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Future challenges for the French power generation paradigm: reliability versus low-carbon issues

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International Days of the
ParisTech Chair Modeling for Sustainable Development
Policies after Fukushima

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.

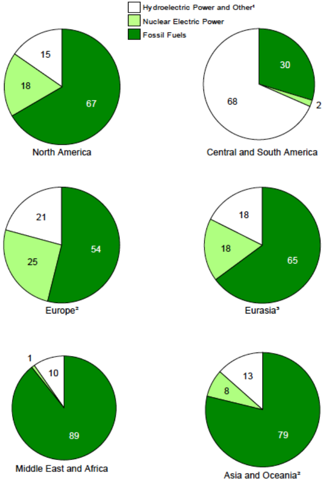


Figure: Power generation by region Source: AER 2009.

Future low-carbon Power Systems

Moving to a low-carbon society

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

☞ Nuclear power is stated as a zero-emission technology

Beyond the debate between pros and cons

the different options induce major technical challenges to shift the paradigm towards new power systems

Future Power generation mix

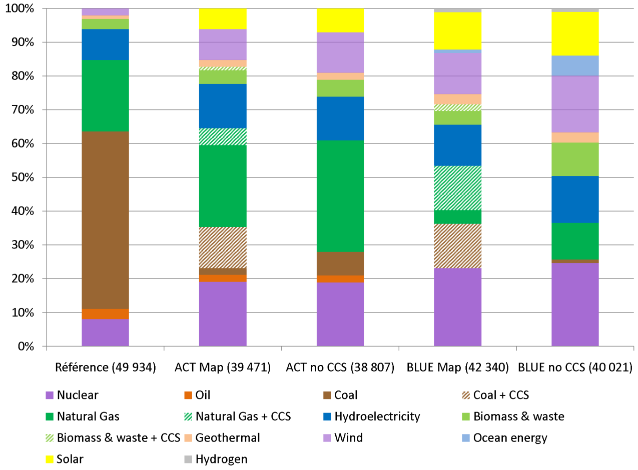


Figure: World generation by share ETP 2008

Future Power Systems appeal for major technical issues

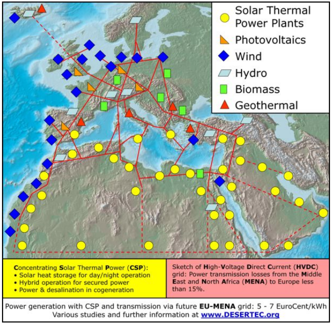
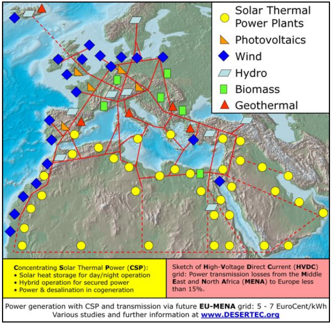


Figure: All-Renewable Electricity Generation in 2050.Source: DESERTEC.

Technical issues for New paradigms based on

1. Decentralized options.
2. Intermittency.

Future Power Systems appeal for major technical issues



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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.

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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

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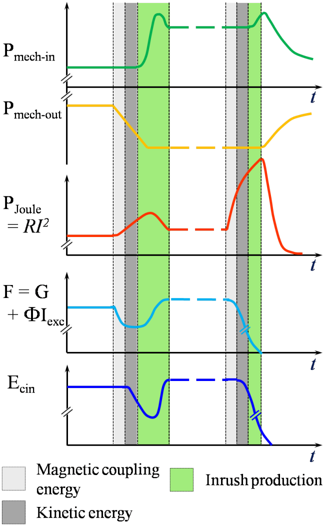
Load fluctuation and stability



energy exchanges between the subsystems involved in the Thermodynamic Framework

Two events experienced by a power system:

an admissible load fluctuation is lifted by the electromagnetic coupling energy (ΦI_{exc}), the kinetic reserve (E_{cin}) and the generation realignement during a load fluctuation (left) ; conversely, a short circuit lowers the coupling energy and the kinetic reserve leading to a collapse of power transmission (right).

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.

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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Prospective versus Prediction

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**

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

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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

Competitions, substitutions and technical issues

A technological energy-sector model:

TIMES based on a 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)

A model to assess future power systems

The TIMES model

A technical linear optimization model driven by demand achieving a **technico-economic optimum**

1. for the **reference energy system** (RES)
2. submit to a set of relevant technical and environmental constraints
3. over a **definite horizon** : long-term (50 years)

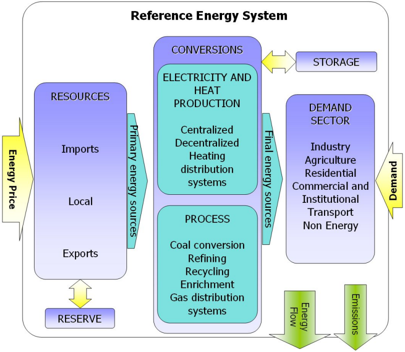

Figure: Reference Energy System

French electricity paradigm

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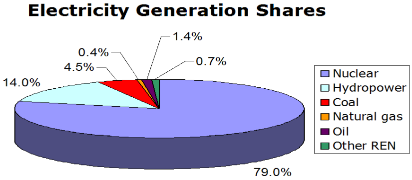
French electricity generation sector

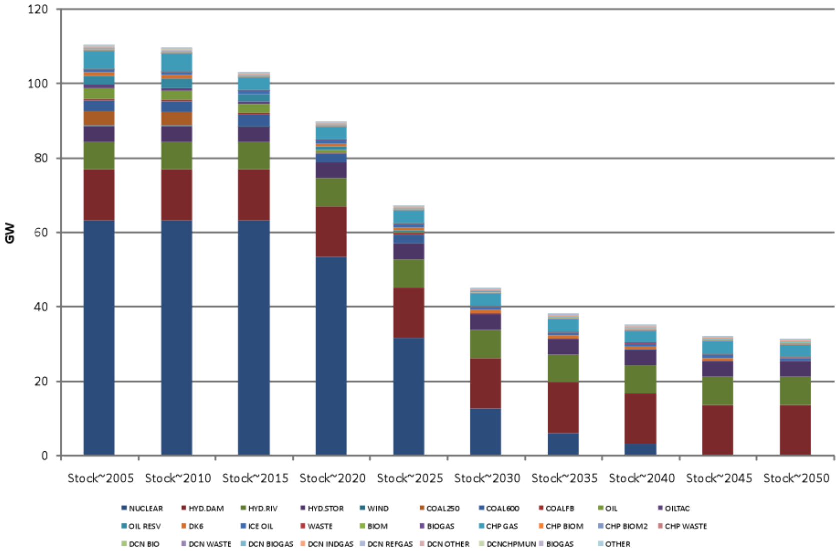
☞ dominated today by nuclear power

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**



~ 500 TWh : Global production
~ 400 TWh : Nuclear thermal production (80%)
~ 30 TWh : Classical thermal production (coal and fioul)

Nuclear power replacement is the main driver for the future



France in Europe : an interconnected grid

French Net Exportation : ∼ 70 TWh

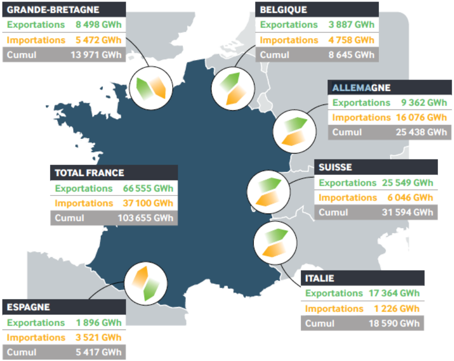


Figure: Contractual Exchanges between European borders in 2010 source RTE

Nuclear Phase out

- Germany : in 2022
- Switzerland : in 2035
- Italy : voted in 2011

Installed capacities are already reaching a critical point

Reliability issues

Missing capacities to meet the demand: foreseen in 2016

	2013	2014	2015	2016
Énergie de défaillance en espérance (GWh)	0.2	0.8	2.8	27.4
Espérance de durée de défaillance	0 h 05	0 h 22	1 h 14	8 h 50
Puissance manquante	-	-	-	2.7 GW

Figure: Reference scenario Source RTE/Bilan Prévisionnel 2011

Following the trend or changing the paradigm ?

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Replacement of nuclear existing capacities

Fukushima accident 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

Last October, 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

Assessing the future of nuclear power for France

Three scenarios existing nuclear power plants

1. Maintain = BAU
   nuclear capacity is maintained to 65 GW (lifetime of existing capacities extended to 60 years and replaced when needed)
2. Progressive Phase-out= PROG:
   lifetime of existing capacities limited to 40 years for one plant over two; the others are extended to 60y with a cost of 600Billions€/plant
3. fast phase-out = FAST: lifetime limited to 40 years

Nuclear residual capacities according to three options

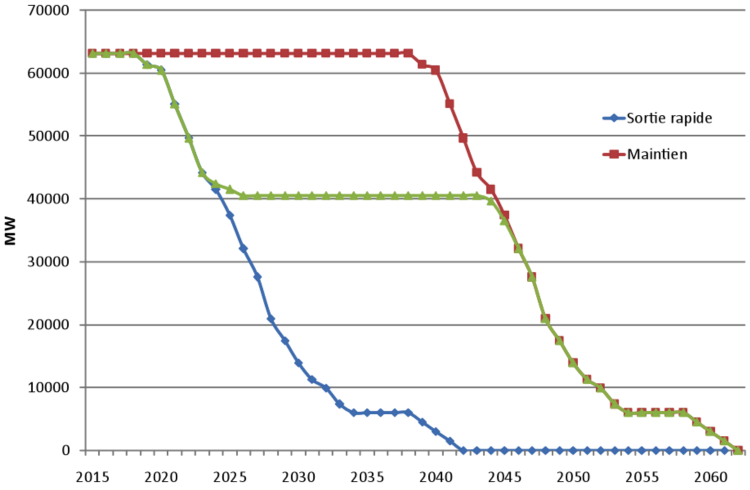

Figure: FAST (lifetime 40y) PROG (lifetime 40y to 60y) BAU (lifetime 60y)

Prices and Carbon Tax Assumptions

- ☞ Final electricity consumption forecast 2050 = Demand scenario forecast (Source: RTE (french TSO)/BP July 2011.)
- ☞ Fix Carbon Tax 20 €/T according to ETS levels
- ☞ Fossil ressources prices : WEO 2010

unit		**2010**	**2020**	**2030**	**2040**	**2050**
\$/tep	oil	60.4	99.0	110.0	117.2	125.2
\$/MBTU	gas (EU)	7.4	11.6	12.9	13.8	14.9
\$/tonne	coal	97.3	101.7	105.6	107.7	110.0

Assessed Scenarios for the French Power System

Scenarios	CO_2 Constraints	Elastic Demand	Nuclear Status	Common assumptions
BAU	ETS tax	Reference	Maintained	**Prices** WEO 2010
PROGt1	taxe ETS	yes	Progressive Withdraw	**Demand**
PROGv1	ETS tax + cap BAU	yes	Progressive Withdraw	reference TSO (RTE)
FASTt1	ETS tax	yes	Fast Withdraw	Variable **exports** 40 to 50 €
FASTv1	taxe ETS + + cap BAU	yes	Fast Withdraw	

Prospective analysis of the results

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Nuclear lifetime sensitivity analysis

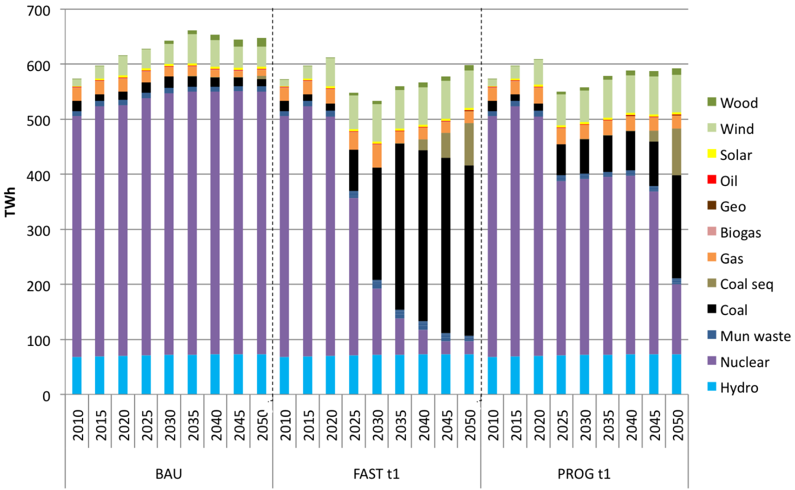

Figure: Power Mix generation (CO_2 tax)

Nuclear as a zero-emission solution

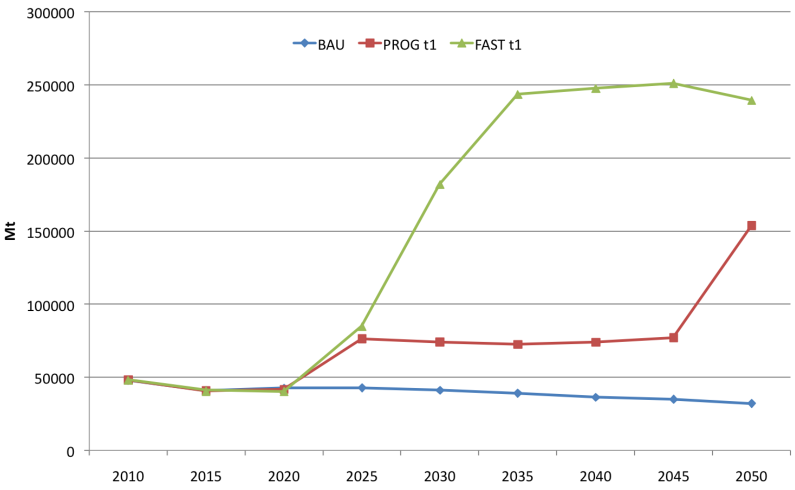

Figure: Sensitivity of the CO_2 emissions of the power sector

Nuclear lifetime sensitivity analysis : tax + cap

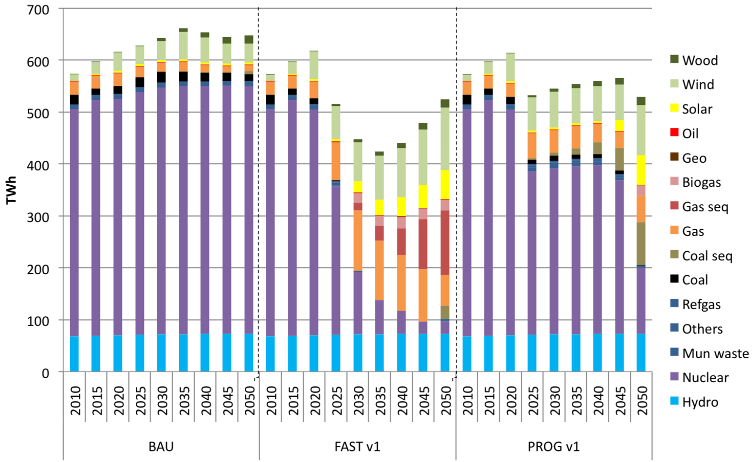

Figure: Power Mix generation (CO_2 tax + cap)

Huge investments are needed

☞ new generation capacities to secure power supply

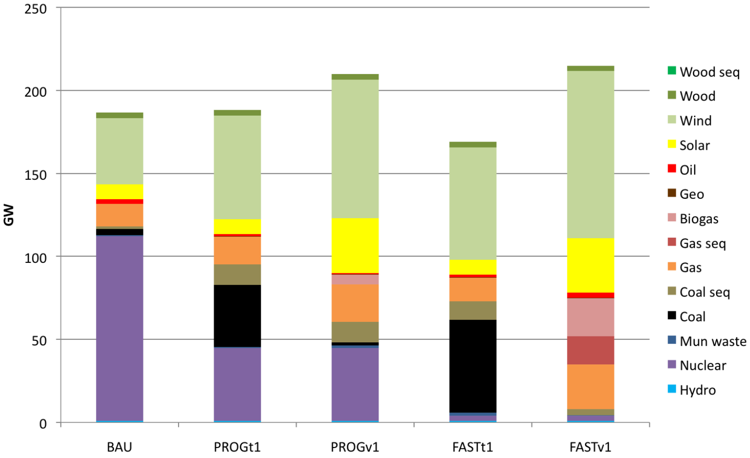

Figure: Lump sum of Power Plants Capacities (with extended nuclear plants)

New capacities Investments to maintain 65 GW

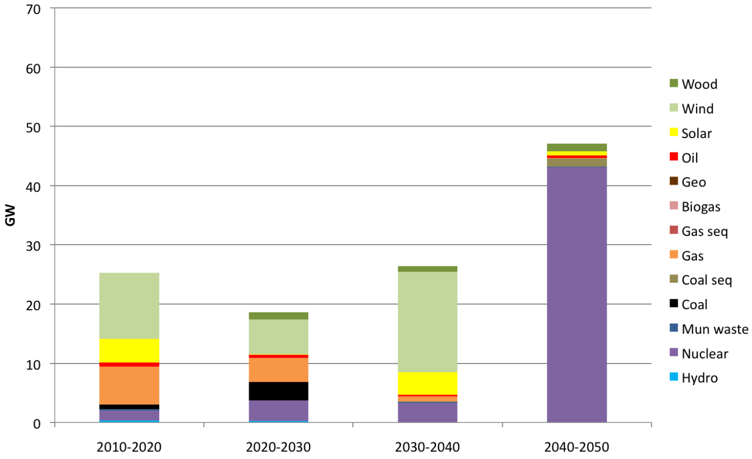

Figure: New installed capacities BAU

New capacities Investments for a fast phase-out

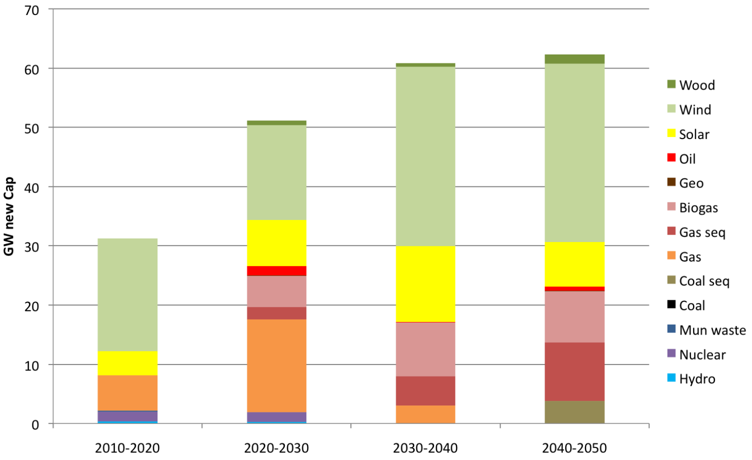

Figure: New installed capacities FASTv1 (lifetime 40y, tax + cap)

Objectif function for TIMES-FR restricted to the power sector

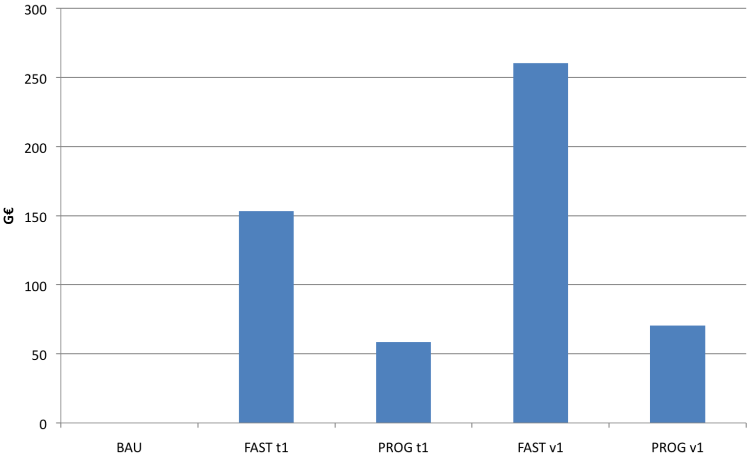

Figure: Overcost total actualised cost (in 2011) as compared to BAU

Beyond the classical results

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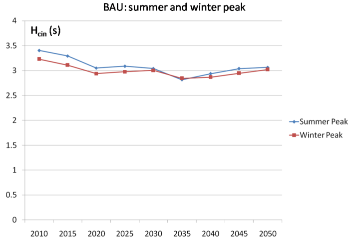
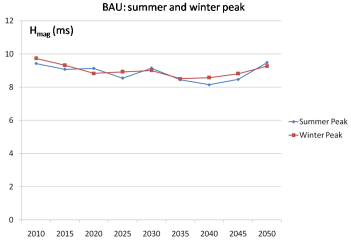
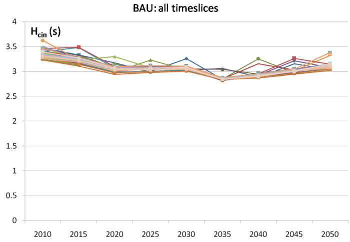
Sensitivity analysis of reliability issues

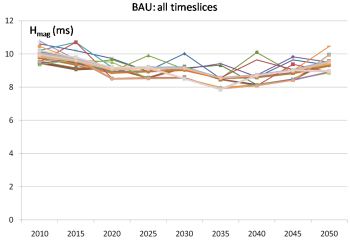




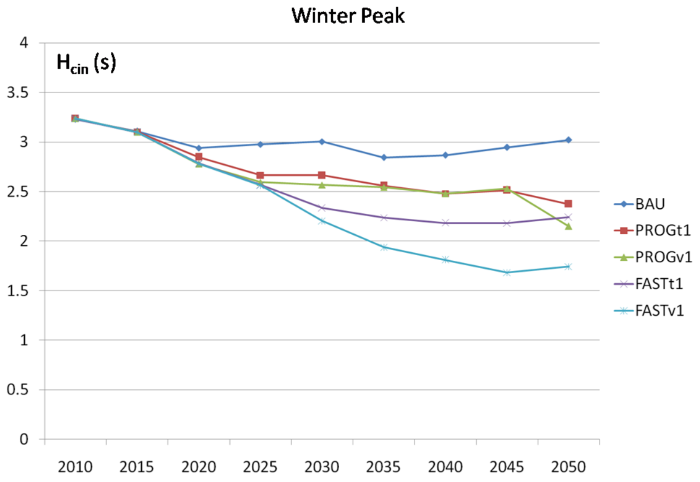
Kinetic Reserves

Magnetic Reserves

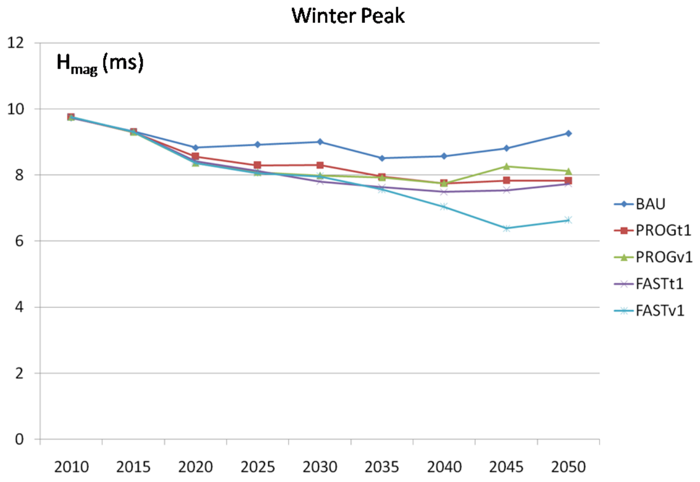




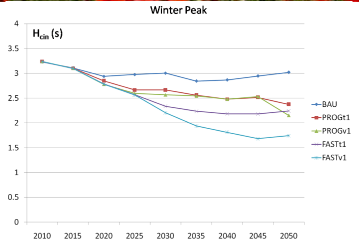
Reliability : kinetic reserve for winter peak

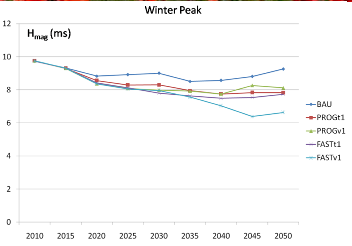


Reliability : magnetic reserve for winter peak



Fiabilité des scénarios évalués





Kinetic Reserves

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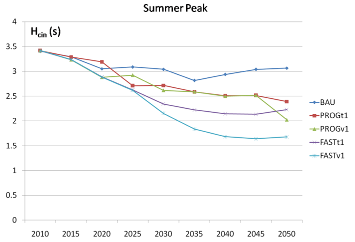

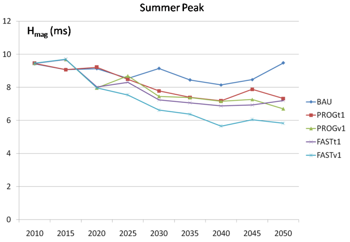

Changing the paradigm, from power mix to consumer

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Consumption, Consumers : the key issues I

1. In order to cope with climate mitigation issues, some technological options are highly recommended and the discussion opposes renewable energy and nuclear supporters;
2. the main outcome of the study delivered to the french Ministry of Energy as it was related by journalists was the recommendation to extend nuclear power plant lifetime to 60y;
3. technical issues such as reliability level might be part of the debate as they give insights about feasibility and relevance of future power mix;

Consumption, Consumers : the key issues II

Beyond technical issue, reliability also speaks about

quality of supply

the load profile

level of supply

that refer to the end of the chain : consumption usage and requirements.

A balance between reliability issue and the spread of renewable energies is required but it has to be related to consumer needs which must be at the center of the debate

Contact

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Web Site

http://www.modelisation-prospective.org/index_en.html

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Puissances installées contraintes par la taxe

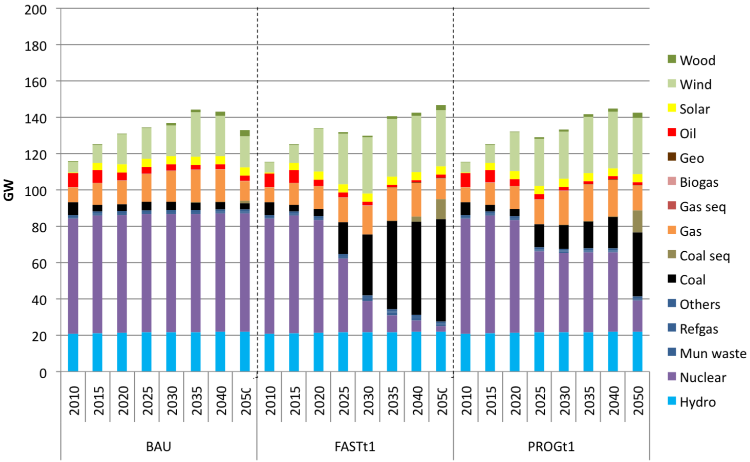

Figure: Capacités (contrainte par la taxe)

Puissances installées contraintes par taxe + quantités

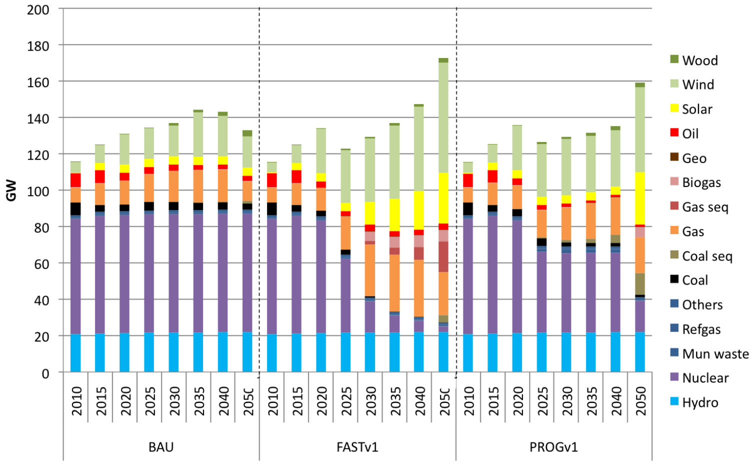

Figure: Capacités (contrainte par la taxe et les quantités)

Nouvelles capacités installées (sans les réacteurs prolongés)

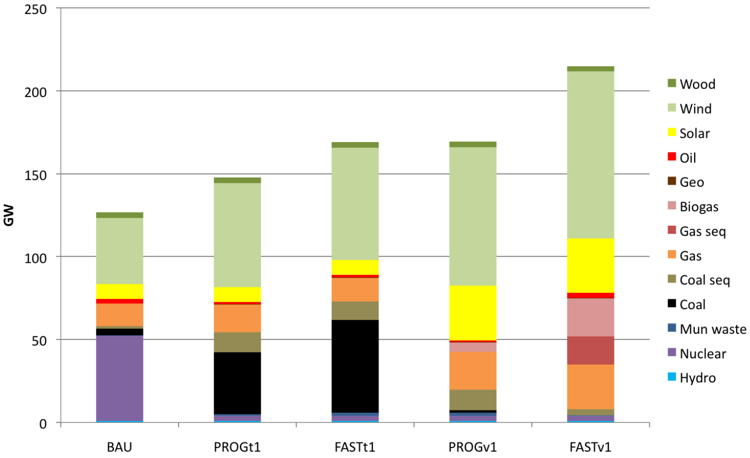

Figure: Nouvelles capacités installées par scénario