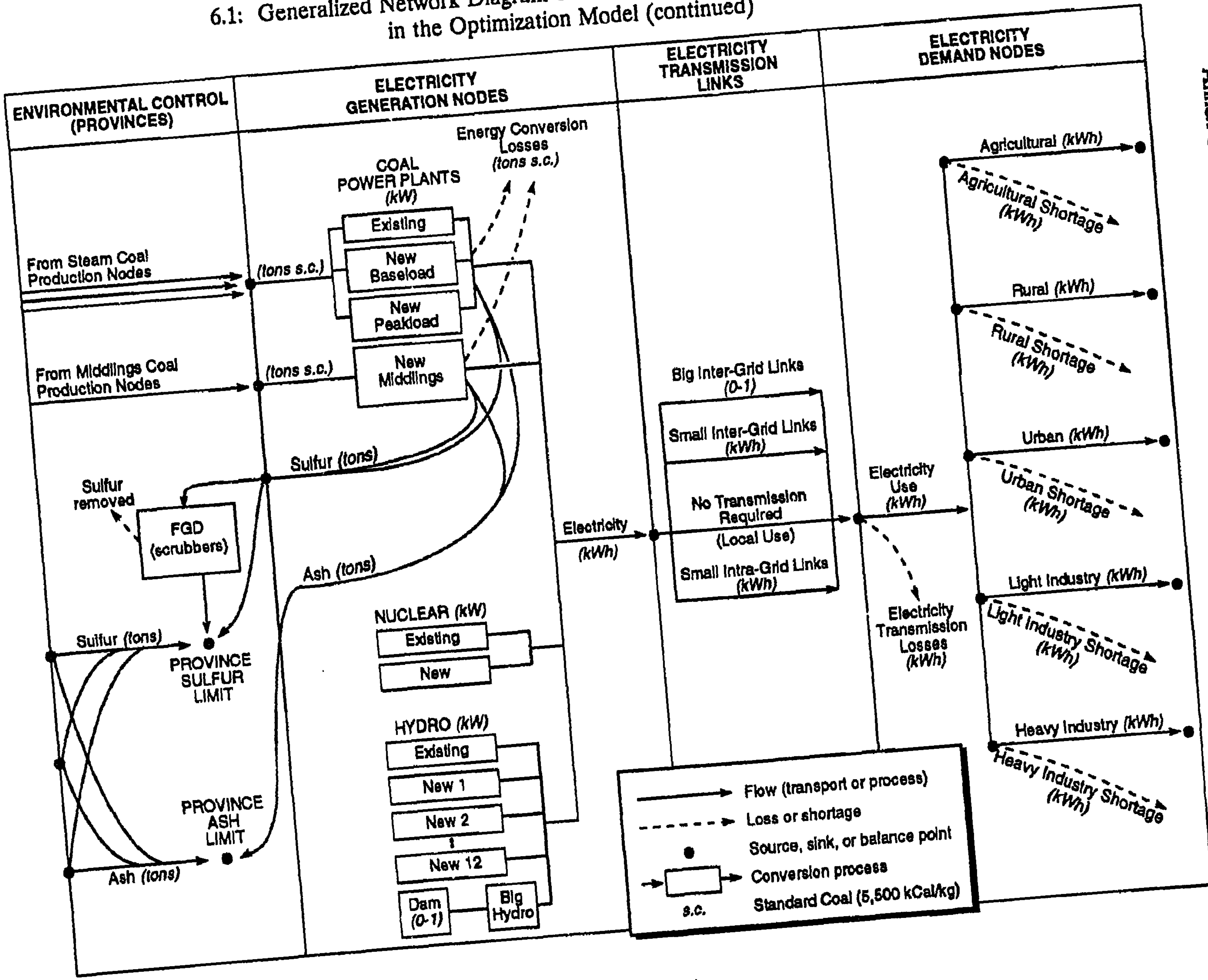
31. Also, might not this model help convince firms to investigate these strategies? In fact, other Bank studies have analyzed coal washing and transmission. Although their results provided many useful insights, these studies had to assume an origin, a destination, a coal type with a particular ash, sulfur and heat content, a distance, a terrain, a mode, etc. If any one of those factors differs, the analysis no longer applies. So, how convincing would those analyses be to a Chinese power or mining company located elsewhere? On the other hand, the CTS model not only considers all of those factors explicitly, but also takes into account whether, in the grand network scheme of things, there is likely to be enough transport capacity. If a Chinese entrepreneur saw these results in which (a) there are likely to be bottlenecks on the routes to his or her city, and (b) that steam coal could not only be washed and transported to his or her city for a cost less than the cost of importing coal, but (c) could pay for itself in terms of weight reduction, might not that be useful information?

Figures and Maps on the CTS Analysis System

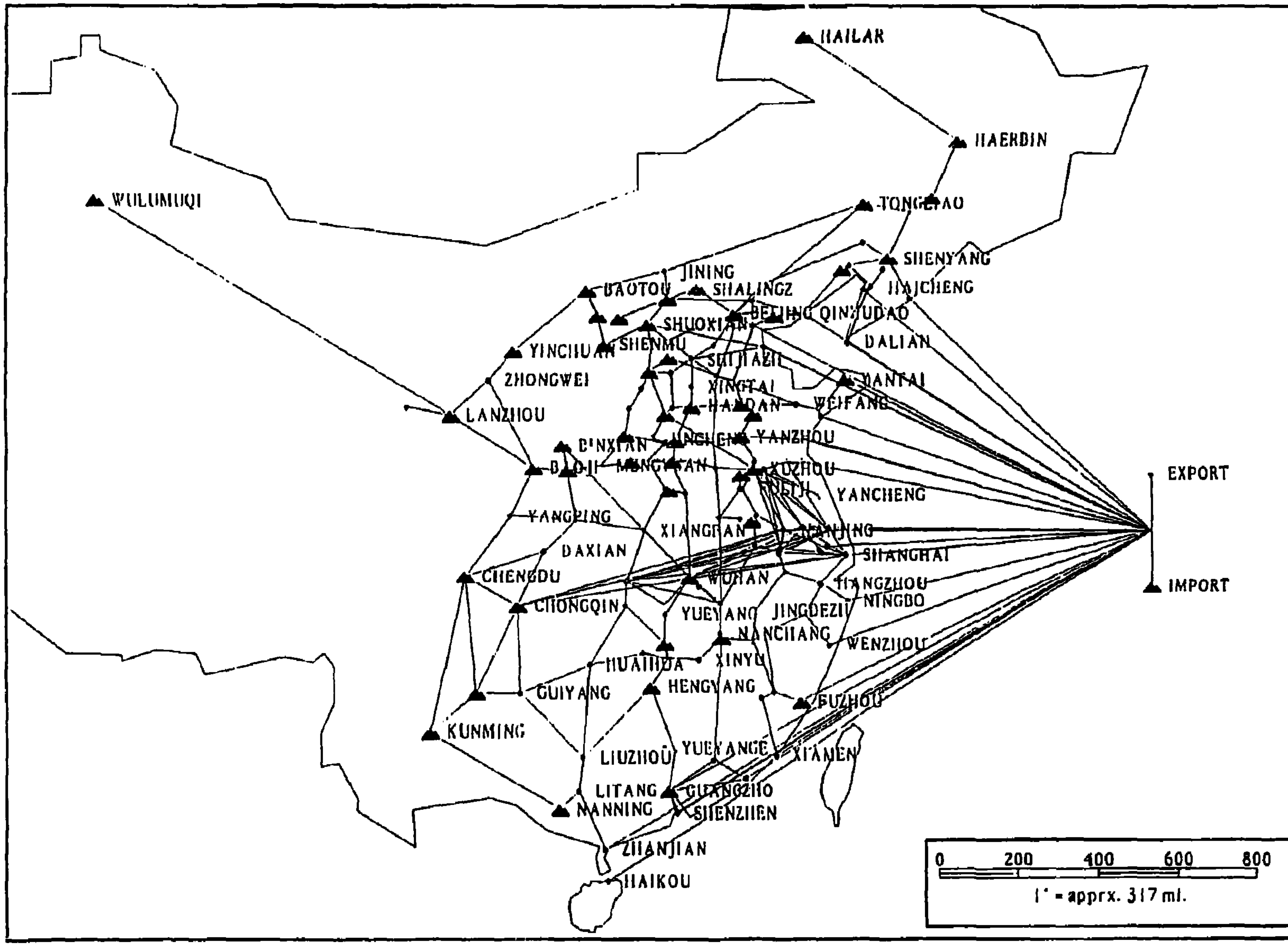
6.1: Generalized Network Diagram of the Coal-Electricity Delivery System in the Optimization Model



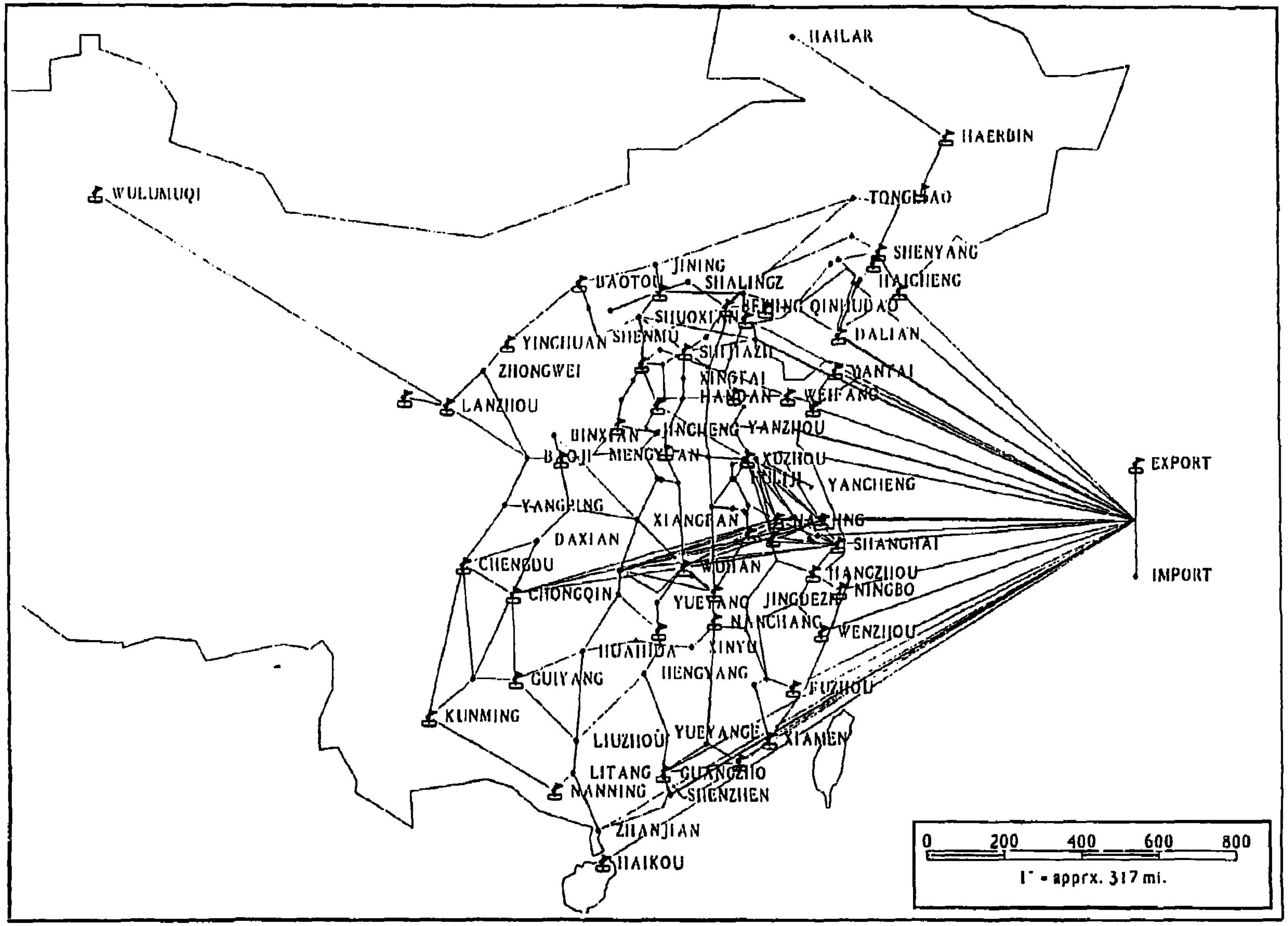
6.1: Generalized Network Diagram of the Coal-Electricity Delivery System in the Optimization Model (continued)



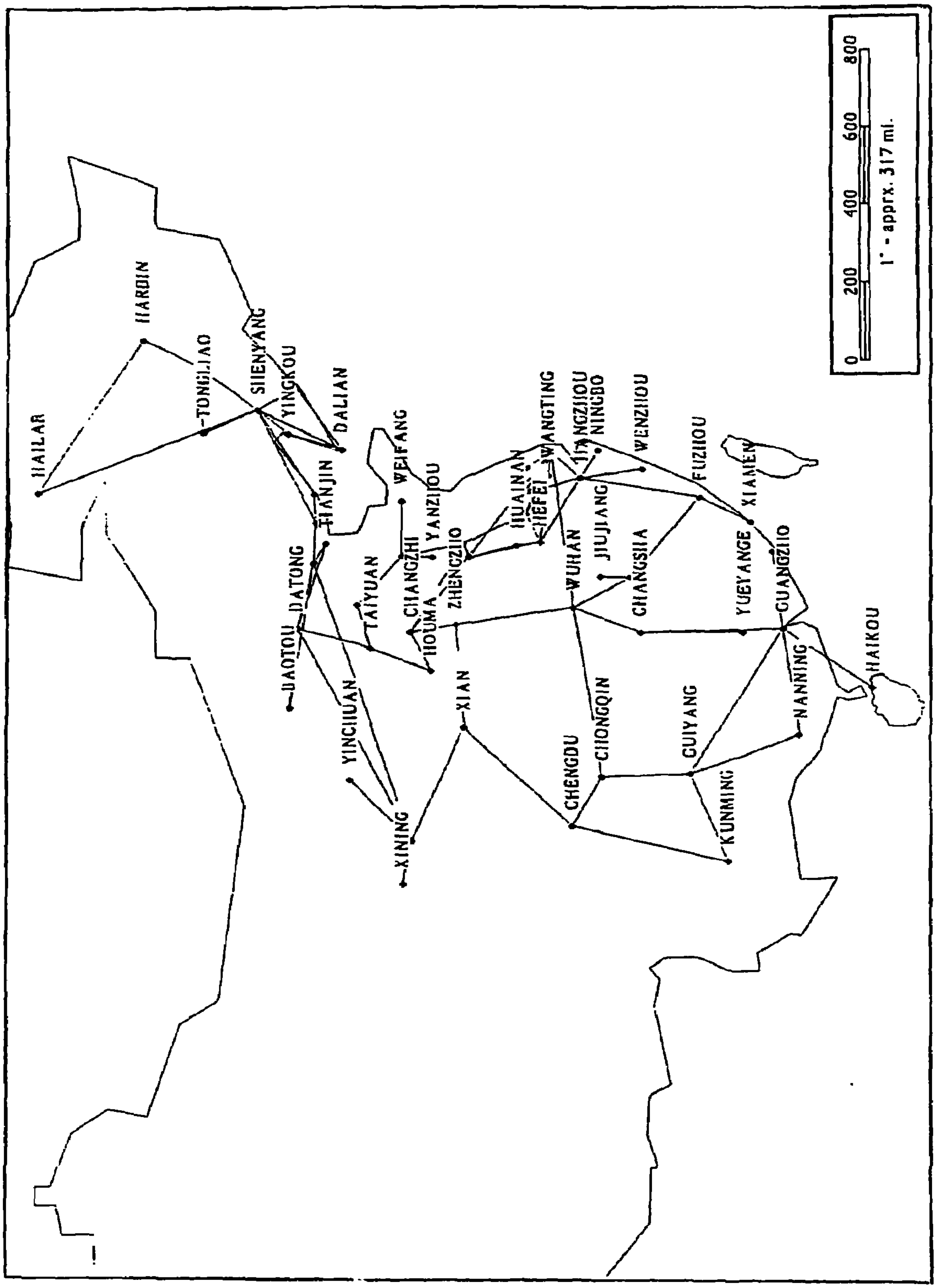
6.2: The CTS Coal Transportation Network with Mine Nodes



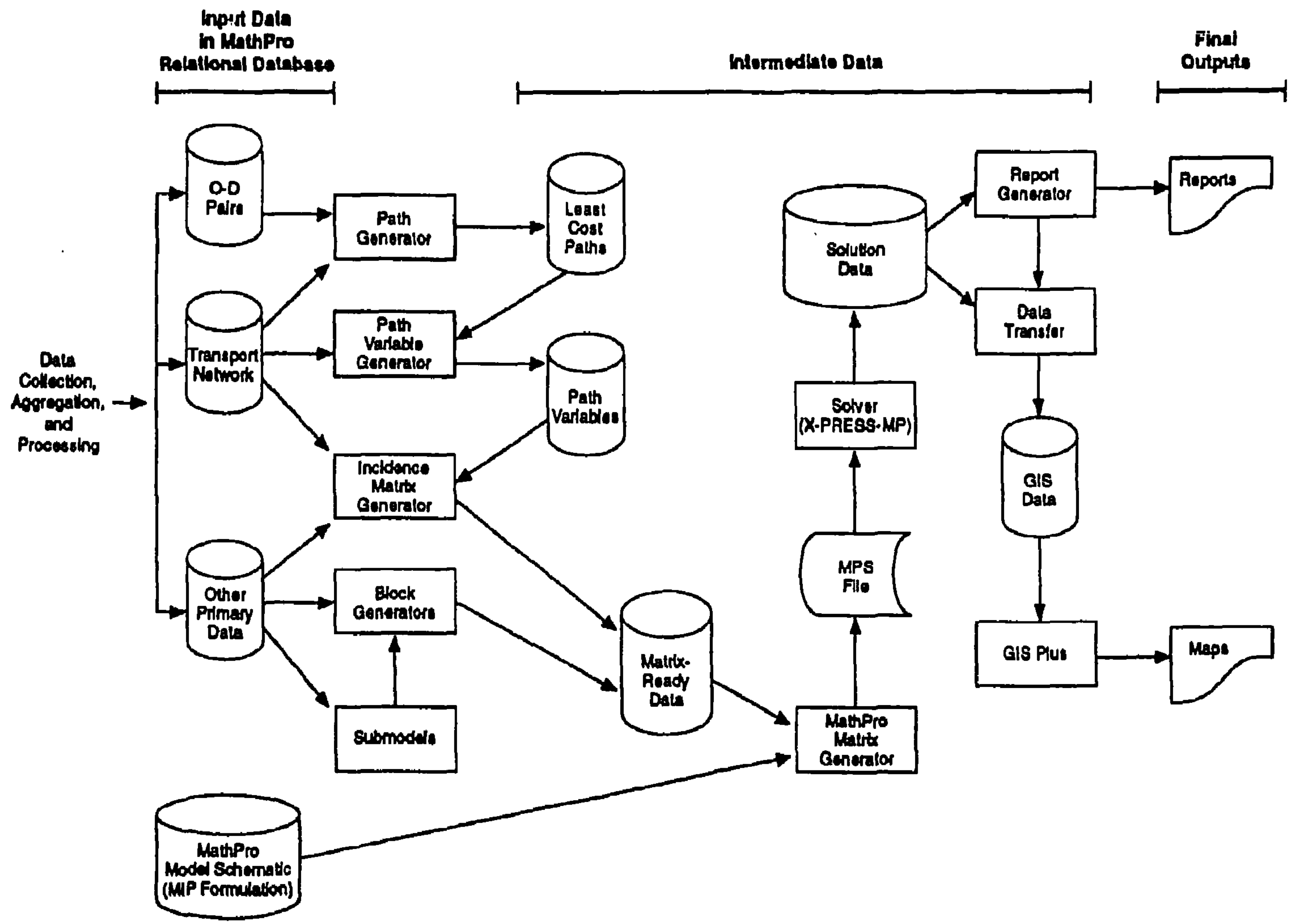
6.3: The CTS Coal Transportation Network with Demand Nodes



6.4: The CTS Electricity Transmission Network



6.5: CTS Data Flow



DESCRIPTION OF 1993 SCENARIO ASSUMPTIONS

Scenario Assumptions

1. Thirteen scenarios were run from July-October, 1993. They can be divided into two groups, according to the handling of the investment decisions for major projects (i.e., transport projects, large dams, and 500 kV DC power lines, modeled with 0-1 variables). In Case 93-1 (the base case) and Case 93-10, the investment decisions for major projects are optimized. These cases are valuable for policy purposes because they endogenously compare transport investments with the nontransport substitutes, like hydropower and coal washing, under various combinations of conditions. (However, it should be noted that the yes-or-no decisions that the model makes about transport projects gives no consideration to other commodities, i.e., the decisions are based on coal's share of the projects' investment cost and capacity.) In the other cases, the major projects were fixed at their values from Case 93-1 (1=to be built, 0=not to be built). In essence, this latter group of cases can tell us how well the set of major projects optimized for the 9 percent GNP forecast would be able to meet China's energy supply needs under various conditions. The exception to these two groups is Case 93-2, which differs from the base case only in assuming that the railway from Shijiazhuang (continuing from Shenmu) to Huanghua (new port) can be completed by 2000.

Case 93-1—Base Case (9 percent GNP, no policy changes)

2. Coal demand in the year 2000 is 906 million tons of standard coal per year, which represents an assumed elasticity of 0.3 (percentage growth in coal demand/percentage growth in GNP). Electricity demand in 2000 is 1.44 trillion kwh, assuming an elasticity of 1.0. No environmental reductions are imposed. Major investment projects are optimized.

Case 93-2—Huanghua Railway Base Case

3. Same as base case, except it assumes that the railway from Shijiazhuang (continuing from Shenmu) to Huanghua (new port) can be completed by 2000, whereas the base case assumed (accurately so, at the time) that the railway could not reach the port by 2000.

4. The main result: shortages in 2000 fall by 7 million tons (18 percent), and systemwide costs fall by 0.22 percent; 6 million more tons of coal washed in 2000.

Case 93-3—Ash and Sulfur Reduced by 10 Percent

5. Constraints were added to forcibly reduce the national total of ash and sulfur content by 10 percent below Case 93-1 (unconstrained) levels. Major investment projects are the same as in Case 93-1.

6. The main result: systemwide costs rise by 3.12 percent compared with base case.

Case 93-4—Ash and Sulfur Reduced by 20 percent

7. Same as Case 93-3, but reduced by 20 percent.

8. The main result: systemwide costs rise by an additional 7.5 percent compared with Case 93-3.

Case 93-5—15 Percent Increase in Coal Washing Investment Costs

9. All coal washing investment costs are increased by 15 percent. Major

investment projects are the same as in Case 93-1. This case determines the cost sensitivity of the coal washing strategy.

10. The main result: the steam coal washing rate falls only 0.1 percent from 16.3 to 16.2 percent.

Case 93-6—15 Percent Increase in Electricity Transmission Investment Costs

11. All electricity transmission investment costs are increased by 15 percent. Major investment projects are the same as in Case 93-1. This case determines the cost sensitivity of the long-distance transmission strategy.

12. The main result: transmission from Nanning falls by 22 percent, most others remain stable.

Case 93-7—Steam Coal Washing Benefit Case

13. Upper bounds were added to forcibly prevent any new steam coal washing capacity from being built. Major investment projects are the same as in Case 93-1. This case is used for estimating the benefit of steam coal washing investments, by comparing the total cost with that of Case 93-1.

14. The main result: systemwide costs increase by almost 2 percent.

Case 93-8—Large Transmission Lines Benefit Case

15. Same as Case 93-7, but for new 500 kV power transmission line capacity.

16. The main result: systemwide costs increase by 0.8 percent.

Case 93-9—10.5 Percent GNP Case (using 9 percent transport capacity)

17. GNP growth is assumed to be rapid. Electricity demand in 2000 is assumed to be 1.66 trillion kwh, 15 percent higher than the 9 Percent case. Coal demand is 926 million tons, 2.2 percent higher than the 9 Percent Case. Major investment projects are the same as in Case 93-1.

18. The main result: coal and electricity shortages in 2000 are a combined 138 million tons. Hydropower and coal washing are increased slightly, but intergrid transmission must fall, as less electricity production is considered surplus available to be transmitted to other grids.

Case 93-10—10.5 Percent GNP Case (with reoptimized transport capacity)

19. Same as Case 93-9, except major project investment variables are reoptimized using a 3-stage heuristic optimization process yielding an all 0-1 but probably suboptimal solution.

20. The main result: the only difference between the railway projects in this case and those in the base case is the addition of the Shijiazhuang-Huanghua railway line; it was assumed that construction could be accelerated given faster growth. All the railway projects that can increase railway throughput were already chosen in the 9 percent GNP case. As with Cases 93-1 and 9302, the addition of the Huanghua port by 2000 results in 7 million tons fewer shortages.

Case 93-11—Triple New Railway Capacity Case

21. A question that can be asked about these runs is whether the model's decisions to invest in "railway substitutes" like coal washing, hydropower, and transmission are really economically optimal from a cost-minimizing point of view, or are they suboptimal investments that are forced into the model's solution due to lack of enough railway project alternatives? This scenario is a hypothetical case that can shed some light on that key theoretical question. In this model run, all assumptions are identical to Case 93-10, except that the 0-1 variables for transport investments are allowed to vary continuously between 0 and 3, meaning that any new railway or port project can be tripled in size by tripling the

investment. This case provides only a rough cut answer to the question, because tripling the size is not a realistic option for some arcs, and because this option was not given to existing railway arcs with no expansion plans.

22. The main result: the steam coal washing rate actually rises, since greater transport capacity allows more washed coal from the energy base to be shipped long-distance, implying that steam coal washing pays for itself by lowering transport costs. Hydropower is virtually unchanged from other high demand cases, but intergrid electricity transmission falls by 40 percent, by far the lowest level of any scenario.

Case 93-12—High Demand, High Shortage Costs

23. Same as Case 93-9 (10.5 percent GNP), except coal and electricity shortage costs are Y 350 per ton instead of Y 300, 17 percent higher. Electricity shortage costs are assumed to be higher by the same percentage. The purpose of this case is to determine the sensitivity of the results to the shortage cost assumption. The results tell us how much of the unsatisfied demand in the high demand scenarios is a logistical shortage and how much is an economic shortage, i.e., demand could be satisfied but at a delivered cost up to 17 percent higher.

24. The main result: the combined coal-electricity shortage drops from 138 million tons in 2000 to 125 million tons, meaning that only 13 million tons of unsatisfied demand is because of too high delivered costs.

Case 93-13—7.5 Percent GNP Case (using 9 percent transport capacity)

25. GNP growth is assumed to be slower. Electricity demand in 2000 is assumed to be 1.25 trillion kwh, 13 percent lower than the 9 Percent case. Coal demand is 885 million tons, 2.4 percent lower than the 9 Percent Case. Major investment projects are the same as in Case 93-1.

26. The main result: virtually no shortages in 2000 (under 1 million tons coal equivalent).

Comparison of Investment Options between the CTS Model and Five-Year Plans

27. The ideal way to test the intersectoral investment strategy is for the potential investment options to outnumber by far the investment requirements for each sector (mining, washing, transport, and electricity). Then the model will be able to choose among them and to coordinate them. In these runs, the model does indeed have this flexibility, but less so for the transport sector. To a certain extent, this does create a situation in which the transport sector, which has the least flexible set of investment projects, may force suboptimal investments to be chosen in the other sectors.

28. In general, all of the planned projects in the relevant sectors have been included as options, either as individual projects or aggregated with others, but they have been supplemented by additional projects to an extent that varies from sector to sector. Generally, two types of data sources were used for identifying a list of potential additional projects to give the model some flexibility in coming up with an optimal investment plan. First, for standardized technologies, such as coal washing, coal power plants, ships, and scrubbers, the model allows any amount of new capacity to be built at all possible places, except in a few cases where water or land availability is an issue. (In the model results, the only place where the water availability constraint on coal washing was binding was in Datong.) Second, for site-specific investments or those constrained by resources, such as coal mining, hydropower, and transmission investments, the specific list of planned projects is supplemented by extra projects that are (a) planned for beyond 9FYP; (b) proposed, but not included in a plan; (c) suggested by CTS team members or by a panel of experts; (d) suggested by the SPC; (e) a modified scale

or timing of planned or proposed projects; or (f) across-the-board capacity expansion potential. Table 7.1 shows the flexibility in investment options accorded to the CTS model relative to experts' estimates of what projects are most likely to be in the FYPs through the year 2000.

Table 7.1: Comparison of Potential Capacity Increases CTS Model versus Experts' Estimates

	Units	Experts' Estimate	CTS Model
Coal Mining/a	million tons	406	855
Coal Washing	million tons	30	No Limit
New Rail Lines/b	route-km	10,339	10,939
Ports/c	million tons	450	203
Ships	million dwt	5	No Limit
Slurry Pipelines	million tons	15	25
Power Plants			
Thermal	million kw	185	No Limit
Hydro	million kw	62	100
Nuclear	million kw	4	45
Transmission Lines			
500 kV DC	km	3,000	2,340
other	km	n.a.	25,760
	kwh	n.a.	No Limit
Scrubbers	million tons	n.a.	No Limit

/a The experts' estimates are not really comparable because the experts' estimates were net of mine retirements, while the CTS model figures are for absolute potential increases. The experts' figures therefore underestimate the real capacity increases, especially for township mines.
/b Both the CTS model and the Experts' Estimates include the Handan-Jinan railway (under long-term consideration, but not in the FYP), the Hailar-Harbin expansion, and the Shenmu-Xian line (not planned). The 600 additional km of railways include possible lines from Shuichen to Chengdu and Chongqin (now planned), and a local line from Xinyi to Nantong. Not shown on this table are the additional capacity, in tkm, on existing or planned lines.
/c The experts' estimate of port capacity is for all commodities, not just for coal. Also, the CTS Model's potential is now known to be too small, having left off planned port expansion at user-owned ports in South China.

CTS Base Case (9 percent GNP growth): Calibration and Selected Results

Calibration of the CTS Model

1. The model was calibrated over nearly a year, and was thoroughly checked against the current or planned system on a number of aggregate performance measures. Table 8.1 summarizes the comparison between the Case 93-2's model results and the targets agreed upon in advance for calibration. Case 93-2 is used because, at this moment, it is deemed to be more realistic than Case 93-1, since the accelerated railway construction program now calls for finishing the Huanghua port and the Shenmu-Huanghua railway by 2000.

2. The targets are based on past, planned, or desired activities on an aggregate level. At this level of aggregation, the test case is roughly in line with expectations on these points. Shortages in the energy base are practically nonexistent (see Table 8.1). Total coal and electricity production are far higher than the targets published in accordance with the 6 percent GNP growth plans, but are within a few percent of the SPC's new unpublished targets for 2000. The thermal and hydropower shares are within 1 percent of their current levels. The biggest deviation from current practice is in the rail-water modal split, which is significantly shifted toward water transport, which is consistent with the planned trend.

3. Table 8.2-8.9 show detailed results for Case 93-2. The tables show subtotals by region or by node for the major sectors in the coal-electricity system. The tables are all produced automatically by the CTS analysis system.

Technical Note Regarding Shortages and Transport Figures in the CTS

4. Some discrepancies between the model and reality may be due to the network structure of the CTS (or any similar model). The CTS network has about 200 nodes, of which only about 100 are origins and destinations for coal. Therefore, the total traffic, tkm, and average railway distances are not strictly comparable to reality or to the Plan. This is especially true with regards to self-supply by individual nodes. A worst case example of this might be Kunming, which represents all of Yunnan province in the model. Coal flows from any part of Yunnan to any other part, no matter how far, are treated as a local flow that is not loaded onto the rail network. Overall, the model tends toward self-supply whenever possible so as to keep the network capacity free for long distance traffic.

5. On the other hand, sometimes the network structure can have the opposite effect, where two nearby places, assigned to different network nodes, are not given the local trucking option in the model. Some of the "structural" shortages that appear in all scenarios may be due to the way that coal mines are aggregated into the Taiyuan and Shijazhuang nodes. In China today, about 20 million tons are transported out of the energy base by truck, and the Plan calls for about 30 million tons. Even Chinese experts cannot say precisely from where to where this coal is trucked, but some of it goes from Taiyuan (in the energy base) to Shijiazhuang (outside of the energy base), which is only about 200 km. However, in the model, all coal from Taiyuan to Shijiazhuang must go by rail because they are in different nodes. This means that some of the precious 360 million tons of capacity leading out of the energy base—all of which is used in every model run—is used for this short distance traffic, thus causing a structural shortage in all runs of the model. The model builds new transmission capacity from Taiyuan to Shijiazhuang, equivalent to 5-10 million tons of coal, but there is little doubt that some of the 30 million tons of shortage that exists in all cases is due to this network problem.

Table 8.1:
Comparison of Case 93-2 Outputs with Base Case Targets

	Target	*Base Case 93-2*
Total Raw Coal Production in Year 2000 (billion tons)	1.5/a	1.6
Total Electricity Production in Year 2000 (trillion kwh)	1.2/b 1.38-1.48/c	1.5
Shortages in Year 2000 (percent of demand)		
Energy Base Area		
Industrial Steam Coal	0/d	0.0
Coking Coal	0/d	0.0
Anthracite Coal	0/d	0.0
China Total		
Industrial Steam Coal	n.a.	0.0
Coking Coal	n.a.	0.0
Anthracite Coal	n.a.	0.1
Electricity	n.a.	3.9
Combined Coal-Electr.	n.a.	1.8
Modal Split in Year 2000 (percent share of ton-km)		
Rail	63.5/e	53.0
Waterway	36.5/e	47.0
Generating Capacity in Year 2000 (percent of total)		
Thermal	75.4/e	77.0
Hydro	24.6/e	22.6
Nuclear	1.6/f	0.4

/a = forecasted target under 8-9 percent GNP target.
/b = forecasted target under 6 percent GNP growth; new target not yet announced.
/c = Yangzhou Thermal Power Project Staff Appraisal Report (November 1993)
/d = desired target.
/e = current share.
/f = under construction share.
n.a. = not applicable, i.e., no basis exists for forecast or reasonable desired target.
Note: The energy base is defined here as the provinces of Shanxi, Shaanxi, Henan, Nei Mongol, Ningxia, and Guizhou.

Table 8.2: National Totals of Coal Production (10,000 tons)

		1995		2000		2005	
Anthracite	Step 1	4155.88		4145.72		4195.76	
	Step 2	4148.34		4531.66		4845.96	
	Step 3	4401.62		5344.23		7120.45	
	Total	12705.84		14021.61		16162.16	
Steamcoal	Step 1	44859.84		49522.66		57375.38	
	Step 2	21321.24		24231.09		27293.97	
	Step 3	34678.63		53104.30		62930.46	
	Total	100859.72		126858.05		147599.80	
Cokingcoal	Step 1	31.50		133.24		123.98	
	Step 2	2359.01		2894.85		2856.45	
	Step 3	14739.72		16756.80		19867.06	
	Total	17130.23		19784.89		22847.49	
	Step 1	49047.23	37.5%	53801.62	33.5%	61695.12	33.1%
	Step 2	27828.59	21.3%	31657.60	19.7%	34996.38	18.8%
	Step 3	53819.97	41.2%	75205.33	46.8%	89917.96	48.2%
	Total	130695.79		160664.55		186609.47	

Step 1 = township.
Step 2 = provincial.
Step 3 = state.

Table 8.3: Regional Subtotals of Coal Production (10,000 tons)

Reg.	Year	Anthracite		Coking Coal		Steam Coal		All Types	
		New	Total	New	Total	New	Total	New	Total
N	1995	1055.0	5236.2	603.2	5827.4	17312.9	40638.5	18971.1	51702.1
	2000	1622.9	5382.9	1047.2	7086.7	33365.6	52291.6	36035.7	64761.2
	2005	2325.4	6524.1	1193.9	7010.0	46795.8	62062.3	50315.1	75596.5
NW	1995	11.0	125.6	322.7	3275.7	4290.7	13490.8	4624.4	16892.1
	2000	12.0	123.1	889.3	3792.3	7181.2	15338.5	8082.5	19253.9
	2005	25.0	132.1	1583.0	4486.0	9147.1	16421.4	10755.1	21039.6
E	1995	359.5	1906.4	1175.4	4021.4	2186.9	11170.8	3721.7	17098.6
	2000	506.1	1856.2	1492.4	4023.4	5172.8	13199.5	7171.3	19079.1
	2005	940.1	2061.7	3662.4	6097.4	8509.9	15677.6	13112.4	23836.7
SC	1995	625.3	3025.1	116.9	1332.2	3594.6	11652.7	4336.8	16010.1
	2000	1263.8	4132.9	183.2	1373.4	6451.6	14236.0	7898.6	19742.3
	2005	2067.0	4557.9	388.9	1541.4	9592.5	15833.7	12048.4	21933.0
SW	1995	248.3	1866.4	60.0	1683.2	3021.5	10801.6	3329.8	14351.2
	2000	445.4	1950.5	352.7	2146.1	5242.1	11620.0	6040.2	15716.5
	2005	872.7	2253.7	405.0	2120.7	7960.2	12759.9	9237.9	17134.2
NW	1995	340.0	546.1	0.0	990.3	6691.8	13105.2	7031.8	14641.7
	2000	380.6	576.1	165.4	1363.1	13431.8	19189.2	13977.9	21128.4
	2005	453.0	632.6	449.8	1592.0	18272.9	23344.9	19175.7	25569.5
TOT	1995	2639.2	12705.8	2278.2	17130.2	37098.3	100859.7	42015.6	130695.8
	2000	4230.8	14021.6	4130.2	19784.9	71828.4	126858.1	80189.4	160664.6
	2005	6683.2	16162.2	7683.0	22847.5	101778.4	147599.8	116144.6	186609.5
EB	1995	1547.7	6166.5	590.5	6066.0	22516.3	52545.5	24654.5	64777.9
	2000	2403.4	6779.9	1060.6	7183.0	45497.5	71094.0	48961.5	85056.9
	2005	3229.4	7736.5	1301.0	7175.4	62970.1	83916.1	67500.5	98828.0
CO	1995	597.8	3093.9	1439.1	7817.7	4753.3	19933.6	6790.1	30845.1
	2000	941.0	3483.3	1870.0	8234.1	9716.2	23386.7	12527.2	35104.1
	2005	1648.0	3889.2	4121.7	10401.4	14166.1	26204.3	19935.8	40494.9

N=NORTH (HUABEI)
NE=NORTHEAST (DONGBEI)
E=EAST (HAUDONG)
SC=SOUTH CENTRAL (ZHONGNAN)
SW=SOUTHWEST (XINAN)
NW=NORTHWEST (XIBEI)
IMP=IMPORTS
TOT=NATIONAL TOTAL
EB=ENERGY BASE (NORTH AND SOUTHWEST)
CO=COASTAL PROVINCES

Table 8.4: Regional Breakdown of Coal Washing (10,000 tons)

Region	Period	Coal Type	Raw Coal Existing	Raw Coal New	Raw Coal Total	Washed Coal
Huabei	1995		7464.9	7402.0	14866.8	10753.9
		Steam-2	4085.3	4954.1	9039.4	6779.6
		Coking	3379.6	2447.8	5827.4	3974.3
		-clean	3291.8			
		-mid	682.5			
	2000		6755.2	11549.4	18304.6	13356.6
		Steam-2	3187.0	8031.0	11218.0	8413.5
		Coking	3568.2	3518.4	7086.7	4943.1
		-clean	4159.6			
		-mid	783.5			
Dongbei	1995		4193.4	1888.3	6081.7	4270.7
		Steam-2	1637.7	1168.3	2806.0	2104.5
		Coking	2555.7	720.0	3275.7	2166.2
		-clean	1724.1			
		-mid	442.0			
	2000		5158.0	2338.6	7496.6	5255.7
		Steam-2	2536.0	1168.3	3704.3	2778.2
		Coking	2622.0	1170.3	3792.3	2477.5
		-clean	1936.8			
		-mid	540.7			
Huadong	1995		3780.0	1048.8	4828.8	3530.2
		Steam-2	190.0	617.4	807.4	605.6
		Coking	3590.0	431.4	4021.4	2924.7
		-clean	2294.7			
		-mid	630.0			
	2000		3606.0	1802.5	5408.5	3956.5
		Steam-2	190.0	1195.1	1385.1	1038.8
		Coking	3416.0	607.4	4023.4	2917.7
		-clean	2331.1			
		-mid	586.5			
Zhongnan	1995		659.1	963.0	1622.1	1193.2
		Steam-2	82.1	207.8	289.9	155.8
		Coking	577.0	755.2	1332.2	1037.4
		-clean	976.6			
		-mid	60.8			
	2000		607.5	2100.9	2708.5	2074.3
		Steam-2	13.3	1321.8	1335.1	1001.3
		Coking	594.2	779.2	1373.4	1073.0
		-clean	1010.1			
		-mid	62.9			

Region	Period	Coal Type	Raw Coal Existing	Raw Coal New	Raw Coal Total	Washed Coal
Xinan	1995		1365.0	1614.2	2979.2	2054.3
		Steam-2	96.0	1200.0	1296.0	972.0
		Coking	1269.0	414.2	1683.2	1082.3
		-clean	888.6			
		-mid	193.7			
	2000		1601.8	1909.1	3510.9	2397.1
		Steam-2	164.8	1200.0	1364.8	1023.6
		Coking	1437.0	709.1	2146.1	1373.4
		-clean	1120.0			
		-mid	253.5			
Xibei	1995		554.0	1869.4	2423.4	1816.2
		Steam-2	104.0	1329.1	1433.1	1074.8
		Coking	450.0	540.3	990.3	741.4
		-clean	559.4			
		-mid	182.0			
	2000		554.0	2961.2	3515.2	2662.6
		Steam-2	104.0	2048.1	2152.1	1614.1
		Coking	450.0	913.1	1363.1	1048.6
		-clean	825.2			
		-mid	223.4			
Total	1995		18016.4	14785.7	32[illegible].1	23680.1
		Steam-2	6195.1	9476.7	15671.9	11753.9
		Coking	11821.3	5308.9	17130.2	11926.2
		-clean	9735.2			
		-mid	2191.0			
	2000		18282.6	22661.6	40944.2	29702.8
		Steam-2	6195.1	14964.2	21159.4	15869.5
		Coking	12087.5	7697.4	19784.9	13833.3
		-clean	11382.7			
		-mid	2450.5			

Table 8.5: Regional Coal Balance (10,000 tons of std coal)

Region	Period	End User	Demand	Supply	Shortage
Huabei	1995	ANTHUSER	3961.2	3961.2	0.0
		COKIUSER	2099.3	2099.3	0.0
		INDUUSER	10654.3	10654.3	0.0
		TOTAL	16714.9	16714.9	0.0
	2000	ANTHUSER	4540.4	4540.4	0.0
		COKIUSER	2467.1	2467.1	0.0
		INDUUSER	11480.3	11480.3	0.0
		TOTAL	18487.8	18487.8	0.0
Dongbei	1995	ANTHUSER	915.1	762.5	152.6
		COKIUSER	1871.4	1871.4	0.0
		INDUUSER	9732.2	9457.0	275.1
		TOTAL	12518.7	12090.9	427.8
	2000	ANTHUSER	1042.6	1042.6	0.0
		COKIUSER	2047.7	2047.7	0.0
		INDUUSER	12025.7	12025.7	0.0
		TOTAL	15116.0	15116.0	0.0
Huadong	1995	ANTHUSER	3916.1	3916.1	0.0
		COKIUSER	2575.7	2575.7	0.0
		INDUUSER	10872.1	10134.7	737.3
		TOTAL	17363.9	16626.6	737.3
	2000	ANTHUSER	4097.2	4097.2	0.0
		COKIUSER	3131.8	3131.8	0.0
		INDUUSER	12406.6	12406.6	0.0
		TOTAL	19635.6	19635.6	0.0
Zhongnan	1995	ANTHUSER	3129.2	3129.2	0.0
		COKIUSER	1374.7	1374.7	0.0
		INDUUSER	9873.5	9873.5	0.0
		TOTAL	14377.4	14377.4	0.0
	2000	ANTHUSER	3220.8	3220.8	0.0
		COKIUSER	1541.5	1541.5	0.0
		INDUUSER	11621.5	11621.5	0.0
		TOTAL	16383.8	16383.8	0.0
Xinan	1995	ANTHUSER	1750.5	1750.5	0.0
		COKIUSER	925.0	925.0	0.0
		INDUUSER	5969.1	5969.1	0.0
		TOTAL	8644.5	8644.5	0.0
	2000	ANTHUSER	1833.4	1833.4	0.0
		COKIUSER	1201.5	1201.5	0.0
		INDUUSER	7653.1	7653.1	0.0
		TOTAL	10688.0	10688.0	0.0

Region	Period	Coal Type	Raw Coal			Washed Coal
			Existing	New	Total	
Xibei	1995	ANTHUSER	526.5	507.1	19.5	
		COKIUSER	444.0	444.0	0.0	
		INDUUSER	5187.8	5187.8	0.0	
		TOTAL	6158.4	6138.9	19.5	
	2000	ANTHUSER	578.5	557.6	20.9	
		COKIUSER	548.2	548.2	0.0	
		INDUUSER	6025.3	6025.3	0.0	
		TOTAL	7152.0	7131.2	20.9	
Export	1995	ANTHUSER	0.0	0.0	0.0	
		COKIUSER	445.0	445.0	0.0	
		INDUUSER	2225.0	2225.0	0.0	
		TOTAL	2670.0	2670.0	0.0	
	2000	ANTHUSER	0.0	0.0	0.0	
		COKIUSER	445.0	445.0	0.0	
		INDUUSER	2670.0	2670.0	0.0	
		TOTAL	3115.0	3115.0	0.0	
Total	1995	ANTHUSER	14198.6	14026.5	172.1	
		COKIUSER	9735.2	9735.2	0.0	
		INDUUSER	54513.9	53501.4	1012.5	
		TOTAL	78447.7	77263.2	1184.6	
	2000	ANTHUSER	15313.0	15292.1	20.9	
		COKIUSER	11382.7	11382.7	0.0	
		INDUUSER	63882.5	63882.5	0.0	
		TOTAL	90578.2	90557.3	20.9	

Table 8.6: Coal Transportation O-D Table, in 2000 (10,000 tons)

Minenode	To: Huabei	Dongbei	Huadong	Zhongnan	Xinan	Xibei	Export	Total
From:								
Huabei	33656	7120	10496	7135		43	2240	60690
Dongbei		17005						17005
Huadong			17099					17099
Zhongnan			3150	15909				19059
Xinan			343	157	13897			14397
Xibei	1506	930	3916	1307	485	11976	156	20276
Import								0
Total	35162	25055	35003	24507	14382	12019	2397	148526

Table 8.7: Electricity Transmission O-D Table (100 million kwh)

		To: Huabei	Dongbei	Huadong	Zhongnan	Xinan	Xibei	Huanan	Total
From:									
Huabei	T1	734.50	325.14	228.33	115.92	0.00	0.00	0.00	1403.89
	T2	1115.86	593.44	288.22	115.92	0.00	0.00	168.00	2281.43
	T3	1499.57	838.26	293.15	84.62	0.00	0.00	336.00	3051.59
Dongbei	T1	0.00	76.49	0.00	0.00	0.00	0.00	0.00	76.49
	T2	0.00	70.97	0.00	0.00	0.00	0.00	0.00	70.97
	T3	0.00	69.45	0.00	0.00	0.00	0.00	0.00	69.45
Huadong	T1	0.00	0.00	1427.54	0.00	0.00	0.00	0.00	1427.54
	T2	0.00	0.00	1640.18	0.00	0.00	0.00	0.00	1640.18
	T3	0.00	0.00	2508.05	0.00	0.00	0.00	0.00	2508.05
Zhongnan	T1	0.00	0.00	0.00	103.21	0.00	0.00	0.00	103.21
	T2	0.00	0.00	0.00	235.68	0.00	0.00	0.00	235.68
	T3	0.00	0.00	0.00	285.88	0.00	0.00	0.00	285.88
Xinan	T1	0.00	0.00	0.00	0.00	44.87	0.00	0.00	44.87
	T2	0.00	0.00	0.00	0.00	90.21	0.00	0.00	90.21
	T3	0.00	0.00	0.00	45.56	122.63	0.00	23.77	191.95
Xibei	T1	0.00	0.00	0.00	47.74	0.00	47.62	0.00	95.36
	T2	0.00	0.00	0.00	47.74	0.00	56.00	0.00	103.74
	T3	0.00	0.00	0.00	456.69	0.00	92.07	0.00	548.76
Huanan	T1	0.00	0.00	0.00	0.00	0.00	0.00	67.07	67.07
	T2	0.00	0.00	0.00	0.00	0.00	0.00	67.07	67.07
	T3	0.00	0.00	0.00	0.00	0.00	0.00	273.12	273.12
Total	T1	734.50	401.62	1655.87	266.88	44.87	47.62	67.07	3218.43
	T2	1115.86	664.41	1928.40	399.34	90.21	56.00	235.07	4489.28
	T3	1499.57	907.71	2801.20	872.75	122.63	92.07	632.89	6928.80

T1=1995
T2=2000
T3=2005

Table 8.8: Power Plant Capacity

Elgnode	Year	Coal Exist	Coal New	Coal Total	Hydro Exist	Hydro New	Hydro Total	Nuclear Exist	Nuclear New	Nuclear Total	Grand
Harbin	T1	693.0	438.6	1131.6	18.8	0.0	18.8	0.0	0.0	0.0	1150.4
	T2	658.3	679.8	1338.2	18.8	0.0	18.8	0.0	0.0	0.0	1356.9
	T3	623.7	783.2	1406.9	18.8	0.0	18.8	0.0	0.0	0.0	1425.7
Hailar	T1	50.0	69.0	119.0	0.0	0.0	0.0	0.0	0.0	0.0	119.0
	T2	47.5	486.1	533.6	0.0	0.0	0.0	0.0	0.0	0.0	533.6
	T3	45.0	927.5	972.5	0.0	0.0	0.0	0.0	0.0	0.0	972.5
Changchu	T1	429.0	7.5	436.5	280.4	15.0	295.4	0.0	0.0	0.0	731.9
	T2	407.5	36.7	444.2	280.4	81.0	361.4	0.0	0.0	0.0	805.6
	T3	386.1	398.8	784.9	280.4	96.0	376.4	0.0	0.0	0.0	1161.3
Shenyang	T1	666.5	27.6	694.1	116.6	10.0	126.6	0.0	0.0	0.0	820.7
	T2	633.2	332.7	965.8	116.6	20.0	136.6	0.0	0.0	0.0	1102.4
	T3	599.8	883.7	1483.5	116.6	120.0	236.6	0.0	0.0	0.0	1720.2
Qinhuang	T1	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
	T2	0.9	0.1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
	T3	0.9	0.1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
Tongliao	T1	172.0	0.0	172.0	0.0	0.0	0.0	0.0	0.0	0.0	172.0
	T2	163.4	263.1	426.5	0.0	0.0	0.0	0.0	0.0	0.0	426.5
	T3	154.8	345.3	500.1	0.0	0.0	0.0	0.0	0.0	0.0	500.1
Dalian	T1	150.0	0.0	150.0	0.0	0.0	0.0	0.0	0.0	0.0	150.0
	T2	142.5	97.1	239.6	0.0	0.0	0.0	0.0	0.0	0.0	239.6
	T3	135.0	266.5	401.5	0.0	0.0	0.0	0.0	0.0	0.0	401.5
Yingkou	T1	60.0	0.0	60.0	0.0	0.0	0.0	0.0	0.0	0.0	60.0
	T2	57.0	0.0	57.0	0.0	0.0	0.0	0.0	0.0	0.0	57.0
	T3	54.0	0.0	54.0	0.0	0.0	0.0	0.0	0.0	0.0	54.0
Dandong	T1	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
	T2	0.9	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.9
	T3	0.9	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.9
Baotou	T1	276.0	84.1	360.1	3.4	0.0	3.4	0.0	0.0	0.0	363.5
	T2	262.2	252.6	514.8	3.4	0.0	3.4	0.0	0.0	0.0	518.2
	T3	248.4	486.1	734.5	3.4	0.0	3.4	0.0	0.0	0.0	737.9
Tangshan	T1	395.0	42.8	437.8	0.0	0.0	0.0	0.0	0.0	0.0	437.8
	T2	375.2	43.6	418.8	0.0	0.0	0.0	0.0	0.0	0.0	418.8
	T3	355.5	45.2	400.7	0.0	0.0	0.0	0.0	0.0	0.0	400.7
Beijing	T1	230.0	0.0	230.0	27.1	0.0	27.1	0.0	0.0	0.0	257.1
	T2	218.5	0.0	218.5	27.1	0.0	27.1	0.0	0.0	0.0	245.6
	T3	207.0	0.0	207.0	27.1	0.0	27.1	0.0	0.0	0.0	234.1
Tianjin	T1	260.0	0.0	260.0	0.0	0.0	0.0	0.0	0.0	0.0	260.0
	T2	247.0	0.0	247.0	0.0	0.0	0.0	0.0	0.0	0.0	247.0
	T3	234.0	0.0	234.0	0.0	0.0	0.0	0.0	0.0	0.0	234.0
Datong	T1	420.0	227.4	647.4	0.0	0.0	0.0	0.0	0.0	0.0	647.4
	T2	399.0	227.4	626.4	0.0	0.0	0.0	0.0	0.0	0.0	626.4
	T3	378.0	605.8	983.8	0.0	0.0	0.0	0.0	0.0	0.0	983.8
Zhungeer	T1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	T2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	T3	0.0	4.5	4.5	0.0	0.0	0.0	0.0	0.0	0.0	4.5
Hebaopia	T1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	T2	0.0	422.5	422.5	0.0	0.0	0.0	0.0	0.0	0.0	422.5
	T3	0.0	644.6	644.6	0.0	0.0	0.0	0.0	0.0	0.0	644.6
Taiyuan	T1	276.0	870.3	1146.3	22.8	0.0	22.8	0.0	0.0	0.0	1169.0

	T2	262.2	1000	1262.2	22.8	102.0	124.8	0.0	0.0	0.0	1387.0
	T3	248.4	1000	1248.4	22.8	242.0	264.8	0.0	0.0	0.0	1513.2
Changzhi	T1	84.0	54.9	138.9	0.0	0.0	0.0	0.0	0.0	0.0	138.9
	T2	79.8	554.9	634.7	0.0	0.0	0.0	0.0	0.0	0.0	634.7
	T3	75.6	1000	1075.6	0.0	0.0	0.0	0.0	0.0	0.0	1075.6
Houma	T1	40.0	481.6	521.6	0.0	0.0	0.0	0.0	0.0	0.0	521.6
	T2	38.0	500.0	538.0	0.0	0.0	0.0	0.0	0.0	0.0	538.0
	T3	36.0	500.0	536.0	0.0	0.0	0.0	0.0	0.0	0.0	536.0
Shijiazh	T1	444.0	31.1	475.1	0.0	0.0	0.0	0.0	0.0	0.0	475.1
	T2	421.8	464.2	886.0	0.0	0.0	0.0	0.0	0.0	0.0	886.0
	T3	399.6	788.6	1188.2	0.0	0.0	0.0	0.0	0.0	0.0	1188.2
Jinan	T1	507.0	30.3	537.3	7.5	0.0	7.5	0.0	0.0	0.0	544.8
	T2	481.6	867.9	1349.5	7.5	0.0	7.5	0.0	0.0	0.0	1357.0
	T3	456.3	1457.9	1914.2	7.5	0.0	7.5	0.0	0.0	0.0	1921.7
Weifang	T1	235.0	0.0	235.0	0.0	0.0	0.0	0.0	0.0	0.0	235.0
	T2	223.2	0.0	223.2	0.0	0.0	0.0	0.0	0.0	0.0	223.2
	T3	211.5	0.0	211.5	0.0	0.0	0.0	0.0	0.0	0.0	211.5
Yanzhou	T1	265.0	0.0	265.0	0.0	0.0	0.0	0.0	0.0	0.0	265.0
	T2	251.8	0.0	251.8	0.0	0.0	0.0	0.0	0.0	0.0	251.8
	T3	238.5	29.1	267.6	0.0	0.0	0.0	0.0	0.0	0.0	267.6
Hefei	T1	88.9	96.2	185.1	52.0	0.0	52.0	0.0	0.0	0.0	237.0
	T2	84.5	364.0	448.5	52.0	0.0	52.0	0.0	0.0	0.0	500.4
	T3	80.0	364.0	444.0	52.0	0.0	52.0	0.0	0.0	0.0	496.0
Huainan	T1	213.5	0.0	213.5	0.0	0.0	0.0	0.0	0.0	0.0	213.5
	T2	202.8	0.0	202.8	0.0	0.0	0.0	0.0	0.0	0.0	202.8
	T3	192.1	388.9	581.1	0.0	0.0	0.0	0.0	0.0	0.0	581.1
Huaibei	T1	102.0	0.0	102.0	0.0	0.0	0.0	0.0	0.0	0.0	102.0
	T2	96.9	57.8	154.7	0.0	0.0	0.0	0.0	0.0	0.0	154.7
	T3	91.8	313.2	405.0	0.0	0.0	0.0	0.0	0.0	0.0	405.0
Xuzhou	T1	416.5	12.2	428.7	0.0	0.0	0.0	0.0	0.0	0.0	428.7
	T2	395.7	12.2	407.9	0.0	0.0	0.0	0.0	0.0	0.0	407.9
	T3	374.9	830.4	1205.2	0.0	0.0	0.0	0.0	0.0	0.0	1205.2
Nanjing	T1	65.0	0.0	65.0	0.0	0.0	0.0	0.0	0.0	0.0	65.0
	T2	61.8	100.0	161.8	0.0	0.0	0.0	0.0	0.0	0.0	161.8
	T3	58.5	100.0	158.5	0.0	0.0	0.0	0.0	0.0	0.0	158.5
Jianbi	T1	617.7	0.0	617.7	0.0	0.0	0.0	0.0	0.0	0.0	617.7
	T2	586.8	444.3	1031.1	0.0	0.0	0.0	0.0	0.0	0.0	1031.1
	T3	555.9	444.3	1000.2	0.0	0.0	0.0	0.0	0.0	0.0	1000.2
Nantong	T1	127.0	0.0	127.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0
	T2	127.0	0.0	127.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0
	T3	127.0	133.1	260.1	0.0	0.0	0.0	0.0	0.0	0.0	260.1
Wangting	T1	122.0	0.0	122.0	0.0	0.0	0.0	0.0	0.0	0.0	122.0
	T2	115.9	0.0	115.9	0.0	0.0	0.0	0.0	0.0	0.0	115.9
	T3	109.8	0.0	109.8	0.0	0.0	0.0	0.0	0.0	0.0	109.8
Shanghai	T1	670.0	87.1	757.1	0.0	0.0	0.0	30.0	0.0	30.0	787.1
	T2	636.5	710.1	1346.6	0.0	0.0	0.0	30.0	0.0	30.0	1376.6
	T3	603.0	988.6	1591.6	0.0	0.0	0.0	30.0	0.0	30.0	1621.6
Hangzhou	T1	117.0	24.0	141.0	233.2	30.0	263.2	0.0	0.0	0.0	404.2
	T2	111.2	317.8	428.9	233.2	60.0	293.2	0.0	0.0	0.0	722.1
	T3	105.3	349.2	454.5	233.2	60.0	293.2	0.0	0.0	0.0	747.7
Ningbo	T1	270.0	0.0	270.0	0.0	0.0	0.0	0.0	0.0	0.0	270.0
	T2	256.5	0.0	256.5	0.0	0.0	0.0	0.0	0.0	0.0	256.5
	T3	243.0	83.3	326.3	0.0	0.0	0.0	0.0	0.0	0.0	326.3
Wenzhou	T1	144.5	0.0	144.5	0.0	0.0	0.0	0.0	0.0	0.0	144.5
	T2	137.3	0.0	137.3	0.0	0.0	0.0	0.0	0.0	0.0	137.3

	T3	130.1	0.0	130.1	0.0	0.0	0.0	0.0	0.0	0.0	130.1
Fuzhou	T1	106.2	0.0	106.2	317.2	45.0	362.2	0.0	0.0	0.0	468.4
	T2	100.9	0.0	100.9	317.2	162.0	479.2	0.0	0.0	0.0	580.1
	T3	95.6	0.0	95.6	317.2	282.0	599.2	0.0	0.0	0.0	694.8
Xiamen	T1	55.0	0.0	55.0	0.0	0.0	0.0	0.0	0.0	0.0	55.0
	T2	52.2	87.2	139.4	0.0	0.0	0.0	0.0	0.0	0.0	139.4
	T3	49.5	205.6	255.1	0.0	0.0	0.0	0.0	0.0	0.0	255.1
Nanchang	T1	171.0	81.1	252.1	139.5	25.0	164.5	0.0	0.0	0.0	416.6
	T2	162.4	293.4	455.8	139.5	50.0	189.5	0.0	0.0	0.0	645.3
	T3	153.9	534.0	687.9	139.5	50.0	189.5	0.0	0.0	0.0	877.4
Changsha	T1	237.5	189.0	426.4	349.7	50.0	399.7	0.0	0.0	0.0	826.1
	T2	225.6	481.2	706.8	349.7	186.0	535.7	0.0	0.0	0.0	1242.6
	T3	213.7	927.0	1140.7	349.7	296.0	645.7	0.0	0.0	0.0	1786.4
Yueyange	T1	70.0	0.0	70.0	0.0	0.0	0.0	0.0	0.0	0.0	70.0
	T2	66.5	0.0	66.5	0.0	0.0	0.0	0.0	0.0	0.0	66.5
	T3	63.0	0.0	63.0	0.0	0.0	0.0	0.0	0.0	0.0	63.0
Wuhan	T1	310.0	0.0	310.0	595.0	50.0	645.0	0.0	0.0	0.0	955.0
	T2	294.5	93.9	388.4	595.0	168.8	763.8	0.0	0.0	0.0	1152.2
	T3	279.0	93.9	372.9	595.0	597.8	1192.8	0.0	0.0	0.0	1565.7
Zhengzho	T1	762.1	0.0	762.1	46.8	0.0	46.8	0.0	0.0	0.0	808.9
	T2	724.0	805.4	1529.4	46.8	0.0	46.8	0.0	0.0	0.0	1576.2
	T3	685.9	805.4	1491.3	46.8	0.0	46.8	0.0	0.0	0.0	1538.1
Guangzho	T1	820.0	0.0	820.0	282.2	35.0	317.2	60.0	0.0	60.0	1197.2
	T2	779.0	208.9	987.9	282.2	70.0	352.2	60.0	0.0	60.0	1400.1
	T3	656.0	208.9	864.9	282.2	70.0	352.2	60.0	0.0	60.0	1277.1
Shantou	T1	1.0	70.5	71.5	0.0	0.0	0.0	0.0	0.0	0.0	71.5
	T2	0.9	95.6	96.6	0.0	0.0	0.0	0.0	0.0	0.0	96.6
	T3	0.9	142.1	143.0	0.0	0.0	0.0	0.0	0.0	0.0	143.0
Haikou	T1	52.3	0.0	52.3	52.8	24.0	76.8	0.0	0.0	0.0	129.1
	T2	49.7	8.9	58.6	52.8	24.0	76.8	0.0	0.0	0.0	135.3
	T3	47.0	43.8	90.9	52.8	24.0	76.8	0.0	0.0	0.0	167.6
Nanning	T1	154.0	7.1	161.1	397.9	45.0	442.9	0.0	0.0	0.0	604.0
	T2	146.3	48.6	194.9	397.9	194.0	591.9	0.0	0.0	0.0	786.8
	T3	138.6	241.4	380.0	397.9	772.1	1170.0	0.0	0.0	0.0	1550.0
Kunming	T1	139.0	17.8	156.8	359.4	30.0	389.4	0.0	0.0	0.0	546.2
	T2	132.0	17.8	149.9	359.4	195.0	554.4	0.0	0.0	0.0	704.2
	T3	125.1	78.3	203.3	359.4	305.0	664.4	0.0	0.0	0.0	867.7
Guiyang	T1	192.9	28.4	221.2	204.3	30.0	234.3	0.0	0.0	0.0	455.6
	T2	183.2	81.9	265.1	204.3	60.0	264.3	0.0	0.0	0.0	529.5
	T3	173.6	81.9	255.5	204.3	425.0	629.3	0.0	0.0	0.0	884.8
Chengdu	T1	249.0	3.5	252.5	398.8	90.0	488.8	0.0	0.0	0.0	741.4
	T2	236.6	3.5	240.1	398.8	634.8	1033.6	0.0	0.0	0.0	1273.7
	T3	224.1	3.5	227.6	398.8	1316.0	1714.8	0.0	0.0	0.0	1942.5
Chongqin	T1	310.0	226.8	536.8	20.0	0.0	20.0	0.0	0.0	0.0	556.8
	T2	294.5	230.4	524.9	20.0	68.0	88.0	0.0	0.0	0.0	612.9
	T3	279.0	236.3	515.3	20.0	226.0	246.0	0.0	0.0	0.0	761.3
Xian	T1	365.6	149.9	515.4	116.8	0.0	116.8	0.0	0.0	0.0	632.3
	T2	347.3	441.3	788.5	116.8	0.0	116.8	0.0	0.0	0.0	905.4
	T3	329.0	1650.3	1979.3	116.8	0.0	116.8	0.0	0.0	0.0	2096.1
Shenmu	T1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	T2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	T3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Yinchuan	T1	105.1	65.1	170.2	27.6	0.0	27.6	0.0	0.0	0.0	197.8
	T2	99.8	97.4	197.3	27.6	44.0	71.6	0.0	0.0	0.0	268.9
	T3	94.6	288.5	383.1	27.6	44.0	71.6	0.0	0.0	0.0	454.7

Xining	T1	40.4	0.0	40.4	174.9	15.0	189.9	0.0	0.0	0.0	230.2
	T2	38.4	0.0	38.4	174.9	227.7	402.5	0.0	0.0	0.0	440.9
	T3	36.3	0.0	36.3	174.9	416.0	590.8	0.0	0.0	0.0	627.2
Lanzhou	T1	198.5	225.1	423.6	233.5	25.0	258.5	0.0	0.0	0.0	682.1
	T2	188.6	237.2	425.8	233.5	81.3	314.8	0.0	0.0	0.0	740.6
	T3	178.7	278.2	456.8	233.5	254.5	488.0	0.0	0.0	0.0	944.8
Wulumuqi	T1	165.7	109.2	274.9	44.5	0.0	44.5	0.0	0.0	0.0	319.4
	T2	157.4	210.1	367.6	44.5	0.0	44.5	0.0	0.0	0.0	412.0
	T3	149.2	406.3	555.5	44.5	0.0	44.5	0.0	0.0	0.0	599.9
Maanshan	T1	79.5	0.0	79.5	0.0	0.0	0.0	0.0	0.0	0.0	79.5
	T2	75.5	0.0	75.5	0.0	0.0	0.0	0.0	0.0	0.0	75.5
	T3	71.6	0.0	71.6	0.0	0.0	0.0	0.0	0.0	0.0	71.6
Jiujiang	T1	75.0	0.0	75.0	0.0	0.0	0.0	0.0	0.0	0.0	75.0
	T2	75.0	0.0	75.0	0.0	0.0	0.0	0.0	0.0	0.0	75.0
	T3	75.0	0.0	75.0	0.0	0.0	0.0	0.0	0.0	0.0	75.0
Total	T1	13268	3758	17026	4523	519	5042	90	0	90	22158
	T2	12615	11678	24293	4523	2429	6951	90	0	90	31334
	T3	11880	20387	32267	4523	5596	10119	90	0	90	42476
(PCT)	T1	78%	22%	90%	10%	1%	0%	77%	23%	0%	
	T2	52%	48%	65%	35%	1%	0%	78%	22%	0%	
	T3	37%	63%	45%	55%	1%	0%	76%	24%	0%	

Table 8.9: Ash and Sulfur Content of Delivered Coal, by Province (in 10,000 tons)

Province	Period	Ash	Sulfur
Beijing	1995	546.0	28.1
Beijing	2000	562.5	29.7
Beijing	2005	517.0	26.4
Tianjin	1995	437.9	27.5
Tianjin	2000	428.5	28.3
Tianjin	2005	464.3	31.5
Hebei	1995	1457.0	91.1
Hebei	2000	1744.1	123.4
Hebei	2005	1959.4	159.8
Shanxi	1995	2324.6	201.5
Shanxi	2000	2722.5	233.5
Shanxi	2005	3006.1	244.7
Neimeng	1995	832.0	60.2
Neimeng	2000	1365.9	93.4
Neimeng	2005	1867.7	120.5
Liaoning	1995	1401.4	79.4
Liaoning	2000	1925.6	98.9
Liaoning	2005	1745.2	93.2
Jilin	1995	1089.9	32.6
Jilin	2000	1082.3	34.8
Jilin	2005	1201.6	35.4
Heilongj	1995	1437.7	45.8
Heilongj	2000	1922.5	58.6
Heilongj	2005	2229.0	62.5
Shanghai	1995	419.2	37.7
Shanghai	2000	627.9	58.3
Shanghai	2005	783.1	74.2
Jiangsu	1995	1373.9	110.2
Jiangsu	2000	1492.1	111.4
Jiangsu	2005	2082.1	151.1
Zhejiang	1995	465.4	36.9
Zhejiang	2000	559.5	38.7
Zhejiang	2005	621.1	47.0
Anhui	1995	601.6	39.5
Anhui	2000	719.0	51.9
Anhui	2005	1229.9	88.3
Fujian	1995	345.1	21.4
Fujian	2000	353.1	24.0
Fujian	2005	459.9	29.3
Jiangxi	1995	606.5	29.2
Jiangxi	2000	803.0	38.3
Jiangxi	2005	731.4	39.4

Shandong	1995	1124.5	133.5
Shandong	2000	1548.1	153.1
Shandong	2005	1539.4	146.6
Henan	1995	1536.6	88.6
Henan	2000	1905.1	125.5
Henan	2005	2039.7	131.4
Hubei	1995	718.2	46.9
Hubei	2000	865.7	60.8
Hubei	2005	982.3	65.1
Hunan	1995	750.5	60.4
Hunan	2000	929.5	78.3
Hunan	2005	1143.3	85.9
Guangdon	1995	760.8	53.1
Guangdon	2000	853.4	65.2
Guangdon	2005	1080.3	77.7
Guangxi	1995	430.6	24.1
Guangxi	2000	458.2	24.9
Guangxi	2005	606.3	33.3
Hainan	1995	41.9	3.3
Hainan	2000	51.7	4.0
Hainan	2005	61.9	4.7
Sichuan	1995	1802.3	197.0
Sichuan	2000	1896.5	194.0
Sichuan	2005	2119.3	220.3
Guizhou	1995	627.7	38.3
Guizhou	2000	767.1	45.6
Guizhou	2005	774.5	49.5
Yunnan	1995	574.3	26.7
Yunnan	2000	719.8	32.5
Yunnan	2005	845.2	38.1
Shaanxi	1995	851.9	46.8
Shaanxi	2000	1065.7	59.1
Shaanxi	2005	1561.9	89.0
Gansu	1995	532.5	18.5
Gansu	2000	575.0	20.3
Gansu	2005	633.0	22.8
Qinghai	1995	58.0	3.1
Qinghai	2000	59.1	3.2
Qinghai	2005	64.7	3.5
Ningxia	1995	299.7	10.1
Ningxia	2000	358.4	12.3
Ningxia	2005	513.8	17.9
Xinjiang	1995	471.7	23.6
Xinjiang	2000	588.2	29.2
Xinjiang	2005	761.0	38.0
Export	1995	334.6	32.7
Export	2000	399.6	27.1

Export	2005	446.1	38.8
Total	1995	24253.9	1647.5
	2000	29349.9	1958.1
	2005	34070.5	2265.8

Summary of Results for All 1993 Scenarios

Table 9.1: Summary Solution Results

Case	Coal Demand in 2000 (million std tons)	Electr. Demand in 2000 (bil. kwh)	Total System Disc. Cost (bil. Y)	Total Invest-ment in 8-9FYP (bil. Y)	Coal Shtg. in 2000 (mil. std tons)	Electr. Shtg. in 2000 (bil. kwh)	Total Shtg. in 2000 (mil. std tons)
93-1. 9% GNP	906	1444	897	660	0.2	67.6	39.3
93-2. 9% GNP w/ New Port Railway	906	1444	895	671	0.2	58.4	32.3
93-3. Sulfur, Ash -10%	906	1444	925	654	3.4	95.6	55.9
93-4. Sulfur, Ash -20%	906	1444	994	637	67.3	110.6	128.2
93-5. Wash Inv Cost +15%	906	1444	898	660	0.2	67.6	37.3
93-6. Transm Inv Cost +15%	906	1444	899	659	0.2	69.2	38.3
93-7. No New Steam Coal Washing	906	1444	914	658	3.5	86.7	51.6
93-8. No New Big Transmiss. Lines	906	1444	904	664	0.2	64.1	35.5
93-9. GNP 10.5%, Same Rail as 93-1	926	1661	1151	748	80.0	105.6	138.1
93-10. GNP 10.5%, Rail Reoptimized	926	1661	1147	759	75.7	101.7	131.6
93-11. GNP 10.5%, Triple New Rail Capac	926	1661	1093	741	47.7	110.2	108.3
93-12. GNP 10.5%, High Shortage Cost	926	1661	1185	766	74.9	91.3	125.1
93-13. GNP 7.5%, Same Rail as 93-1	885	1258	713	571	0.04	1.1	0.65

Table 9.2: Coal Production Sector Results

Case	Coal Production in 2000 (million tons)	Yr. 2000 Coal Prod. from North and SW Energy Base (mil tons.)	Yr. 2000 Coal Prod. from Coastal Regions (mil. tons)	Tons Washed in 2000 (mil. tons)	Steam Coal Washing Rate in 2000 (percent)
93-1. 9% GNP	1601	855	349	403	16.3
93-2. 9% GNP w/ New Port Railway	1607	851	351	409	16.7
93-3. Sulfur, Ash -10%	1576	839	341	550	28.5
93-4. Sulfur, Ash -20%	1488	808	305	582	33.4
93-5. Wash Inv Cost +15%	1601	855	349	403	16.2
93-6. Transm Inv Cost +15%	1599	853	349	404	16.3
93-7. No New Steam Coal Washing	1589	842	349	n.a.	n.a.
93-8. No New Big Transmiss. Lines	1604	857	350	405	16.4
93-9. GNP 10.5%, Same Rail as 93-1	1638	867	359	417	16.5
93-10. GNP 10.5%, Rail Reoptimized	1643	865	361	429	17.3
93-11. GNP 10.5%, Triple New Rail Capac.	1655	895	347	437	18.2
93-12. GNP 10.5%, High Shortage Cost	1648	868	363	451	18.9
93-13. GNP 7.5%. Same Rail as 93-1.	1514	814	326	384	16.3

Table 9.3: Electricity Production Sector Solution Results

Case	Electricity Generated in 2000 (billion kwh)	Total Thermal Capacity by 2000 (million kw)	Total Hydro Capacity by 2000 (million kw)	Nuclear Capacity Built by 2000 (million kw)	Thermal-Hydro Shares of Elec. Prod. in 2000 (percent)
93-1. 9% GNP	1507	240	70	.90	81.8 - 17.8
93-2. 9% GNP w/ New Port Railway	1515	243	70	.90	82.1 - 17.5
93-3. Sulfur, Ash -10%	1478	234	71	.90	80.4 - 19.1
93-4. Sulfur, Ash -20%	1459	229	73	.90	80.4 - 19.1
93-5. Wash Inv Cost +15%	1507	240	70	.90	81.8 - 17.8
93-6. Transm Inv Cost +15%	1505	240	70	.90	81.8 - 17.8
93-7. No New Steam Coal Washing	1490	236	71	.90	81.2 - 18.3
93-8. No New Big Transmiss. Lines	1511	244	69	.90	82.1 - 17.5
93-9. GNP 10.5%, Same Rail as 93-1	1702	279	73	.90	83.2 - 16.4
93-10. GNP 10.5%, Rail Reoptimized	1704	280	73	.90	83.2 - 16.4
93-11. GNP 10.5%, Triple New Rail Capac.	1688	277	73	.90	83.1 - 16.6
93-12. GNP 10.5%, High Shortage Cost	1716	282	74	.90	83.2 - 16.4
93-13. GNP 7.5%, Same Rail as 93-1	1372	216	63	.90	81.9 - 17.7

Table 9.4: Electricity Transmission Solution Results

Case	Total Intergrid Electricity Transmission in 2000 (bil. kwh)	Electricity Transmission from Shanxi Pr. in 2000 (bil. kwh)	Electricity Transmission from E. Nei Mongolia in 2000 (bil. kwh)	Net Electricity Transmission to Huadong big grid in 2000 (bil. kwh)	Electricity Transmission from Nanning in 2000 (bil. kwh)	Electricity Transmission to Hunan, Hubei, & Henan in 2000 (bil. kwh)
93-1. 9% GNP	135.3	131.4	48.4	31.3	12.0	23.6
93-2. 9% GNP w/ New Port Railway	121.3	131.4	49.1	28.8	6.7	16.4
93-3. Sulfur, Ash -10%	127.3	125.5	40.0	41.8	10.3	18.8
93-4. Sulfur, Ash -20%	102.3	119.1	24.4	26.2	10.9	26.1
93-5. Wash Inv Cost +15%	135.4	131.4	48.3	31.4	12.1	23.6
93-6. Transm Inv Cost +15%	133.9	131.5	46.1	31.3	9.3	22.8
93-7. No New Steam Coal Washing	147.8	134.4	55.5	30.1	14.1	27.5
93-8. No New Big Transmiss. Lines	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
93-9. GNP 10.5%, Same Rail as 93-1	115.9	135.6	51.0	19.5	14.8	19.3
93-10. GNP 10.5%, Rail Reoptimized	102.4	142.0	45.1	16.9	12.0	13.4
93-11. GNP 10.5%, Triple New Rail Capac.	81.4	114.9	11.6	28.6	0	16.1
93-12. GNP 10.5%, High Shortage Cost	104.8	143.1	16.6	15.6	13.2	15.4
93-13. GNP 7.5%, Same Rail as 93-1	99.3	89.1	48.4	23.4	6.9	11.7

Table 9.5: Transportation Sector Solution Results

Case	Total Traffic in 2000 (million tons)	Ton-km in 2000 (billion tkm)	Average Transp. Distance in 2000 (rail km/ waterkm	Rail-Water Shares of Tonnage in 2000 (percent)	Rail-Water Shares of Tkm in 2000 (percent)	Shipping Fleet Invstmnt. by 2000 (bil. Y)	Number of Bottle-necks in 2000
93-1. 9% GNP	952	952	671/2268	79-21	53-47	8.64	58
93-2. 9% GNP w/ New Port Railway	937	941	671/2310	80-20	53-47	10.43	64
93-3. Sulfur, Ash -10%	925	996	670/2806	81-19	50-50	8.29	63
93-4. Sulfur, Ash -20%	909	984	671/2860	81-19	50-50	7.81	59
93-5. Wash Inv Cost +15%	950	953	673/2210	79-21	54-46	8.64	61
93-6. Transm Inv Cost + 15%	952	953	667/2369	80-20	53-47	8.65	58
93-7. No New Steam Coal Washing	970	968	663/2248	79-21	53-47	8.79	62
93-8. No New Big Transmiss Lines	961	947	670/2280	79-21	54-46	9.03	60
93-9. GNP 10.5%, Same Rail as 93-1	971	962	642/2362	80-20	52-48	8.65	57
93-10. GNP 10.5%, Rail Reoptimized	968	981	624/2662	81-19	50-50	11.43	61
93-11. GNP 10.5%, Triple New Rail Capac.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
93-12. GNP 10.5%, High Shortage Costs	974	1000	629/2675	80-20	49-51	11.35	56
93-13. GNP 7.5%, Same Rail as 93-1	914	797	666/2939	83-17	63-37	7.94	55

Table 9.6: Environment Sector

Case	Total Ash Delivered in 2000 (mil. tons)	Total Sulfur Delivered in 2000 (mil. tons)	Scrub. Capacity Built by 2000 (mil. tons)	Tons of Steam Coal Washed in 2000 (mil. tons)	Hydro Capacity Built by 2000 (mil. kw)	Nuclear Capacity Built by 2000 (mil. kw)
93-1. 9% GNP	293	19.6	0	206	70	.9
93-2. 9% GNP w/ New Port Railway	294	19.6	0	211	70	.9
93-3. Sulfur, Ash -10%	266	17.8	.79	353	71	.9
93-4. Sulfur, Ash -20%	236	15.9	1.38	387	73	.9
93-5. Wash Inv Cost + 15%	293	19.6	0	205	70	.9
93-6. Transm Inv Cost + 15%	293	19.6	0	206	70	.9
93-7. No New Steam Coal Washing	308	19.9	0	n.a.	71	.9
93-8. No New Big Transmiss. Lines	294	19.6	0	207	69	.9
93-9. GNP 10.5%, Same Rail as 93-1	300	19.9	0	213	73	.9
93-10. GNP 10.5%, Rail Reoptimized	300	19.9	0	224	73	.9
93-11. GNP 10.5%, Triple Rail Capac.	301	20.1	0	239	73	.9
93-12. GNP 10.5%, High Shortage Cost	299	19.9	0	246	74	.9
93-13. GNP 7.5%, Same Rail as 93-1	277	18.8	0	194	63	.9

FIGURES AND MAPS ON RESULTS OF THE ANALYSIS

(All figures are for 9 Percent GNP Growth,
Case 93-2, unless otherwise indicated.)

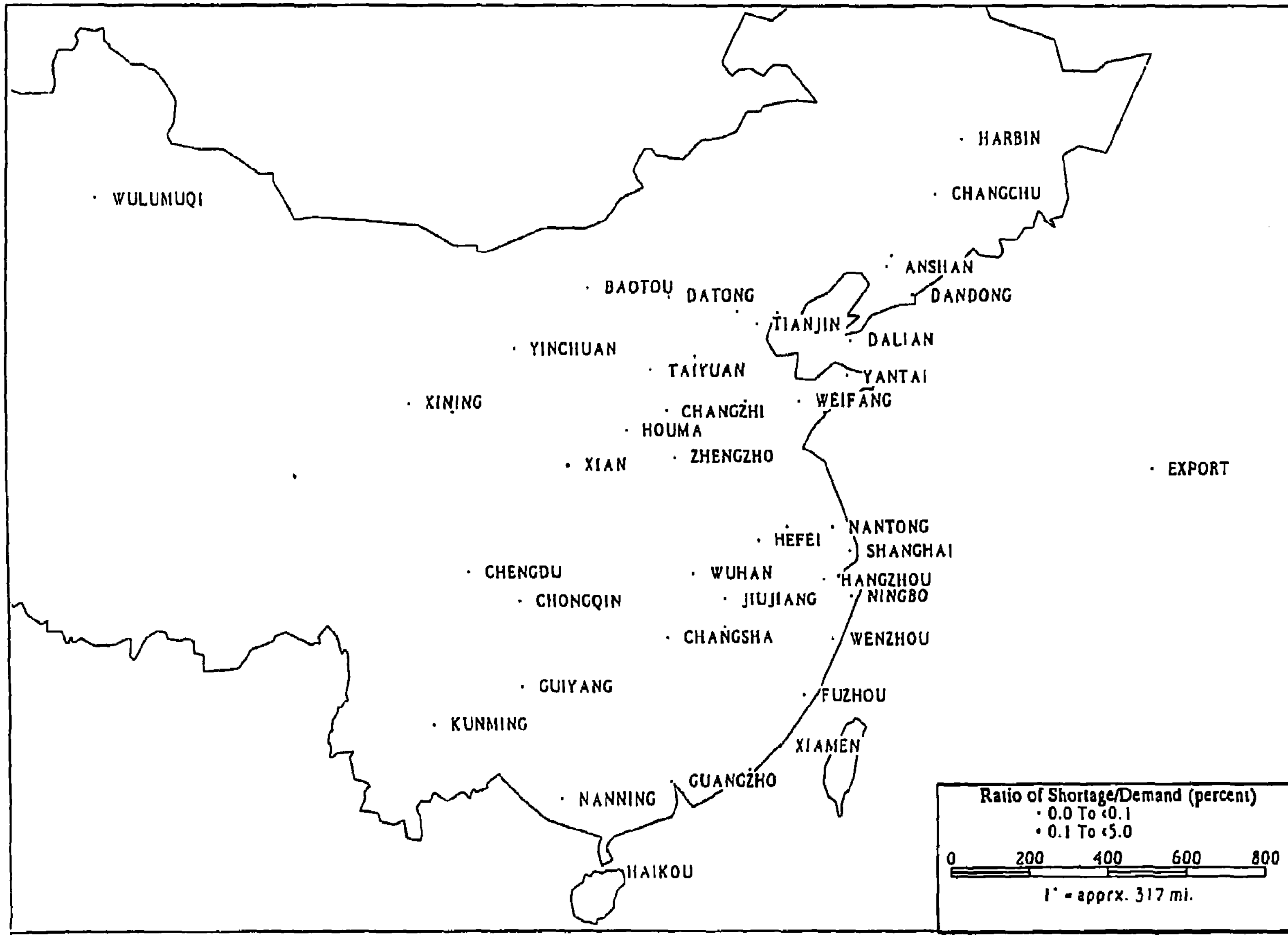


Figure 10.1: Coal Shortages, 2000, Medium Demand

Figure 10.2: Electricity Shortages,2000,Medium Demand

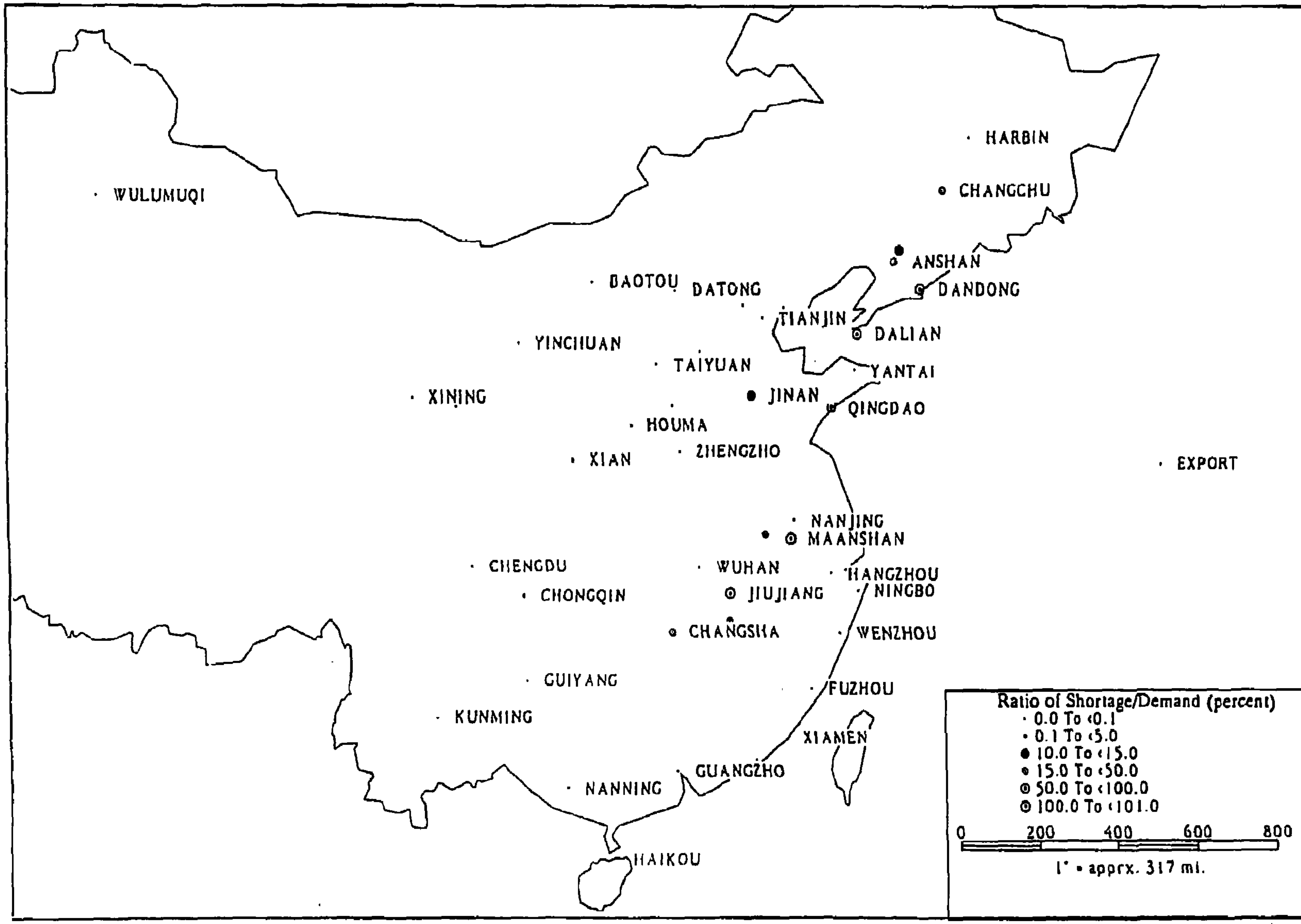


Figure 10.3: Coal Shortages,2000, High Demand

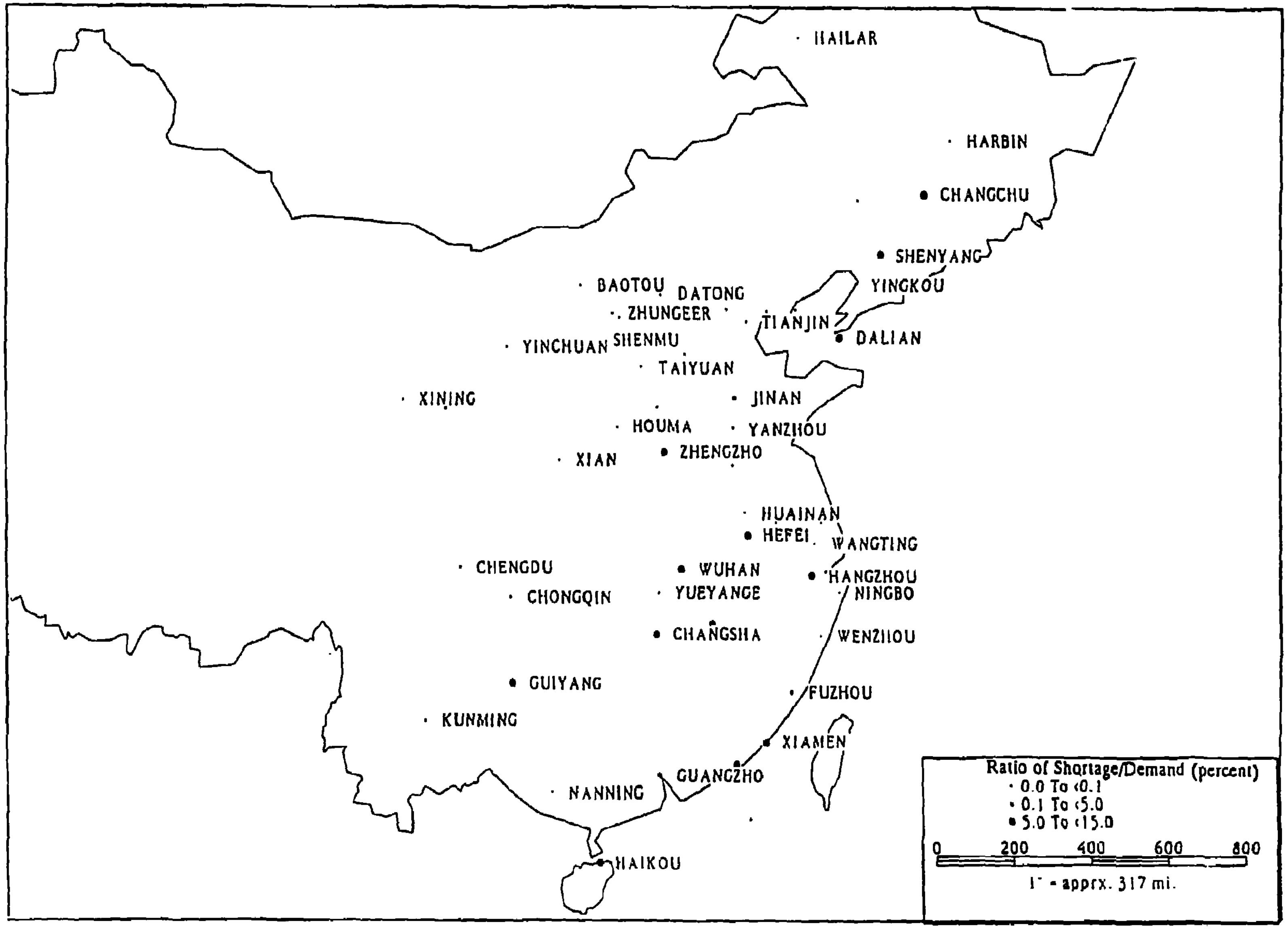
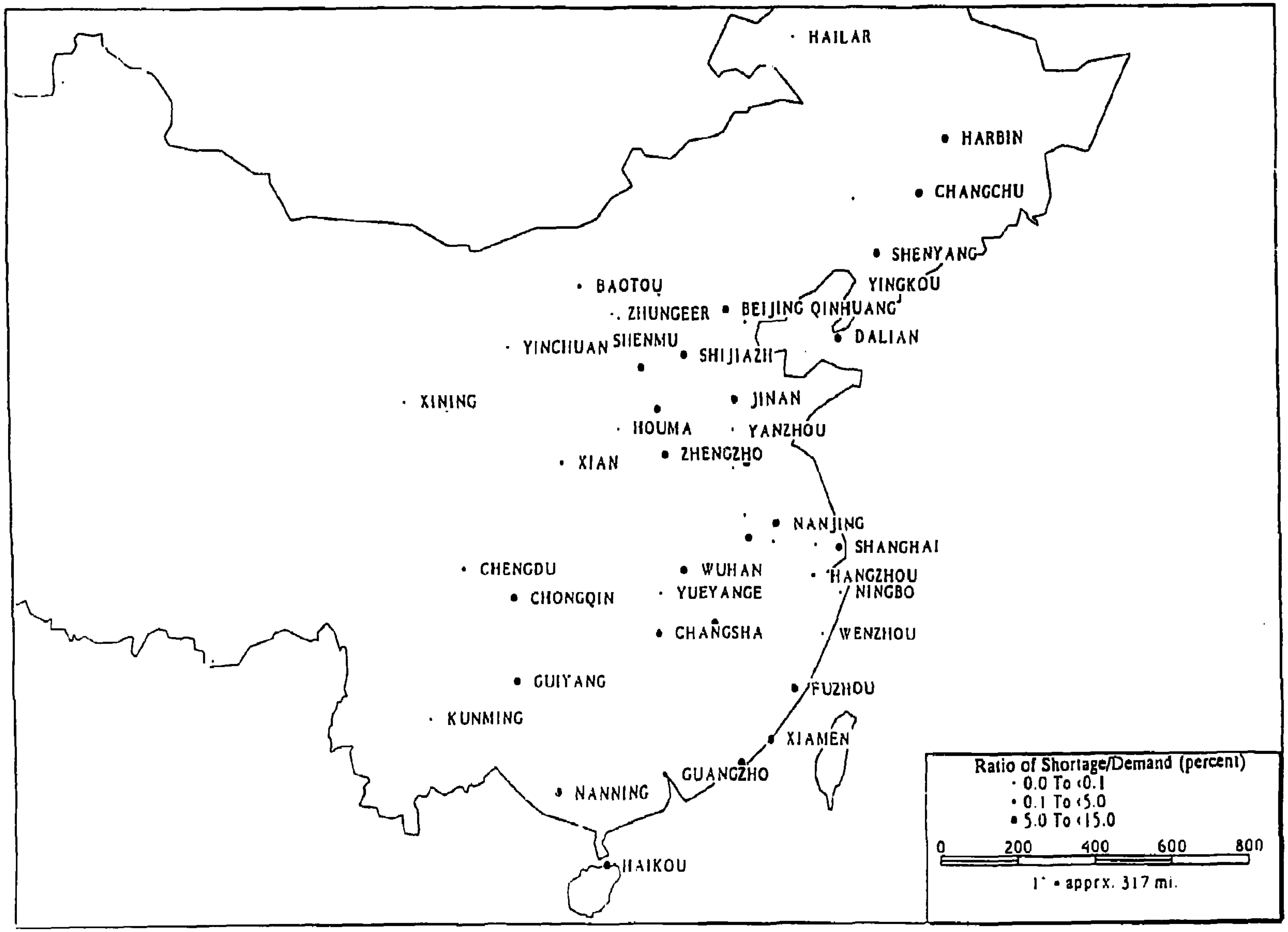


Figure 10.4: Electricity Shortages, 2000, High Demand



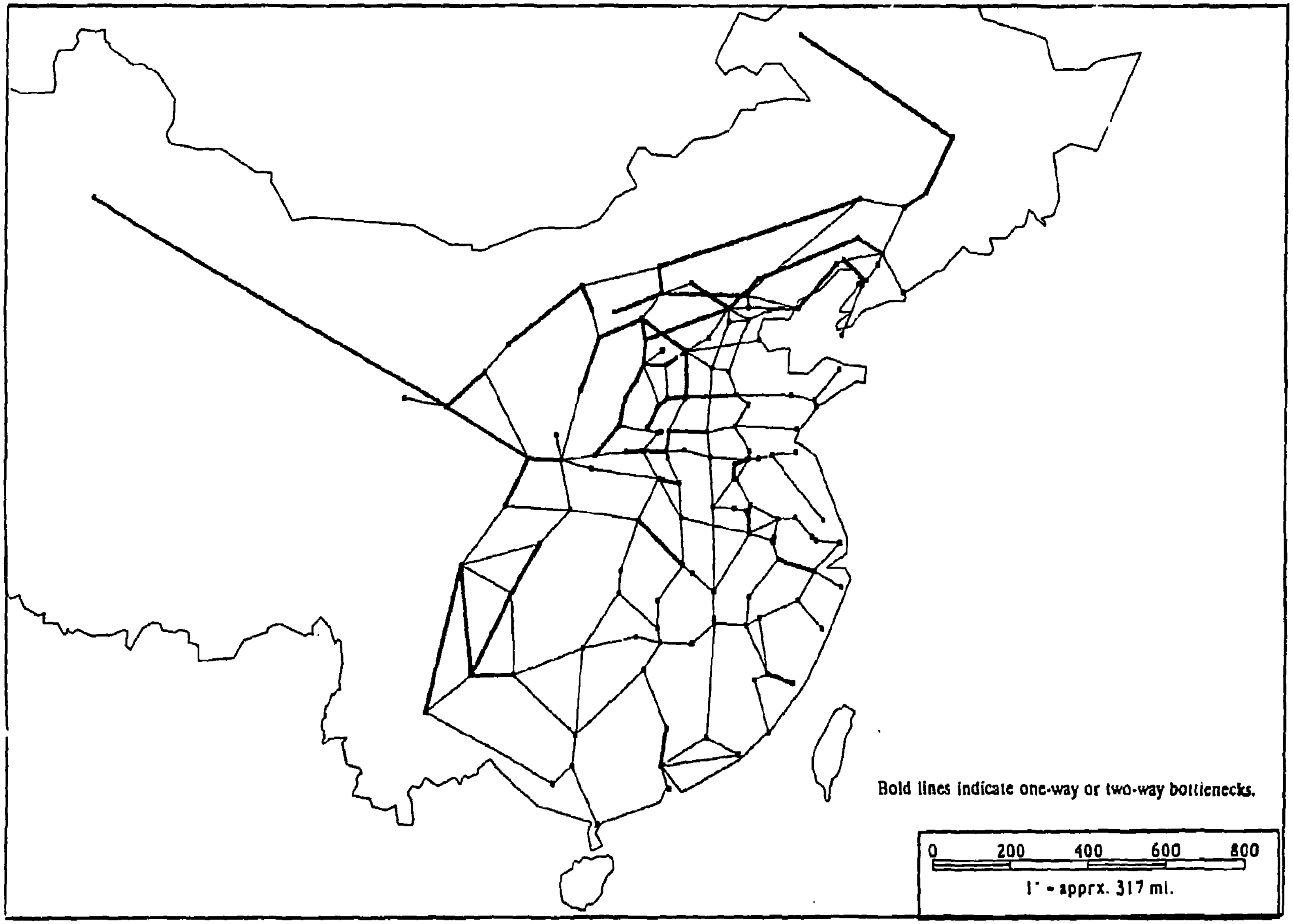


Figure 10.5: Rail Bottlenecks, 2000, Medium Demand

Figure 10.6: Rail Bottlenecks, 2000, High Demand

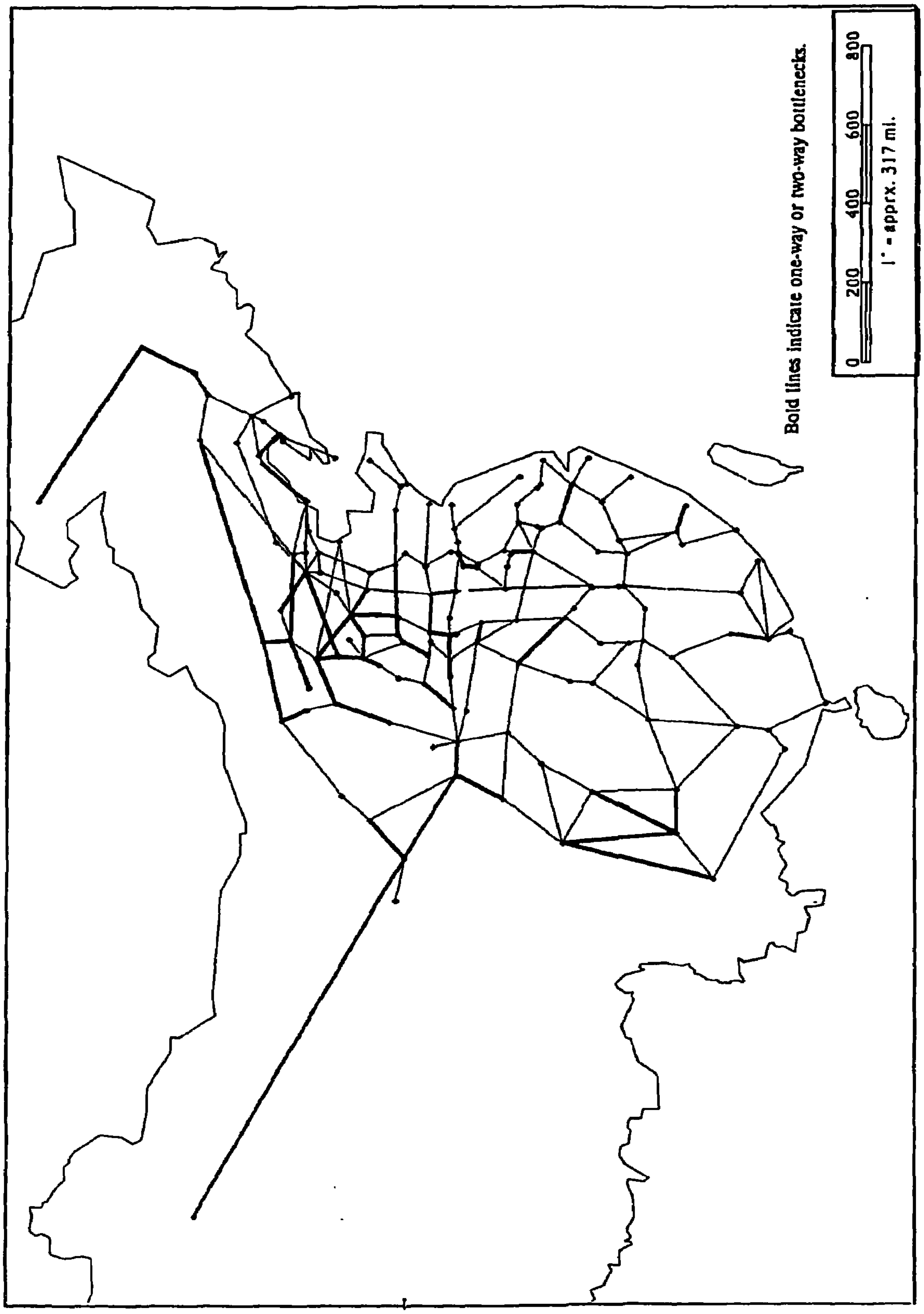


Figure 10.7: New Transport Projects Built

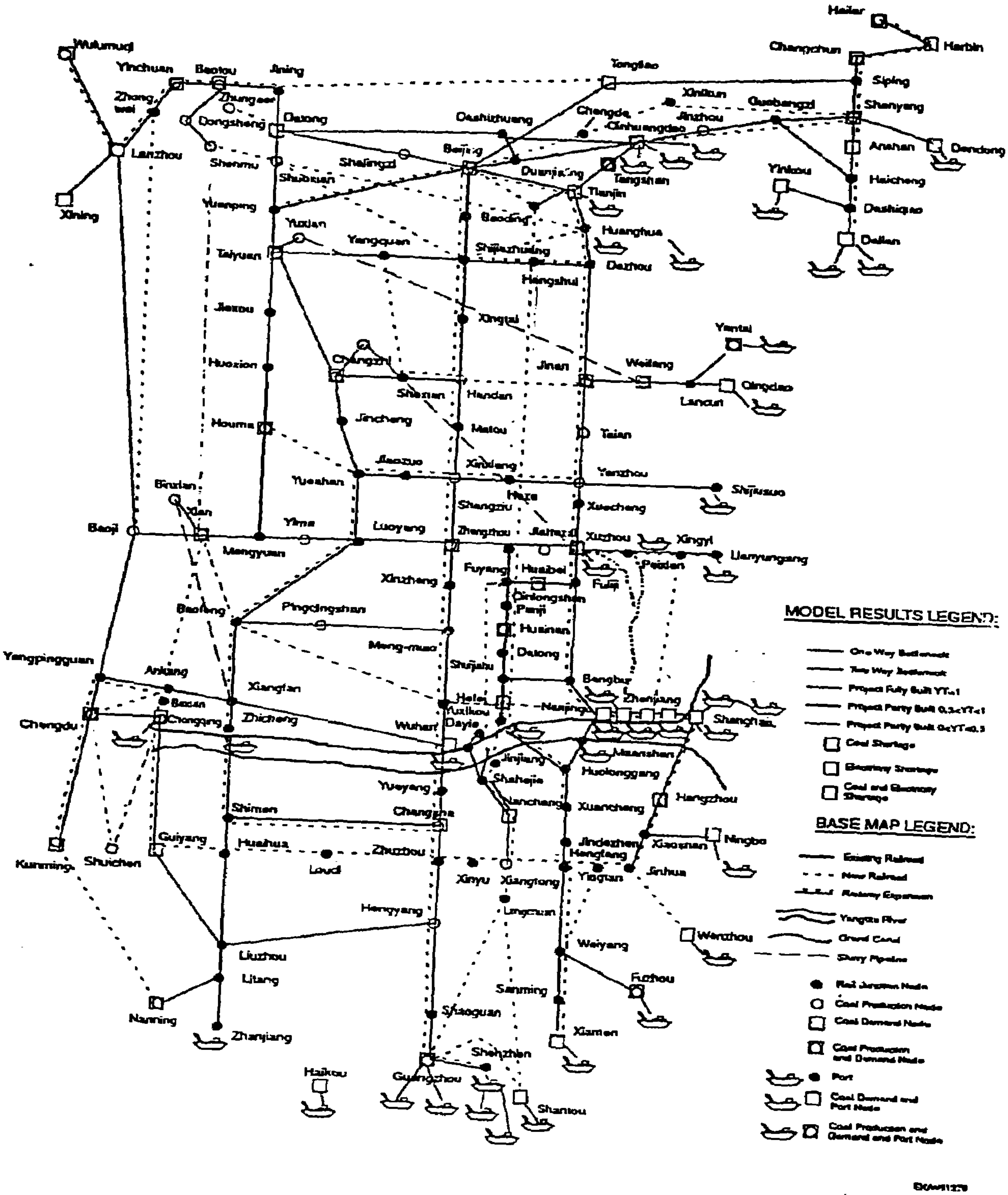


Figure 10.8: Port Bottlenecks, 2000, Medium Demand

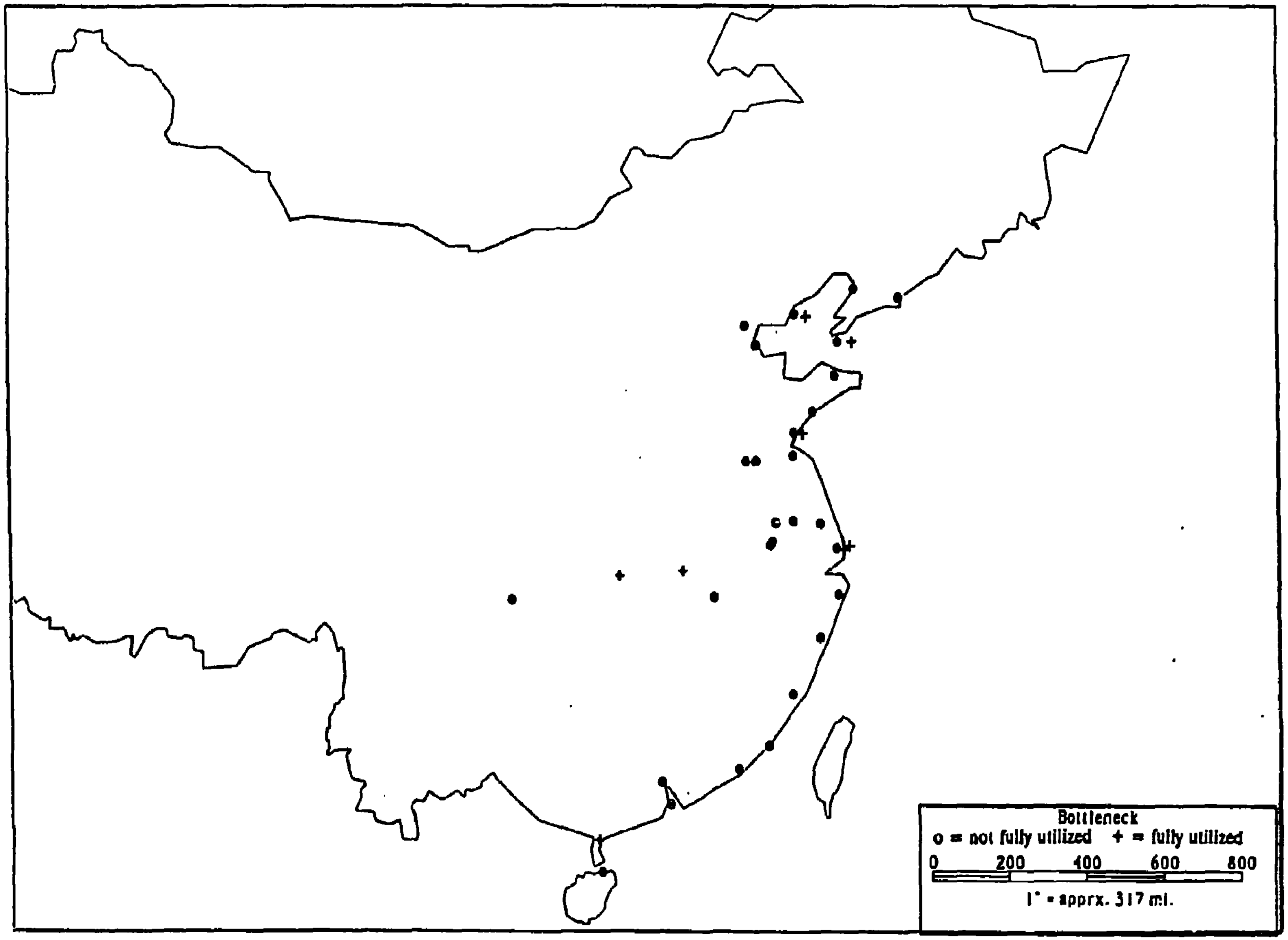


Figure 10.9: Port Bottlenecks, 2000, High Demand

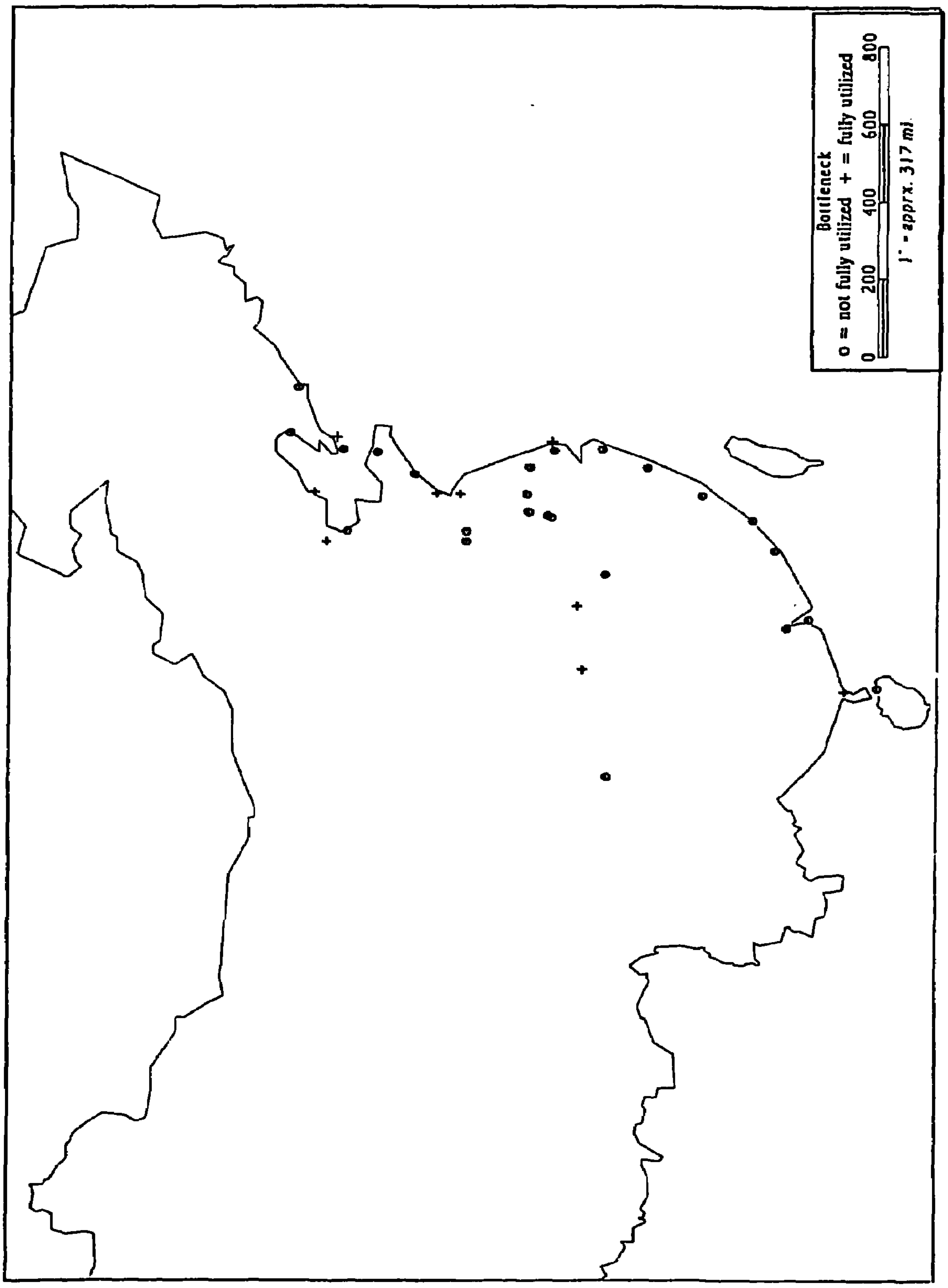


Figure 10.10: Rail Coal Flow Map, 2000, Medium Demand

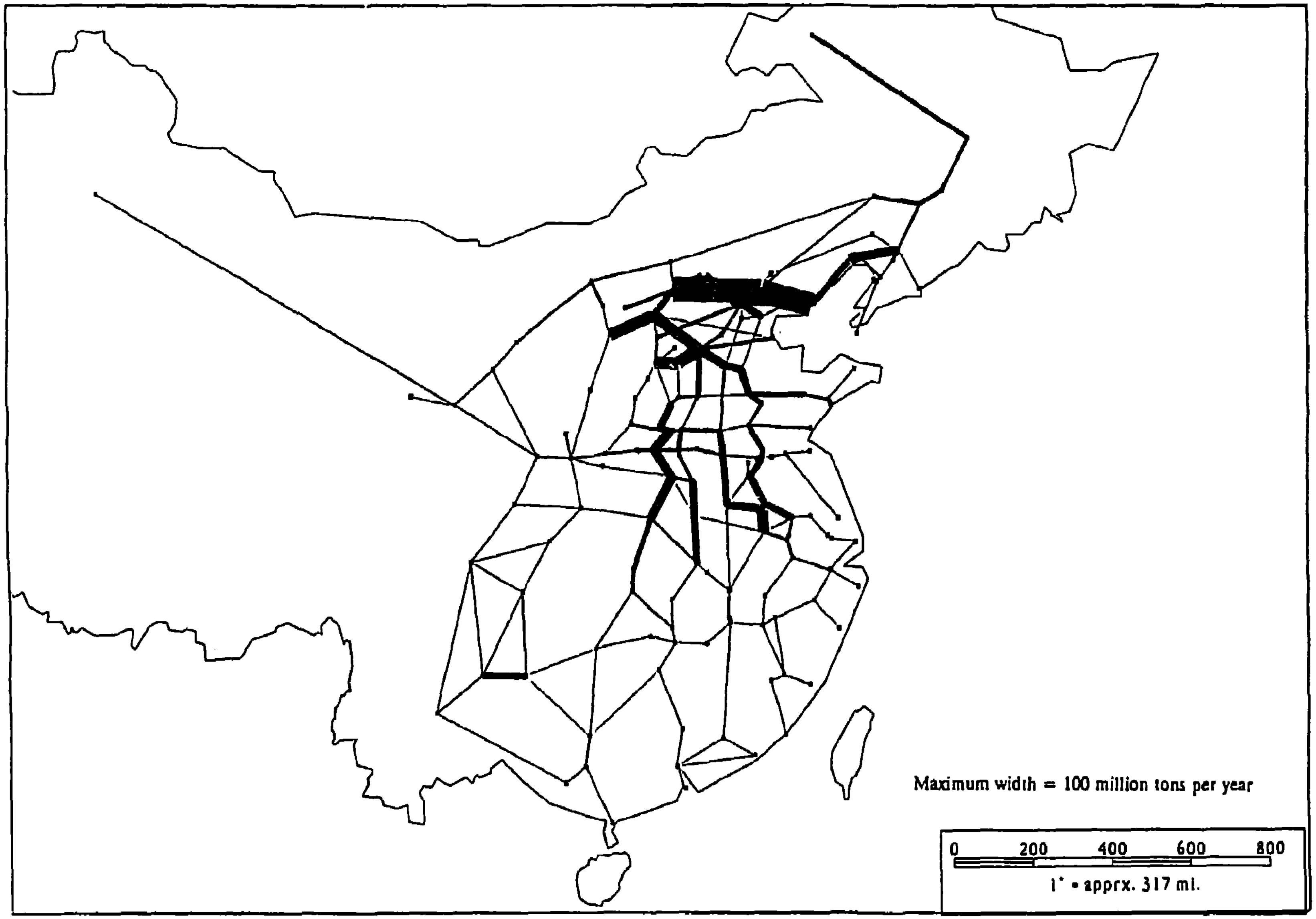
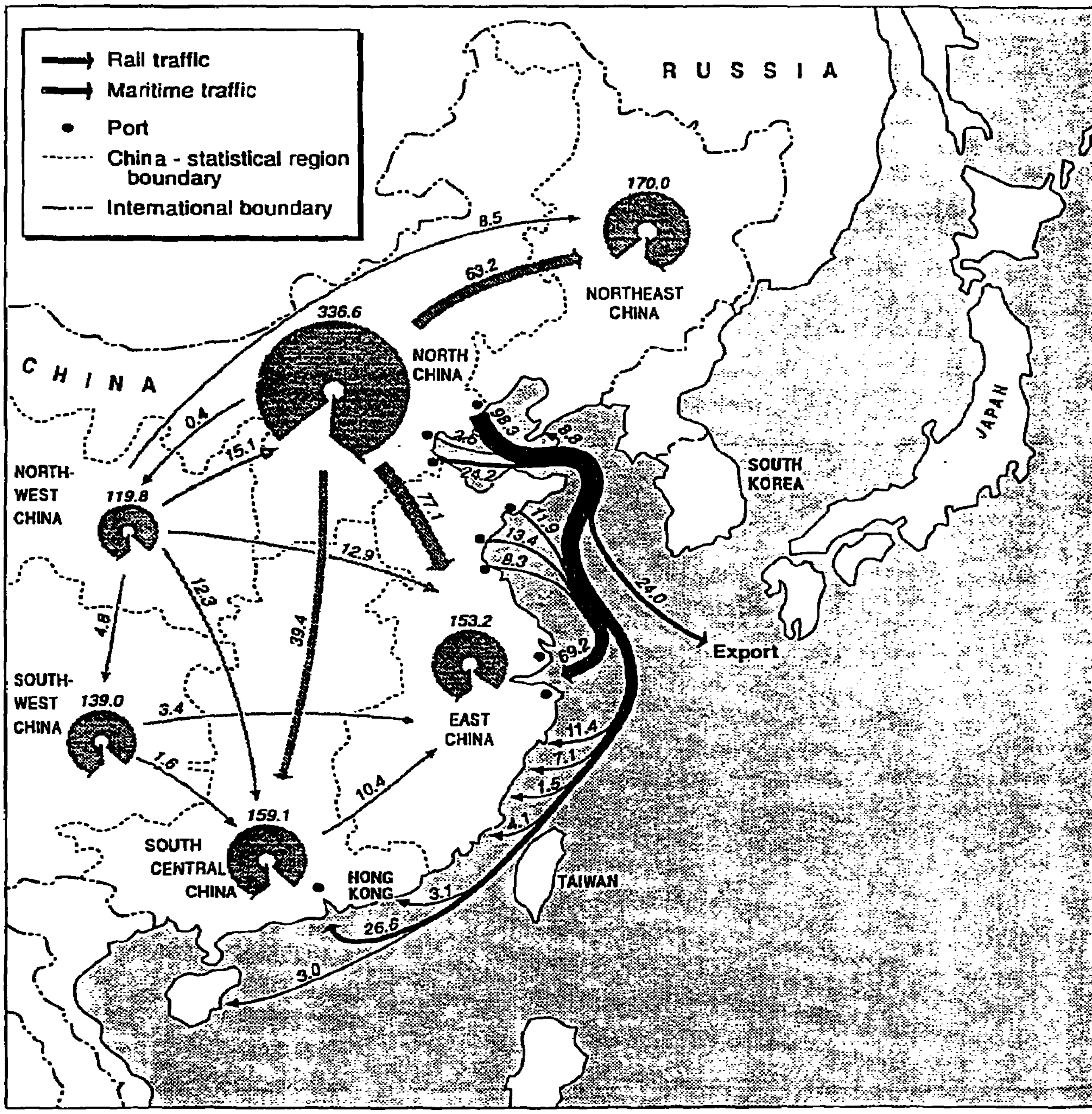


Figure 10.11: Optimal Interregional Coal Flows, 2000, Medium Demand
(Millions of Metric Tons)



* Case 93-2

Figure 10.12: Optimal Coal Allocation by Heat Content, from Coal Base in the Year 2000 (6 percent GNP Growth, Case 92-1)

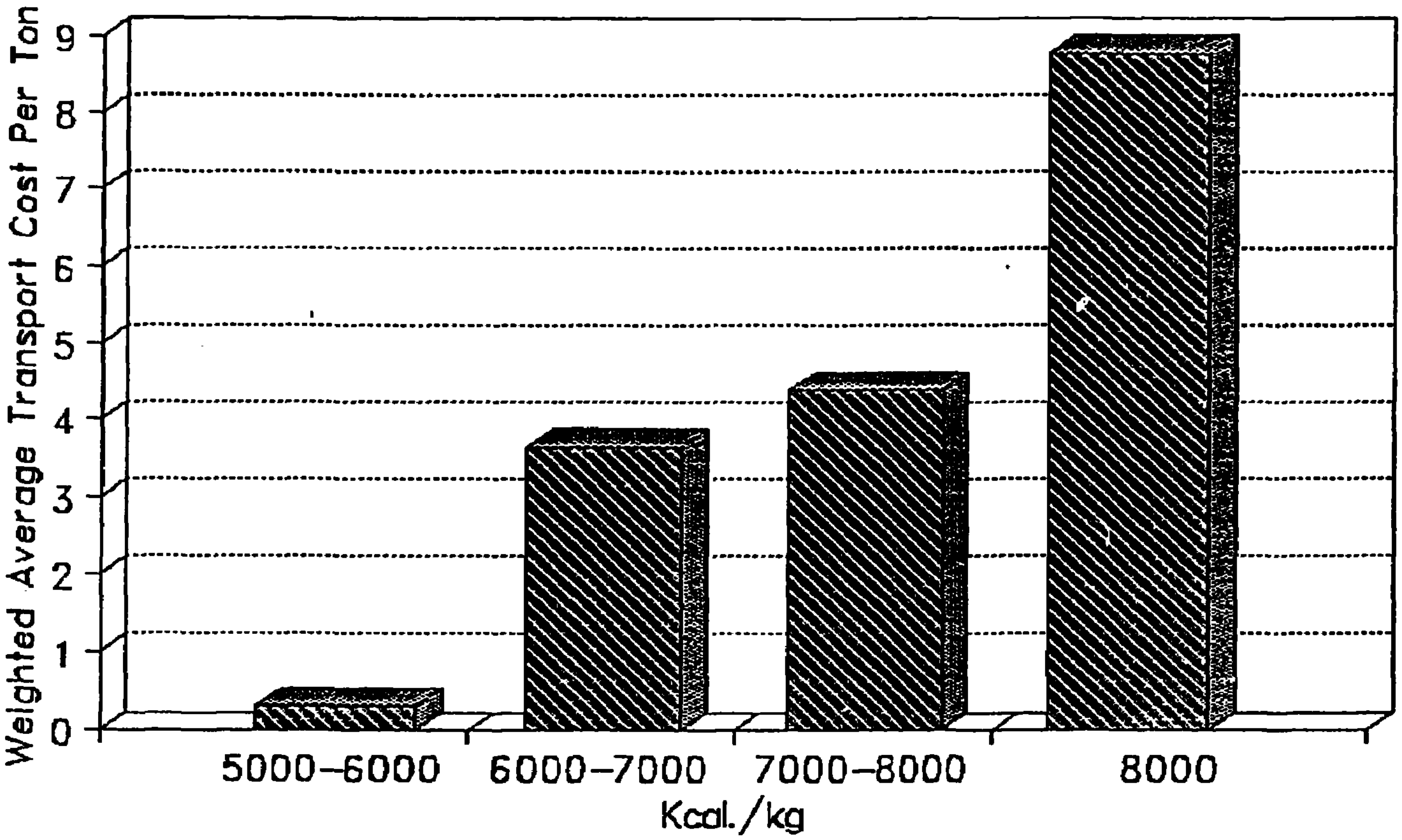
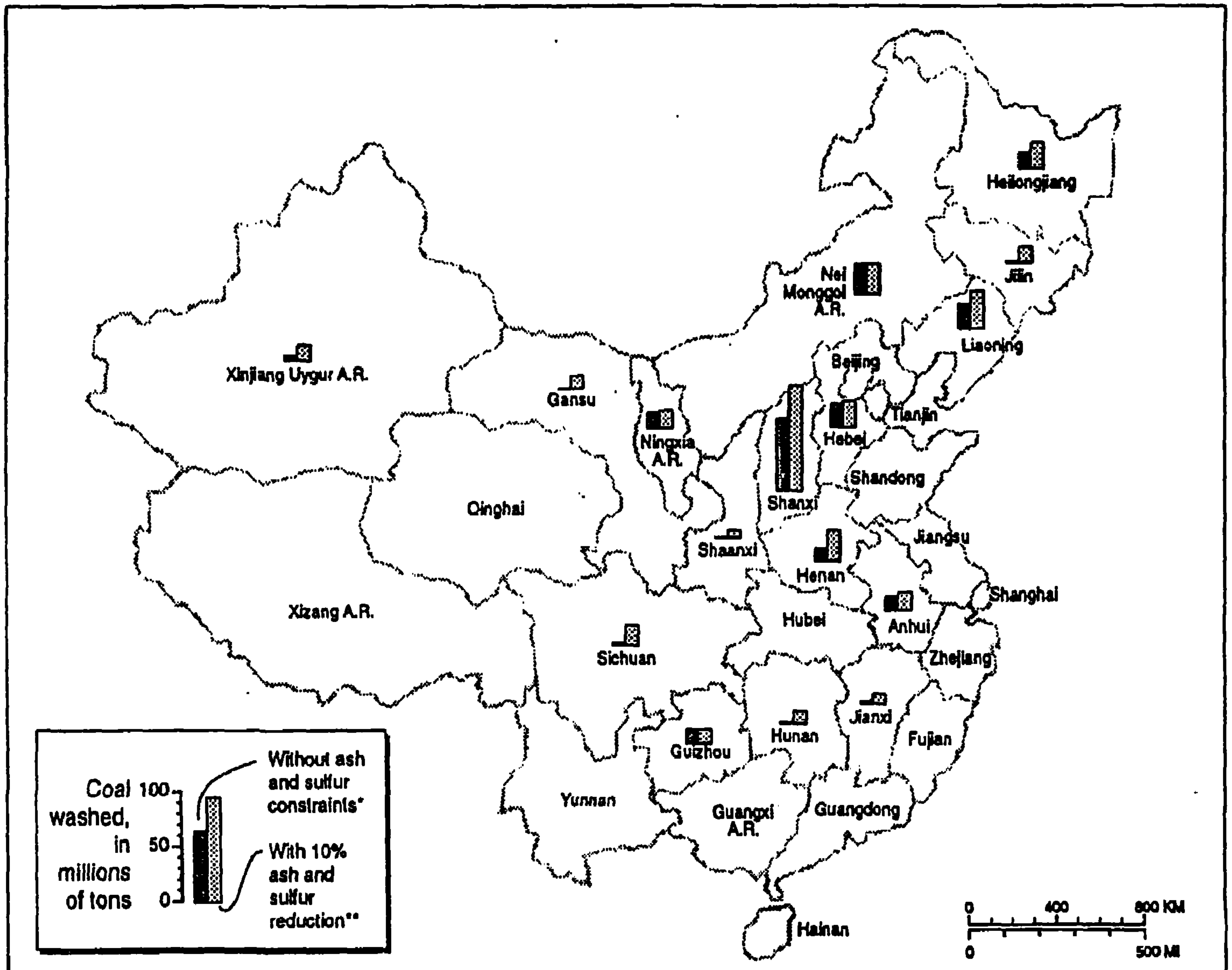


Figure 10.13: Steam Coal Washing By Province, 2000, Medium Demand



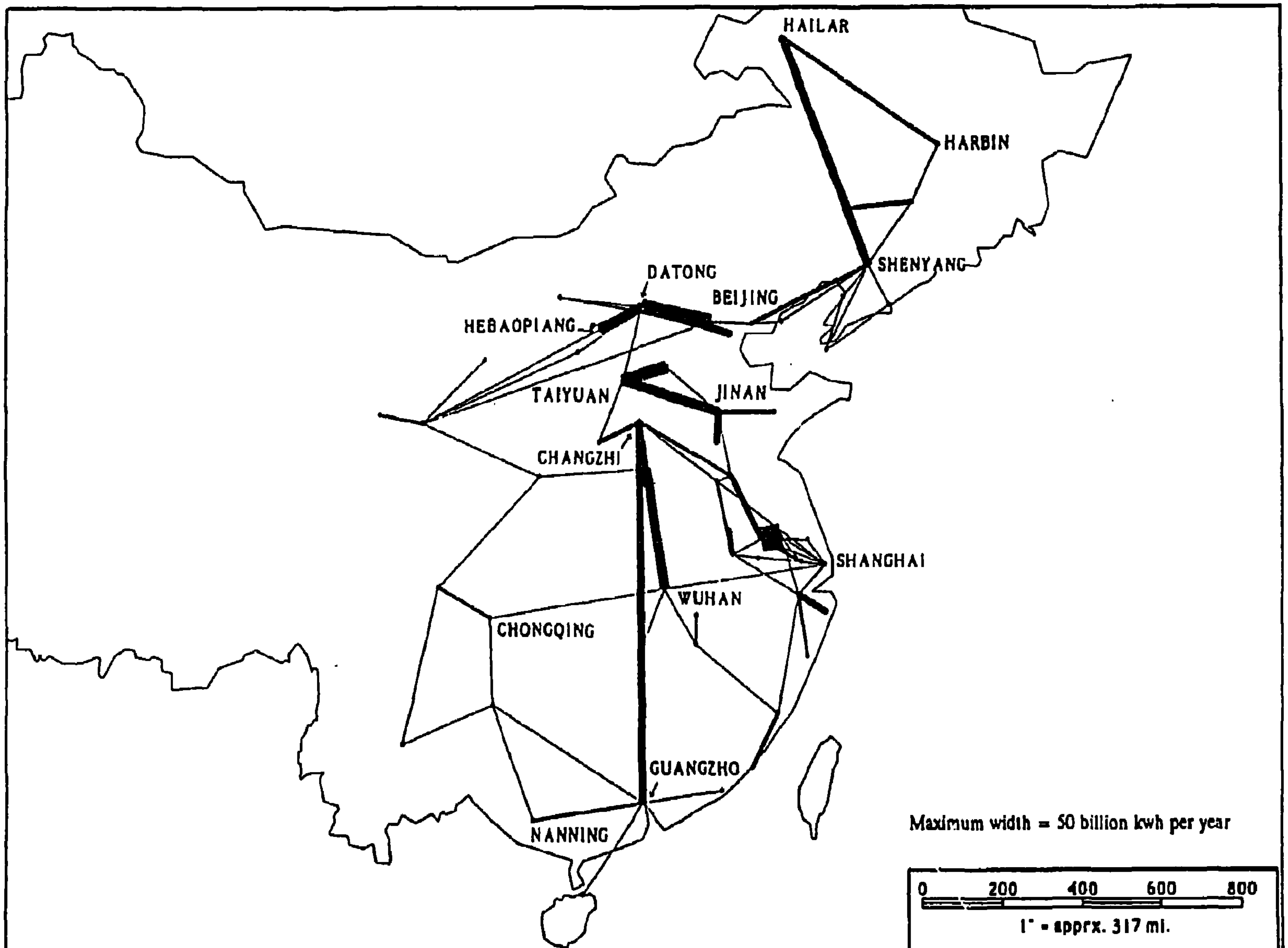


Figure 10.14: Electricity Flow Map, 2000, Medium Demand

Figure 10.15: Electricity Flow Map, 2000, High Demand

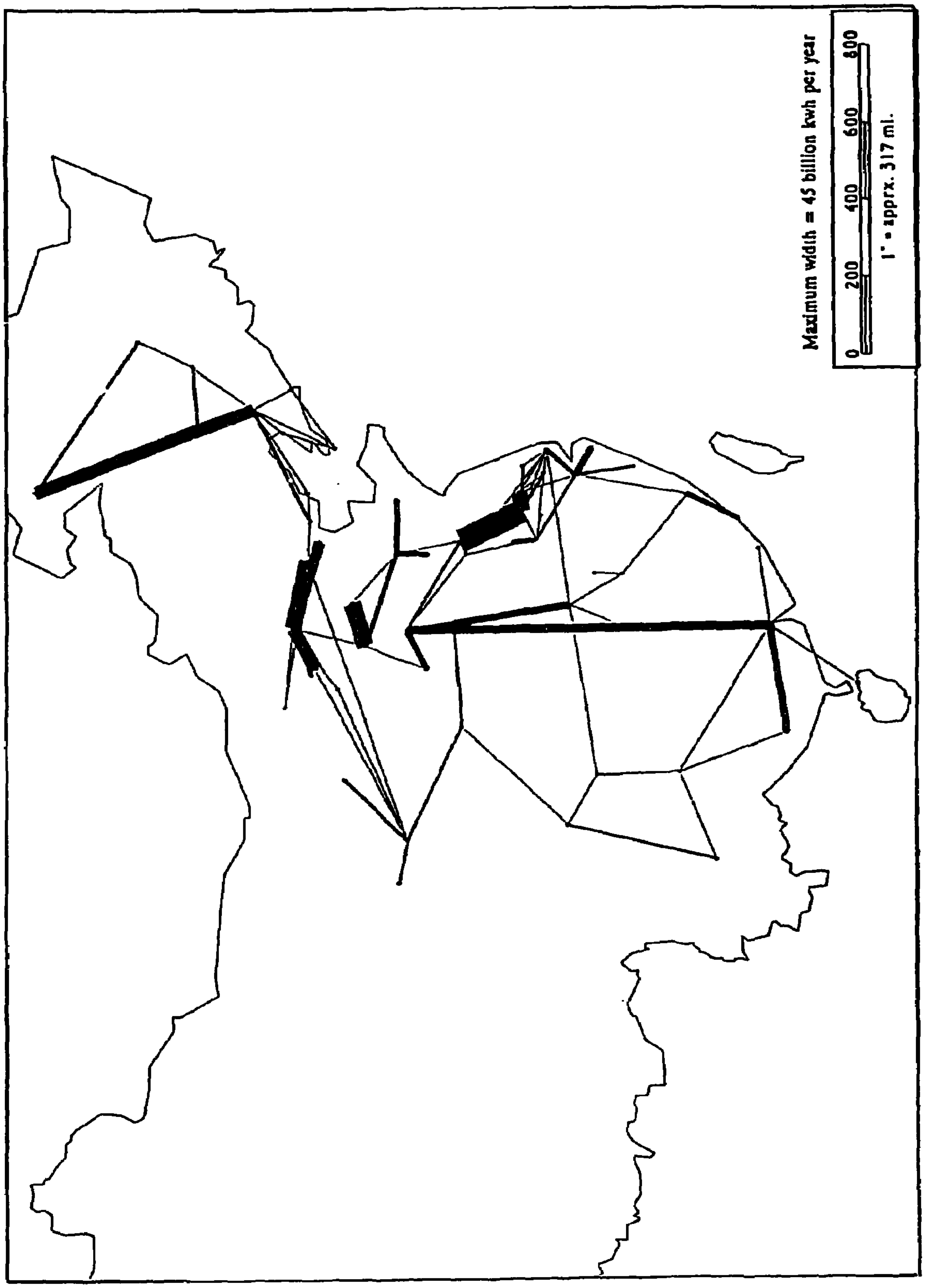
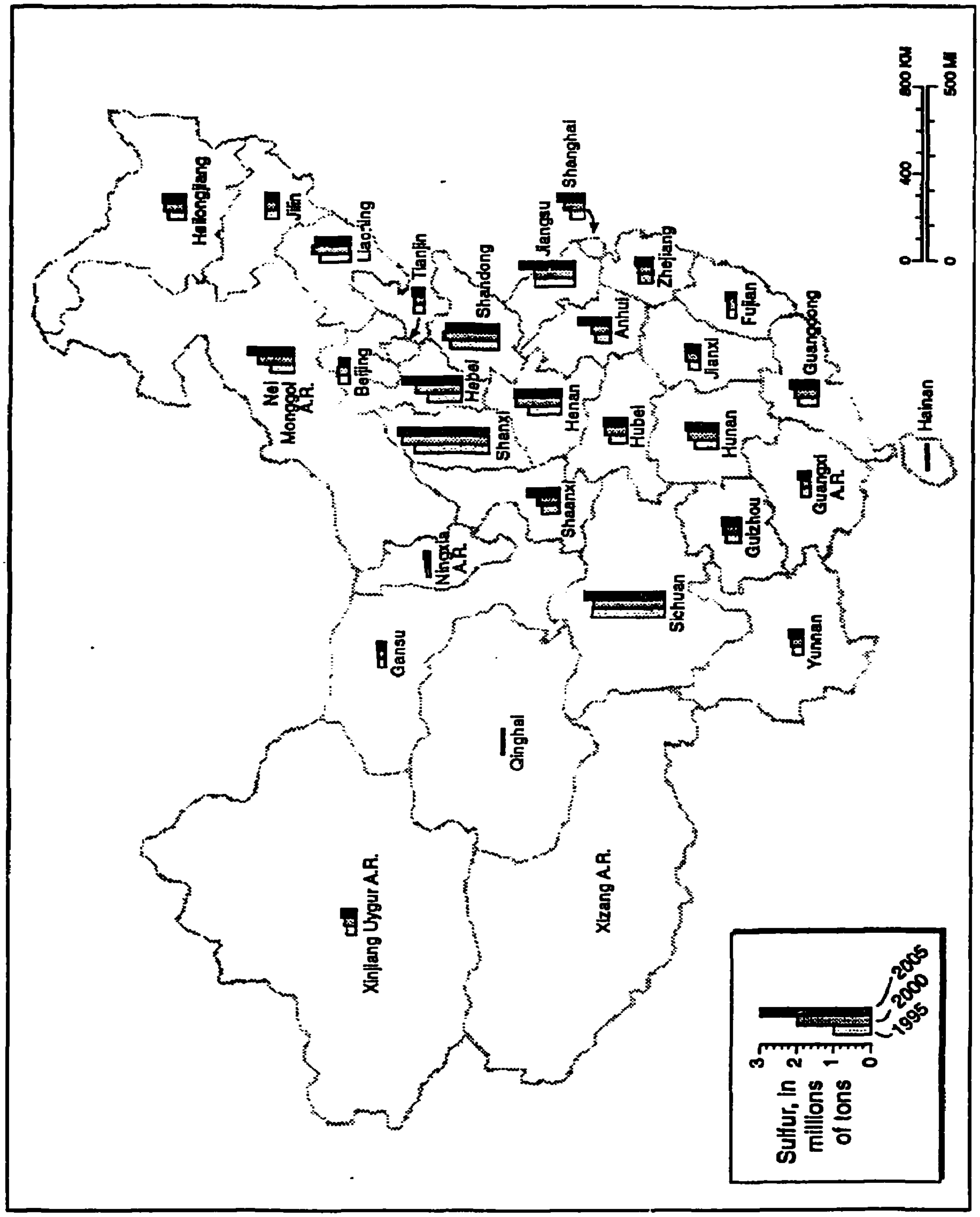
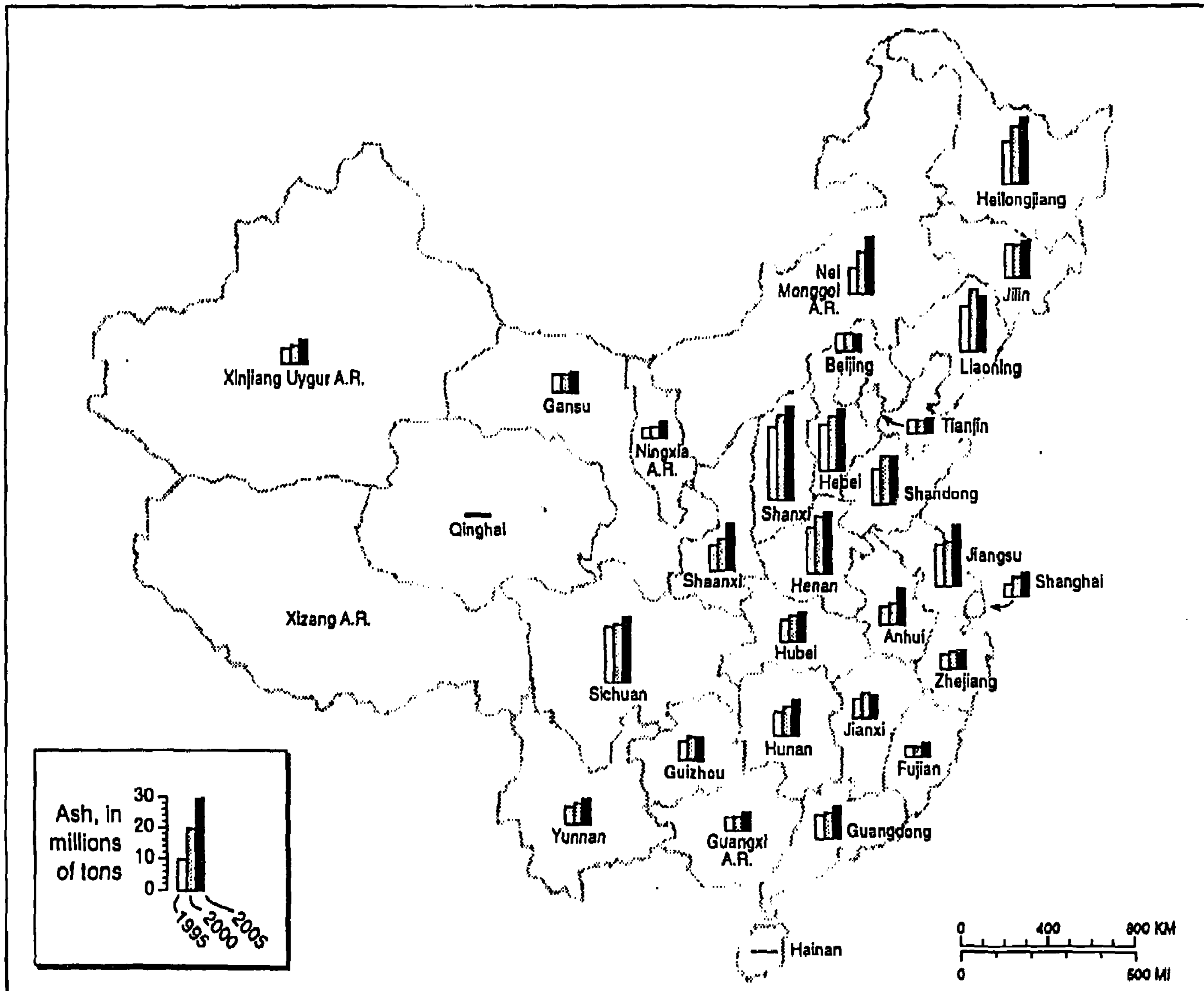


Figure 10.16: Sulfur in Delivered Coal by Province, 1995-2005, Medium Demand



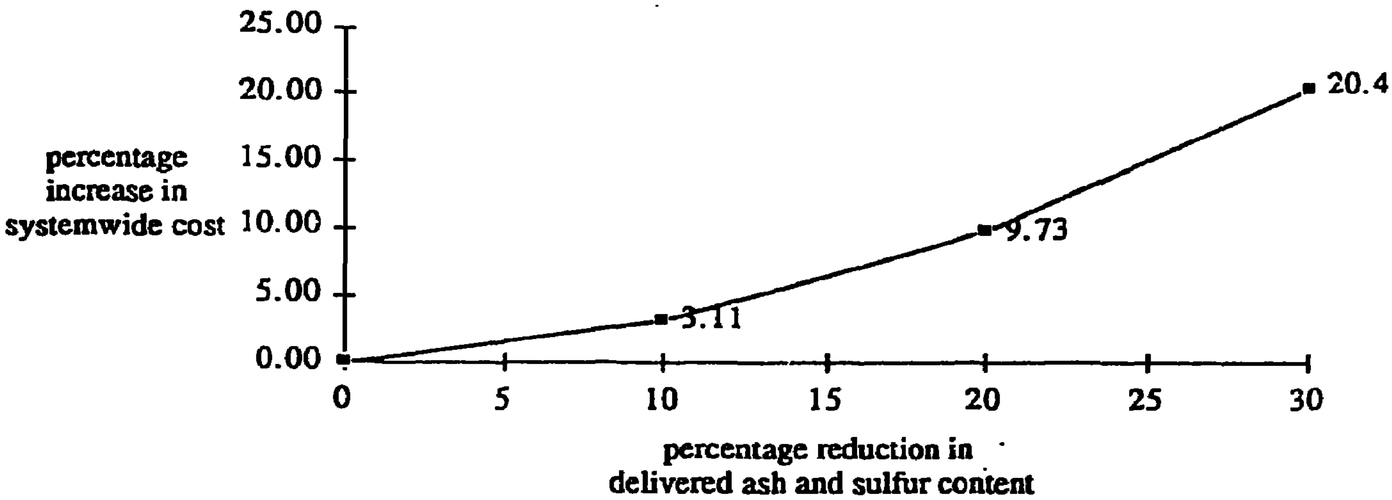
* Case 93-2

Figure 10.17: Ash in Delivered Coal by Province, 1995-2005, Medium Demand



* Case 93-2

Figure 10.18: Multiobjective Tradeoff Curve for Cost and Pollution



DESCRIPTION OF 1992 SCENARIO ASSUMPTIONS

Scenario Assumptions

1. The 16 scenarios can be divided into two groups, according to the handling of the investment decisions for major projects (i.e., transport projects, large dams, and 500 kV DC power lines, modeled with 0-1 variables). In Case 92-1 and Cases 92-13 to 92-16, the investment decisions for major projects are optimized. These cases are valuable for policy purposes because they endogenously compare transport investments with the nontransport substitutes, like hydropower and coal washing, under various combinations of conditions. (However, it should be noted that the yes-or-no decisions that the model makes about transport projects gives no consideration to other commodities, i.e., the decisions are based on coal's share of the projects' investment cost and capacity.) In the second group of cases (Cases 92-2 to 92-12), the major projects were fixed at their values from Case 92-1 (1=to be built, 0=not to be built). In essence, this latter group of cases can tell us how well the set of major projects optimized for the medium demand forecast would be able to meet China's energy supply needs under various conditions.

2. The other important differences among the new scenarios is the demand level assumed and whether environmental policy goals are adopted to reduce the total ash and sulfur content. Three cases assume higher demand levels, while one assumes lower levels. Five scenarios adopt ash and sulfur reduction constraints. The 16 policy scenarios are summarized in Annex 12.

Case 92-1—Medium Demand, No Policy Changes Case

3. Coal demand in the year 2000 is 880 million tons of standard coal per year, which represents an assumed growth rate of 2.93 percent per year, and an assumed elasticity of 0.5 (percentage growth in coal demand/percentage growth in GNP). Electricity demand in 2000 is 1.08 trillion kwh, assuming a 6.1 percent annual growth rate from 1990 to 1995 and a 7.4 percent growth rate from 1995 to 2000 (and an elasticity greater than 1). No environmental reductions are imposed. Major investment projects are optimized.

Case 92-2—High Demand Case

4. Coal demand in all time periods is 7.5 percent higher than in the Medium Demand case. Electricity demand is 8.7 percent higher than the Medium Demand case. These assumptions are based on forecasts by the Energy Research Institute, assuming GNP growth of 9 percent and a slightly lower coal demand elasticity of 0.4. Major investment projects are the same as in Case 92-1.

Case 92-3—Low Demand Case

5. Coal demand in all time periods is 3.2 percent lower than in the Medium Demand case. Electricity demand is 2.2 percent lower than the Medium Demand case. Major investment projects are the same as in Case 92-1.

Case 92-4—Reduced Allocation of Transport Capacity to Coal

6. All transport capacities in the network are reduced by 10 percent, so as to simulate the effect of allocating more railway capacity to passenger traffic. Major investment projects are the same as in Case 92-1.

Case 92-5—Increased Allocation of Transport Capacity to Coal

7. Same as Case 92-4, but increased by 10 percent. Cases 92-4 and 92-5

are both useful for indicating the sensitivity of energy shortages to transport bottlenecks.

Case 92-6—Doubled Operating Costs for Railways and Ports

8. All transport operating costs are increased by 100 percent. Major investment projects are the same as in Case 92-1. This case is useful for anticipating the possible effects of raising transport tariffs, including substitution of non-transport alternatives.

Case 92-7—Ash and Sulfur Reduced by 10 Percent

9. Constraints were added to forcibly reduce the national total of ash and sulfur content by 10 percent below Case 92-1 (unconstrained) levels. Major investment projects are the same as in Case 92-1.

Case 92-8—Ash and Sulfur Reduced by 20 Percent

10. Same as Case 92-7, but reduced by 20 percent.

Case 92-9—Ash and Sulfur Reduced by 30 Percent

11. Same as Cases 92-7 and 92-8, but reduced by 30 percent.

Case 92-10—Investment Budget Reduced by 10 Percent

12. Constraints were added to forcibly reduce the capital budget for the entire coal-electricity delivery system by 10 percent below Case 92-1 (unconstrained) levels. Major investment projects (ports, railways, dams, 500 kV DC transmission lines) are the same as in Case 92-1, which means that budget reductions must come from among mining, washing, shipping, power plant (except four large dams), and transmission lines (except nine 500 kV DC lines) investments.

Case 92-11—Steam Coal Washing Benefit Case

13. Upper bounds were added to forcibly prevent any new steam coal washing capacity from being built. Major investment projects are the same as in Case 92-1. This case is used for estimating the benefit of steam coal washing investments, by comparing the total cost with that of Case 92-1.

Case 92-12—Large Transmission Lines Benefit Case

14. Same as Case 92-11, but for new 500 kV power transmission line capacity.

Case 92-13—SPC Request Case

15. The parameters of this case were set by SPC request. Coal demand is the same as the High Demand case (Case 92-2), but electricity demand is even higher—fully 14.7 percent higher than in the Medium Demand case. Coal and electricity shortage costs are 39 percent higher than in Case 92-1. Plus, the total national ash and sulfur content is forcibly reduced by 10 percent below Case 92-1 levels. Major transport, dam, and power line investments are treated as continuous variables and are reoptimized. The purpose of this case is to simulate conditions in a wealthier China with higher demand levels and with less tolerance for either shortages or environmental damage.

Case 92-14—"Combination" or "Economic Limitations" Case

16. This case was designed by the CTS Team as one that combines several of the limitations imposed in previous cases. It can be thought of as an "economic limitations" case, in the sense that three of China's most severe problems—transport capacity, capital budgets, and environment—simultaneously impinge on coal and electricity supply. Demand is at the Medium level, but 10 percent reductions are imposed

simultaneously on ash and sulfur contents, all transport capacities, and the total capital budget available for each time period. To help offset these limitations, shortage costs are increased by 39 percent over Case 92-1 levels. Major project investment variables are reoptimized using a 3-stage heuristic optimization process yielding an all 0-1 but probably suboptimal solution.

Case 92-15—High Demand Case with Additional Options

17. This case was one of the last scenarios solved, and represents the CTS Team's recognition that in order to meet the new high growth goals espoused by Premier Deng, the dimensions of the transport bottleneck problem will be so large that new options for energy supply must be evaluated. In this case, demand is at the High level. The CTS Team hasopened up a number of new options, including extra capacity (and cost) for some key coal-only railway arcs, extra mining capacity in the corresponding energy base nodes, three coal slurry pipelines, and unlimited coal imports for a number of coastal demand zones. The SPC had previously told the CTS Team not to consider slurry pipelines and coal imports as part of any base case analysis. Major project investment variables are reoptimized using a 3-stage heuristic optimization process yielding an all 0-1 solution.

Case 92-16—Triple New Railway Capacity Case

18. A question that can be asked about these runs is whether the model's decisions to invest in "railway substitutes" like coal washing, hydropower, and transmission are really economically optimal from a cost-minimizing point of view, or are they suboptimal investments that are forced into the model's solution due to lack of enough railway project alternatives? This scenario is a hypothetical case that can shed some light on that key theoretical question. In this model run, all assumptions are identical to Case 92-1, except that the 0-1 variables for transport investments are allowed to vary continuously between 0 and 3, meaning that any new railway or port project can be tripled in size by tripling the investment. This case provides only a rough cut answer to the question, because tripling the size is not a realistic option for some arcs, and because this option was not given to existing railway arcs with no expansion plans.

Summary of Results for All 1992 Scenarios

Table 12.1: Summary Solution Results

Case	Coal Demand in 2000 (million std tons)	Electr. Demand in 2000 (bil. kwh)	Total System Disc. Cost (bil. Y)	Total Invest-ment in 8-9FYP (bil. Y)	Coal Shtg. in 2000 (mil. std tons)	Electr. Shtg. in 2000 (bil. kwh)	Total Shtg. in 2000 (mil. std tons)
92-1. Med. Dem.	946	1176	771	994	2.26	62.3	36.53
92-2. High Dem.	1018	1279	931	1110	51.00	74.0	91.70
92-3. Low Dem.	916	1151	726	952	1.20	61.2	34.86
92-4. Transport Capacity -10%	946	1176	795	992	12.74	63.1	47.45
92-5. Transport Capacity +10%	946	1176	756	996	0.52	60.4	33.74
92-6. Transport Cost +100%	946	1176	818	990	6.48	62.3	40.75
92-7. Sulfur, Ash -10%	946	1176	795	996	12.74	70.6	51.57
92-8. Sulfur, Ash -20%	946	1176	846	970	69.12	75.1	110.43
92-9. Sulfur, Ash -30%	946	1176	929	934	181.63	78.9	225.03
92-10. Budget -10%	946	1176	781	880	21.95	84.1	68.21
92-11. No New Steam Coal Washing	946	1176	780	973	10.20	62.4	44.53
92-12. No New Big Transmission Lines	946	1176	773	961	3.17	61.4	36.94
92-13. SPC Case (High Dem., Environment, High Sh. Cost)	1018	1349	1,119	1230	105.18	65.4	141.15
92-14. "Combined" or Econ. Limits	946	1176	876	886	46.19	72.6	86.12
92-15. High Dmnd. w/ Extra Options	1018	1279	911	1123	18.4	63.4	53.27
92-16. Triple New Rail Capacity	946	1176	743	977	0.53	59.6	33.31

Table 12.2: Coal Production Sector Results

Case	Coal Production in 2000 (million tons)	Yr. 2000 Coal Prod. from North and SW Energy Base (mil tons.)	Yr. 2000 Coal Prod. from Coastal Regions (mil. tons)	Tons Washed in 2000 (mil. tons)	Steam Coal Washing Rate in 2000 (percent)
1. Med. Demand	1498	793	334	417	18.7
2. High Demand	1567	839	348	428	18.4
3. Low Demand	1456	767	328	398	18.1
4. Transport Capacity -10%	1485	781	335	406	18.4
5. Transport Capacity +10%	1496	799	331	395	16.8
6. Transport Cost +100%	1489	783	336	414	19.0
7. Sulfur, Ash -10%	1465	791	311	512	28.3
8. Sulfur, Ash -20%	1397	769	280	549	33.3
9. Sulfur, Ash -30%	1265	712	226	529	36.7
10. Budget -10%	1467	784	324	392	18.1
11. No New Steam Coal Washing	1485	787	332	257	5.4
12. No New Big Transmission Lines	1494	791	332	414	18.4
13. SPC Case (High Demand, Environment, High Sh. Cost)	1538	821	340	594	32.3
14. "Combined" or Econ. Limits	1441	755	331	496	28.1
15. High Dmnd. w/ Extra Options	1593	856	346	427	17.7
16. Triple New Rail Capacity	1495	800	329	389	16.3

Table 12.3: Electricity Production Sector Solution Results

Case	Electricity Generated in 2000 (billion kwh)	Thermal Capacity Built by 2000 (million kw)	Hydro Capacity Built by 2000 (million kw)	Nuclear Capacity Built by 2000 (million kw)	Thermal-Hydro-Nuclear Shares of Elec. Prod. in 2000 (percent)
1. Med. Demand	1214	185	64	.90	79.8/19.7/0.5
2. High Demand	1313	201	69	.90	79.7/19.8/0.5
3. Low Demand	1186	181	63	.90	78.9/19.5/0.5
4. Transport Capacity -10%	1215	183	66	.90	78.9/20.6/0.5
5. Transport Capacity +10%	1215	186	64	.90	79.9/19.6/0.5
6. Transport Cost +100%	1214	185	65	.90	79.5/20.0/0.5
7. Sulfur, Ash -10%	1205	180	69	.90	78.1/21.3/0.5
8. Sulfur, Ash -20%	1198	176	70	2.56	76.7/21.8/1.5
9. Sulfur, Ash -30%	1194	175	70	3.30	75.9/22.1/1.9
10. Budget -10%	1187	183	60	.90	80.8/18.7/0.5
11. No New Steam Coal Washing	1214	184	66	.90	79.3/20.2/0.3
12. No New Big Transmission Lines	1212	187	65	.90	79.5/20.0/0.5
13. SPC Case (High Demand, Environment, High Sh. Cost)	1397	214	72	2.34	79.5/19.3/1.2
14. "Combined" or Econ. Limits	1202	183	65	.90	79.2/20.3/0.5
15. High Demand with Extra Options	1325	204	69	.90	79.8/19.7/0.5
16. Triple New Rail Capacity	1216	186	63	.90	80.1/19.3/0.5

Table 12.4: Electricity Transmission Solution Results

Case	Total Intergrid Electr. Transmisn. in 2000 (bil. kwh)	Electricity Transmisn. from Shanxi Pr. in 2000 (bil. kwh)	Electricity Transmisn. from E. Nei Mongolia in 2000 (bil. kwh)	Net Electr. Transmisn. to Guizhou Province in 2000 (bil. kwh)	Electricity Transmisn. from Nanning in 2000 (bil. kwh)	Electricity Transmisn. to Hunan, Hubei,Henan in 2000 (bil. kwh)
1. Med. Demand	284.3	66.5	15.3	+1.4	8.0	4.5
2. High Demand	323.9	85.6	20.6	+3.3	10.1	28.0
3. Low Demand	263.1	61.0	11.6	+0.9	8.4	2.6
4. Transport Capacity -10%	315.3	84.1	20.8	+1.4	8.0	16.7
5. Transport Capacity +10%	269.8	60.0	11.6	+1.4	8.0	2.5
6. Transport Cost +100%	293.7	74.2	15.0	+1.4	8.0	11.8
7. Sulfur, Ash -10%	298.8	67.1	13.4	+1.4	12.0	13.3
8. Sulfur, Ash -20%	273.6	52.9	11.6	+1.3	11.4	22.2
9. Sulfur, Ash -30%	257.5	14.8	7.9	+1.3	10.1	12.8
10. Budget -10%	245.7	48.2	12.5	+1.3	9.2	2.5
11. No New Steam Coal Washing	300.2	76.3	17.6	+1.4	9.1	11.2
12. No New Big Transmission Lines	262.9	50.8	15.2	+1.4	9.1	6.0
13. SPC Case (High Demand, Environment, High Sh. Cost)	323.2	66.4	13.7	0	10.9	19.3
14. "Combined" or Econ. Limits	290.4	68.7	14.0	+1.3	13.6	13.8
15. High Demand w/ Extra Options	329.9	69.5	19.8	+3.3	9.4	17.7
16. Triple New Rail Capacity	264.0	63.5	11.6	+1.4	7.4	2.4

Table 12.5: Environment Sector

Case	Total Ash Delivered in 2000 (mil. tons)	Total Sulfur Delivered in 2000 (mil. tons)	Scrub. Capacity Built by 2000 (mil. tons)	Tons of Steam Coal Washed in 2000 (mil. tons)	Hydro Capacity Built by 2000 (mil. kw)	Nuclear Capacity Built by 2000 (mil. kw)
1. Med. Demand	273	18.4	0	215	64	.9
2. High Demand	287	19.2	0	223	69	.9
3. Low Demand	268	18.1	0	203	63	.9
4. Transport Capacity -10%	272	18.3	0	212	66	.9
5. Transport Capacity +10%	278	18.7	0	193	64	.9
6. Transport Cost +100%	273	18.5	0	218	65	.9
7. Sulfur, Ash -10%	249	16.9	.547	321	69	.9
8. Sulfur, Ash -20%	222	15.0	1.151	361	70	2.6
9. Sulfur, Ash -30%	194	13.1	1.266	361	70	3.3
10. Budget -10%	269	18.2	0	207	59	.9
11. No New Steam Coal Washing	290	19.0	0	62	66	.9
12. No New Big Transmission Lines	273	18.3	0	211	65	.9
13. SPC Case (High Demand, Environment, High Sh. Cost)	250	16.8	1.257	383	72	2.3
14. "Combined" or Econ. Limits	246	16.8	.328	317	65	.9
15. High Dmnd w/ Extra Options	291	19.7	0	218	69	.9
16. Triple New Rail Capacity	278	18.7	0	187	63	.9

SHORTAGE COST DATA ASSUMPTIONS

1. In this study, the term "shortage costs" connotes something different from the usual meaning of "shadow prices" in a Bank study. Shadow price refers to the economic cost, as opposed to the financial cost, of any economic activity. In this study, the financial costs that were adopted were determined to be mostly market-determined, and therefore no shadow price conversion factors were applied. Shortage costs, on the other hand, refer to the penalty imposed in the CTS model against any shortfall in the final products of coal or electricity at demand nodes.

2. Theoretically, ash and sulfur emissions also have a shadow price in the Chinese economy, based on the social cost of pollution. However, the CTS team decided that determining the shadow prices of ash and sulfur emissions with any accuracy was beyond the scope of this study, and therefore environmental impact is measured in physical quantities—the ash and sulfur content of delivered coal—and is not *endogenously* traded off against cost in the model.

Shortage Cost Methodology

Background to Shortage Cost Discussion

3. In the CTS model, shortage variables and shortage costs are introduced for coal and electricity end uses. There were three original purposes for introducing shortage variables in the CTS model. First, in a constrained optimization model, the demands have to be met in every zone for every user type in every time period. The balances between supply and demand are constrained by many capacities of different activities and other technical constraints. If shortages are real and not just an artificial result of the model, the model should not be forced to give us unrealistic results, which would be expected if the model had no shortage variables. Second, because unit energy delivery costs vary from region to region, analysing the allocation or distribution of shortages by region will be informative for policy analysis. Third, a very ambitious idea originally proposed for interpreting the shortage variables was that the model could endogenously decide when it is more economically reasonable to have a shortage than to continue to deliver more energy even when it is logistically possible to do so. In this case, shortages are neither strictly nor solely interpreted as logistical bottlenecks, but also as instances where it is more economical to (a) go without energy, (b) substitute another fuel, or (c) conserve energy.

Specification of Shortage Costs for the CTS Model

4. Because the CTS model is a cost-driven model, the methodology for setting the numerical values of shortage costs in the objective function will determine which of the above-mentioned roles the shortage variables will play. Various economic meanings can be attached to the shortage costs in the CTS model, which determine how to specify the value of shortage costs.

5. For the first purpose described above (getting a feasible solution to a realistic scenario), the specific value of shortage cost is not important, although its general level is. This method could be described as a "penalty cost method," in that it simply discourages any shortages from occurring unless absolutely necessary. The value of the shortage cost should be significantly higher than any possible delivered cost of energy, and then adjusted downwards in steps. The second purpose mentioned above (to find the geographic allocation pattern of shortages) is partly achieved in the penalty cost approach as

well. The third purpose mentioned above (letting the model decide the tradeoff between delivering more coal and suffering the shortage cost) requires us to give the exact value of shortage costs to each end user to find out the value of economic losses if shortages occur.

6. *Value-Added Approach (not adopted).* From the point of view of an economist, the shortage cost is what will be lost from the entire economic system if energy is in short supply, not only from the energy sector itself. An activity-based value-added approach was considered but rejected because of three methodological and theoretical problems. First, suppose that 1 ton of coal is used to produce 1 unit of a particular product. One cannot assume that supplying an additional ton of coal will necessarily lead to production of an additional unit of product because coal is only one of the raw materials of input and not the only one in short supply. Second, the opportunity cost due to the coal shortage is not a stable linear function of the shortage, but a nonlinear increasing function of the volume of coal shortage. Third, in the CTS analysis system, all industries or activities that use the same type of coal have been aggregated into a single category. But surely the economic loss for each economic activity in a coal type user group is not the same. For these three reasons, it was decided that it would not be feasible to try to estimate from an activity analysis the loss to the economy of coal and electricity shortages.

7. Two alternatives to the activity analysis approach for determining energy shortage costs are market prices and substitution costs. The latter—specifically import prices for coal—was eventually adopted for this study.

8. *Market Prices (not adopted).* Using real market prices of coal and electricity as the shortage costs for each demand node seems at first to be a plausible approach, but does not hold up under scrutiny. The dual track price system is too distorted. In-plan prices do not depend on the willingness-to-pay of the users, but on the balances planned between sectors and whether the users are owned by the central, local, or township government. A second pricing track has emerged outside the planned system, but the market is still far from perfect. Because the distribution of coal reserves is uneven, and transportation is still a rigid constraint combined with the barriers between administrative regions, idle production capacity and severe shortages exist simultaneously in different parts of China. In regions where shortages were severe, coal and electricity prices soared upwards, while in the regions where idle capacity still existed, the market coal price remained lower than the planned price. Also, the out-of-plan market is not close to being independent of the planned economy, since in-plan producers must get their marginal supplies from the out-of-plan market. Thus, out-of-plan prices can fluctuate widely from time to time and place to place.

9. The SPC has conducted a survey on market coal prices. Table 13.1 gives a rough idea of market coal prices in 1989 in some cities. The figures are results processed from many different survey reports. In Table 13.1, the market price is found to differ greatly from place to place. The extremely low price in the coal base is the result of spare coal production capacity there and because some small township mines, equipped with very backwards technology, had produced coal at a much lower cost but were unable to access the transport facilities. These mines would sell their products at prices lower than their normal price, in order to pay the salaries for workers and managers to prevent the mines from closing. Clearly, such a market price cannot be used as a shortage cost in the model, because the model would choose to not supply any coal at all.

10. The electricity price system in China is similar to that for coal prices in that a multi-track price system has been introduced. The basic situation is that in an electricity grid, a basic price of electricity is fixed, but many additional fees are added for various reasons. Surcharges are added for high price fuels, for construction funds of

energy and transportation that are charged by central government (and sometimes again by the local government separately), and for many miscellaneous reasons. Local governments will charge high prices for electricity from new power plants, as the investment for new plants is comparatively high and the return to the investment should be recouped from the prices charged to the users. Similarly, power plants constructed by the semi-autonomous HuaNeng Inc. are mainly funded from abroad, and are allowed to charge high prices to users because of the high cost of investment and shorter payback period for foreign capital. Because of severe electricity shortages in some coastal areas, some diesel or gasoline generators are even loaded at peak times, which may cost as much as 40-50 fen per kwh.

11. It is not reasonable to take these kinds of market prices for coal and electricity to be valid measures of the economic loss to society due to coal or electricity shortages. Taking into account the complexity and data difficulties of market prices, we have concluded that it would be inappropriate to use the market price as the shortage cost in the CTS model.

12. *Substitution Costs (adopted).* Since the CTS model is primarily intended to choose investments for economic reasons (it really is a long-term strategic planning model), not because of logistical constraints, estimating the economic values of energy shortages cannot be avoided, no matter how difficult. Therefore, the shortage costs to be employed in the CTS model must be based on economic considerations. The approach adopted for this study is to find the cost of substitutes for coal or electricity supply. The basic idea is that the economic loss should not be higher than the cost of a substitute form of energy, such as oil, gas, energy conservation investment, or imported coal. For example, if users stand to lose, say, Y 500 for every ton of coal that they are denied, but they could buy imported coal for only Y 300 per ton, a rational user would choose to buy the imported coal and reduce their losses by Y 200. In this way, the cost of a substitute form of energy, if available, is an upper bound on the economic loss from shortages, in the sense that they could avoid that loss by paying for the substitute.

13. *Estimation of Coal Substitution (Import) Cost.* For coal, the international border price of coal comes closest to meeting this criterion. The CIF (cost, insurance, and freight) price of steam coal at coastal Chinese ports was computed as follows. First, the price of standard international steam coal (6,700 Kcal/kg) FOB (freight on board) New Castle, Australia, is assumed to equal US$32/ton. So, the CIF price of standard international coal at a Chinese coastal port is US$32 + US$10 = US$42/ton.Multiplying by the currency conversion factor of 8.8 then yields Y 370/ton. Converting this price to the equivalent price of standard Chinese raw coal (5,500 Kcal/kg) on the basis of heat content alone gives Y 370 x 5,500/6,700 or about Y 300/ton. This CIF price of standard Chinese coal at coastal ports of Y 300 per ton is adopted as the base case value for the cost of coal shortage.

14. *Estimation of Electricity Substitution Cost.* Since about 0.5 kg of coal can generate 1 kwh of electricity, one ton of coal can generate about 2,000 kwh of electricity in the model. In this case, if Y 300 were the coal shortage cost, then 1 kwh of electricity shortage should be priced at about Y 0.16 plus the annualized investment cost and nonfuel operating cost of one kwh of electricity, with the total value around Y 0.2 to Y 0.3 per kwh. Using diesel power as the substitute, however, yields a high estimate around Y 0.5 per kwh.

15. Like any linear program, the CTS model is sensitive to the coefficients of variables. Competition for coal supplies between electricity demand and direct coal demand is a basic characteristic of the CTS model. During calibration, electricity shortage cost levels were moved up and down. Higher electricity shortage costs caused there to be no electricity shortages, while lower electricity shortage costs caused there to be no coal shortages. Electricity shortage costs in the CTS are implicitly represented by a step function. A single

shortage cost is specified for each of five user groups, but taken together, the five groups constitute a step function.

16. The electricity shortage costs finally adopted were calibrated to create a balance between coal and electricity shortages in high demand runs. The electricity shortage costs increase step-wise from 21 fen per kwh for rural users to 33 fen per kwh for light industry users. The upper range, 33 fen per kwh, roughly corresponds to the long-run marginal cost (LRMC) of thermal electricity, while the lower end, 21 fen per kwh, roughly corresponds to the short-run marginal cost.

17. *Conclusion.* Recognizing the great uncertainties inherent in estimating shortage costs on an economic basis, the approach adopted in the CTS is one of simplicity: (a) use the same level of shortage costs for coal and electricity throughout the model, regardless of time and place; and (b) use sensitivity analysis to find out the effect of the shortage costs on the choice of transport and energy projects.

Table 13.1: Market Price of Coal in 1989 (yuan per ton) \a

City	Coal Price	City	Coal Price
Beijing	120	Fuzhou	150
Tianjin	170	Xiamen	150
Shijiazhuang	80	Nanchang	90
Tangshan	110	Jinan	90
Datong	35	Weifang	90
Taiyuan	42	Qingdao	120
Changzhi	37	Yantai	100
Houma	35	Zhengzhou	60
Baotou	30	Wuhan	140
Shenyang	120	Changsha	95
Dalian	130	Guangzhou	250
Dandong	120	Shantou	200
Anshan	100	Nanning	120
Changchun	120	Haikou	200
Harbin	85	Chongqing	50
Shanghai	200	Chengdu	90
Xuzhou	55	Guiyang	30
Nanjing	200	Kunming	30
Nantong	150	Xian	110
Hangzhou	250	Lanzhou	50
Ningbo	250	Xining	50
Wenzhou	200	Yinchuan	40
Hefei	150	Wulumuqi	25

\a Because market prices of coal varied very much in these years, prices of coal in this table are a summary of surveys conducted in 1989 and 1990. The necessary processing, modification, and estimation have been introduced.

Coal Sector Data Assumptions

Coal Type Primary Data Base

Spatial and Technological Assumptions

1. Coal types are catalogued into three categories: steam coal, coking coal, and anthracite. In the CTS, all the coking coal produced in one zone is aggregated into a single type of coking coal, and likewise for anthracite. For steam coal, two kinds can be defined within one zone having different coal qualities. These two kinds are generally high and low ash steam coal, and all steam coal within the zone must be aggregated into one of these two categories.

2. The coal types are identified according to the users' technical requirements, meaning that coal is classified according to how it is used rather than its inherent physical properties. In order to simplify the model, coking coal in CTS is the coal which be used as metallurgical coking coal. Coking coal used as steam coal has been identified as steam coal. Generally speaking, main coking coal, fat coking coal and gas coking coal are classified as coal used for coking in the CTS. Thin coking coal and other coking coal are put into the steam coal category because they are generally used in steam boilers in China. All the township mine coking coal output is aggregated into steam coal except for several township mines that produce the highest quality coking coal.

3. The anthracite coal category includes all anthracite coal mines plus some steam coal mines in certain regions where no anthracite is available and steam coal is commonly used for residential and commercial purposes.

4. Coal quality in the CTS is measured in three physical characteristics: thermal value, sulfur content and ash content. In general, coal produced in different nodes should have different qualities. These coal quality data are based on the typical resources of the region. The ash content, sulfur content and thermal value of CW, SW, MI are get from washing submodel.

5. Coal type data are organized by mine node and coal type. Coal types included in CTS are the following:

A1	raw anthracite;
C1	raw coking coal;
S1	raw steam coal with high quality (low ash content, not washed);
S2	raw steam coal with low quality (high ash content, can be washed);
CW	clean coking coal (after washing);
SW	clean steam coal (after washing);
MI	middlings (after washing).

Cost Data Assumptions

None.

Capacity Data Assumptions

None.

Other Technological Factors Assumptions

None.

Coal Mine Nodes Primary Data base

Spatial and Technological Assumptions

6. In the CTS, mines around China are aggregated into some (47 at present) production zones. Each zone is represented by a centroid which is also a node on the transport network. Mines were aggregated into zones based on several often conflicting considerations, such as the transportation network, province boundaries, coal type localization, and model size. Generally speaking, aggregation into zones should

enable the model to identify all significant flows while at the same time reducing the number of coal production nodes.

7. Some important coal supply provinces are divided into several nodes for more accurate modeling of intra- and inter-provincial flows, while in other cases provinces can be represented by one node. In the coal base area, where large amounts of coal are exported to other places, each production zone reflects a subprovincial region from which coal is generally transported by a different railway line. For instance, there are five nodes in Shanxi province, which has five typical routes out. Another reason for subdividing Shanxi province is that some regions predominantly produce steam coal, while others produce mostly coking coal.

8. Another reason for disaggregating a province into several nodes is if coal production is related with a specific railway project. In such cases, the node aggregation should allow all major flows to be modeled. For instance, Shandong province is separated into two production nodes, Jinan and Taian because the model considers a new rail project between Jinan and Taian. Most other provinces take one node to represent the total coal production of each province such as Harbin as the centroid for Heilongjiang, Changchun as the centroid for Jilin, and so on.

9. For mine step 1, more than 50,000 township mines were aggregated into the 47 nodes. For mine step 2, more than 2500 local mines capacity were aggregated according to coal type and location. For mine step 3, according to geographic location, a total of more than one hundred existing and new state mine bureaus were aggregated into 47 nodes.

10. In each production node, there are three kinds of mine steps. Different mine steps have different costs and capacities. Taken together, mine steps aprroximately represent an increasing step function for coal production costs. In the CTS, mine step 1 indicates those mines that only have access to the shallow resources of coal using low technical level equipment. This set of labor-intensive mines is taken as the set of township mines. Mine step 2 includes those mines which can access the middle level reserves of coal with general equipments. In the CTS, local mines are included as mine step 2. Mine step 3 are those mines which can access the deep reserves and some surface reserves with advanced technology, which are assumed to be all of the state mines. While in some cases, township, local, and state mines may employ technology that is more typical of other levels, these assumptions are generally valid.

11. Coal mine data are organized by mine node, raw coal type, and mine type. Raw coal types included following:

A1	raw anthracite
C1	raw coking coal
S1	raw steam coal (low ash content)
S2	raw steam coal (high ash content)

Raw mine types included following:

1	Mine step 1
2	Mine step 2
3	Mine step 3

Cost Data Assumptions

12. Cost data for existing coal mines are based on statistical data from the local and state coal mine companies. Cost data for new coal mines are based on planning data and experts from the local and state coal mine companies. The source is the 1989 statistics book of the coal industry published by China State Coal Mine Company, October 1990 and the 1989 statistics book of provincial and county local coal mines published by China Local Coal Mine Company, May 1990. Data for the Eighth Five Year Plan and Ninth Five Year Plan also come from these two companies.

13. Different mine steps have different operating costs and investment costs, even in the same zone. Operating cost includes labor, material, power, maintenance and others (including management, administration, safety, and insurance). Depreciation is excluded from the operating cost for both existing and new coal mine of three steps. Investment cost not only includes mine

engineering but also includes infrastructure, that is, the comprehensive investment cost. Inflation is not considered in cost data, and it is assumed that the same technology for mining will be used over the next 15 years.

Both investment and operating costs are higher for state mines than for township and local mines, and for mines in coastal areas than in the coal base. Table 14.1 shows the ranges for each category of costs and mines.

Table 14.1: Coal Production Costs in the CTS Model, by Region and Ownership (yuan per ton)

	Coal Base	Coastal
Operating Cost		
Township	12-46	40-60
Local	20-50	40-70
State	35-58	50-120
Investment Cost		
Township	100-140	125-150
Local	160-200	200-240
State	200-250	250-300

14. For mine step 1, operating and investment costs were based on a survey of plans for 200 key counties of coal production. Township mine production costs are lower than for local mines because of lower administrative expenses and less support for the workers in terms of housing, medical, etc. The investment cost used for mine step 1 in the CTS is higher than the historical figures for the already existing township mines in order to get reliable capacity.

15. For mine step 2, operating cost data for existing mines came from the statistics of local mines. Several typical mines were identified for each node and each coal type. These mines are relatively bigger than others in the node. Weighted average cost of these mines was taken as operating cost. The investment cost for new step 2 mines was based on the planning of Local Mine Company and on experts' opinions.

16. For mine step 3, the weighted average operating cost of existing mines was taken for each node and coal type.

Capacity Data Assumption

17. The sources of mine capacity data statistics are the same as for the cost data. Existing capacity refers to capacity existing at the end of 1989.

18. Existing capacity data of mine step 1 are taken from statistics of township mines. New capacity data are based on the 8th and 9th FYPs made by the local mine companies. New capacity was calculated as the planned key year output minus the existing capacity remaining in that year. In rich reserve areas, greater capacity than what is planned was given to provide some flexibility in where and how much capacity is built.

19. Existing capacity of mine step 2 comes from the statistics book of the local mine companies. New mine capacity is also based on the planned key year output minus the existing capacity remaining in that year.

20. Existing capacity of mine step 3 come from the statistics book of state mine companies. Each state mine capacity was collected according to the mine node and

coal type. New capacity is from the planning of new mine projects for the Eighth and Ninth Five Year Plans. In order to give the CTS optimization model more choices than provided by the Five Year Plans, some new capacity currently slated for development after the year 2005 is also added into the 2001-2005 time period new capacity.

21. There is a big difference in mine depreciation rate among the three kinds of mines. The existing capacity remaining in each key year reflects the fact that big state mines will retire one by one. Each big state mine to be retired in the next 15 years is treated uniquely. But the existing capacity of township mines is assumed to decline at least 25 percent during each five year period in all nodes. The average decline rate used for local mines is about 10 percent for each five year period. So there is not a constant depreciation rate applied to all mines or node. Therefore, the remaining capacity of existing mines in the years 1995, 2000, and 2005 for each mine step were calculated exogenously and put into the primary data base directly, and the depreciation rate is given as 1 in primary data base.

Other Technological Factors Assumptions

22. The lead time for coal mine construction and the mine lifetimes are based on Chinese experts' suggestions. Generally speaking, a new mine with 30,000 ton capacity per year needs two years to be set up; a 300,000 ton capacity new mine needs 4 years; and a 1.2 million ton capacity new mine needs 6 years. These three kinds of mine were taken as typical mine sizes for the three mine steps respectively. For mine step 1, two years is the lead time and 15 years is the lifetime. For mine step 2, four years is the lead time and 25 years is the lifetime. For mine step 3, six years is the lead time and 50 years is the lifetime.

Coal Washing Nodes Primary Data Base Spatial and Technological Assumption

23. Only coking coal (coal type C1 in the primary data base) and high ash content steam coal (coal type S2) are considered for washing. Washing is optional for high ash steam coal, but it is required for coking coal. In the CTS model, coal washing is permitted at every coal mining node that has the ability to produce coking coal or high ash steam coal.

24. It is assumed that all coking coal will be washed with standard technology, that is heavy medium separation approach. This standard technology is assumed to produce two outputs: clean coking coal with a standard ash content of 10 percent, and a usable byproduct known as "middlings." Steam coal is always assumed to be washed using a jigging approach to get clean steam coal with no middlings byproduct. The thermal value, sulfur content and the weight ratio of washed coal to input coal will be calculated by the washing submodel based on the thermal value, sulfur content, and ash content of the input coal.

Cost Data Assumption

25. The source for coal washing data is the 1989 statistics book of the coal industry published by China State Coal Mine Company, October 1990 and the 1989 statistics book of provincial and county local coal mines published by China Local Coal Mine Company, May 1990. This is the same data resource as for mining data.

26. Since a standard washing technology is adopted in the CTS for coking coal, the same operating cost, 4 yuan per ton, was applied everywhere. Depreciation is excluded from this operating cost. The investment cost of coking coal washing is also the same, 50 yuan per ton of capacity, no matter where it is. These numbers are the averages for the whole country. The same assumptions are made for washing steam coal. Because steam coal washing technology is simpler than coking coal washing technology, the operating cost and investment cost are less than fr washed coking coal. The operating cost for jigging steam coal in the CTS is 2 yuan per ton and the investment cost is 30 yuan per ton of capacity.

Capacity Data Assumption

27. The data for coal washing capacity are also based on the statistics book of the State Mine Company. The existing capacity as of the end of 1989 was 189 million tons annually. This total was identified as either steam or coking coal plants and aggregated into the same zones as were the existing mines. Some washing nodes have no existing washing capacity for steam coal and/or coking coal.

28. The upper bound on the amount of new washing capacity that can be built in the model depends on the water resources and other technological considerations. Based largely on the opinion of Chinese experts consulted by the CTS, water resources are a limitation on the extent of coal washing, especially in the coal base area where lack of water is a problem. In Northwest China, some high sulfur content coal is difficult to wash for technical reasons. Technology constraints for this area is the major concern.

29. For all other nodes, the maximum possible washing capacity was only limited by the coal production at this node, which, essentially, is no limit at all. Plans do exist for construction of washing plants by the State Coal Mine Company, but in the CTS, much more choice is given. The 8th and 9th Five Year Plans call for 100 million tons of washing capacity to be constructed, but the total potential capacity allowed to be built in the CTS is much higher.

Other Technological Factors Assumptions

30. The standard weight loss factors and final ash contents for coal washing are described in the write-up of the coal washing submodel (see Volume II). However, SPC experts suggested that the washing submodel not be used. Instead, they suggested that the thermal value of washed steam coal be increased in order to capture the increased efficiency from burning washed coal. Therefore, a carbon loss rate of 0 percent was assumed for the CTS Yellow Cover model runs.

31. The lead time for building new washing plants and the lifetime of new washing plants are based on the suggestions by experts from the State Coal Mine Company. The CTS assumes a three year lead time and a 25 year lifetime. Washing plant retirement within the next 15 years is ignored. That means no retirement of existing washing plant in CTS from 1990 to 2005. This assumption is reasonable because 50 percent of existing washing plants were built within the last 10 years.

Coal Demand Nodes Primary Data Base

Spatial and Technological Assumptions

32. The data on coal demand are based on the coal demand forecast made by Energy Research Institute of SPC. The report was published in 1988 under the title "Coal Base Area Development Strategy in 2000 and Balance of Coal Supply and Demand."

33. In the CTS, there are presently 49 coal consumption zones around the country. Every province has one node at least. Some provinces have several nodes because there are several consumption centers in these provinces and they will influence transportation flow direction. For example, Shanxi province has four nodes, and Jiangsu has two. Another reason for disaggregating a province is because shipping and port investment for coal transportation is one of the major concerns of the CTS. Usually in China, there is no transshipment from ship to railway, so some province which have different ports will be divided into several nodes. For instance, in Guangdong province there are two nodes: one is Guangzhou, one is Shantou; and in Fujian province, there are two nodes: one is Fuzhou, the other is Xiamen.

34. Coal demand in CTS is divided into three kinds of users. Anthracite user, coking coal user and steam coal user. Anthracite users include sectors which use anthracite, those are the residential and commercial sectors, and part of the metallurgical, chemical and building materials

industries. For the 9 percent GNP growth case, total anthracite demand is around 142 million tons of standard coal in 1995, 153 million tons in 2000, and 177 million tons in 2005. For the anthracite demand constraints, heat content of coal is taken into account, so that the exact amount of anthracite produced and consumed may vary from these figures even if there are no shortages.

35. Coking coal users are strictly the metallurgical industry, with the industry's anthracite demand subtracted out. It uses washed coking coal only. Raw coking coal will not be delivered unless it is cataloged as steam coal (see coal types, above). Only washed coking coal will be transported to the user. Middlings are assumed only to be used locally, mainly by minemouth fluidized bed combustion (FBC) power plants. For the medium demand case, metallurgical uses 97 million tons washed coking coal in 1995, 114 million tons in 2000, and 132 million tons in 2005. The heat content of coking coal is ignored in the coking coal demand constraints, since metallurgical plants require a given tonnage, not a given heat content.

36. Steam coal users are separated into two. One is utilities, the other is general industry. Both can use steam coal 1, steam coal 2 and washed steam coal. Coal demand of utilities depends on electricity demand. Thus, electricity demand is given exogenously, but utility consumption of coal is endogenous. General industry demand for steam coal includes all sectors which use steam coal except utilities. For the medium demand case, general industry demand is 570 million tons in 1995, 668 million tons in 2000, 770 million tons in 2005.

37. In the medium demand case, the total demand for coal not including utility demand, that is, the sum of the three parts separately discussed above, is 784 million tons in 1995, 906 million tons in 2000, and 1,046 million tons in 2005.

Shortage Cost and Shortage Upper Bounds

38. The base figure for coal shortage costs is Y 300 per ton of standard coal, which corresponds to the international price for coal (see Annex 13). This is the figure used for steam and anthracite coal shortages in most of the country.

39. No upper bounds are imposed on coal shortages in the Yellow Cover model runs. Shortages are free to go as high or low as possible, as determined by the supply and demand situation. This is important because it means that all of the investments that the model builds are used to deliver energy at a reasonable cost—none are subeconomic projects forced in by a upper bound on the size of coal shortages. On the electricity side, upper bounds are necessary to make the step function work; however, in our computational experience, rarely did a shortage reach the upper bound on the highest cost step.

Transport Sector Data Assumptions

Origin-Destination (OD) Pairs Primary Data Base

Spatial Assumptions

1. The O-D pairs data base is used by the path generator to control the creation of path variables. The CTS model does not permit coal to be shipped from every origin to every destination. Instead, we exogenously define which origins can serve which destinations, and also exogenously define how many different routes between the origin and destination will be generated.

2. The O-D pairs data are based on several principles. The first principle is that paths should be generated for all existing O-D flows, by coal type. The current and future O-D pattern is to ship coal from west to east and from north to south. However, sometimes reverse flows are necessary because of the difference in the coal types between regions. Sometimes coal must be shipped to the coal-rich areas if the coal-rich areas do not have any resources of a particular kind of coal.

3. The second principle is to allow some new scenarios or policies. One such new policy is to supply nearly all places in China from the major new coal fields in the Coal Base region, particularly Shenmu, Dongsheng, Zhungeer, and so on. Another new coal distribution policy is to accommodate new plans for industrial distribution. Industrial development in western areas is expected to increase, and therefore more O-D pairs must be defined to supply coal to these western areas. A third new policy to be evaluated is to increase coal imports to coastal economic zones. Although there have been sporadic imports of coal in the late 1980s during the severe shortages, there has been no steady stream of imports to China, and no import policy. The policy tested in the base case is to allow only minor (less than 100,000 tons) coal imports to three of the nodes most highly impacted by shortages: Shanghai, Xiamen, and Guangzhou. Plus, a few other new options are tested in the CTS.

4. The source of the O-D pairs data is the current annual coal distribution plan, modified to suit the CTS model. The O-D pairs data base has been checked and revised by experienced experts and planners from the State Planning Commission (SPC) and the Institute of Comprehensive Transportation (ICT).

5. The total number of O-D pairs defined for this study was around 550. The total number of routes (paths) used for this study was about 2,500. This number is limited by the hardware and software requirements. Of course, not all viable routing options can be included in this limited number.

6. The number of transportation routes is uniquely specified for each O-D pair. Generally, for short distance O-D pairs, a small number of routes are defined. Sometimes only one route is defined, for instance from Beijing to Tianjin. As the distance between the origin and destination lengthens, more routes are defined. If coastal shipping is an option for an O-D pair, an even larger number of routes is defined. The largest number of routes (paths) between any O-D pair is 20 (e.g., from Datong to Guangzhou or Shanghai), but the CTS software can accommodate up to 35 paths for any O-D pair.

7. The paths used in this study were generated by the CTS model's path generator. These paths were then edited one at a time to check them, delete unwanted paths, and add missing paths. This task took about three person-weeks.

Transportation Network Primary Data Bases (existing and new)

Spatial and Technological Assumptions

8. The transportation network is divided into two separate primary data

bases. The existing arcs data base (PDBTRANA) is designed for the transport network links which have no expansion projects, that is, they have no investment costs. Both brand new arcs and existing arcs with proposed expansion projects are input in the new and expansion arc primary data base (PDBTRANB). The existing part of an expansion project is not input in PDBTRANA.

9. The modes included in the CTS model are rail, port, and all shipping, both coastal and inland waterway. Canals are also described in the CTS network, linking Xuzhou and Peixian to the Yangzi River. Figure 1 shows a schematic map of the CTS transport network which shows all of the existing and new rail, port and pipeline arcs, but does not show the shipping arcs because there are too many to be displayed.

10. The network of existing arcs is based on the current pattern of major coal flows, and also considers coal distribution policy. Each arc represents a rail line between two major points, but small substations are ignored. Rail nodes, that is origins and destinations of single arcs, cover all supply and demand nodes in the CTS data base. The network also covers all major junction points where arcs meet, but which do not have supply or demand activities, such as Yuanping in Shanxi province or Baxian in Hebei province. Marshalling yards are not treated as arcs in their own right. Marshalling yard costs and capacity are factored into the cost and capacity of several arcs that begin or end at the marshalling yard.

11. Because the network design follows the current flow patterns and current distribution policy, some arcs are considered as bi-directional arcs, but most are uni-directional. By prohibiting backhauls on most arcs, the CTS model will not achieve a perfect global optimum, but it adheres more closely to the current policies and helps to calibrate the model. For the most part, arcs flow only in a single direction, generally from north to south and from west to east, based on the geographical distribution of supply and demand. For example, the rail arcs from Beijing to Shijiazhuang are bi-directional because coal from Taiyuan (west of Shijiazhuang) must be able to flow northeastward to the steel plants in Northeastern China. Other example of bi-directional corridors are from Hailar to Dalian; Tangshan to Baotou; Beijing to Zhengzhou; Changsha to Hengyang; and Tianjin to Fuliji.

12. Generally, most ports are defined as a single arc, which means that various berths have been aggregated into a single variable. These various kinds of berths include state-owned and user-owned berths, both at the port and in port power plants. However, some ports have been defined with several arcs in order to accurately describe the real shipping situation. Because some ports have different kinds of facilities that can handle different sizes of ships or have drastically different costs, they are represented by two or more arcs. For instance, Qinhuangdao port is defined as three arcs: the first is the old 9m existing port; the second is the modern 9-12m existing port; and the third is a existing 9-14m port with proposed expansion measures.

13. Two kinds of transshipment are allowed at ports in the CTS network: rail-to-water, and water-to-water. Some dummy arcs have been defined for technical reasons for water-to-water transshipment, such as at Shanghai, Shenzhen, and Nanjing. Some ports can have incoming and outgoing flows. For instance, Nanjing both receives and ships coal by river. Also, Shenzhen is defined as a port where large ships can come in small ships can go out.

14. There are no existing coal slurry pipelines in China. Three new proposed pipeline projects are evaluated in the CTS. The network had to be designed in a special way to prevent ridiculous results using the slurry pipelines. The slurry pipelines are not designed to handle transshipments at either end of the pipeline; they are dedicated links between a single origin and a single destination. In order to prevent coal being transshipped from rail to pipeline, a separate supply node is defined

as the pipeline's origin, with no rail arcs to it, as in the node Changzhi1 (node ID = 8003). A dummy rail arc is defined from the special supply node to the main supply node (e.g., from Changzhi1 to Changzhi) so that if the pipeline is not built in the model run, the mining capacity can still be built and sent by rail. Furthermore, the coal cannot be transshipped from the end of the pipeline to the railroad network because no O-D pairs are defined for the pipeline origin node except to the pipeline destination node.

15. *Project Packages*. The CTS model allows for as many as two investment packages in order to choose between the different project alternatives. However, in the Yellow Cover model runs, only one package was considered for each railway and port arc because because of the model's running time.

16. Rail projects are of two types: brand new lines and expansion projects. Railway expansion measures mainly include double-tracking and electrification. Port expansion projects are for increasing the number of berths and improving the loading, unloading or storage yard facilities. Brand new rail projects include single track lines; double track lines; double track electrified lines; and unit train lines on the DaQing line and the proposed line from Shuoxian to Huanghua port. Some packages on crucial lines were made larger than they are in the Plans. They were given a larger new capacity, and also a proportionally larger investment cost.

Cost and Price Data Assumptions

17. The cost data for the transportation network comes from several sources. Rail operating and investment cost data are based on internal data bases from the Railway Investment Study (RIS) and from ICT. Shipping, inland waterway, port, and pipeline data are also based on ICT data bases. All cost data are in 1989 financial costs, with no adjustment made to 1990 levels. No published data are available yet for 1990.

18. *Operating Costs*. The financial operating cost for all modes includes labor, fuel, maintenance, management, and other variable costs. The financial operating cost never includes depreciation of any kind. Depreciation of transportation equipment and infrastructure on existing arcs is not included anywhere, because these things have already been built. For new arcs, investment in new lines, rolling stock, ships, etc. is considered as an up-front investment cost instead of as a depreciation cost per ton. These assumptions put the operating cost of existing and new lines on an equal footing when finding least-cost paths.

19. Financial operating costs for expansion projects are considered to be the same as for the existing line. No adjustment is made in this study for adjusting the operating cost to lower or higher post-expansion cost levels, even though the model has the capability to do so.

20. For rail, financial operating costs range from a low of .012 yuan per tkm to a high of .05 (e.g., for the Da-Qing line) depending on geographic conditions, technology used, and modernity. For shipping, financial operating costs vary depending on the ship's size, type, and whether existing or new (see Table 15.1). Operating costs for slurry pipelines average around .75 per ton-km, based on the estimate for the Yuexian to Weifang line.

21. The so-called fake operating costs in the primary data bases are only used to fool the path generator into generating paths which may not actually be the cheapest ones. Generally, the fake costs are set equal to the financial operating costs, with the exception of a few brand new rail lines, for which lower fake costs are used. This is because the financial operating costs of the new lines is very high, and the path generator—like many shippers!—would try to avoid those arcs. But since the CTS model would have a lot of unused rail capacity and a lot of shortages if these arcs were avoided, they are forced in by using a lower "fake" cost. But for the objective function coefficient in the optimization

model, the real financial operating cost is used.

22. *Type of 0-1 Variable Used (in the New Arcs Data Base).* Ideally, all transportation investment decisions would be made on a 0-1 basis, but we have had to limit the number of 0-1 variables to maintain good computational performance. In the results reported here, about 35 of the most important brand new projects are defined as 0-1 or "B"-type variables. To save on the number of 0-1 variables, about 90 transport projects—mostly expansion arcs, or less important brand new projects—are defined as continuous "C"-type variables. The remaining 60 projects are already under construction or the investment funds have definitely been allocated. These are represented as "U"-type variables, that is, the 0-1 variable is set to a value of 1.

23. *Investment Costs.* The figures for investment costs are based on the total financial investment costs which have been estimated for each project by MOR, MOC, ICT, or, in the case of slurry pipelines, the local coal companies. The total investment for a project does not consider inflation—all investment costs are in 1989 Y.

24. The actual investment cost used in the CTS primary data bases is coal's share of the total investment cost. The percentage of a project's capacity that will be used for coal has been exogenously estimated by ICT (see capacity data, below). This same percentage is applied to the project's total investment cost.

25. Each railway and port project has been appraised uniquely to determine its investment cost. Examples of some of the more costly projects are Y 500 million for each half of the proposed new port at Huanghua; Y 1-2 billion for new slurry pipelines; and Y 16 billion for the proposed new rail line from Shuoxian to Huanghua port.

26. For railways, the total investment cost for both expansion projects and brand new lines includes line investment and rolling stock investment. The amount of rolling stock needed for each project has been estimated based on ICT data. A LOTUS spreadsheet model was developed to estimate rolling stock requirements, using the same method used by the China International Engineering Consulting Company (CIECC) in appraising new projects. In general, the assumption is that if the new line provides, say, 50 million tons of capacity, then enough rolling stock to haul 50 million tons annually on this particular line must be included in the project's cost. We do not assume that rolling stock can be shifted from other lines to a new line. Generally speaking, rolling stock accounts for approximately one-third of the total investment cost.

27. A special situation is involved in the case of new or expansion bi-directional arcs. In the CTS model, the two directions of an arc are considered as completely separate arcs. But in reality, when investment is added to a line, both directions get higher capacities. To deal with this situation, the data had to be manipulated and a new constraint was added by hand. The total investment cost is given to the direction of the arc that has heavier traffic volume. The reverse, low-volume direction is given no investment cost. Thus, to use the main direction's new capacity, the investment cost must be paid, but to use the reverse direction's new capacity is free. But the added constraints act to prevent usage of the reverse direction's new capacity unless the 0-1 variable for the main direction is equal to 1.

Capacity Data Assumptions

28. There are two kinds of capacities for arcs in the CTS model: existing and new. The existing arc capacities are based on 1989 data. New capacities are estimated for the future by MOR and ICT.

29. Generally speaking, existing arc capacities are considered constant over the model's 15 year time horizon. Arc capacities are the capacity for coal only. But since capacities are based on the estimated ratio of coal traffic to all traffic on the arc, there are instances where this ratio is expected to be adjusted over time. For arcs

Table 15.1: Shipping Costs in the CTS Model

Type of Ship	Deadweight Tons (thousand tons)	Financial Operating Cost (yuan per tkm)	Financial Investment Cost (million yuan per ship)
General Bulk			
9m	20-25	0.0067	120
12m	60	0.0067	260
14m	100	0.0067	300
Self-Unloader			
9m	27	0.0120	150
Pusher Barge			
9m		0.0200	
Shallow Draft			
9m	35	0.0120	150

with new projects, the ratio of coal traffic to total traffic is forecasted exogenously by MOR and by the Plans. This ratio ranges from 20 percent to 90 percent.

30. Expansion arcs have both an existing capacity and a new capacity, where the new capacity is the additional or incremental capacity. Brand new arcs have no existing capacity. The largest of the new arcs have around 100 million tons of annual capacity.

31. Lead times and lifetimes of projects are specified based on MOR and ICT estimates. Different phases of a single project sometimes have different lead times. Lead time for rail projects usually depends on the length of the line and the scale of the project. Lead times range from 2 to 10 years for rail; from 2 to 8 years for ports; and from 3 to 5 years for slurry pipelines. Lifetimes of transportation arc projects are generally 30 years.

32. In Case 15, extra transport capacity was given to selected arcs, including imports, some railway lines from the energy base (DaQing line +60 million tons), most ports (+10 percent in cost and capacity), and the three proposed slurry pipelines.

Fleet Primary Data Base

Spatial and Technological Assumptions

33. Rail and shipping vehicle fleet are handled differently in the CTS. The investment cost for new rail vehicles is included in the rail line investment cost. But the investment for new ships could not be included in the new port investment cost because the necessary ship capacity would depend on the shipping distance. Since ports can serve different destinations, the shipping distances for a port are indeterminate. Therefore, the cost of new ships is handled in a different way than the cost of rail vehicles.

34. Vehicle fleet data are organized by transport mode. The modes included in the CTS are the following (although the fleet data assumptions apply only to the shipping modes, not to RAIL, PORT, and PIPELINE):

RAIL	railroads
PORT	ports
PIPELINE	slurry pipelines
INLANDWW	inland waterway
9MGENRL	9-meter draft general class vessels

9MPUSHB	9-meter draft pusher barges
9MSELFU	9-meter draft self-unloaders
9MSHALL	9-meter draft shallow draft vessels
12MGENRL	12-meter draft general class vessels
12MPUSHB	12-meter draft pusher barges
12MSELFU	12-meter draft self-unloaders
12MSHALL	12-meter draft shallow draft vessels
14MSUPER	14-meter draft supercolliers

Capacity Data Assumptions

35. The shipping fleet capacities are measured in deadweight tons (dwt), not in annual capacity. Unfortunately, the only data available to us were the annual tonnages by vessel class in 1989. Data on the number of ships used for carrying coal were unavailable. From this we worked backwards to infer the deadweight ton capacity of the ships. Since we know that the tonnage shipped was limited by ship availability, we assumed that the number of tons carried by each vessel class in a year, divided by the average number of voyages per year, is a reasonable estimate of the deadweight tonnage of the ships used for carrying coal. The final estimates were 300,000 dwt of inland waterway barges (and a proportional number of tug boats); 2.29 million dwt of 9m general class ships; and 100,000 dwt of 12m general class ships. These capacities were assumed to decline by about one-tenth every five years due to vessel retirement.

36. In the existing transportation arcs data base, there is a column of numbers called DELTAAV. This is the number of trips per year made by a ship serving that particular O-D route. This figure is used by the model to determine the amount of deadweight tonnage capacity needed to carry a given number of annual tons. For instance, if a ship makes 10 trips per year on a certain route, then the annual tonnage divided by 10 is the amount of dwt capacity needed. The average number of trips per year on each shipping route is determined according to distance.

Cost Data Assumptions

37. It is assumed that new ships are produced domestically, rather than purchased second-hand from abroad. The lifetime of new ships is considered to be 30 years; while the lead time ranges from one year for barges to five years for 14m super-colliers. The financial investment costranges from Y 2,147 per dwt for barges or tugs to Y 7,500 per dwt for 14m supercolliers. The unit investment cost increases with size because Chinese ship-building companies charge international prices for all except the standard 9m general bulk vessels. The average tow size for inland waterways is assumed to be 6 barges.

ELECTRICITY SECTOR DATA ASSUMPTIONS

Electricity Demand Nodes Primary Data Base

Spatial and Technological Assumptions

1. Electricity demand for the entire country was aggregated into nodes according to where the consumption centers are, present electricity consumption patterns, and characteristics of transportation and geography. There is at least one node for every province, and several provinces are split into two or three or four nodes. For instance, Shanxi province is defined into four nodes (northern, middle, southern, and southeastern) according to current patterns of coal distribution. Likewise, Liaoning province is defined into two nodes (Shenyang and Dalian) according to present industrial allocation and consumption. Presently, the CTS model has 38 electricity demand nodes.
2. All electricity demand nodes are also electricity generating nodes, but the converse is not true. The set of generating nodes also includes some remote generating stations with no significant independent electricity demand.
3. Electricity consumers at each node are defined into five sectors. Agricultural electricity demand is defined as the electricity demand for agricultural production. Light industry electricity demand is defined as the electricity demand for light industry production. Heavy industry electricity demand is defined as the electricity demand for heavy industry production. Urban electricity demand is defined as the nonproduction electricity demand in cities, consisting primarily of residential, commercial, and transportation demand. Rural electricity demand is defined as the nonproduction electricity demand in rural areas, consisting of the same components as urban demand.

Electricity Demand Data Assumptions

4. Determining electricity demand for China for 1995, 2000, and especially for 2005 is a very difficult research task. If we try to forecast electricity demand for these three key years by methods such as from input-output tables, we could not finish the CTS in a timely fashion. Fortunately, China has several institutions which have been studying energy demand nationally. With practical experience of the past few years, some demand forecasts are very accurate. The CTS team studied these reports and then used some useful study results from them, including electricity demand projections.
5. Total electricity demand for the medium demand case in the CTS for the year 1995 is about 10,441 (10^8 kwh); demand for the year 2000 is 14,436 (10^8 kwh); and demand for the year 2005 is 19,891 (10^8 kwh). The demand elasticity with respect to GNP is assumed to be 1.0.
6. The electricity demand projections from this earlier study were checked by a team of State Planning Commission (SPC) experts in a data conference in January 1991. Several changes were identified and made to the primary data base. In addition, the overall level of electricity demand was scaled during the calibration process to make it consistent with other CTS primary data bases. However, the relative demand levels from node to node used in the CTS are based on this earlier study.
7. The "Comprehensive Equilibrium and Systematic Optimal Study," upon which CTS electricity demand projections were based, was one of the Chinese precursor models that led up to the CTS. To briefly explain the basis for these demand projections, electricity and coal demand were endogenously produced by an optimization model not only considering produc-

tion, transportation, and transmission operating cost and investment, but also considering productive allocation and investment cost and local utilization efficiency of energy. The study tried to model the tradeoffs between production and transportation costs on the one hand and utilization efficiency on the other hand. For instance, according to coal production and transportation costs, the model would tend to supply more coal to be consumed near the coal base, but considering the utilization efficiency and economic efficiency, it may tend to ship coal to Shanghai. So the model used for this study traded off these facts to produce reasonable electricity and coal demand or consumption.

8. Electricity demand scenarios in the CTS are generated in two ways. One way is to amplify the base case demand by a given percentage across the board (about 6 to 7 percent) to keep the same growth rate with the economy but increasing speed for the different zones and time periods. Another way is to collect demand data forecasted by authoritative agencies like the State Planning Commission or the MOEP.

Electricity Shortage Data Assumptions

9. Shortage costs for electricity vary by sector. When looked at as a group, they form a step function. Shortage costs start at 0.21 yuan per kwh for heavy industry and increase in steps of 0.03 yuan. The shortage cost is 0.24 yuan per kwh for light industry, 0.22 yuan for agriculture, 0.30 yuan for the rural residential sector, and 0.33 yuan for the urban sector. These shortage costs were calibrated to create a reasonable balance between coal shortages and electricity shortages. They are slightly less than the cost of diesel electricity generation (0.50 per kwh), which represents a higher cost substitute for thermal, hydro, or nuclear power (see Annex 13 for an explanation of shortage costs).

10. The upper bound on the size of any electricity shortage, for any sector or time period, is 9 percent of demand. Therefore, the way the step function would work is that heavy industry would incur up to a 9 percent shortage at a cost of 0.15 yuan per kwh. Following that, if there were still a shortage of electricity supplied at under 0.20 yuan per kwh at a node, then a shortage would be incurred for light industry at 0.20 yuan per kwh up to 9 percent of the light industry demand, and so on. For the node as a whole, the total electricity shortage cannot exceed 9 percent of the total demand. This approach effectively approximates the condition that marginal shortage costs are increasing, and that the electricity users who can afford to pay the least, in monetary terms, would be the first ones to be outbid for electricity in a shortage situation.

Hydropower Primary Data Base

11. All data including hydropower projects, investment, leading time, and technical data were supplied by the State Planning Commission, the Ministry of Energy, and the Planning Institute of Hydropower Resources, and were checked at a CTS-sponsored conference held in January 1991.

Hydropower Plant Spatial Assumptions

12. As we know, China has very abundant hydropower. How best to exploit hydropower has very important implications for changing the energy structure, transportation system, and environmental situation of China, not to mention its implications for loss of agricultural land, flood control, water supply, etc.

13. Most hydropower sites are located far from consumer centers, meaning that in several cases, separate nodes independent of the set of electricity demand nodes had to be defined. Because sites and locations are different, the economic and technological characters can vary significantly, so in the CTS we had to define each new hydro power plant uniquely. However, to have a separate node for each hydropower site would have created an unmanageably large set of nodes. The approach taken in the CTS is to aggregate hydro power plants into a smaller set of nodes, but have up to twelve separate projects in each node. In

order not to make the transmission line system in the CTS model too complicated, we consider the investment for building transmission lines from hydropower stations to consumer center as part of the investment for the plant itself, thus taking into account the distance from the remote sites to the consumption centers.

Cost Data Assumptions

14. Hydropower plant investment costs average around Y 3,000 to Y 4,500 per kw of capacity, depending on different locations of hydropower plants. They range from an extreme low of Y 1,200 per kw of capacity to a maximum high of Y 6,000 per kw. Operating costs include water fees, materials, salaries, worker welfare, maintenance fees, and other fees, but do not include depreciation. Operating costs range from Y 5.10 to Y 37.51 per kwh for existing plants.

15. Transmission line investment costs range from 210 yuan to 1,098 yuan per kw depending on different distance and different voltages. Operating costs include materials, salaries, worker welfare, maintenance, and other fees, but do not include depreciation. They range from Y 0.43 to Y 0.68 per kwh for existing lines.

16. For some very large projects, the investment cost of the dam is separated out from the investment cost of the generating station and considered as a 0-1 investment decision. In these cases, the size of the dam and the dam's investment cost is exogenously determined from the Five-Year Plans.

Capacity Data Assumption

17. In the CTS's hydropower primary data base, existing capacity for hydropower plants is defined as the total capacity of plants both already built and currently under construction and due to be completed by 1995. All new hydropower plant options have posted feasibility studies with the Grid Planning Institute of Hydropower Resource, meaning that these new hydropower plants can be built by the year 2005 given projected technological appreciation. Total new hydropower plant capacity available for construction in the CTS is about 10,000 x 10^4kw.

Other Technical Assumptions

18. Lead and life times of hydropower investments are taken from planning data. Lead times are uniquely defined for each project, and range from 4 to 12 years. All projects except the big hydro projects that are modeled with 0-1 variables can be built in any of the three time periods. The large dam projects can either be built for the years 2000 or 2005, depending on their real lead times. Lifetimes are assumed to be 50 years.

19. The annual hours of operation, which is a technical data for a hydropower plant, is determined by natural conditions and varies by hydropower site.

Thermal Power Primary Data Base

Thermal Power Plant Spatial Assumptions

20. Thermal power plant nodes were created according to coal allocation patterns, existing thermal distribution, and the transportation network. At least one node is defined for every province, while several provinces are defined as two or three or four nodes in order that major intra-provincial coal flows can be accounted for. Presently, the CTS model has 47 thermal plant nodes.

21. Each generating node has an existing thermal power plant variable (EX_COAL) and a new base load thermal power plant variable (NEWC1 in the primary data base, operation hours defined as 5,000 to 5,500 hours per year). A few nodes where electricity is in severe shortage have a new peak load thermal power plant variable (NEWC2, operation hours defined as 3000 hours per year) plant. Also, nodes that are in both the sets of thermal power nodes and coking coal production nodes have a mid-

dling coal power plant variable (MID) related with coking coal washing.

Thermal Power Plant Technological Assumptions

22. In the current Chinese situation with widespread coal shortages, one of the key parameters is the coal consumption rates of thermal power plants. For existing thermal power plants, the CTS uses present (1990) average conversion factors of electricity supply, which ranges from 525 gram per kwh (standard raw coal) in Shanghai regions to 826 gram per kwh in Qinhai regions. For new thermal power plants, the CTS assumes higher efficiency conversion factors for electricity generating, based on 300-600 mW generator units that are proposed to be the main type used for the next 15 years. We also assume that the energy conversion factors for new plants range from 460 gram per kwh to 500 gram per kwh.

Cost and Investment Data Assumptions

23. For all thermal power plants, the operating cost is the 1990 average operating cost of electricity supply (financial cost minus fuel cost and depreciation charges).

24. For new power plants, the investment cost used in the CTS is defined as the investment for a 300 mW generator. The investment cost for new thermal capacity is Y 2,200 per kw of capacity. This figure is assumed to be the same everywhere because the investment in equipment accounts for the major part of total investment. All data were checked by experts.

Capacity Data Assumptions

25. Because water resources are the main constraining factor for building thermal power plants at mine mouth locations in the coal base of northern China, new thermal power plant capacity was determined mainly according to water resource availability. For instance, new thermal capacity proposed at mine mouths from 1991 to 2005 has been constrained to be less than 10,000 mW in Datong. With the exception of mine mouth thermal power plants, and Qinhuangdao, where the rail line capacity is mainly reserved for the port, there is no upper limit on new thermal capacity.

Nuclear Power Primary Data Base Assumptions

Nuclear Power Plant Spatial Assumptions

26. At present, there are two nodes with existing (that is, under construction) nuclear power plants. Because nuclear power plant equipments heavily rely on imports, and because its investment is very much higher than that of thermal and hydropower plants, the proposals for increased scale and new nodes for nuclear power are very limited. Further limitations are imposed by nuclear resources. In the CTS model, the two existing nodes are made available for nuclear capacity expansion, and three new nodes are defined at Shenyang, Changsha, and Jinan—zones with severe electricity shortages.

Cost Data Assumptions

27. Because there is not a single nuclear power plant built yet in China, operating and investment cost data from other countries were revised and adopted. The assumed cost of new capacity is Y 6,000 per kw, compared with 2,200 per kw for thermal base load plants. The operating cost is assumed to be four times higher than thermal power plant.

Capacity Data Assumptions

28. No upper bound was used for nuclear capacity construction. Because the cost is so high, we have assumed it would be the choice of last resort.

Other Technical Assumptions

29. The lead time is assumed to be five years and the lifetime is assumed to be 30 years. It is assumed that it is feasible to

construct new nuclear capacity by 1995 in all three nodes.

Transmission Line Primary Data Base

Transmission Line Spatial and Technological Assumptions

30. As we know, transmission lines are one of the options for energy shipment which is especially significant in the Chinese case where the transportation network is very congested. But because the physical transmission network is very complex, it is necessary to simplify it. The criteria of simplification are as follows.

31. The small transmission lines with voltage under 110 kV are ignored. Because low level voltage is mainly suitable for very short distance intra-provincial electricity transmission, ignoring these transmission lines just ignores the problem of coordinating short distance intra-provincial allocation, which is not part of the scope of the CTS.

32. Existing transmission lines were aggregated and defined to be consistent with the spatial aggregation of the electricity generating and demand nodes, and the existing network of transmission lines.

33. Proposed new transmission lines for the CTS were based on options proposed by the Planning Institute of Electrical Power, the State Planning Commission, and the Ministry of Energy.

34. The voltages of new proposed transmission lines are consistent with existing levels of each grid. For instance, the northwestern grid has two voltage levels: 220 kV and 330 kV; and other grids have two or three voltage levels: 220 kV, 500 kV (AC) and 500 kV (DC). Which voltage is assumed for each line depends on the length of the transmission line proposed. Generally, for distances under 300 km, 220 kV technology is adopted. For distances between 300 and 800 km, 500 kV (AC) lines are adopted except for the northwestern grid where 330 kV lines are adopted. For distances over 800 km, which for the most part are lines connecting separate grids, 500 kV (DC) lines are usually adopted.

Cost and Investment Data Assumptions

35. Operating costs and investment data for transmission lines used in the CTS were based on practical data for 1990, from the Ministry of Energy and statistical reports. Investment for building new proposed transmission lines includes line investment and transformer investment, the cost of which is related to which level voltage is adopted and the length of the line in miles. The four linear regression equations for estimating line investment costs are shown below.

For 500 kV DC lines:
$I = 700 + .31*L \quad (800 < L < 1500)$

For ~500 kV lines:
$I = 100 + .70*L \quad (600 < L < 800)$

For ~330 kV lines:
$I = 125 + 1.458*L \quad (400 < L < 700)$

For ~220 kV lines:
$I = 150 + 1.25*L \quad (L < 600)$

where:

I = financial investment cost per kw of capacity; and
L = distance, in km.

For reference purposes, a 500 kV DC line has a capacity of 2.4 million kw.

Capacity Data Assumptions

36. Capacity for existing transmission lines is defined as the natural transmission capacity. Because both generating plants and demand are aggregated into artificial nodes, the existing line capacity is also aggregated. Capacity of transmission lines is handled in two different ways in the CTS. New transmission lines with voltages under 500 kV (AC) are defined as continuous variables, while new transmission lines with voltage of 500 kV (DC) are defined as 0-1

variables. For the continuous variables, no a priori upper bound on new capacity is imposed. The solution results of the variables gives a total kw of capacity built, and from these it is possible to calculate how many new lines are needed in each time period. For the 0-1 variables, the a priori assumption is that a maximum of one new large transmission line can be built on any proposed origin-destination pair, with a capacity of 2,400 mW.

37. The actual volume of electricity in kwh that can be transmitted on a line is equal or less to the capacity built in kw times the annual hours of operation. The number of hours for existing and new lines is exogenously set at 7000 hours per year, based on technical standard.

ENVIRONMENT SECTOR DATA ASSUMPTIONS

1. As there are almost no sulfur scrubbers equipped for coal boilers in China at present, the data assumptions for sulfur scrubbers are roughly estimated. It is estimated that sulfur scrubber will cost about 20 percent of the total investment for power plant, the investment for scrubber is 500 yuan per kw power generator. Assuming that the average sulfur content of coal is 1.5 percent, that 3 tons of coal will be consumed for 1 kw generator capacity with 6,000 hours of operation time, and that the disposal rate of sulfur is 90 percent, then the unit investment cost for scrubbers is calculated as 12,500 yuan. The operation cost for removal of 1 ton of sulfur is estimated as 300 yuan.

2. Sulfur scrubbers are only designed for coal power plants in the CTS model, as up to now there is no plan to equip sulfur scrubbers to small and medium size boilers. The boilers of power plants are all of big size, and are most likely to be the first to be equipped with scrubbers in the future.

3. No specific constraints on sulfur and ash contents are given exogenously to the nodes for the base case. What we suppose is that once we get the emission volume of ash and sulfur in each node from the base case, we will use 90 percent or 95 percent of the original emission volume as the constraint for scenario analysis, to find out the percentage cost increase for lowering ash or sulfur emissions for the energy supply system, and what is the most economical strategy for doing so.

METHODOLOGY FOR ESTIMATING BENEFITS BY COMPARING SCENARIO COSTS: STEAM COAL WASHING, ELECTRICITY TRANSMISSION, SHENMU-HUANGHUA RAILWAY COMPLETION

Overview

1. The total national benefit from some kind of investment measure is estimated in the following way. The method relies on comparing systemwide costs in "with" and "without" scenarios, and then adjusting that cost differential. The two scenarios must differ by only one assumption for it to work properly.

Cost Differentials Between Scenarios

2. To estimate the benefit of steam coal washing, a separate scenario was run assuming that no new steam coal washing is allowed to be built in any of the three time periods. This is done by imposing an upper bound of 0 on all ZW (new washing capacity) variables. Of course, with no steam coal washing investment allowed, the model must adjust the entire optimal system to compensate and replace it. Consequently, there are more shortages, more transmission, more hydropower, more shipping and railway flows (where possible). Readers may refer to the summary tables in Annex 9 to see exactly which substitution measures are adopted when steam coal washing is eliminated. Overall, the systemwide cost is increased from Y 197 billion to Y 201 billion.
3. This cost differential of about Y 4 billion is considered as an estimate of the cost savings made possible by new steam coal washing. Were we to optimize the system without considering steam coal washing, and if the Chinese failed to build any new plants, the cost of satisfying coal and electricity demands would be about 2 percent higher.
4. Likewise, for electricity transmission, a scenario was run in which no new 500 kV intergrid power lines were allowed to be built. The scenario adjusts the system to the absence of this option, substituting other measures and incurring greater shortages. The differential between the optimal cost with and without these options is the basis for the benefit estimation. The difference between objective functions of the base case and the no-new-intergrid-transmission case is Y 1.6 billion, or slightly less than 1 percent of the overall costs.
5. Note that only the *intergrid* lines are eliminated from this scenario, because intergrid lines represent the real policy change taking shape in China. They have long used intragrid lines to create a reliable power grid. It should be further noted that intergrid lines number only 16, compared to about 100 intragrid lines. In fact, Shanxi and Nei Monggol are in the same grid as Beijing and Tianjin, and likewise, Nanning and Guangdong are in the same grid. Examples of intergrid lines eliminated from the scenario are Tangshan-Shenyang, Chongqing-Wuhan, Guiyang-Guangdong, Changzhi-Xuzhou, and Changzhi-Shanghai.
6. Scenarios 93-1 and 93-2 can be compared to estimate the benefit of building the Shenmu-Huanghua railway. Despite the added cost of building the line, systemwide costs are reduced by 0.2 percent.

Adjustments to Cost Differentials

7. In percentage terms, the benefit (cost savings) calculations are accurate, but adjustments must be made to get an accurate measure in terms of yuan. This is because the model's objective function includes only the discounted costs for the three "key years" (1995, 2000, and 2005) of each FYP. However, the cost differential cannot simply be multiplied by five, because that would overstate the benefits. The following adjustments must be made to get a more accurate

measure of the savings in economic terms.

8. First, estimate the ratio of the average demand for the entire FYP to the key year demand. This must be done separatelyfor coal and electricity because the growth rate assumptions are different (1.8 percent for coal, 9 percent for electricity).

For electricity:

$$\frac{(1.09) + (1.09)^2 + (1.09)^3 + (1.09)^4 + (1.09)^5}{(1.09)^5} =$$

$$= 6.52/1.538$$

$$= 4.23$$

For coal:

$$\frac{(1.018) + (1.018)^2 + (1.018)^3 + (1.018)^4 + (1.018)^5}{(1.018)^5} =$$

$$= 5.2765/1.0933$$

$$= 4.826$$

9. Second, factor in the different size of the coal and electricity demands. Nonelectricity demand for coal in 2000 in the 9 percent demand cases is 905.78 million tons. Electricity demand in 2000 is 14,436 x10^8 kwh. Using a conversion factor of 55,000 kwh per ton of coal, the electricity demand in 2000 converts to 793.98 million tons of coal. Thus, coal accounts for 53.3 percent of demand, and electricity accounts for 46.7 percent. We apply these percentages to the two ratios calculated above to arrive at an average ratio of key year demand to total demand:

$$(.533 * 4.826) + (.477 * 4.23) = 4.54775$$

10. Finally, we multiply the cost differentials between scenarios by 4.54775 to arrive at an estimate of the total cost savings over the model's 15 year time horizon.

For Steam Coal Washing:

$$Y\ (2.0104 - 1.9718)\ x10^{11} * 4.54775 = Y\ 17.55 \text{ billion}$$

For Intergrid Power Transmission:

$$Y\ (1.9873 - 1.9718)\ x10^{11} * 4.54775 = Y\ 7.05 \text{ billion}$$

For Accelerating Shenmu-Huanghua Railway:

$$Y\ (1.9718 - 1.9684)\ x10^{11} * 4.54775 = Y\ 1.55 \text{ billion}$$

11. This same method is used in estimating the total systemwide discounted cost in Table 9.1 in Annex 9, e.g., Y 197 billion x 4.54775 = Y 897 billion for all 15 years.

CHINESE EVALUATION OF THE CTS (DECEMBER 1991)

1. The China Coal Transport Study (CTS) aims at finding out the relationships among energy production, transportation, consumption and environment protection as well as issues concerning their long-term developments. The project is coordinated by the Institute of Economics. Under the supervision of the World Bank experts and with the participation of the Institute of Energy, the Institute of General Transportation and the Institute of Technical Economy of the State Planning Commission and other related institutions of China, the project has completed studies on the systematic optimization for the production and transportation (transmission) of coal and electric power, consumption and environment protection for 8th, 9th and 10th (1991-2005) five-year plans separately in three years. This study is important both in theory and reality. It is a great achievement in the field of soft science studies which has provided methodology and tools of high level for the improvement of existing management work for economic planning. Great number of valuable information and data for decision-making provided by CTS has enabled long-term development plans and policies for energy production and transportation, demand and environment protection to be made scientifically. Further development, application and popularization of CTS model is of great importance for acceleration of scientific and modernized decision-making for China's economic planning.

2. CTS not only has made good use of modern systematic engineering theory but also advanced theories and methods for economic management. CTS model is an outcome of a systematic study of China's present situation of energy production, transportation and consumption and their future trends. The model is an optimized one which is suitable for China's reality of coal and electric power production, transportation, demand and environment control.

3. From the point of view of the function, scale and structure of the model, it is the first of its kind that has ever been built and is also quite advanced to compare it with those similar models in the world.

4. This study has produced large number of data and information concerning coal production, selection and washing, power production and transmission, construction of transportation network, allocation of traffic flows, environment control and the demand for coal and electric power etc. These data and information are very valuable for decision makers of related departments. In addition, policy options and suggestions about relationships among different industries made on the basis of the calculation and analysis are new and applicable.

5. The latest software (Mathpro-express) for linear planning and advanced GIS graphic display system software have been used in the study. In addition, good systematic users interface software also have been established for a more convenient data inputs and output. Therefore, it is highly atomized and is easy for making corrections of the data and even the structure of the model. Mix integer programming model (MIP model) has also been applied in the study to get solution by using PC 486 desktop computer. This has provided better base for the maintenance and expansion in usage of the model.

6. Further development and improvement could be done to the study so as to provide a more efficient service to decision-makers and planners. New subjects for further study could be determined on the basis of this study. Priorities should be given to those subjects like study on the transportation price of coal and electric power; comparative study on the energy reserve and opening up; study on the coordinated development of economy, energy and environment and so on.

This evaluation was issued by the CTS Evaluation Committee and is quoted here in its entirety.

Members of Chinese Evaluation Committee for the CTS

No	Name	Department	Title
1	Guo Hongtao	China Communication and Transport Association, SPC	Chairman, Central Advisory Commission
2	Sun Shangqing	Development Research Center State Council	Vice President
3	Gui Shiyong	State Planning Commission (SPC)	Vice Chairman
4	Wang Chaozong	Planning Department, China Energy Investment Co.	Deputy Director
5	Shi Dinghuan	Industry Department State Science and Technology Commission	Director
6	Wu Jiapei	National Information Center	Deputy Director
7	Fu Jiaji	Management Research Institute, Qinghua University	Director Professor
No	Name	Department	Title
8	Li Xuesheng	Planning Department, China National Coal Corp.	Deputy Director
9	Li Weimin	Long-term Planning Department, SPC	Deputy Director

10	Li Duanshen	Communication, Transport and Telecommunication Department, SPC	Deputy Director
11	Yang Zhengguo	Management Institute, Harbin Industry University	Professor
12	Zhou Dawen	Planning Department, MOR	Director
13	Lin Pinya	Planning Department, MOC	Director
14	Zhang Jianqiu	Institute of Comprehensive Transport, SPC	Assistant Researcher
15	Qin Shengtao	Science and Technology Department, SPC	Director
16	Xu Zhen	Economic Research Center, SPC	Deputy Director
17	Tu Zhuming	Energy Department, SPC	Director
18	Huang Zhijie	Energy Research Institute, SPC Researcher	
No	Name	Department	Title
19	Huang Yuqing	China Communication and Transport Association, SPC	Deputy Secretary-in-General
20	Huang Fanzhang	Economic Research Center, SPC	Deputy Director

21	Lei Ting	China Communication and Transport Association, SPC	Vice Chairman
22	Wei Quanling	Information Department, People's University	Professor

LIST OF PARTICIPANTS AT CTS REPORT MEETING (OCTOBER 1993)

Mr. Wei Liqun	General Secretary of SPC
Mr. Xu Zhen	Deputy Director of Economic Research Center (ERC)
Mr. Huang Fanzhang	Deputy Director of ERC
Mr. Ling Zoomu	Deputy Director of ERC
Mr. Meng Guangbing	Deputy Director of ERC
Mr. Tu Zuming	Director of Energy Department of SPC
Mr. Lan Shiliang	Director of (Long-term) Planning Department of SPC
Mr. Jiang Junru	Deputy Director of Science Department of SPC
Mr. Ma Deqing	Director of Policy, Regulation, and Law Department, Ministry of State-owned Coal Mines
Mr. Lu Qi	Huaneng Energy Group Co.
Mr. Shi Shanxin	Ministry of Railways
Ms. Ren Hong	Ministry of Communications
Mr. Zhang Jianxian	State Energy Investment Co.
Mr. Zhou Caiyu	Director of Institute of Economy of ERC
Mr. Xu Shoubo	Director of Technical Economic Research Institute of ERC
Ms. Liu Liru	Director of Institute of Comprehensive Transportation of ERC
Ms. Li Lianpu	China Offshore Oil Development Co.
Mr. Zhang Jianping	Transport Department of SPC

BACKGROUND ON EDELMAN AWARD

1. The Coal Transport Study has been awarded one of the six Finalist prizes for the prestigious 23rd Annual International Competition for the Franz Edelman Award for Management Science Practitioners. All finalists can be considered prize winners, since each finalist has a paper published in the January 1995 issue of the journal *Interfaces*, has their presentation videotaped for sale to universities, and receives a cash prize. The Grand Prize Winner receives a $10,000 award.

2. The Edelman Award is given by The Institute of Management Sciences (TIMS), the main professional association for the operations research/management science (OR/MS) community (along with their sister organization, the Operations Research Society of America (ORSA)). The award is given for completed, practical applications "that had significant, verifiable, and preferably quantifiable impact on the performance of the client organization."

3. This year's finalists include, in addition to the CTS: Digital Equipment Corp., The U.S. Military Downsizing, Bellcore, the Hanshin Expressway (Japan), and Tata Iron and Steel Co. (India). Each finalist must give an oral presentation of the project at the Boston Meeting of TIMS on April 24, 1994. A high-ranking official of the client organization (in our case, the SPC) must attend the conference and be available to answer questions about the impact of the modeling work on the client organization.

4. Recent Edelman Award winners have included:

(a) American Airlines Decision Technologies, for their Sabre Reservation System, a series of statistical and mathematical models to 'sell the right seats to the right customers at the right prices." This yield management work has generated more than $1.4 billion in revenue for American Airlines during the last three years. (Grand Prize Winner, 1991 competition)

(b) The Columbus-America Discovery Group, which made innovative use of classical search theory and a collection of supporting models to successfully find the sunken SS Central America, after many other groups had failed to locate it. They recovered an estimated $1 billion in gold coins. (Runner-up, 1991 competition)

(c) The AIDS Division of the New Haven Health Department, for evaluating the New Haven needle exchange program. They designed data collection mechanisms for tracking needles and built a mathematical model for the transmission of HIV, which showed convincingly that the program had reduced the HIV incidence rate by 33 percent. (Grand Prize Winner, 1992 competition)

(d) Bellcore, the R&D consortium for the seven regional telephone operating companies in the United States, for developing a mathematical program for maximizing the total project utility received by the operating companies givent heir budget constraints. This resulted in an average of 23 additional R&D projects for each operating company at no additional cost in 1991. (Runner-up, 1992 competition)

5. Other Finalists during 1991 and 1992 included the Gas Research Institute; Mexico's Vilpac Truck Company; The City of New York arrest to arraignment system; Merit Brass Co.; the New Haven Fire Department; GE Capital Corporation; GTE Telephone Operations; The U.S. Military Airlift Command; Prudential Securities Inc.; The U.S. Postal Service; and Yellow Freight System, Inc.

Speech by Mr. Gui Shiyong at Edelman Competition

6. The results and conclusions of the CTS are guidance for achieving the long

term goals of the coal, electricity, and transportation system. The CTS, using scientific methods, systematically described the deeper problems and contradictions in the system. It is of great value for the adjustment of planning and decision-making, as demonstrated by the following seven policy impacts.

7. First, one conclusion from CTS, is that, for the capacity of coal, electricity, and transportation system in China, it is possible to meet GNP growth of 8-9%, but it is difficult to meet that of 10%. This conclusion was reflected in the Eighth Five Year National Economic Plan.

8. Second, relevant departments are preparing to adjust their plans for coal, electricity, and transportation system, taking CTS results as reference. For example, we are considering to increase the coal output from 1.4 billion tons in the former Eighth Five Year Plan to more than 1.5 billion tons.

9. Third, the CTS showed that coal transportation is still the main factor limiting the future coal supply, and strongly supports the urgency of constructing a second major railway from the energy base to the ports. Recently, the Vice Premier, Mr. Zhu Rongji, held a special meeting to discuss how to finance it and finish its construction before 2000.

10. Fourth, the CTS gives quantitative analysis for the first time showing that coal washing is an effective way to transport more energy over the same railway capacity. In 1993, China passed a rule that all new steam coal mines that export coal to other provinces should include coal washing plants.

11. Fifth, some provinces and enterprises are considering to carry out some electricity transmission projects suggested by the CTS. For example, transmission from the coal base to the Shanghai region has entered the stage of preparation, and hydroelectricity transmission to Guangdong is under consideration by the Central Government. Furthermore, China has announced plans to integrate its separate grids into a single power grid.

12. Sixth, CTS has shown that such an energy structure with coal as the main energy resource will bring heavy and long term burden on the environment protection of China. Relevant departments are thinking about how to deal with these problems by the measures of energy conservation, increasing coal washing, expanding hydropower, and installing more de-sulfur and de-ash equipment, etc.

13. Seventh, opening of the Chinese domestic market to the outside world will bring an even greater impact upon the energy equilibrium of China. Considering these reforms, the CTS used shadow prices and international market prices to adjust plans according to market requirements. For example, CTS proposed for the first time that it is reasonable to import coal in the coastal areas to alleviate the coal shortage. Presently, some provinces like Guangdong have followed this proposal.

14. In December 1991, I served as co-chairman of the CTS Inspection Committee. In that meeting, the officials from different agencies, and directors of several SPC planning departments reviewed the CTS optimization model and found it to be suitable for China's reality.

15. In 1993, another conference was held to report updated results of the model. In this meeting, the officials and experts said that the CTS has had an important influence on China's economy and should be used more widely. The CTS represents the first time that model results of this kind have been used at this level in China.

16. The uses of CTS in China are just beginning. As the Vice Chairman of the State Planning Commission, I will support further applications of the CTS, including making economic forecasts for the year 2010 and planning in the departments of Transportation, Energy, and Science and Technology. Also, some large enterprises such as China Energy Group, China Ocean Oil Corp, and China Oil and Natural Gas Corporation, are preparing to make analysis and forecasts using CTS results.

17. In summary, in a country that uses as much coal as China, solving the problems of coal production, transportation, and consumption scientifically will benefit the economic and social development of all of China and the environmental protection of the entire world.

Note: The English version of this speech was shortened and edited from the original Chinese version.

CTS Implementation Conference and Franz Edelman Award Ceremony (October 1994)

1. On October 28, 1994, a conference was jointly sponsored by the World Bank and the Economic Research Center (ERC) of the SPC in Beijing to discuss implementation issues relating to the recommendations of the CTS Phase 2 policy analysis. Attendees were also introduced for the first time to Ms. Xie Zhijun's findings on energy conservation using the enhanced CTS model she developed during her McNamara Fellowship. Afterwards, a ceremony was held honoring the CTS team for being Finalists in the 1994 Franz Edelman Competition for Management Science Achievement. Publication and continuation of the CTS were also discussed. A Chinese translation of the Green Cover report was distributed to all attendees.

2. The main purpose of this meeting was to review the CTS recommendations and to discuss issues relating to their implementation. The CTS model suggests economically efficient strategies for producing and delivering enough coal and electricity to satisfy China's projected economic growth. The central question of the meeting, then,was how should China implement these recommendations, given that it is in transition to a market economy and the central government can no longer dictate all investments? Because of barriers and distortions, the market often does not send the right economic signals to enterprises.

3. The Bank's presentations defined a distortion as something that makes an enterprise want to do the wrong thing, and a barrier as something that prevents an enterprise from doing the right thing even when they want to do it. An example of a distortion is a subsidized price, such as low energy costs, which encourages an enterprise to be wasteful. An example of a barrier is when a coastal province cannot make a long-term contract with a minemouth power plant that can be relied upon. The risk that no electricity will be delivered to them, and the difficulty of managing that risk, is a barrier.

4. Distortions can be removed and barriers can be overcome with market mechanisms such as prices that are representative of costs, reliable contracts, open markets, and corrective taxes. The Central Government must try to provide an enabling legal and market environment for them to choose the best decisions.

5. Coal washing was used to illustrate this kind of policy analysis. The recent guidelines issued by the Government that call for new coal mines to build washeries do not address the underlying reasons why the mining companies do not want do it. While scarcity of capital is perhaps the greatest problem, the fact is that there is a lot of capital being invested in other part the coal-electricity system. Enterprises are choosing not to spend scarce capita on coal washing because it does not look as profitable as some other uses of capital in the coal-electricity system.

6. The biggest distortion in the coal washing area is that coal buyers are not penalized for polluting the environment. Pollution is a real cost to the economy as a whole, but polluters are not accountable for it. Market mechanisms used in other countries to internalize such externalities were reviewed, including pollution taxes and tradeable pollution allowances. Higher rail rates were mentioned as another price signal that would give an incentive to wash coal, so that coal with 30 percent of ash would not be shipped over thousands of km.

7. Barriers were discussed next. Even if distortions were removed and buyers began to demand washed coal, there would still be barriers making it risky for the buyers and sellers. The proper legal framework is necessary for willing buyers and sellers to enter into long-term contracts that guarantee a reliable market for

the washery's products and a reliable supply for the special boilers designed to burn washed coal. Otherwise, buyers won't invest in the special boilers, and sellers won't invest in the washeries.

8. The responses of the Chinese discussants focused on the coal washing example. Most experts agreed that the CTS recommendation to wash at least 30 percent of coal by 2000 is reasonable, and perhaps low, from an efficiency standpoint. The Chinese participants mentioned a number of different barriers and distortions:

(a) the inability to pass higher costs on to electricity consumers;
(b) how to finance coal washing investment
(c) how to dispose of waste from coal washing;
(d) inefficient methods for matching needs of coal suppliers and coal buyers;
(e) coal washing investment costs can be Y100 per ton, compared with Y400 per ton for mining investment costs;
(f) resource taxes are higher for good quality coal, lower for poor quality coal;
(g) local governments will levy taxes for expansion of existing facilities, such as adding washeries to mines; and
(h) the electricity price is not high enough to support coal washing at minemouth power plants, because although electricity can be sold at the load center end of a grid at a high price, this high price is not passed back to power generators at the input end of the grid, i.e., the grid benefit is not shared. (Of course washing coal for minemouth plants would not create any transport savings anyway.)

9. In summary, while the CTS is very useful for identifying least cost strategies, the meeting demonstrated how essential it is that Government officials try to remove the distortions and barriers that make least-cost strategies look like high cost strategies, and then set up market mechanisms to send the right price signals.

10. After the discussion meeting, a ceremony was held to present the Franz Edelman Finalist Award to the CTS team. The ceremony was chaired by Mr. Pieter Bottelier, head of the Bank's Resident Mission in China. A plaque was presented to Mr. She Jianming, Vice Chairman of the SPC, and certificates were presented to the ERC and to CTS team members. The Government leaders expressed strong support for continuing the CTS. The ceremony was filmed and reported on both Chinese and English language TV news broadcasts over the next few days. A complete list of attendees is included in the next page.

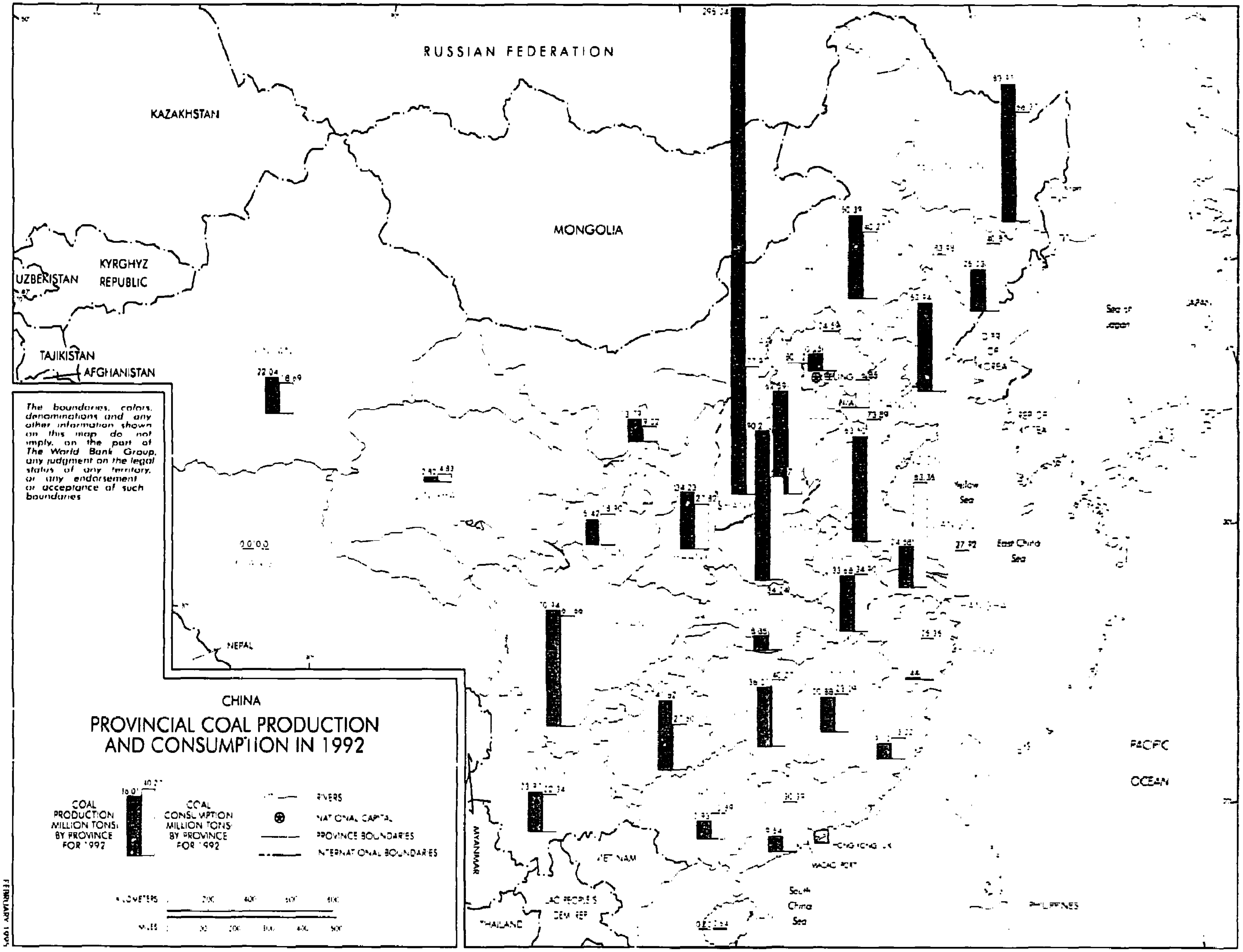
List of Attendees:

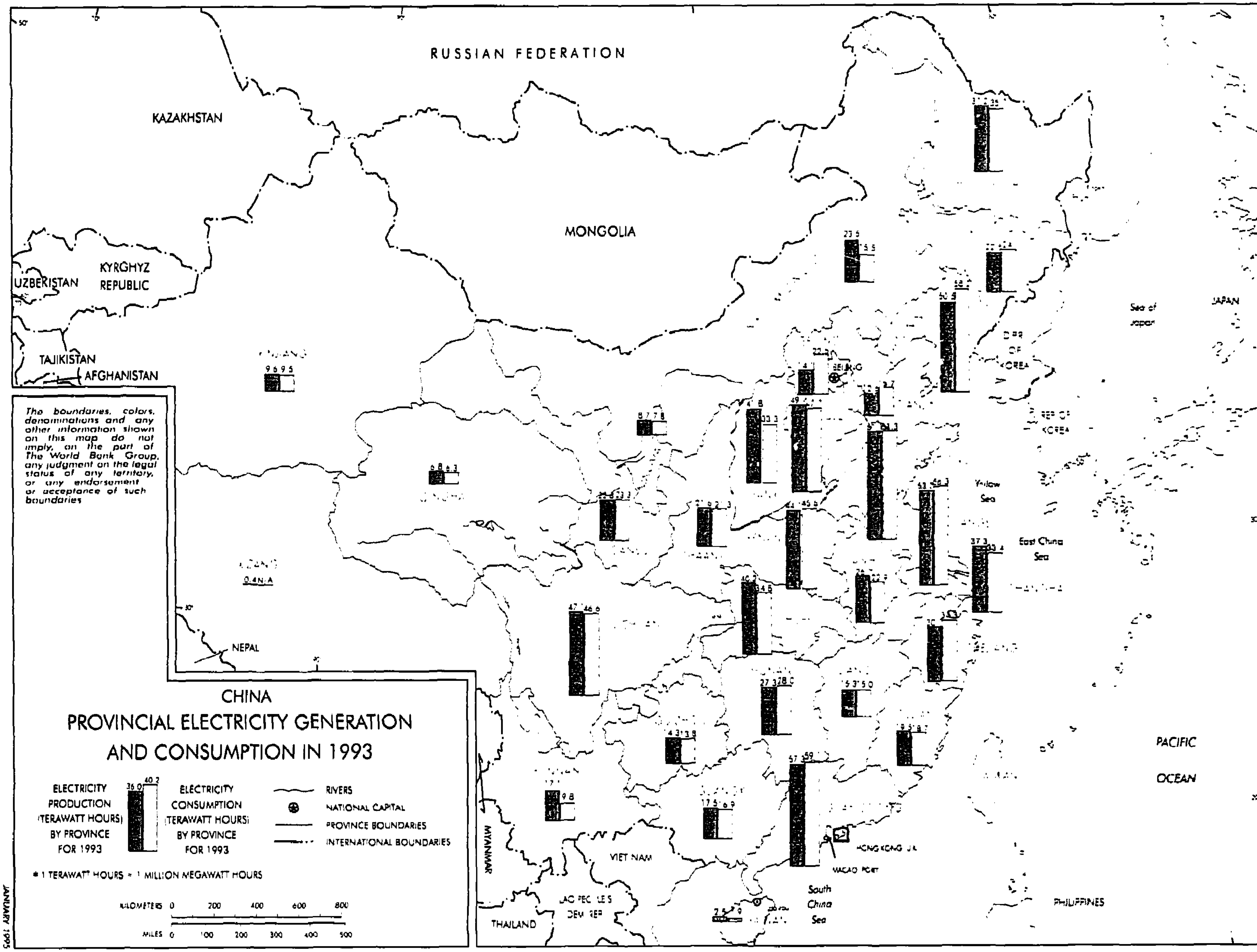
Gui Shiyong	Former Vice Chairman of SPC and Deputy President of the Administrative Institute of China;
She Jianming	Vice Chairman of SPC;
Wu Jingru	Director, Electricity Bureau, State Development Bank
Li Qun	Director, Policy Bureau, State Bank Development Bank
Zhao Kunming	Division Chief, Transportation Bureau, State Development Bank
Zhang Guocheng	Division Chief, Industry Department, State Development Bank, Science and Technology Commission
Jia Qinxiu	Ministry of Coal, Senior engineer
Sun Jianqi	Division Chief, Information Division, SPC
Zhang Xiaojian	Information Division, SPC
Xu Zhen	Deputy Director of ERC
Huang Fanzhang	Deputy Director of ERC
Wang Xingjia	Deputy Director of ERC
Lin Zhaomu	Deputy Director of ERC
Bian Bingyin	Deputy Director of ERC
Li Ping	Division Chief of ERC
Jiang Chunze	Division Chief of ERC
Tian Jun	Division Chief, Long-term Planning Department of SPC
Wei Yuanpeng	Division Chief, Energy and Transportation Department of SPC
Ren Long	Division Chief, Policy Department of SPC
Li Peng	General Secretary, Academic Committe, of SPC
Guo Yibing	Huaneng Energy Group Co.
Zhou Fengqi	Director of Energy Research Institute of ERC

Zhou Xiaping	Director of Institute of Comprehensive Transportation of ERC

Press:

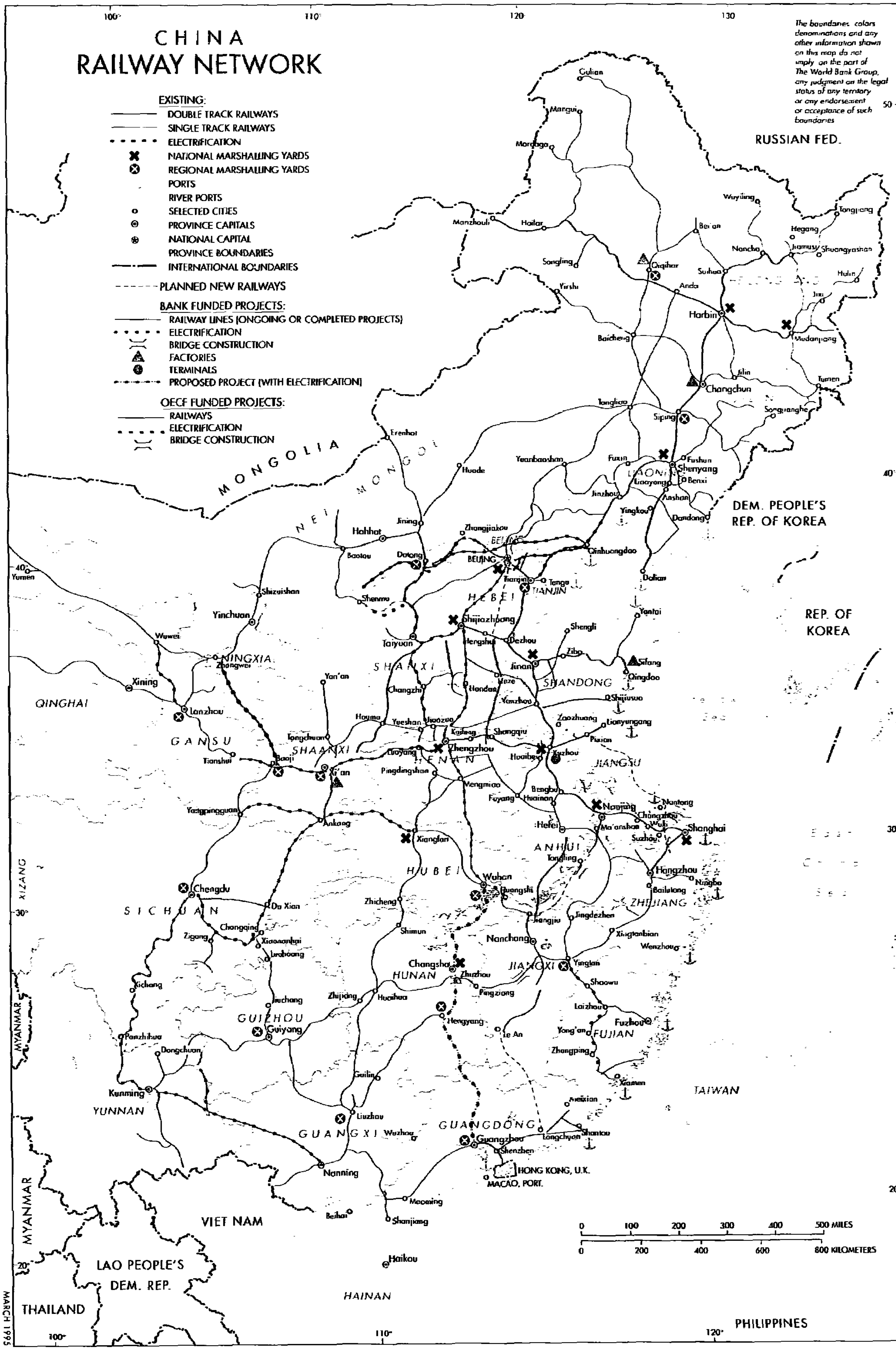
People's Daily	CCTV
Central Broadcasting Co.	Economic Daily
Guangming Daily	China News Agency

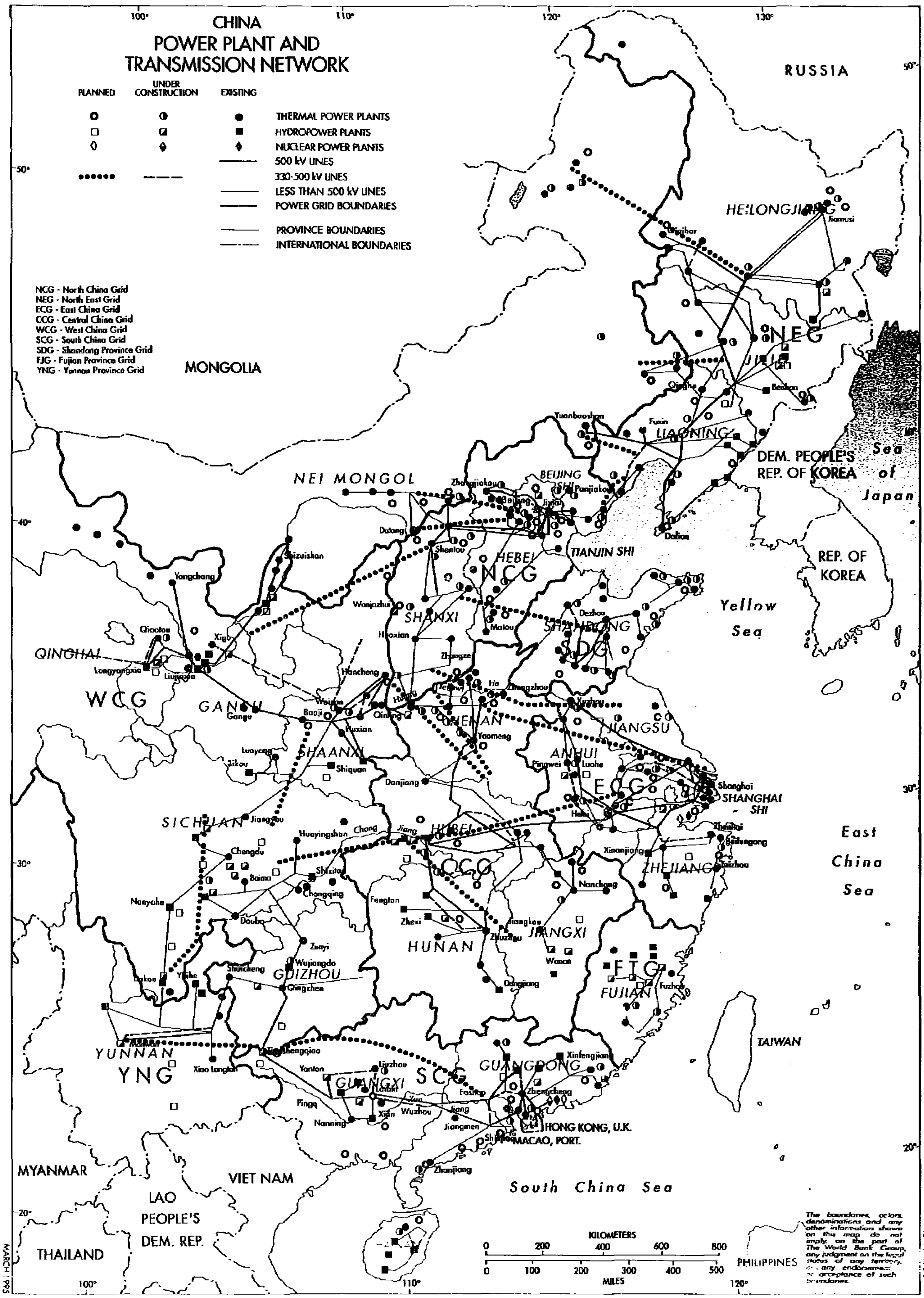

RUSSIAN FEDERATION
KAZAKHSTAN
MONGOLIA
UZBEKISTAN
KYRGHYZ REPUBLIC
TAJIKISTAN
AFGHANISTAN
NEPAL
MYANMAR
THAILAND
VIET NAM
LAO PEOPLE'S DEM REP
PHILIPPINES
Sea of Japan
Yellow Sea
East China Sea
South China Sea
PACIFIC OCEAN
BEIJING
295.04
93.91
50.39
63.94
90.2
63.40
63.36
27.92
22.04
5.42
70.34
41.92
The boundaries, colors, denominations and any other information shown on this map do not imply, on the part of The World Bank Group, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries
CHINA
PROVINCIAL COAL PRODUCTION AND CONSUMPTION IN 1992
COAL PRODUCTION MILLION TONS BY PROVINCE FOR 1992
COAL CONSUMPTION MILLION TONS BY PROVINCE FOR 1992
RIVERS
NATIONAL CAPITAL
PROVINCE BOUNDARIES
INTERNATIONAL BOUNDARIES
KILOMETERS
MILES
FEBRUARY 1995
IBRD 26594



JANUARY 1995

IBRD 26596


CHINA
RAILWAY NETWORK
EXISTING:
DOUBLE TRACK RAILWAYS
SINGLE TRACK RAILWAYS
ELECTRIFICATION
NATIONAL MARSHALLING YARDS
REGIONAL MARSHALLING YARDS
PORTS
RIVER PORTS
SELECTED CITIES
PROVINCE CAPITALS
NATIONAL CAPITAL
PROVINCE BOUNDARIES
INTERNATIONAL BOUNDARIES
PLANNED NEW RAILWAYS
BANK FUNDED PROJECTS:
RAILWAY LINES (ONGOING OR COMPLETED PROJECTS)
ELECTRIFICATION
BRIDGE CONSTRUCTION
FACTORIES
TERMINALS
PROPOSED PROJECT (WITH ELECTRIFICATION)
OECF FUNDED PROJECTS:
RAILWAYS
ELECTRIFICATION
BRIDGE CONSTRUCTION
The boundaries, colors, denominations and any other information shown on this map do not imply, on the part of The World Bank Group, any judgment on the legal status of any territory or any endorsement or acceptance of such boundaries.
RUSSIAN FED.
MONGOLIA
NEI MONGOL
DEM. PEOPLE'S REP. OF KOREA
REP. OF KOREA
QINGHAI
GANSU
NINGXIA
SHAANXI
SHANXI
HEBEI
BEIJING
TIANJIN
SHANDONG
HENAN
JIANGSU
ANHUI
HUBEI
SICHUAN
XIZANG
ZHEJIANG
JIANGXI
HUNAN
GUIZHOU
FUJIAN
YUNNAN
GUANGXI
GUANGDONG
TAIWAN
HAINAN
MYANMAR
VIET NAM
LAO PEOPLE'S DEM. REP.
THAILAND
PHILIPPINES
HONG KONG, U.K.
MACAO, PORT.
Harbin
Changchun
Shenyang
Dalian
Beijing
Tianjin
Shijiazhuang
Taiyuan
Jinan
Qingdao
Zhengzhou
Xi'an
Lanzhou
Xining
Yinchuan
Hohhot
Baotou
Datong
Xuzhou
Nanjing
Shanghai
Hangzhou
Hefei
Wuhan
Nanchang
Changsha
Chengdu
Chongqing
Guiyang
Kunming
Nanning
Guangzhou
Shenzhen
Fuzhou
Xiamen
Haikou
0 100 200 300 400 500 MILES
0 200 400 600 800 KILOMETERS
MARCH 1995
IBRD 26857



CHINA
POWER PLANT AND
TRANSMISSION NETWORK
PLANNED
UNDER CONSTRUCTION
EXISTING
THERMAL POWER PLANTS
HYDROPOWER PLANTS
NUCLEAR POWER PLANTS
500 kV LINES
330-500 kV LINES
LESS THAN 500 kV LINES
POWER GRID BOUNDARIES
PROVINCE BOUNDARIES
INTERNATIONAL BOUNDARIES
NCG - North China Grid
NEG - North East Grid
ECG - East China Grid
CCG - Central China Grid
WCG - West China Grid
SCG - South China Grid
SDG - Shandong Province Grid
FJG - Fujian Province Grid
YNG - Yunnan Province Grid
RUSSIA
MONGOLIA
HEILONGJIANG
NEG
JILIN
LIAONING
DEM. PEOPLE'S REP. OF KOREA
Sea of Japan
REP. OF KOREA
Yellow Sea
NEI MONGOL
BEIJING SHI
TIANJIN SHI
HEBEI
NCG
SHANXI
SHANDONG
SDG
QINGHAI
WCG
GANSU
SHAANXI
HENAN
JIANGSU
ANHUI
ECG
SHANGHAI SHI
SICHUAN
HUBEI
CCG
ZHEJIANG
East China Sea
HUNAN
JIANGXI
FJG
FUJIAN
GUIZHOU
YUNNAN
YNG
GUANGXI
SCG
GUANGDONG
TAIWAN
HONG KONG, U.K.
MACAO, PORT.
South China Sea
MYANMAR
VIET NAM
LAO PEOPLE'S DEM. REP.
THAILAND
PHILIPPINES
KILOMETERS
0 200 400 600 800
0 100 200 300 400 500
MILES
The boundaries, colors, denominations and any other information shown on this map do not imply, on the part of The World Bank Group, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries.
MARCH 1995
IBRD 26595