

WORKING PAPER

INTERACTIVE ENERGY DEMAND ANALYSIS: A CASE STUDY OF SHANXI PROVINCE, PRC

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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, ie. 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 around 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 scenaria, 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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The opinions expressed in the report are those of the authors and do not necessarily reflect those of ILASA or of ILASA's National Member Organizations or IAEA. Neither the collaborating institutes, the International Atomic Energy Agency (IAEA), Vienna, nor any person acting on behalf of the above is responsible for the use which might be made of the information in this report.

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INTERACTIVE ENERGY DEMAND ANALYSIS: A CASE STUDY OF SHANXI PROVINCE, PRC

B. Vallance and E. Weigkricht

1. SUMMARY DESCRIPTION OF THE PROJECT

The planning of a rational and coordinated development of a region requires not only a large amount of complex and often technical information on, for example, economics, environmental factors, availability and requirements of resources, socio-economic and political implications, it also needs a profound understanding and simultaneous consideration of the problems on one hand and the numerous inter-relationships between all the related factors on the other. In addition, there is the influence of regional planners and decision makers that should also be taken into consideration. A number of complex scientific models and methodologies would 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,c,d) for a case study of the Shanxi province, 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 design and analysis of possible development strategies. The system was designed so that both non-scientific, 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^{*)}

With a total output of primary commercial energy (coal, petroleum, natural gas, and hydropower) of 880 Mtce, 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 to 449.59 TWh.

^{*)} Based on the paper by Zhou Fengqi, *China's Energy Production Situation and a Global Analysis Model of the Coal Economy in Shanxi Province, PRC*, presented at the workshop held at IIASA from February 22-26, 1988, on Expert Systems for Integrated Development: A Case Study of Shanxi Province, PRC.

The level of energy consumption is low: in 1985 its 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, with 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 600 Mtce in 1980 to 1200 Mtce by the end of the century; this means that, first of all, the technical remodeling of existing coal mines has to be accelerated; secondly, for long-term planning, the construction of new mines, in particular the exploitation of large open-pit coal mines, natural conditions permitting, must be emphasized; thirdly, 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 to 60 Gt. Deposits with about 5.5 M km² 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. The petroleum industry plans to double, by the year 2000, using 1980 as a base year, both the annual output of crude oil and of natural gas, to reach 200 Mt or more of crude oil and 250 x 10⁸m³ of natural gas. This means that they will have to emphasize geological exploration and increase investments for the production of oil. New regions must be explored and opened up for new types of oil-gas deposits with the application of modern science and technology, and new techniques (eg. 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 amounts 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 Mkw, China's water power reserves are first in the world (Wen, 1984). In 1986 only 4.2% of China's total primary energy consumption came from hydropower. The resources are distributed over the whole country, but mainly centered in the southwest regions. Despite the rapid growth of the *power industry* during the last 40 years the demands of the consumers have still not been satisfied. There are still serious shortages of electricity; the government has to accelerate the development of its power industry and to 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 moderately develop nuclear power plants to meet its goal to have 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;*) 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. Shanxi's raw coal production makes about 25% of the total Chinese coal production. Therefore Shanxi is a main component in China's coal supply and in the national economy.

*) Zhou Fengqi, *China's Energy Production Situation and a Global Analysis Model of the Coal Economy in Shanxi Province, PRC*, presented at the workshop held at IIASA from February 22-26, 1988, on Expert Systems for Integrated Development: A Case Study of Shanxi Province, PRC.

Some of the 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.

山西总体发展研究专家系统 Geographical Data Bases

IIASA

Legend:

city	*
major town	•
county boundaries	—
province boundaries	—
major rivers	////
major railways	—
major mines	●
mining areas	■
river basin	□
population	人

geographical db MENU:
edit geographical DB
industrial locations
cities database
display river basin
display major rivers
display major mines
display mining areas
display major railways
population database
EXPLAIN MENU OPTIONS
RETURN TO UPPER MENU

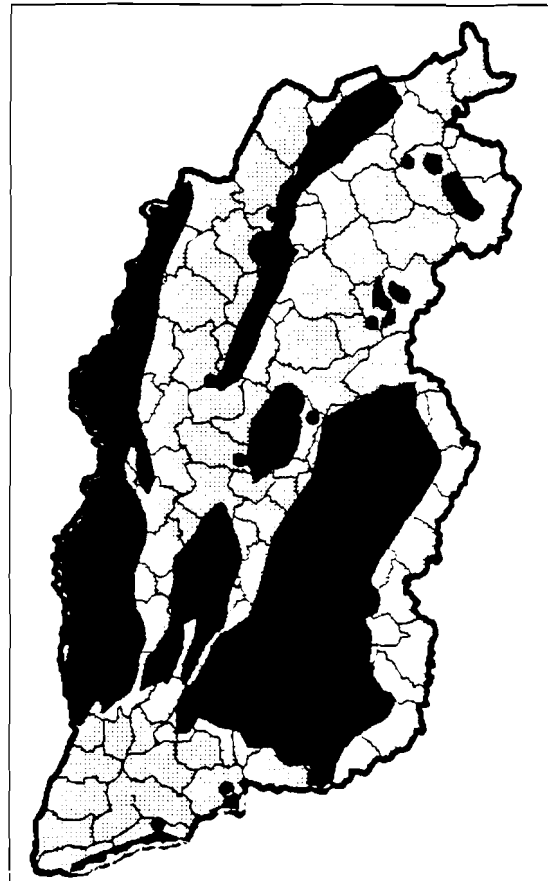


Figure 1: Shanxi's major mining areas

- 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 outstanding resource is coal, which spreads over an area of about 58,000 square kilometers, the estimated reserves are 860 billion tons and the proven reserves 200 billion tons; the coal also is of superior quality (ie. 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, therefore easy to extract). The export target (within China) for Shanxi is set to 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- and village-owned and individual coal mines, became more and more significant. These mines are relatively small, require relative low investment, are in operation after a short time period; but they also cause significant damage to the environment and contribute to the depletion of resources; they use poor technologies and 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; they are governed by the state or local governments; they will have to increase their efficiency and adopt new technologies and rational 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; The dryness of the region brings the annual evaporation 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 sideline 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 percentage of the mining industry in the total industrial output value is 26%; of 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 (32% of the total industrial output value, 210 million tons of output of raw coal in 1985, that is around one fifth of the annual production of the whole country). Coal from Shanxi is exported to 26 provinces and has significant influence on the development of their economy. The coal-fired power generation and distribution is concentrated about coal fields, large power stations generate more than 2.4 gigawatt at the Datong Second Power Plant connected via 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 (5% of the power industry of 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, liquefaction, 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* (main products are mining machinery, pumps, ventilators and compressors, electric appliances, farm machinery, etc.)
 - the light industry*, using mainly farm products as raw material.
- 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). 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%.

Electricity production 1,000 GWh		
datongcity	6.00	23.26%
ningwu	4.80	18.60%
yangquancity	2.40	9.30%
taiyuancity	4.80	18.60%
huoxian	3.00	11.63%
xiangning	0.60	2.33%
yunchengcity	1.20	4.65%
changzhicity	2.40	9.30%
jingchengcity	0.60	2.33%
TOTAL PRODUCTION:	25.80	100.00%

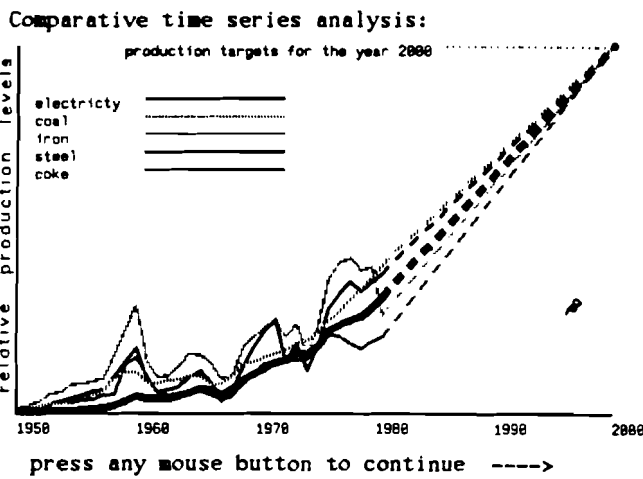
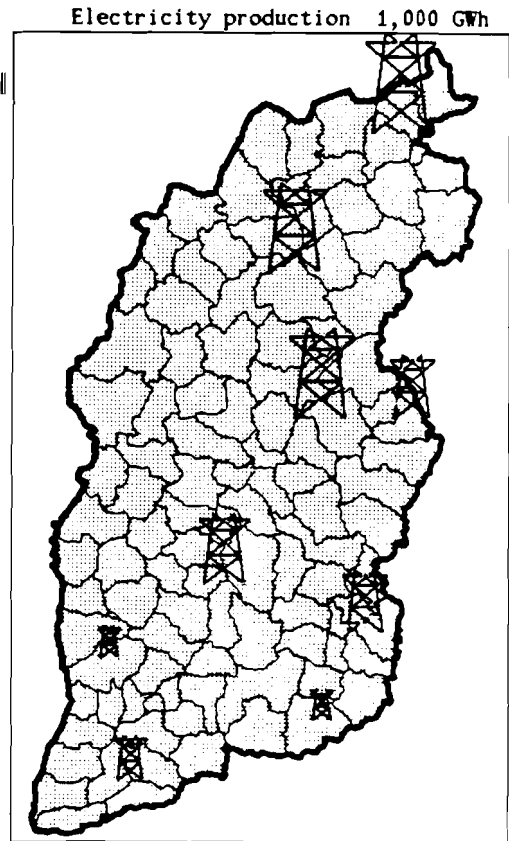


Figure 2: Spatial distribution of electricity production

- 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, namely air and water pollution, soil erosion.
- the shortage of skilled labor.

1.3. Components of the Overall System

The DSS developed should support the strategic planning of intergrated industrial development based on the existing resources (namely coal) and infrastructure, under the given constraints (eg. shortage of water and skilled labour, insufficient transportation, limited capital for investment), maximizing revenues from industrial production, minimizing external (ie. 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 as different layers: a macroeconomic level, representing the entire province; a sectoral level, ie. optimization and simulation models (eg. PDAS, describing a broad set of industries); inter-sectoral models, such as the water resources model MITSIM; and finally the data bases. Of course, there is considerable overlap in this classification.

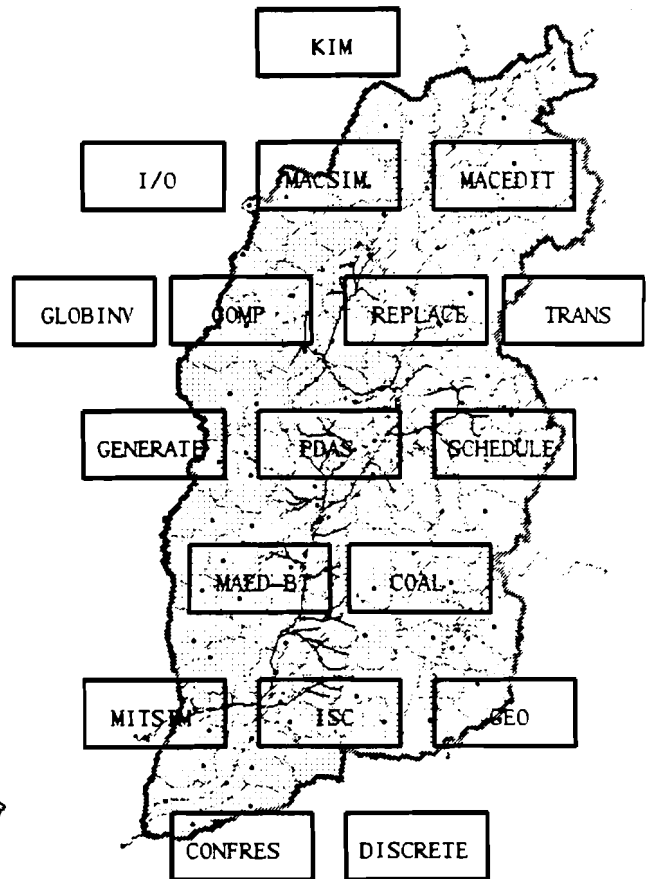
In its current form the system comprises the following major modules, in addition to the MAED-BI model described in this paper.

山西总体发展研究专家系统 ShanXi Regional Development DSS 

Prototype Release Version 2.0 July 1988
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This software system is developed under contract to State Science and Technology Commission (SSTCC) Beijing, The People's Republic of China, by the International Institute for Applied Systems Analysis IIASA, A-2361 Laxenburg, Austria.

ShanXi Development DSS MASTER MENU:	
Interactive Problem Definition	KIM
Long-term Macroeconomic Model	MACSIM
Economic Sector Interaction	MACEDIT
Input/Output Modeling and Analysis	I/O
Global Investment Analysis	GLOBINV
Macroeconomic Regional Comparison	COMP
Site-suitability Analysis	REPLACE
Transportation Systems Analysis	TRANS
Industrial Structure Optimization	PDAS
Global Energy Demand Analysis	MAED-BI
Global Coal Mining Sector Analysis	COAL
Water Resources Planning Model	MITSIM
Environmental Impact Assessment	ISC
Geographical & Regional Data Bases	GEO
Urban/Rural Economic Model	CONFRES
Multi-criteria Data Evaluation	DISCRETE
EXPLAIN ONE OF THE CURRENT MENU OPTIONS	
STOP AND EXIT DECISION SUPPORT SYSTEM	



select a menu item with the mouse (left button) ---->

Figure 9: Start-up screen of the Shanxi DSS

- **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 impacts each sector has on the other sectors with regard to seven indicators) showing the outcome of the user's investment decision for each sector, 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.
- **The I/O Model System** combines a number of classical econometric models of various degrees of aggregation (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 of the same 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, permits the exploration of feasible locations, requirements or constraints in locations for the siting of industrial or socio-economic activities in a certain region.
- **PDAS**, for *Production-Distribution Area, Spatial*, a linear and spatially disaggregated optimization model that describes a broad set of industries, including mining, the energy production sector, 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, ie. the distribution of production capacities (and thus investments and resources) to obtain a certain set of products under specific boundary conditions (eg. constraints on certain capacities or input materials) and minimizing or maximizing 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 eg. defined by PDAS, in terms of water availability and possible re-allocation.
- **ISC**, the air pollution model based on EPA's Industrial Source Complex model 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 multi-criteria 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, 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 a comparison with scenario, targets and results of the I/O model system possible. MAED-BI integrates a large number of products and provides a link with the macroeconomic level of each country or region studied.

MAED-BI also provides 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 and skilled labor, and capital). These indicators could be further taken into consideration by using them for some other modules; eg. 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; 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 co-exist 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 (Model for Analysis of Energy Demand in Basic Industries) 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 of 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—in the two following areas:

- the treatment of basic industries
- the link with the macro-economic 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. As finance and education are, together with energy supply, among the most important bottlenecks in the development process of developing countries, so investment and manpower are, 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 (cf. 3 below).

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 non-industrial 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. Further, the user will have to assess the results of the refined scenario within the framework of the overall macro-economic 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 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 (ie. products that could be exported or imported)
- evolution, over the period, of respective penetration coefficients for competing energy media (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 (1) steam, (2) direct heat and furnace (competitive uses) and (3) 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 of the feedstock uses)
- when all the economic sectors are integrated (SUN version), 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 potential of growth. 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-à-vis external macroeconomic and environmental constraints. The final results of these comparisons may lead to a reformulation of the scenario so as to release the current constraints. Then, new runs can be made until a satisfactory scenario is designed.

MAED-BI aims neither to deterministically forecast future economic development nor to find a hypothetical optimum for it. It is, rather, 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 given below:*

“**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)”.

“**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 ie. a consumer whose main economic activity is not the processing of energy; that includes activities of extraction eg. coal mining and crude oil production, but excludes processing of primary energies from the second type (ie. 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*).

*The quoted material is taken from Château and Lapillone (1982)

“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 a 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, ie. use for generating steam on the one hand and direct and furnace heat on the other hand, and can be satisfied out of 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 ($T < 120^{\circ}\text{C}$, $120^{\circ}\text{C} < T < 250^{\circ}\text{C}$, $250^{\circ}\text{C} < T$ for steam uses and $T < 350^{\circ}\text{C}$, $350^{\circ}\text{C} < T < 800^{\circ}\text{C}$, $800^{\circ}\text{C} < T$ 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. For more information about the specification of these data see Appendix A.

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 (Figure 4). Each process belongs to one economic sector and produces one unique main product, which is the process output, and possibly some co-products. Each product belongs to the sector to which belong(s) the process(es) producing it as (a) main product(s). Process inputs may be classified into two categories, namely:

- *Products*
- *Other inputs* which consist of (1) utilities (ie. direct and furnace heat, steam, electricity for mechanical and specific uses), (2) input and output water, (3) 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

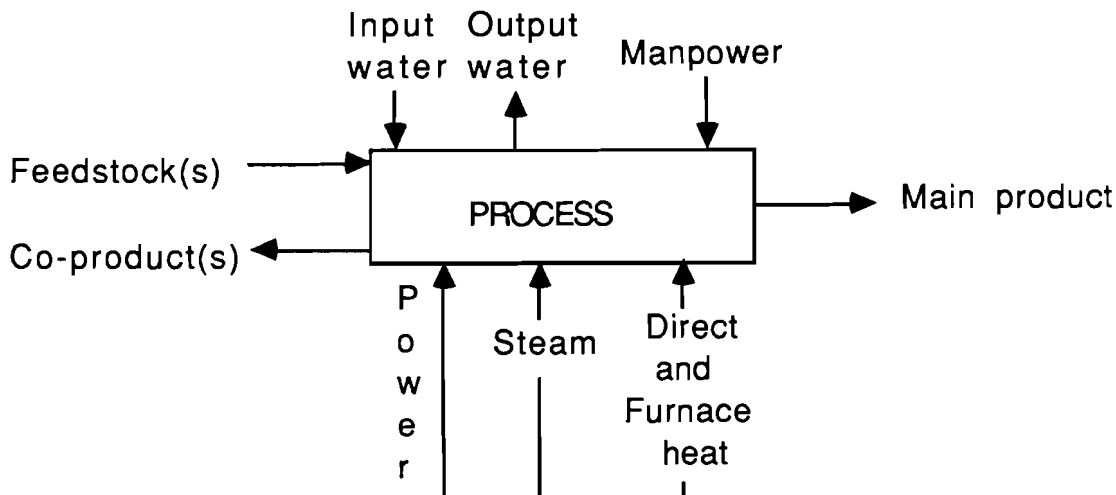


Figure 4: Input-Output representation of processes

- Intermediate products, used upstream* of final or energy products in production routes
- 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 (cf. Appendix A). A negative input is used in order to represent co-production. That makes the implicit assumption that exists an inflexible relation between the respective production levels of the main product and its co-product(s).

The model uses projections of final products production in order to calculate the demand for other products but does not aim to calculate any final product demand. Due to this fact, only final product inputs with a negative flow (co-production) are considered by the model; others, when specified, can be ignored.

Among the possible material inputs, some products, like most 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 a life time have to be stipulated for each process, in ord-

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

er 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 (cf. 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 will proceed 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 than one sector; such intermediates, which creates 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 (ie. common intermediate production) are skipped in a first time by the algorithm and are treated last by the model when the overall requirements addressed by different downstream production have been calculated, ie. 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 concerned 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. Anyway, each process is allocated to one scale level among the three available (large, medium, small); that 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 (cf. section 4.3). Further, the penetration coefficients of energy media, which are specified at each scale level, allow the user to simulate contrasted patterns of energy demand; for in-

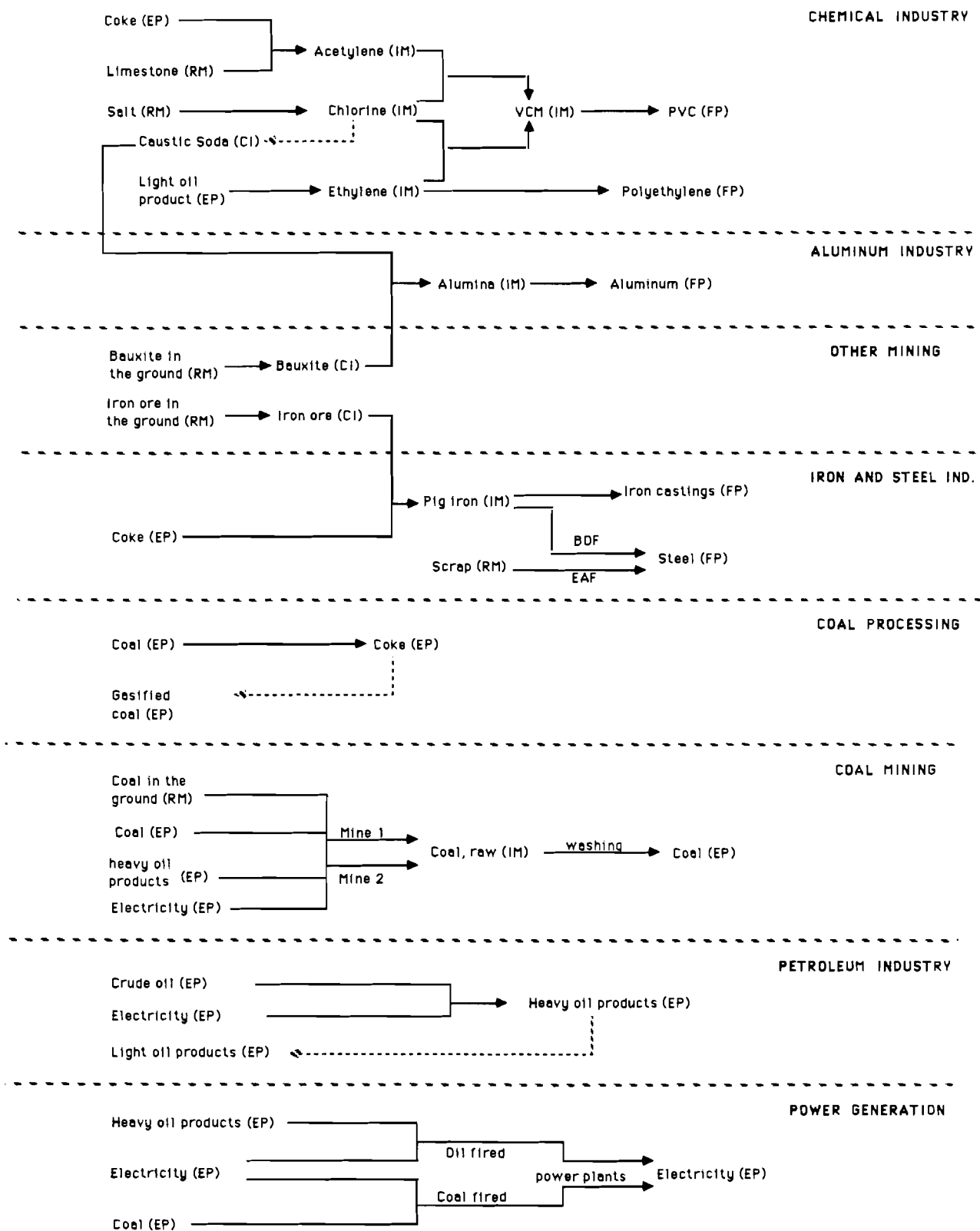


Figure 5: Process-product representation for some industrial sectors
 (RM, FP, IM, CI, EP are resp., for raw materials, final, intermediate, common intermediate and energy products; each arrow represents one process except hatched ones which are for co-production)

stance, 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 in italics below (*op. cit.* pp.190-191).

First of all, *"in order to explore the impact of structural changes in the socio-economic development on long-term energy demand, it is necessary to disaggregate the social, economic and technological system so as to be able to take these changes explicitly into account"*. The flexibility offered by MAED-BI in its representation of the *"social, economic and technological system"* must be used to 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, with, in the SUN version of MAED-BI, 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 (cf. Figure 6).

"Energy demand is induced by socio-economic determinants that is, by economic activities and by the satisfaction of social needs". These socio-economic 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 socio-economic need for mobility of persons (passenger/kilometers) or goods (ton/kilometers), or for space heating (number of flats). They may themselves be further disaggregated in order to consider different types of steel products, subsectors (with various energy intensities), kinds of goods, or classes of flats.

"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". Upstream of final production, any combination of processes and any technology alternative can be represented in MAED-BI eg. various possibilities available for steel production: from iron ore, through 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: (to 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 considered production activity); 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"*. 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 bal-

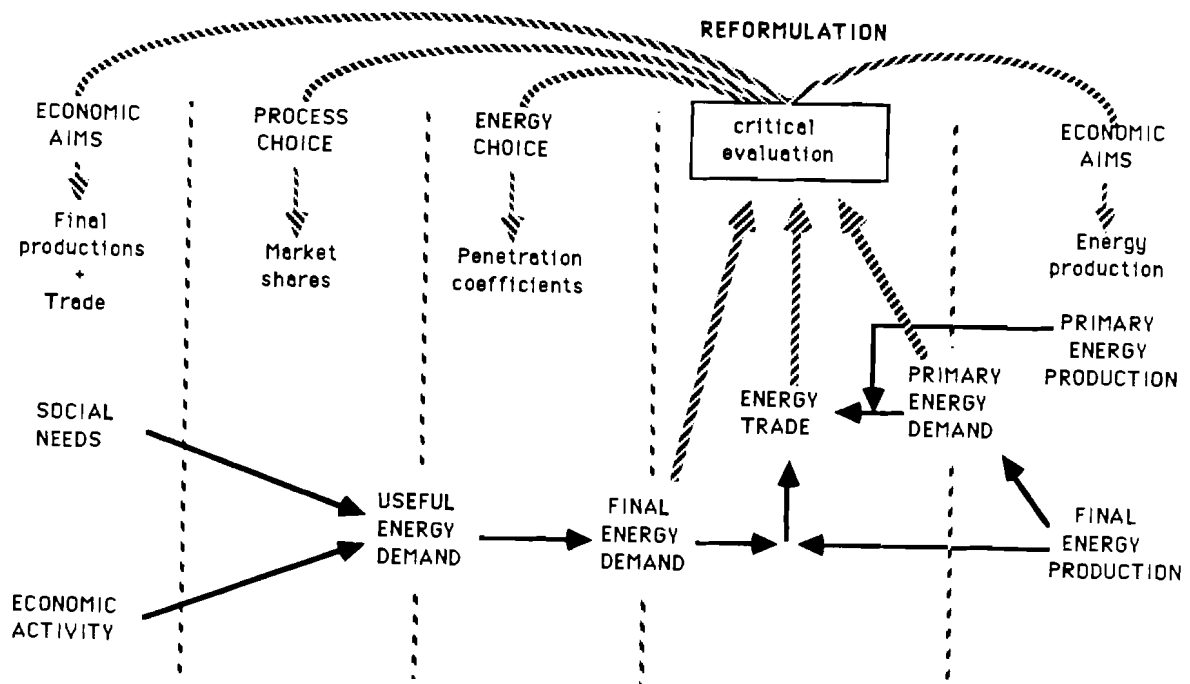


Figure 6: General scheme for energy demand analysis in MAED-BI

ance, 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 which consumes energy.

The breakdown of the sectoral final energy demand between energy commodities is facilitated by the disaggregation, pre-existing in the process representation, between non-substitutable (feedstock) energy uses, which are directly allocated, and substitutable ones. The allocation of the substitutable energy demand (not implemented in the PC version) 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). They indicate relative shares of different energy media in the satisfaction of precise parts of the energy demand for competitive uses.

Penetration coefficients which depend on a specific use (steam, heat) or temperature level (high, medium, low) eg. the relative share of high temperature steam raised by co-generation ie. 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 (ie. 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 (ie. 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 no penetration coefficient is specified for a given sector, its whole energy demand for substitutable uses is allocated to the balancing fuel.

When energy sectors are included (ie. in the SUN version), 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 here required that the energy inputs of any energy-producing technology be directly specified as feedstocks (ie. 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 it, some scenario assumptions may be adjusted or sensibly modified before a new run.

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 (cf. 3.2 process-product representation, above). This tree is constructed during the scenario definition. A *set of final products* (†) is first defined; then, the constitution of process-products pairs (ie. *process choice* (†) for this primary set determines normally 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, (ie. be empty or only contain raw materials or energy feedstocks). At this point, no process choice has to be formulated any more 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 (ie. not also co-produced). 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 here 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 co-products which are no more required or co-produced upstream in any production line of the sectoral tree are selected among the whole set of inputs.

For these, the overall requirement and co-production are raised by the production of the sectoral final products. Therefore, at this point it is known which amounts have still to be produced for satisfying their overall requirements, allowing for possible co-production. These products are thus 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 more a purely exogenous input. As a matter

The items marked by † refer to exogenous inputs, ie. which are part of the scenario definition.

of fact, two types of products may be encountered at this level:

- final products which have been co-produced before
- intermediate products (whether or not co-produced before).

In the first case, the co-production 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 co-production. This approach implies that when a product is obtained as a co-product, priority is given to the technology producing it as a co-product; technologies generating it as a main product just fill up the gap left by these. 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, that is until the new resulting set of products contain no more intermediates. When all sectors have been treated, the set of common intermediates is introduced in 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.

This last step being completed, the production structure is completely determined and, with it, the cumulative requirements of the respective inputs that are required as well as the implementation planning of new capacities for all the considered technologies. Among the inputs: the requirements of utilities (ie. heat, steam, power), energy feedstocks, input and output water, 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) (cf. Figure 5). The requirements of monomers (ie. ethylene and vinyl chloride (VCM)) for producing these products are calculated in a first time (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. So, after having allowed for a possible trade of VCM, 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, 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, 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, trade having been taken into account, the input requirements for producing chlorine are calculated. Chlorine being a chemical product, the demand of 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 before according to the procedure described in section 3.3 dealing with the methodology of energy demand analysis. 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 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 reference for the sectoral final energy demand. Then, (on the SUN version), the substitutable part of the final energy demand is allocated among the different energy commodities according to *penetration*

coefficients (\dagger) (cf. 3.3 above). 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 (ie. coal, natural gas, crude oil, biomass) or as a secondary energy demand (ie. products of oil and coal processing, 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 before. An implicit assumption of this way 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 (ie. upstream) getting the properly so-called "(primary energy) coal" (cf. Figure 5). It would be, nevertheless, 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 (\dagger) and its final and primary or secondary demand. In the case of electricity, the relative part of production which is lost on the distribution network (\dagger) is deducted before calculating electricity trade, which relates to electricity as a whole (ie. primary and secondary electricity). Biomass is considered as non-tradable and thus its production is set equal to the level of the 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) they concern, 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*) (\dagger) according to its market share in 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 (eg. 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, eg. 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 (eg. 50,000 tons/year). At 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* (\dagger), eg. 90%), of the reference capacity, a new unit of this capacity is planned for construction a few years before (in accordance with the standard construc-

tion 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 of the description of each individual plant on stream at the base year, with indication of its capacity, start-up year and, possibly, anticipated shut-down year. The initial capacity decreases over the period according either 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 (cf. 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.

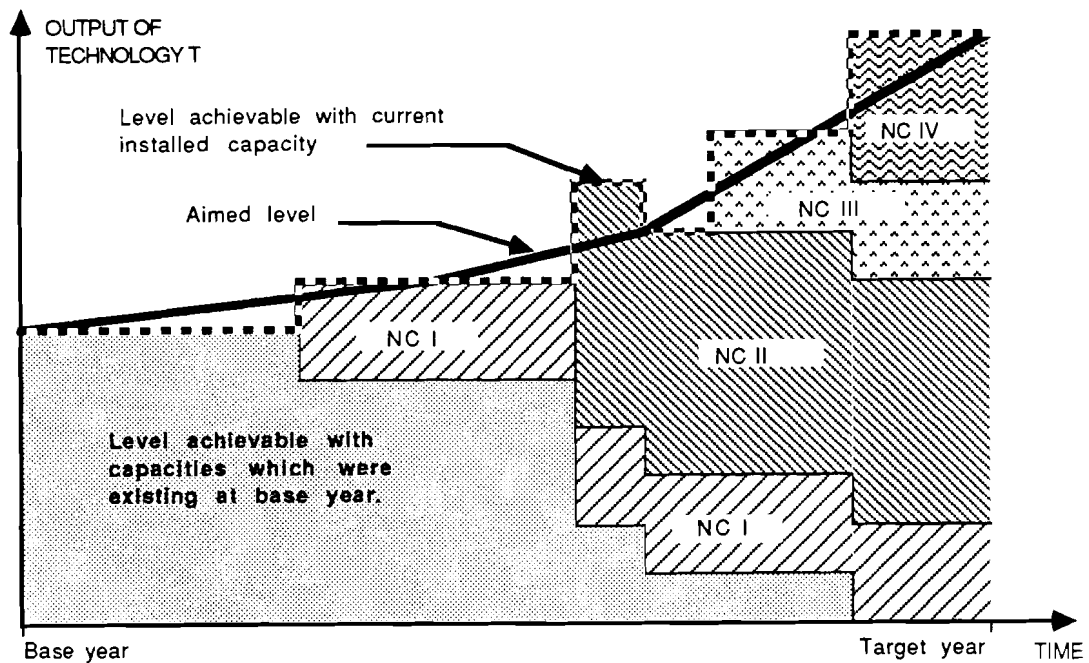


Figure 7: Determination of new capacities (NC)

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 reference. The existing capacities are evaluated to their value of replacement and the expenditure for maintaining this capital stock is set to a fixed percentage (eg. 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 at this year, is simply the product of the number of new units of the reference capacity needed at 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 so as 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 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

For the time being, MAED-BI has been implemented in the framework of two case studies, one of the Brazilian cement and fertilizer industries for the period 1970-1983, the other for all the economic sectors of Shanxi province, PRC, for the period 1985-2000.

The first implementation was for the International Atomic Energy Agency (IAEA), Vienna, with the PC version, in order to test the methodology and the program on a real-life situation. The results for the cement industry (cf. Figures 8, 9 and 10) are quite good due to the excellent statistical and engineering data* obtained. For the fertilizer industry, inconsistencies appeared in the data about trade and production collected from national directories, essentially concerning the phosphatic fertilizers, therefore, it was difficult to obtain significant results.

The second implementation is a part of the Shanxi DSS. Here 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, facilitates the scenario definition. The present implementation is based on a basic disaggregation of the economy into 24 sectors, (corresponding to those in the input-output model, plus households and administration). It incorporates about 200 products and as many technologies. A data set for MAED-BI was provided by the Shanxi provincial government. The technology data base used by this model, as well as several others in the overall DSS, was developed by the Institute for Chemical Technology of the GDR Academy of Sciences.

6. 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 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 (eg. 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 one data set, implemented by Mr. Jiang, PRC, and one implemented in China by members of the Institute for Chemical Technology, GDR Academy of Sciences, together with local experts). This choice defines the economic development scenario.

*)The input data needed by MAED-BI for this industry were taken or estimated from the CEMBUREAU directories (CEMBUREAU 1965, 1976, 1978, 1980) for data on initial capacities, and market shares, from the publication *Cimento e Desenvolvimento* (Sindicato Nacional da Industria do Cimento, 1985) for data on production and trade, from Fives-Cail Babcock (Paris) for technology descriptors.

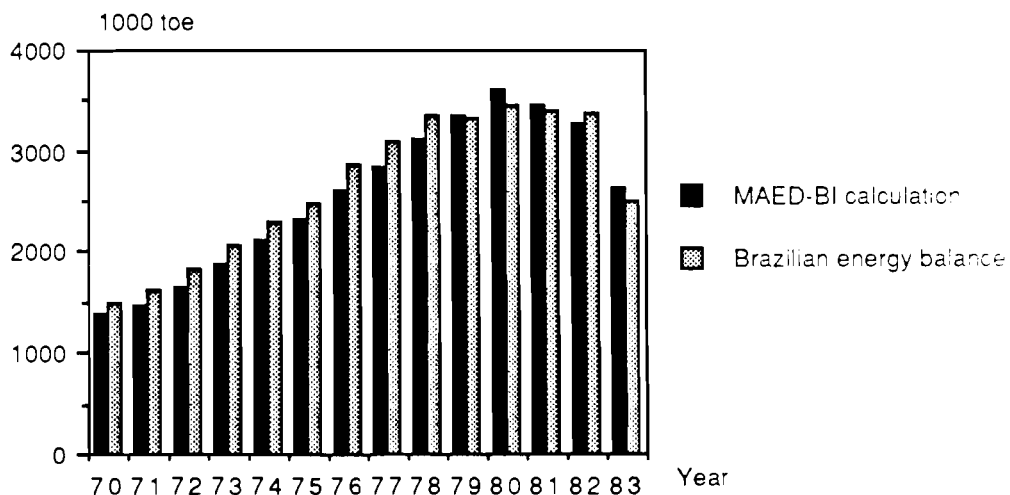


Figure 8: Total final energy demand of the Brazilian cement industry

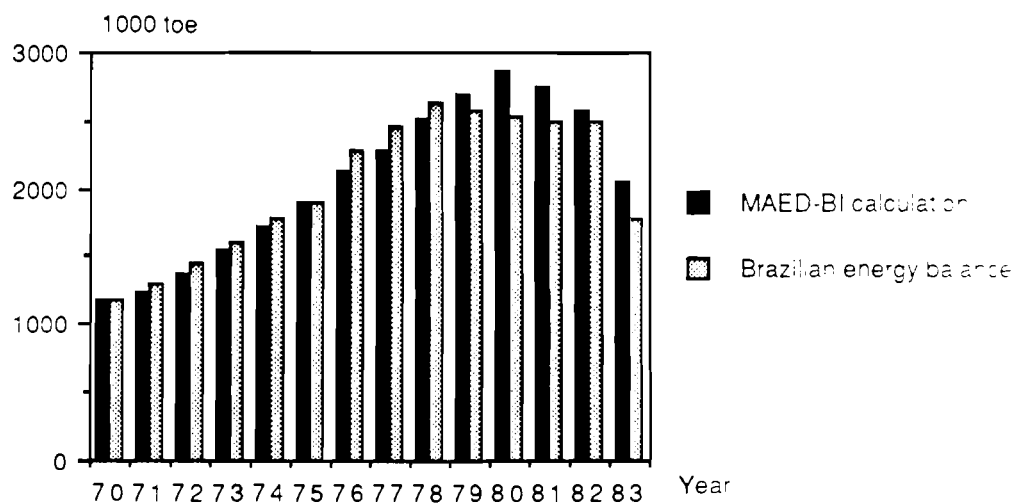


Figure 9: Final fuel demand of the Brazilian cement industry

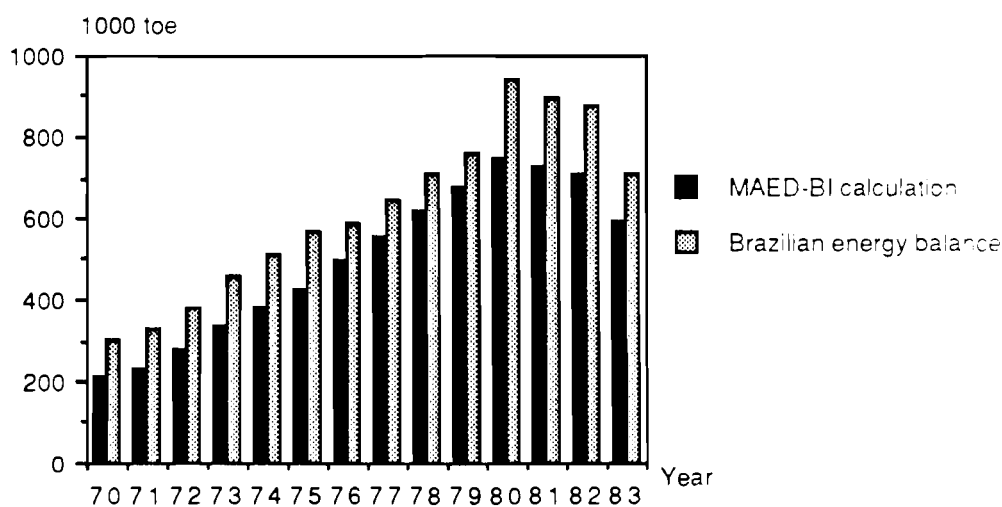


Figure 10: Final electricity demand of the Brazilian cement industry

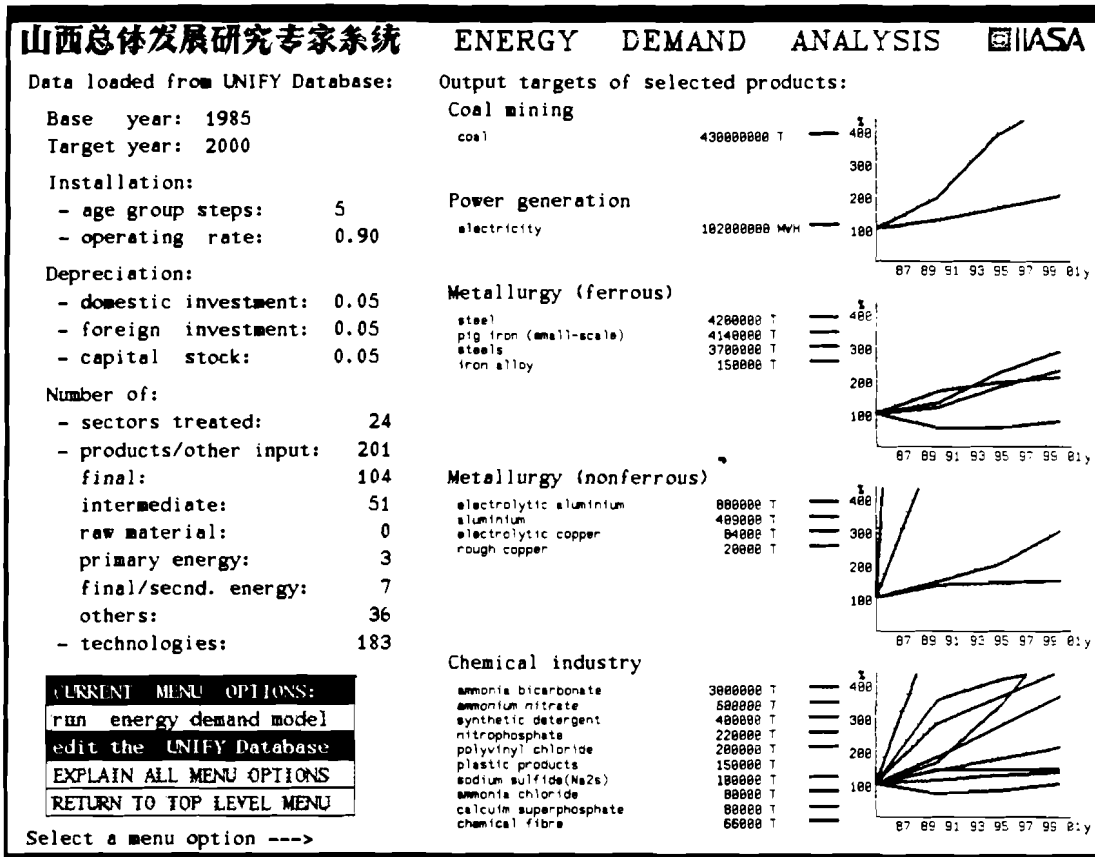


Figure 11: MAED-BI Start-up page

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 chemical industry), such as coal, electricity, etc. (see Figure 11). 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.

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 12), aggregated over all sectors. The summary includes basic descriptors, ie. final energy demand (electricity, coal, oil, gas, coke, liquefied coal, gasified coal, biomass), water demand (input water, output water), demand of labor (unskilled, clerical, and technical labour), and investment (cumulative investment and year-

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ENERGY DEMAND

ANALYSIS IIASA

	base 1985	target 2000	relative increase
FINAL ENERGY DEMAND (1000 tce)			
Electricity	430.3	500.5	16.3%
Coal	20790.6	20889.8	0.5%
Oil	0.0	0.0	
Gas	4955.1	4955.1	0.0%
Coke	0.0	0.0	
Liquified coal	0.0	0.0	
Gasified coal	0.0	0.0	
Biomass	0.0	0.0	

WATER DEMAND (Mm3)

	base 1985	target 2000	relative increase
Input water	100.1	101.2	1.1%
Output water	5.3	10.7	103.6%

LABOUR (Mmanhours)

	base 1985	target 2000	relative increase
Unskilled	24.3	25.0	2.9%
Clerical	56.2	76.0	35.2%
Technical	32.7	78.9	141.4%

INVESTMENT (million 1985 Yuan)

	base 1985	target 2000	relative increase
Cumulative investment	12.7	144.8	
Yearly investment	12.7	6.1	-51.9%

- OUTPUT OPTIONS:
- primary energy forms
- secondary energy forms
- output by sector
- output by indicator
- EXPLAIN MENU OPTIONS
- RETURN TO UPPER MENU



Final energy demand



Labour

SUMMARY OF RESULTS:

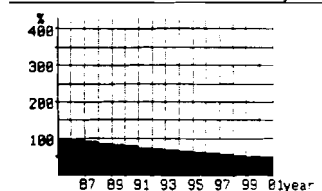
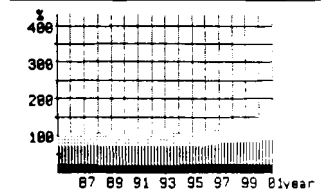
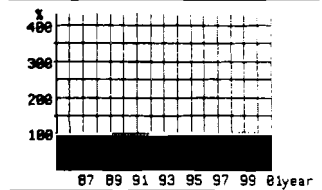
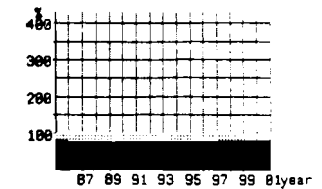


Figure 12: General output page

ly investment), for the base and the target year, as well as the relative increase between 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:

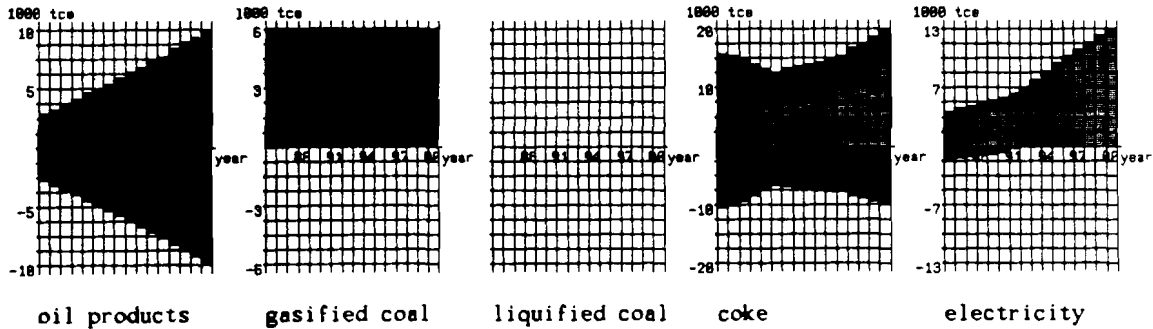
- *primary energy forms*: shows a page on demand, import, export and production of the primary energy forms (crude oil, biomass, coal, natural gas, electricity) including their time evolution over the period in the form of graphs (one per primary energy form) on the top half of the screen, as well as 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, see Figure 13) 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)
- *sector-specific output*: shows disaggregated results for one sector chosen from a list of the 24 sectors (see Figure 14) represented in MAED-BI.

For the chosen sector, the same type of information and display is shown as on the summary page on the models result (see also Figure 12).

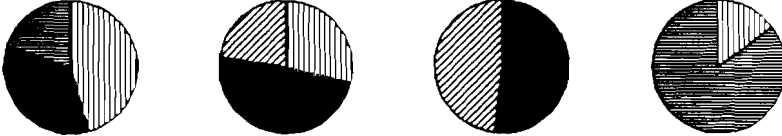
- *output per indicator*: the user chooses one subindicator on the screen (eg. coal, see Figure 15) to see a disaggregation of the result per indicator (as opposed to a disaggregation per sector); the demand calculated by MAED-BI for the specified in-

山西总体发展研究专家系统 ENERGY DEMAND ANALYSIS IIASA

SECONDARY ENERGY FORMS : Production: — Demand: ■ Import: ■ Export: ■



RELATIVE DISTRIBUTION OF SECONDARY ENERGY FORMS FOR THE YEAR 2001:



	production	demand	import	export
oil products	0.0000 %	22.7447 %	47.8645 %	0.0000 %
gasified coal	19.9310 %	0.0000 %	0.0000 %	85.3777 %
liquified coal	0.0000 %	0.0000 %	0.0000 %	0.0000 %
coke	34.4997 %	48.3940 %	52.1355 %	0.0000 %
electricity	45.5692 %	28.8613 %	0.0000 %	14.6223 %

press any button to return to upper level --->

Figure 13: Primary energy forms

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: agriculture, heavy industry, light industry, construction, transportation, commerce and administration), including a pie chart on the overall sectoral share of the demand of the chosen indicator in the target year.

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.

7. 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; 1974) especially suitable for the quick and easy development of user applications (for a detailed description, refer to Sun Microsystems, 1986).

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 (eg. 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.

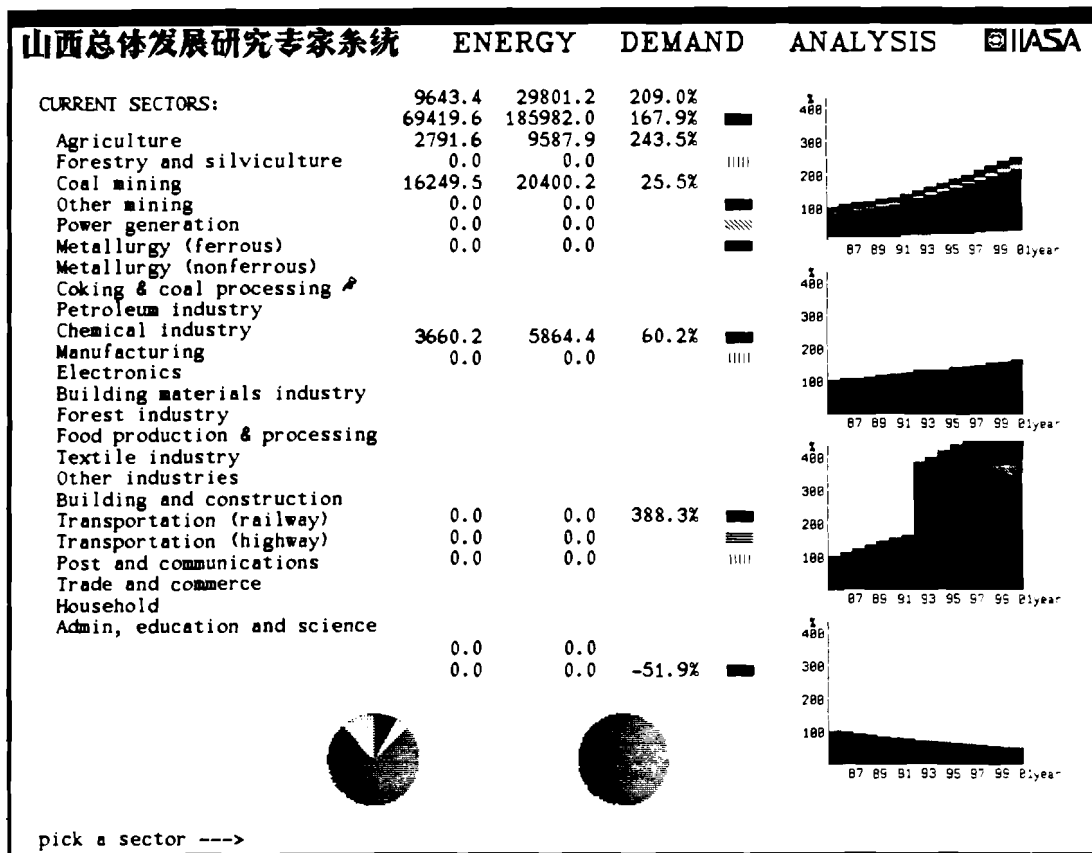


Figure 14: Choose a sector for disaggregated results

The standard window (see Figure 16) 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 (eg. definitions of tables, properties, browsing through the data base). For each record type (topic or subtopic) to be 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 16) 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 (eg. field name, primary key, data type, etc.).

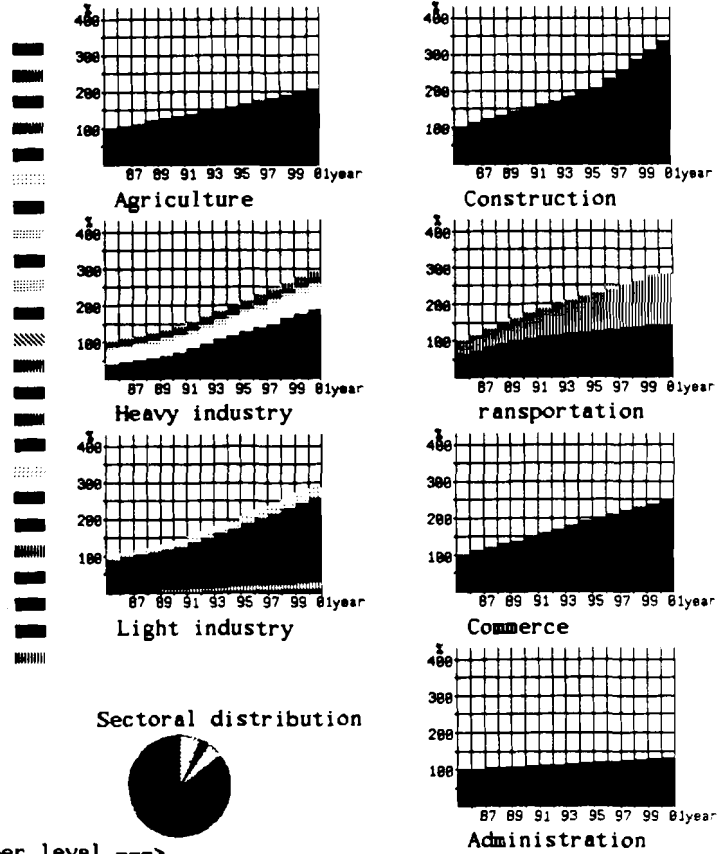
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ENERGY DEMAND ANALYSIS

IIASA

INDICATOR CHOSEN: Coal

- Agriculture
- Forestry and silviculture
- Coal mining
- Other mining
- Power generation
- Metallurgy (ferrous)
- Metallurgy (nonferrous)
- Coking & coal processing
- Petroleum industry
- Chemical industry
- Manufacturing
- Electronics
- Building materials industry
- Forest industry
- Food production & processing
- Textile industry
- Other industries
- Building and construction
- Transportation (railway)
- Transportation (highway)
- Post and communications
- Trade and commerce
- Household
- Admin, education and science



press any button to return to upper level ---->

Figure 15: Output per Indicator

- *datbrowse* is a program to interactively browse and edit a data base. All data manipulation again is done via the mouse (different from eg. 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 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.

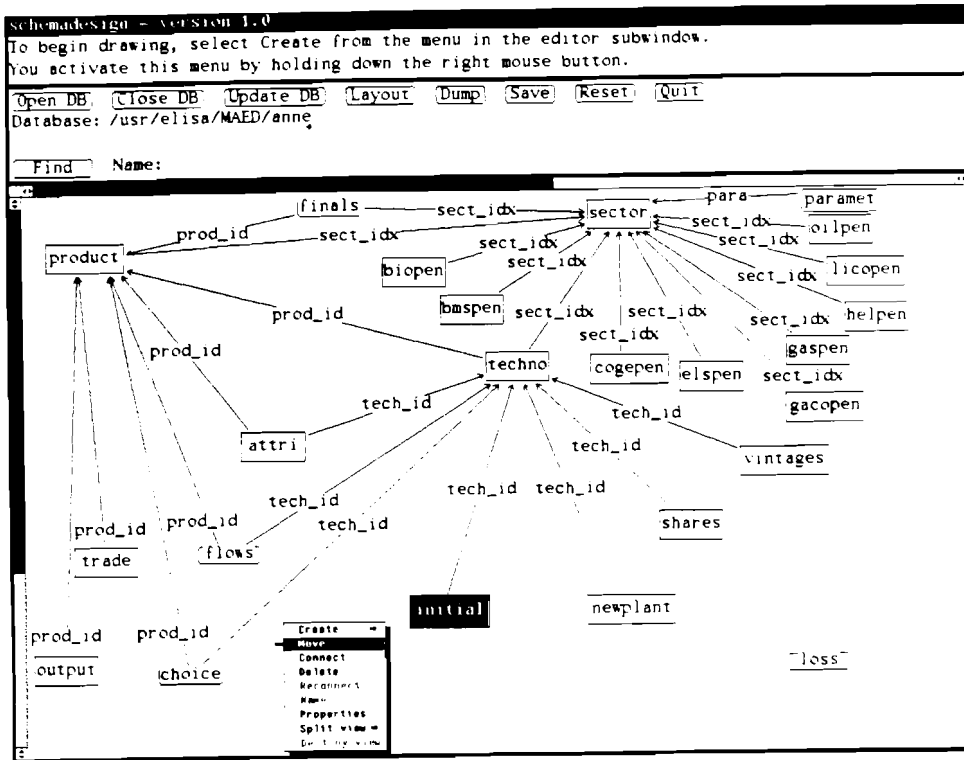


Figure 16: *Schemadesign* structure of the MAED-BI data base

The basic structure of the data base developed with *schemadesign* is shown in Figure 16: 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 socio-economic system. These pairs are ordered by sectors in order to pursue a disaggregated analysis of the socio-economic system and to fit the sectoral breakdown of other models included in the Shanxi case study (eg. input/output model). Therefore, data relative to process, products and sectors are fundamental to the model's application. A detailed description of the data base structure is given in Appendix C (Tables and Properties). The properties within a table are described by their name, an abbreviated name (used for C routines to load the corresponding field), the type of data (string, numerical, combined fields, etc.), the length of the field, and either the reference to another table or the reference to the corresponding field declaration in C. The primary (unique) key for a table is marked with an asterisk.

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APPENDIX A: SPECIFICATION OF INPUT FLOWS

1. Indexes

Indexes are used in order to identify products (as well as sectors and processes) within the system. Concerning other inputs (cf. process representation), the case is different between the SUN version where products and other inputs have a similar place in the DB structure, (other inputs are identified by specific indexes), and the PC version where information about other inputs is recognized through its specific place in the input data file (no use of indexes). The only constraints concerning the index of one non-energy product are that it must be unique and not equal to zero. For energy products, (and also other inputs in the case of the SUN version), which have a central place in the model calculations, indexes to be used are those listed in the include file para.h (cf. Software Cross-reference Manual) between the definition of the symbolic codes which refer to each of them within the program and some brief comments. This situation has important practical consequences:

- indexes for energy product and other inputs cannot be changed without recompiling
- changing the list of energy products or introducing new energy products implies some modifications in the program itself.

(NB: These last restrictions do not concern non-energy products)

2. Units

Input flows are specified in their respective units, per unit of the main product. The unit choice is free for every product except energy products (cf. below). As an example, let us consider the process for the synthesis of urea from ammonia and let us assume that both products have the metric ton as the unit; a value of 0.58 for the input flow of ammonia means that 0.58 ton of ammonia are required in order to synthesize one ton of urea. Among the others inputs, the imposed units are: ton for steam and water, manhour for manpower, and MWh for power. Concerning the inputs of heat and energy feedstocks the following considerations must be taken into account.

3. Special case of energy feedstock and direct or furnace heat inputs

For the same energy commodity, the SUN version of MAED-BI may use up to 5 different indexes in its calculations. This is due to the input-output representation which is energy-use oriented. So, beside the index identifying the commodity (and under which reference the aimed production level as well as the demand and trade addressed to the commodity are stored), 4 indexes are used in order to differentiate among the 4 energy uses for which an energy commodity E may be input in a process:

- feedstock use
- use for producing high temperature direct or furnace heat
- use for producing medium temperature direct or furnace heat
- use for producing low temperature direct or furnace heat.

(NB: Under feedstock use, the non-competitive use by a technology of the specific energy commodity E should be specified, for instance, the use of coke in a blast furnace).

Thus, an input of one energy commodity in a process must be specified under one of these 4 categories; (if the commodity were used for raising steam, the input would have to be specified as a steam input at one of the three available levels of temperature). The unit used for measuring the input flow is a physical unit, the metric ton (per unit of main product produced by the considered process).

Besides this, any energy commodity input belonging to one of the last 3 categories may be alternatively represented as input of, respectively:

- high temperature direct or furnace use
- medium temperature direct or furnace heat
- low temperature direct or furnace heat.

The unit is now an energy unit, the Gigajoule (GJ) per unit of main product produced by the considered process.

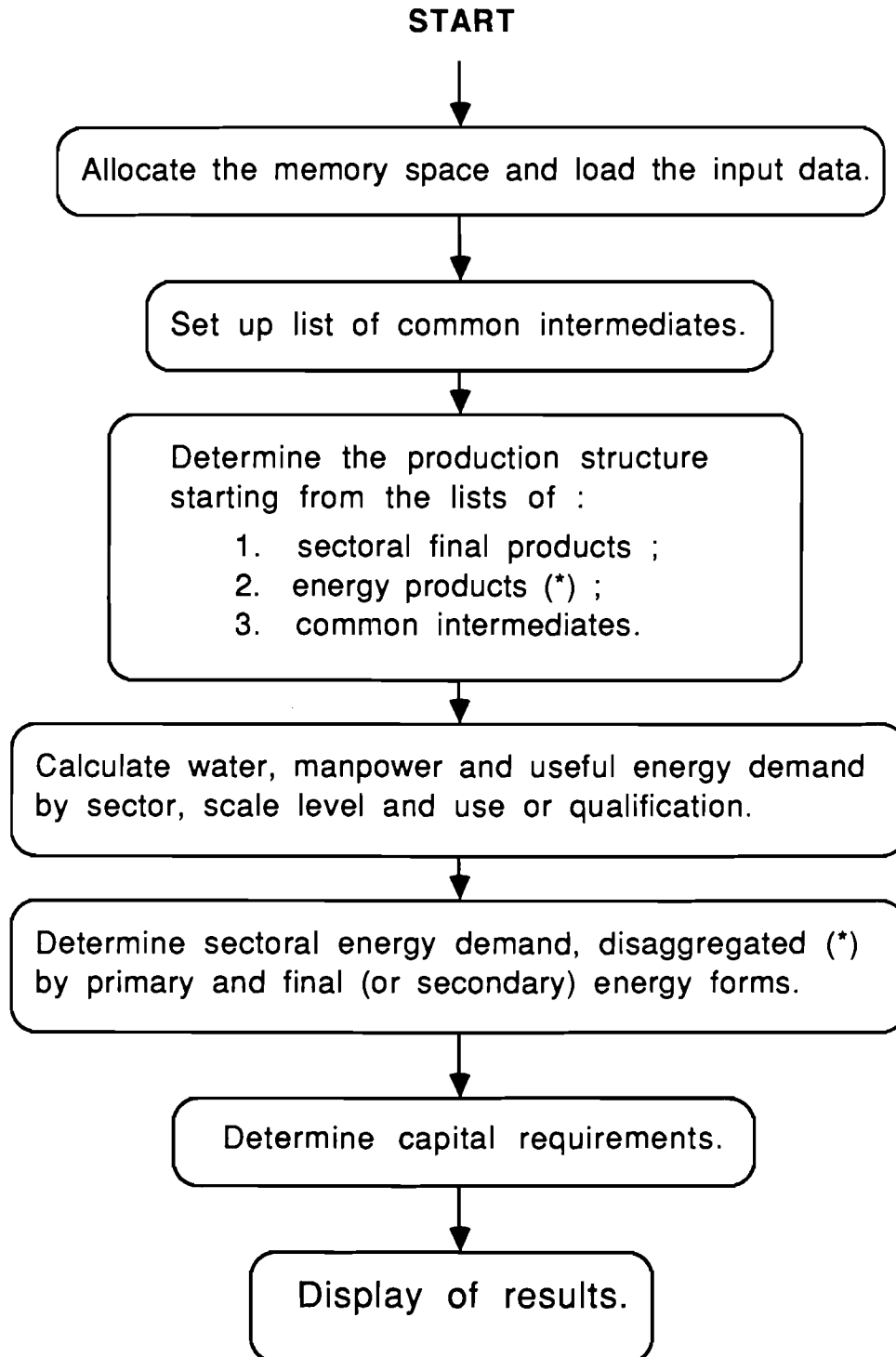
It is worthwhile noting that the first option, which leads to a multiplicity of indexes for the same commodity, allows the automatic conversion from physical values of energy input data (in tons), to their energy values (in GJ) but has absolutely no impact on the energy demand structure. As a matter of fact, in MAED-BI, one heat input corresponds to a use which is not captive of a specific energy commodity, that is a use subject to energy substitutions; (otherwise, it should be specified as a feedstock use). So, whenever an heat input is specified in physical units of a given energy commodity, it is converted during the program execution to its equivalent energy content, in GJ, according to the relevant heating value and stored at the place it would have occupied if it would have been specified directly in GJ according to the second option. There is, thus, no fundamental difference between the two modes of specification; whatever specification is chosen, a similar requirement for heat will be calculated, in energy units, and, later on, allocated among the different energy forms, as part of the whole substitutable energy demand of one sector, according to penetration coefficients. So, whenever information about energy input flows have been obtained in physical units, a trade-off must just be found between the automatic conversion, using the small fixed set of heating value coefficients provided by the system (first option), and the more flexible, but more time-consuming, individual conversion of given input data with, possibly, better fitted coefficients (second option). Data corresponding to feedstock uses must be specified in physical units (ie. tons) anyway.

In the PC version, the specification of any heat, (as well as feedstock), input is in energy unit, GJ (ie. no automatic conversion is provided) and the index used for identifying an input as feedstock is that of the respective energy commodity. There is thus only one index per energy commodity and no use of heating values within the system.

NB: In any case, the indexes that have to be used are those predefined in the include file para.h (cf. Software Cross-reference Manual).

APPENDIX B: FLOW CHARTS OF MAED-BI

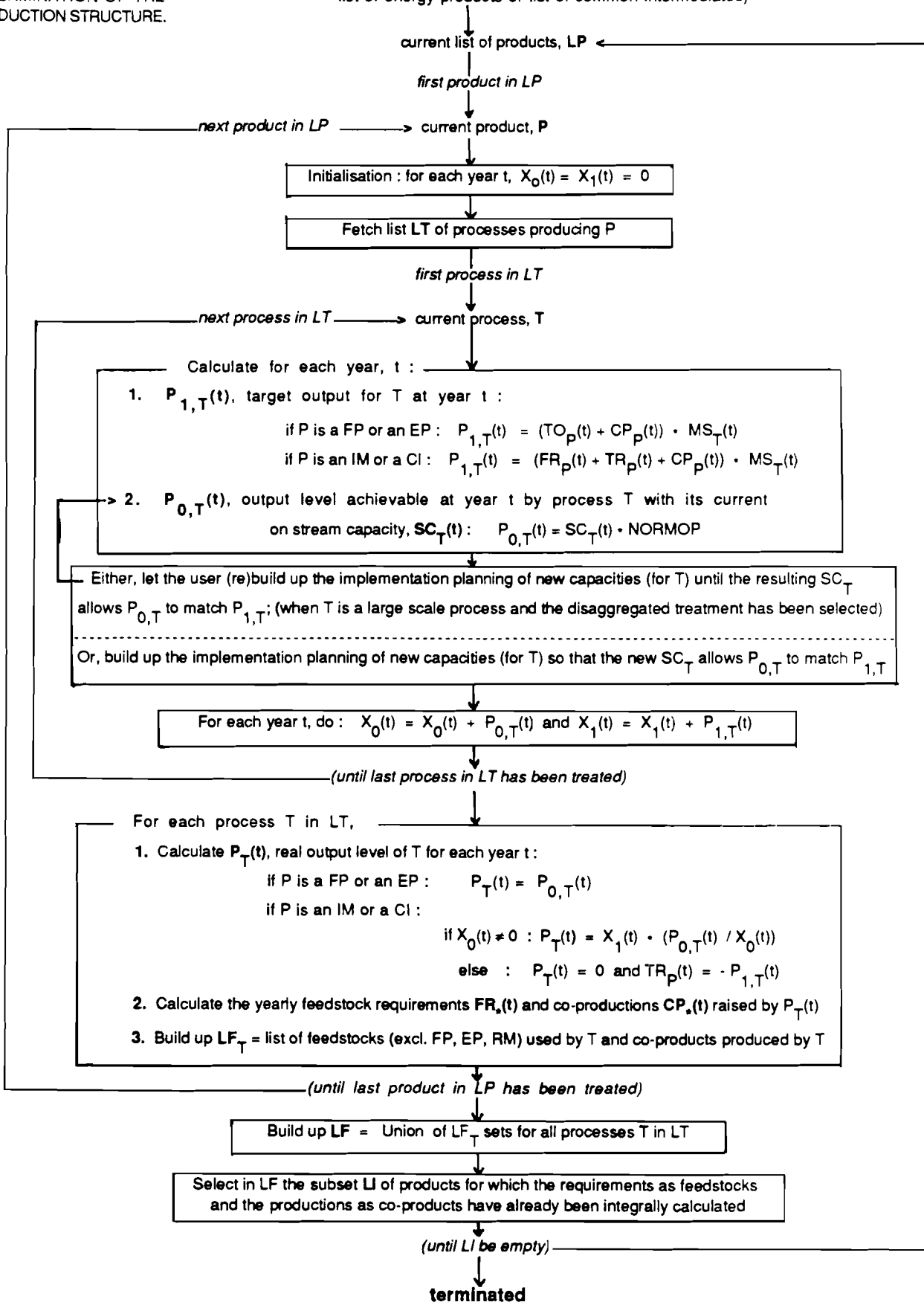
ORGANISATION of the MAED-BI COMPUTER PROGRAM :



(*) : only implemented on the SUN version.

FLOW CHART :
DETERMINATION OF THE
PRODUCTION STRUCTURE.

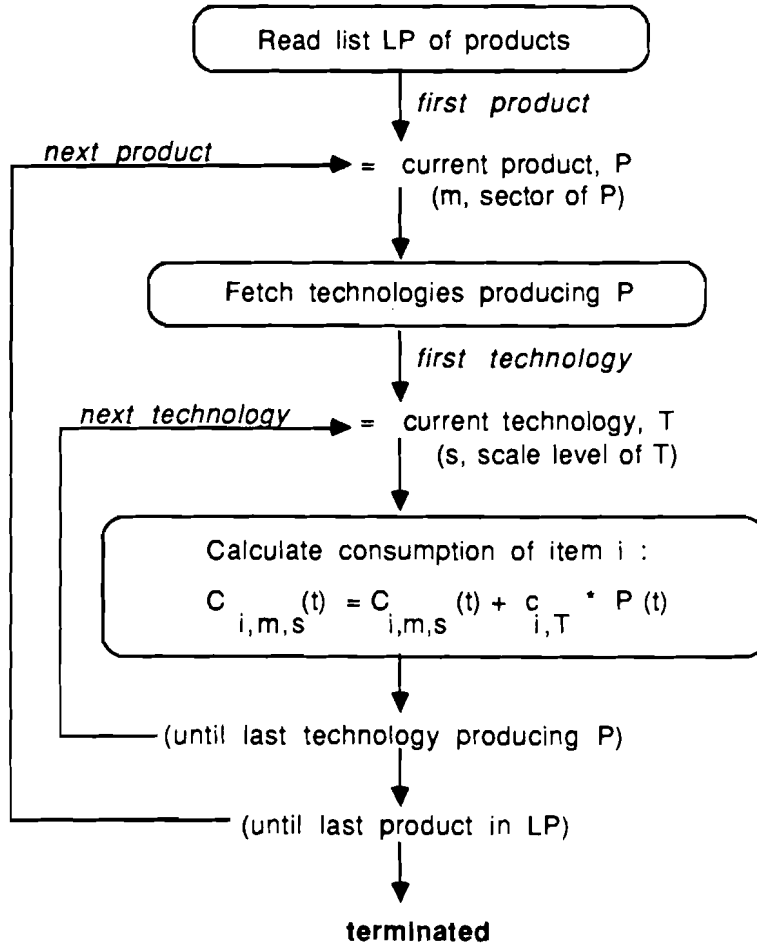
Starting list of products (i.e., list of sectoral final products,
list of energy products or list of common intermediates)



LEGEND of flow chart "Determination of the production structure" :

- t = current year ;
- $TO_P(t)$ = current target output for (final) product P ;
- $CP_P(t)$ = current amount of product P produced as co-product ;
- $FR_P(t)$ = current amount of product P required as feedstock ;
- $TR_P(t)$ = current amount of product P which is traded (exported or imported) ;
- $MS_T(t)$ = current market share of technology T in the production of P, (main product of T) ;
- NORMOP = Normal operating rate (i.e, ratio of the production to the installed capacity which is considered as normal) ;
- RM, FP, IM, CI, EP are respectively for raw materials, final, intermediate, common intermediate and energy products.
-

CALCULATION of WATER, MANPOWER and USEFUL ENERGY DEMAND by SECTOR, SCALE LEVEL and USE or QUALIFICATION.



LEGEND :

$C_{i,m,s}(t)$: aggregated consumption of item i (steam, heat, power water or manpower) at scale level s and at year t ;

$c_{i,T}$: specific consumption of item i by current technology T ;

$P(t)$: amount of current product P produced by T at year t.

DETERMINATION OF SECTORAL ENERGY DEMAND

A. For each scale, year, calculate :

- (1), electricity demand for direct heat and furnace uses at each level of temperature :

$$(1) = \sum_T [\text{HEAT}(T) * \text{pen}(1, T)] ;$$
- (2), biomass demand for direct heat and furnace uses at each level of temperature :

$$(2) = \sum_T [\text{HEAT}(T) * \text{pen}(2, T)] ;$$
- (3), remaining demand for direct heat and furnace uses (satisfied with conventional fuels) : (3) = HEAT - (1) - (2) ;
- (4), contribution of on-site cogeneration to steam raising : (4) = $\sum_T [\text{STEAM}(T) * \text{pen}(4, T)] ;$
- (5), fuel demand for cogenerating steam : (5) = (4) / EFFCOG ;
- (6), remaining energy requirements for steam raising (satisfied by (conventional) boilers) :

$$(6) = \text{STEAM} - (4) ;$$
- (7), electricity demand for boilers : (7) = (6) * pen(7) ;
- (8), remaining energy requirements for steam raising (satisfied with fuels) :

$$(8) = (6) - (7) ;$$
- (9), total demand of fuel for steam raising : (9) = (5) + (8) ;
- (10), biomass contribution to steam raising : (10) = (9) * pen(10) ;
- (11), remaining energy requirements for steam raising (satisfied with conventional fuels) :

$$(11) = (9) - (10) ;$$
- (12), total demand for conventional fuels : (12) = (3) + (11) ;
- (13), total demand for biomass : (13) = (2) + (10) ;
- (14), contribution of on-site cogeneration to the electricity demand : (14) = (5) * HELRAT ;
- (15), total demand for electricity : (15) = SPEL + (1) + (7) - (14) ;
- (16, i), demand for each conventional fuel i (excl. balancing fuel) : (16,i) = (12) * pen(i) ;
- (17), demand for balancing fuel : (17) = (12) - $\sum_i (16, i) ;$

B. Then, Calculate :

- (18, j), setoral energy demand for each energy energy form j ; (18, j) is obtained by aggregating the results (13), (15), (16, i) and (17) upon the three scale levels and adding the demand for j raised by feedstock uses (and calculated before with the production structure) ;
- (19), total setoral energy demand : (19) = $\sum_j (18, j) ;$
- (20), ratio of setoral energy demand as available from statistical sources or estimated, (findem0), to the value calculated by the model : (20) = findem0 / (19)_{base-year} ;
- (21, j), definitive results of setoral energy demand for each energy form j : (21, j) = (18, j) * (20) ;

Terminated.

LEGEND of flow chart "Determination of sectoral energy demand" :

- HEAT(T) = heat requirement for direct heat and furnace use at the T temperature level for the current sector, scale and year ;
- HEAT = $\sum_T \text{HEAT}(T)$;
- STEAM(T) = steam requirement at the T temperature level for the current sector, scale and year ;
- STEAM(T) = $\sum_T \text{STEAM}(T)$;
- SPEL = electricity requirements for mechanical and specific uses for the current sector, scale and year ;
- EFFCOG = system efficiency of cogeneration ;
- HEL RAT = ratio heat/electricity in cogeneration systems ;
- pen(*, T), pen(*) = for the current sector, scale and year : penetration coefficients of the different energy medias in the respective parts of the energy demand, (possibly temperature specific).

NB : In the PC version of MAED-BI, the part A is simplified and works exactly as if all penetration coefficients were equal to zero.

APPENDIX C:

1. TABLES AND THEIR PROPERTIES

Note: The meaning of default values is that the system *behaves as if* the corresponding variables were set to the values indicated as default and possibly *different* from the values which may appear in the DB, if these are not valid.

PARAMET TABLE :

paramet paramet 1

*title	pa_title	Str	40
enter	pa_enter	Num	1
result	pa_outpu	Num	1
implepla	pa_imple	Num	1
base_year	pa_base	Num	4
nb_years	pa_nb_je	Num	2
nb_products	pa_nb_pr	Num	3
nb_technos	pa_nb_te	Num	3
tec_pro	pa_tec_p	Num	1
agestep	pa_agest	Num	1
normop	pa_normo	Real	4.2
maint	pa_maint	Real	5.3
domact	pa_domac	Real	5.3
foract	pa_forac	Real	5.3

Table storing basic parameters required for operating MAED-BI.

*title	title of the study.
enter	if set to 1, display and modifications of some input data is possible during the model run. Changes are not recorded in the DB (lost for next runs).
result	if set to 1, numerical results can be shown during the model run.
implepla	if set to 1, interactive entering of new capacities for technologies relevant to a disaggregated treatment can be performed during the model run and is recorded in the DB (part of the scenario for next runs).
base_year	base year, referred to hereafter as BY.
nb_years	time span of the study (in years), referred to hereafter as RNY; (RNY <= NY, cf. para.h).
nb_products	indicative upper boundary for the number of products and other inputs in product table (nb-products <= NP, cf. para.h) for allocating memory space.
nb_technos	indicative upper boundary for the number of technologies in techno table (nb_technos <= NT, cf. para.h) for allocating memory space.
tec_pro	indicative upper boundary for the number of technologies which may be available for producing the same product; (tec_pro <= K, cf. para.h).
agestep	amplitude (years) of age-groups used for the breakdown (according to age) of initial capacities of technologies relevant to an aggregated treatment.
normop	normal operating rate for technologies (0 <= normop <= 1).
maint	percentage value to obtain the expenses for maintaining capital stock.
domact	actualization rate for domestic capital (0 <= domact <= 1)
foract	actualization rate for foreign capital (0 <= foract <= 1)

SECTOR TABLE :

sector sector 30

*sect_idx	se_sect	Num	2	(1)
name	se_name	Str	32	(2)
findem0	se_finde	Real	8.0	(3)

Table storing basic features on sectors.

(1)	sect.h	sect_idx	(1 <= (1) <= number of sectors)
(2)	"	name	
(3)	"	findem0	

Default value : findem0 is considered to be equal to the level of the sectoral useful energy demand calculated by MAED-BI for the base year.

PENETRATION TABLES :

For all penetration tables, records have only to be created for the sectors and scale levels where there is some penetration of the considered energy medium in the considered use; where this is not the case, 0 default values will be used for the entire period. A value of 1 for a penetration field means that the corresponding use is integrally satisfied with the considered medium at the reference year and scale level in the referenced sector. The scale field has to be filled up with 1, 2 or 3 for large, medium and small, respectively, scale levels. Data on penetration should be given at a few benchmark years (at least base and target year), and are linearly interpolated over the period.

helpen helpen 300

*key	he_key	Comb	--	
^sect_idx	he_sect	Ref	2	sector/sect_idx
^scale	he_scale	Num	1	(1)
^year	he_year	Num	4	(2)
hhtelpen	he_hhtel	Real	4.1	(3)
hmtelpen	he_hmtel	Real	4.1	(4)
hltelpen	he_hltel	Real	4.1	(5)

Table storing the penetration of electricity in direct and furnace use for the different sectors and scale levels at a few benchmark years.

(1)	-	scale level	(either 1, 2 or 3)
(2)	-	benchmark year	(BY <= (2) <= BY+NY-1)
(3)	sect.h	shhtelpen[^scale][^year - BY]	(between 0 and 1)
(4)	sect.h	shmtelpen[^scale][^year - BY]	(between 0 and 1)
(5)	sect.h	shltelpen[^scale][^year - BY]	(between 0 and 1)

biopen biopen 300

*key	bi_key	Comb	--	
^sect_idx	bi_sect	Ref	2	sector/sect_idx
^scale	bi_scale	Num	1	(1)
^year	bi_year	Num	4	(2)
hhtbmpen	bi_hhtbm	Real	4.1	(3)
hmtbmpen	bi_hmtbm	Real	4.1	(4)
hltbmpen	bi_hltbm	Real	4.1	(5)

Table describing the penetration of biomass in steam uses for the different sectors and scale levels at a few benchmark years.

(1)	-	scale level	(either 1, 2 or 3)
(2)	-	benchmark year	(BY <= (2) <= BY+NY-1)

- (3) sect.h shhtbmpen[^scale][^year - BY] (between 0 and 1)
- (4) sect.h shmtbmpen[^scale][^year - BY] (between 0 and 1)
- (5) sect.h shltbmpen[^scale][^year - BY] (between 0 and 1)

cogepen cogepen 300

*key	co_key	Comb	--	
^sect_idx	co_sect	Ref	2	sector/sect_idx
^scale	co_scale	Num	1	(1)
^year	co_year	Num	4	(2)
shtcpen	co_shtcg	Real	4.1	(3)
smtcpen	co_smtcg	Real	4.1	(4)
sltcpn	co_sltcg	Real	4.1	(5)

Table describing the penetration of cogeneration for generating steam (share of steam uses satisfied by cogenerated steam) for the different sectors and scale levels at a few benchmark years.

- (1) - scale level (either 1, 2 or 3)
- (2) - benchmark year (BY <= (2) <= BY+NY-1)
- (3) sect.h shhtcpen[^scale][^year - BY] (between 0 and 1)
- (4) sect.h shmtcpen[^scale][^year - BY] (between 0 and 1)
- (5) sect.h shltcpen[^scale][^year - BY] (between 0 and 1)

oilpen oilpen 300

*key	oi_key	Com	--	
^sect_idx	oi_sect	Ref	2	sector/sect_idx
^scale	oi_scale	Num	1	(1)
^year	oi_year	Num	4	(2)
oilpen	oi_oilpe	Real	4.1	(3)

Table describing the penetration of oil products in thermal uses for the different sectors and scale levels at a few benchmark years.

- (1) - scale level (either 1, 2 or 3)
- (2) - benchmark year (BY <= (2) <= BY+NY-1)
- (3) sect.h soilpen[^scale][^year - BY] (between 0 and 1)

gaspen gaspen 300

*key	ga_key	Comb	--	
^sect_idx	ga_sect	Ref	2	sector/sect_idx
^scale	ga_scale	Num	1	(1)
^year	ga_year	Num	4	(2)
gaspen	ga_gaspe	Real	4.1	(3)

Table describing the penetration of natural gas in thermal uses for the different sectors and scale levels at a few benchmark years.

- (1) - scale level (either 1, 2 or 3)
- (2) - benchmark year (BY <= (2) <= BY+NY-1)
- (3) sect.h sgaspen[^scale][^year - BY] (between 0 and 1)

licopen licopen 300

*key	li_key	Comb	--	
^sect_idx	li_sect	Ref	2	sector/sect_idx
^scale	li_scale	Num	1	(1)
^year	li_year	Num	4	(2)

licopen li__licop Real 4.1 (3)

Table describing the penetration of liquefied coal in thermal uses for the different sectors and scale levels at a few benchmark years.

- (1) - scale level (either 1, 2 or 3)
- (2) - benchmark year (BY <= (2) <= BY+NY-1)
- (3) sect.h slicopen[[^]scale][[^]year - BY] (between 0 and 1)

gacopen gacopen 300

*key	ga__ky	Comb	--	
[^] sect_idx	ga__sct_d	Ref	2	sector/sect_idx
[^] scale	ga__scl	Num	1	(1)
[^] year	ga__yr	Num	4	(2)
gacopen	ga__gacop	Real	4.1	(3)

Table describing the penetration of gasified coal in thermal uses for the different sectors and scale levels at a few benchmark years.

- (1) - scale level (either 1, 2 or 3)
- (2) - benchmark year (BY <= (2) <= BY+NY-1)
- (3) sect.h sgacopen[[^]scale][[^]year - BY] (between 0 and 1)

elspen elspen 300

*key	el__key	Comb	--	
[^] sect_idx	el__sect	Ref	2	sector/sect_idx
[^] scale	el__scale	Num	1	(1)
[^] year	el__year	Num	4	(2)
elspen	el__elspe	Real	4.1	(3)

Table describing the penetration of electricity in steam use for the different sectors and scale levels at a few benchmark years.

- (1) - scale level (either 1, 2 or 3)
- (2) - benchmark year (BY <= (2) <= BY+NY-1)
- (3) sect.h spen[[^]scale][[^]year - BY] (between 0 and 1)

bmспен bmспен 300

*key	bm__key	Comb	--	
[^] sect_idx	bm__sect	Ref	2	sector/sect_idx
[^] scale	bm__scale	Num	1	(1)
[^] year	bm__year	Num	4	(2)
bmспен	bm__bmspe	Real	4.1	(3)

Table describing the penetration of biomass in steam use for the different sectors and scale levels at a few benchmark years.

- (1) - scale level (either 1, 2 or 3)
- (2) - benchmark year (BY <= (2) <= BY+NY-1)
- (3) sect.h sbmспен[[^]scale][[^]year - BY] (between 0 and 1)

LOSSES TABLE :

losses losses 50

*year	lo__year	Num	4	(1)
loss	lo__loss	Real	5.3	(2)

Table storing losses in the electrical distribution network ; field (2), loss, is the share of

the electricity demand which is lost for the benchmark year given in the key field (1) ; percentage values must be given, at least for the base and target years; data given here is linearly interpolated over the period.

NB : default (empty table) is 0 value for losses over the period.

PRODUCT TABLE :

product product 300

*prod_id	pr_prod	Num	6	(1)
name	pr_name	Str	32	(2)
unit	pr_unit	Str	8	(3)
class	pr_class	Num	1	(4)
sect_idx	pr_sect	Ref	2	sector/sect_idx
price	pr_price	Real	6.2	(5)
output_vol	pr_outpu	Real	6.0	(6)
flag_trade	pr_flag	Num	1	(7)
vol_trade	pr_vol_t	Real	6.0	(8)

Table storing basic features of products.

(1)	prod.h	id	(must be != 0)
(2)	"	name	
(3)	"	unit	
(4)	"	class	
(5)	"	price	(not used by MAED_BI)
(6)	"	ption	
(7)	"	trade_flag	
(8)	"	trade_vol	

NB : no default values.

TECHNO TABLE :

techno techno 300

*tech_id	te_tech	Num	8	(1)
name	te_name	Str	40	(2)
scale	te_scale	Num	2	(3)
sect_idx	te_sect	Ref	2	sector/sect_idx
prod_id	te_prod	Ref	6	product/prod_id
refer_capacity	te_refer	Real	6.0	(4)
construct_delay	te_const	Num	2	(5)
starting_time	te_start	Num	2	(6)
life_time	te_life	Num	2	(7)
investment	te_inves	Real	8.2	(8)
capacity_expon	te_capac	Real	6.2	(9)
domestic_share	te_domes	Real	6.2	(10)
unskilled	te_unski	Real	6.2	(11)
technical	te_tchnc	Real	6.2	(12)
clerical	te_cleri	Real	6.2	(13)
initial_capacity	te_initi	Real	12.2	(14)

Table storing basic features of technologies.

(1)	maedtech.h	id	(must be != 0)
(2)	"	name	
(3)	"	scale	(must be != 0)
(4)	"	cap	(must be != 0)

(5)	~	delay	
(6)	~	start	(not used yet in MAED_BI)
(7)	~	life	(must be != 0)
(8)	~	investment	
(9)	~	iexp	
(10)	~	dom	
(11)	~	unskill	
(12)	~	cleric	
(13)	~	techni	
(14)	init.h	aggreicap	
Default values :	life	-	25 (years)
	cap	techno	aggreicap / 10.

FLOWS TABLE :

flows flows 10000

*key	fl_key	Comb	--	
^prod_id	fl_prod	Ref	6	product/prod_id
^tech_id	fl_tech	Ref	8	techno/tech_id
flow	fl_flow	Real	10.5	(1)

Table storing the input-output structure of technologies.

(1) number of units of the referenced product consumed per unit of main product produced by the referenced technology.

NB : an algebraic description is used: a positive flow is for consumption, a negative flow is for co-production, flows of output water are positive, the flow of the main product which should be equal to -1 (due to the representation) must not be included.

MAED_BI uses this information and transforms it in order to fill up the fields which are used in its internal calculation; the fields which are built out of this information are the following (all in maedtech.h) : heat_ht, heat_mt, heat_st, steam_ht, steam_mt, steam_lt, electr, (struct) feed. Appendix A gives some more information about the specification of input flows.

NB : no default values.

CHOICE TABLE :

choice choice 1000

*key	ch_key	Comb	--	
^prod_id	ch_prod	Ref	6	product/prod_id
^tech_id	ch_tech	Ref	8	techno/tech_id
tech_share	ch_tch_s	Real	3.0	(1)

Table storing process choices.

(1) prod.h bysha

Item (1) (tech_share) is the share of the referenced technology in the production of the referenced product (market share), at the base year. The referenced product must be the main product for the referenced technology.

Default value : If only one technology is available for producing a given product as a main product, the corresponding variable of tech_share in MAED-BI is automatically set to 100, independent of the value of tech_share in DB, which can be left equal to 0.

OUTPUT TABLE :

output output 5000

*key	ou_key	Comb	--	
^prod_id	ou_prod	Ref	6	product/prod_id
^current_year	ou_year	Num	4	(1)
output	ou_outpu	Real	8.1	(2)

Table storing the production targets for final and energy products (i.e., products, the field class (cf. product table) of which is equal to 1, 4 or 7) for a few benchmark years, (at least for target year if the value for the base year has already been given in the product record (field output_vol)); data given here are linearly interpolated over the period.

(1) - benchmark year (BY <= (1) <= Y+NY-1)
 (2) act.h prod[^current_year - BY]

Default values: prod[0] product output_vol
 prod[NY-1] product output_vol

TRADE TABLE :

trade trade 5000

*key	tr_key	Comb	--	
^prod_id	tr_prod	Ref	6	product/prod_id
^year	tr_year	Num	4	(1)
current_trade	tr_trade	Real	8.1	(2)

Table storing the trade targets for tradable products (i.e. products for which the field flag_trade (cf. product table) has been set equal to 1), for a few benchmark years, (at least for target year if the value for the base year has already been given in the product record (field vol_trade)); data given are linearly interpolated over the period.

(1) - benchmark year (BY <= (1) <= BY+NY-1)
 (2) - act.h trade_vol[^year-BY]

Default values : trade_vol[0] product vol_trade
 trade_vol[NY-1] product vol_trade

SHARES TABLE :

shares shares 5000

*key	sh_key	Comb	--	
^tech_id	sh_tech	Ref	8	techno/tech_id
^year	sh_year	Num	4	(1)
current_share	sh_tchs	Real	3.0	(2)

Table storing the market shares evolution of technologies at a few benchmark years, (at least for target year if the value for the base year has already been given in the choice record (field tech_share)); data given here is linearly interpolated over the period. It has only to be filled up for technologies which compete for producing the same main product (case of a technology mix); otherwise the share is implicitly considered equal to 100% over the period.

(1) - benchmark year (BY <= (1) <= BY+NY-1)
 (2) act.h tech_share[^tech_id][^year - BY] (0 <= (2) <= 100)

Default values : tech_share[^tech_id][0] choice
 either : tech_share[^tech_id][NY-1] choice
 or : tech_share[^tech_id][0] 100
 tech_share[^tech_id][NY-1] 100

VINTAGES TABLE :

vintages vintages 2000

*key	vi_key	Comb	--	
^tech_id	vi_tech	Ref	8	techno/tech_id
^age_group	vi_age_g	Num	2	(1)
age_share	vi_age_s	Real	3.0	(2)

Table storing age-breakdown at base year for initial capacities (existing at base year) of technologies relevant to an aggregated treatment (with scale index equal to -1, 2, 3). This breakdown applies to the aggregated capacity at base year given in the table techno (field aggregap).

- (1) - age-group number (< NAG ; cf. para.h)
- (2) init.h descr.aggre.share[^age_group] (between 0 and 100 (%))

Default value : descr.aggre.share[0] = 100; the whole capacity is considered as belonging to the first age group.

INITIAL TABLE :

initial initial 2000

*key	in_key	Comb	--	
^tech_id	in_tech	Ref	8	techno/tech_id
^number	in_numbe	Num	2	(1)
location	in_locat	Str	20	(2)
capacity	in_capac	Real	8.2	(3)
start_year	in_start	Num	4	(4)
shut_down	in_shut	Num	4	(5)

Table storing capacities existing at base year for technologies with scale index equal to 1, that is technologies which are relevant to a disaggregated treatment. Whatever the value in the field aggregap of the techno record, the technology will be considered as having no capacities at base year as long as no information is put in this table.

- (1) - site number (< LSC ; cf. para.h)
- (2) init.h descr.disag[^number].location
- (3) " descr.disag[^number].cap
- (4) " descr.disag[^number].start_up
- (5) " descr.disag[^number].shut_down ((5) = 0 or (5) >= BY)

NB: No default values.

NEWPLANT TABLE :

newplant newplant 500

*key	ne_key	Comb	--	
^tech_id	ne_tech	Ref	8	techno/tech_id
^start_up	ne_start	Num	4	(1)
capacity	ne_capac	Real	8.2	(2)

Table used for storing implementation planning of new capacities for technologies with

scale index equal to 1, that is technologies which are relevant to a disaggregated treatment. The relevant information can be entered interactively from the keyboard during the program execution when the parameter implepla (cf. paramet) has been set to 1.

- (1) new.h new.newls[^start__up].new__start (BY <= (1) <= BY+NY-1)
- (2) new.h new.newls[^start__up].new__cap

NB : no default values.

FINALS TABLE :

finals finals 100

*key	fi__key	Comb	--	
^sect__idx	fi__sect	Ref	2	sector/sect__idx
^prod__id	fi__prod	Ref	6	product/prod__id

Table used for defining the sectoral final products to be considered in the scenario. Creating a record in this table means that the referenced product has been selected for the current scenario from among the products of the referenced sector which are defined as final products (class field equal to 1) in the product table.

NB : no default values.

ATTRI TABLE :

attri attri 100

*att__key	at__att__key	Comb	--	
^prod__id	at__prod	Ref	6	product/prod__id
^tech__id	at__tech	Ref	8	techno/tech__id
energ__type	at__energ	Num	2	(1)
percent	at__perce	Real	6.2	(2)

Table used to handle aggregation/disaggregation of energy products to run MAED and PDAS on the same technology data: relates a percentage (2) of a flow to a substitutable energy type (1).

- (1) para.h energy types to be used for flows
- (2) - percentage of flow that is related to an energy type (0. <= (2) <= 100.)

NB : no default values.