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*Institut d'Economie et  
de Politique de l'Energie*

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# **POLES 2.2.**

**- General Description -**

**• MODEL & GOALS :**

**POLES**

**(Prospective Outlook on Long-term Energy Strategy)**

A world simulation model for long-term (2010-2030) energy demand, supply and prices scenarios or projections.

In particular, the model aims at :

1. reducing the uncertainties and identifying the margins of freedom in future developments of energy consumption and corresponding CO<sub>2</sub> emissions ;
2. providing elements for a global cost-effectiveness analysis of emission reduction options in the perspective of the on-going international negotiation ;
3. analysing the impacts of technological breakthroughs on the energy systems and on CO<sub>2</sub> emissions while taking into account the corresponding price feed-backs ;
4. helping in the identification of appropriate RTD strategies for the EU in a world context.

**• CONTRIBUTIONS TO MODEL DEVELOPMENT**  
**(early stage)**

The model development has been initially funded under the « JOULE II » programme of EU-DG XII with the contribution of the CNRS-ADEME « ECODEV » programme.

• in 1993-1995, the « LETS » (Long-term Energy Technology Strategy) network allowed IEPE to develop, with the help of ECOSIM, a first version of the model, associated with a set of in-depth studies :

1. long-term economic growth by world regions (CEPII)
2. trends in sectoral energy demand for OECD countries (FhG-ISI and ENERDATA)
3. trends in sectoral energy demand for developing countries (SPRU)
4. technical potentials and costs of new energy technologies (ETSU)

**• CONTRIBUTIONS TO MODEL DEVELOPMENT**  
**(operational phase)**

In 1996-1997, the POLES model development has been pursued in the EU-DG XII « JOULE III » programme. This has been done in complementarity with other EU models such as PRIMES (energy sector - EU) and GEM-E3 (General Equilibrium - EU)

- in the « Climate Technology Strategy » project, new developments and improvements of the model have been carried-out (electricity system, renewables, non-conventional oil), leading to POLES 2.2. Version

- common sets of hypotheses have been developed jointly with other modelling teams on macro economic assumptions and technology costs and performances

- a consistent set of projections has been produced, they encompass :

1. A « Baseline » or « Reference Case » which corresponds to the probable evolution of the world energy system, without new policies

2. A set of CO<sub>2</sub> emission reduction projections with « shadow carbon taxes », which allow to assess the marginal and average cost of emission reductions in every sector and every countries

3. A set of 5 « Technology Stories » which simulate the impacts of breakthroughs in the development of some key technologies

**• CONTRIBUTIONS TO MODEL DEVELOPMENT**  
**(future prospects)**

In 1998-1999, the POLES model improvement and utilisation will continue in the EU-DG XII « JOULE III » programme and in the framework of the « TEEM » project, dedicated to the Endogenisation of Technological change in Energy Models.

• in this activity :

1. the model will be maintained and the database updated and extended (RTD indicators)

2. modifications of the model will be introduced in order to properly deal with new promising technologies, such as fuel-cells (stationary, centralised or decentralised, and mobile for road vehicles) (POLES 2.3.)

3. indicators of RTD activity (inputs and outputs) will be gathered in order to provide information for the analysis of RTD impacts and for the endogenisation of technical change

4. features of the ERIS « maquette model » for technology endogenisation will be as much as possible incorporated in POLES in order to account both for stochastic and path-dependent phenomena in technical change (POLES 3.)

**• ACTUAL SITUATION**

- The POLES 2.2. model is a complete recursive simulation model at world level, working on a year by year basis, from 1992 to 2030.
- The model incorporates 60 000 variables of which :
  - 10 000 exogenous variables
  - 15 000 endogenous
  - 35 000 definitions
- It is thus built of a system of 50 000 equations organised in modules for the different countries/regions and energy consuming sectors or activities.
- The model provides regularly updated reference cases, with associated CO<sub>2</sub> reduction costs, « technology stories » and other cases or sensitivity analyses on exogenous hypotheses.
- The model is implemented in Grenoble (IEPE) and in Brussels (DG XII) ; a new version with more detail on the Mediterranean region will also be developed, implemented and used in Sevilla (IPTS, in the MEMA project).
- The model will also be used as a support for world energy analyses and forecasts, in the framework of the Shared Analysis program of DG XVII.

**• ACTUAL SITUATION : Data Bases**

**25 000 Time-series, of which :**

**- 16 000 managed with the in-house SPIDIAL software  
(mostly international energy balances)**

**7 000 « raw » time series**

**9 000 computed from identities**

**- 9 000 managed on EXCEL**

**Sources of data :**

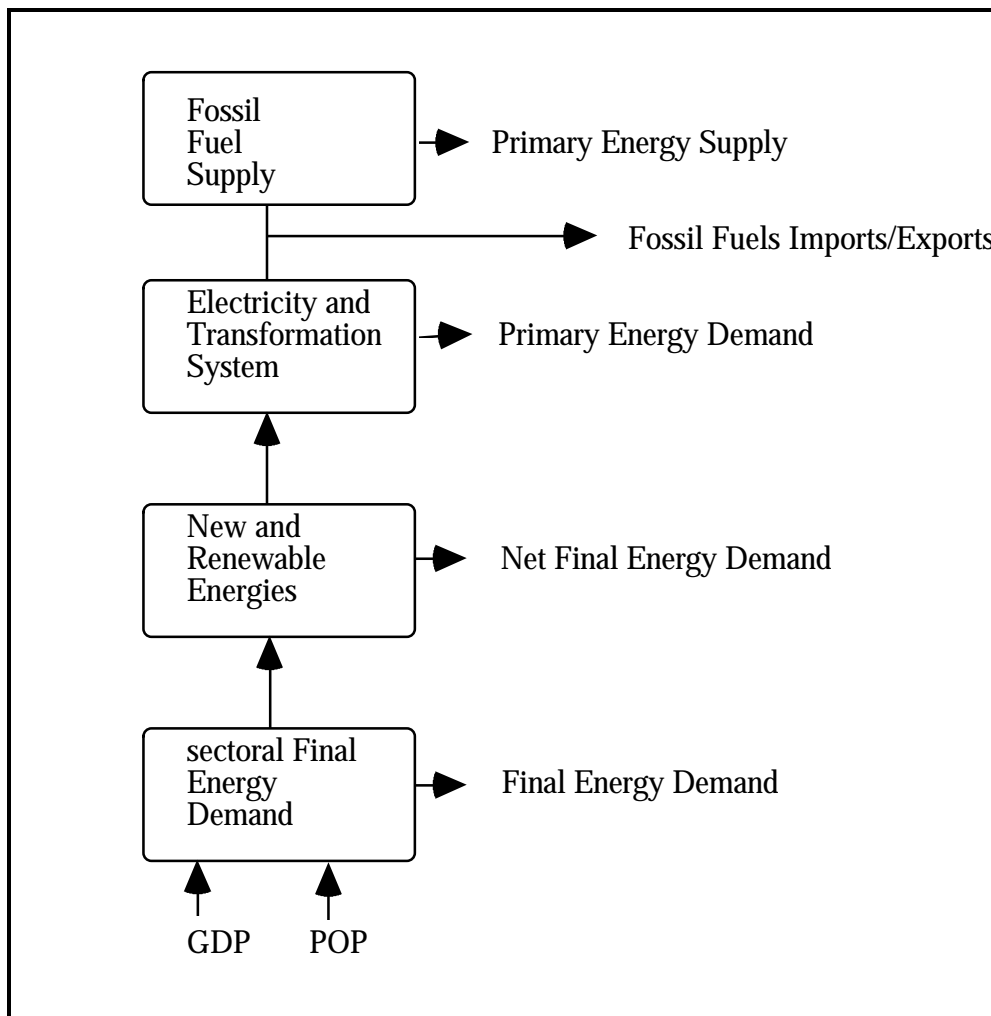
- international energy balances produced by ENERDATA, from IEA, UN and national information**
- international macro-economic data from CEPIL, World Bank and UNIDO**
- final energy prices from IEA and other national sources**
- techno-economic data (steel production, transport flows and automobiles, dwellings ...) from international and national sources**
- supply-side data on the oil and electricity industries activity and on the current development of renewable sources**
- technology databases from the « Technology Cost and Performance Data Base » in CTS and TEEM JOULE III projects.**

• **SCOPE 1 : A global model for the energy sector**

*"Vertical integration" of the energy systems for 14 large countries and 12 regions :*

1. Final energy demand, by sector and type of use (techno-economic approach), with income and price-effects.
2. Development of new and renewable forms of energy while taking into account resources, learning curves and market penetration.
3. Conversion from final to primary energy, with a simulation of capacities and electricity production for different power plant categories.
4. Production of fossil fuels (coal, oil, gas) on a country by country basis.

**POLES 2.2. : The "vertical integration" process**

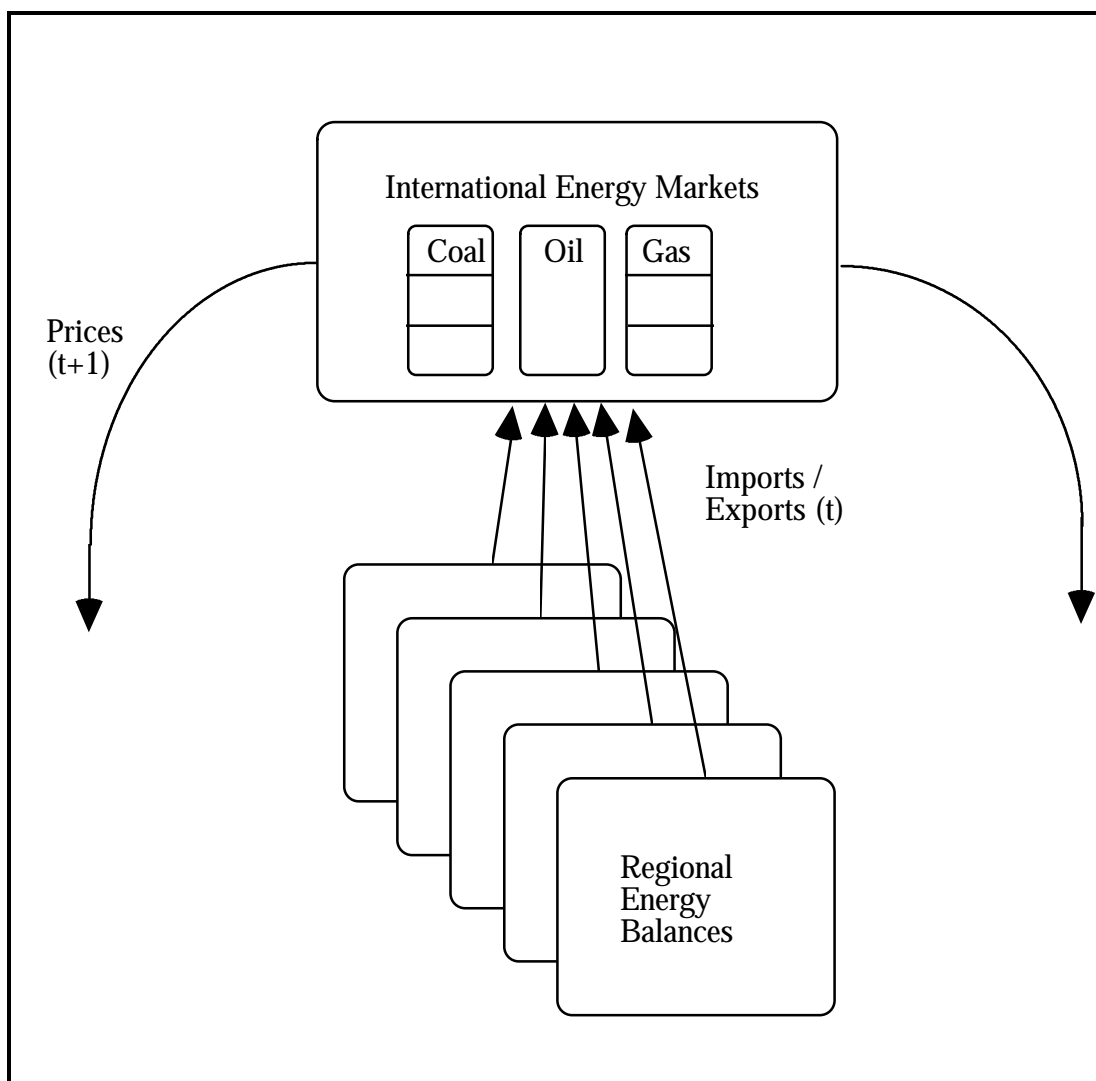


**• SCOPE 2 : A global model for the energy sector**

***"Horizontal integration" through the international energy markets :***

- 1. Analysis of the swing-producers and capacity constraints on the oil market ; world oil price as a function of the world R/P ratio (including non conventional oil) and of the Gulf capacity utilisation rate ;**
- 2. Three regional gas markets and gas trade matrices ; gas prices as a function of regional R/P ratios and world oil price**
- 3. Three regional coal markets and coal trade matrices, coal price as a function of cost components in major producers.**

**POLES 2.2. : The "horizontal integration" process**



## **• MODELLING CHARACTERISTICS**

World disaggregation in 26 main areas, with detailed national models for the main countries .

Hierarchical system of interconnected modules for :

1. international energy markets ;
2. regional energy balances ;
3. national energy demand, new technologies, electricity production and primary energy production systems.

### ***• International databases***

Built and maintained by IEPE, with data from international organisations, from ENERDATA for the energy balances and CHELEM-CEPII for GDP (PPP).

### ***• Time horizon***

Long-term : 2010 and 2030

### ***• Economic analysis***

Recursive year by year simulation process, with behavioural equations for energy demand, conversion, production so as for price-making processes.

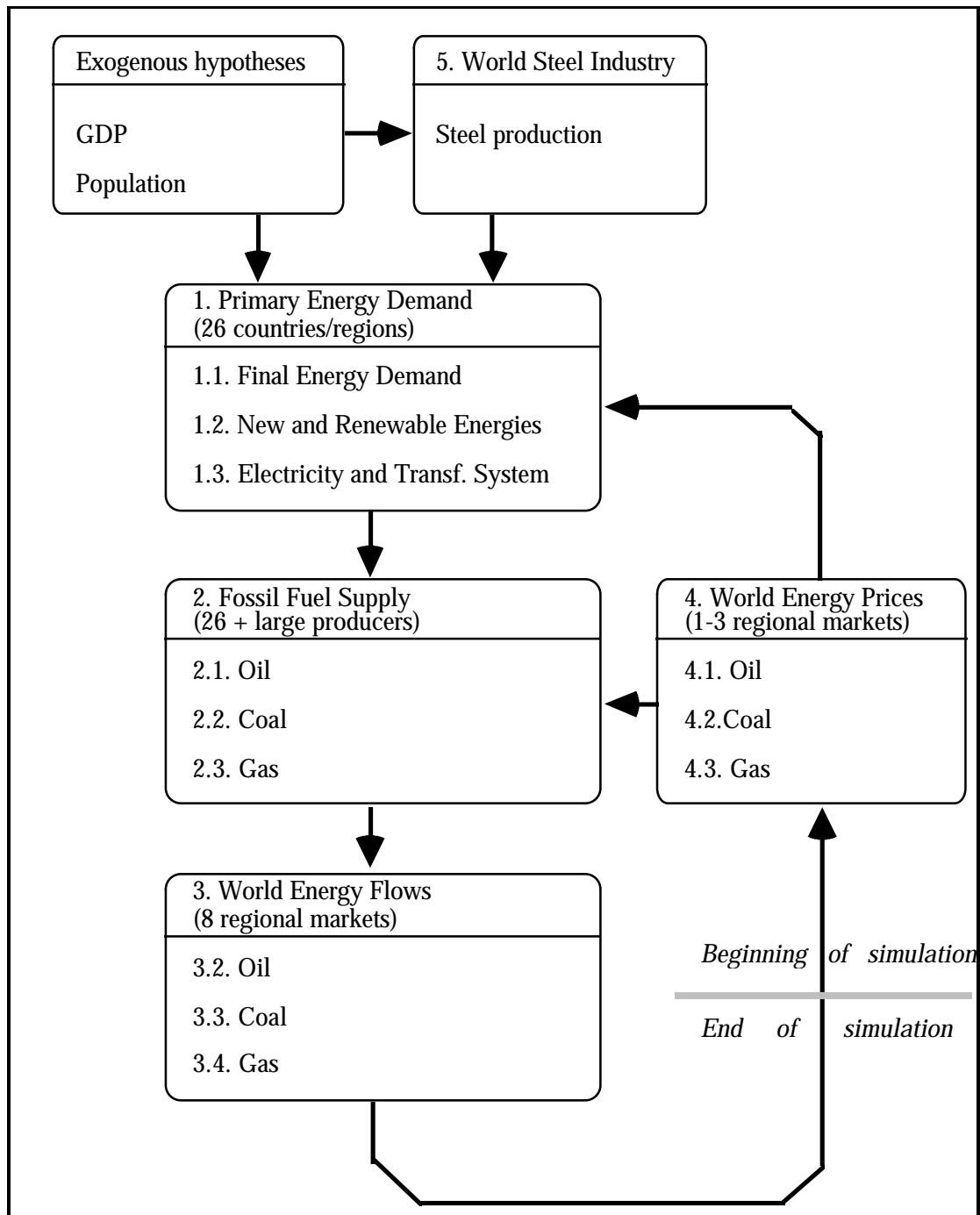
**• OUTPUTS**

- **World long-term energy scenarios or projections :**

**Reference Case,  
Internalisation of Externalities,  
Technological Breakthroughs  
Other cases (GDP, Ressources)**

- **National-regional energy balances and GHG emissions simulation, flows on energy markets, international prices**
- **Analysis of new energy technologies potentials, markets and diffusion**
- **Test of energy policies and energy RTD strategies**
- **Impacts on international markets and prices**

**POLES 2.2. : Modules and simulation process**



**POLES 2.2. : Geographical coverage and disaggregation of the primary demand models**

Market	AMM american market		
Regions	NOAM north amer	CEAM central amer	SOAM south amer
Countries	<b>CAN</b> <b>USA</b>	<b>MEX</b>	<b>BRA</b>
Remainders		RCAM	RSAM

Market	EAM euro-african market				
Regions	EECF EEC 15	OWEU other west eur	NOAF north africa	SSAF south of sah afr	MIEA middle east
Countries	<b>RFA</b> <b>FRA</b> <b>GBR</b> <b>ITA</b> <b>RECS</b> <b>RECN</b>	OWEU	NOAF	SSAF	MIEA

Market	EEM east-european market	
Regions	CEUR central eur	FSUN (NIS)
Countries	CEU4	FSUN
Remainders	RCEU	

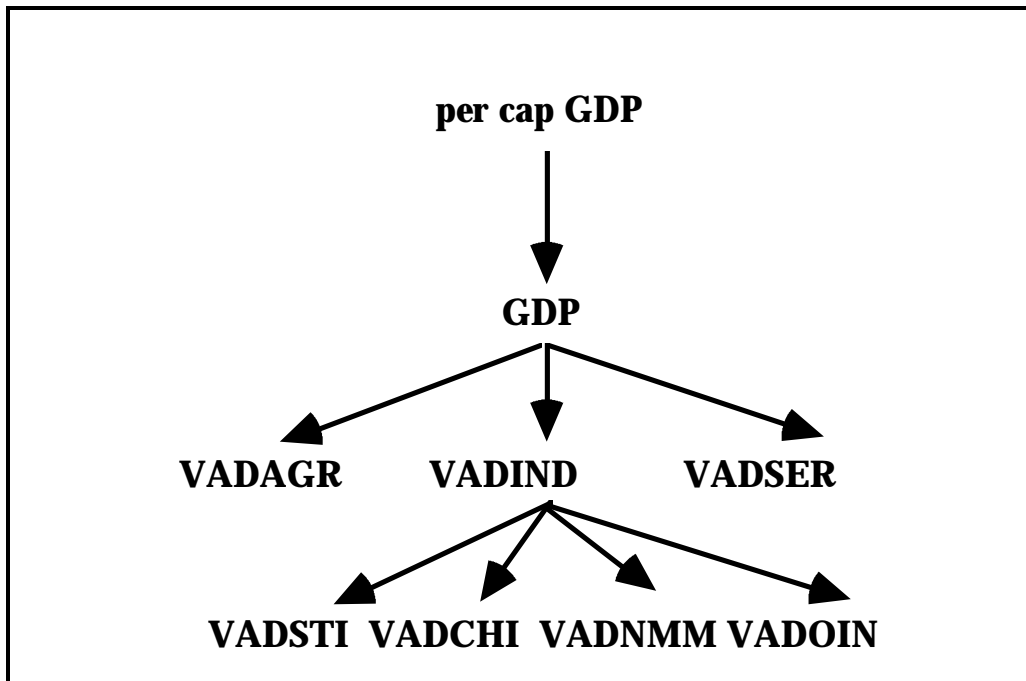
  

Market	ASM asian market			
Regions	SOAS south asia	SEAS south east asia	COAS continental asia	JANZ pacific oecd
Countries	<b>NDE</b>	<b>COR</b>	<b>CHN</b>	<b>JPN</b>
Remainders	RSAS	RSEA		RJAN

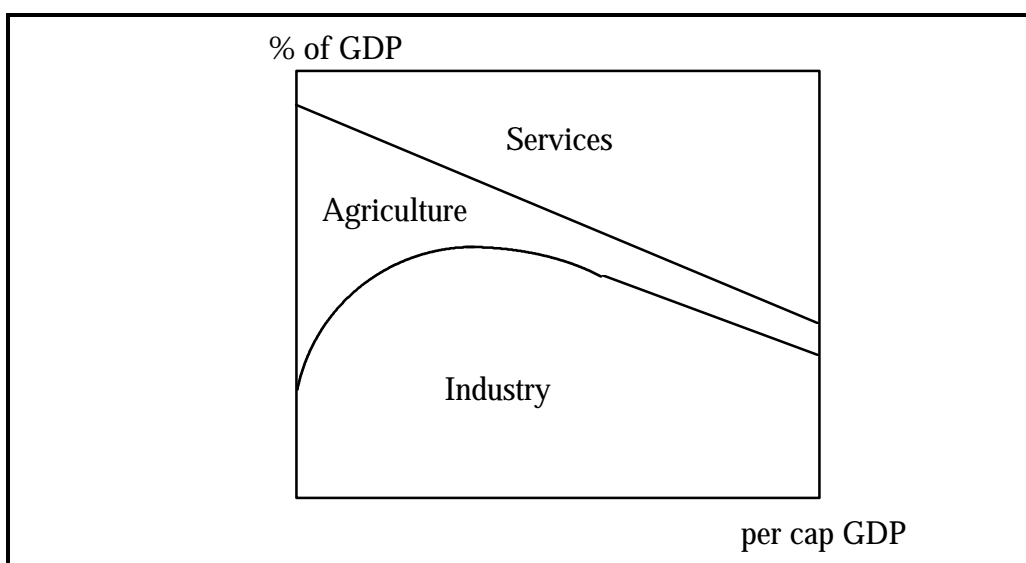
**POLES 2.2. : Demand disaggregation for 11 main sectors**

Sector	Sub-sector		Fuels	Elec.
INDUSTRY	Steel Industry	STI		
	Chemical Ind. (+ Feedstocks)	CHI+CHF		
	Non Metallic Minerals Ind.	NMM		
	Other Ind. (+ Non Energy Use)	OIN+ONE		
TRANSPORT	Road Transport	ROT		
	Rail Transport	RAT		
	Air Transport	ART		
	Other Transports	OTT		
RAS	Residential Sector	RES		
	Service Sector	SER		
	Agriculture	AGR		

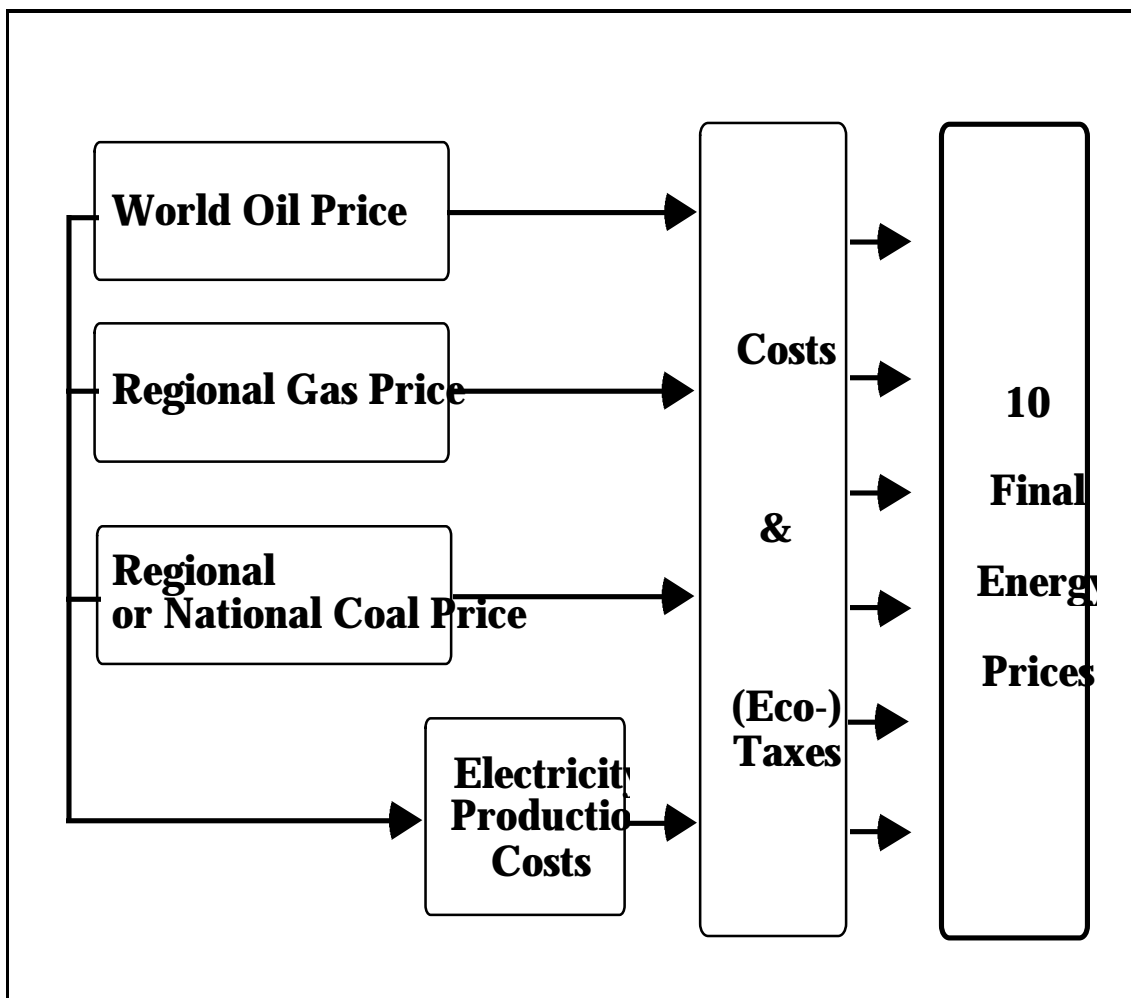
**POLES 2.2. : The projection of Economic Structures**



• Profiles of economic structure



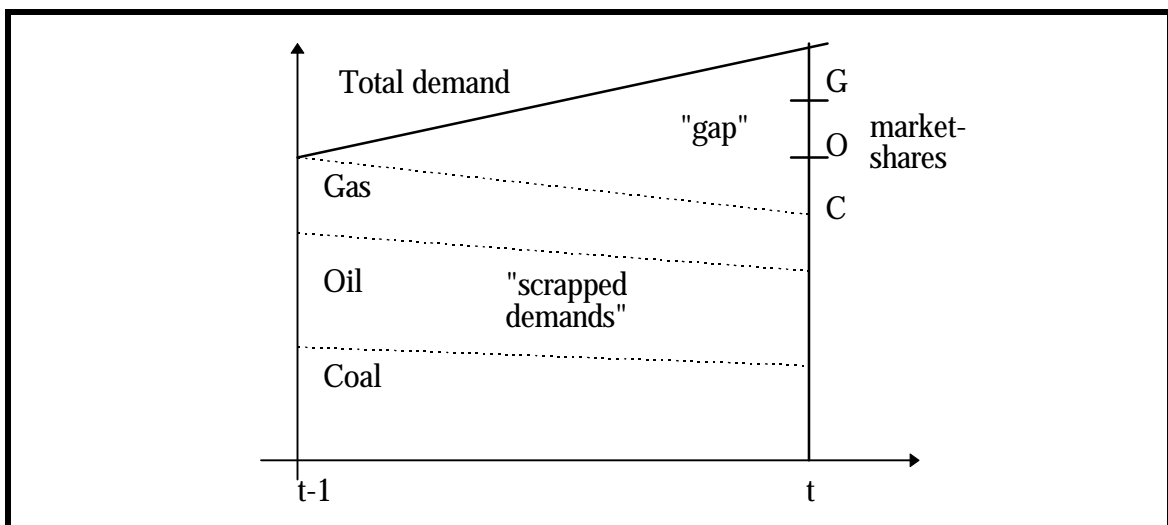
POLES 2.2. : From international prices  
to national final energy prices



**POLES 2.2. : Energy demand functions and interfuel substitution**

**Eq. 1 STANDARD FINAL ENERGY DEMAND FUNCTION**

$$\begin{aligned} \text{Ln(FC)} = & \text{RES\_FC} + \text{Ln(FC[-1])} && \text{residual and lagged variable} \\ & + \text{ES} * (0.67 * \text{Ln(AP/AP[-1])} + 0.33 * \text{Ln(AP[-1]/AP[-2]))} + && \\ & && \text{short-term price effect, current year and year -1} \\ & + \text{EL} * \sum_{i=-1 \text{ to } -\text{DP}} \frac{6 * \text{DI}[i-1]}{(\text{DP} * (\text{DP}^{**2} - 1)) * (i^{**2} + \text{DP} * i)} * \text{Ln(AP}[i-1]/\text{AP}[i-2]) && \\ & && \text{long-term price effect with distributed lag and dissymetry factor} \\ & + \text{EY} * \text{Ln(VA/VA[-1])} && \text{income/activity elasticity} \\ & + \text{Ln}(1 + \text{TR}/100) && \text{autonomous technological trend} \end{aligned}$$

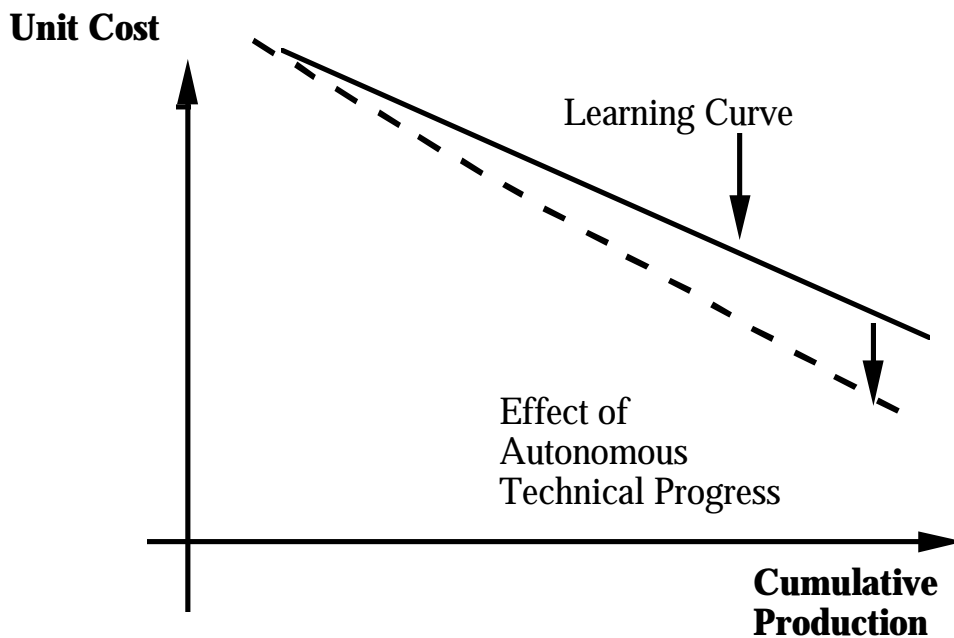


**POLES 2.2. : 12 New and Renewable Energy Technologies**

<b>1. Combined Heat and Power, (small to medium-size cogeneration in industry)</b>	<b>CHP</b>
<b>2. Small Hydro Power plants (&lt;10 MWe)</b>	<b>SHY</b>
<b>3. Wind power plants for network electricity production according to wind resources</b>	<b>WND (WN1, WN2, WN3)</b>
<b>4. Solar Power Plants (thermal technologies for network electricity production)</b>	<b>SPP</b>
<b>5. Decentralised building integrated PV systems with network connection</b>	<b>DPV</b>
<b>6. PV systems for Decentralised rural electrification in DCs</b>	<b>RPV</b>
<b>7. Low Temperature Solar systems in residential sector</b>	<b>LTS</b>
<b>8. Biofuels, conventional technologies (woodfuels, elec. from wastes, biofuels)</b>	<b>BF1, BF2, BF3</b>
<b>9. Biomass gasification for electricity production in GT</b>	<b>BGT</b>
<b>10. Proton exchange Fuel Cells for road Vehicles</b>	<b>FCV</b>
<b>11. Proton exchange Membrane Fuel Cells, stationary</b>	<b>MFC</b>
<b>12. Solid oxyde Fuel Cells, in cogeneration</b>	<b>SFC</b>

POLES 2.2. : New and Renewable Energy Technologies

**STEP 1 : from Learning Curves to ROI ratio**



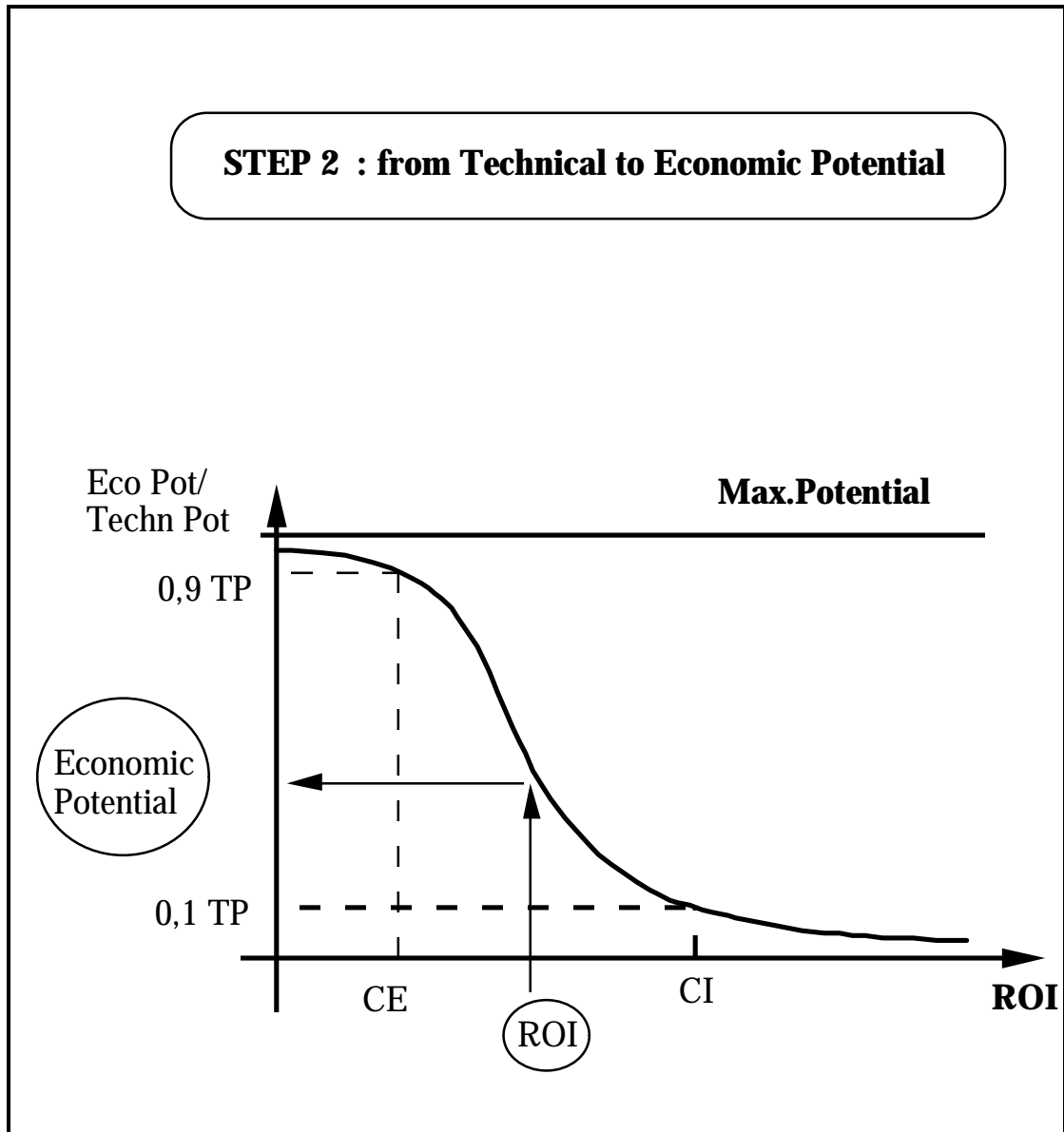
$$UC = UC(-1) * (CV / CV(-1)) ** LC x (1-TP)$$

**Return on Investment : ROI**

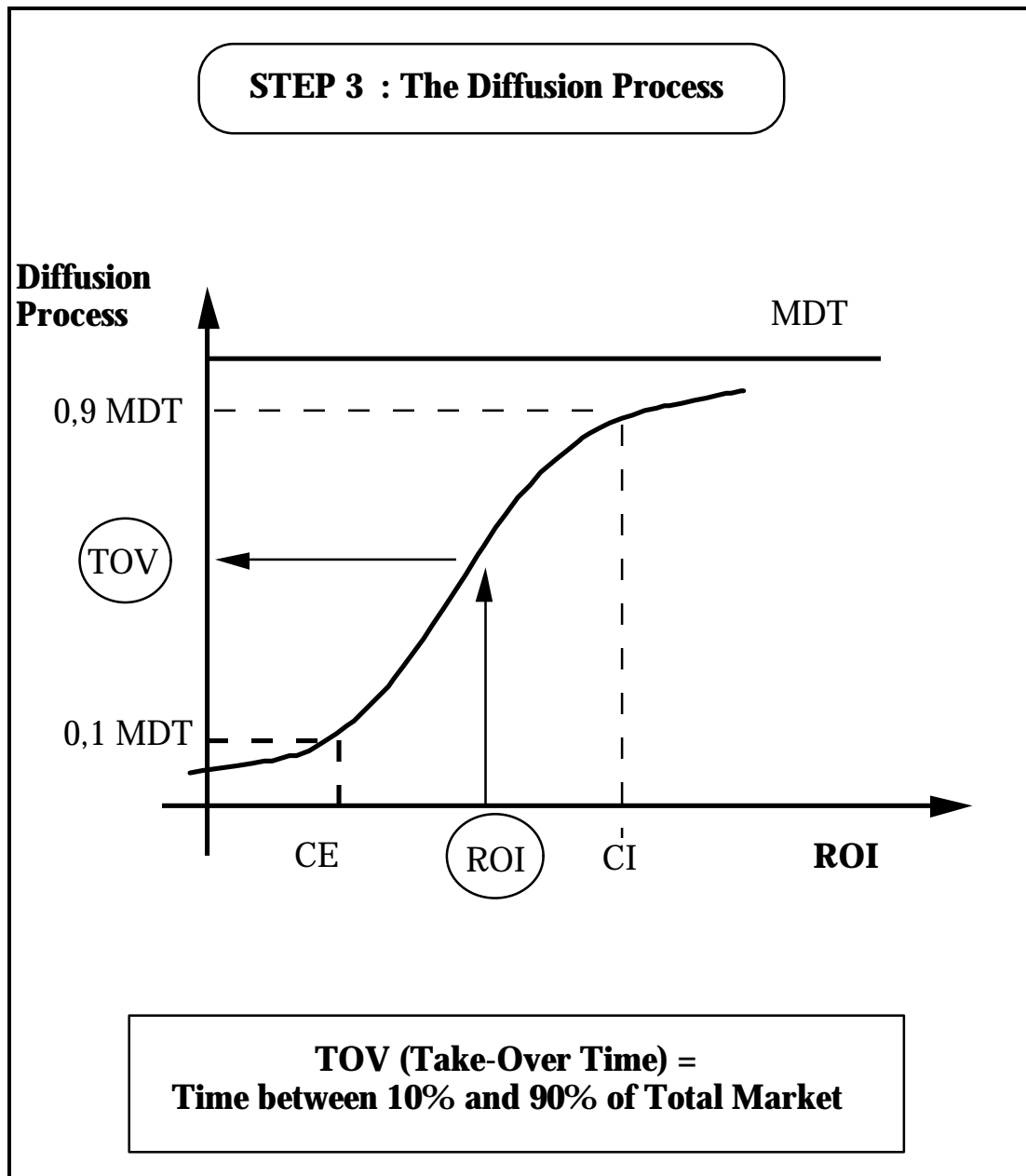
$$ROI = UC / AP * f(DISC,LT)$$

POLES 2.2. : New and Renewable Energy Technologies

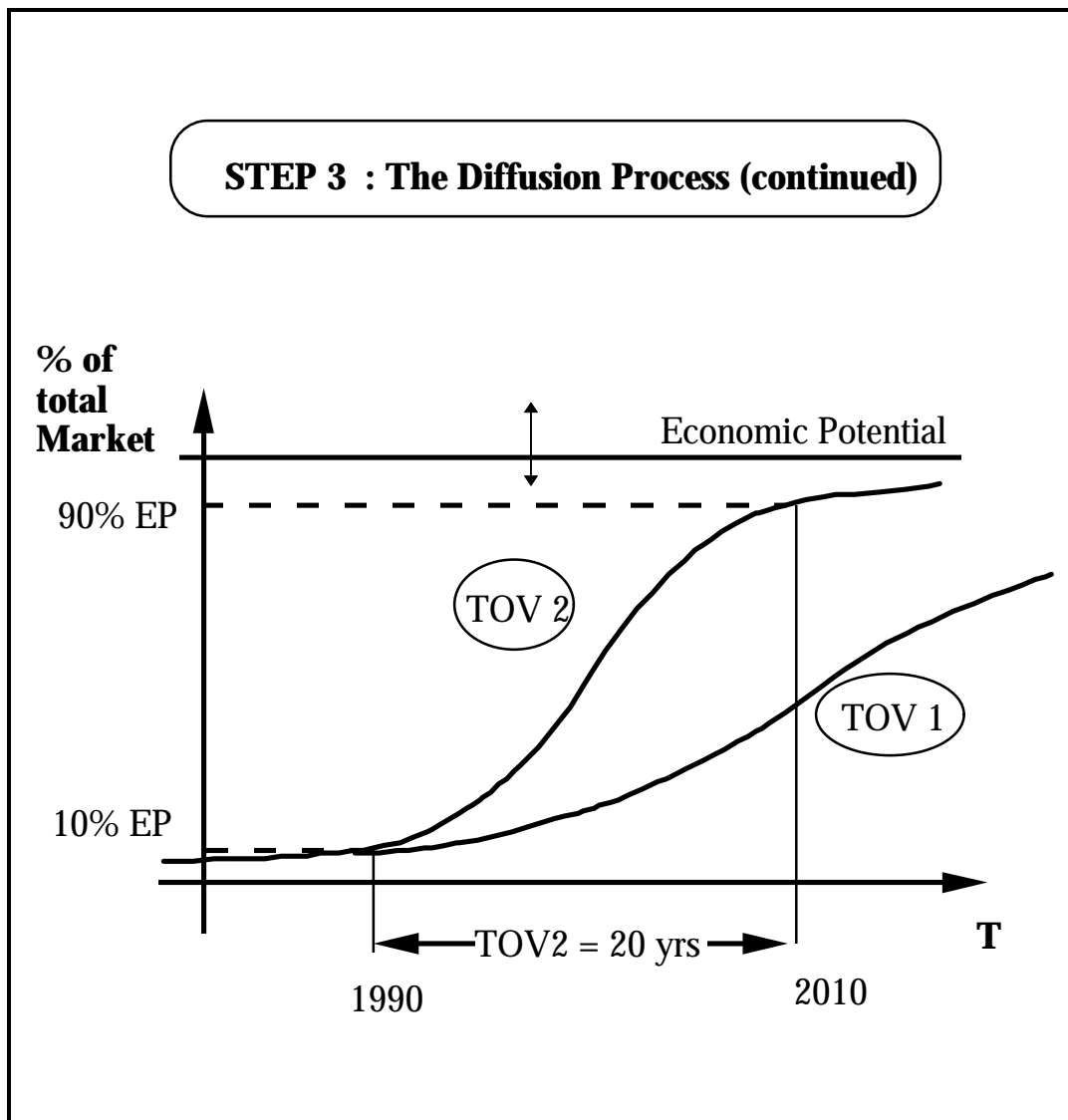
**STEP 2 : from Technical to Economic Potential**



POLES 2.2. : New and Renewable Energy Technologies



**POLES 2.2. : New and Renewable Energy Technologies**

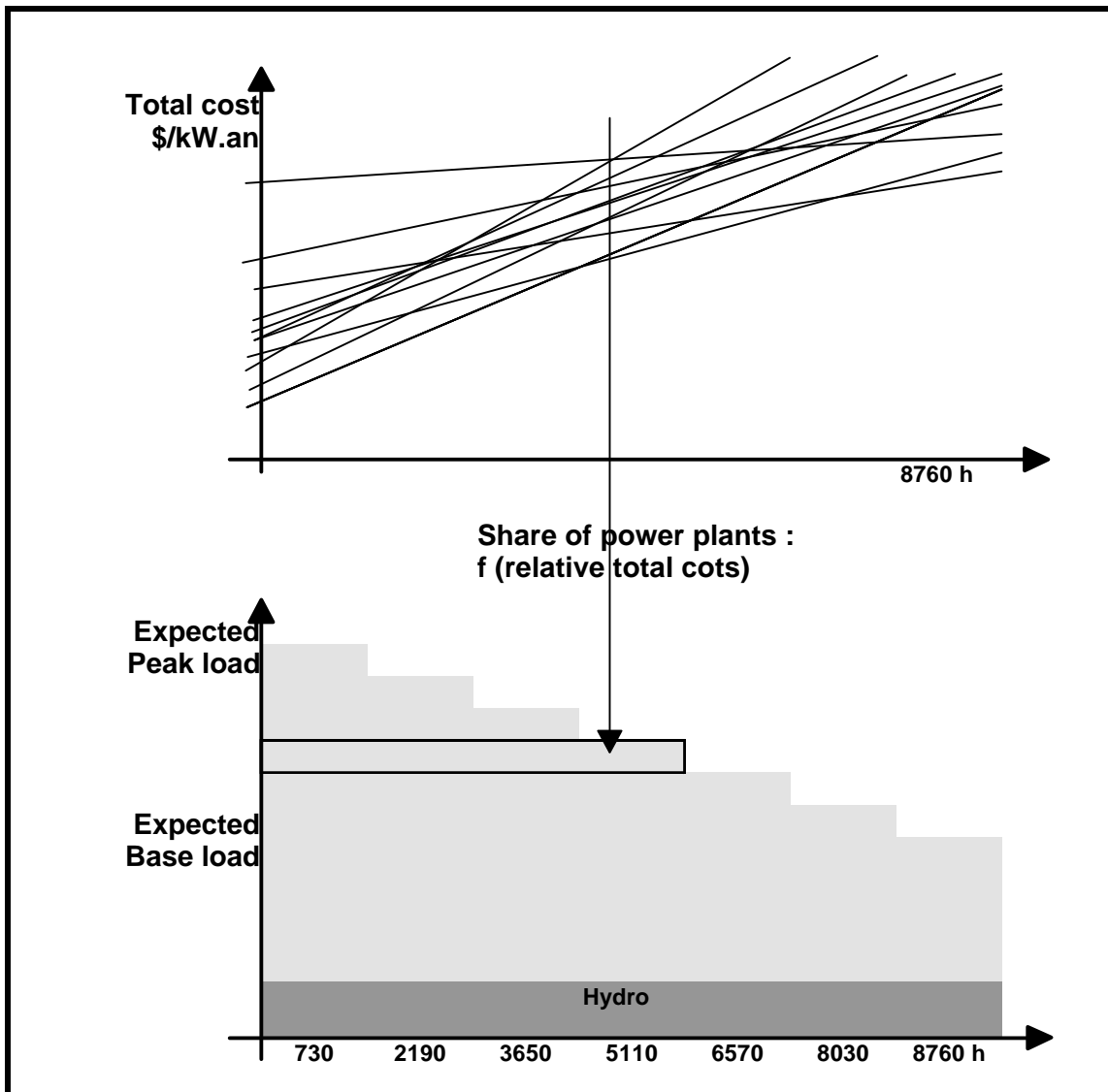


**POLES 2.2. : 12 Power plant categories**

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

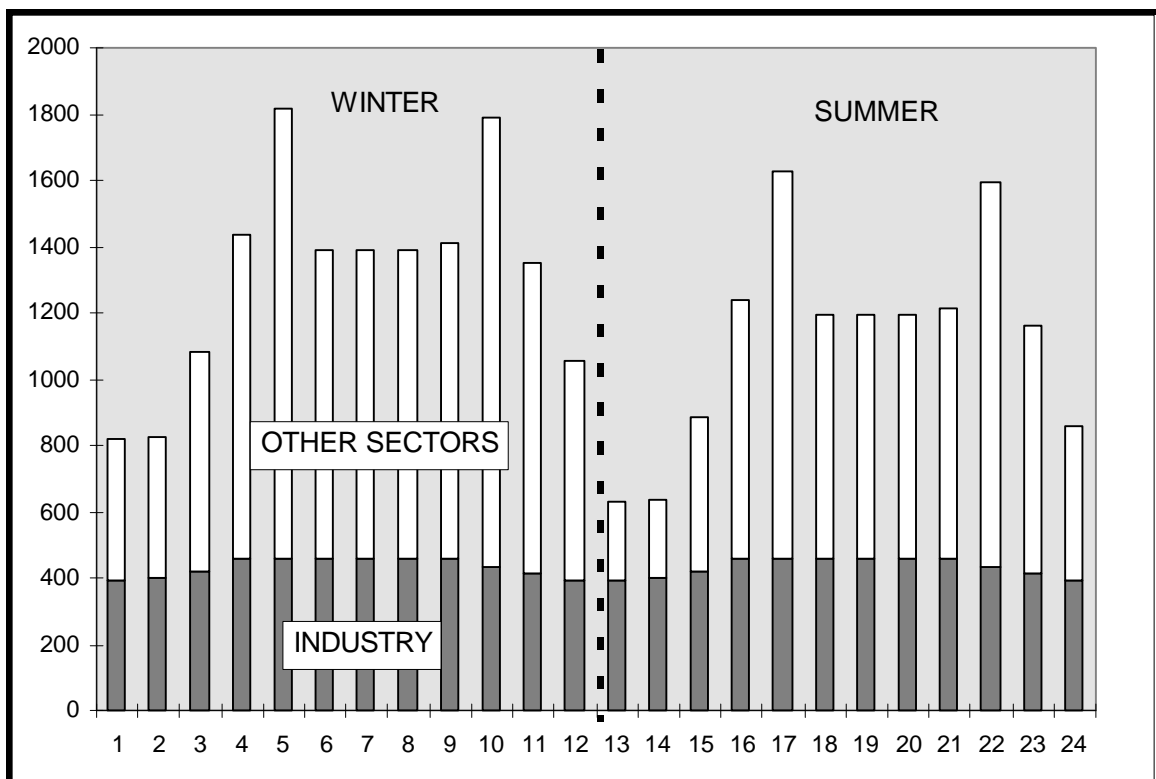
**POLES 2.2. : Electricity expected costs and capacity planning**

- Technology costs from CTS Technology database
- Fuel costs endogenous from model



**POLES 2.2. : Electricity load curve  
and power plant production**

- Load-curves are endogenous from sectoral electricity demand profiles and structure
- For each time-block in the load-curve, the production shares are a function of the relative variable costs of power plants
- Production by type of power plant is computed taking into account capacity constraints



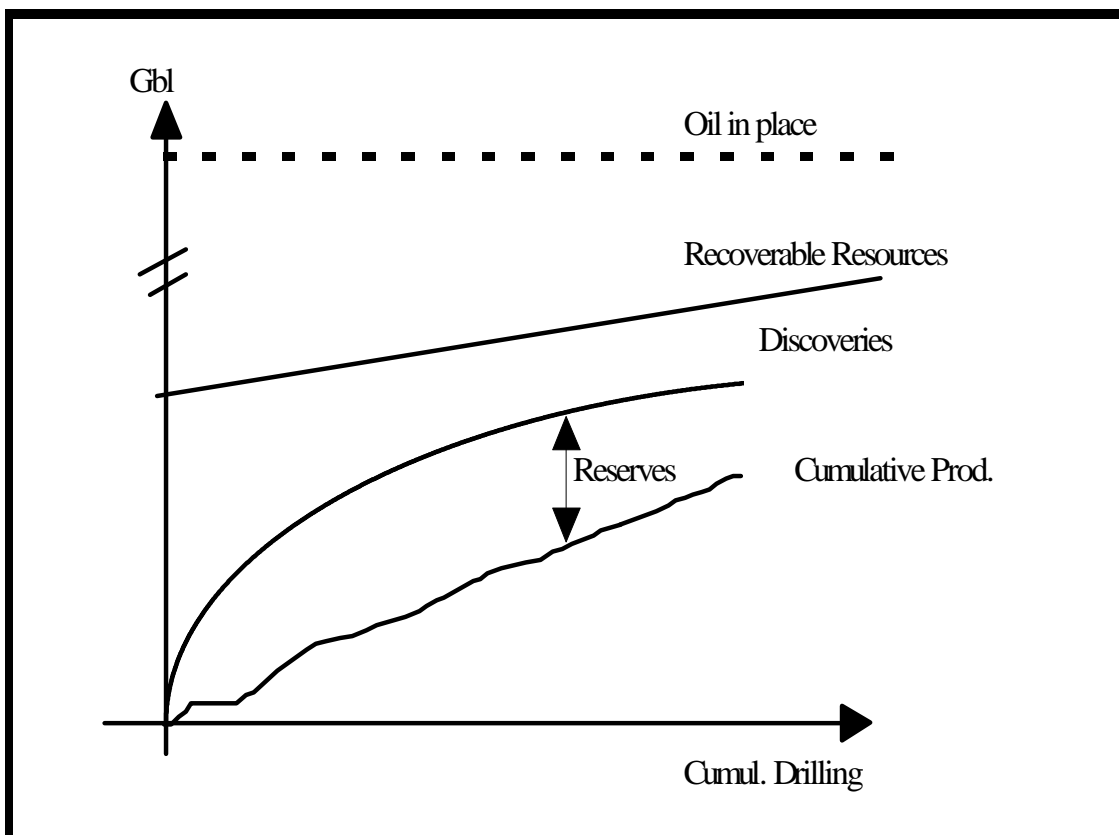
**POLES 2.2. : 30 major Oil & Gas producers**

- **Oil production profiles are simulated individually for all major producers**

- **Canada, USA, Mexico ;**
- **Brasil, Colombia, Ecuador, Venezuela ;**
- **Great Britain, Norway ;**
- **Algeria, Libya, Egypt, Angola, Gabon, Nigeria ;**
- **Saudi Arabia, Kuwait, Neutral Zone,  
United Arab Emirates, Oman, Iraq, Iran ;**
- **Former Soviet Union ;**
- **India, Brunei, Indonesia, Malaysia, China, Australia ;**

## POLES 2.2. : The Oil & Gas discovery process model

- **Ultimate Recoverable Ressources**  
= Oil in Place \* Recovery Rate
- **Discoveries follow an asymptotic path, function of the cumulative drilling effort**
- **Reserves = Discoveries - Cumulative Production**
- **for the « non swing - producer » countries, the production is derived from reserves and a variable R/P ratio**



**POLES 2.2. : Non Conventional Oil and Liquefaction**

- **Assessment of resources, recovery factors and current and future costs for :**

	<b>Recoverable 95 Gbl</b>	<b>Benchmark 95 \$/boe</b>
Extra-Heavy Oil	<b>290</b>	<b>22</b>
Tar-Sands	<b>250</b>	<b>26</b>
Oil-Shales	<b>335</b>	<b>45</b>
<b>Total non conv. (Conv. Oil 1995</b>	<b>875 2360)</b>	

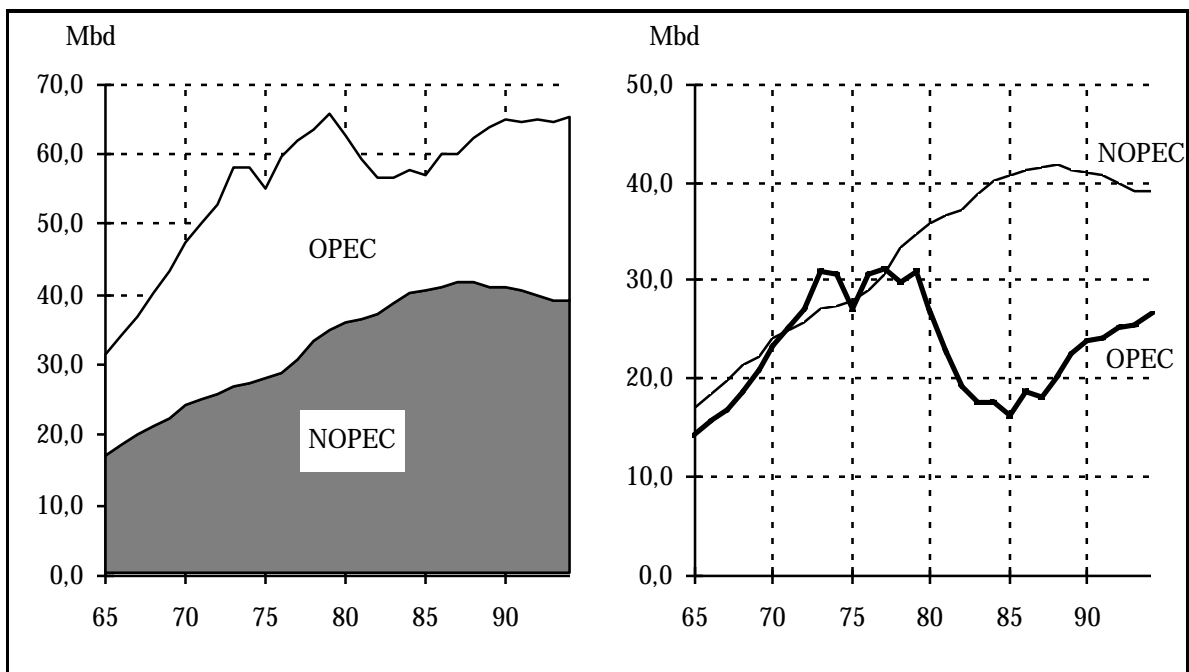
- **Assessment of current and future efficiency and conversion costs for :**

	<b>1995</b>	<b>2030</b>
Coal liquefaction	<b>35 \$ - 60%</b>	<b>27 \$ - 70%</b>
Gas liquefaction	<b>25 \$ - 70%</b>	<b>18 \$ - 82%</b>

- **Simulation of potentials and production driven by oil price for NCO and coal and gas relative prices for Liquefaction**

## POLES 2.2. : World Energy Flows and Markets

### 1. The Oil Market "non swing" and "swing" producers



- Non OPEC production = « fatal production »,  $f$  (oil price, reserves)
- OPEC non-Gulf production =  $f$  (residual demand for OPEC oil)
- Gulf countries production =  $f$  (res. demand for Gulf oil, capacities)

**POLES 2.2. : World Energy Flows and Markets**

**2. The Natural Gas Trade Matrix  
(8 import markets, 18 key exporters)**

**The Market Closure Equation**

$$ZZZ\_GASMKT = ZZZ\_PEGAS - \_ (SPZ\_PEGAS) - \_ (FPZ\_PRTGAS)$$

Imp Exp	USA	RAMM	EECF	REAM	REEM	FSUN	JPN	RASM	WRD
CAN	102,8								17,4
USA							2,7		0,4
MEX	-5,2								-0,9
VNZ									0,0
GBR									0,0
RECN			27,0	11,3					13,9
NOR			15,9						8,1
FSUN			35,8	77,4	99,5				31,0
DZA	2,4		20,3	11,3	0,5				11,0
LBY			1,1						0,6
NGA									0,0
SAU									0,0
ARE							6,5		1,1
IRN									0,0
QAT									0,0
IDN							47,4	83,5	9,9
BRN							13,5		2,2
MYS							18,2	16,5	3,4
AUS							11,8		1,9
• 18+(1)	100		100	100	100		100	100	100
	16,9		50,8	1,9	11,4		16,5	2,5	100

**POLES 2.2. : World Energy Flows and Markets**

**3. The Coal Trade Matrix  
(8 import markets, 10 key exporters)**

**The Market Closure Equation**

$$ZZZ\_COLMKT = ZZZ\_PECOL - \_ (SPZ\_PECOL) - \_ (FPZ\_PRTCOL)$$

Imp Exp	USA	RAMM	EECF	REAM	REEM	FSUN	JPN	RASM	WRD
USA		63,4	34,3	30,7	10,6		10,3	9,1	23,8
CAN		8,9	3,4	1,0			14,4	6,8	7,3
COL		7,9	7,4	6,9			0,3	0,8	3,8
VNZ									
POL		4,6	8,5	1,0	27,5				4,9
FSUN			6,7	4,0	52,9		4,2	0,7	6,5
ZAF		1,7	20,3	38,6	0,5		5,5	12,9	12,8
AUS		12,5	16,1	17,8	7,4		54,9	46,7	32,2
IDN		1,0	1,2				4,8	9,5	3,7
NDE									
CHN			2,1		1,1		5,7	13,4	5,0
• 10+(1)		100	100	100	100		100	100	100
		7,7	37,7	2,6	4,8		28,1	19,0	100

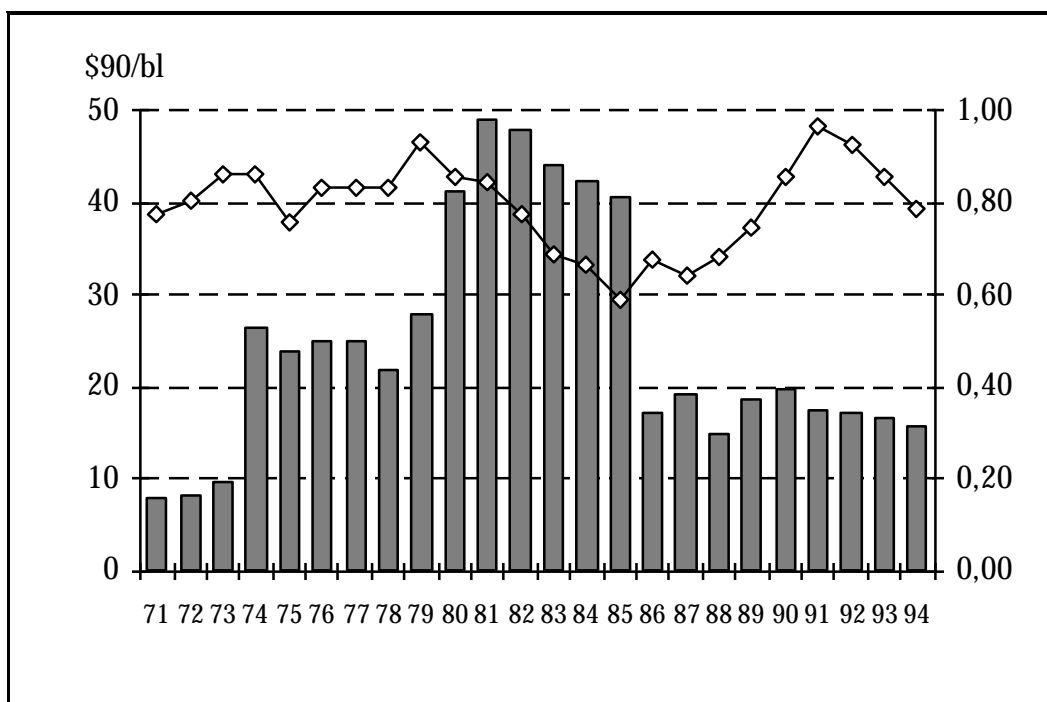
**POLES 2.2. : International Energy Prices**

**1. Oil price :**

**World average oil R/P ratio  
(with recoverable reserves from NCO)**

**+**

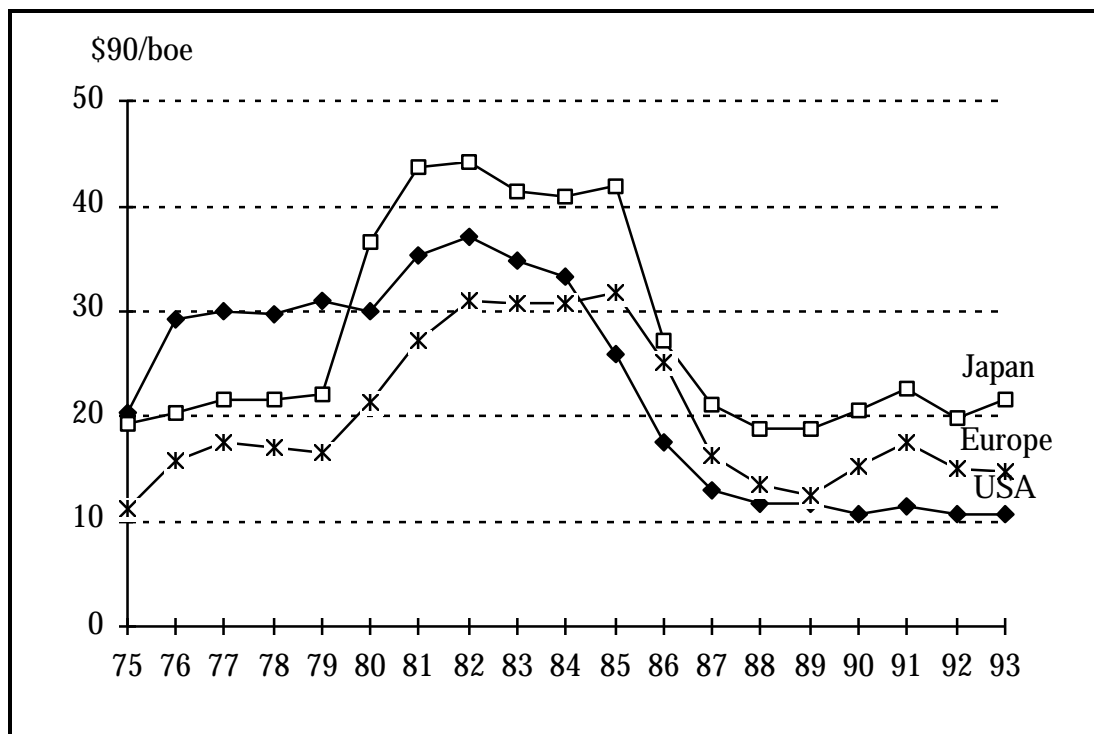
**The Gulf Countries capacity utilisation rate**



**POLES 2.2. : International Energy Prices**

**2. The Gas prices :**

**The Regional Gas R / P ratios  
+  
World Oil Price**



**POLES 2.2. : International Energy Prices**

**3. The Coal prices :**

**Production and production costs  
in the key world producers**

