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Low-Carbon growth of electricity systems

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Future power mix issues

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Future power mix : a major issue for the next decades

- Huge investments are forecasted in the power sector
- Electricity environmental impact are consequent: power generation stands for more than 45% of Carbon Dioxide emissions.

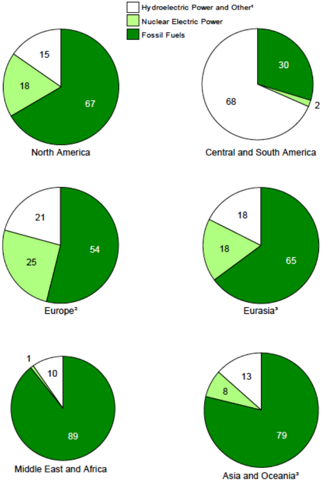

Figure : Power generation by region Source: AER 2009.

Multiple recommendations for a low carbon electricity system

Generation Solutions

☞ *Renewable and distributed energy sources* are attractive alternatives for power generation

☞ *Nuclear* is stated as a zero-emission technology

☞ Claim that *new capture and storage technologies* may provide major opportunities in several areas

Policies and Tools

- *Markets* (carbon, power,. . .): taxes, prices, incentives,. . .
- *National commitments*: POPE law 13/07/2005 and Grenelle (in France) , dividing by 4, RT,. . .
- International commitments: 3x20, post Cancùn, . . .
- Nuclear policy options: phasing out or continuation . . .

New paradigms present major technical challenges

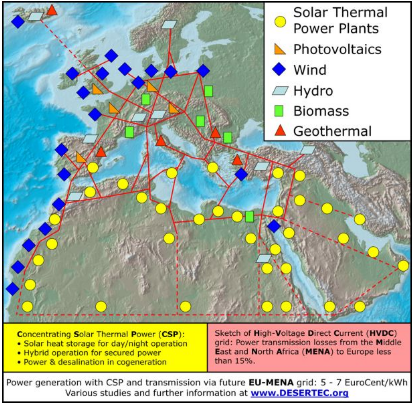

Figure : All-Renewable Electricity Generation in 2050.Source: DESERTEC.

Technical Solutions

- embedded solutions
  - *Energy Efficiency*
  - *Smart* solutions : grids, water, sustainable cities . . .
- *integration of intermittency at large scale*;
- *mobility* : electric, biofuels,..
- *centralized / decentralized grid*.

In order to design a future power sector

it is mandatory to sort out the **imbroglio of technical recommendations and policies** throughout a long term approach, always revisited and that allows to:

- reconcile time and space scales
- assess the global impact of the proposed solutions
- consider the externalities
- propose a trade-off to taking into account competitions and substitutions

Whilst Prediction **imposes** the future,

Prospective

- **envisions** all the possible futures
- in order to **lighten** tomorrow's consequences of today's choices and decisions

In other words Prospective exercises enable to :

- **be prepared** to unexpected trends or events thanks to the assessment of a **diversity of imagined futures**
- i.e. **to build a prosthesis** for the stake-holders or decision-makers who desire a **calculated adventure**

Pierre Massé

☞ Tools are needed to think, debate, and to evaluate decisions and measures

TIMES as a Prospective tool

"What we have the right to ask a conceptual model is that is seize on the strategic relationships that control the phenomenon it describes and that it thereby permit us to manipulate, i.e., **think about the situation**"

Source: R. Dorfman, P. A. Samuelson,R. M. Solow

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Competitions, substitutions and coherence

TIMES

A technical linear optimization model, **open-source** developed in the framework of **ETSAP**: Energy Technology Systems Analysis Program initiated by the IEA (in 1980)

- demand driven
- on a long term horizon: (50/100 years)
- in order to achieve **a technico-economic optimum** minimizing the overall actualized cost of the reference energy system

1. whose flows are balanced
2. satisfying a set of relevant technical constraints (peak reserve for the power system,. . .)

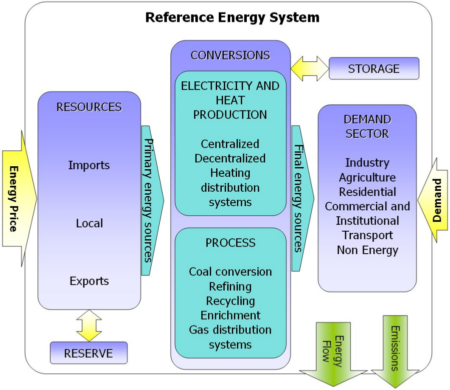

Figure : The Integrated MarkAl (market allocation)-EFOM Reference Energy System

Based on an optimality paradigm

derived from **von Neumann** (1930) and **Sraffa**

☞ *How much should a nation save ?*

The objective

establish a production plan (programme) $x_1, \ldots, x_n$ *in order to minimize the production cost taking into account the potentiels of the production factors and driven by a demand*

The plan is formulated as follows

$$\min_{x_j} z = \sum_{j=1}^{n} c_j x_j$$

$$\sum_{j=1}^{n} a_{ij} x_j \leqslant b_i \quad i = 1, \ldots, m \qquad x_j \geqslant 0 \quad j = 1, \ldots, n$$

$$\sum a_{ij} x_j \geqslant D$$

The use of scenarios: prospective versus prediction

Energy planning modelling through TIMES enables to:

- **envision** all the possible futures
- in order to **lighten** tomorrow's consequences of today's choices and decisions

- Instead of using **scenarios kept in a stock**
- each question requires **a flow of dedicated scenarios**, to assess a future power system

Desirable, Plausible, Sustainable

Following the trend or changing the paradigm

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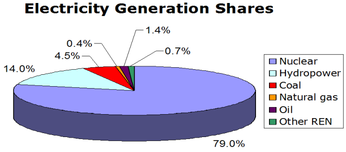
French electricity generation sector

☞ dominated today by nuclear power

Installed Capacities 1/1/2011	thermal nuclear	thermal fossil	thermal Ren	Hydro power	wind power	Solar PV
(GW)	**63.1**	**27.1**	**1.2**	**25.2**	**5.8**	**0.9**

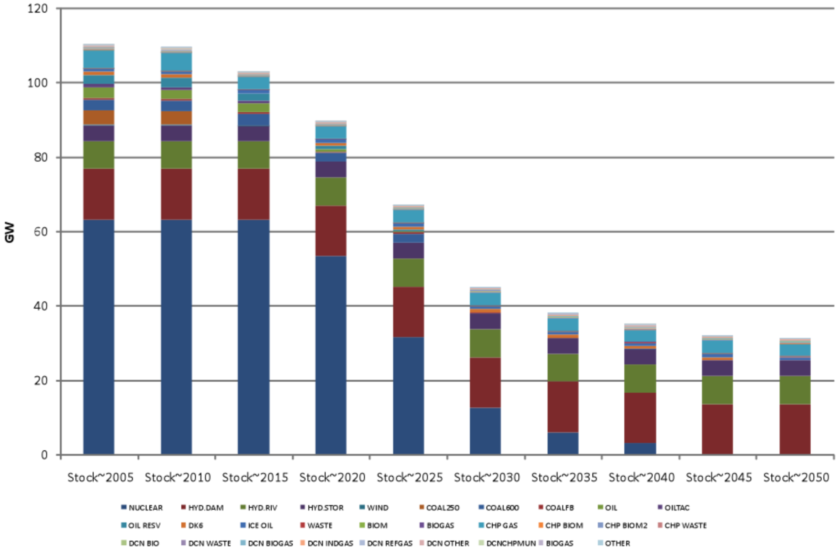


$\sim$ 500 TWh : Global production

$\sim$ 400 TWh : Nuclear thermal production (80%)

$\sim$ 30 TWh : Classical thermal production (coal and fioul)

Nuclear power replacement is the main driver for the future



Replacement of nuclear existing capacities

Fukushima triple disaster has opened the debate

- ☞ lifetime : discussion has moved from 30 to 60 years
  - debate in 1999 : between 30 and 40 years [Bataille, Galey 1999] (nominal 30)
  - today discussions : between 40 and 60 years
  - ☞ more than 40 years submitted to ASN (french nuclear safety agency) agreement
  - our assumption: Smooth profile

In October 2011, The Ministry for Energy asked for a study in order to assess different options for the future nuclear power in France including **phase-out** options

Nuclear lifetime sensitivity analysis

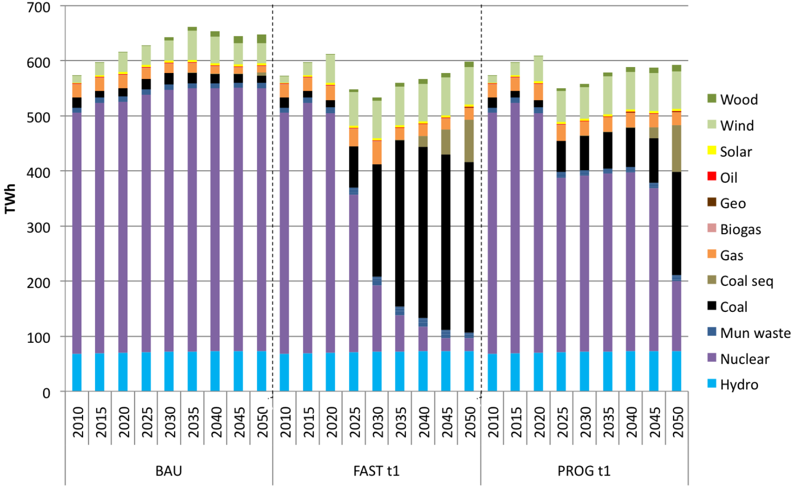


Figure : Power Mix generation (CO_2 tax)

Nuclear as a zero-emission solution

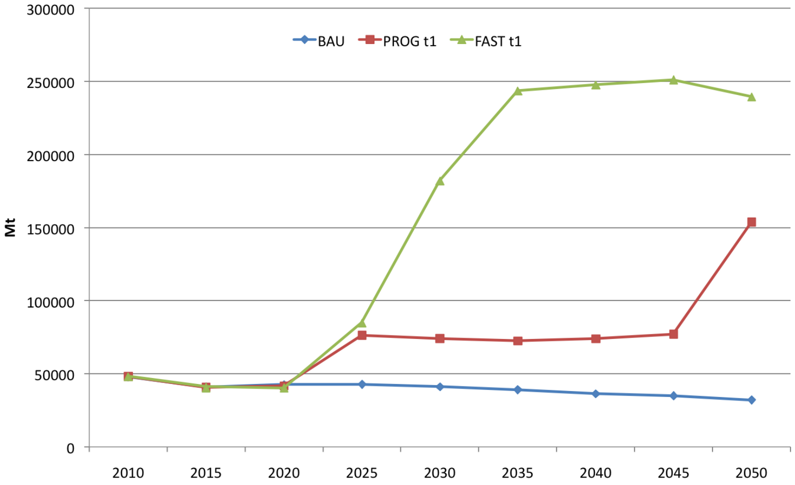


Figure : Sensitivity of the CO_2 emissions of the power sector

Nuclear lifetime sensitivity analysis : tax + cap

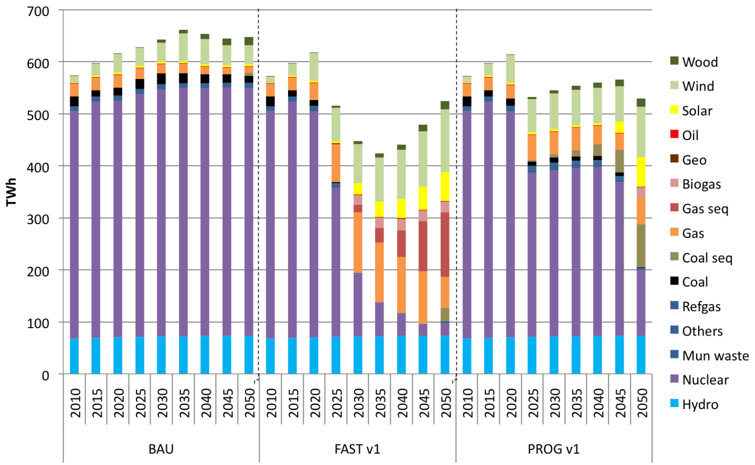


Figure : Power Mix generation (CO_2 tax + cap)

Huge investments are needed

☞ new generation capacities to secure power supply

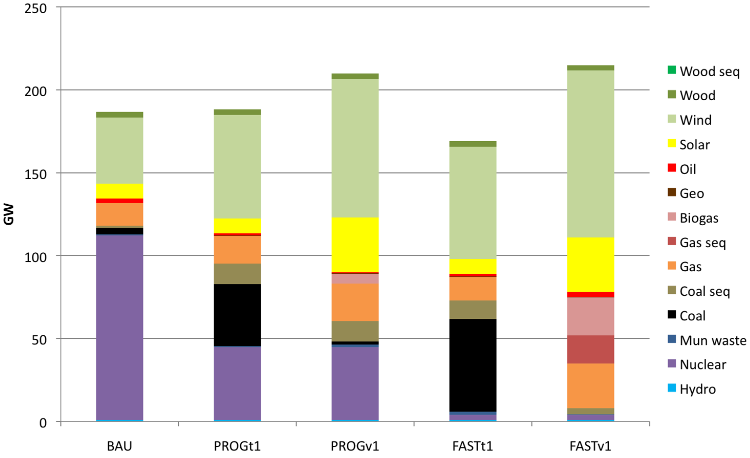


Figure : Lump sum of Power Plants Capacities (with extended nuclear plants)

Adressing dynamics issues of future power systems

☞ we might question the implementation **relevance** and **plausibility** of the future energy mix through Prospective exercises

Long-term planning models

deal with several years or decades

Stability studies

involve time scales ranging from a few milliseconds to a few hours

Future Power System : Reliability of electricity supply

Figure : Europe from orbit during the Italian blackout (Sept. 28th, 2003). Source: French TSO.

Technical constraints binding the operation of the future power system are related to:

- the given level and spatial distribution of loads and capacities;
- the expected level of reliability to prevent from power outages.

☞ Where **reliability** is the capability of the power system to withstand sudden disturbances due to load fluctuations.

Deriving reliability indicators (Patent FR 11 61087)

☞ In order to ensure system reliability enough reserve levels must be provided:

- magnetic reserve : transmission maintenance ;
- kinetic reserve : frequency maintenance.

☞ **The higher the reserves, the more reliable the system is.**

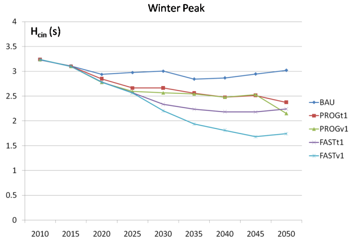
Reliability criteria

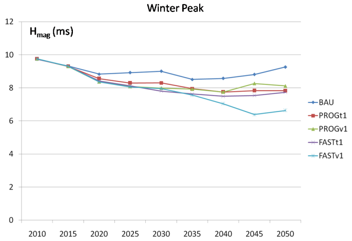
- The reserves are associated to two indicators H_{cin} H_{mag}
- They refer to **dynamic properties** of the installed capacities, each contributing to the reserves level in a specific way

The level of reliability is characterized by H:

the time you have to recover the stability of the system after a load fluctuation (equivalent to the whole system capacity) by monitoring its reserves.

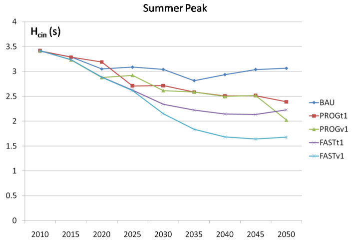
Kinetic and magnetic reserves for peak periods

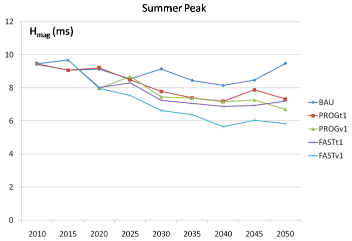




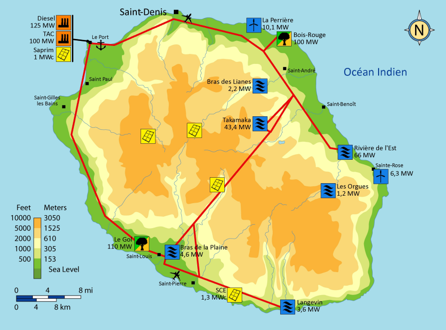
Kinetic Reserves

Magnetic Reserves





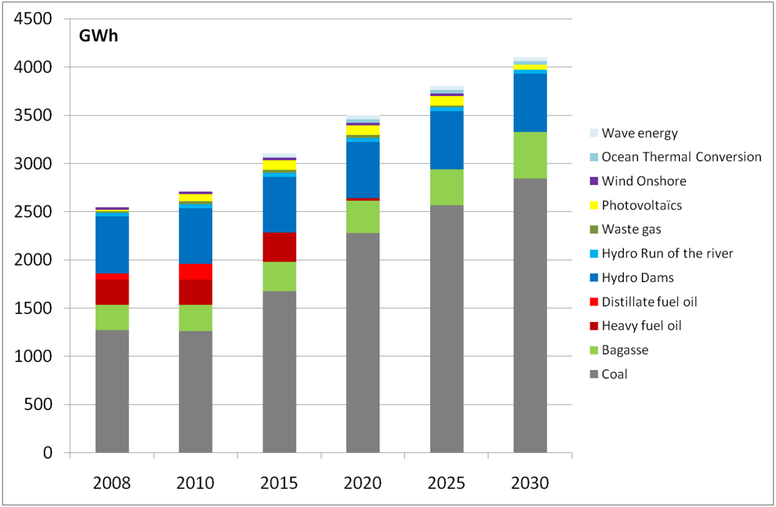
Reliability Indicators as constraints



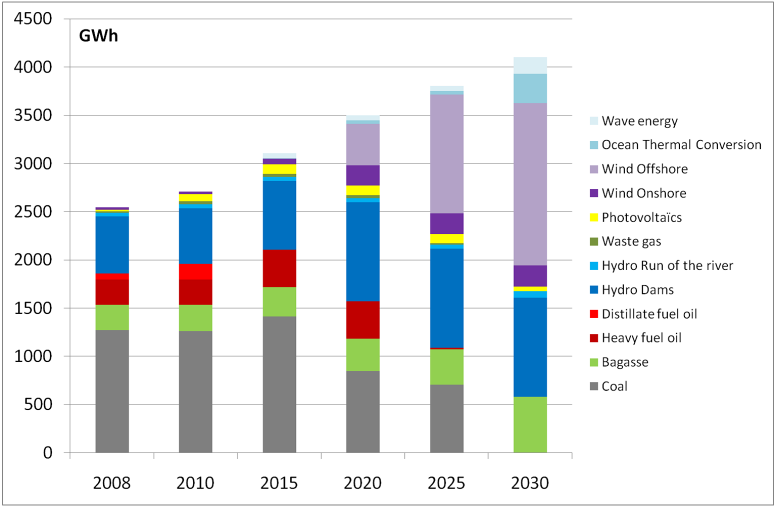
power production: 100% renewable in 2030

1. Blessed with high renewable energy potentials
2. Small, weakly-meshed and remoted power system
3. Binding target in 2030: 100% renewable sources in power generation
4. Maximum : 30% EnR **intermittency**

BASE Scenario : production (GWh)

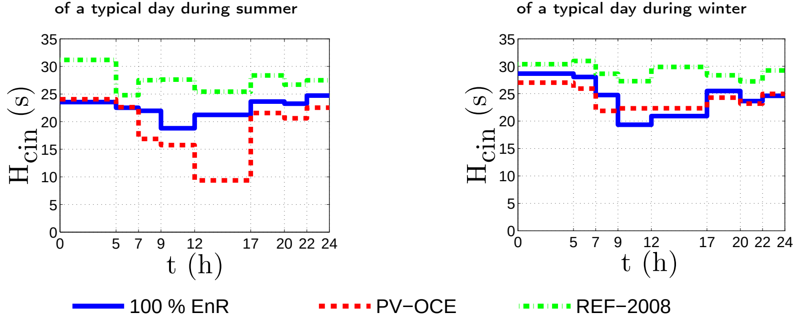


noFOS Scenario : production (GWh)



Is 30% the maximum share ?

Electricity production mix in 2030



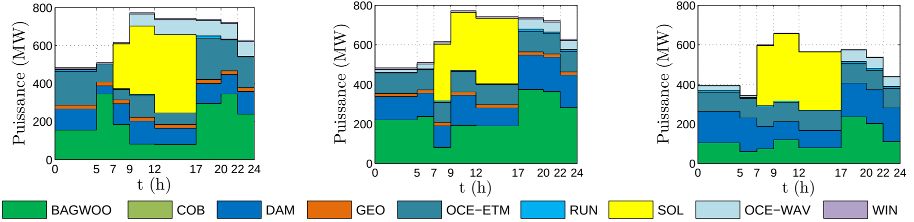
- 100 % EnR : limitation of 30 % of instantaneous power production issued from intermittent sources
- PV-OCE : no constraint on intermittency
- REF-2008 : kinetic reserve level in 2008

Impact on Demand Side Management and Storage

DSM = postponing demand from peak to off-peak periods + EE

Electricity production mix of a typical day during summer in 2030

Without reliability constraint	$\forall t : H_{cin,t} \geqslant \min(H_{cin,2008})$	Reliability + DSM + Storage



- share of intermittent sources $\geqslant$ 50%
- $\nearrow$ total installed capacities of 9.4 %

- share of intermittent sources $\geqslant$ 50%
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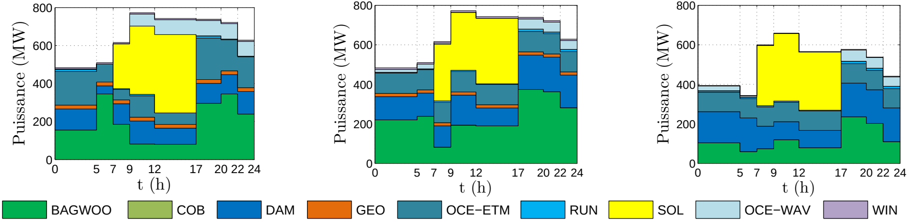

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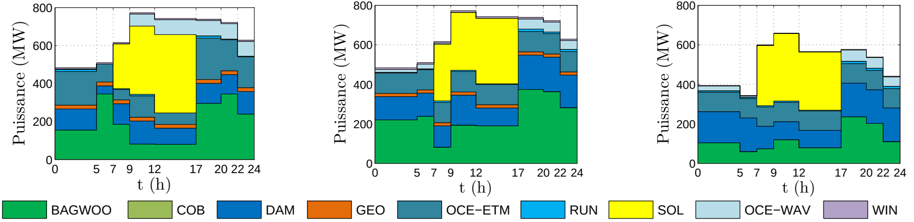

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Policies dealt separetely but... interdependecy

Growing issues for water and energy

- Energy sector: depletion of fossil resources, environmental impacts
- Water supply: availability and sustainability of water resources

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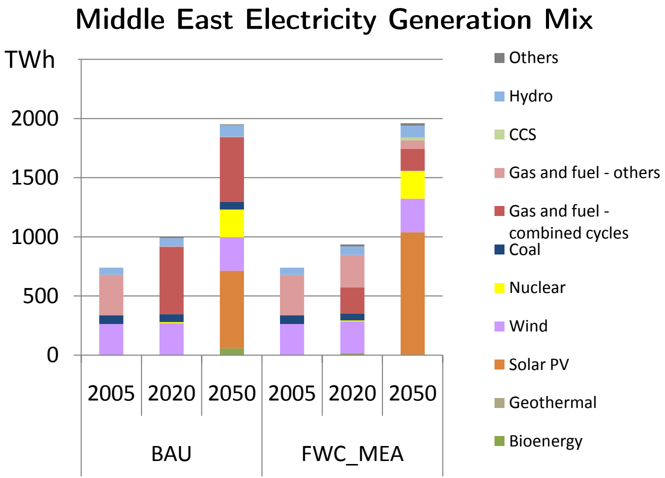
Water for energy

- Cooling systems
- Hydropower
- Extraction and mining
- Fuel production
- Emission controls

Energy for water

- Pumping
- Transport
- Treatment
- Desalination

Water as a constraint



- FWC_MEA: fresh water consumptions in Middle East until 2100 $\leqslant$ consumptions in 2005

Technical plausibility of power generation assessed scenarios

In order to cope with environmental issues, some technological options are highly recommended.

Strategic factors impact technical feasibility and relevance of future power mix

1. **Water** as an output commodity and as a constraint
2. **Level of reliability** of an assessed power mix system

Prospective issues have been raised using planning tools : the power mixes must fulfill a balance :

a global optimum associating water and energy

between reliability issue and the spread of renewable energies

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Web Site : http://www.modelisation-prospective.org/

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- A prospective analysis of waste heat management at power plants and water conservation issues using a global TIMES model Energy, S. Bouckaert, E. Assoumou, N. Maïzi to appear in Applied Energy (2014)

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