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# Preface

Within the framework of collaboration between IIASA's *Advanced Computer Applications* project (ACA) and the State Science and Technology Commission of the People's Republic of China (SSTCC), ACA has developed an integrated set of information and decision support systems for development planning in China. The system is implemented for a case study of Shanxi, a province in north central China, which is very rich in coal and several mineral resources, but is still at an early stage of development, lacking, for example, a well developed infrastructure, or sufficient water.

The decision support system combines several data bases, simulation, and optimization models, and AI components, in an easy-to-use *Expert System* framework. A graphical and largely symbolic user interface, relying exclusively on menu techniques and providing extensive *help* and *explain* functions, makes access to the system's functions easy for the planner and decision maker, who might have little or no computer experience.

The system is designed to assist the five-year planning process in Shanxi Province, which, in the Chinese philosophy of *integrated development*, includes investment distribution, i.e., primarily economic, but also technological, resource, environmental, and socio-political considerations. The scope of the system, consequently, ranges from the macroeconomic level down to sectoral and more engineering-oriented models.

The energy sector certainly plays one of the most important roles in Shanxi's economic development. Shanxi is China's power house: with annual coal production approaching 250 Mt, economic and industrial development is centered on the production and use of coal.

In the Shanxi software system, modeling the energy demand (and also related investment, labor, and water requirements) of planned production schemes, or more generally, the economic and social development, is done with the help of the **MAED-BI** (Model for Analysis of Energy Demand in Basic Industries). While centered on heavy industry, the model has been extended to cover the full range of economic sectors for compatibility with the overall system. Connection to a relational data base management system for the definition of input scenarios, and an interactive, graphical user interface for the selective display of model results, are important features.

The model was developed in collaboration with the International Atomic Energy Agency (IAEA), and is based on previous work done at IIASA's Energy Program. It is not only a valuable component in the overall software system, but also provides an example of the model-based decision support philosophy that is at the core of the overall project.

Kurt Fedra
*Project Leader*
Advanced Computer Applications

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# Interactive Energy Demand Analysis: The MAED-BI Model Application in the Shanxi Province, PRC

*B. Vallance and E. Weigkricht*

## 1. Summary Description of the Project

Planning the rational and coordinated development of a region requires a large amount of complex and often technical information on, for example, economic and environmental factors, the availability of resources, and the socioeconomic and political implications of development. It also needs a profound understanding of the problems on the one hand and the numerous inter-relationships between all the related factors on the other. In addition, the influence of regional planners and decision makers should be taken into consideration. A number of complex scientific models and methodologies could help to deal with these kinds of problems if made available to the planner and decision maker.

A model-based, interactive information- and decision-support system (DSS) for integrated development planning (Fedra *et al.*, 1987; Fedra, 1988a) has been developed and implemented (Fedra, 1988b, 1988c, and 1988d) for a case study of the Shanxi province, in the People's Republic of China, in collaboration with the State Science and Technology Commission of the People's Republic of China (SSTCC). It will assist the regional government in questions of development planning in Shanxi and should meet their basic requirements with regard to, for example, background information on the current situation and easy access to methodologies for the design and analysis of possible development strategies. The system was designed so that both non-scientific and non-technical users, as well as experts, can make use of it via a menu-driven, largely symbolic user interface which provides the link between man and machine, and gives immediate feedback to any user input. The structure and mode of interaction are natural and familiar, so that the user does not have to worry about learning any special, rigid language. The information is made available to the user in compact, understandable formats via interactive graphics on high-resolution color-graphics workstations.

## 1.1 China's energy production[1]

With a total output of primary commercial energy (coal, petroleum, natural gas, and hydropower) of 880 Mtce (million tons coal equivalent), China ranks third in the world. From 1949 to 1986 raw coal output increased from 32 Mt to 894 Mt; petroleum from 0.12 Mt to 130.6 Mt; natural gas from 0.07 $\times 10^8 m^3$ to 136.9 $\times 10^8 m^3$; and power generation from 4.3 TWh (terawatt hours) to 449.59 TWh.

The level of energy consumption is low: in 1985 per-capita commercial energy consumption was only 0.731 tce (40% of the world average). The energy utilization efficiency is low; China has great potential for the efficient use of energy. Apart from a major, general increase in energy production, China is moving from a basically unitary structure of coal production to a more diversified production consisting basically of coal, oil, gas, and hydropower. In 1986 China was the biggest coal producer, producing 23% of the world's total annual coal production.

China's coal reserves are estimated to be 640,000 Mt (Wen, 1984). The Chinese government plans to increase the total annual output of *coal* from the 1980 level of 600 Mtce to 1200 Mtce by the end of the century. In order to achieve this goal, (a) the technical remodeling of existing coal mines has to be accelerated; (b) for long-term planning, the construction of new mines (natural conditions permitting), in particular the exploitation of large

[1] Based on Zhou Fengqi (1988).

open-pit mines, must be emphasized; (c) the government has to continue its development policy for the coal industry, namely to develop large (state-owned: products marketed following the state distribution plan), medium (under local administration), and small-sized (collective-owned) mines simultaneously. In 1985, the output of coal by local mines was 53.4% of the total coal output in China.

The Chinese *petroleum resources* are estimated to be in the range of 30 Gt (gigatons) to 60 Gt. Deposits with about 5.5 M $km^2$ of oil sedimentation basins (with large amounts of crude oil and gas reserves) have been discovered. There are also rich reserves of *natural gas* which have yet to be fully exploited. Using 1980 as a base year, by the year 2000 the petroleum industry plans to double the annual output of crude oil to a level of 200 Mt or more and of natural gas to 250 $\times 10^8 m^3$. This means that emphasis will have to be placed on geological exploration and an increase in investment for the production of oil. New regions must be explored and opened up for new types of oil–gas deposits by the application of modern science and technology and new techniques (e.g., exploration of China's marine sedimentary strata). The petroleum reserves in China's sea area are estimated to be tens of billions of tons.

The consumption of hydropower in China amounted to 28.2 Mt of oil equivalent in 1986, a 145.2% increase since 1978, which corresponds to 5.4% of world consumption (British Petroleum, 1987). China has great potential for development, with a total potential of 680 MkWh (million kilowatt-hours), China's water power reserves are the highest in the world (Wen, 1984). In 1986 only 4.2% of China's total primary energy consumption came from hydropower. Although the resources are distributed over the whole country, they are mainly concentrated in the southwest regions. Despite the rapid growth of the *power industry* during the last 40 years consumer demand has still not been satisfied. There are still serious shortages of electricity and the government has to accelerate the development of its power industry and take measures for its rational use. China has to place emphasis on the development of thermal power plants and the use of hydropower resources, as well as to moderately develop nuclear power plants in order to achieve its goal of having a total installed capacity of 185 to 250 TW in the year 2000.

## 1.2 Shanxi province

Shanxi province is China's largest coal producer. By the end of 1985 the coal reserves of China were estimated to amount to 769.18 GT (Zhou Fengqi, 1988); more than half of these reserves are concentrated in Shanxi province and the Inner Mongolia Autonomous Region of North China, while only a few are distributed in the more industrialized east and central south China. Since Shanxi's raw coal production accounts for about 25% of total Chinese coal production, it is not only of major importance to China's coal supply but also to the national economy.

Some important characteristics of Shanxi province are described below (see also Fedra, 1987):

- Shanxi is situated in the middle of north central China (total area about 156,000 square kilometers with a population, estimated in 1982, of 26 million).
- The *climate* is moderate-continental, suitable for agriculture.
- Shanxi is rich in *mineral resources*, including coal, aluminium, iron, copper, molybdenum, titanium, lead, gold, silver, gypsum, mirabilite, refractory clay, limestone, etc. (see *Figure 1*). The most abundant resource is coal, which spreads over an area of about 58,000 square kilometers, the estimated reserves are 860 billion tons with proven reserves of 200 billion tons; the coal is also of superior quality (i.e., good heating value) and there are diverse varieties (coking coal, anthracite, high-grade coal for power generation, etc.). The cost of mining is relatively low (the seams are stable, concentrated, and close to the surface and therefore extraction is easy). The export target (within China) for Shanxi is set at 270 Mt of coal in addition to 30 TWh of electrical energy by the end of the century.

  Coal mining is the key industry in Shanxi. During the mid-eighties the number of town-owned, village-owned, and individual-owned coal mines, became more and more significant. On the one hand, because these mines are relatively small, they require less investment and are in operation after a short time period. On the other hand, they cause significant damage to the environment, contribute to the depletion of resources, use poor technologies, are unstable in their supply, the cheap coal produced disturbs the coal market, and the transportation sector is overloaded. Alternatively, there is large-scale, state-owned exploitation of coal resources. These mines operate at very high cost, with low profits,

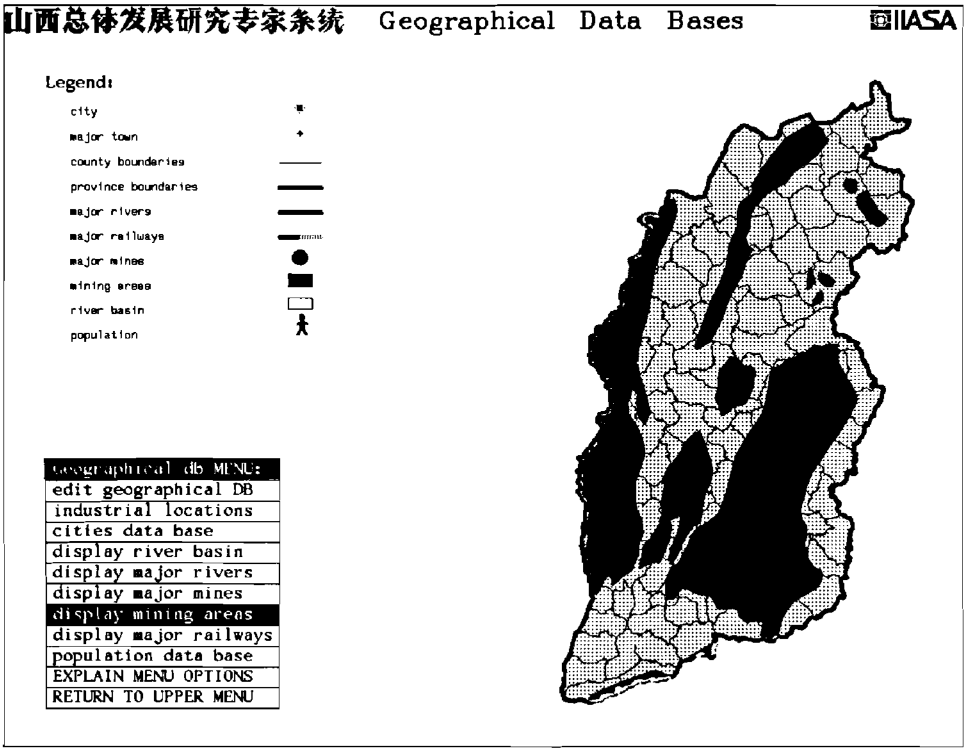


**Figure 1.** Shanxi's major mining areas.

are governed by the state or local governments, and need to increase their efficiency and adopt new technologies and efficient policies.

- Shanxi suffers from *water shortages* affecting industrial and domestic demand: The water loss (because of the large proportion of limestone and the porous soil) from drainage is critical and the dryness of the region results in annual evaporation of up to 416 mm, versus an average annual precipitation of 534 mm.
- The *agricultural activities* are as follows: labor-intensive crops represent 59% of the total agricultural output value (80% grain, 14% industrial crops, 6% others); 5.5% is generated by forestry, 9.5% from livestock, and 26% from by-products and rural industries. Annual production of grain is 8 million tons or 308 kilograms per capita.
- Shanxi has a large proportion of heavy, primary, and labor-intensive *industries*. The mining industry accounts for 26% of total industrial

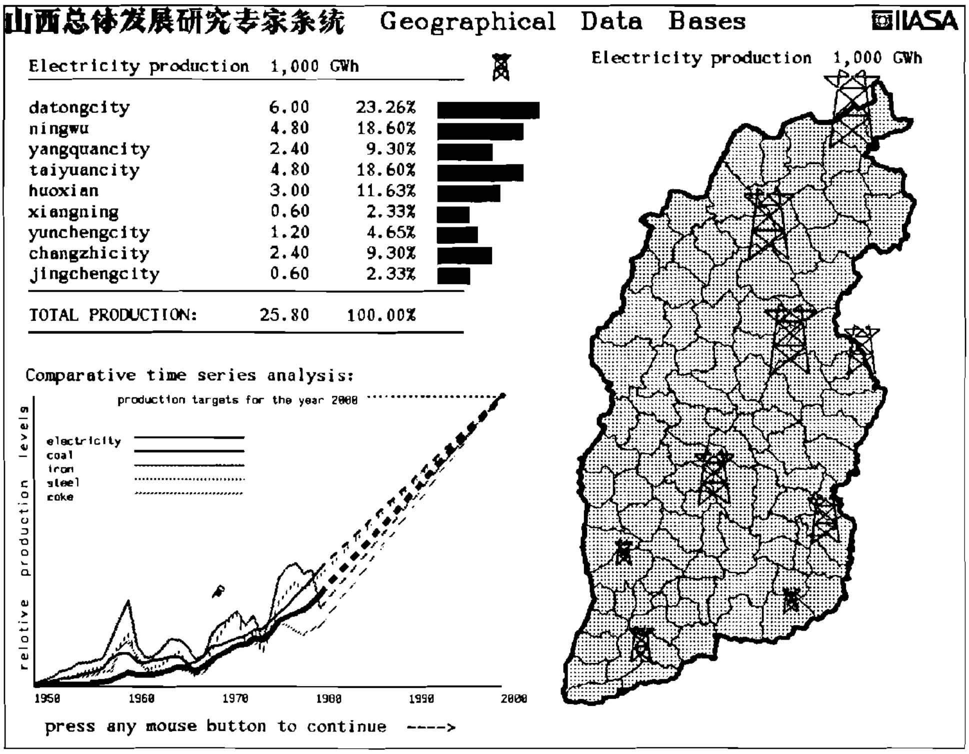


**Figure 2.** Spatial distribution of electricity production.

output value, the raw material industry 21%, and the manufacturing industry only 22%. The main industries are:

*The energy industry*, core sector of the economy in Shanxi (accounting for 32% of total industrial output value, and an output of 210 million tons of raw coal in 1985 which is one fifth of annual production for the whole country). Coal from Shanxi is exported to 26 provinces and has a significant influence on the development of their economies. The coal-fired power generation and distribution is concentrated around coal fields, large power stations generate more than 2.4 gigawatts at the Datong Second Power Plant connected via the Datong-Beijing 500,000 volt high-tension power line; Shantou and Zhangze Power stations contribute another 3 gigawatt to the system. The growth of the electric power industry is rather slow accounting for only 5% of the power industry for the whole nation, see *Figure 2*.

*The metallurgical industry*, with an annual output of iron of about 2 million tons, of steel about 1.6 million tons, and of steel products 1 million tons. The ratio of output of the iron and steel industry to the non-ferrous industry is almost 100:1.

*The chemical industry* (coking, coal gasification, liquefication, coal-based fuels and feedstocks, intermediates etc.), with a total of about 150,000 workers in 1000 enterprises of different sizes (main products: inorganic salts (sodium sulfide and sulfate), sulfuric acid, fertilizer, rubber, soda, pesticides, etc.).

*The manufacturing industry* (the main products are mining machinery, pumps, ventilators and compressors, electric appliances, farm machinery, etc.).

*The light industry*, using mainly farm products as raw materials.

- A *transportation* network of trunk railways and highways has already been established in Shanxi with a total length of 30,870 kilometers (2,170 km railways and 28.700 km roadways). Some problems in highway transportation are limited trackage and roads, low construction standards, and low capacity for traffic flow.

The major constraints in Shanxi province are:

- Capital: in 1984 the level of investment was about 40 billion yuan, and the projected yearly growth rate for the province by the year 2000 is 7.5%.
- Water resources: Shanxi suffers from severe water shortages, the problem is, however, also one of location and distribution.
- The transportation network is not sufficient.
- The impacts on the environment, such as air and water pollution and soil erosion.
- The shortage of skilled labor.

## 1.3 Components of the overall system

The DSS that has been developed should support the strategic planning of integrated industrial development based on the existing resources (namely coal) and infrastructure, under the given constraints (e.g., shortage of water and skilled labour, insufficient transportation, and limited capital for investment), maximizing revenues from industrial production and minimizing external (i.e., environmental) costs. The system is designed for use by the regional government of Shanxi Province (see *Figure 3*).

The background information needed for strategic planning and policy making is characterized by a broad range of disciplines, a variable degree of resolution and uncertainty, and requires therefore a strong element of human expertise and judgement in addition to scientifically-based analytical techniques. Planners and policy makers must consider technological, economic, environmental, and socio-political factors simultaneously. The purpose of the system is to provide the non-technical user with a set of scientific tools and methods, integrating common sense, intuition and experience, etc. for the assessment of such complex and large problems.

The model-based interactive information and decision support system implemented is a hybrid system: it combines data base and information management, simulation, operations research techniques such as optimization, interactive data analysis, elements of advanced decision technology, and Artificial Intelligence (AI), and includes a user-friendly, intelligent, graphics-oriented user interface to guide the user through the system and assist in the communication between man and machine.

The system can be seen in different layers: a macroeconomic level, representing the entire province; a sectoral level, i.e., optimization and simulation models (e.g., PDAS, describing a broad set of industries); inter-sectoral models, such as the water resources model MITSIM (see list below for explanation); and finally the data bases. Of course, there is considerable overlap in this classification.

In its current form the system comprises the following major modules, in addition to the MAED-BI model (Model for Analysis of Energy Demand in Basic Industries) described in this paper.

- **KIM**, the *Knowledge-based Integration Manager*, at present, a pilot implementation, KIM/Invest, has been developed for the problem-oriented study of investment distribution.
- **MACSIM**, the *Macroeconomic Symbolic Simulator*, provides the user with the possibility to conduct a dynamic simulation of the macroeconomic behavior of Shanxi Province, which, from this perspective, is viewed as the interaction of 22 macroeconomic sectors (represented as the impact each sector has on the other sectors with regard to seven indicators) showing the outcome of the user's investment decision for each sector and for each timestep.
- **MACEDIT** is a special-purpose editor (for the cross-impact matrices) or the first step towards an interactive knowledge acquisition tool complementing MACSIM.

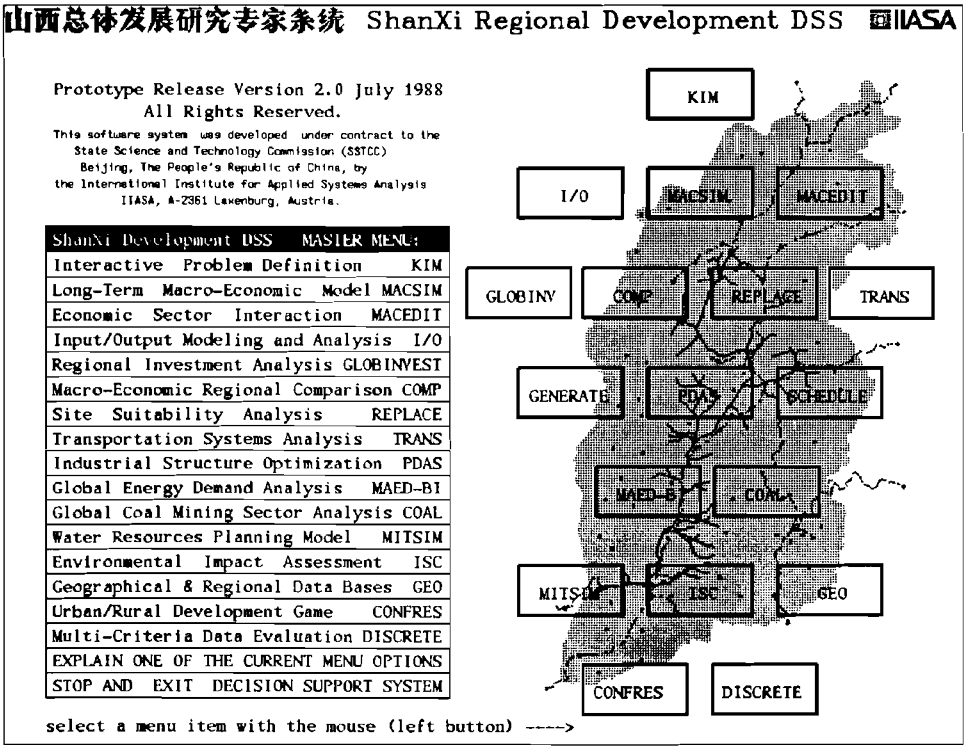


**Figure 3.** Start-up screen of the Shanxi DSS.

- The **I/O Model System** combines a number of classical econometric models with various degrees of aggregation (from 3 up to 56 sectors). The system, developed in the PRC, includes interactive implementations of static, semi-dynamic, and dynamic models, including multi-criteria optimization and scenario comparison modules.
- **GLOBINV**, an investment analysis for the integrated economic development of Shanxi, also developed in the PRC.
- **COMP**, an *Inter-regional Comparison at a Macroeconomic Level*: To compare different regions, or different development stages within a region at a very high level of aggregation, an interface to a data base of basic and macroeconomic indicators for regional comparison is part of the system.
- **TRANS**, a transportation system analysis model, developed in the PRC, allowing optimization of the current transportation system, an analysis

of current deficiencies, and an analysis of the investment requirements for capacity extensions.

- **REPLACE**, a Prolog-based model of spatial choice and siting (Reitsma, 1990) permits the exploration of feasible locations, requirements or constraints in locations for the siting of industrial or socioeconomic activities in a certain region.
- **PDAS**, *ProductionDistribution Area, Spatial*, a linear and spatially disaggregated optimization model that describes a broad set of industries, including mining, the energy production sector, the chemical industry and metallurgical industries, and the building materials sector. The model uses an external hierarchical aggregation system that allows for selective high resolution while maintaining the model's broad coverage. It is designed to analyze and optimize industrial structures, i.e., the distribution of production capacities (and thus investments and resources) to obtain a certain set of products under specific boundary conditions (e.g., constraints on certain capacities or input materials) and minimize or maximize criteria such as production costs or total revenues.
- **COAL**, a global analysis model of the coal economy in Shanxi province, based on dynamic simulation concepts, also developed in the PRC.
- **MITSIM** is a hydro-economic simulation model that provides a dynamic analysis of water demand-supply budgets for river basins. Simulating the water demand and allocation in a system of river reaches, reservoirs, diversions and groundwater wells and municipal, industrial, and agricultural users, it can evaluate a development plan, as e.g., defined by PDAS, in terms of water availability and possible reallocation.
- **ISC**, the air pollution model based on EPA's Industrial Source Complex model (EPA, 1979) is designed to calculate the short- and long-term ground-level concentration or total deposition of an inert pollutant on a local scale. It is based on an extended Gaussian plume equation of Pasquill (1961), describing the concentration/deposition of substances in time and space.
- **GEO: The Geographical & Regional DB**: The geographical and regional data base module provides interactive access to the contents of the system's geographical and regional data bases. Topics such as mines, mineral resources, industrial locations, road networks etc., are represented graphically and in a list-oriented fashion via the interface and different data base management tools have been incorporated to provide the user with the required information.

- **CONFRES**, a model describing conflict resolution between urban and rural development in terms of investment distribution, based on the theory of cooperative games; developed in the PRC.
- **DISCRETE**, a specific stand alone implementation of a discrete multicriteria decision support system of the DIDASS family of programs. The models using explicit optimization in this system (one of the input/output model implementations and PDAS) are all based on the DIDASS (Dynamic Interactive Decision Analysis and Support System) approach. Developed at IIASA largely in the SDS (Systems and Decision Sciences) program, it is based on methodology derived from the paradigm of satisficing decision making and the methodology of linear and nonlinear programming Wierzbicki (1979 and 1980), Grauer (1983) and Grauer *et al.* (1984).

## 1.4 The MAED-BI model in the Shanxi DSS

As coal mining and the energy industry in general are the two major supports of Shanxi's economy, energy demand and production are of no small importance in any developing policy under consideration. MAED-BI is a dynamic simulation model, which, for a country, region or economy described (the user sets up the scenario), essentially projects energy demand, given the user's target growth rates and product output. Currently, MAED-BI takes 24 economic sectors into consideration; 22 sectors correspond to the 22 sector aggregation of the I/O model system, plus two additional sectors (households and administration). The results of MAED-BI can also be represented at a disaggregated, sectoral level. This same form of economic aggregation makes possible a comparison with scenarios, targets, and results of the I/O model system. MAED-BI integrates a large number of products and provides a link with the macroeconomic level of each country or region studied.

MAED-BI was conceived to also provide the user with indicators concerning water demand (input and output water) and labor demand (unskilled, clerical, technical), as well as investment. These additional descriptors concern some of the major bottlenecks in Shanxi (namely shortage of water, skilled labor, and capital). These indicators could be further taken into consideration by using them for some other modules, e.g., the water demand could be treated by MITSIM, or "raising" of skilled labor could be influenced in MACSIM by encouraging the sector for Education (demand of capital within GLOBINV, etc.).

MAED-BI itself does not treat any economic evaluation. To answer questions related to coal production such as possible future development and management policy options, influences of prices, taxation, transportation capacity, market, environment, etc., the economic activities of the coal industry have been put into the dynamic simulation model COAL. In this model, coal demand, investment, and transportation capacity are external variables; the results of MAED-BI can be used for setting parts of the scenario for the model run.

Other weak points in Shanxi are technology and management: the elimination of old technologies and structures and the building of new ones can only be done gradually and slowly. Old and new structures will have to coexist for some time in the future. MAED-BI allows the selection of three scale levels, and within them, capacity exponents, as well as the definition of different technologies for the same product and is therefore also able to handle this problem of discontinuities and introduction of new capacities and technologies within the simulation period.

# 2. General Description of MAED-BI

MAED-BI is an accounting, one-year step dynamic simulation model which performs essentially energy-demand projections for a country, or a region, according to exogenous assumptions about its economic and social development.

It was initially designed to run on an IBM-PC, for the International Atomic Energy Agency (IAEA) in order to improve the effectiveness of the existing MAED model (IAEA, 1986), used by IAEA for its energy demand simulations, the two following areas:

- The treatment of basic industries.
- The link with the macroeconomic level of each country or region studied.

The MAED-BI representation, which can fit any industrial structure, even very complicated ones, was conceived so as to accommodate the specific development aspirations of any developing country in the basic industrial sectors. Since finance and education, together with energy supply, are among the most important bottlenecks in the development process of developing countries, investment and manpower are, therefore, next to energy demand, the two main fields of analysis which have been integrated in MAED-BI. For this purpose, MAED-BI, which deals first with energy demand, adopts the MEDEE methodology (Château and Lapillone, 1982) of energy demand analysis with a process–product representation of economic activity and an input-output representation of industrial processes (see Section 3).

For the Shanxi Decision Support System (DSS) (Fedra *et al.*, 1987), the MAED-BI approach has been extended to run on a SUN workstation in order to treat the global economy of the province, particularly the nonindustrial and energy sectors.

MAED-BI is used in an interactive and iterative procedure. First, the user roughly defines a preliminary development scenario, then it is completed and transformed interactively in preliminary runs. The user will then have to assess the results of the refined scenario within the framework of the overall macroeconomic constraints. The absence of any optimization procedure in MAED-BI compels the user to formulate a precise statement of what is required for future economic and social development. The model input organizes this development scenario into a set of hierarchical, exogenous information specifying:

- Sectors to be considered and respective sets of final products.
- Evolution, over the period, of the production level for final and energy products.
- Choice of technologies to be used, process choice (which determines the production lines ending at these final products as well as the intermediate products and raw materials that have to be considered).
- Evolution, over the period, of the market shares of respective technologies, for any production giving rise to a technology alternative.
- Evolution, over the period, of the trade level for tradable products (i.e., products that could be exported or imported).
- Evolution, over the period, of respective penetration coefficients for competing energy types (oil, gas, etc.) in the competitive part of the sectoral energy demand.

For each such scenario, the model output describes:

- Sectoral useful energy demand for utilities disaggregated between steam, direct heat and furnace (competitive uses), and mechanical and specific uses of electricity (satisfied by electricity).
- Sectoral final (for non-energy sectors) or primary and secondary (for energy sectors) energy demand, disaggregated among the various energy forms (after allocation of the energy demand for competitive uses between the available energy forms with the penetration coefficients and accounting for the feedstock uses).

- Energy demand and trade for all energy forms, especially primary energy (coal, biomass, crude oil, natural gas, and primary electricity).
- Sectoral input and output water.
- Sectoral gross fixed capital formation disaggregated between domestic and foreign sources.
- Sectoral manpower requirements according to three categories (unskilled, technical, and clerical).

In itself, MAED-BI does not incorporate any explicit economic evaluation. This must be done in two different phases. First, by defining for each sector a strategy which integrates expert knowledge of the available growth potential. This requires a global survey from raw materials resources to final demand prospects and can hardly be modeled. The strategy has to constitute the core of the scenario which gathers the exogenous inputs required for running MAED-BI. Second, the trends revealed in the model output have to be evaluated against results of related studies or expert judgements in order to assess the feasibility of the simulated scenario *vis-á-vis* external macroeconomic and environmental constraints. The final results of these comparisons may lead to a reformulation of the scenario in order to release the current constraints. New runs can then be made until a satisfactory scenario is designed.

MAED-BI does not aim at deterministically forecasting future economic development nor does it aim at finding a hypothetical optimum for it. Rather, it is conceived as a tool for interactive scenario analysis. MAED-BI must be seen as an accounting tool which aims at discerning strategies which are acceptable with regard to a certain number of constraints (energy, capital, manpower, environment). Since these constraints apply, globally and with low elasticity, to cumulative development, they are basic boundary conditions for long-term development.

## 2.1 The main energy concepts used in the description of MAED-BI

In the MAED-BI model the concepts used are as follows:[2]

"**Primary energy** represents both energy sources which have been taken from nature and which may eventually be used as such (petroleum and natural gas for example) and those which have no economic value before being processed (hydropower, geothermal energy, fissile materials)".

[2]The material quoted is taken from Château and Lapillone (1982).

"**Secondary energy** represents any form of primary energy of the first type which has been processed once or several times: this could also be called *derived energy*".

"**Final energy** represents any form of primary or secondary energy which is available to the final consumer ..." in the sense of energy accounting, i.e., a consumer whose main economic activity is not the processing of energy; this includes extraction activities, e.g., coal mining and crude oil production, but excludes processing of primary energies from the second type (i.e., hydropower, geothermal and nuclear energy); "if the latter produces goods or services, then the final energy is considered as an intermediate good" (in the sense of the Leontief matrix); "if the consumer is a household, then it is considered a final consumer good" (*idem*).

"Theoretically, and in the physical sense, **useful energy** represents energy in the form which is actually required by the consumer: heat for heating, light for lighting, mechanical power for movement, etc." It is of interest to adopt the concept of useful energy because final energy demand will depend on the choice (more or less free) that the consumer will make for fulfilling his (useful energy) need and afterwards on the possible disparities between end use efficiencies. Hence, useful energy must be measured at a level which is anterior to the choice of final energy and in a way which is independent of this choice. On the other hand, it is difficult to measure useful energy outside of a precise technological and economic context; or, useful energy would be then something like the theoretical minimum of energy required for a given production (in keeping with the laws of physics), a value which, in most cases, would have absolutely no link with the energy consumption of real processes available. Hence, there are two possibilities. Either take the concept of "relative useful energy" which is "the consumption of the most efficient energy in the most efficient technology". But this supposes that competing technologies are perfectly substitutable, that is, they satisfy exactly the same energy need, which is not always realistic. Therefore a concept of *standard useful energy* attached to each particular technology has been adopted here. For each technology, the energy uses are shared between *substitutable (competitive)* and *non-substitutable (or captive) uses.* The first ones are principally thermal uses, i.e., for generating steam on the one hand and direct and furnace heat on the other hand, and can be satisfied by several final energy forms. The second ones, on the contrary, require a specific final energy form. The standard requirements for heat and steam are specified according to three levels of temperature (T < 120°C, 120°C < T < 250°C, 250°C < T for steam uses and T < 350°C, 350°C < T < 800°C, 800° C <

T for heat uses). For captive uses, including specific uses of electricity, the standard requirements of the respective final energy form are directly specified. In any case, the consumption values should correspond to "normal exploitation" of the processes.

# 3. Methodology

Sectors, processes (or technologies), and products are the three basic elements used in MAED-BI to model economic activity. MAED-BI uses a process–product representation of economic activity and an input-output process representation.

## 3.1 Process representation

Each process is modeled as a linear input-output system (see *Figure 4*), belongs to one economic sector, and produces one unique main product, which is the process output, and possibly some coproducts. Each product belongs to the same sector as the process(es) which produces it as a main product(s). Process inputs may be classified into two categories, namely:

- Products.
- Other inputs which consist of utilities (i.e., direct and furnace heat, steam, electricity for mechanical and specific uses), input and output water, and manpower requirements.

Products are classified into four main classes:

- Final products, for which the output aims are specified, that constrain the growth within the different non-energy sectors.
- Energy products, which play a role similar to that of final products for the energy sectors but which are subject to a lot more specific treatment since the model calculates their demand as a function of the production of the whole set of products.
- Intermediate products, used upstream[3] of final or energy products in production routes.

[3]The words upstream and downstream used in this paper refer to the direction of production streams; the solving algorithm goes top down in the opposite direction to that of production streams.

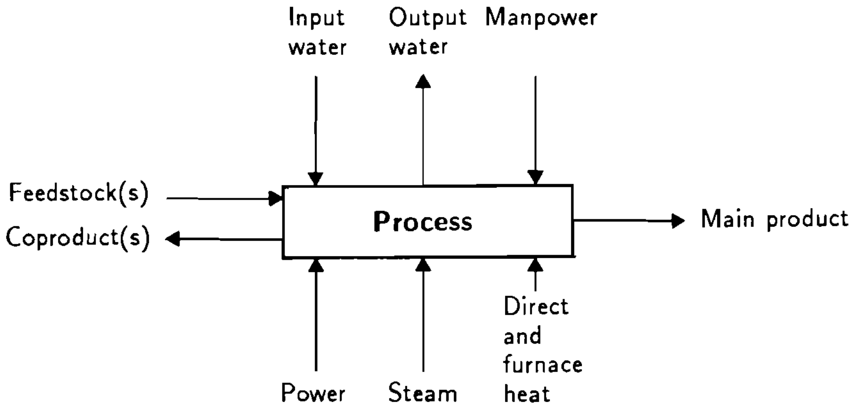


**Figure 4.** Input-Output representation of processes.

- Raw materials, which are like intermediates, but whose production is not included in the model – they are, thus, not attached to any particular sector.

An input of any energy product should correspond to a feedstock (captive) use of this specific energy product, like coke input to a blast furnace. Among utilities, a direct or furnace heat, or a steam input corresponds to an energy use which can be satisfied by different energy forms, that is, giving rise to energy substitutions. In order to facilitate the analysis of these substitutions, heat and steam inputs are specified according to the three levels of temperature mentioned in Section 2.1. The power input for mechanical or specific uses represents, in fact, an electricity feedstock. Input water is the external water requirement in addition to the water recirculated in order to fulfill the water demand of the process. The difference between water input and output, (released to the environment as wastewater), gives the effective water consumption. Manpower requirements are disaggregated into three categories: unskilled, technical, and clerical labor.

Input flows are specified in their respective units per unit of the main product. A negative input is used in order to represent coproduction. This makes the implicit assumption that exists, an inflexible relation between the respective production levels of the main product and its coproduct(s).

Among the possible material inputs, some products (e.g., catalysts), which are used in very small amounts in the whole economy, are not worth integrating in the representation since their possible production would not have any significant impact in the fields of analysis retained in MAED-BI. In particular, MAED-BI does not integrate any evaluation of production costs. On the other hand, information such as investment cost, delays in construction, and the lifetime for each process has to be stipulated, in order to study investment.

The processes used in the representation should, in principle, correspond to well-defined technologies for which specific characteristics such as input–output flows and data related to investment can be provided from engineering knowledge. Nevertheless, for some industrial sectors and most non-industrial sectors, notions like products and technologies cannot be well defined. A solution may generally be found if we consider, for instance, the sectoral value added as a final product, and create, on a statistical basis, a pseudo-technology, consuming specific amounts of energy inputs per unit of value added that it produces.

## 3.2 Process–product representation

Each product considered in the model is placed in relation to a set of processes which can produce it (and have been explicitly selected for the current scenario). This relation defines process–product pairs. Since a process ordinarily uses some product inputs, the systematic definition of these inputs and of the associated processes producing them determines, *in fine*, production routes merging into trees (see *Figure 5*) going from final products down to raw materials through any combination of processes and intermediate products as freely chosen by the user, within the limits of technological possibilities.

The solving algorithm proceeds sector by sector, top down along each sectoral tree, calculating the input requirements raised by the final production aims. Since energy production is treated within the energy sectors, production trees of non-energy sectors are thus not continued upstream of an energy input; in this way, only the demand of energy products, and not their production, is considered at the level of non-energy sectors. As a consequence, energy products as well as raw materials may constitute roots for production trees. In fact, processes without any material input or intermediates whose global requirements are imported may also be found at the bottom of the trees and raw materials may be absent.

Sectoral production trees, which have necessarily distinct tops defined by the respective sets of final products, may somehow overlap in their lower parts. This happens when an intermediate has to be considered in more

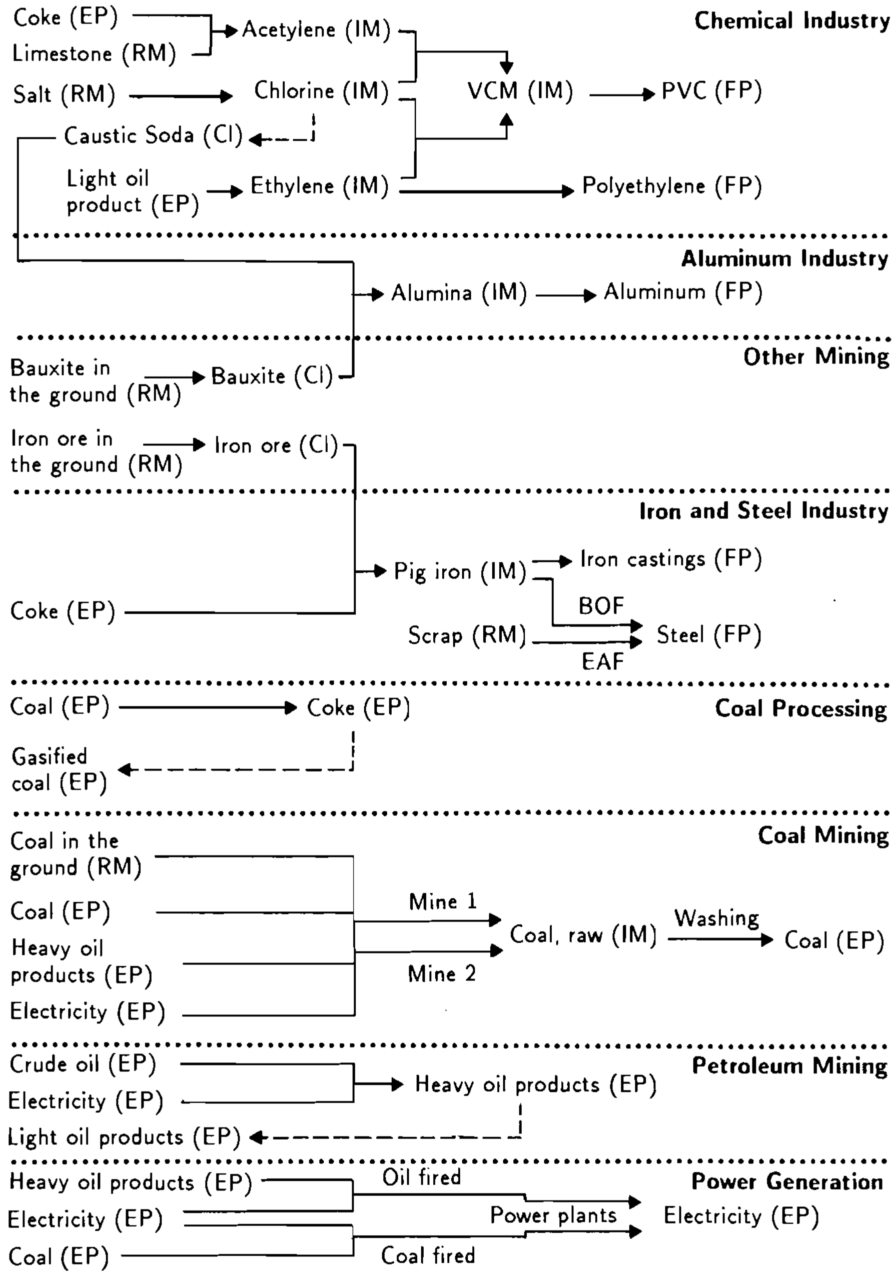


**Figure 5.** Process–product representation for some industrial sectors. (RM – raw materials, FP – final, IM – intermediate, CI – common intermediate, and EP – energy products. Each arrow represents one process except hachured ones which represent coproduction.)

than one sector; such intermediates, which create overlaps (for instance, bauxite produced by mining and used in the aluminum industry, or caustic soda produced by the chemical industry and used in the Bayer process of the aluminum industry), are recognized during the model run and put in a special class as common intermediates. The overlapping parts of sectoral trees (i.e., common intermediate production) are not treated in the first instance by the algorithm and are treated last by the model when the overall requirements addressed by different downstream production have been calculated, i.e., after treatment of the non-overlapping parts of all sectoral trees.

Obviously, more than one process (a technology mix) may be available for turning out one product; for instance, electric (EAF) and oxygen (BOF) furnaces may be used for producing steel. In any case, where a technology mix is available, a set of input data (market shares) specifies the dynamic evolution of the shares of the relative technologies for producing the product. A technology mix may especially be defined when production takes place at different scale levels, in order to render technological discontinuities or economies of scale; China is a good example of a production system where small-sized and large modern plants coexist within the same sector. In this respect, each process is allocated to one scale level among the three available (large, medium, small); this allows the user, if he takes advantage of the existing option, to introduce a more precise treatment of selected large-scale production in the model calculations, particularly concerning the dynamics of production capacities and the related capital costs (see Section 4.3). In addition, the penetration coefficients of energy media, which are specified at each scale level, allow the user to simulate contrasted patterns of energy demand; for instance, small-sized plants are generally more dependent on local resources than large-sized ones, which have more possibilities to use electricity or imported oil.

## 3.3 Energy demand analysis

MAED-BI is based on the basic postulate of the MEDEE methodology, which defines "the final energy demand of a society ... [as] ... directly related to its social, economic and technological pattern of development" (Château and Lapillonne, 1982, p. 191). MAED-BI takes advantage of the facilities offered by its representation in order to follow, in another approach, the guidelines defined in MEDEE and quoted below.

First of all, "in order to explore the impact of structural changes in the socioeconomic development on long-term energy demand, it is necessary to

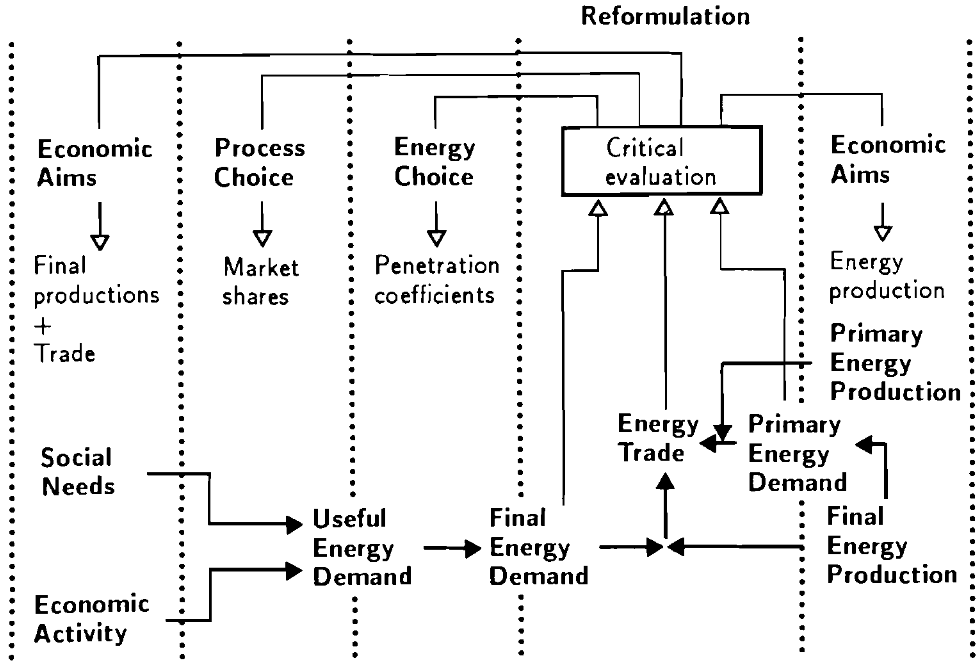


**Figure 6.** General scheme for energy demand analysis in MAED-BI.

disaggregate the social, economic and technological system so as to be able to take these changes explicitly into account" (Château and Lapillonne, 1982, p. 190–191). The flexibility offered by MAED-BI in its representation of the "social, economic and technological system" must be used for this purpose. The various aspects of the development of a society, which determine the long-term energy demand are, as in MEDEE, described in a scenario in the SUN version of MAED-BI, with the support of a data base developed within the SunSIMPLIFY/SunUNIFY data base management system.

The logic of energy demand analysis is very close to the one defined in MEDEE. Some of this logic is recalled below and what MAED-BI does with it is discussed (see *Figure 6*).

"Energy demand is induced by socioeconomic determinants that is, by economic activities and by the satisfaction of social needs" (Château and Lapillonne, 1982). These socioeconomic determinants are represented in MAED-BI under the extended concept of final production which may include production of steel (measured in tons) as well as a sectoral value added (monetary units), a socioeconomic need for mobility of persons (passenger/kilometers) or goods (ton/kilometers), or for space heating (number of households). They may themselves be further disaggregated in order to consider different types of steel products, subsectors (with various energy intensities), kinds of goods, or types of households (e.g., rural, urban).

"These determinants lead to a demand for useful energy whose intensity depends on the technologies used to satisfy the social needs or to perform the economic activities" (Château and Lapillonne, 1982). Upstream of final production, any combination of processes and any technology alternative can be represented in MAED-BI, e.g., various possibilities available for steel production: from iron ore, trough pig iron production in a blast furnace, and an oxygen converter (BOF), or directly from scrap in an electric furnace (EAF), and eventually through different kinds of rolling, to steel products; energy saving measures in one sector, subsector or even related to one precise industrial process: (for this purpose, a mix between a technology with negative energy (utility or feedstock) flows representing the saving potential and a dummy technology to maintain the status quo is introduced, on line, downstream to the production activity considered); different modes of transportation (car, bus, diesel, electric, or steam train, truck, barge, aeroplane, etc.); different modes of space heating (central heating or other), insulation measures for some kinds of flats. All this may be simulated by simply manipulating the symbolism of product and technology used in MAED-BI.

The useful energy demand is induced by the output flows of the technologies included in the overall scheme according to their respective inputs of utilities (heat, steam, power) and energy feedstocks. "The demand for energy commodities, or final energy ... can be calculated from the level of useful energy demand and will depend upon the efficiency of the equipment used to convert the final energy into useful energy" (Château and Lapillonne, 1982). MAED-BI calculates for each sector, the ratio of the calculated useful energy demand for the base year to the final energy demand registered in the national (or regional) energy balance, or estimated for this year. This coefficient is applied to the sectoral final energy so that its level becomes adjusted to the reference available for the base year. This coefficient brings a global correction, both to the equipment efficiency and to the necessary non-exhaustivity of the approach. As a matter of fact, techno-economic approaches concentrate on a selection of activities, which are believed to explain the greater part of the energy demand, and cannot always deal with every activity where energy is consumed.

The breakdown of the sectoral final energy demand between energy commodities is facilitated by the disaggregation, preexisting in the process representation, between non-substitutable (feedstock) energy uses, which are directly allocated, and substitutable ones. The allocation of the substitutable energy demand is made with penetration coefficients. They are specified, when desired (if not, zero default values are provided by the model) for any individual sector at each of the three scale levels (large, medium, small).

Penetration coefficients which depend on a specific use (steam, heat) or temperature level (high, medium, low), e.g., the relative share of high temperature steam raised by co-generation, i.e., together with electricity, in the large-scale chemical sector, are first applied to the relevant components of the substitutable energy demand. These penetration coefficients concern biomass (temperature-specific), electricity (use-specific), and co-generation (use, i.e., necessary steam and temperature specific). Then, penetration coefficients for all but one fossil fuel (coal, oil, gas, etc.) are applied to the remaining thermal (heat plus steam) energy demand. The last fossil fuel (i.e., coal in the model implementation for the Shanxi case study) is used as a balancing fuel, that is, it covers the whole remaining demand for competitive energy uses. Consequently, whenever a penetration coefficient is not specified for a given sector, its whole energy demand for substitutable uses is allocated to the balancing fuel.

MAED-BI calculates the primary and secondary energy consumption induced by the energy production aims specified in the scenario. Energy production is treated last by the model, according to a simplified procedure, since it is required that the energy inputs of any energy-producing technology be directly specified as feedstocks (i.e., no calculation of useful energy demand and no use of penetration coefficients). It is worthwhile noting that the energy production is not directly linked to the level of final energy demand. This link is constituted *ex post* by the energy trade results (trade = production – demand) for the different energy forms; thus, a critical evaluation of these results must be made, and according to these findings, some scenario assumptions may be adjusted or sensibly modified before a new run is made.

# 4. The Assessment Process

## 4.1 Determination of the production structure

The determination of the production structure is done sector by sector, top down along every sectoral production tree (see Section 3.2 process–product representation). This tree is constructed during the scenario definition. A *set of final products* (†)[4] is first defined; then, the constitution of process–products pairs (i.e., *process choice* (†) for this primary set normally determines a second set of products (used as inputs) for which a process choice may define again a set of input products, and so on, until the obtained set of input products contain no more intermediate products, (i.e., be empty or only contain raw materials or energy feedstocks). At this point, no process choice has to be formulated and the sectoral tree is completed.

From the list of final products produced by the current sector, the program selects those which are only obtained as main products (i.e., not also coproduced). For every selected final product, the production levels of the related technologies are calculated from its *global production aim* (†) according to their *relative market shares* (†). The new capacities for the different technologies, required over the period in order to sustain the respective output growths, are then generated (see below) and the global production is reallocated (proportionally) according to the resulting installed capacities. Some market shares may be slightly modified, depending on the respective implementation schedules of new capacities. The input requirements are then computed from the respective output levels and input structures of the competing technologies. Intermediate products (with the exception of common intermediates) and coproducts which are no longer required or coproduced upstream in any production line of the sectoral tree are selected from the whole set of inputs.

For these, the overall requirement and coproduction are raised by the production of the sectoral final products. Therefore, at this point it is known which amounts have still to be produced in order to satisfy the overall requirements, allowing for possible coproduction. These products are treated next by the program. The treatment is the same as for final products, including the generation of new capacities. The only difference is that the production level is no longer a purely exogenous input. As a matter of fact, two types of products may be encountered at this level:

[4] † refers to exogenous inputs, i.e., they are part of the scenario definition.

- Final products which have been previously coproduced.
- Intermediate products (whether or not previously coproduced).

In the first case, the coproduction is deducted from the production aim. In the second case, the level of production is calculated by summing the possible *trade aim* (†) (for a tradable product) to the calculated requirement and deducting the possible coproduction. This approach implies that when a product is obtained as a coproduct, priority is given to the technology producing it as a coproduct; technologies generating it as a main product just fill up the remaining gap. After the calculations are made, it results in a new set of input products from which a subset is selected according to the same principle as before and treated in the same way. This algorithm is continued until we reach either the bottom of the tree or some overlapping part(s), delimited by common intermediates, i.e., until the new resulting set of products contain no more intermediates. When all sectors have been treated, the set of common intermediates is introduced into the algorithm (as with the sets of final products before) and the production structure for these products is determined as that of a supplementary sector.

When this last step is completed, the production structure is determined and, with it, the cumulative requirements of the respective inputs that are needed as well as the implementation planning of new capacities for all the technologies considered. Among the inputs: the requirements of utilities (i.e., heat, steam, power), energy feedstocks, input and output water, and manpower are cumulated according to the sectoral breakdown so that sectoral results become available.

Let us take the chemical industry as an example and assume that it produces only two final products: polyethylene and polyvinyl chloride (PVC) (see *Figure 5*). The requirements of monomers [i.e., ethylene and vinyl chloride (VCM)] for producing these products are calculated in the first instance (first loop). At this point, the overall requirement for VCM is known, (since PVC is its only outlet), but it is not yet the case for ethylene since ethylene is used with chlorine in order to produce VCM. Thus, after having allowed VCM to be traded, the ethylene and chlorine requirements raised by the VCM production are calculated (second loop); (in this example, we do not consider the possible alternative production of VCM out of acetylene). Then, with the overall demand for ethylene being known, the corresponding light oil requirement, (assuming that ethylene comes from naphtha cracking), is calculated (third loop). Here, since the remaining products are either energy products (light oil) or common intermediates (chlorine as used, let us say, in the paper industry), the treatment of the chemical industry is stopped. When all the sectors have been treated, the global requirement for chlorine is known and, having taken trade into account, the input requirements for producing chlorine are calculated. Since chlorine is a chemical product, the demand for energy (as well as water and manpower) inputs raised by its production will contribute, with those of other chemicals, to the energy (as well as water and manpower) demand of the chemical industry.

## 4.2 Determination of final and primary energy demands

The final energy demand is determined, sector by sector, from the demand for utilities and energy feedstocks (= useful energy demand) calculated according to the procedure described in Section 3.3. An efficiency coefficient is first applied to the useful energy demand so that the resulting level of energy demand is adjusted at the base year to a *reference level* (†), (which should be the final energy demand given in the national (or regional) energy balance). If no reference level is provided, the efficiency coefficient is set equal to one, that is, the level of useful energy demand calculated by the model is taken as the reference level for the sectoral final energy demand. Then, the substitutable part of the final energy demand is allocated among the different energy commodities according to *penetration coefficients* (†) (see Section 3.3). A demand for energy feedstocks results from the treatment of energy production, which, according to its nature, is classified either as a primary energy demand (i.e., coal, natural gas, crude oil, biomass) or as a secondary energy demand (i.e., products of oil and coal processing and electricity).

The total demand for the respective primary energy forms is obtained by adding the demand issued from energy sectors to the final demand calculated previously. An implicit assumption in this type of calculation is that a primary energy form such as coal is used as such by final consumers, in other words, it is assumed that all light operations of pre-processing which may make a raw energy commodity directly usable by final consumers are included on the production side. For instance, an activity like coal washing should be located before (i.e., upstream) obtaining the so-called proper (primary energy "coal") (see *Figure 5*). Nevertheless, it would be possible to consider an activity like coal washing as belonging to the coal-processing sector; in this case, the primary energy coal would be a product of the coal-processing sector. Primary energy production of electricity is electricity produced by hydropower, nuclear or geothermic energy. Energy trade is calculated as the difference between the production level of each energy commodity (†) and its final and primary or secondary demand. In the case of electricity, the part of production that is lost on the distribution network (†) is deducted before calculating electricity trade, which relates to electricity as a whole (i.e., primary and secondary electricity). Biomass is considered as non-tradable and thus its production is set equal to the level of demand.

## 4.3 Model dynamics and calculation of gross fixed capital formation

The model is essentially driven by exogenous variables such as:

- Final and energy production.
- Trade.
- Market shares.
- Penetration coefficients, the evolution of which is specified in the scenario and determines the dynamics of the production structure or that of energy demand.

For every product (final or energy production, trade), technology (market share) or sector, and use (penetration coefficient) with which they are concerned, these variables take values linearly interpolated over the period from levels given for a few benchmark years (that is, at least for the base and target years). Nevertheless, the dynamics of the production structure depends in the last resort on the implementation planning of new capacities. As a matter of fact, the production level of a given product is broken down among the competing processes in proportion to their installed capacities. The determination of the new capacities to be implemented is done for each process from the knowledge of the capacities existing at base year (*initial capacities*) (†) according to the market share at the global production level calculated or fixed for its output.

This is ordinarily done automatically by the program. In this case the initial capacity is described by the data of its aggregated amount and of its age structure at the base year [e.g., aggregated initial capacity = 350,000 tons/year; age structure = group 1: 40%, group 2: 30%, group 3: 30%, where group $i$ contains capacities which were between ($i$-1)*$A$ and $i$*$A$ years old at the base year ($A$ is the amplitude of one age group or age group step, e.g., 5, for a 5-year step)]. The initial capacity decreases along the period according to a given life time. A reference is chosen for the output level of a productive unit using the process (e.g., 50,000 tons/year). In one year, when the gap between the production achievable with the installed capacity and the aimed production level becomes greater than a certain percentage (percentage considered as *normal operating rate* (†), e.g., 90%), a new unit for this capacity is planned for construction a few years prior (in accordance with the standard construction delay) so that the production gap will be filled. For processes implemented at the large-scale level, the user has the possibility to choose an option, a disaggregated treatment, allowing him to design interactively (thus, in a less rough manner) the implementation planning of new capacities. In this case, the description of initial capacities is made from the description of each individual plant on stream at the base year, with an indication of its capacity, start-up year and, possibly, anticipated shut-down year. The initial capacity decreases over the period either according to the life time or to the shut-down deadlines. A display of the curves showing the respective evolution of the production aims and of the production achievable with the installed capacity, can be selected during the program run and any production gap can be filled up from the keyboard by entering new capacities. The implementation planning designed or modified by the user (*Figure 7*) according to this procedure will not be lost at the end of the program execution but integrated in the scenario for the next runs.

The calculation of the gross fixed capital formation is done by assessing, for each technology, the yearly expenditures required in order to maintain the already installed capacities and to build new ones. The common standard used in this procedure is the capital cost of the capacity defined as a reference. The existing capacities are evaluated on their value of replacement and the expenditure for maintaining this capital stock is set to a fixed percentage (e.g., 5%) of the global value [percentage called *depreciation rate of capital stock* (†)]. For new capacities, the calculation depends on what treatment has led to their determination. Ordinarily, the expenses which have been necessary, for any given year, in order to bring into operation the new plants starting up in this year, is simply the product of the number of new units of the reference capacity needed in this year by its capital cost. In the case of disaggregated treatment, the size of the new capacity put into operation one year is explicitly specified and may be quite different from the reference. So, a capacity exponent is applied in order to represent the possible economies of scale arising when capital cost is not proportional to capacity. In both cases, the total cost is equally spread over the standard study and construction delay defined for the reference capacity. A share of the capital cost whose counterpart may be found locally is also defined for each technology. This coefficient is applied to both components of the respective gross capital formation, together with different *actualization rates for*

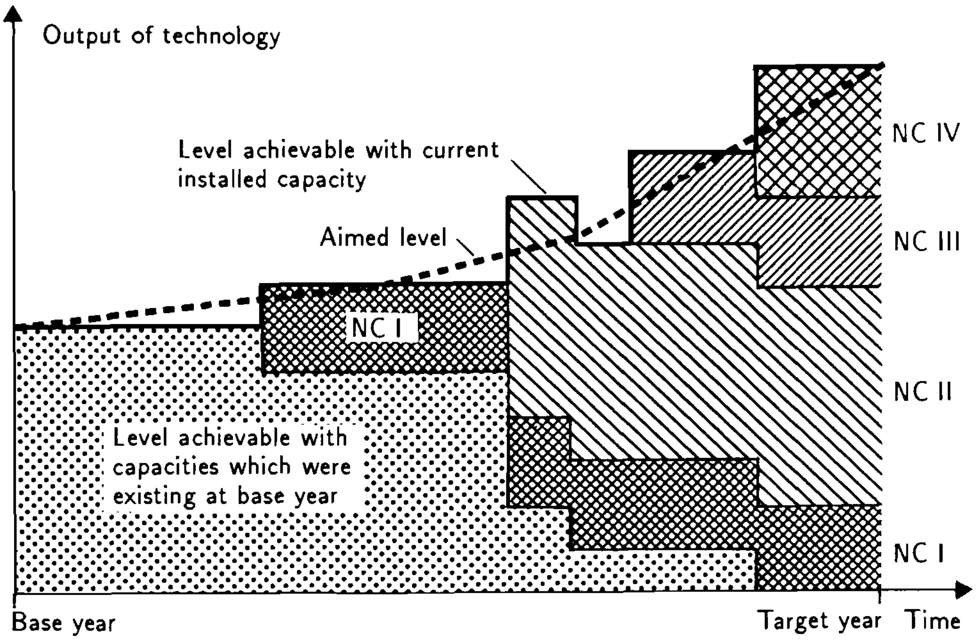


**Figure 7.** Determination of new capacities (NC).

*foreign and domestic capital* (†). The sectoral results of capital formation and their disaggregation between domestic and foreign should be of some help in assessing the feasibility of the simulated scenarios.

## 5. Implementations of MAED-BI

MAED-BI was integrated in the Shanxi DSS after the methodology and program were developed and tested on a case study of the Brazilian cement and fertilizer industries for the International Atomic Energy Agency (IAEA).

Within the framework of the Shanxi DSS, MAED-BI is one component of a system of macroeconomic and sectoral models which should be used as a tool for economic planning in the Province. A DB built within the framework of the SunUNIFY/SunSIMPLIFY DBMS (Data Base Management System), facilitates the scenario definition. The present implementation is based on a disaggregation of the economy into 24 sectors:

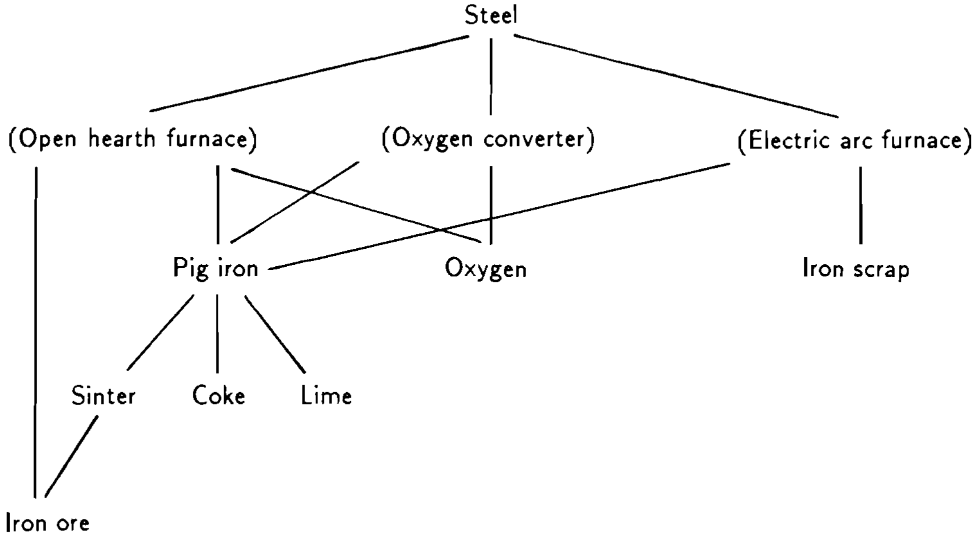


**Figure 8.** Representation of steel production.

1. Agriculture
2. Forestry and silviculture
3. Coal mining
4. Other mining
5. Power generation
6. Metallurgy (ferrous metals)
7. Metallurgy (non ferrous metals)
8. Coking and coal processing
9. Petroleum industry
10. Chemical industry
11. Manufacturing
12. Electronics
13. Building materials industry
14. Forest industry
15. Food production and processing
16. Textile industry
17. Other industries
18. Building and construction
19. Transportation (railway)
20. Transportation (highway)
21. Post and Communications
22. Trade and Commerce
23. Households
24. Administration, education and science

Three of these sectors (forestry and silviculture, the petroleum industry, and post and communications), whose share in energy demand should remain well below 1%, have not been treated. The remaining 21 sectors include about 180 products and 190 technologies. *Figure 8* shows the flow-chart corresponding to the production of steel as it is simulated by the model.

The coking and coal processing and power generation sectors transform primary energy (i.e., coal) into secondary energy forms (i.e., electricity and coke); they constitute the so-called energy sectors. For electricity, transportation and distribution losses have been simulated by applying specific percentages to electricity production. In the case of coal, these losses have not been taken into account. A way to introduce them into the calculation would be to specify explicitly – within the railway transportation sector – the amount of coal transported and to define a technology associated with this transportation, the coal consumption of which would then allow for the losses.

# 6. Results and Comments[5]

Since there is a lack of input data concerning water and investment costs, the corresponding results are not representative. In the following, we will therefore focus on energy demand and trade results.

## 6.1 Total energy consumption

*Table 1* presents two equivalent breakdowns of the total energy consumption:

(a) Breakdown according to supply:
Total energy consumption = consumption of primary energy forms (i.e., coal + hydropower) + energy imports – energy exports.

(b) Breakdown according to demand:
Total energy consumption = final demand (i.e., consumption by non-energy sectors) + net consumption by energy sectors (i.e., coal processing and power generation).

These results show the monopolistic role of coal on the supply side and the increasing weight of energy sectors on the demand side.

From the complete set of results available in Appendices A to D, various aspects should be outlined:

- The share of coal mining in final demand slightly decreases over the period from 14.1% in 1985 to 12.7% in 2000, while its share in total energy demand (i.e., including the energy sectors) drops from 11.4 % to 6.3 % over the same period.
- The share of basic industries in final demand slightly increase from 38.0% to 44.7%.

From *Figure 9*, where non-energy sectors have been aggregated into five groups, it can be seen that the structure of final energy demand does not

[5]This section was written in collaboration with Mr. Jianhua Zhou, CUEPE, University of Geneva.

**Table 1.** Total energy consumption.

(a) Breakdown by supply sources[a]

| Year | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|
| Primary consumption: | | | | |
| Coal | 41,133 | 55,988 | 79,783 | 178,380 |
| Hydropower | 91 | 133 | 176 | 308 |
| (+) Imports: | | | | |
| Oil products | 1,322 | 2,426 | 3,613 | 5,052 |
| Electricity | 776 | 0 | 0 | 0 |
| (–) Exports: | | | | |
| Coke | 2,178 | 1,184 | 1,999 | 10,543 |
| Electricity | 0 | 64 | 2,372 | 17,275 |
| (=) Total energy consumption: | 41,499 | 57,299 | 79,202 | 155,921 |

(b) Breakdown by sector of demand[a]

| Year | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|
| Final demand | 33,544 | 44,532 | 56,168 | 78,012 |
| % of total | 81 | 78 | 71 | 50 |
| (+) Energy for power generation[b] | 4,862 | 9,738 | 19,850 | 71,186 |
| % of total | 12 | 17 | 25 | 46 |
| (+) Energy for coke production | 3,093 | 3,029 | 3,183 | 6,722 |
| % of total | 7 | 5 | 4 | 4 |
| (=) Total energy consumption : | 41,499 | 57,299 | 79,201 | 155,921 |

[a]All data have been converted into thousand tce (tons of coal equivalent); power consumption and production figures have been converted from TWh (terawatt hours) using 123 as the conversion factor (Electrical Energy Consumption Equivalence Factor).
[b]Including losses on the transportation and distribution network.

dramatically change over the period. The main structural evolution affecting the total energy demand in Shanxi clearly concerns the relation between energy and non-energy sectors.

Compared with information taken from The Annual Statistics of China, the results obtained for Shanxi in 1985 show an energy consumption per capita of 1.57 times higher than the Chinese average. This over-consumption can be explained by the importance of basic industries and energy sectors in Shanxi and by the abundance of energy supplies, which does not incite energy conservation practices. The climate and the standard of living in Shanxi are within the average for China; in this respect, the simulated energy consumption for households, which is equal to the Chinese average, is quite representative.

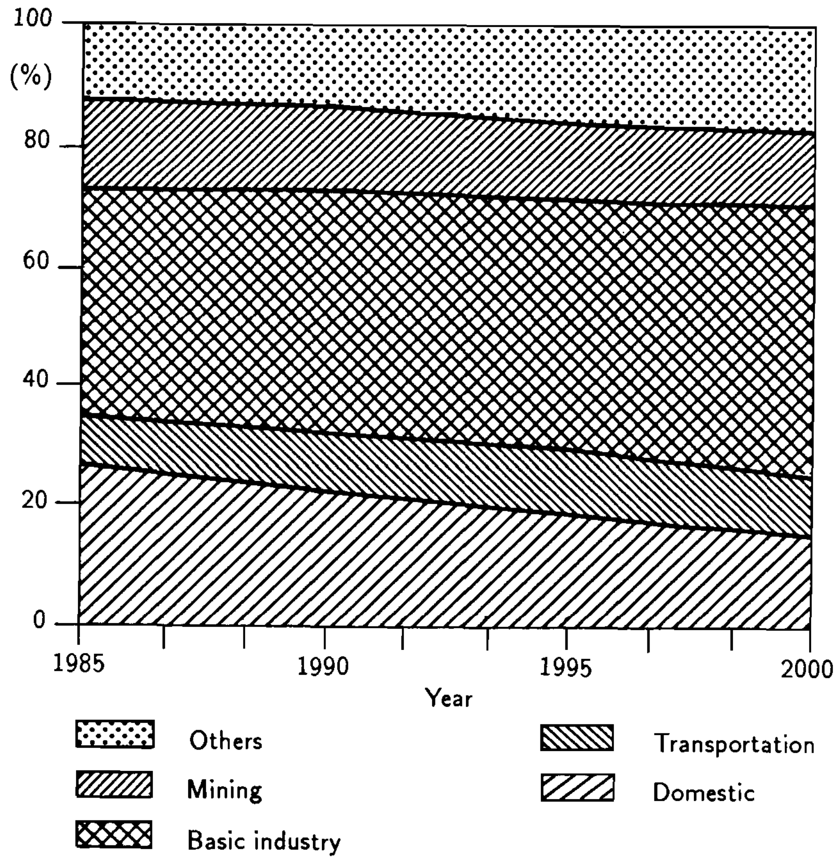


**Figure 9.** Distribution of final energy demand.

Comparing our results with energy demand projections by the World Bank (1985) and allowing for non-commercial energy consumption which is not included in the World Bank study, let us conclude that there will be a dramatic increase in Shanxi's share of total energy consumption in China, from 4% in 1985 to approximately 8% in 2000.

## 6.2 Energy imports and exports

Shanxi has been exporting coke and coal for many years, but has no oil field and must therefore rely on oil imports from other provinces (see *Figures 10* and *11*). The results obtained are qualitatively correct, but the final demand for oil and consequently the oil imports are under-estimated since the penetration of oil products (for satisfying the substitutable part of the

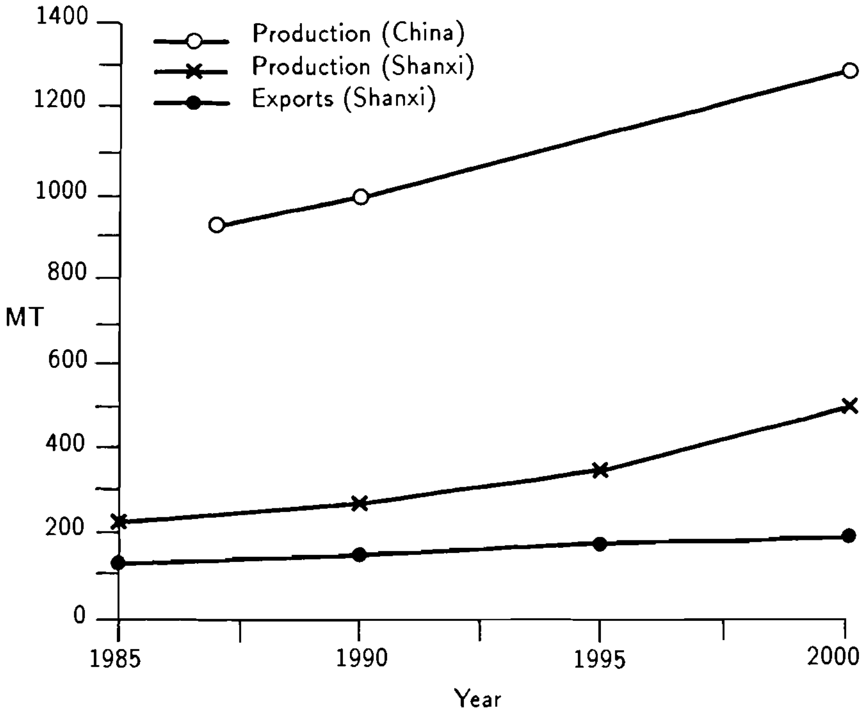


**Figure 10.** Coal production in China and Shanxi and coal exportation in Shanxi.

energy demand of the different sectors) has generally not been specified in the DB. In spite of the fact that numerous power plants have been built over the last ten years in Shanxi, the electric supply still remains a serious problem because of the low operating rate of the plants. Hence, the persistence of electricity imports in 1990 is representative of the state of the Province.

Compared with the projections of the World Bank, our results show that the Shanxi Province could export coal and electricity in an amount representing more than 10% of the coal and electricity consumption of the rest of China.

## 6.3 Concluding remarks

In the year 2000, about 40% of the coal production of the world's largest producer, China, will be concentrated in Shanxi.

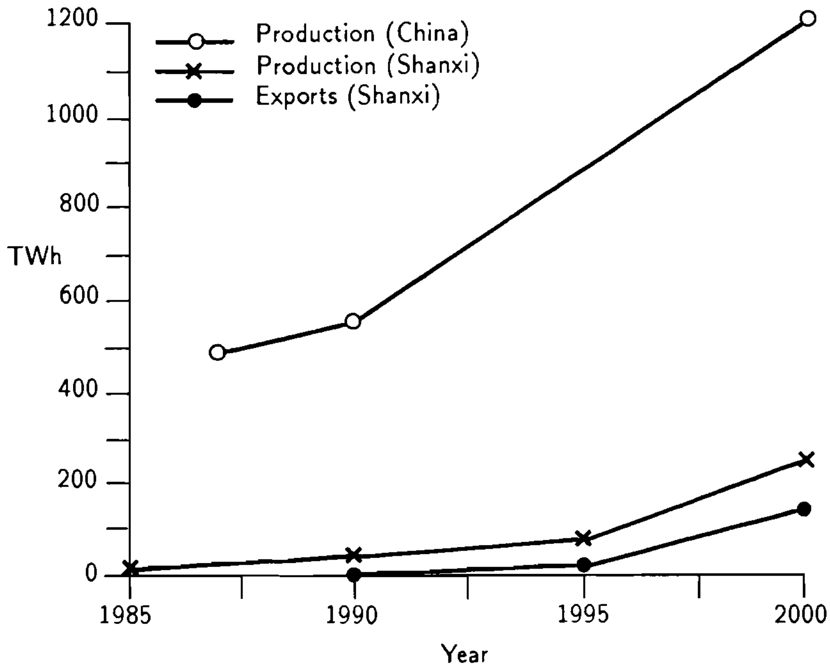


**Figure 11.** Electricity production in China and Shanxi and electricity exportation in Shanxi.

From 1985 to the year 2000, the increase in coal production in Shanxi can be roughly broken down as follows:

- Satisfying the exponential increase in domestic energy demand (50%).
- Developing power exports, especially after 1995 (18%).
- Continuously increasing coke and coal exports (32%).

In the year 2000, energy exports by Shanxi should mobilize about 65% of its primary energy production and the transformation and transport losses by its energy sector represent about 50% of its total energy consumption. Recalling that, in 2000, total energy consumption in Shanxi could amount to approximately 8% of the Chinese energy consumption, we can conclude that Shanxi will occupy a predominant place in the Chinese energy balance, not only as supplier but also as consumer and transformer of energy.

# 7. Interface Description

A friendly, user-oriented interface guides the user through the model. It handles the dialog between the user(s) and the machine on the one hand, and the model(s) with each other or with the data bases on the other hand; it is largely menu driven: at any point the user is allowed to choose among several possible actions which he can select from a menu of options offered by the system. Handling and representation are consistent through the overall system (e.g., the location of all menus at the lower left corner of the screen, explain functions etc.), the style of the user interface and interactions with the system are always the same at the user end. It incorporates a number of display and report styles, including color graphics.

MAED-BI is largely data base driven: first, the user has to select one appropriate basic data set he wants to work with, out of the available alternatives (currently there are two data sets available, one implemented by Mr. Jiang, PRC, and one implemented in China by members of the Institute for Chemical Technology, Academy of Sciences of the (former) German Democratic Republic (GDR), together with local experts). This choice defines the economic development scenario.

The chosen data base is loaded into the system and an overview on its content is displayed on the screen, including base and target year, information on capital depreciation and technical installations, numbers of sectors, products, and technologies treated, as well as information on output targets over the simulation period specified by the user in the data base (in the form of functions on a graph showing time period versus percentage output growth) for selected products of a few selected sectors (namely coal mining, power generation, ferrous and non-ferrous metallurgy, and the chemical industry) (see *Figure 12*). During the loading of the data, several checks on values, consistencies, missing data, etc. are made and warning messages might appear on the screen.

At this level, access to the SunUNIFY/SunSIMPLIFY data base management system (DBMS) is provided, for editing the current data base (describing the scenario): changes at this level will be stored in the data base and included in the subsequent runs. By setting a switch in the data base the user can choose to modify his basic scenario interactively and iteratively, during the model run; these transformations will be included in the current run, but then be lost for later runs. Therefore the user has the option of testing different modifications with the same basic scenario and later make permanent adjustments in the data base via the DBMS.

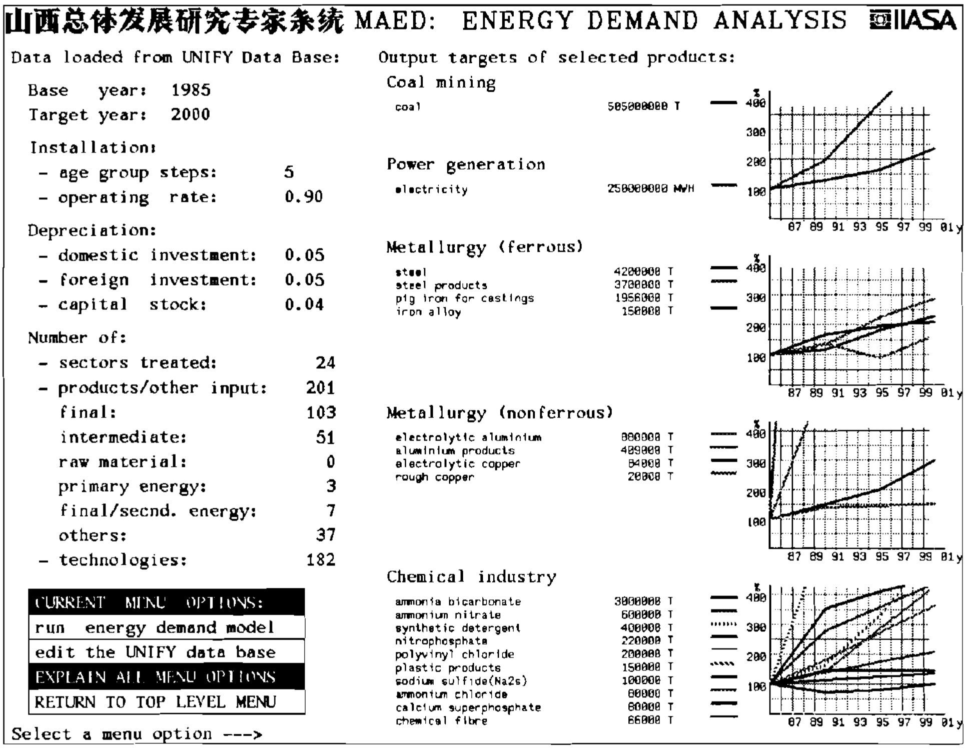


**Figure 12.** MAED-BI Start-up page.

The second menu option at this level is to run the MAED-BI submodels and to show an output page with a general description and a summary of the results of the model run (see *Figure 13*), aggregated over all sectors. The summary includes basic descriptors, i.e., final energy demand (electricity, coal, oil, gas, coke, liquefied coal, gasified coal, biomass), water demand (input water, output water, and waste water), demand of labor (unskilled, clerical, and technical labor), and investment (cumulative investment and yearly investment) for the base and the target year, as well as the relative increase between the base and target year. For each basic descriptor, a graphical representation summarizing the relative increase over the period is displayed, as well as two pie charts describing the share of final energy demand indicators and labor indicators in the target year.

The user now has the following menu options to go into more detail and for a less aggregated form of presenting the results:

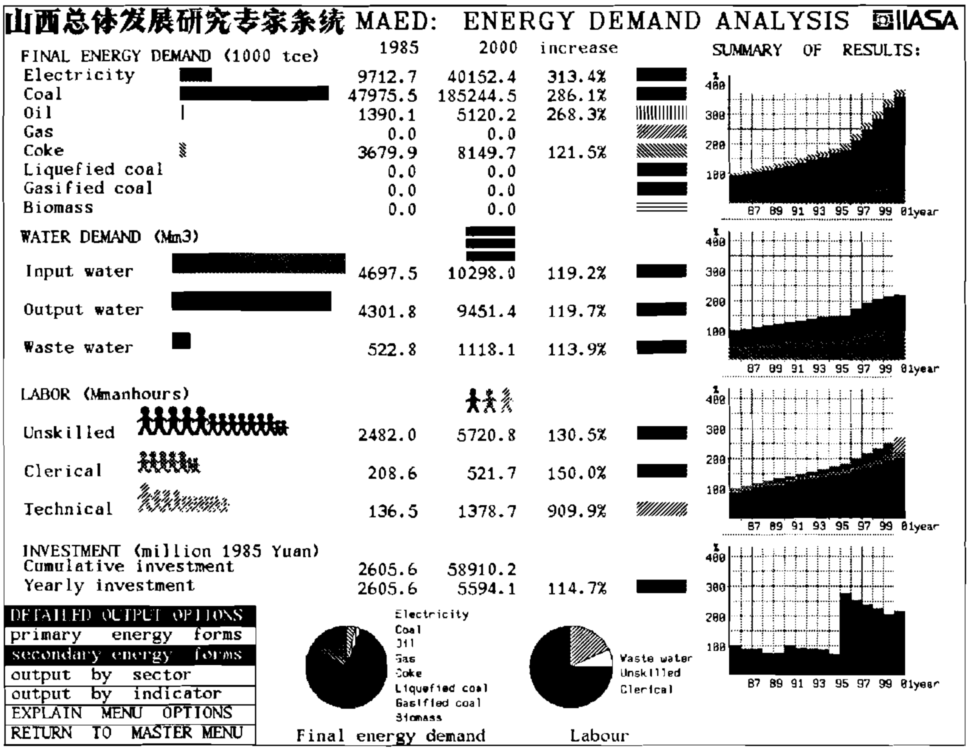


**Figure 13.** General output page.

- *Primary energy forms*: shows a page on demand, import, export, and production of the primary energy forms (crude oil, biomass, coal, natural gas, electricity, i.e., hydropower) including their time evolution over the period in the form of graphs (one per primary energy form) on the top half of the screen, as well as pie charts on their relative distribution for the target year (production, demand, import, and export with one pie chart each, showing the share of the different primary energy forms on the lower part of the screen.
- *Secondary energy forms*: same display as described above, for secondary energy forms (oil products, gasified coal, liquefied coal, coke, electricity) (see *Figure 14*)
- *Sector-specific output*: shows disaggregated results for one sector chosen from a list of the 24 sectors (see *Figure 15*) represented in MAED-BI.

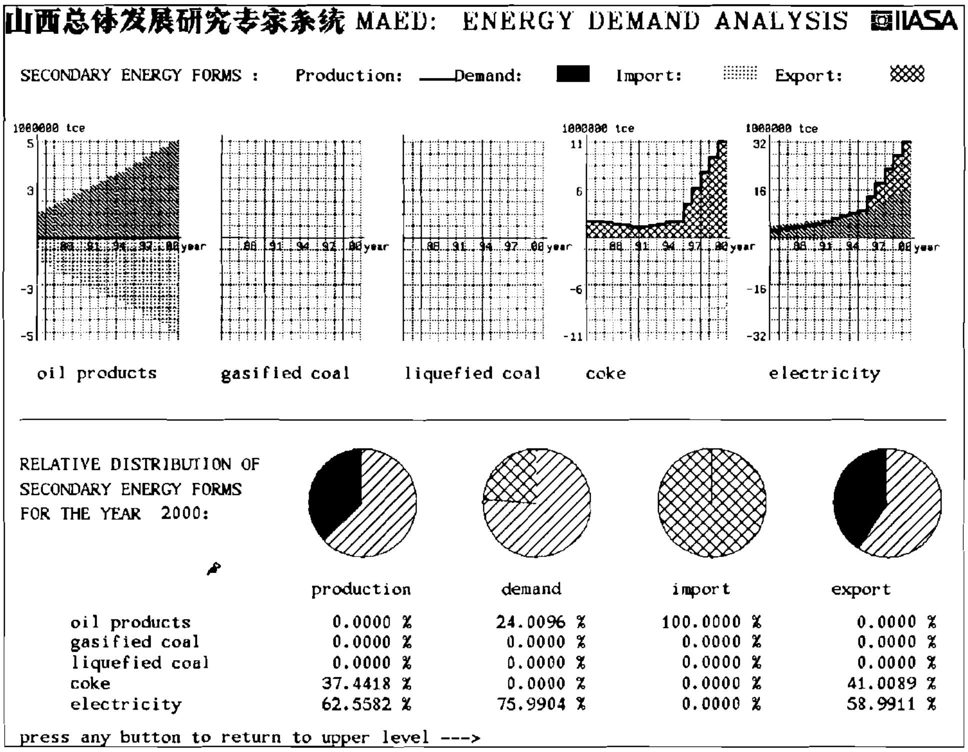


**Figure 14.** Secondary energy forms.

For the chosen sector, the same type of information and display is shown as on the summary page of the model's result (see also *Figure 13*).

- *Output per indicator*: the user chooses one subindicator on the screen (e.g., coal, see *Figure 16*) to see a disaggregation of the result per indicator (as opposed to a disaggregation per sector); the demand calculated by MAED-BI for the specified indicator is displayed for each of the 24 sectors over the period on graphs (one graph per aggregated sector group corresponding to the aggregation made in the I/O model in 6 sectors: commerce and administration, agriculture, heavy industry, light industry, construction, and transportation), including a pie chart for the overall sectoral share of the demand of the chosen indicator in the target year.

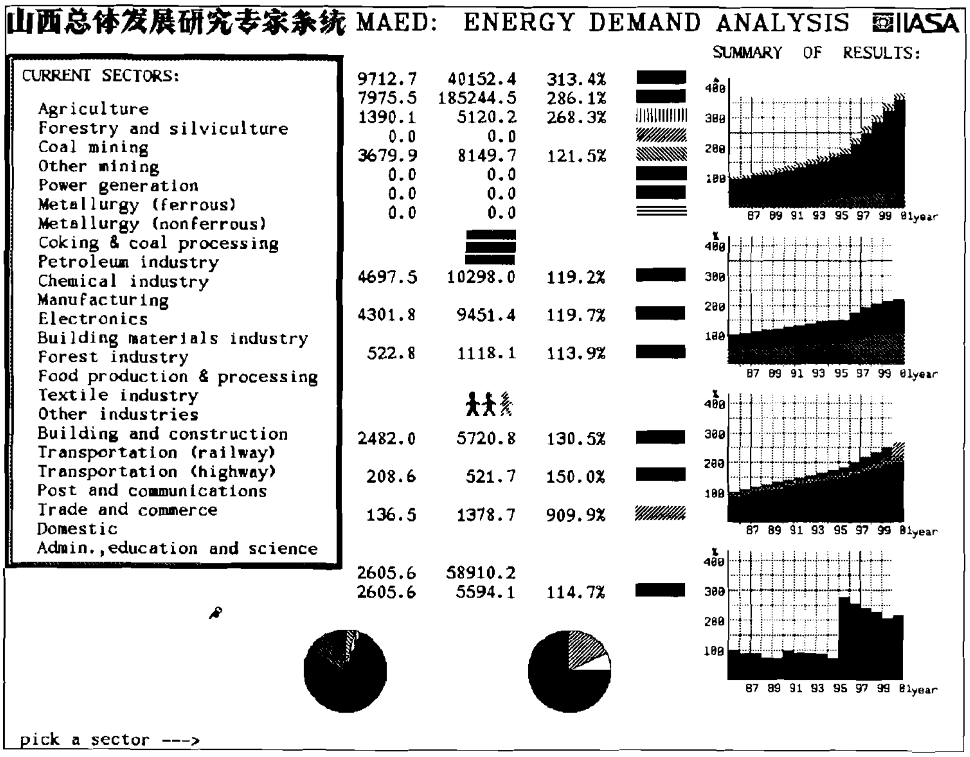


**Figure 15.** Choose a sector for disaggregated results.

After looking at the results presented in various forms, the user can go back and change the scenario via the DBMS, load the new data base, and run the model again.

# 8. Data Base Implementation with the DBMS SunUNIFY/SunSIMPLIFY

As mentioned above, MAED-BI has been implemented within the Shanxi DSS; the data base has been developed using the SunUNIFY/SunSIMPLIFY, a relational data base management system (DBMS) (Codd, 1970 and 1974) especially suitable for the quick and easy development of user applications (for a detailed description, refer to Sun Microsystems, 1986 various revisions).

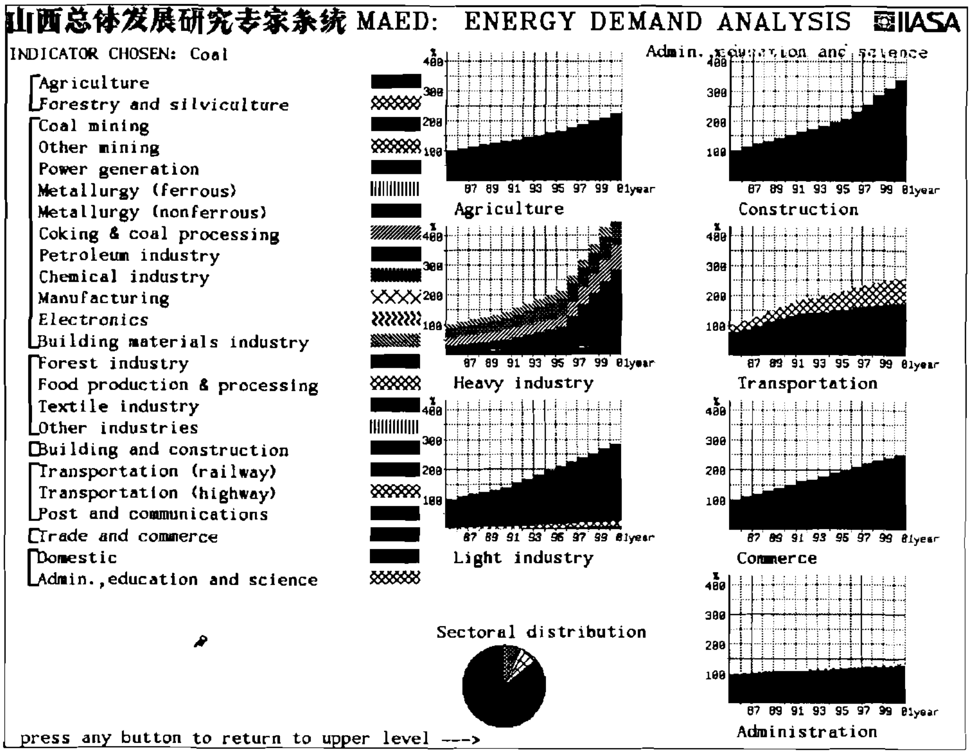


**Figure 16.** Output per indicator.

SunUNIFY is the DBMS's kernel; it handles the data base management *per se*. In addition, SunUNIFY provides the user with a set of supplementary tools that help to process and handle data in different ways (e.g., the SQL query language, the RPT report processor). SunSIMPLIFY is a package built around SunUNIFY which provides the user with a set of interfaces and tools to assist with the use and development of data base applications; it runs in the window system only.

The standard window (see *Figure 17*) is divided into three subwindows. The message subwindow is located at the top: it displays information on the current status and error messages. In the center is the menu subwindow where the user can find the general options currently available. It is in the (lowest) editor subwindow that most of the user's developments and specific functions will be carried out (e.g., definitions of tables, properties, browsing through the data base). For each record type (topic or subtopic) to be

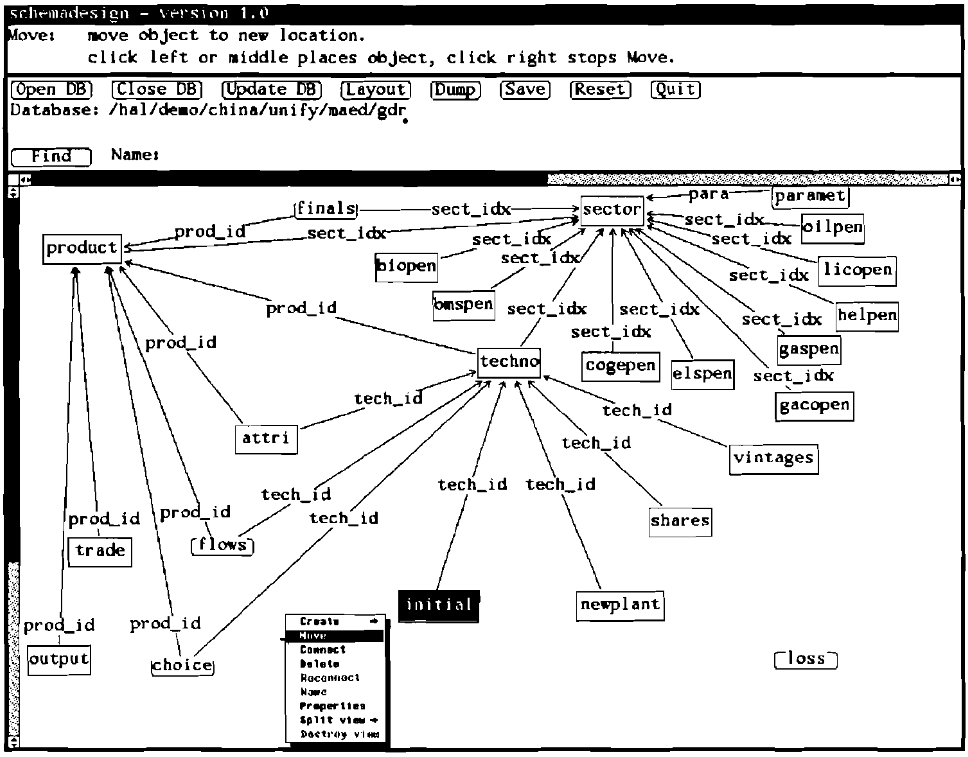


**Figure 17.** *Schemadesign* structure of the MAED-BI data base.

represented in the data base, a separate table has to be defined: numerous relatively small, relationally organized data entities are used.

The main components of the package used for the implementation of the data base for the MAED-BI model are *schemadesign* and *databrowse*:

- *Schemadesign* (see *Figure 17*) is a tool to define and modify the structure of a data base. It is an interactive interface to a data base to define record types, relations, etc. and uses SunUNIFY to actually create and update the data base: the user interactively manipulates the graphics representation of the data structure. The display of the data base's structure is based on the entity relationship (Chen, 1976) data model: there are two kinds of tables, entity tables (record types) and relationship tables (associations between entities), both are represented as icons in the editor subwindow. Relations between tables are drawn as lines between the icons. Manipulation during the design process is done with the help of the mouse (to select pop-up menus and their options, to place icons, etc.) and the keyboard (to name the icons) and is very simple.

After developing the rough structure of the data base, the user goes into greater detail: the properties of the tables have to be defined and described (e.g., field name, primary key, data type, etc.).

- *Databrowse* is a program to interactively browse and edit a data base. All data manipulation again is done via the mouse (different from, e.g., a query language or forms) by just pointing and clicking a button. Data are displayed in the editor subwindow that can be scrolled horizontally and vertically. The user can select an entire table, as well as specified entities (all information on that entity – possibly from various logically related tables – are shown at once by picking the entity's key) to be displayed or edited. The specification of one or more entities can be done in different ways: by typing in the table name and key of the record, or by picking its key on the screen, or by specifying parts of the key – in this case the DBMS searches the whole data base for records matching these defined parts and shows all of them. A history of the user's manipulation can be viewed in a pop-up menu and previous options can be selected again.

Part of the SunUNIFY product is the UNIFY host language interface. It provides the user with a set of library routines for C programs to manipulate (add, delete, read, etc.) the content of the data base. SunUNIFY automatically generates an include file ('file.h'), where all tables and properties of the data base are defined in the C programming language. Calls of the routines and include files are loaded in the programmer's routines. The next step is to run a C-language preprocessor (ucc and upp) to compile these UNIFY application programs. In addition, a command file (uld) for loading the routines (object files) is available. This interface makes it possible to have direct access from the different modules of the Chinese system to the data bases without any intermediate auxiliary programs or shell scripts to retrieve data and to be passed on to the modules. Also the MAED-BI model uses these libraries for the loading of data from the data base.

The basic structure of the data base developed with *schemadesign* is shown in *Figure 17*. Entity tables are represented as icons, relationships between tables as arrows connecting the icons. The name of the field realizing the connection between two tables is written along the arrow. The data entry has been performed with the *databrowse* tool. The user has to fill up and/or complete this data base to enable MAED-BI to treat the economy of the province: the content of the data base defines the scenario for the model. Process–product pairs (see Section 3.2 on process–product representation) are the basic active elements throughout the representation of the socioeconomic system. These pairs are ordered by sectors in order to pursue a disaggregated analysis of the socioeconomic system and to fit the sectoral breakdown of other models included in the Shanxi case study (e.g., input/output model). Therefore, data relative to process, products, and sectors are fundamental to the model's application.

# Appendix A: Sectoral Production Volumes

| | Unit | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|---|
| **Agriculture** | | | | | |
| *Final products* | | | | | |
| Tobacco | 1000t | 5 | 10 | 15 | 20 |
| Sugar beet | 1000t | 249 | 500 | 750 | 1000 |
| Oil-bearing crops | 1000t | 445 | 700 | 900 | 1500 |
| Pork | 1000t | 209 | 325 | 450 | 600 |
| Grain | 1000t | 8227 | 9500 | 11000 | 15000 |
| Cotton | 1000t | 74 | 100 | 150 | 200 |
| **Coal mining** | | | | | |
| *Final products* | | | | | |
| Coal | 1000t | 214000 | 270000 | 350000 | 505000 |
| **Other mining** | | | | | |
| *Final products* | | | | | |
| Salt | 1000t | 143.6 | 153.8 | 200.6 | 255.9 |
| Sulfur-iron ore | 1000t | 354.3 | 507.3 | 633.4 | 838.3 |
| Lime | 1000t | 891.8 | 1262.7 | 1934 | 2732.7 |
| Bauxite | 1000t | 48.2 | 267.2 | 656.1 | 4744.1 |
| Iron ore | 1000t | 18058.1 | 12560.7 | 14648 | 19388.7 |
| **Power generation** | | | | | |
| *Final products* | | | | | |
| Electricity | 1000MWh | 18459 | 36000 | 71500 | 250000 |
| **Metallurgy (ferrous)** | | | | | |
| *Final products* | | | | | |
| Steel | 1000t | 1837 | 2150 | 3300 | 4200 |
| Steel products | 1000t | 1289 | 1720 | 2890 | 3700 |
| Iron alloy | 1000t | 72 | 120 | 140 | 150 |
| Pig iron (for casting) | 1000t | 1190 | 1617 | 1064 | 1956 |
| *Other products* | | | | | |
| Oxygen | 1000t | 75.7 | 79.5 | 108 | 119.7 |
| Pig iron (for steel) | 1000t | 1359.5 | 1433.4 | 1958 | 2183.9 |
| Sinter | 1000t | 1359.5 | 1433.4 | 1958 | 2183.9 |
| **Metallurgy (non ferrous)** | | | | | |
| *Final products* | | | | | |
| Rough copper | 1000t | 13 | 18 | 19 | 20 |
| Electrolytic copper | 1000t | 28 | 42 | 56 | 84 |
| Electrolytic aluminium | 1000t | 8 | 50 | 120 | 880 |
| Aluminium products | 1000t | 1 | 40 | 200 | 409 |
| *Other products* | | | | | |
| Aluminium oxide | 1000t | 15.6 | 97.3 | 233.4 | 1711.6 |

| | Unit | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|---|
| **Coking & coal processing** | | | | | |
| *Final products* | | | | | |
| Coke | 1000t | 5470 | 6120 | 7500 | 19000 |

| | | | | | |
|---|---|---|---|---|---|
| **Chemical industry** | | | | | |
| *Final products* | | | | | |
| Dyes | 1000t | 4 | 2 | 3 | 4 |
| Ammonium nitrate | 1000t | 285 | 400 | 500 | 600 |
| Aluminium sulfate | 1000t | 14 | 20 | 30 | 40 |
| Sodium sulfide (Na2S) | 1000t | 69 | 100 | 100 | 100 |
| Chemical fibre | 1000t | 15 | 42 | 54 | 66 |
| Ammonium sulfate | 1000t | 15 | 20 | 25 | 30 |
| Ammonia chloride | 1000t | 22 | 40 | 60 | 80 |
| Ammonia bicarbonate | 1000t | 2200 | 2500 | 2800 | 3000 |
| Calcium superphosphate | 1000t | 17 | 60 | 70 | 80 |
| Nitrophosphate | 1000t | 220 | 160 | 180 | 220 |
| Carbon disulfide | 1000t | 6 | 9 | 12 | 15 |
| Paint | 1000t | 15 | 30 | 35 | 40 |
| Magnetic materials | 1000t | 1 | 0.8 | 2 | 4 |
| Polyvinyl chloride | 1000t | 7 | 46 | 90 | 200 |
| Phenolic & cresylic plastics | 1000t | 3 | 4 | 4 | 4 |
| Caprolactam | 1000t | 0 | 5 | 5 | 5 |
| Nylon-66 resin | 1000t | 0 | 5 | 5 | 5 |
| Polyacrylonitrile | 1000t | 0 | 0 | 15 | 30 |
| Chemical medicine | 1000t | 1 | 1 | 2 | 3 |
| Car outer tyres | 1000t | 293 | 600 | 900 | 1200 |
| Bicycle outer tyres | 1000t | 631 | 1300 | 2000 | 2600 |
| Pushcart outer tyres | 1000t | 433 | 900 | 1200 | 1800 |
| Soap | 1000t | 17 | 28 | 31 | 34 |
| Synthetic pesticides | 1000t | 61 | 100 | 200 | 400 |
| Chemical pesticides | 1000t | 3 | 7 | 9 | 11 |
| *Other products* | | | | | |
| Nitric acid | 1000t | 356.2 | 413.6 | 505.4 | 608.8 |
| Methanol | 1000t | 90.2 | 252.2 | 324.2 | 396.2 |
| Urea | 1000t | 0.6 | 0.4 | 0.4 | 0.6 |
| Hydrochloric acid (36 Phenol | 1000t | 1.2 | 1.6 | 1.6 | 1.6 |
| Formaldehyde | 1000t | 0.3 | 0.4 | 0.4 | 0.4 |
| Hydrogen | 1000t | 0.2 | 1.6 | 2.7 | 5.3 |
| Propylene | 1000t | 0 | 0 | 22.5 | 45 |
| Synthetic ammonia | 1000t | 893.4 | 1029.3 | 1179.1 | 1305.1 |
| Sulfuric acid | 1000t | 116.8 | 166.4 | 206.1 | 274.7 |
| Anyhdr. sodium Sulfate ($Na_2SO_4$) | 1000t | 121.5 | 177.2 | 178 | 178.6 |
| Carbon dioxide | 1000t | 2024.1 | 2241.1 | 2432.8 | 2530.2 |
| Block sulfer | 1000t | 47.3 | 67.9 | 85.1 | 112.2 |
| Calcium carbide | 1000t | 743.2 | 1052.2 | 1611 | 2277.2 |
| Pure benzene | 1000t | 15.6 | 26.6 | 36.1 | 45.6 |
| Caustic soda (NaOH) | 1000t | 6.5 | 10 | 11.8 | 13.7 |
| Chloroprene rubber | 1000t | 183 | 244.6 | 366.9 | 489.3 |
| Nitrogen | 1000t | 54.9 | 73.4 | 110.1 | 146.8 |
| Chlorobenzene | 1000t | 44.5 | 59.4 | 89.2 | 118.9 |
| Toluene | 1000t | 40 | 53.5 | 80.2 | 107 |

| | Unit | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|---|
| **Manufacturing** | | | | | |
| *Final products* | | | | | |
| Hammering machines | 1000set | 1 | 3 | 6 | 12 |
| Metal-cutting machines | 1000set | 1 | 2 | 6 | 18 |
| Cranes | 1000t | 8 | 16 | 32 | 64 |
| Transport equipment | 1000t | 7 | 10 | 15 | 25 |
| Water pumps | 1000set | 42 | 60 | 80 | 150 |
| Bearings | 1000Kset | 5 | 6 | 10 | 15 |
| Parts and components | 1000t | 50 | 100 | 200 | 400 |
| Mining equipment | 1000t | 16 | 30 | 50 | 80 |
| Metal rolling equipment | 1000t | 2 | 5 | 6 | 7 |
| Chemical equipment | 1000t | 7 | 15 | 20 | 30 |
| Tractors (small) | 1000set | 16 | 20 | 25 | 30 |
| Tractors - drawn | 1000set | 9 | 20 | 40 | 60 |
| Threshers | 1000set | 11 | 20 | 40 | 60 |
| Bicycles | 1000unit | 175 | 250 | 300 | 400 |
| Household sewing machines | 1000set | 10 | 20 | 40 | 100 |
| Locomotives | 1000unit | 276 | 500 | 750 | 1000 |
| Motor cars | 1000unit | 2 | 3 | 6 | 12 |
| AC motors | 1000KW | 1208 | 1208 | 2400 | 4800 |
| Transformers | 1000KVA | 2000 | 2500 | 5000 | 8000 |
| Batteries | 1000Kpiece | 51 | 70 | 100 | 150 |
| Washing machines (domestic) | 1000set | 234 | 300 | 500 | 700 |
| Internal-combustion engines | 1000HP | 210 | 400 | 700 | 1000 |
| Refrigeration | 1000set | 3 | 20 | 40 | 80 |
| **Electronics** | | | | | |
| *Final products* | | | | | |
| Televisions | 1000set | 180 | 400 | 600 | 800 |
| Tape recorders | 1000set | 29 | 30 | 60 | 120 |
| **Building materials industry** | | | | | |
| *Final products* | | | | | |
| Brick | 1000Kpiece | 13258 | 20000 | 25000 | 30000 |
| Plate glass | 1000box | 1130 | 3650 | 5000 | 6200 |
| Cement | 1000t | 4580 | 7160 | 10000 | 15000 |
| Plaster | 1000t | 900 | 1600 | 2000 | 2300 |
| Domestic ceramics | 1000Kpiece | 239 | 450 | 650 | 750 |
| Firebrick | 1000t | 253 | 315 | 317 | 320 |
| **Forest industry** | | | | | |
| *Final products* | | | | | |
| Processed wood | 1000Kyuan | 133 | 300 | 900 | 1800 |
| **Food production and processing** | | | | | |
| *Final products* | | | | | |
| Cigarettes | 1000box | 187 | 300 | 450 | 600 |
| Wine | 1000t | 84 | 200 | 300 | 400 |
| Sugar | 1000t | 30 | 60 | 100 | 150 |
| Edible vegetable oils | 1000t | 45 | 75 | 100 | 150 |

| | Unit | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|---|
| **Textile industry** | | | | | |
| *Final products* | | | | | |
| Silk, fabricated | 1000Km | 9 | 20 | 25 | 30 |
| Woolens | 1000Km | 3 | 4 | 5 | 6 |
| Knitting wool | 1000t | 2 | 3 | 4 | 5 |
| Cloth | 1000t | 376 | 430 | 520 | 620 |
| Yarn (knitted goods) | 1000t | 8 | 11 | 14 | 17 |
| Clothing | 1000Kyuan | 286 | 600 | 1200 | 2400 |
| Leather shoes | 1000pair | 2290 | 3000 | 4500 | 6000 |
| Cotton yarn | 1000t | 56.8 | 65 | 78.6 | 93.7 |
| **Other industries** | | | | | |
| *Final products* | | | | | |
| Art & handicrafts trade | 1000Kyuan | 41 | 82 | 164 | 328 |
| Cultural & educational goods | 1000Kyuan | 14 | 28 | 56 | 110 |
| Printing trade | 1000Kyuan | 150 | 300 | 600 | 1200 |
| Machine paper | 1000t | 188 | 250 | 300 | 400 |
| Fodder | 1000Kyuan | 38 | 76 | 152 | 304 |
| Aluminium production | 1000t | 1 | 2.4 | 4.8 | 9.6 |
| Enamelware | 1000t | 2 | 4 | 8 | 16 |
| **Building and construction** | | | | | |
| *Final products* | | | | | |
| Building | 1000Kyuan | 6058 | 9000 | 12000 | 20000 |
| **Transportation (railway)** (in passenger/tons kilometers) | | | | | |
| *Final products* | | | | | |
| Passenger traffic volume | 1000Kpkm | 9326 | 10000 | 13500 | 17000 |
| Freight traffic volume | 1000Ktkm | 36098 | 60000 | 70000 | 80000 |
| **Transportation (highway)** (in passenger/tons kilometers) | | | | | |
| *Final products* | | | | | |
| Passenger traffic volume | 1000Kpkm | 3104 | 6000 | 9000 | 13000 |
| Freight traffic volume | 1000Ktkm | 5229 | 10000 | 15000 | 20000 |
| **Trade and commerce** | | | | | |
| *Final products* | | | | | |
| Trade and commerce | 1000Kyuan | 2604 | 3000 | 4000 | 5000 |
| **Households** (h-h) | | | | | |
| *Final products* | | | | | |
| Household-urban | 1000h-h | 1157 | 1463 | 2000 | 2632 |
| Household-rural | 1000h-h | 5160 | 5273 | 5160 | 5064 |
| **Administration, education, and science** (in million employees) | | | | | |
| *Final products* | | | | | |
| Admin., education, and science | 1000K-p | 2 | 2.4 | 5 | 9 |

# Appendix B: Final Energy Demand

## Total

| | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|
| Fuels ('000 tce) | 30939 | 40987 | 51294 | 69679 |
| Power (TWh) | 21.2 | 28.8 | 39.6 | 67.8 |
| Total ('000 tce) | 33545 | 44532 | 56168 | 78012 |

## Sectoral breakdown

| | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|
| **Agriculture** | | | | |
| Fuels ('000 tce) | 312.6 | 398.3 | 503.9 | 680.2 |
| % of fuel demand | 1.0 | 1.0 | 1.0 | 1.0 |
| Power (TWh) | 0.391 | 0.464 | 0.559 | 0.759 |
| % of power demand | 1.8 | 1.6 | 1.4 | 1.1 |
| Total ('000 tce) | 360.7 | 455.4 | 572.7 | 773.6 |
| % of Final Demand | 1.1 | 1.0 | 1.0 | 1.0 |
| **Coal mining** | | | | |
| Fuels ('000 tce) | 4116.5 | 5016.6 | 6273.3 | 8720.2 |
| % of fuel demand | 13.3 | 12.2 | 12.2 | 12.5 |
| Power (TWh) | 4.922 | 5.833 | 7.072 | 9.498 |
| % of power demand | 23.2 | 20.2 | 17.8 | 14.0 |
| Total ('000 tce) | 4721.9 | 5734.1 | 7143.2 | 9888.5 |
| % of Final Demand | 14.1 | 12.9 | 12.7 | 12.7 |
| **Other mining** | | | | |
| Fuels ('000 tce) | 239.1 | 303.3 | 304.5 | 427.7 |
| % of fuel demand | 0.8 | 0.7 | 0.6 | 0.6 |
| Power (TWh) | 0.267 | 0.334 | 0.335 | 0.47 |
| % of power demand | 1.3 | 1.2 | 0.8 | 0.7 |
| Total ('000 tce) | 271.9 | 344.4 | 345.7 | 485.5 |
| % of Final Demand | 0.8 | 0.8 | 0.6 | 0.6 |
| **Metallurgy (ferrous)** | | | | |
| Fuels ('000 tce) | 2804.7 | 3534.3 | 3656.6 | 5232.7 |
| % of fuel demand | 9.1 | 8.6 | 7.1 | 7.5 |
| Power (TWh) | 0.932 | 1.305 | 1.99 | 2.577 |
| % of power demand | 4.4 | 4.5 | 5.0 | 3.8 |
| Total ('000 tce) | 2919.3 | 3694.8 | 3901.4 | 5549.7 |
| % of Final Demand | 8.7 | 8.3 | 6.9 | 7.1 |

| | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|
| **Metallurgy (non-ferrous)** | | | | |
| Fuels ('000 tce) | 52.9 | 276.8 | 684.3 | 4414.8 |
| % of fuel demand | 0.2 | 0.7 | 1.3 | 6.3 |
| Power (TWh) | 0.176 | 1.012 | 2.476 | 16.986 |
| % of power demand | 0.8 | 3.5 | 6.2 | 25.1 |
| Total ('000 tce) | 74.5 | 401.3 | 988.8 | 6504.1 |
| % of Final Demand | 0.2 | 0.9 | 1.8 | 8.3 |
| **Chemicals** | | | | |
| Fuels ('000 tce) | 4870 | 7072 | 9281.5 | 11861.1 |
| % of fuel demand | 15.7 | 17.3 | 18.1 | 17.0 |
| Power (TWh) | 4.942 | 6.932 | 9.905 | 13.599 |
| % of power demand | 23.3 | 24.1 | 25.0 | 20.1 |
| Total ('000 tce) | 5477.9 | 7924.6 | 10499.8 | 13533.8 |
| % of Final Demand | 16.3 | 17.8 | 18.7 | 17.3 |
| **Manufacturing** | | | | |
| Fuels ('000 tce) | 526 | 914.8 | 1609.4 | 2940.2 |
| % of fuel demand | 1.7 | 2.2 | 3.1 | 4.2 |
| Power (TWh) | 0.68 | 1.285 | 2.398 | 4.494 |
| % of power demand | 3.2 | 4.5 | 6.1 | 6.6 |
| Total ('000 tce) | 609.6 | 1072.9 | 1904.4 | 3493 |
| % of Final Demand | 1.8 | 2.4 | 3.4 | 4.5 |
| **Electronics** | | | | |
| Fuels ('000 tce) | 3.1 | 6.1 | 9.4 | 13.3 |
| % of fuel demand | 0.01 | 0.01 | 0.02 | 0.02 |
| Power (TWh) | 0.001 | 0.003 | 0.004 | 0.006 |
| % of power demand | 0.00 | 0.01 | 0.01 | 0.01 |
| Total ('000 tce) | 3.2 | 6.5 | 9.9 | 14 |
| % of Final Demand | 0.01 | 0.01 | 0.02 | 0.02 |
| **Building materials** | | | | |
| Fuels ('000 tce) | 3970 | 5838.5 | 7133.7 | 8591.9 |
| % of fuel demand | 12.8 | 14.2 | 13.9 | 12.3 |
| Power (TWh) | 2.564 | 3.687 | 4.501 | 5.491 |
| % of power demand | 12.1 | 12.8 | 11.4 | 8.1 |
| Total ('000 tce) | 4285.4 | 6292 | 7687.3 | 9267.3 |
| % of Final Demand | 12.8 | 14.1 | 13.7 | 11.9 |

| | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|
| **Forest industry** | | | | |
| Fuels ('000 tce) | 24.5 | 55.4 | 166.3 | 332.5 |
| % of fuel demand | 0.1 | 0.1 | 0.3 | 0.5 |
| Power (TWh) | 0.032 | 0.072 | 0.217 | 0.434 |
| % of power demand | 0.2 | 0.2 | 0.5 | 0.6 |
| Total ('000 tce) | 28.4 | 64.3 | 193 | 385.9 |
| % of Final Demand | 0.1 | 0.1 | 0.3 | 0.5 |
| **Food production and processing** | | | | |
| Fuels ('000 tce) | 118.6 | 246 | 363.7 | 502.6 |
| % of fuel demand | 0.4 | 0.6 | 0.7 | 0.7 |
| Power (TWh) | 0.041 | 0.085 | 0.131 | 0.184 |
| % of power demand | 0.2 | 0.3 | 0.3 | 0.3 |
| Total ('000 tce) | 123.6 | 256.5 | 379.8 | 525.2 |
| % of Final Demand | 0.4 | 0.6 | 0.7 | 0.7 |
| **Textile** | | | | |
| Fuels ('000 tce) | 2054.1 | 2688.7 | 4004.6 | 5335.8 |
| % of fuel demand | 6.6 | 6.6 | 7.8 | 7.7 |
| Power (TWh) | 0.906 | 1.166 | 1.692 | 2.248 |
| % of power demand | 4.3 | 4.0 | 4.3 | 3.3 |
| Total ('000 tce) | 2165.5 | 2832.1 | 4212.7 | 5612.3 |
| % of Final Demand | 6.5 | 6.4 | 7.5 | 7.2 |
| **Other industries** | | | | |
| Fuels ('000 tce) | 270.1 | 385.3 | 522.3 | 794.6 |
| % of fuel demand | 0.9 | 0.9 | 1.0 | 1.1 |
| Power (TWh) | 0.185 | 0.263 | 0.357 | 0.544 |
| % of power demand | 0.9 | 0.9 | 0.9 | 0.8 |
| Total ('000 tce) | 292.9 | 417.6 | 566.2 | 861.5 |
| % of Final Demand | 0.9 | 0.9 | 1.0 | 1.1 |
| **Building and construction** | | | | |
| Fuels ('000 tce) | 314.7 | 467.6 | 623.4 | 1039.1 |
| % of fuel demand | 1.0 | 1.1 | 1.2 | 1.5 |
| Power (TWh) | 0.51 | 0.758 | 1.01 | 1.684 |
| % of power demand | 2.4 | 2.6 | 2.5 | 2.5 |
| Total ('000 tce) | 377.4 | 560.8 | 747.6 | 1246.2 |
| % of Final Demand | 1.1 | 1.3 | 1.3 | 1.6 |

| | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|
| **Transportation (railway)** | | | | |
| Fuels ('000 tce) | 1207.4 | 1860.6 | 2219.5 | 2578.4 |
| % of fuel demand | 3.9 | 4.5 | 4.3 | 3.7 |
| Power (TWh) | 0.628 | 0.967 | 1.153 | 1.34 |
| % of power demand | 3.0 | 3.4 | 2.9 | 2.0 |
| Total ('000 tce) | 1284.6 | 1979.5 | 2361.3 | 2743.2 |
| % of Final Demand | 3.8 | 4.4 | 4.2 | 3.5 |
| **Transportation (highway)** | | | | |
| Fuels ('000 tce) | 1361.6 | 2608 | 3912 | 5280.6 |
| % of fuel demand | 4.4 | 6.4 | 7.6 | 7.6 |
| Power (TWh) | 0.364 | 0.701 | 1.051 | 1.459 |
| % of power demand | 1.7 | 2.4 | 2.7 | 2.2 |
| Total ('000 tce) | 1406.4 | 2694.2 | 4041.3 | 5460.1 |
| % of Final Demand | 4.2 | 6.1 | 7.2 | 7.0 |
| **Trade and commerce** | | | | |
| Fuels ('000 tce) | 25.8 | 37.6 | 50 | 62.6 |
| % of fuel demand | 0.1 | 0.1 | 0.1 | 0.1 |
| Power (TWh) | 0 | 0 | 0 | 0 |
| % of power demand | 0.0 | 0.0 | 0.0 | 0.0 |
| Total ('000 tce) | 25.8 | 37.5 | 50 | 62.5 |
| % of Final Demand | 0.1 | 0.1 | 0.1 | 0.1 |
| **Households** | | | | |
| Fuels ('000 tce) | 8619.3 | 9219.7 | 9855.7 | 10653.8 |
| % of fuel demand | 27.9 | 22.5 | 19.2 | 15.3 |
| Power (TWh) | 3.178 | 3.393 | 3.614 | 3.893 |
| % of power demand | 15.0 | 11.8 | 9.1 | 5.7 |
| Total ('000 tce) | 9010.2 | 9637 | 10300.2 | 11132.6 |
| % of Final Demand | 26.9 | 21.6 | 18.3 | 14.3 |
| **Administration, education, and science** | | | | |
| Fuels ('000 tce) | 48.1 | 57.7 | 120.2 | 216.5 |
| % of fuel demand | 0.2 | 0.1 | 0.2 | 0.3 |
| Power (TWh) | 0.464 | 0.557 | 1.16 | 2.088 |
| % of power demand | 2.2 | 1.9 | 2.9 | 3.1 |
| Total ('000 tce) | 105.2 | 126.2 | 262.9 | 473.3 |
| % of Final Demand | 0.3 | 0.3 | 0.5 | 0.6 |

# Appendix C: Net Energy Consumption of Energy Sectors

All data have been converted in thousand TCE (ton of coal equivalent); Power consumption and production figures have been converted from TWh using 123 as the conversion factor (Electrical Energy Consumption Equivalence Factor).

| | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|
| **Coking and coal processing** | | | | |
| Fuels Consumption | 8370 | 8930 | 10411 | 25025 |
| (+) Power Consumption | 4 | 8 | 13 | 42 |
| (-) Coke Production | 5281 | 5909 | 7241 | 18345 |
| (=) Net Consumption | 3093 | 3029 | 3183 | 6722 |
| **Power generation** | | | | |
| Fuels Consumption | 6605 | 13221 | 26933 | 96530 |
| (+) Hydropower Consumption | 91 | 133 | 176 | 308 |
| (+) Power Consumption | 187 | 369 | 744 | 2639 |
| (+) Losses | 250 | 443 | 792 | 2460 |
| (-) Total Power Generation | 2271 | 4428 | 8795 | 30750 |
| (=) Net Consumption | 4862 | 9738 | 19850 | 71186 |
| **Total of energy sectors** | | | | |
| Fuel Consumption | 14975 | 22151 | 37344 | 121555 |
| (+) Power Consumption | 282 | 510 | 933 | 2989 |
| (+) Losses | 250 | 443 | 792 | 2460 |
| (-) Energy Production | 7552 | 10337 | 16036 | 49095 |
| (=) Net Consumption | 7424 | 11814 | 21308 | 72460 |

# Appendix D: Production, Consumption, and Trade Results by Energy Type

| | Production | Consumption | Trade |
|---|---|---|---|
| **Coal ('000 t)** | | | |
| 1985 | 184483 | 59181 | 125302 |
| 1990 | 232759 | 80144 | 152615 |
| 1995 | 301724 | 112248 | 189476 |
| 2000 | 435345 | 237318 | 198027 |
| **Coke ('000 t)** | | | |
| 1985 | 5470 | 3583 | 1887 |
| 1990 | 6120 | 4893 | 1227 |
| 1995 | 7500 | 5430 | 2070 |
| 2000 | 19000 | 8080 | 10920 |
| **Electricity (GWh)** | | | |
| 1985 | 18459 | 24767 | −6308 |
| 1990 | 36000 | 35483 | 517 |
| 1995 | 71500 | 52217 | 19283 |
| 2000 | 250000 | 109552 | 140448 |
| **Oil products ('000 t)** | | | |
| 1985 | 0 | 919 | −919 |
| 1990 | 0 | 1689 | −1689 |
| 1995 | 0 | 2515 | −2515 |
| 2000 | 0 | 3520 | −3520 |

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