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The POLES model

POLES State of the Art **LEPII-EPE, CNRS Grenoble, January 2006**

The POLES model

The POLES model provides a complete system for the simulation and economic analysis of the sectoral impacts of climate change mitigation strategies. The POLES model is not a General Equilibrium Model, but a dynamic Partial Equilibrium Model, essentially designed for the energy sector but also including other GHG emitting activities, with the 6 GHG of the "Kyoto basket". The simulation process is dynamic, in a year by year recursive approach that allows to describe full development pathways from 2005 to 2050.

The use of the POLES model combines a high degree of detail on the key components of the energy systems and a strong economic consistency, as all changes in these key components are at least partly determined by relative price changes at sectoral level. Thus each mitigation scenario can be described as the set of consistent transformations of the initial Reference case that are induced by the introduction of a carbon constraint or carbon value/penalty.

As the model identifies 46 regions of the world, with 22 energy demand sectors and about 40 energy technologies – now including generic Very Low Energy end-use technologies – the description of climate policy induced changes can be quite extensive (see below for a brief presentation of key features, technologies and modelling principles).

As far as induced technological change is concerned, the model provides dynamic cumulative processes through the incorporation of Two Factor Learning Curves, which combine the impacts of "learning by doing" and "learning by searching" on the technologies' improvement dynamics. As price induced diffusion mechanism (such as feed-in tariffs) can also be included in the simulations, the model allows for a taking into account of the key drivers to the future development of new energy technologies.

One key aspect of the analysis of energy technology development with the POLES model is indeed that it relies in all cases on a framework of permanent inter-technology competition, with dynamically changing attributes for each technology. In parallel, the expected cost and performance data for each key technology are gathered and examined in the *Techs-DB* database that is developed at LEPII-EPE for any modelling and policy-making purpose.

Finally one can emphasise the fact that, although the model does not provide the total indirect macro-economic costs of mitigation scenarios, it however allows to produce reliable economic assessments that are principally based on the costs of developing low or zero carbon technologies, thus benefiting of a strong engineering background.

POLES 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 different EU research programmes (JOULE, FP5, FP6), the model is fully operational since 1997. It has been used for policy analyses by EU-DG Research, DG Environment and DG TREN, as well as by the French Ministry of Ecology and Ministry of Industry. The model enables to produce:

- Detailed long term (2050) world energy outlooks with demand, supply and price projections by main region;
- CO2 emission Marginal Abatement Cost curves by region and/or sector, 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.

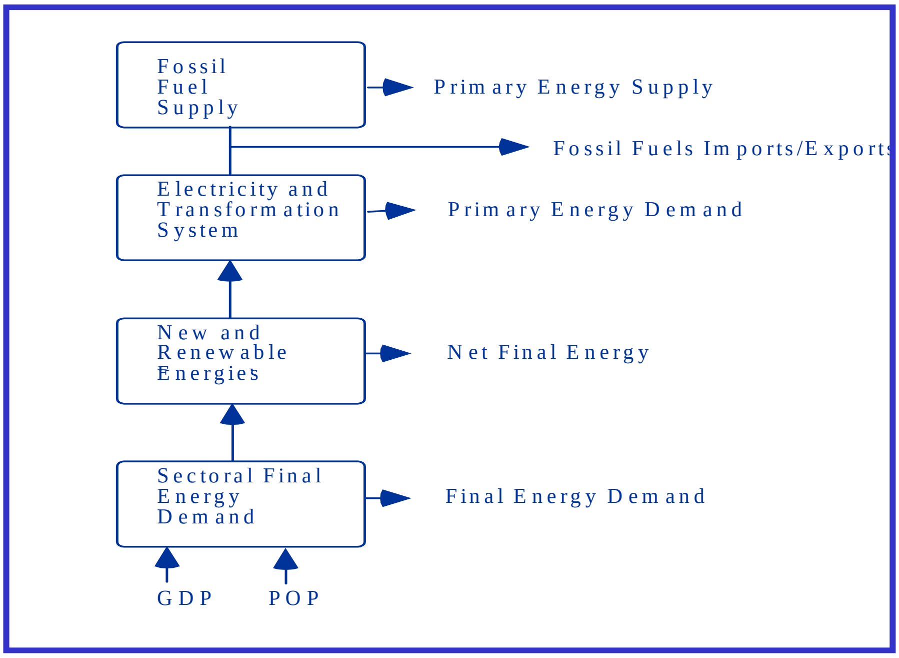
Beyond the research community, the target users of the model are international organisations and policy makers and energy analysts in the field of global energy markets and environmental issues.

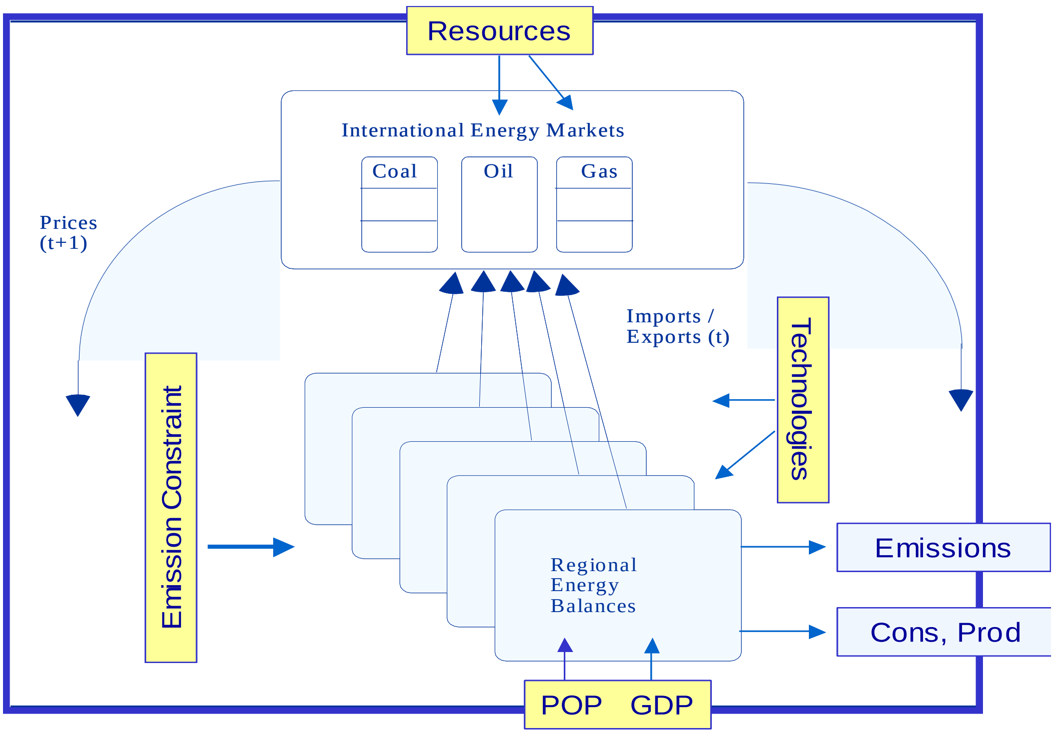
Key issues addressed

- Long-term (2050) simulation of world energy scenarios / projections and international energy markets.
- World energy supply scenarios by main producing country/region with consideration of reserve development and resource constraints.
- Outlook for energy prices at international, national and sectoral level (10 products)
- National / regional energy balances, integrating final energy demand, new and renewable energy technologies diffusion, electricity, Hydrogen and Carbon Capture and Sequestration systems, fossil fuel supply.
- Impacts of energy prices and tax policies on regional energy systems. National Greenhouse Gas emissions and abatement strategies.
- Costs of international GHG abatement scenarios with different regional targets / endowments and flexibility systems. Emission Quotas Trading Systems analysis at world or regional level.
- Technology diffusion under conditions of sectoral demand and inter-technology competition based on relative costs and merit orders
- Endogenous developments in energy technology, with impacts of public and private investment in R&D and cumulative experience with “learning by doing”. Induced technological change of climate policies

The POLES model is a global sectoral model for 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





In the current geographic disaggregation of the model, the world is divided into 46 countries or regions, with a detailed national model for each Member State of the European Union (25), four industrialised countries (USA, Canada, Japan and Russia) and five major emerging economies (Mexico, Brazil, India, South Korea and China). The other countries/regions of the world are dealt with a simplified but consistent demand model.

This allows to identify the key world regions of most energy studies: North America; South America; 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
		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
Other Western Europe	R Western Europe Turkey		

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

NB: The current POLES 5 version of the model includes a full national model for each country of the EU 25

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

- final energy demand by main sector
- new and renewable energy technologies
- the Hydrogen and Carbon Capture and Sequestration technologies and infrastructures
- 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 of the variation of the prices for the subsequent periods.

In the detailed demand model for the main countries or regions, the energy consumption is disaggregated into homogeneous sectors which allow to identify the key energy intensive industries, the main transport modes 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.

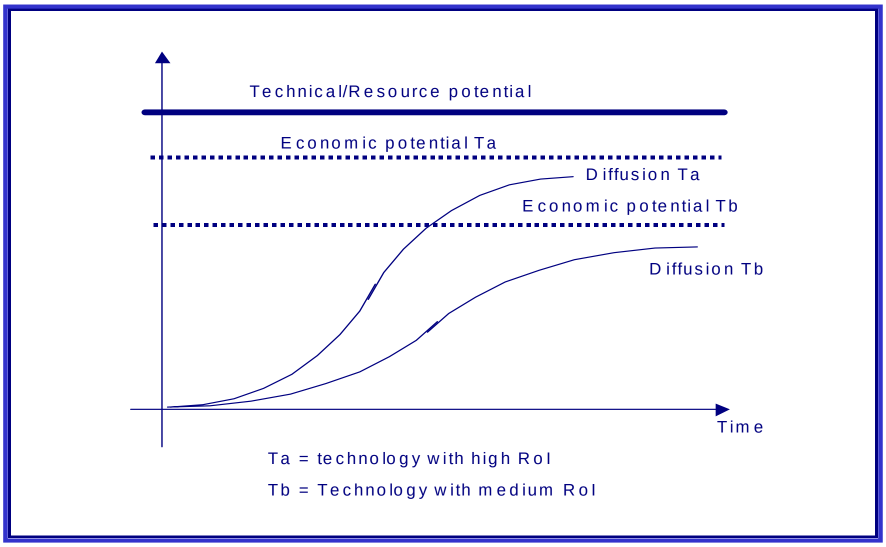
	Substituable Fuels	Electricity	Transport Fuels
Industry	X	X	
Steel industry	X	X	
Chemical industry	X	X	
Non Metallic Mineral	X	X	
Other industries	X	X	
Transport			
Road / passenger			X
Road / goods			X
Rail / passenger		X	
Rail / goods		X	
Air transport			X
Other			X
Tertiary	X	X	
Residential	X	X	
Agriculture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

Energy consumption is calculated in each sector on the one hand for substitutable fuels and on the other hand for electricity, 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 dynamic impacts of price of price effects.

Recent developments in the POLES 5 version of the model have also allowed to represent the development of Very Low Energy/Emission end-use technologies (VLE). While going beyond the concept of energy efficiency through new concepts and product designs, these technologies may allow to considerably improve the energy performance in the two strategic sectors of buildings and road vehicles. In the building sector two generic VLE buildings are considered with energy consumption being cut by a Factor of 2 (Low Energy Building, new and retrofitting) or 3-4 (Very Low Energy Building, new). In the transport sector, the competition between six types of vehicles is described, allowing for the potential introduction of Hydrogen and/or electricity in road transport (while biofuels are mixed, according to relative costs, to conventional petroleum products).

6 Competing Vehicles	
Conventional ICE vehicle	ICE
Hybrid vehicle	HYB
Battery electric car	BEC
Direct H2-ICE vehicle	HCE
Methanol FCV	FCVM
Hydrogen Fuel-Cell Vehicle	FCVH

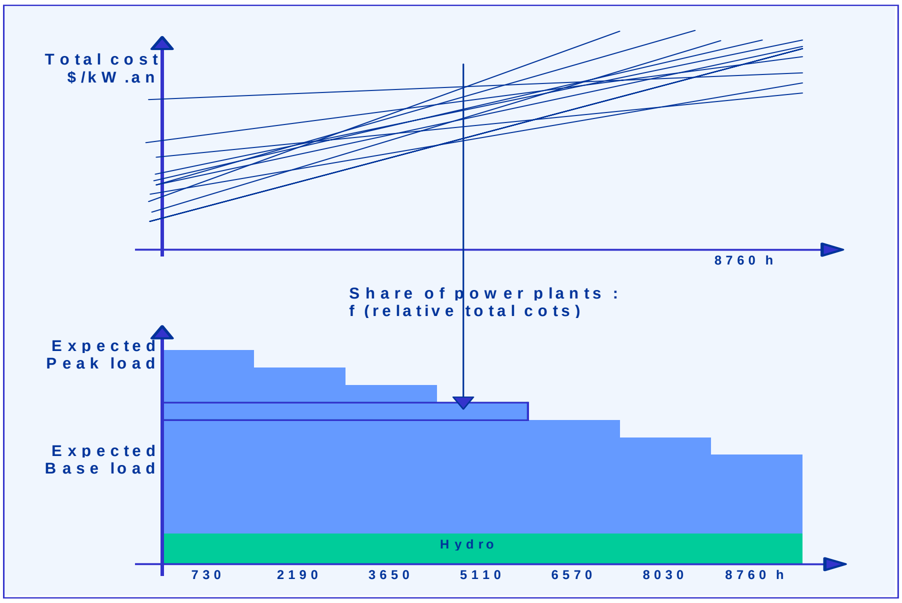
Many studies on international energy perspectives either disregard new and renewable energy technologies as offering insufficient economic potential for development in the medium term or, conversely, try to assess their potential in a purely technical approach in order to identify their overall potential contribution to world energy supply. 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 constants that characterise the diffusion process. Elements such as learning-curves and "niche-markets" have been introduced, which allow for a truly dynamic approach of the development and diffusion of these technologies.



The module that is dedicated to the simulation of new and renewable technologies identifies the generic technologies which are representative of the solutions to be implemented in different types of countries and might have a significant quantitative contribution in the long-term development of energy systems. The time horizon of the model (2050) 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 :

	New and Renewable Technologies	
	Waste Incineration CHP	BF2
	Biomass Gasif. with Gas Turbines	BGT
	Combined Heat and Power	CHP
	Photovoltaics (windows)	DPV
	Proton Exch. Membr. Fuel Cell (Fixed)	MFC
	Solid Oxide Fuel Cell (Fixed Cogen.)	SFC
	Rural Photovoltaics	RPV
	Solar Thermal Powerplants	SPP
	Small Hydro	SHY
	Wind Turbines	WND
	Biofuels for transport	BF3
	Fuel Cell Vehicle (PEM)	FCV

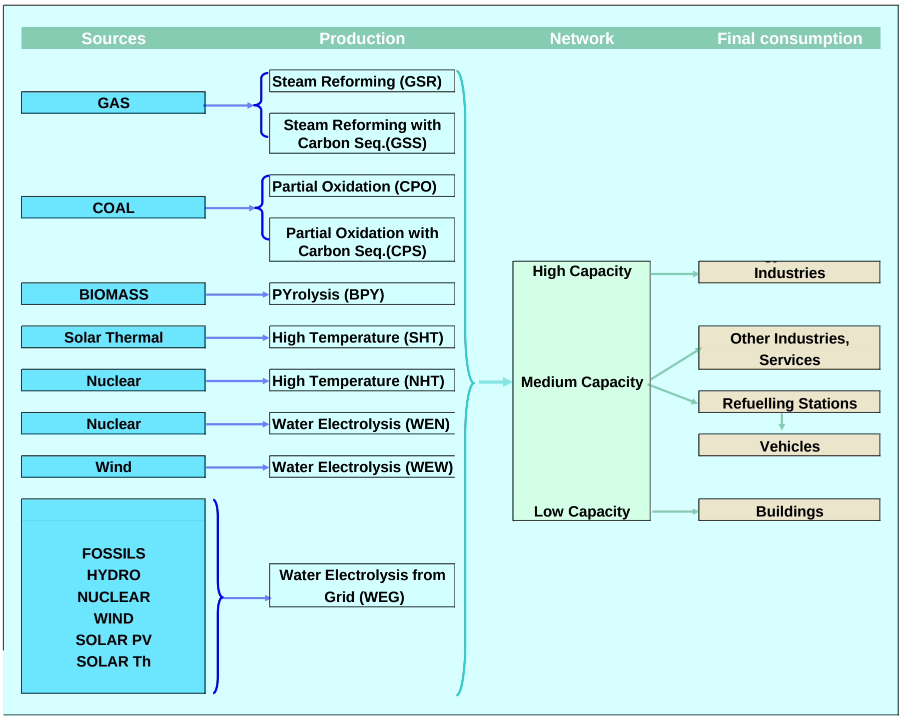
While the transformation system for conventional fossil fuels is treated in a relatively aggregated way through the use of conversion, transport and distribution efficiency ratios, which is acceptable in a world model, the electricity system deserves a much more detailed treatment. In fact the electricity 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. Carbon Capture and Sequestration has also been introduced for two coal and one gas generation plant.

	Large Scale Power Generation	
	Advanced Thermodynamic Cycle	ATC
	Super Critical Pulverised Coal	PFC
	Integrated Coal Gasif. Comb. Cycle	ICG
	Coal Conventional Thermal	CCT
	Lignite Conventional Thermal	LCT
	Large Hydro	HYD
	Nuclear LWR	NUC
	New Nuclear Design	NND
	Gas Conventional Thermal	GCT
	Gas Turbines Combined Cycle	GGT
	Oil Conventional Thermal	OCT
	Oil Fired Gas Turbines	OGT

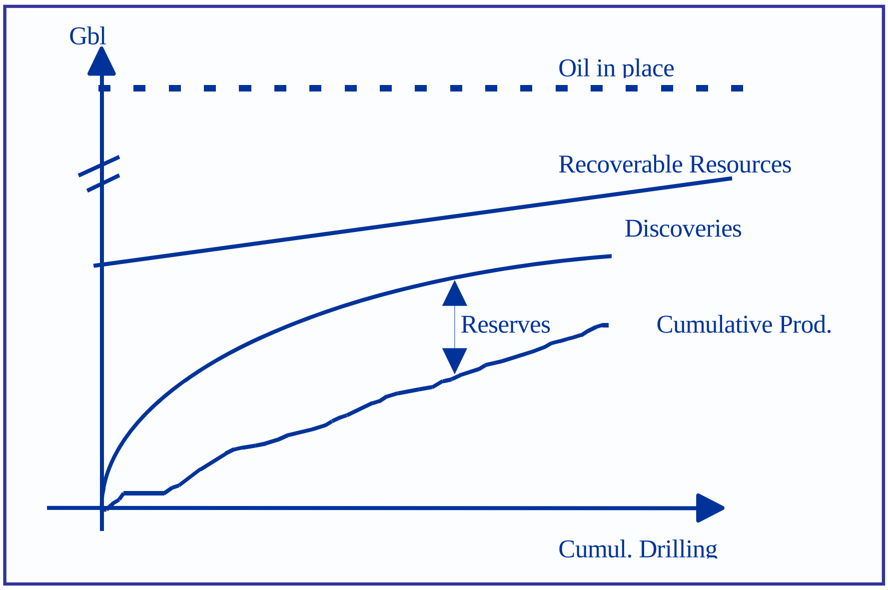
Recent developments in the POLES 5 Version of the model have allowed to introduce a full description of future Hydrogen production, transport and consumption technologies. While Hydrogen is only an energy carrier, great attention is paid to the description of the many technological solutions to produce H2, to transport costs in new infrastructures and to the interfaces of the H2 system with the conventional electricity system.



Currently ten competing options are identified for the mass production of Hydrogen, relying on fossil fuels (coal or gas, with or without Carbon Capture and Sequestration) or electrolysis, from network electricity or dedicated nuclear or renewable electricity. Two end-use markets are considered for Hydrogen: distributed electricity with cogeneration and Very Low Emission vehicles in road transport with fuel cells (direct injection in a conventional ICE is also considered).

2 H2 End-use technologies	
Hydrogen Fuel-Cells for stationary uses	**HFC**
Hydrogen Fuel-Cell Vehicles	**FCVH**
10 H2 Production technologies	
Hydrogen from Gas Steam Reforming	**GSR**
Gas Steam Reforming with CO2 Sequ.	**GSS**
Coal Partial Oxidation	**CPO**
Coal Partial Oxidation with CO2 Seque.	**CPS**
Biomass Pyrolysis	**BPY**
Solar High-temp. Thermochemical cycles	**SHT**
Dedicated Wind Electrolysis	**WEW**
Nuclear High-Temp. Thermochemical cycles	**NHT**
Water Electrol., dedicated Nuclear Power	**WEN**
Water Electrol., baseload elec. from Grid	**WEG**

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. Regular updates of the database are provided by ENERDATA.

Outputs

For a regularly updated **Energy Outlooks**, 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.

2004-2005: WETO-H2, for DG-Research

World Energy Technology and climate policy Outlook-Hydrogen. This project aims at drawing long term energy scenarios for the European Union in a world context. A particular emphasis will be given to the study of potential radical, climate policy-induced innovations to the year 2050. Among these potential innovations the perspectives of Hydrogen technologies, fuel-cells and Carbon Capture and Sequestration will be thoroughly studied with the POLES model. This project will provide a significant extension in the scope and time-horizon of the WETO project below. (under publication, spring 2006)

2003-2004: Reference Projection and Factor 4 scenarios for France, for the Ministry of Industry

The POLES model is used jointly with the MEDPRO energy demand and environmental model in order to provide a medium term (2030) energy scenario for France. In a second stage, POLES and MEDPRO are used in order to simulate and analyse in detail the consequences of a “Factor 4” reduction target for GES emissions in 2050.
http://www.industrie.gouv.fr/energie/prospect/pdf/oe-facteur-quatre.pdf

2002-2004: SAPIENTIA, for DG-Research

Systems Analysis for Progress and Innovation in Energy Technologies for Integrated Assessment. This project is the natural continuation of the SAPIENT project below. SAPIENTIA addresses the issue of energy systems analysis by considering driving forces that influence technology improvement and particularly the role of R&D in inducing and accelerating it. The project allows to enhance the capabilities of the POLES model concerning endogenous technical change and to dvelop a new technology database: TECHPOL.

2002-2004: European Carbon Trading Schemes and Endogenous Energy Technology Scenarios, for the Institut Français de l’Energie

These twin studies allow for an extension of analyses and modelling exercises in a direction that respond to the preoccupations of key energy industries. In particular the European Carbon Trading Schemes has already allowed to specify the key features and to analyse in economic terms a consistent scenario that would regulate industry through emissions quotas, according to the Directive and the other sectors through a carbon tax complemented by government purchases of permits on the emission trading system.

2001-2003: GRP, for DG-Environment

Greenhouse gas emission Reduction Pathways in the UNFCCC process to 2025. LEPII-EPE has coordinated this project that aimed at identifying the building blocks of a European climate policy and international negotiation strategy in a Post-Kyoto perspective. The project has identified two different GHG concentration profiles that may be compatible with the EU’s climate targets, reviewed and assessed with different economic models the main international endowment schemes and finally identified some of the key benefits of GHG abatement policies for the emerging regions of the world.
http://europa.eu.int/comm/environment/climat/pdf/pm_summary2025.pdf

2001-2003: WETO, for DG-Research

World Energy Technology and climate policy Outlook. This project has allowed to define 2030 energy scenarios for Europe in an international context accounting for the dynamic balance of world energy demand, supply and international prices. The role of Europe on the international gas market and the conditions for gas supply has received a particular attention,

as did a limited set of technology stories that allowed to illustrate the potential impacts of technological breakthrough in some key technologies. The WETO study has provided a global framework, encompassing emission reduction policies, for the design of the European energy RTD strategies.
http://europa.eu.int/comm/research/energy/gp/gp_pu/article_1257_en.htm

2001-2003: KPI, for DG-Environment

Kyoto Protocol Implementation. This study, in support to the definition of the European Directive on the European “Emission Quota Trading System” for industry has allowed to explore the consequences of the opening and linking of the EQTS to the international emission permit system (intra Annex I allowance trading and project-based flexibility mechanisms). It showed in particular that the linking may change the supply, demand and price conditions compared a pure or closed EQTS system, but not in a dramatic way.
http://europa.eu.int/comm/environment/climat/pdf/kyotoprotocolimplementation.pdf

2000-2002: GECS, for DG-Research

Greenhouse gas Emission Control Strategies LEPII-EPE has been co-ordinator of the project, which aimed at enlarging the scope of General Equilibrium or sectoral energy models used for the assessment of climate negotiation to non-CO2 gas and sinks. This project primarily encompassed the development of the non-CO2 gas and sinks modules of the POLES model and its linkage with dedicated models for agriculture and land-use. It also dealt with the design of medium-term (2010) and long-term (2030) world emission reduction and entitlement scenarios.

2000-2002: ARES, for the GICC programme of the French Ministry of Environment

Emission Reductions Scenarios Analysis. This project has been coordinated by LEPII-EPE and has allowed to develop in parallel a full world economic growth scenario to 2030 and an original international emission permit endowment scheme: the “Soft Landing”. This scheme has then been fully assessed consecutively with the POLES energy sector model and with the IMACLIM general equilibrium model.

2000-2001: Blueprints for international climate negotiation, for DG Environment

Aimed at studying the conditions of operationalisation of the Kyoto Mechanisms, this project provided in particular the economic analyses that were necessary to support the policy design and international negotiation process for the EU-DG ENV, in the The Hague COP-6 and Bonn COP-6.2 context. The project allowed to define, prior to each conference, some “Blueprints for the international negotiation”, while using a decision-tree analysis. It thus allowed to characterise the possible “negotiation deals” and to quantify their economic consequences with a new version of the ASPEN software, developed for this purpose and focusing on the Supply-Demand relationships on the permit market: the ASPEN-sd software.
http://europa.eu.int/comm/environment/climat/pdf/blueprints.pdf

1999-2001: ASPEN, for the French Ministry of the Environment (1999-2001)

Analyse des Systèmes de Permis d’Emission Négociables: ASPEN a dedicated software. Using the Marginal Abatement Cost Curves produced by the POLES model, the ASPEN software allows to explore, in a framework that is both user-friendly and also fully consistent in a micro-economic perspective, different market configurations and trading rules for emission permits. In particular the ASPEN software allows to simulate the consequences of Concrete Ceilings on permit trading as well as to study international and national markets among different POLES sectors.
http://www.upmf-grenoble.fr/iepe/Recherche/Aspen.html