Energy mix planning for the French electricity production sector

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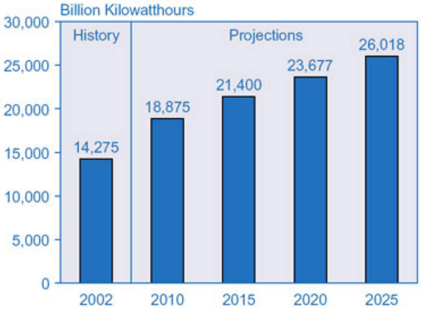
Agenda

1. Introduction
2. Energy planning models: MARKAL
   - The Reference Energy System
   - The constraints
   - The optimization problem
3. The French paradigm
   - Flexible MARKAL
   - Alternative nuclear future: scenario simulation
   - Prospective sensitivity analysis
4. Conclusion

Predicting electricity consumption

Electricity supply for the next decades (2002-2025)

Figure 58. World Net Electricity Consumption, 2002-2025



Sources: **2002:** Energy Information Administration (EIA), *International Energy Annual 2002*, DOE/EIA-0219(2002) (Washington, DC, March 2004), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2005).

The interest of energy planning models

Stakes for energy field decision-makers in the electricity sector:

- **future investments** for the mix?
- **measures** for the environmental impact?
- what **susbtitution** between energies?
- how to handle the **huge losses**?

Energy planning modelling approach is needed to answer the questions raised for electricity sector issues.

The class of techno-economical models

TECHNO-ECONOMICAL MODELS

TECHNICAL	ECONOMIC
energy sector disaggregated	energy sector aggregated
deviations permitted regarding historical trends	no possible deviation regarding historical trends
energy = function (efficiency, usage) energy units	energy = function (GDP, price, inflation) monetary units

Motivations for MARKAL

A technological energy-sector model: MARKAL (MARKet ALlocation)

- **a highly detailed technological representation** for existing and future technologies enabling:
  - a complete description of consumption trends,
  - a precise analysis of substitutions between types of energy,
  - an interpretation of the notion of energy needs in terms of services and equipments,
  - a better evaluation of renewable energy sources.
- an **open-source** model developed in the framework of **ETSAP**: Energy Technology Systems Analysis Program initiated by the IEA (in 1980)

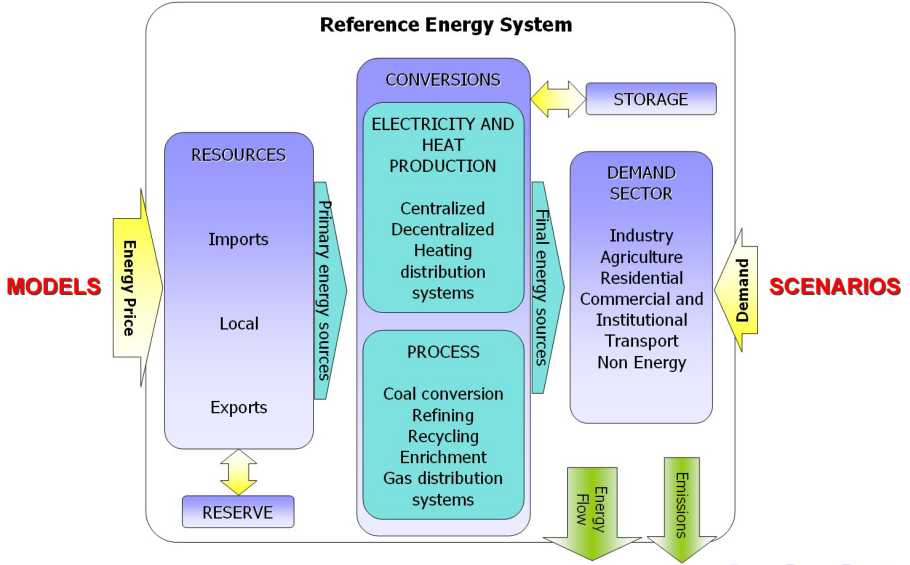
MARKAL uses an optimization approach

The MARKAL model
A technical linear optimization model driven by demand

MARKAL achieves **a technico-economic optimum**

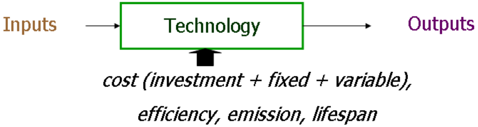
1. for the **reference energy system** (RES):
   from raw materials to final end-use energy sectors,
2. driven by **demand** while respecting constraints
3. over a **set horizon** : mid- or long-term (20/50/100 years)
4. for an **objective** : technical/economical/environmental :
   (economic costs, pollutant emissions, etc.)

The Structure of the Reference Energy System



The structure of the RES

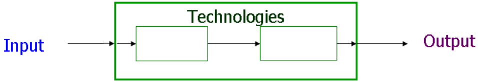
An elementary block as an energy vector converter



thermal power-plant: **input**=coal, gas or fuel, **output**=electricity

lamp: **input**=electricity, **output**=lighting useful demand (lumens or W.m^2)

The elementary blocks are connected through energy vectors



connected / disaggregated

An example of the hierarchical disaggregation

From oil to passenger

Input = imported oil

$\longrightarrow$ **Output** = final annual demand km.passenger

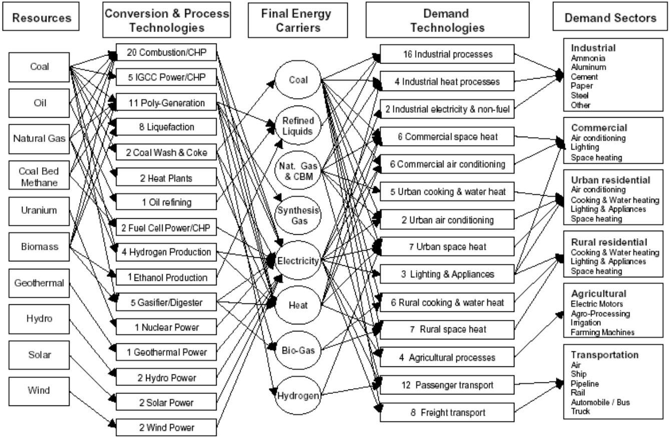
An example of the hierarchical disaggregation

From oil to passenger

Input = imported oil
$\longrightarrow$ refinerie technology
$\longrightarrow$ unleaded gasoline
$\longrightarrow$ distribution network technology
$\longrightarrow$ unleaded gasoline available at the gas station
$\longrightarrow$ car technology
$\longrightarrow$ **Output** = final annual demand km.passenger

Simplified Representation of MARKAL model structure

A technological and sectorial disaggregation



MARKAL constraints

Technical constraints

- Energy flows (through energy vectors)
- Peak capacity reserve
- Activity/Capacity constraints
- etc.

Possible users constraints

- environmental constraints
- regional specificities
- etc.

Solutions given by MARKAL

MARKAL solves a linear programming problem:

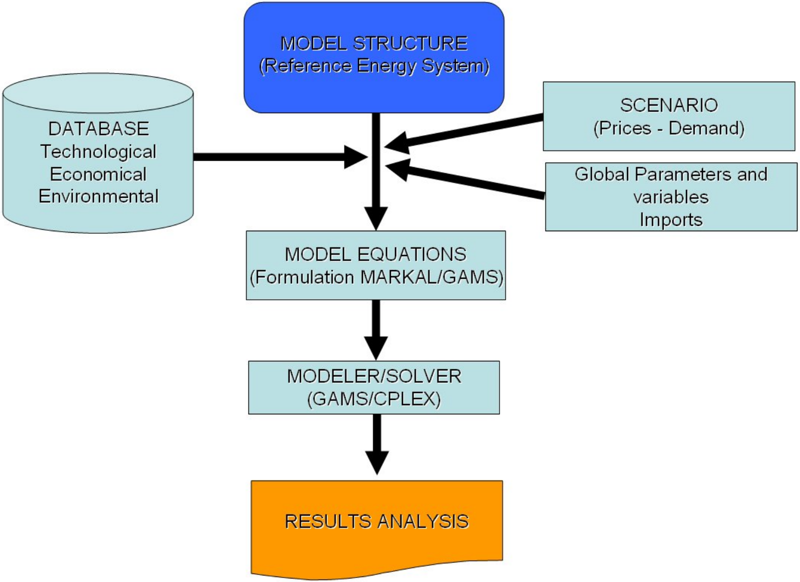
minimizes the RES actualized global cost
over a certain model horizon
while respecting all constraints

assessing the energy mix to satisfy the demand over time

for each technology, for each period

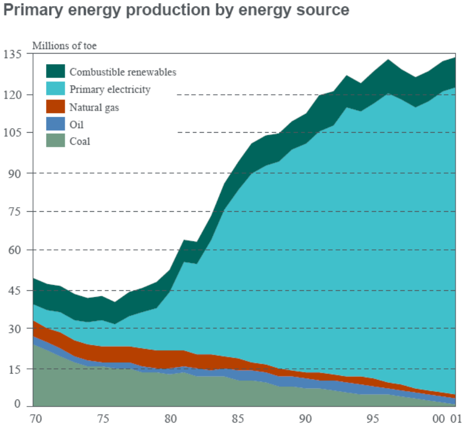
1. levels of activity (energy)
2. levels of investment (power)
3. associated costs (reduced and marginal costs)
4. if available : level of emissions, level of taxes, etc.

Software approach



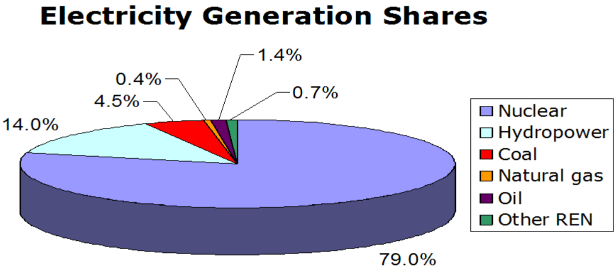
The specifities of the French electricity sector

The weight of primary electricity supply



Primary energy production by energy source (DGEMP 2004)

Overview of French electricity generation sector



$\sim$ 500 TWh : A global production dominated by nuclear power (79%)

25 to 30 TWh : A classical thermal production (relying on fossil plants) (less than 6%)

Why classical thermal production?

- A key for **system operations**
  - Keep the reliability of the network
  - Guaranty the quality of the supply

  According to TSO (RTE)

  1. 7 - 8TWh : Dynamic constraints (time duration of operation for each plant)
  2. 6TWh : Adjusting nuclear unscheduled changes
  3. 2 - 4TWh : Congestion and reserve
  4. 2TWh : Economic stop and go cycles decision
- Essential for **peak demand**
- Only plants that are **responsible for CO2 emissions**

What are the specific features of classical thermal production ?

Corresponding flexible dynamical features

- Coal plants are used to respond to **semi-base** (operate between 2000 and 4000 hours per year)
- Oil plants are used to respond to **peak** demand (operate between 500 and 1000 hours per year)

classical MARKAL: Competition only relies on **economical criteria**

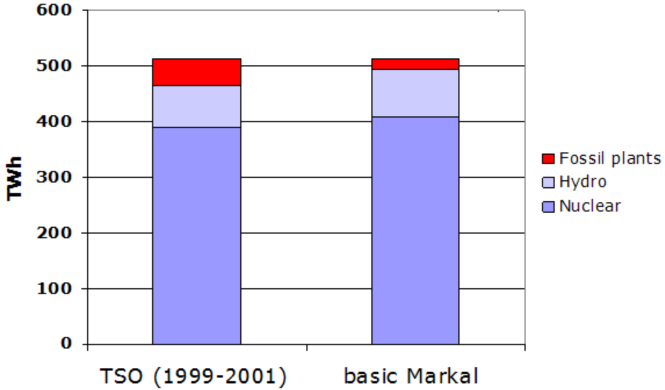
flexible MARKAL: **Flexibility of plant operation (Dynamic features)** are added into plants selection criteria.

Classical MARKAL leads to a wrong assessment

Electricity production by resource options

We strongly

- underestimate fossil plants use
- overestimate nuclear power plants use



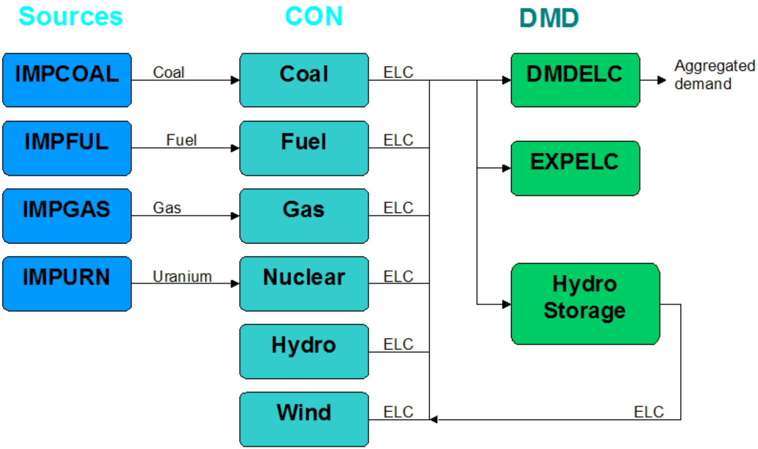
The enhanced flexible MARKAL approach

A method to guide the results towards flexibility
relies on **differing plant operation modes**:

- Generation: *Define flexibility by needed “type” of plant*
- Load: *Quantify the need of each “type” of plant*
- Technical points: *Allow competition to fulfill those needs*

Enables us to select the right fossil plants.

French RES for electricity generation

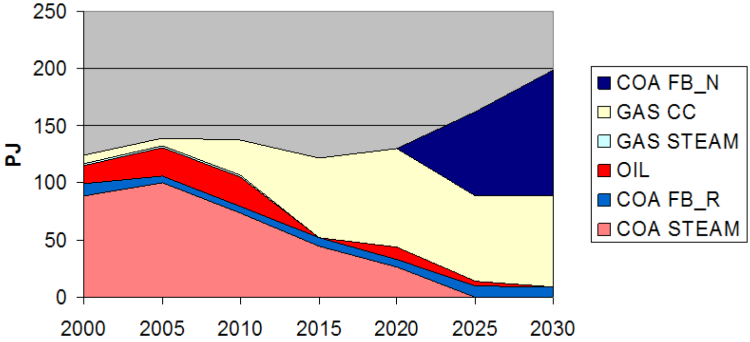


Economical hypotheses

- **Discount rate**: 5%
- **Fuel costs**: Conservative EU prospective
- **Line Losses**: 7%
- **Time horizon**: 2000-2030
- **Lifespan** of existing nuclear power plants : 40 years (1 EPR in 2012)
- **Nuclear specific costs**: nuclear-waste treatment costs (fuel price) and decommisioning costs (plant operation costs)
- **Trade**: Fixed 252 PJ electricity exportation
- No constraint on **CO2 emissions**
- **Renewable**: 21% of domestic demand in 2010
- **Demand**: RTE (TSO) aggregated scenario

A good result

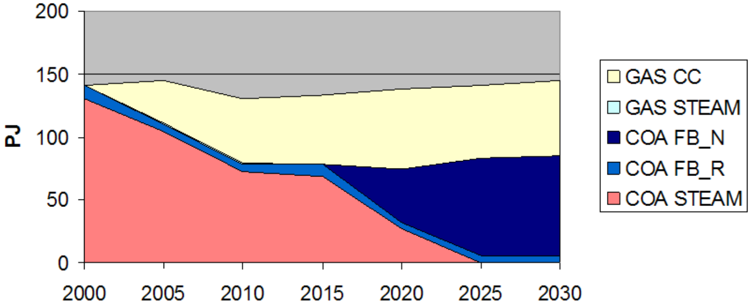
Effective use of residual peaking plants



Fossil plants production 2000-2030 : the flexible MARKAL approach

A bad result

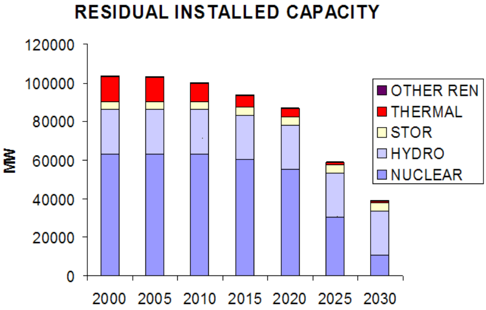
No use of oil plants



Fossil plants production 2000-2030 : the classical MARKAL approach

Nuclear power replacement is the main driver for the future

- Replacement of existing capacities
- Future mix: Nuclear + Hydro + Fossil + Wind ?



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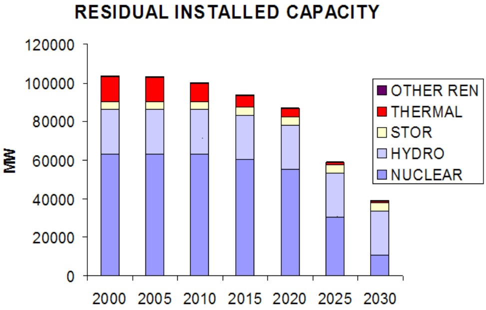
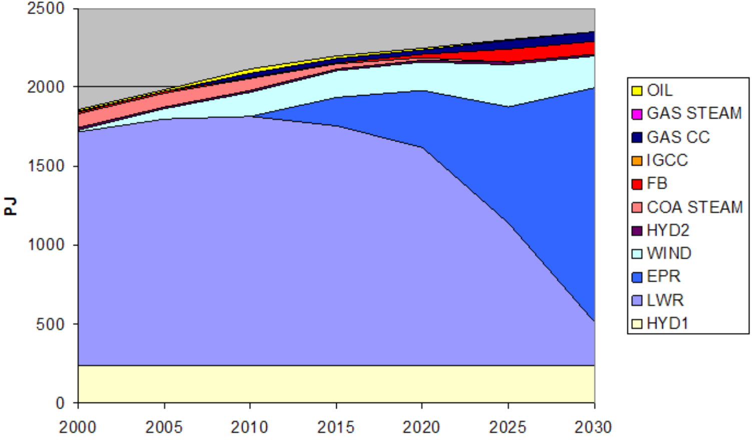


The Simulated scenarios

- Reference scenario: **Nuclear no limit**
- Alternative scenario: **“Limited” nuclear share**

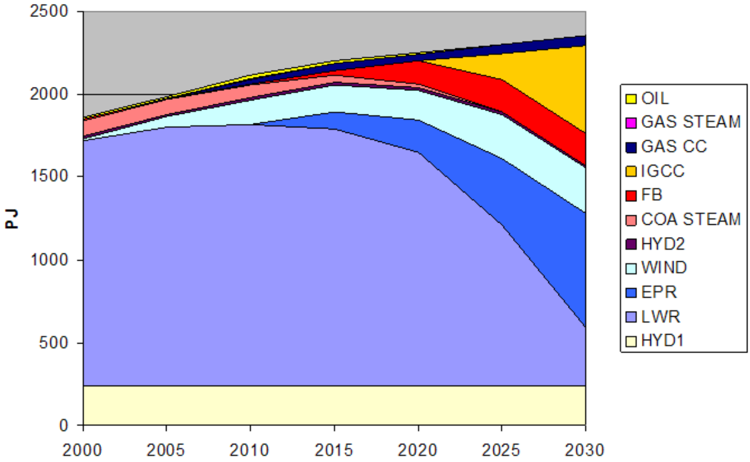
Nuclear no limit scenario results

French electricity supply 2000-2030



Limited Nuclear share scenario results

French electricity supply 2000-2030

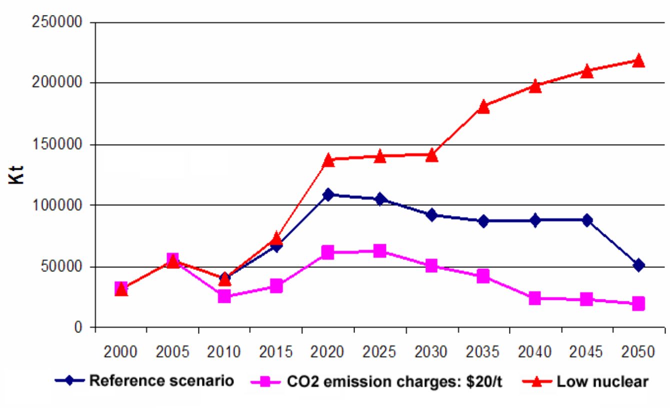


Questions raised by both scenarios

- Is the EPR growth feasible? (reference scenario)
- Wind power: Fossil plants production share coherent with wind power production? (both scenarios)
- Are the emission constraints compatible with the growth of Fossil Plant share? (alternative scenario)

Sensitivity to environmental measures

CO2 emissions



Summary

1. With the continued depletion of fossil fuels, the importance of electricity in the decades to come will increase.
2. The electricity sector will
   - drive huge demand and investments,
   - be responsible for huge environmental impacts.
3. Prospective tools relying on techno-economic optimization models are useful to assess impacts of future investments, measures and decisions.
4. The French energy system's context is relevant because
   - it has one of the biggest existing electronuclear capacities
   - it boasts very low relative CO2 emissions
   - it can be used as a standard case study for the energy futures of other countries.