POLES Model

Prospective **O**utlook on **L**ong-term **E**nergy **S**ystems

A World Energy Model

Alban Kitous – 09th February 2006
1

The POLES model

POLES :

- is an **econometric**, **partial-equilibrium** world model (equilibrium between energy demand & supply, but economic assumptions remain exogenous)
- has been developed first by CNRS (France) and now by CNRS / UPMF university, Enerdata and IPTS (Spain, European Commission research centre)
- has been used in many European studies as well as for French ministries to evaluate energy and GHGs emissions reductions policies

It allows :

- Projections of energy demand and supply by region/country and international oil/gas/coal prices
- Simulation of technology development for electricity supply
- Simulation of CO_2 emissions and analysis of CO_2 abatement policies and carbon values

Agenda

Long-term energy forecasts

> The energy forecasts are carried out at 3 levels:

1. final demand (electricity, oil products, etc..) : demand models (like the models MAED, MEDEE)

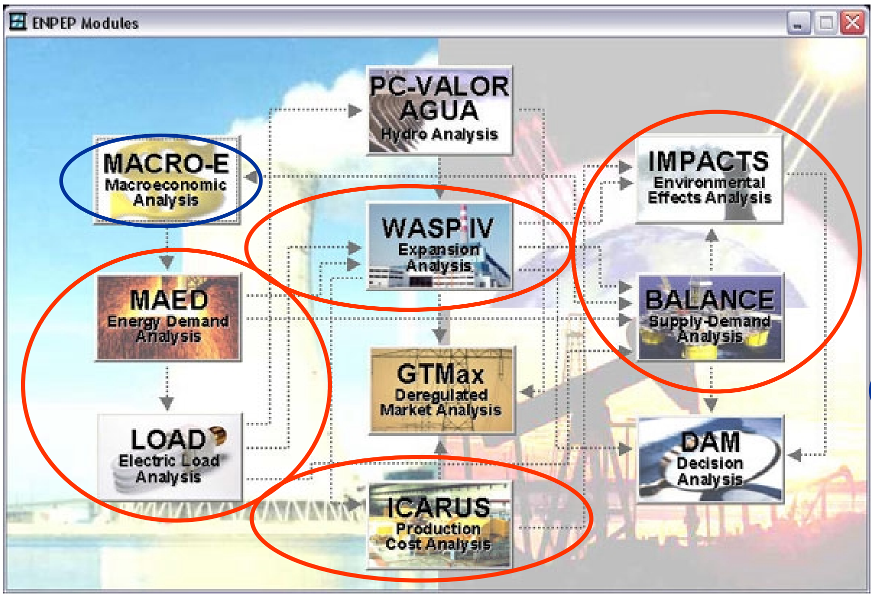
2. electricity production & its related energy demand : electricity models (like the model WASP)

3. fossil fuel productions and related transformation (refineries, etc..) (like the model BALANCE)

> Modular models like ENPEP allow connections between these different modules

> Global energy models (like POLES, or the IEA's?) are fully integrated models that aggregate the different modules through feedback effects and recursive process

Modular models, example of ENPEP



POLES model

IMACLIM, from CIRED, or models at CEPII (France)

Econometric vs. Bottom-up models, generalities

> **Econometric models** : the energy demand is deduced from economic variables (GDP, added values, private consumption, ..) and energy prices through statistical (“econometric”) relations based on “elasticities”.

> In **Bottom-up models** the energy demand is represented at a detailed level (equipment, uses, ..) and is affected by variables indicating a level of activity (equipment for a given consuming good, etc..) and technical variables regarding the consumption per unit of consuming good.

> Econometric and Bottom-up models are complementary and may be used simultaneously (eg “Factor 4” study for the French Ministry of Industry where POLES and MEDEE were both used)

Econometric vs. Bottom-up models, example : the households electricity consumption

> **Econometric equation :**

The energy demand is a function of the electricity price (P) and of the private consumption of Households (PC)

$E = k * P^a * PC^b$ $\qquad$ $Ln(E) = a*Ln(P) + b*Ln(PC) + k'$

a : price elasticity (elasticity of demand related to the *electricity price*)

b : activity elasticity (elasticity of demand related to the *private consumption*)

> **Bottom-up equation :**

The energy demand is equal to the sum of the equipments (Eq) and of the unit consumption of each equipment (UC, in kWh/equipment)

$E = \Sigma_i (Eq_i * UC_i)$

Enerdata
Enerdata SERVICES

Econometric models : elasticities

> Elasticities measure the demand responsiveness to price variation (**price elasticity**) or activity variation (**activity elasticity**)

Example : an activity elasticity of 1.2 of gasoline demand to GDP means that the demand is growing 1.2 times faster than GDP :

➔ if GDP increases by 5%/year, then gasoline demand increases by 6%/yr

> **Price elasticity** : should be < 0 (when price increases, energy demand decreases)

> When an elasticity is close to 0, the demand is said to be "**inelastic**"

> **The equations are based on theory and expertise**

> Elasticities are calculated by means of **statistical regressions** on historical values

$$Ln(E) = a*Ln(P) + b*Ln(PC) + k'$$

Agenda

The POLES model

> World energy model, with a year-by-year simulation

> Simulation of energy balances for 32 countries and 18 world regions

> Disaggregation into 15 energy demand sectors, 12 new/ renewable technologies and 12 power generation technologies

> Simulation of oil and gas: discoveries and reserves for main producers

> International energy prices and markets are endogenous

> Model jointly developed by IEPE-CNRS , IPTS , and Enerdata

> Databases produced and updated by Enerdata

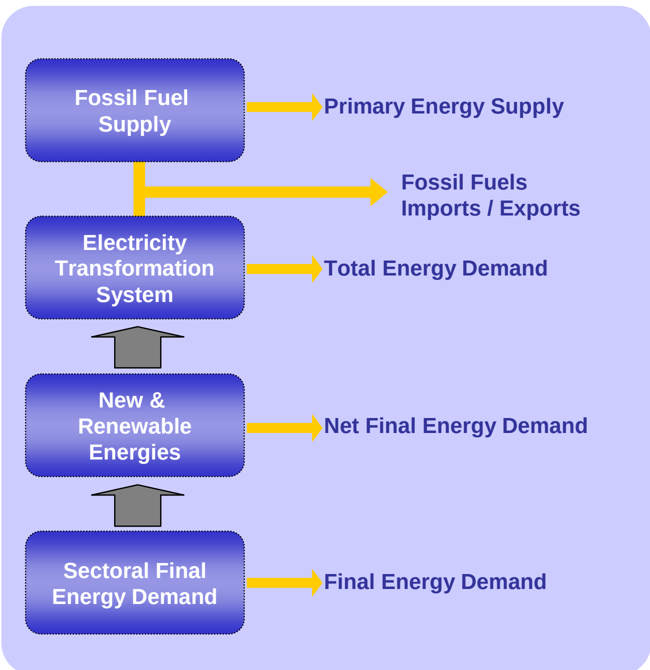
> Model used by EU Commission (DG Research , DG-TREN , DG-Environment), French Ministries (Energy, Environment), Shell, GDF, IFE, EDF, RWE, ADEME

POLES : the world in 7 regions, 11 sub regions and 32 countries

Region	Sub-Region	Countries
North America		Unites States, Canada
Europe	EU-15 EU-25 EU-27	> Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, UK, Turkey > Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovak Republic
Japan – South Pacific	South Pacific	Japan, Australia & New Zealand
CIS		Russia, Ukraine
Latin America	Central America South America	Brazil, Mexico
Asia	South Asia South-East Asia	India, South Korea, China
Africa / Middle-East	North Africa Sub-saharian Africa Middle-East	Egypt

Enerdata Enerdata SERVICES

Modeling of national/regional energy systems (32 countries and 18 world regions): from final demand to total demand



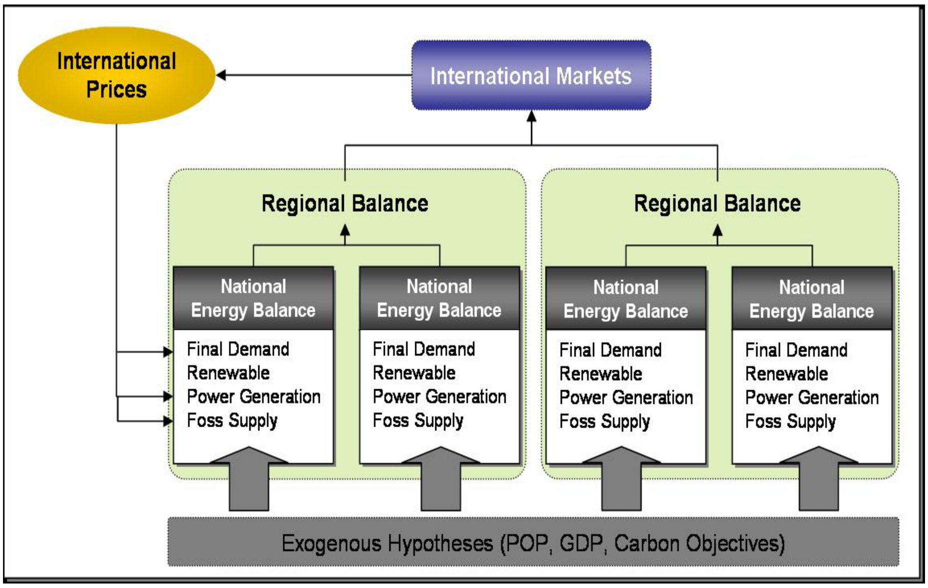
Fossil fuel production (coal, oil, gas)

Simulation of electricity production and capacities for different power plant categories

Diffusion of new technologies and renewables

Final energy demand (electricity, oil, gas, coal, heat and biomass), by sector, with income, price-effects and technological trends; representation of technologies for cars, buildings and steel

POLES : modeling of international energy markets

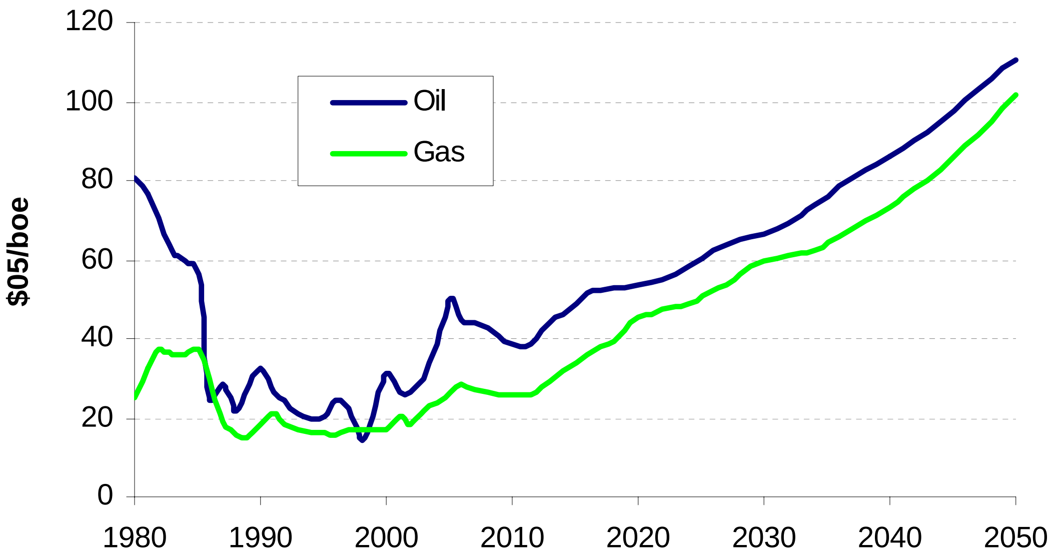


International oil market: trends in world oil price endogenous function of the capacity utilization rate and world R/P ratio

Three regional gas markets and gas trade matrixes; gas prices as a function of regional R/P ratios

Three regional coal markets and coal trade matrixes, coal price as a function of cost components in major producers

Oil and gas prices simulation : example of WETO-H2



Agenda

POLES : Final energy demand disaggregation

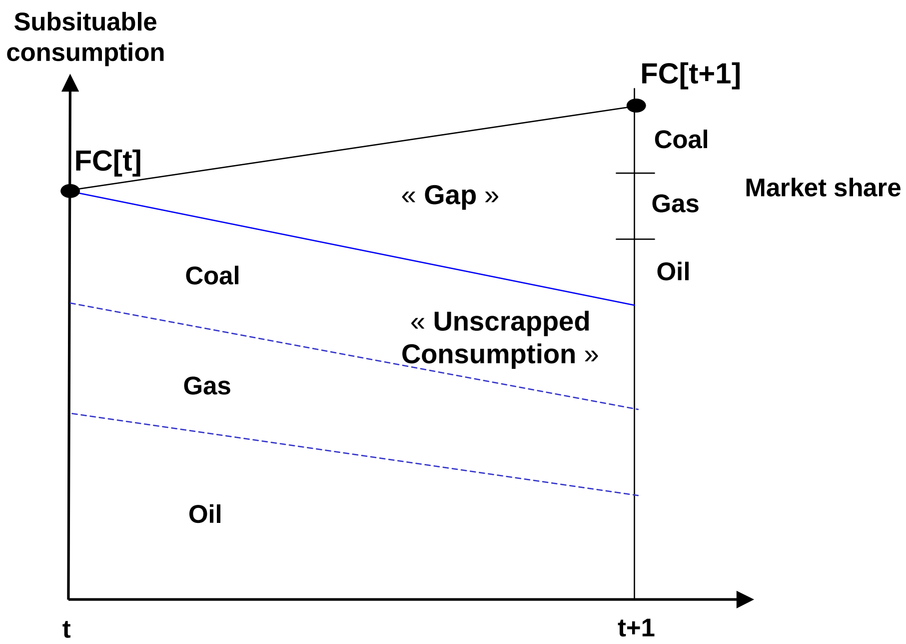
	Substituable Fuels	Electricity	Transport Fuels
Industry	X	X	
Steel industry	X	X	
Chemical industry	X	X	
Non Metallic Mineral	X	X	
Other industries	X	X	
Transport			
Road / passenger			X
Road / goods			X
Rail / passenger		X	
Rail / goods		X	
Air transport			X
Other			X
Tertiary	X	X	
Residential	X	X	
Agriculture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

Demand Equations : the key variables

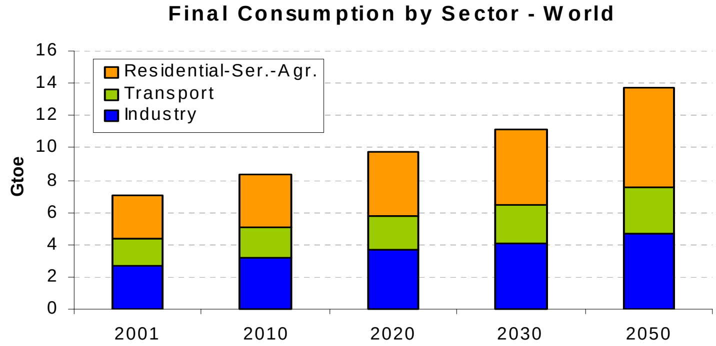
Ln(FC) =

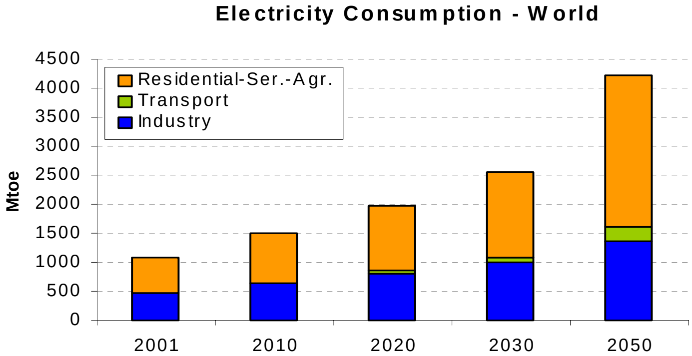
RES + Ln(FC[-1])	**residual and lagged variable**
+ ES * f(P,P[-1],P[-2])	**short-term price effect, behaviour related, current and preceding year price variation**
+ EL * g(P[-2], P[-3], …)	**long-term price effect, investment related**
+ EY * Ln(A/A[-1])	**income / activity elasticity**
+ Ln(1+Tr/100)	**autonomous technological trend (sectoral AEEI)**

POLES : Substituable fuels in final consumption



Final Energy Consumption: WETO-H2





Agenda

0. Introduction to econometric models
1. Key Features of the POLES model
2. Final Consumption
3. Electricity module
4. Supply
5. Total consumption
6. Carbon Emissions and Constraint
7. Recent Works with the POLES model

The Electricity Module, 0 : general structure

Total Electricity Consumption

- **New & Renewables**
- **Net imports + losses + elec sector autoconsumption**

Total Electricity Production from large scale plants

1 **Load curve**

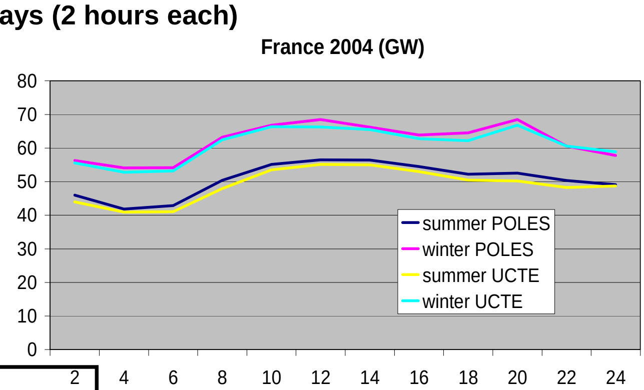
2 **New plants planning**

The Electricity Module, 1 : the load curve

Total Electricity Production

Sectoral Consumption

Distribution for 2 typical days (winter & summer) and 12 time arrays (2 hours each)



Load curve

Electricity production for each plant = f (existing capacity, variable cost)

The Electricity Module, 2a : large scale capacities planning

Electricity Consumption

↓

Expected power for the next 10 yrs
= f(last 10 yrs growth)

↓

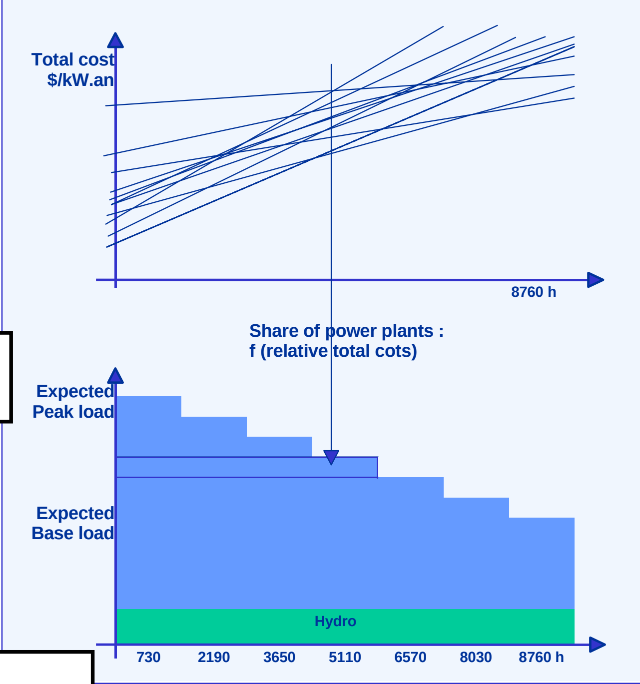
Distribution over 6 yearly durations
(8760h, 8030h, 6570h, 5110h, 3650h, 2190h, 730h)

↓

Expected Capacity (EC) by technology
(= f(prod cost, load curve parameter))

↓

Year t+1 = installation of 1/10 of EC
(check of the actual evolution of the elec consumption)



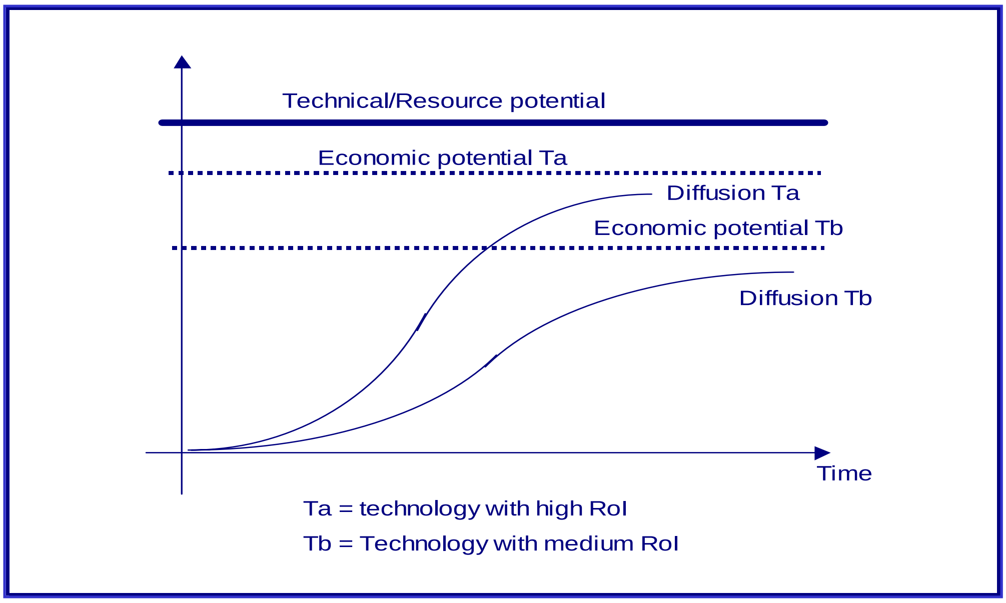
The Electricity Module, 2b : large scale technologies

Large Scale Power Generation
Super Critical Pulverised Coal
Integrated Coal Gasif. Comb. Cycle
Coal Conventional Thermal
Lignite Conventional Thermal
Large Hydro
Nuclear LWR
New Nuclear Design
Gas Conventional Thermal
Gas Fired Gas Turbines
Gas Turbines Combined Cycle
Oil Conventional Thermal
Oil Fired Gas Turbines

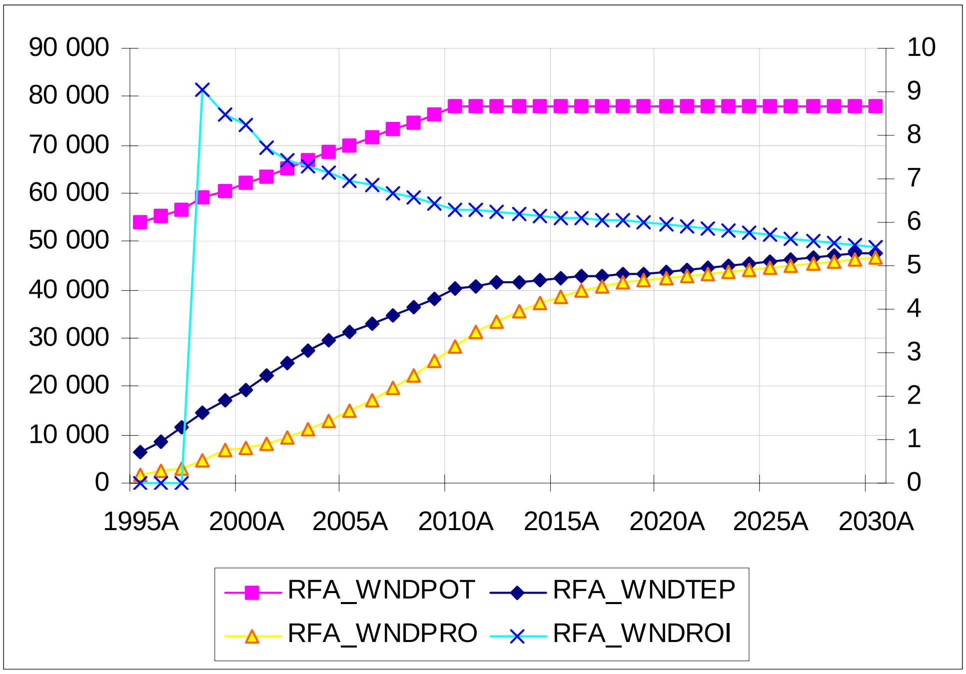
Coal and gas technologies considered with and without “carbon capture and storage” technology

The Electricity Module, 3a : modeling of New & Renewables technologies

Market potential and speed of diffusion increase with cost-competitiveness (ROI)



The Electricity Module, 3b : example of wind (Germany)



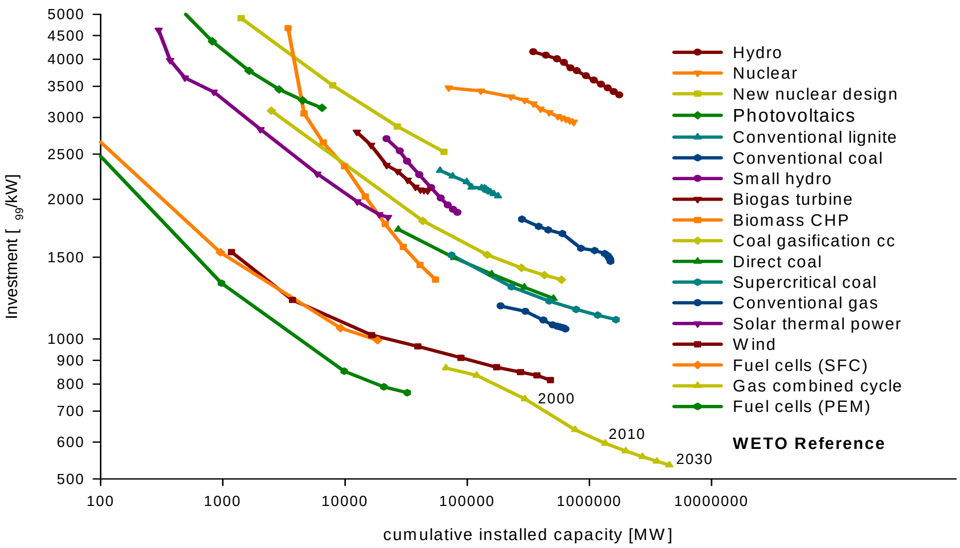
The Electricity Module, 3c : 12 New and Renewables Technologies

New and Renewable Technologies
Combined Heat and Power
Biomass Conventional thermal
Biomass Gasif. with Gas Turbines
Photovoltaic (windows)
Rural Photovoltaic
Solar Thermal Power plants
Small Hydro
Wind Turbines (on-shore & off-shore)
Biofuels for transport
Fuel Cell Vehicle (PEM)
Stationary Fuel Cell (Gas and Hydrogen)

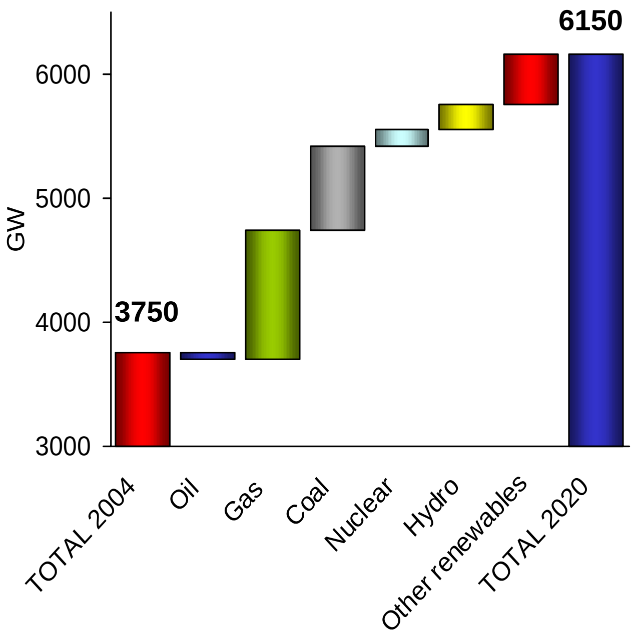
Enerdata Enerdata SERVICES

The Electricity Module, 4 : The investment costs

- Investment costs are from TECHPOL data base, with endogenous simulation of cost reduction , function of cumulative capacities
- Fuel costs are endogenous to the model



The Electricity Module, 5 : World Capacity growth up to 2020 (GW)



Gas and coal should represent about 70% of the growth of electrical capacities

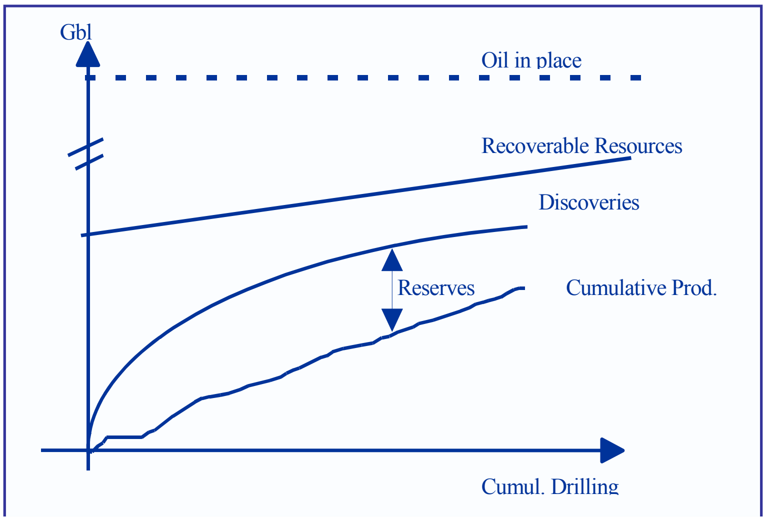
Hydro and wind power about 25%

The nuclear increases very slowly, it compensates for the decrease of thermal oil capacities

Agenda

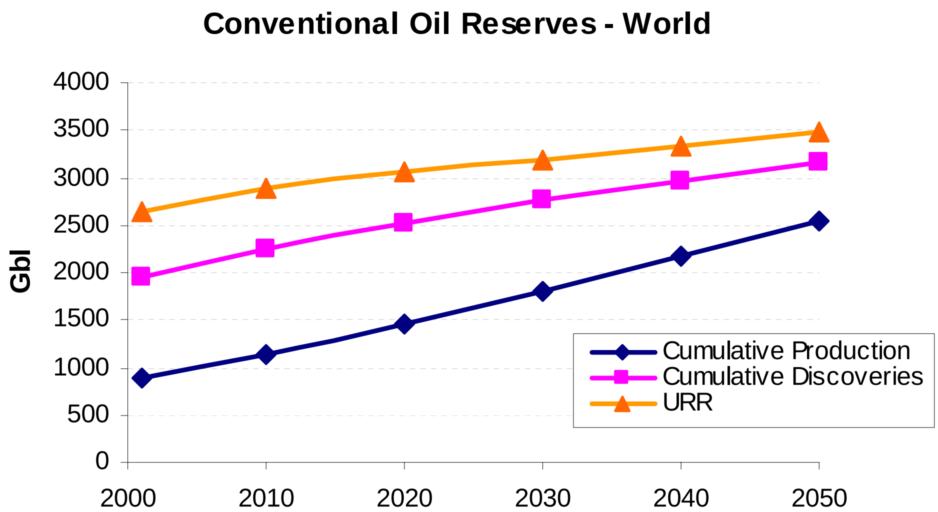
POLES : Simulation of Oil & Gas Discovery

- Ultimately Recoverable Resources = Oil in Place * Recovery Rate$_t$
- Discoveries increase with cumul. drilling (diminishing returns)
- Reserves = Discoveries - Cumulative Production
- Oil Price = f(Reserve/Production)
- Non Conventional Oil development = f(oilprice)



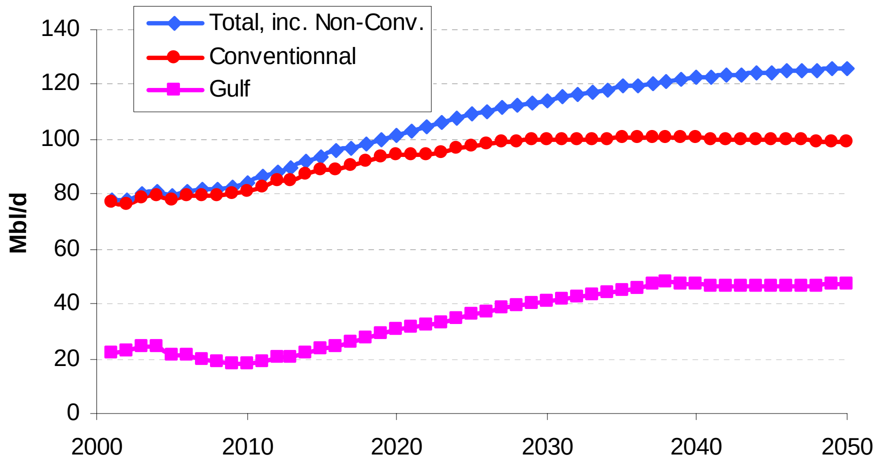
POLES : Oil & Gas Reserves

- The conventional oil reserves decrease : 650 Gbl in 2050 vs 1100 Gbl today
- World oil recovery rate reaches 47% in 2050 (vs. 35% today)



POLES : World Oil production

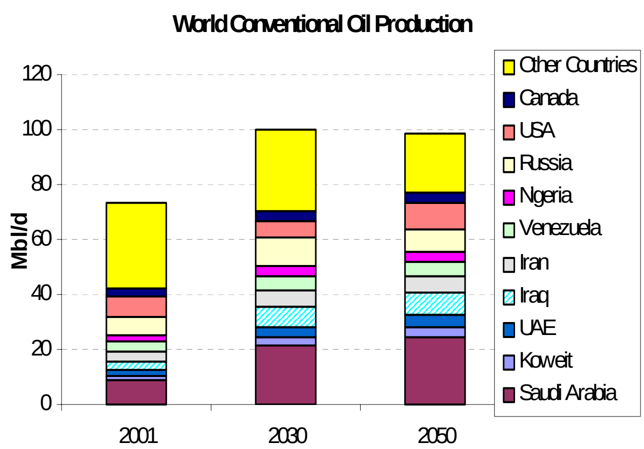
- The conventional oil production plateaus at around 100 mbl/d, it is even decreasing a bit in 2040-2050
- Non-conventional production (from Venezuela, USA, Canada) is increasing fast after 2020 and reaches 30 Mbl/d in 2050

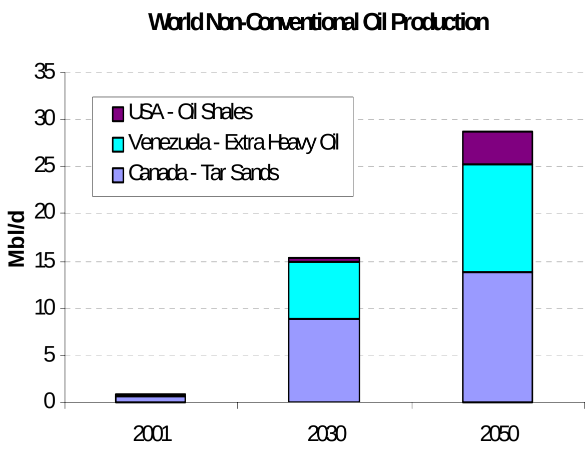


POLES : simulation of oil production

> Conventional oil production concentrates on some major producers, especially in the Gulf countries (Saudi Arabia produces 25 Mbl/d, more than twice its current production)

> Non-conventional production comes mostly from Canada (tar sands) and Venezuela (extra heavy oil). USA oil shales start developing after 2030.

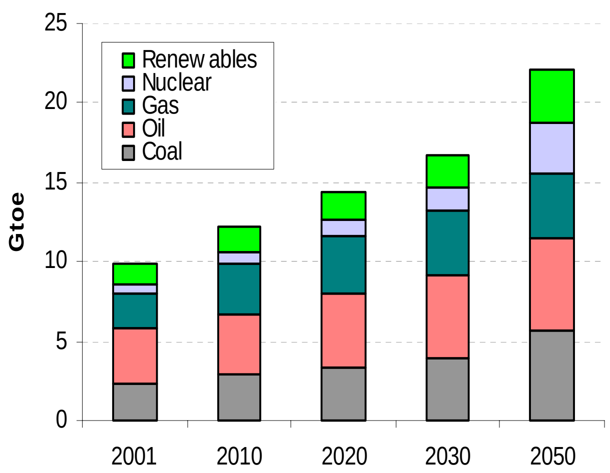


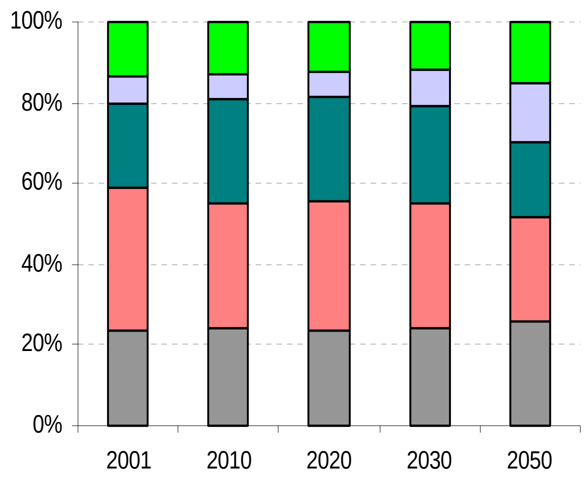


Agenda

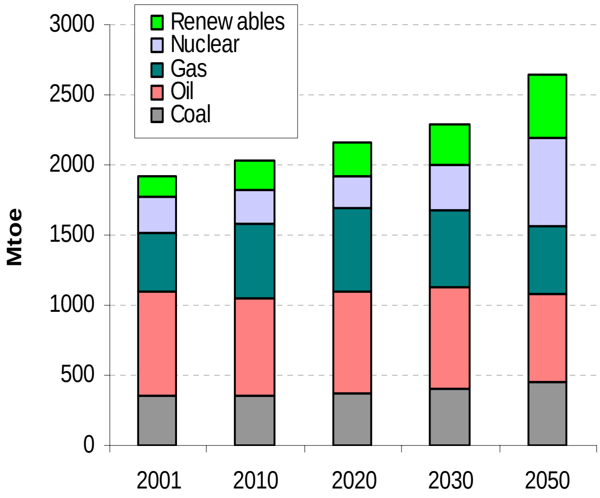
World Total Energy Consumption: WETO-H2

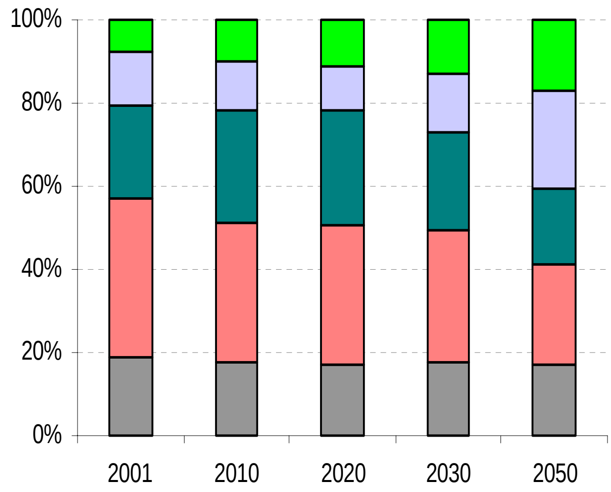
> The total energy consumption is calculated as the sum of the final energy consumption and the inputs of the electricity sector. It includes also energy losses and self-consumption in the energy sector.





Europe Total Energy Consumption: WETO-H2





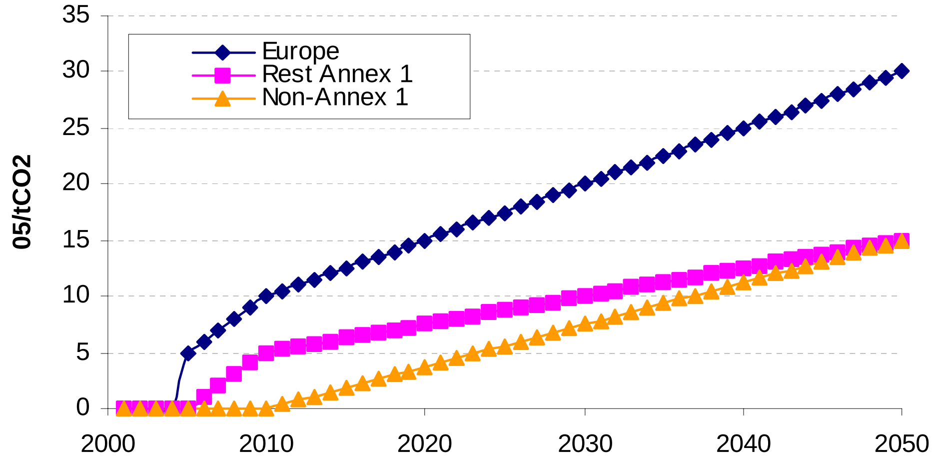
Agenda

0. Introduction to econometric models
1. Key Features of the POLES model
2. Final Consumption
3. Electricity module
4. Supply
5. Total consumption
6. Carbon Emissions and Constraint
7. Recent Works with the POLES model

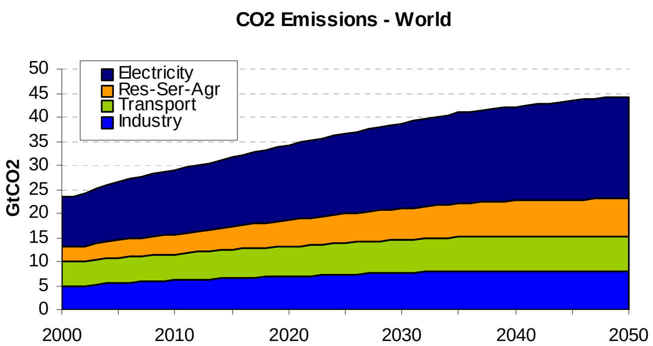
POLES: accounting for carbon constraints

> In the « Reference » case a **Carbon Tax** is applied on the CO2 emissions to integrate minimal policies related to climate change

> This Carbon Tax considers a « willingness to pay » in Europe twice the WTP in the rest of the world

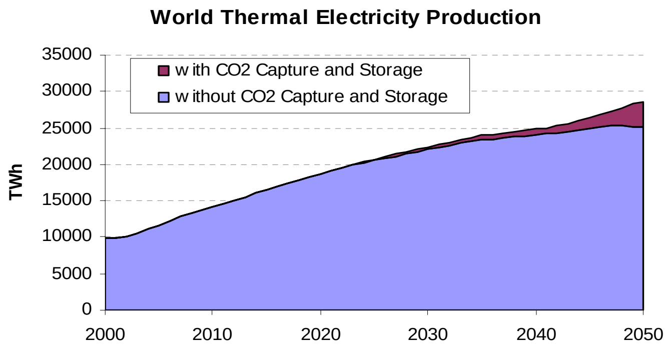


Simulation of CO2 emissions and of CO2 capture and storage

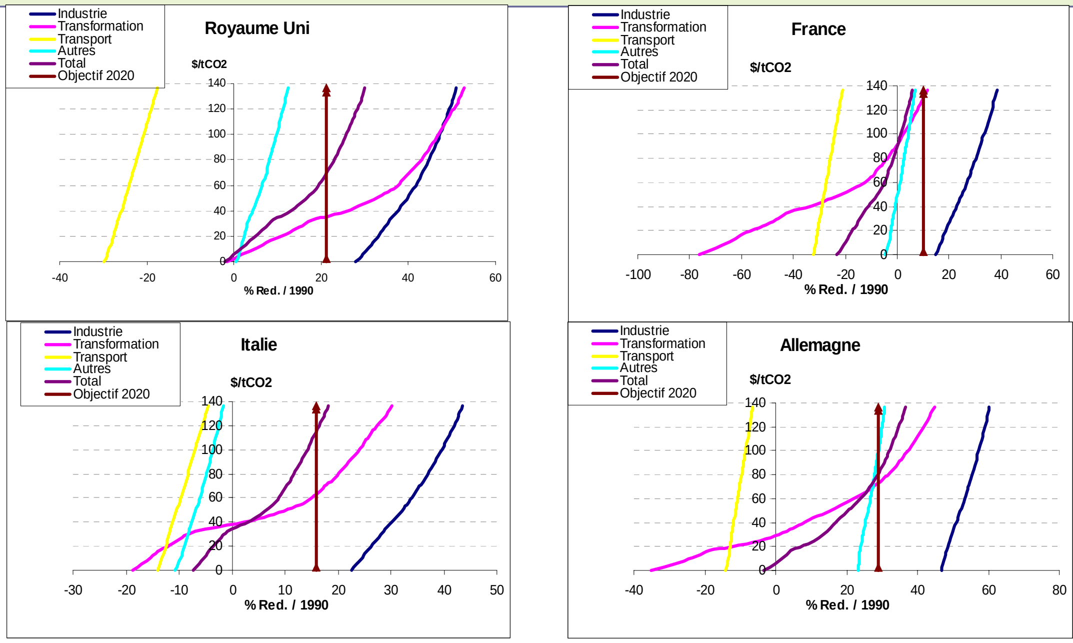


> CO2 emissions double over the next 50 yrs. The power sector remains the main contributor.

> CO2 capture and storage technology develops after 2020 and remains at a modest level



Marginal CO2 Reduction Cost Curves (2020) produced by POLES



POLES could also produced curves to evaluate sectoral energy conservation potentials (based on elasticities and price responsivness)

Agenda

Recent studies on energy forecasting and CO2 emissions reduction carried out with the POLES model

- 2004-2005: World Energy Technology Outlook 2050 (WETO-H2, DG-RTD) (on-going)
- 2003-2004: Emission reduction scenario for France (Factor 4 scenario, Min. of Ind.-F) http://www.industrie.gouv.fr/energie/prospect/pdf/oe-facteur-quatre.pdf
- 2002-2004: Endogenous technical change in a world energy model (SAPIENT + SAPIENTIA, DG-RTD)
- 2001-2003: Greenhouse emission Reduction Pathways and international endowments in the post-Kyoto perspective (GRP, DG-ENV) with NTUA, RIVM, KUL

  http://europa.eu.int/comm/environment/climat/pdf/pm_summary2025.pdf
- 2001-2003: Economic analysis of the linking of the European EQTS with the international market (Kyoto Protocol Implementation, DG-ENV)

  http://europa.eu.int/comm/environment/climat/pdf/kyotoprotocolimplementation.pdf
- 2001-2003: World energy technology and climate policy framework scenario to 2030 (WETO, DG-RTD) with ENERDATA, FPB-Belgium, IPTS

  http://europa.eu.int/comm/research/energy/gp/gp_pu/article_1257_en.htm
- 2000-2002: Multi-gas assessment of greenhouse gas emission reduction strategies (GECS, DG-RTD) with NTUA, RIVM, KUL, IPTS
- 2000-2001: Economic assessment of climate negotiation options, before and after COP-6 (Blueprints for International Negotiation, DG-ENV)

  http://europa.eu.int/comm/environment/climat/pdf/blueprints.pdf
- 1999-2001: ASPEN a software for the analysis of emission quota trading systems with MAC curves from the POLES model (Min. of Env.-F)

  http://www.upmf-grenoble.fr/iepe/Recherche/Aspen.html