



INSTITUT D'ECONOMIE ET
DE POLITIQUE DE L'ENERGIE

POLES
Prospective Outlook on Long-term Energy Systems

Patrick Criqui

2001

Unité mixte de recherche du Centre National de la Recherche Scientifique
et de l'Université Pierre Mendès France (UFR DGES) - UMR 5111

IEPE, BP 47, 38040 Grenoble Cedex 09, France
Tél : +33 (0)4 76 51 42 40 ; Fax : +33 (0)4 76 51 45 27
Mél : iepe@upmf-grenoble.fr ; URL : <http://www.upmf-grenoble.fr/iepe>

General information

The POLES model is a world simulation model for the energy sector. It works in a year-by-year recursive simulation and partial equilibrium framework, with endogenous international energy prices and lagged adjustments of supply and demand by world region. Developed under EU research programmes, the model is fully operational since 1997. It has been used for policy analyses by EU-DGs Research, Environment and TREN and by the French Ministry of Environment. The model enables to produce:

- detailed long term (2030) world energy outlooks with demand, supply and price projections by main region;
- CO2 emission Marginal Abatement Cost curves by region, and emission trading systems analyses, under different market configurations and trading rules;
- technology improvement scenarios – with exogenous or endogenous technological change – and analyses of the value of technological progress in the context of CO2 abatement policies.

Target users of the model are international organisations and policy makers and energy analysts in the field of global energy markets and environmental issues.

Issues addressed

Long-term (2030) simulation of world energy scenarios / projections and international energy markets analysis.

National / regional energy balances, integrating final energy demand, new and renewable energy technologies diffusion, electricity and the transformation system, fossil fuel supply.

Impacts of energy prices and taxes policies. Energy RTD strategies. Greenhouse Gas emissions and abatement strategies.

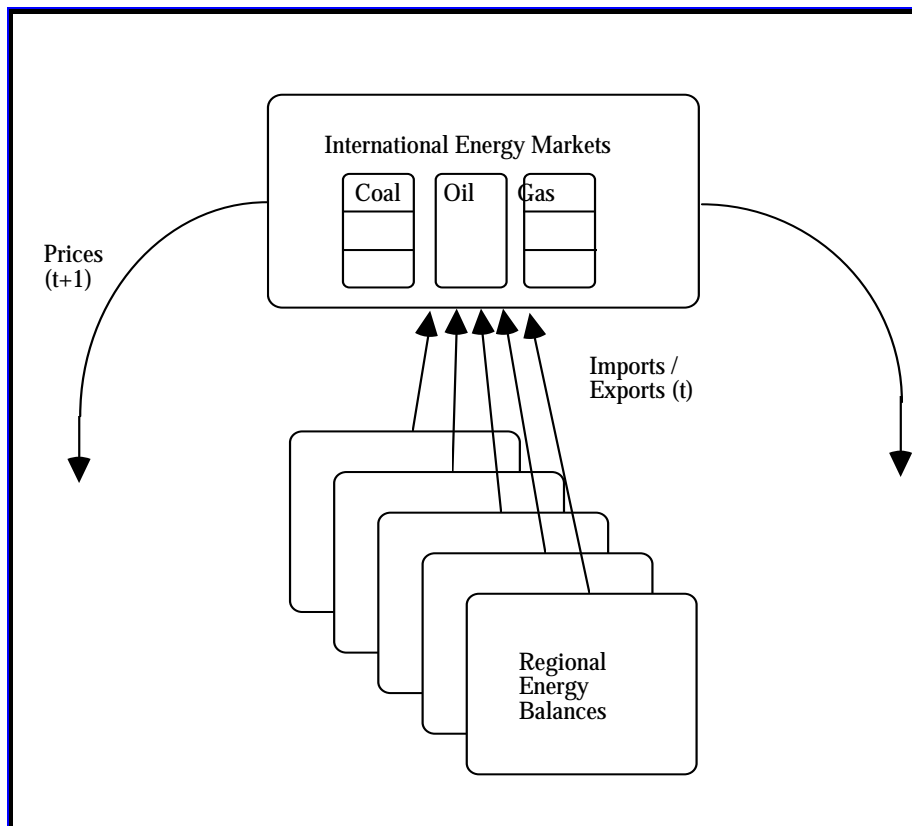
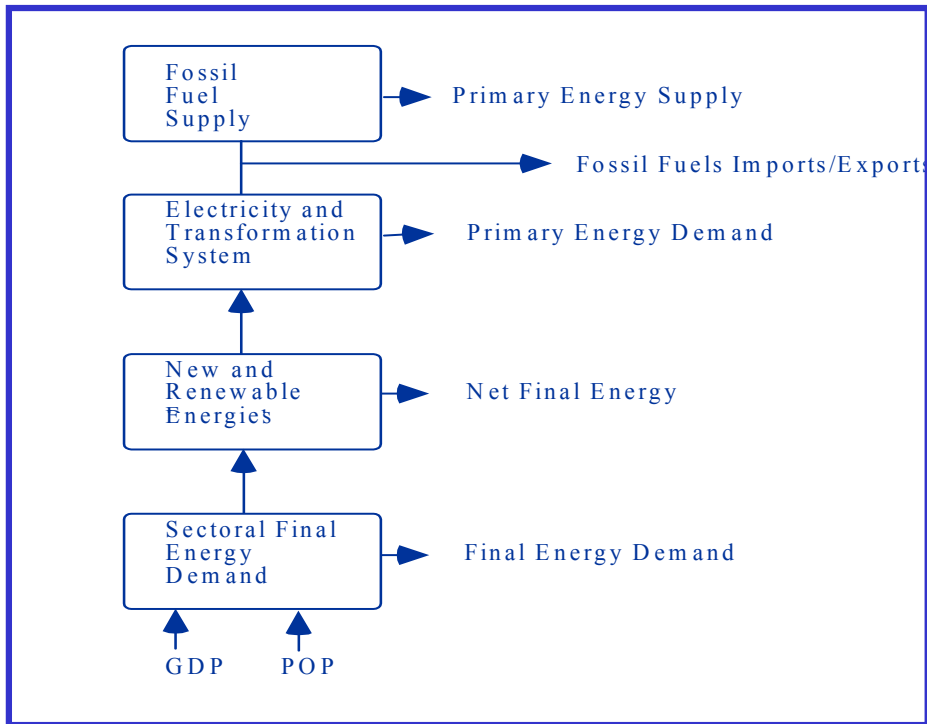
Costs of international GHG abatement scenarios with different targets, entitlements, flexibility systems. Tradable Emission Permit Systems analysis.

Endogenous developments in energy technology, with impacts of public and private investment in R&D and cumulative experience with “learning by doing”.

Model characteristics

The POLES model is a global sectoral model of the world energy system. It has been developed in the framework of a hierarchical structure of interconnected sub-models at the international, regional, national level. The dynamics of the model is based on a recursive (year by year) simulation process of energy demand and supply with lagged adjustments to prices and a feedback loop through international energy prices.

The POLES model



Structure of the model

In the current geographic disaggregation of the model, the world is divided into thirty eight countries or regions, allowing to identify the key world regions of most energy studies: North America; South America; Western Europe; Central Europe; Former Soviet Union; North Africa and Middle-East; Africa South of Sahara; South Asia; South East Asia; Continental Asia; Pacific OECD.

AMERICAN MARKET

North America	USA Canada	Central America	Mexico R Central America
		South America	Brasil R South America

EURO-AFRICAN MARKET

European Union	France Germany Italy United-Kingdom Spain Portugal Belgium + Lux Netherlands Denmark Ireland Sweden Finland Austria Greece	Central Europe	Pol+Hung+Cs+Slov R East Eur Ann B R East Eur Non Ann B
Other Western Europe	R Western Europe Turkey	Former Soviet Union	Former SU Ann B Former SU Non Ann B
		North Africa	Egypt North Africa Non OPEP North Africa OPEP
		Middle East	Gulf R Middle-East
		South of Sahara Africa	South of Sahara Africa

ASIAN MARKET

Pacific OECD	Japan Australia + New Zealand	South Asia	India R South Asia
		South East Asia	Korea R South-East Asia
		East Asia	China

In most of these regions the larger countries are identified and treated, as far as energy demand is concerned, by a detailed model. In the current version these countries are the G7 countries plus two groups for the rest of the European Union (North and South) and five key developing countries : Mexico, Brazil, India, South Korea and China. The other countries are dealt with in more compact but homogeneous models.

For each region, the model articulates four main modules dealing with :

- final energy demand by main sector
- new and renewable energy technologies
- the conventional energy and electricity transformation system
- fossil fuel supply

While the simulation of the different energy balances allows for the calculation of import demand / export capacities by region, the horizontal integration is ensured in the energy markets module, the main inputs of which are import demand and export capacities of the different regions. Only one world market is considered for the oil market (the "one great pool" concept), while three regional markets (America, Europe, Asia) are identified for coal, in order to take into account for different cost, market and technical structures. Natural gas production and trade flows are modelled on a bilateral trade basis, thus allowing for the identification of a large number of geographical specificities and the nature of different export routes.

The comparison of import and export capacities and the changes in the Reserves/Production ratio for each market determines the variation of the prices for the subsequent periods.

Final Energy Demand module

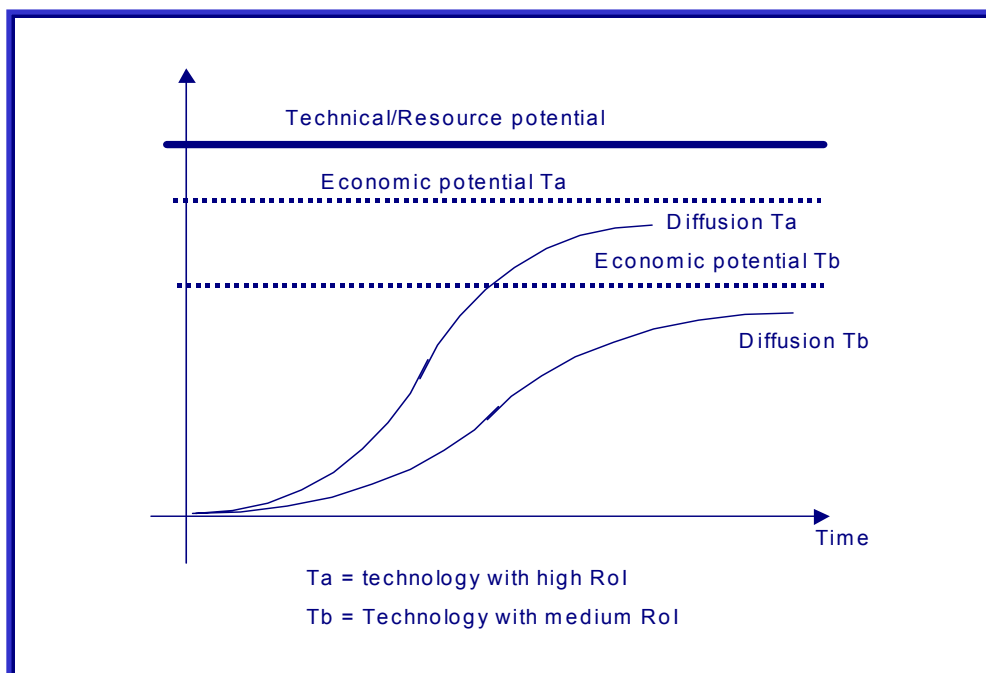
In the detailed demand model for the main countries or regions (14 in the current version, the consumption of energy is disaggregated into homogeneous sectors which allow to identify the key energy intensive industries, the main modes of transport and the residential and tertiary activities: Steel industry ; Chemical industry ; Non metallic mineral industries ; Other industries ; Road passenger transport ; Road freight transport ; Rail passenger transport ; Rail freight transport ; Air transport ; Residential sector ; Tertiary sector ; Agriculture.

	Substituable Fuels	Electricity	Transport Fuels
Industry	X	X	
Steel industry	X	X	
Chemical industry	X	X	
Non Metallic Mineral	X	X	
Other industries	X	X	
Transport			
Road / passenger			X
Road / goods			X
Rail / passenger		X	
Rail / goods		X	
Air transport			X
Other			X
Tertiary	X	X	
Residential	X	X	
Agriculture	X	X	

In each sector energy consumption is calculated for substitutable fuels on one hand and for electricity on the other, while taking into account specific energy consumption (electricity in electrical processes and coke for the other processes in steel-making, feedstock in the chemical sector, electricity for heat and for specific uses in the Residential and Tertiary sectors). Each demand equation combines a revenue or activity variable elasticity, price elasticity, technological trends and, when appropriate, saturation effects. Particular attention has been paid to the treatment of price effects.

New and Renewable Energy technologies diffusion module

Most studies on international energy perspectives either disregard new and renewable energy technologies as offering insufficient economic potential for development in the medium term or, conversely, try to assess their potential in a purely technical approach in order to show that their contribution to world energy supply can be important. The approach adopted in the New and Renewable Energy module of the POLES model tries to supersede these limits while recognising the difference between technical and economical potentials as well as the time-constant which characterise the diffusion process. Elements such as learning-curves and "niche-markets" have been introduced, which allow a truly dynamic approach of the development and diffusion of these technologies.

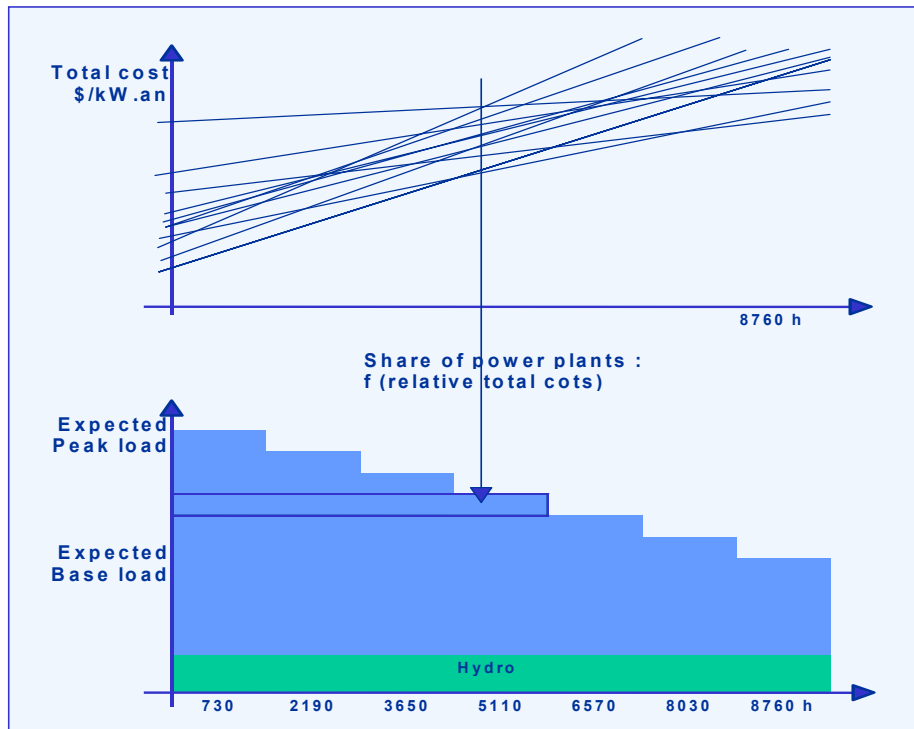


The module dedicated to the simulation of new and renewable technologies identifies ten generic technologies which are representative of the solutions to be implemented in different types of countries and might have a non negligible quantitative contribution in the long-term development of energy systems. The time horizon of the model (2030) in fact allows to consider that, given the development time-constants, the technologies that might have a significant role to this horizon should today be at least identified and have passed the first stages of development. Twelve technologies have been selected in the current version of the model :

- | | |
|--|---------------|
| 1. Combined Heat and Power, (small co-generation) | CHP |
| 2. Small Hydro Power plants (<10 MWe) | SHY |
| 3. Wind power plants for network electricity | WND |
| 4. Solar Thermal Power Plants | SPP |
| 5. Decentralised building integrated PV systems | DPV |
| 6. PV systems for Decentralised rural electrification in DCs | RPV |
| 7. Low Temperature Solar systems in residential sector | LTS |
| 8. Biofuels, three conventional technologies | BF1, BF2, BF3 |
| 9. Biomass gasification for electricity production in GT | BGT |
| 10. Proton exchange Fuel Cells for road Vehicles | FCV |
| 11. Proton exchange Membrane Fuel Cells, stationary | MFC |
| 12. Solid oxide Fuel Cells, in cogeneration | SFC |

Electricity and Transformation System module

While the transformation system for conventional fossil fuels is treated in a relatively aggregated way through the use of conversion, transport and distribution efficiency ratios, which is acceptable in a world model, the electricity system deserves a much more detailed treatment. In fact the electricity system is in any country not only one of the main energy consuming sectors but also probably the major sector for inter-fuel substitution. A last characteristic is that, because of the particularly long lifetime of equipment, this sector displays much higher price-elasticities in the long-term than in the short-term.

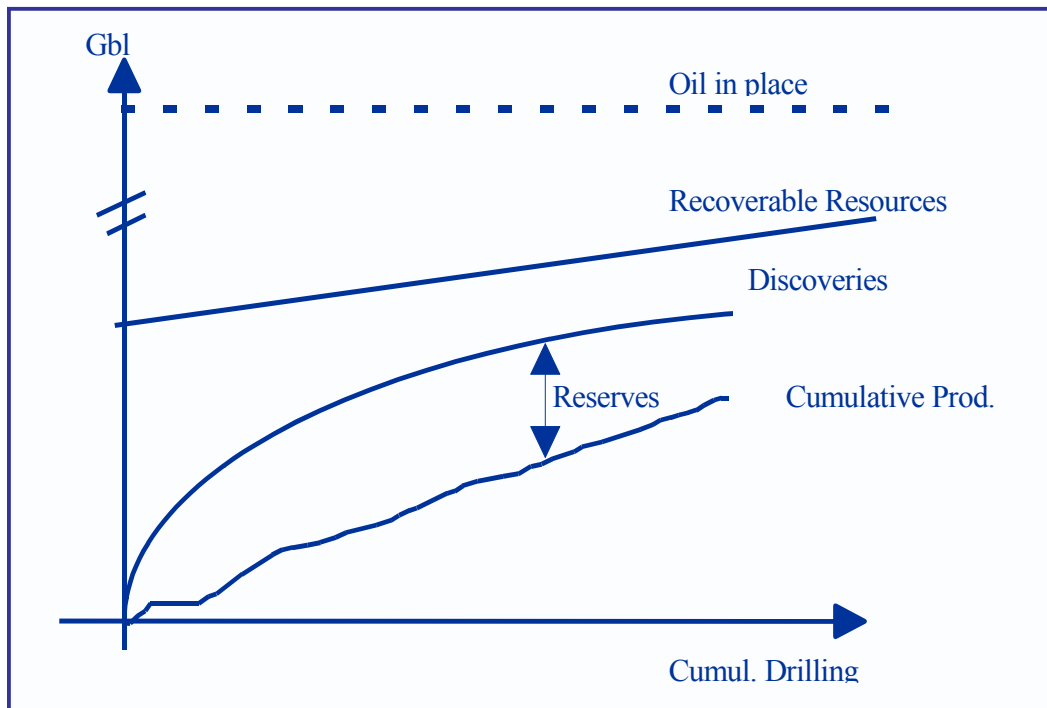


In order to take into account the capacity constraints in the electricity production system the module simulates the evolution of existing capacities at each period as a function of equipment development decisions taken in preceding periods and thus of the anticipated demand and costs at the corresponding time. In the current version of the model, twelve electricity generation technologies, conventional and new are identified:

- | | |
|---|-----|
| 1. Conventional, large-size hydroelectricity | HYD |
| 2. Conventional Light-Water nuclear Reactor | NUC |
| 3. New Nuclear Design | NND |
| 4. Pulverised Fuel Super Critical Coal | PFC |
| 5. Integrated Coal Gasification with Combined Cycle | ICG |
| 6. Advanced Thermodynamic Cycle (coal powered) | ATC |
| 7. Lignite-powered Conventional Thermal | LCT |
| 8. Coal-powered Conventional Thermal | CCT |
| 9. Oil-powered Conventional Thermal | OCT |
| 10. Gas-powered Conventional Thermal | GCT |
| 11. Oil-powered Gas Turbine in Combined Cycle | OGT |
| 12. Gas-powered Gas Turbine in Combined Cycle | GGT |

Oil and gas production module

Oil and gas production is simulated for each region using a full discovery-process model for the main producing countries and simplified relations for minor producing countries.



For each main producing country the available data cover the estimate of Ultimate Recoverable Resources for oil and for gas, the cumulative drilling and cumulative production since the beginning of fields development and the evolution of reserves. Cumulative discoveries are then calculated as the sum of cumulative production and remaining reserves. For base producers, oil or gas production then depends on a depletion ratio, applied to the remaining reserves (discoveries - cumulative production) in each period.

International Energy Prices module

In the current version of the model, the basis for international oil price modelling combines a Target Capacity Utilisation Rate model for the Gulf countries and the global oil R/P ratio as a long-term explanatory variable. This reflects the fact that most applied analyses of the oil market points to the fact that, as experienced in the seventies and eighties, the shorter term variations or shocks in the price of oil can be explained by the development of under- or over- capacity situations in the Gulf region.

Coal and natural gas prices are computed for each one of the three main regional markets with regional coal and gas trade matrixes and price variations linked respectively to coal production capacities and to the gas R/P ratio of the key residual producers for each region.

Inputs

The energy balance data for the POLES model are extracted from an international energy database, which also includes international macro-economic data concerning GDP, the structure of economic activity, deflators and exchange rates. Technico-economic data (energy prices, equipment rates, costs of energy technologies ...) are gathered both from international and national statistics.

Outputs

For a regularly updated **Global Energy Outlook**, the model provides endogenous international energy prices and all information on energy flows for each country / region, in a structure similar to that of a standard IEA-type energy balance. A summary balance provides a synthesis of information on energy consumption and transformation, new energy technologies and electricity production capacities.

Costing studies for CO2 abatement policies are currently performed using the model by the systematic introduction of a “shadow-carbon tax” wherever it is relevant. Multiple simulations of the model then allow to analyse the impacts on emissions by sector and regions, to build the Marginal Abatement Cost curves and to analyse emission trading issues. A dedicated software, **ASPEN** (Analyse des Systèmes de Permis d’Emission Négociables), allows to calculate – on robust micro-economic bases – the MAC, permit price, total cost and quantities exchanged under different market configurations.

The **impact of technological change in the Baseline and in Emission Control Scenarios** can be addressed either with a set of exogenous “Technology Story” alternatives or with a module of R&D driven endogenous technology improvement, which also includes “learning by doing” or experience effects.