Will Nuclear Generations Fight Together Or Each Other In The Global Energy Market Competition ?

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4 CEA/ITESE, Saclay

5 CEA/DRT/LITEN

6 G2ELAB, CNRS, Université Grenoble-Alpes

7 Georessources, CNRS, Nancy

8 GEOPS, CNRS, Université Paris Sud Orsay

A. Bidaud et al. @ GLOBAL 2015
A. Bidaud et al. @ ICAPP 2015

World Energy Transition

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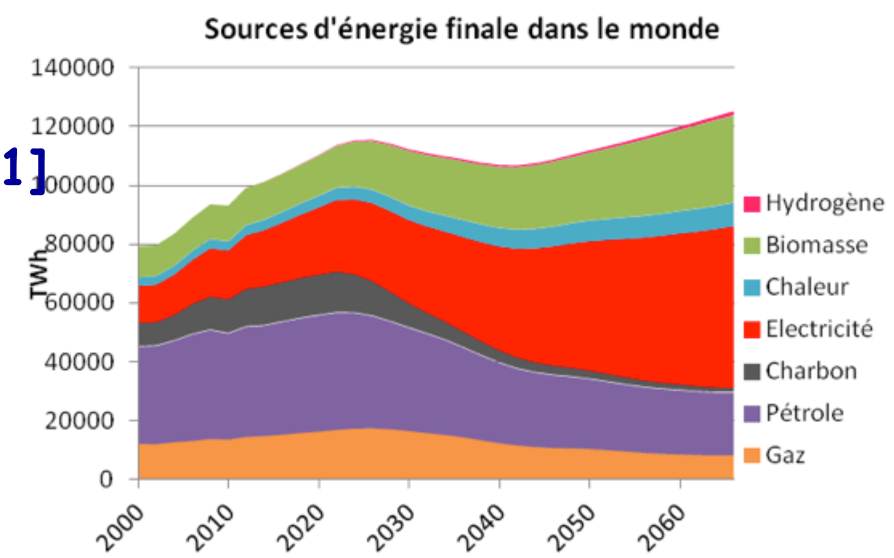

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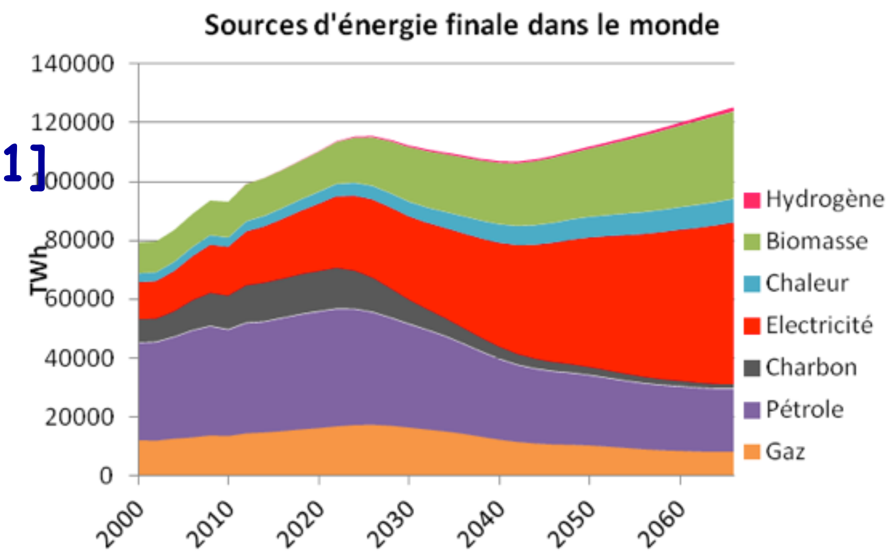

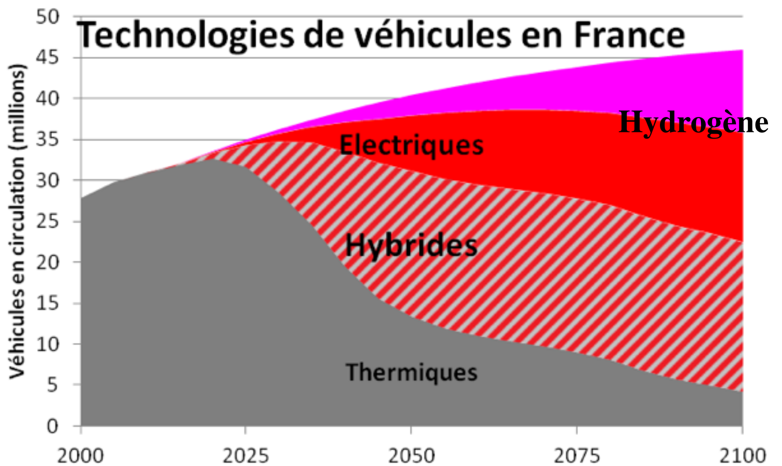

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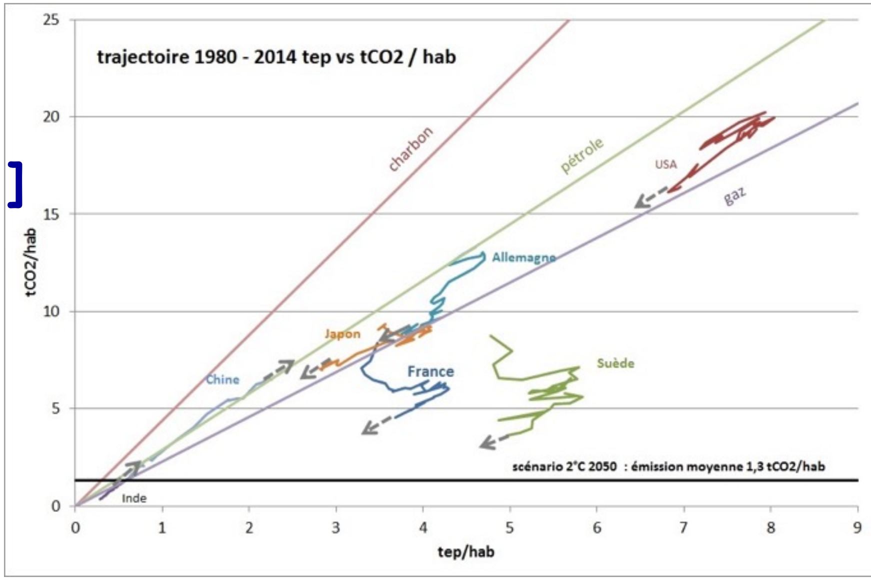

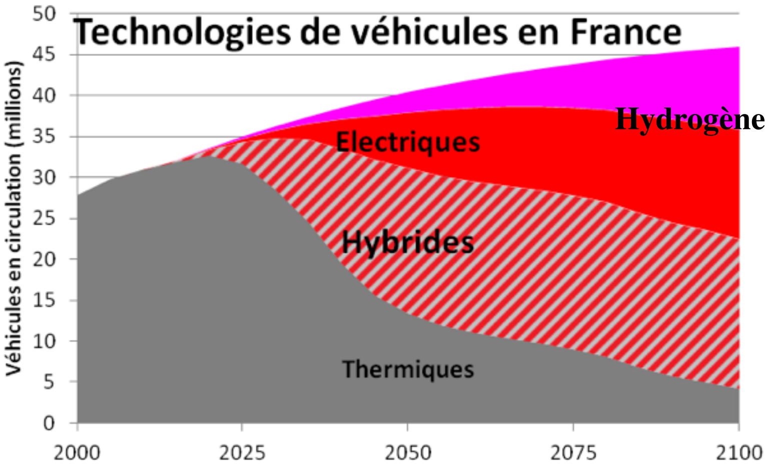

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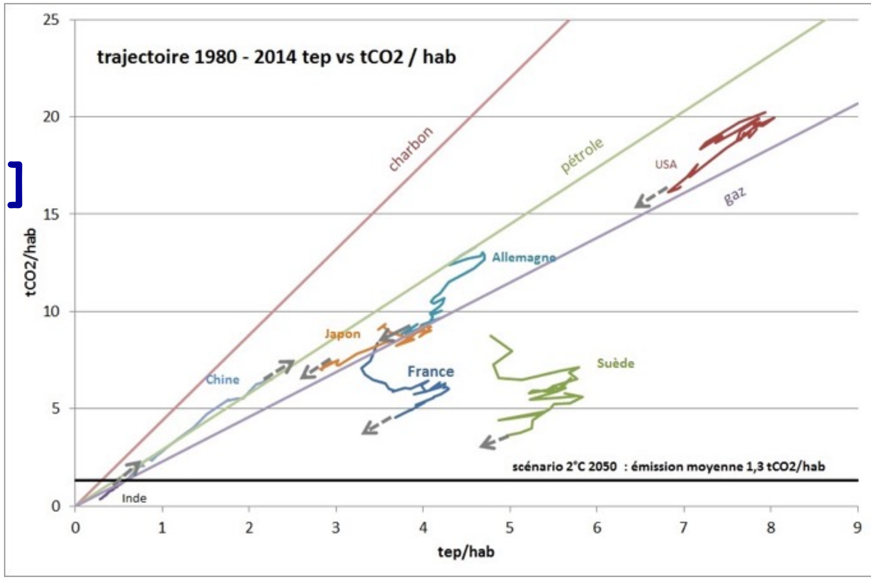

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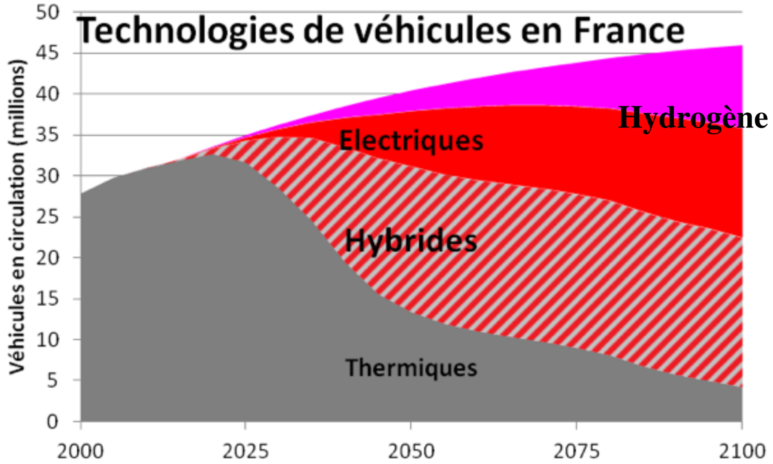

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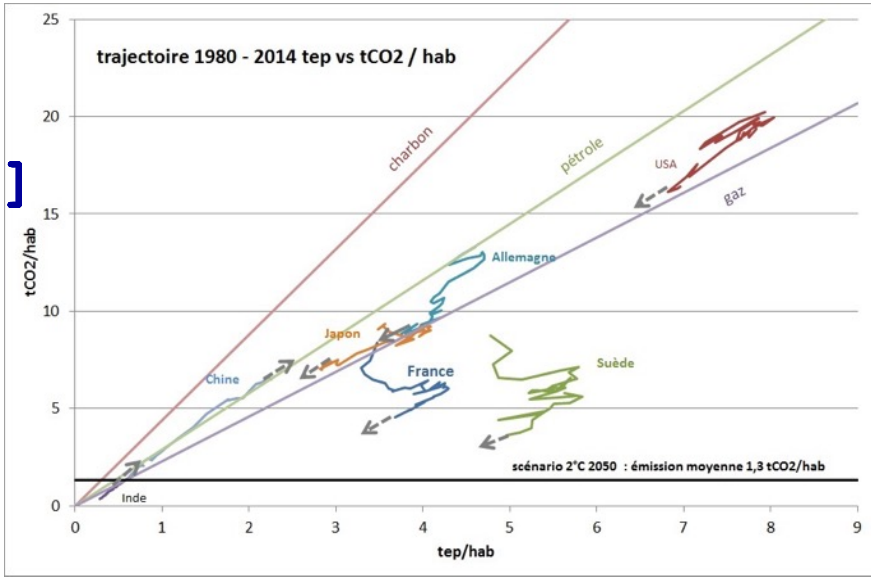

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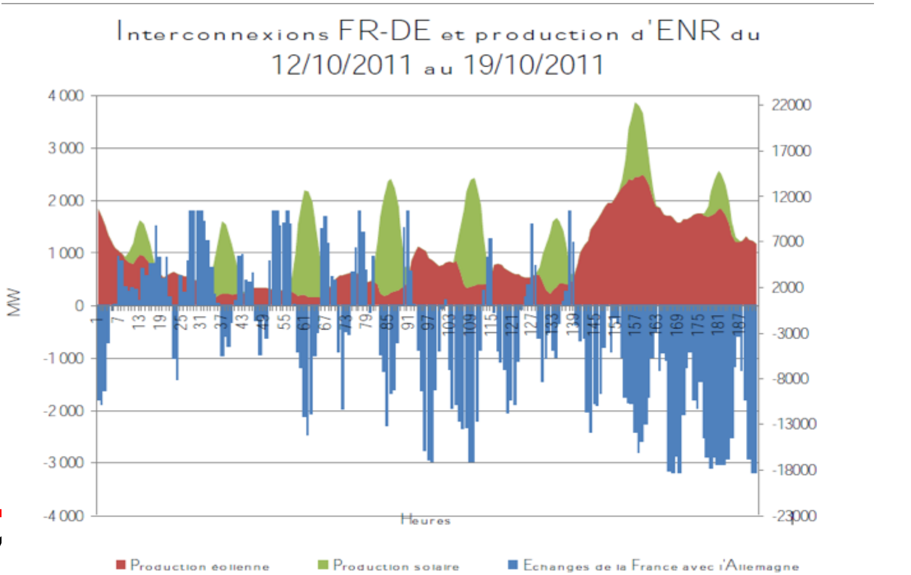

- Time Horizon Diversity
  - Investissements = decades
  - Usage / Production < hours

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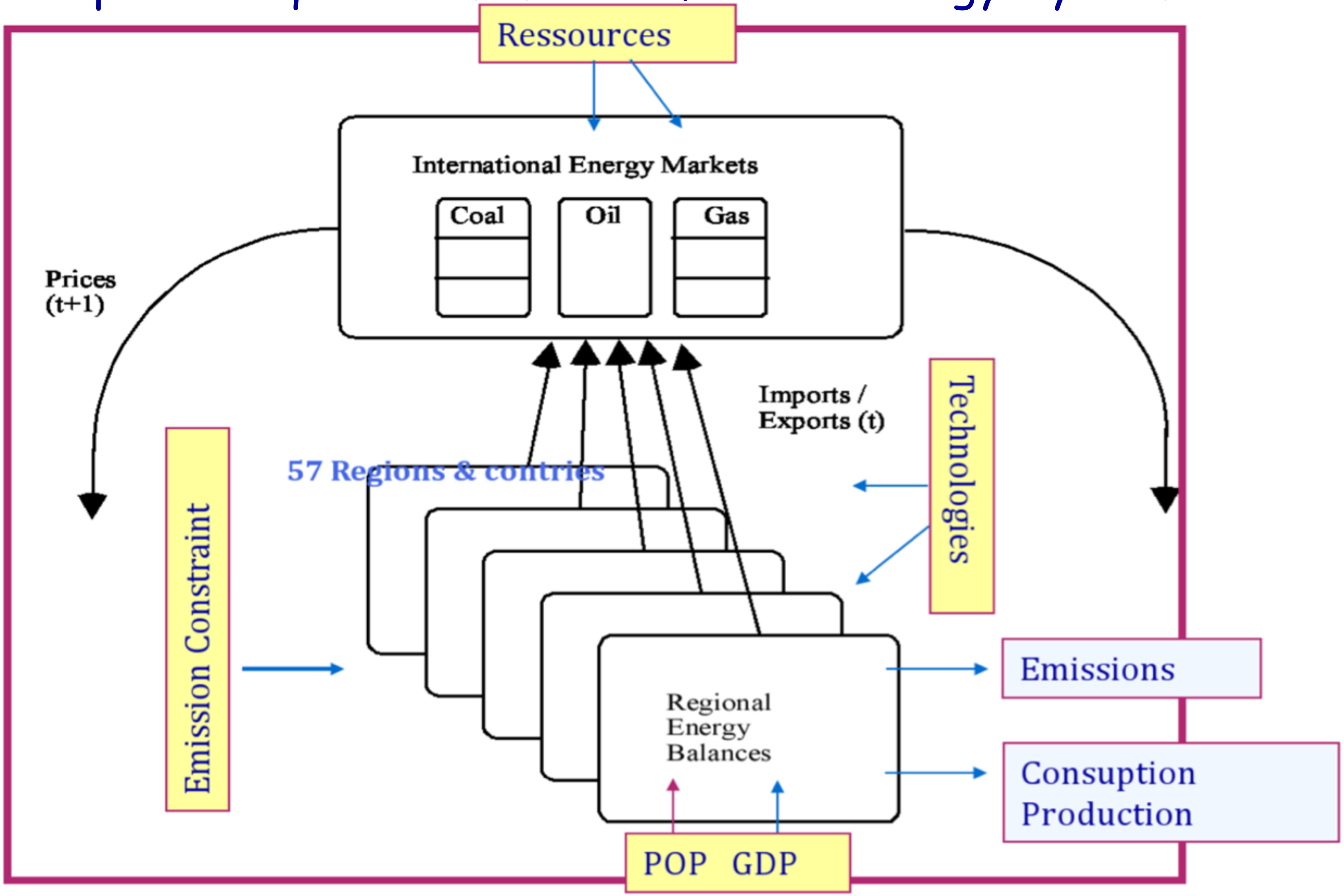
POLES : « Prospective Outlook on Long Term Energy System » partial equilibrium model of world Energy System



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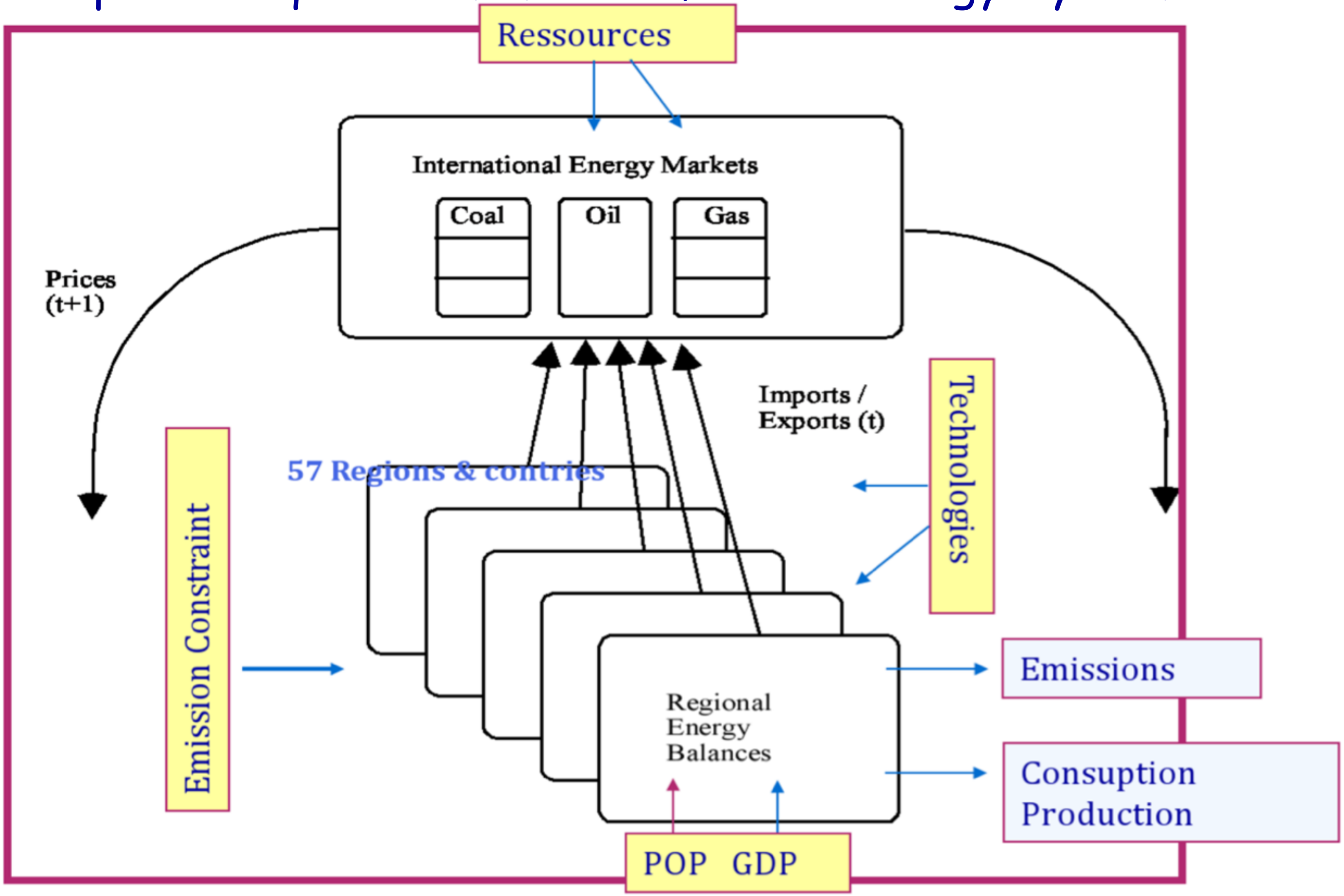

2 Nuclear technologies simulated : Thermal Neutron Reactors using natural U and Fast Neutron Breeders using recycled TR used fuels as startup inventories

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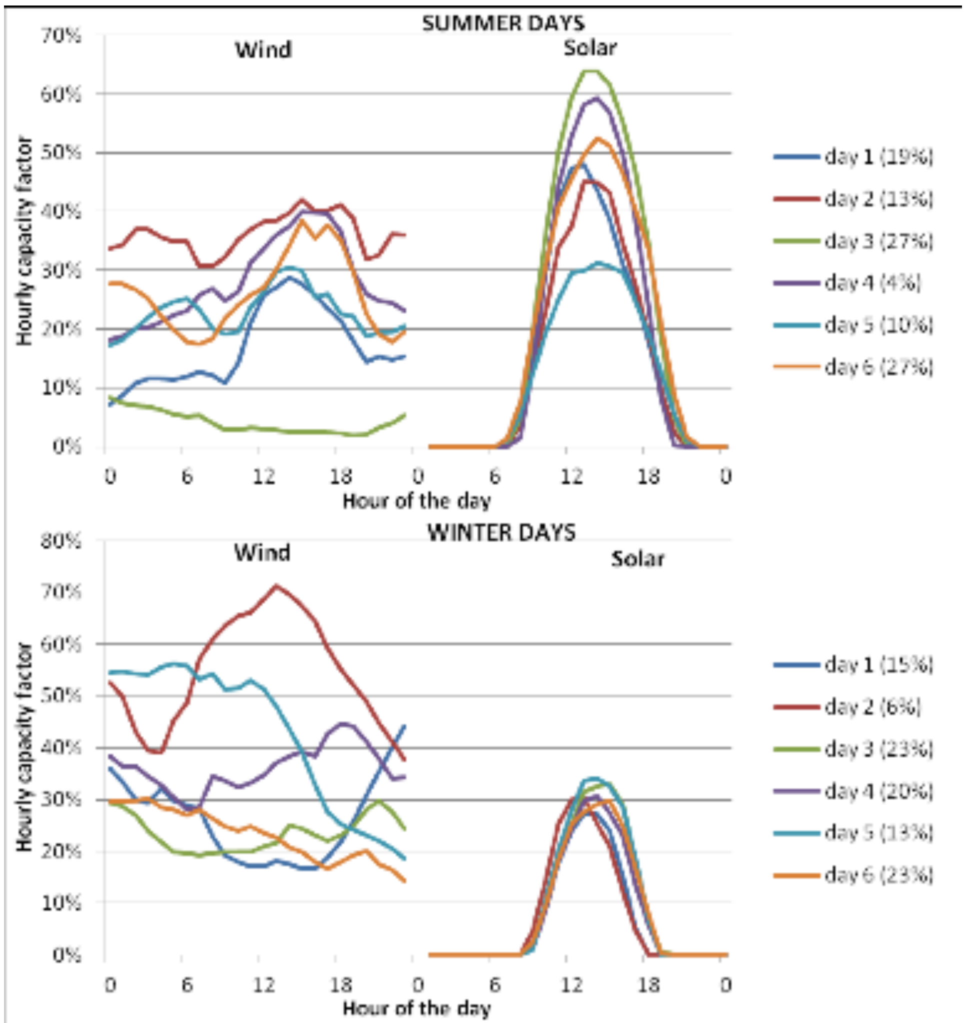

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European Commitment and Dispatch (EUCAD)

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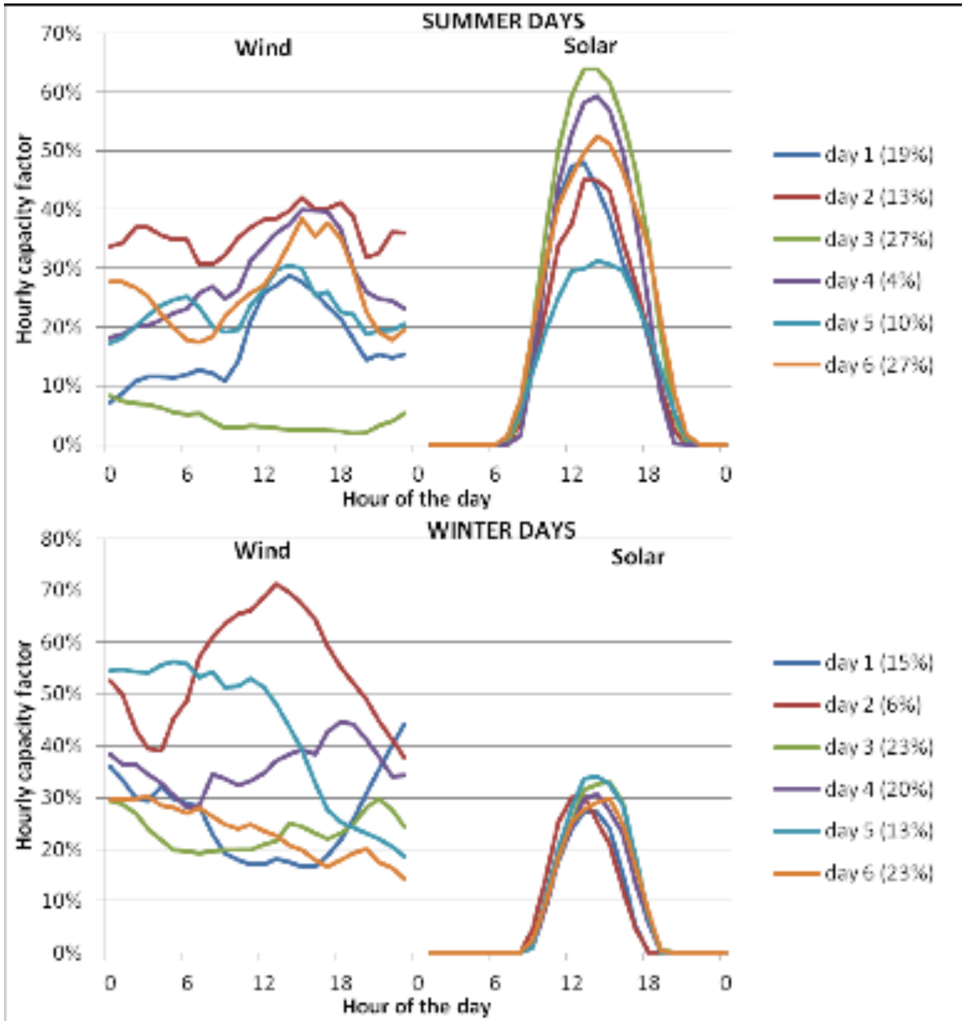

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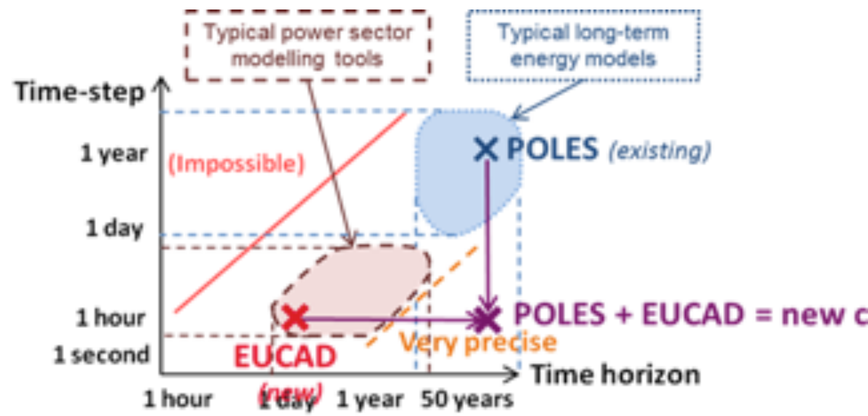

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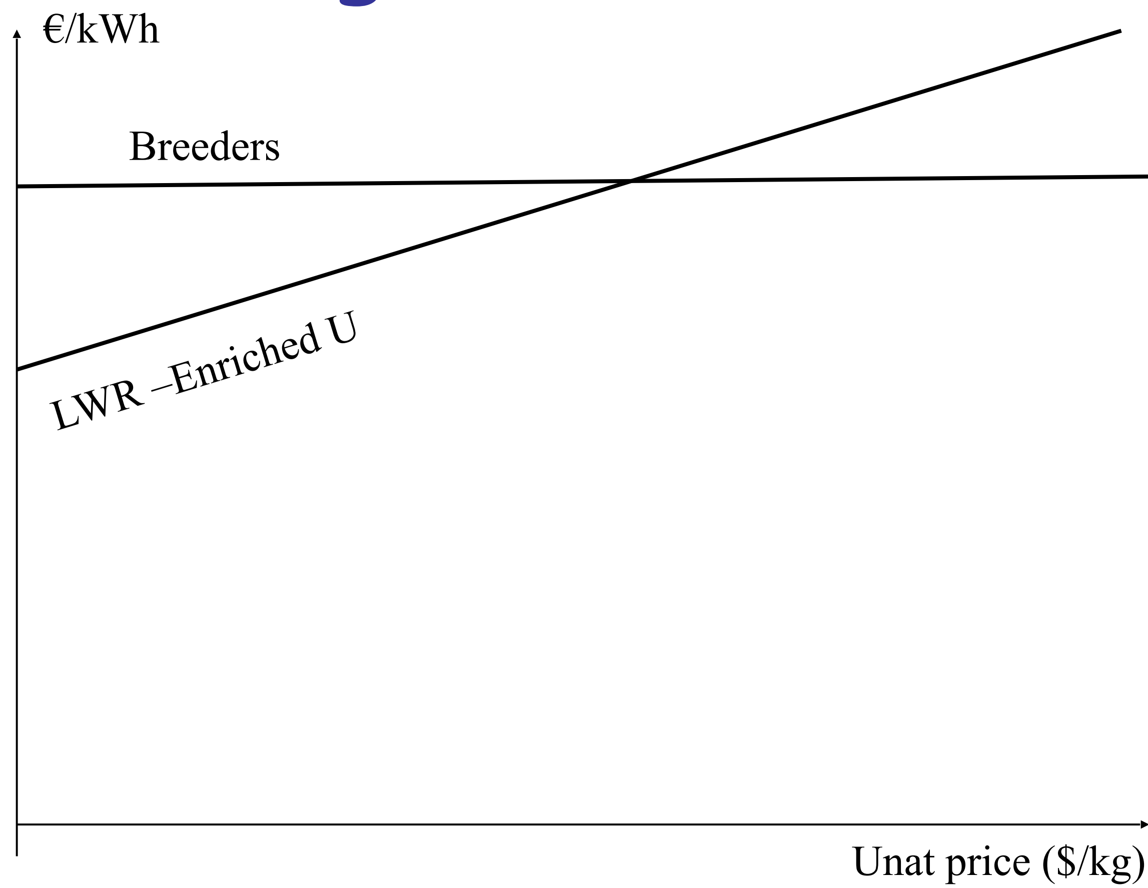

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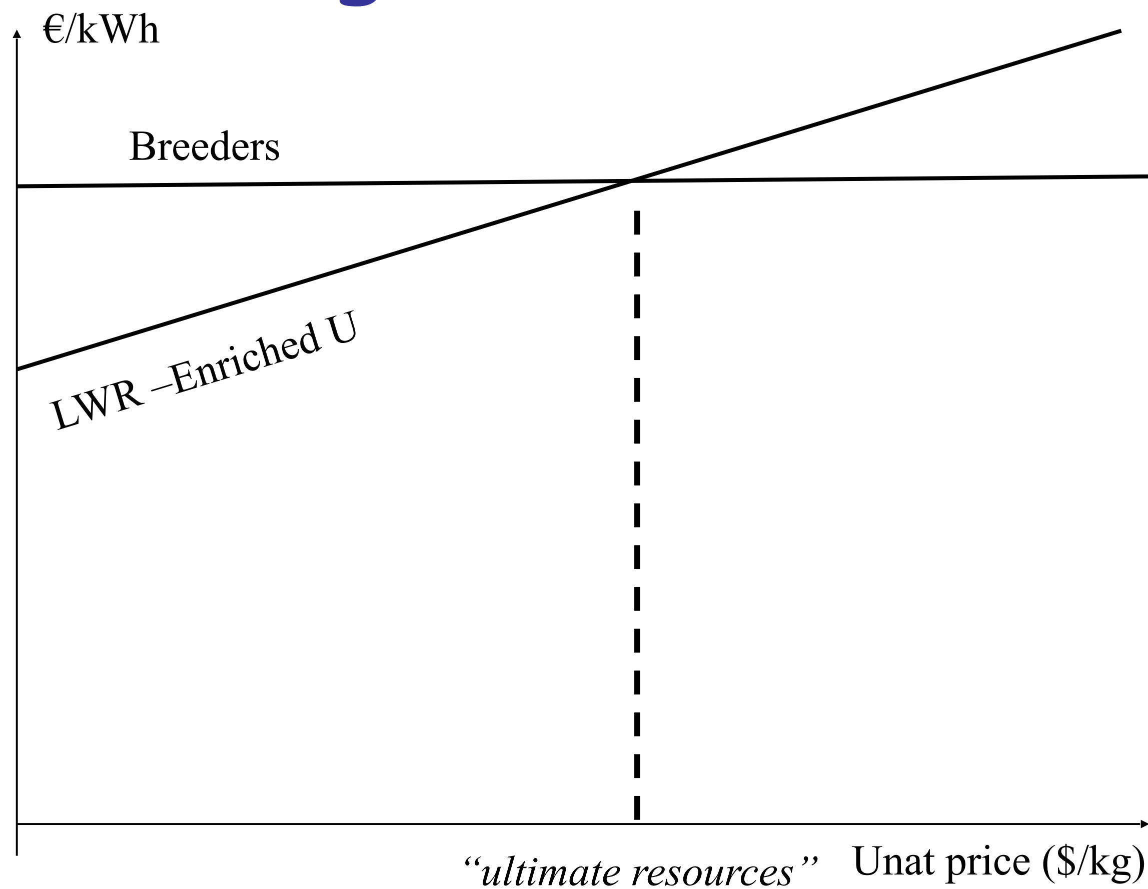

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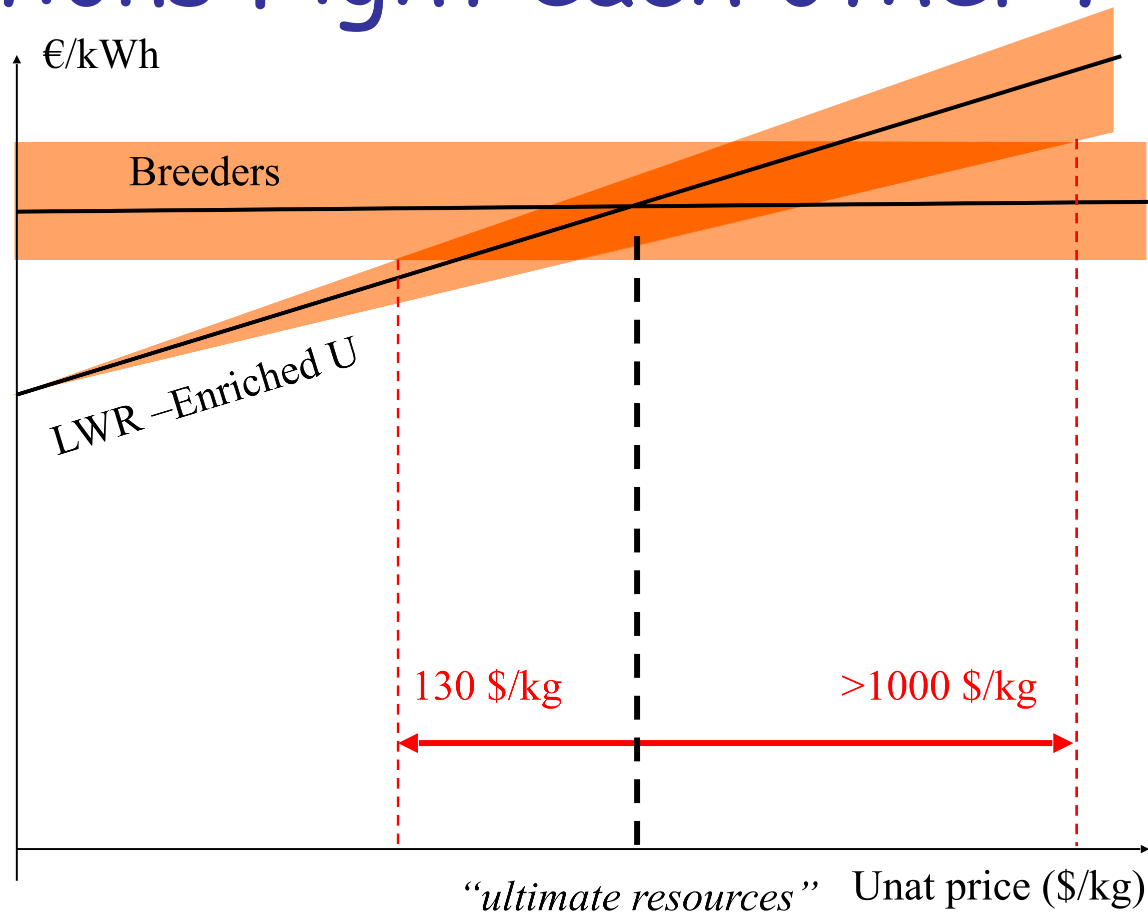

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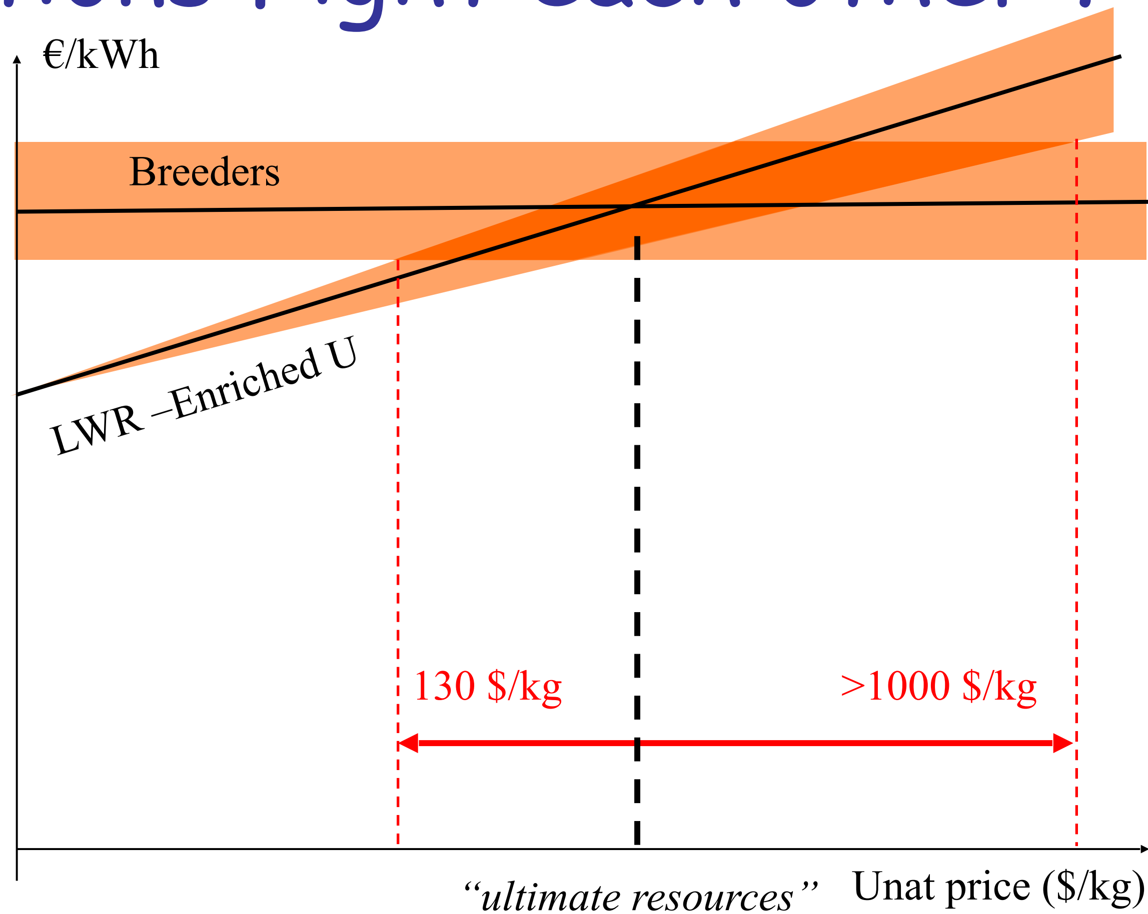
- => In France, those materials should come from used MOX fuels (« matières valorisables »).



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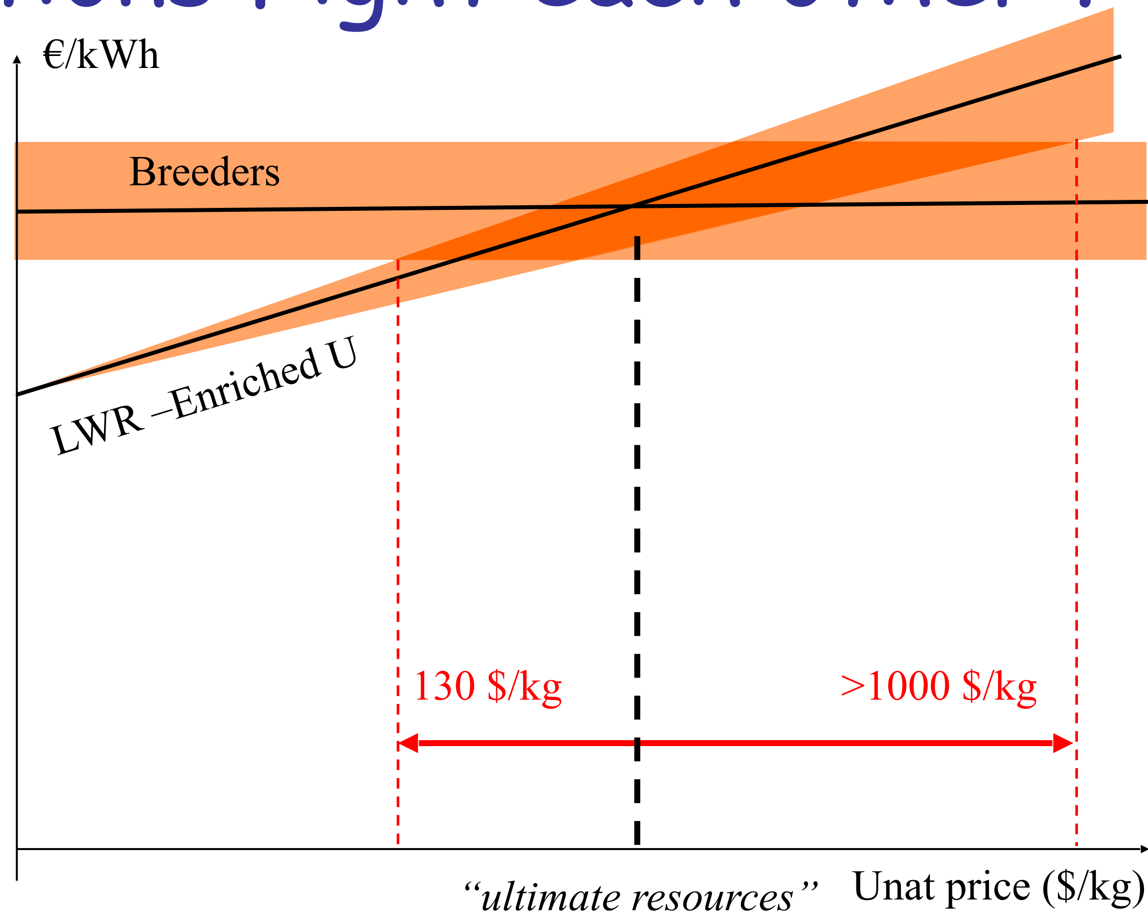

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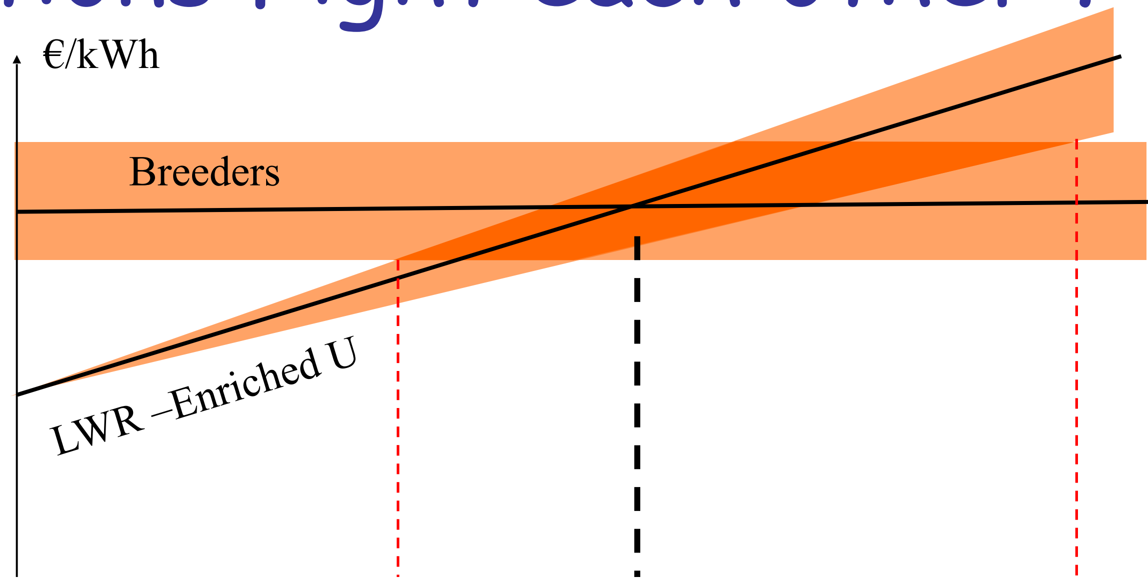

See A. Baschwitz yesterday or GLOBAL 2015

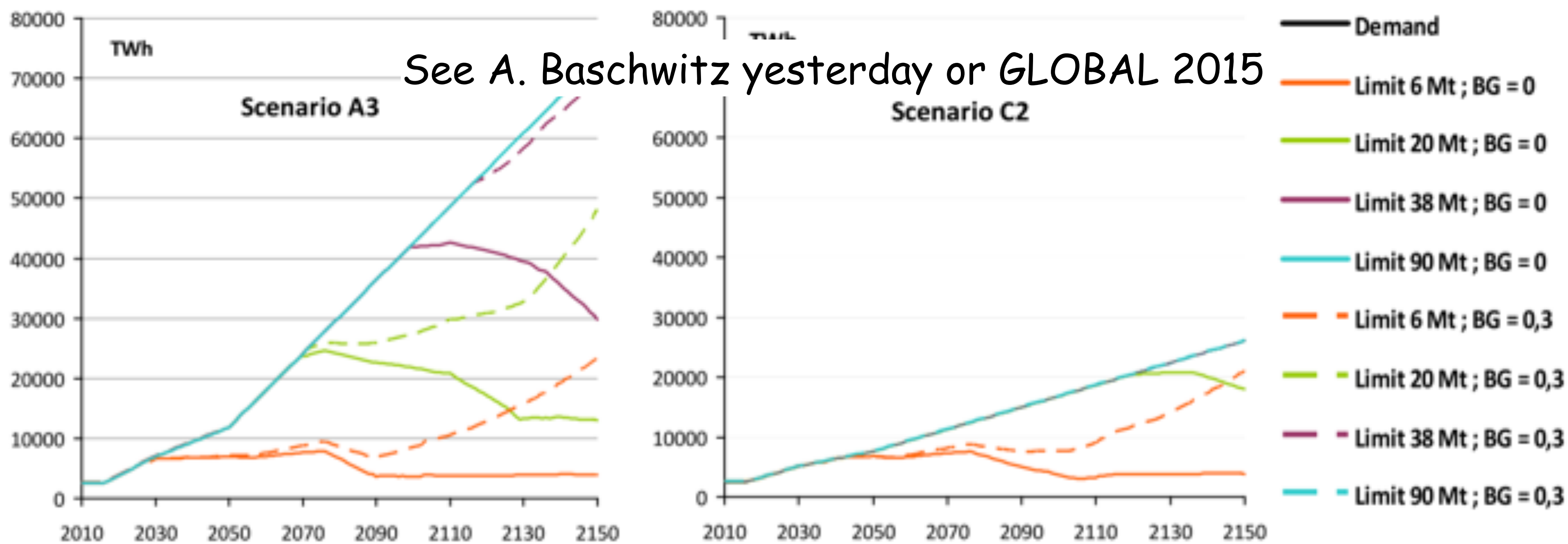

Fig. 3. Light water reactors and fast reactors – demand and power production according to the natural uranium limit (TWhe).

URANIUM RESOURCES

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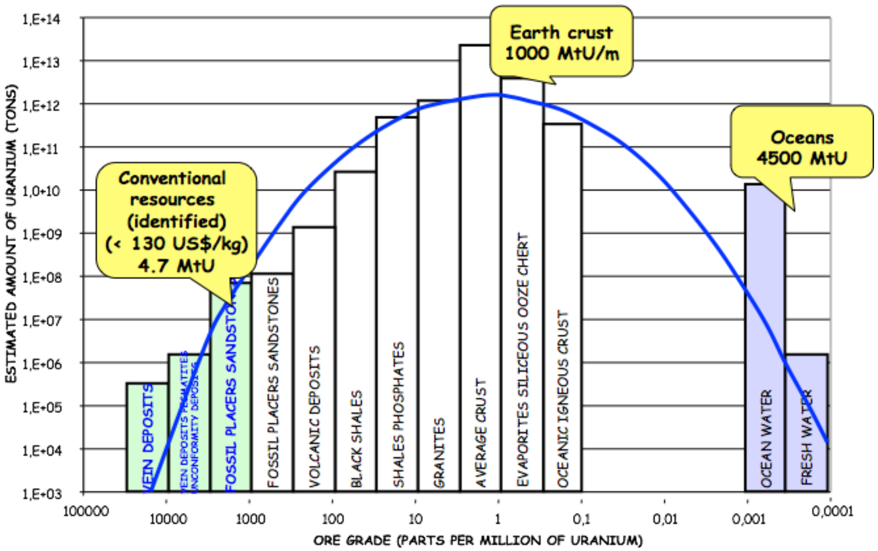

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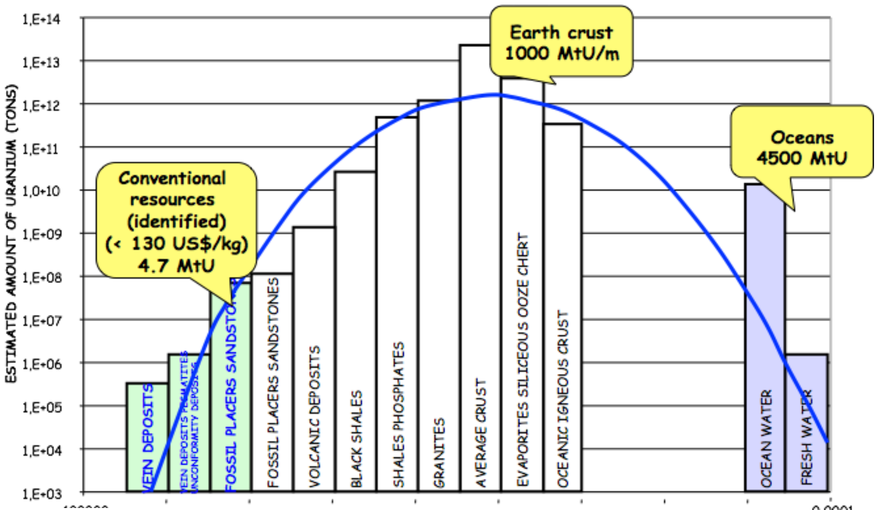
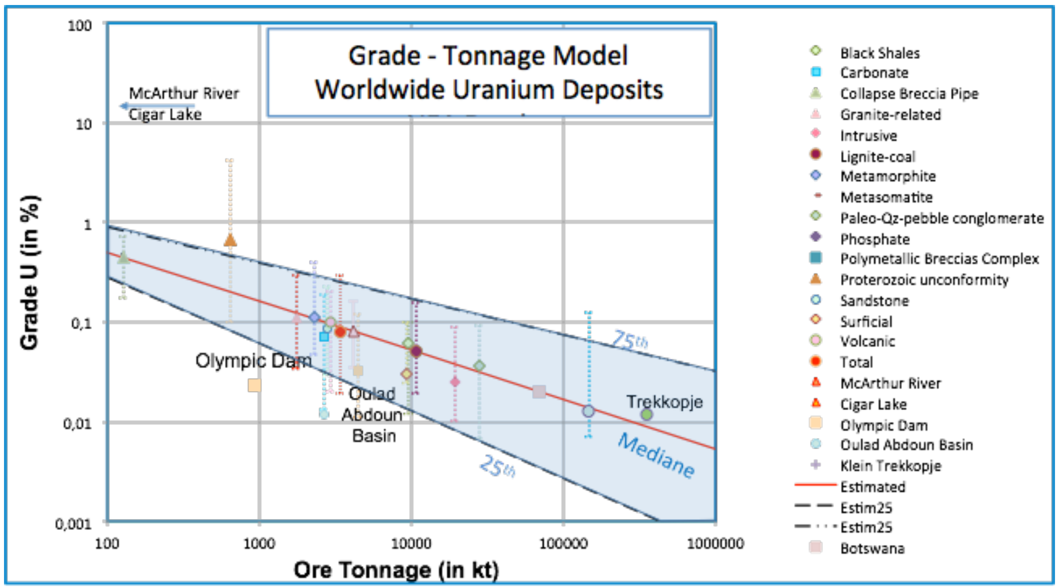


Royer et Cuney, journées Uranium 2013



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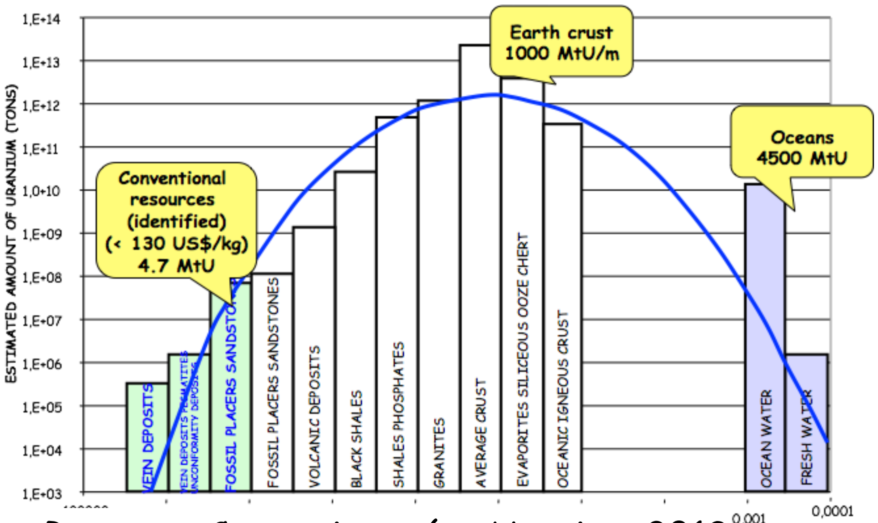
Schneider et al. Energy Policy 2013



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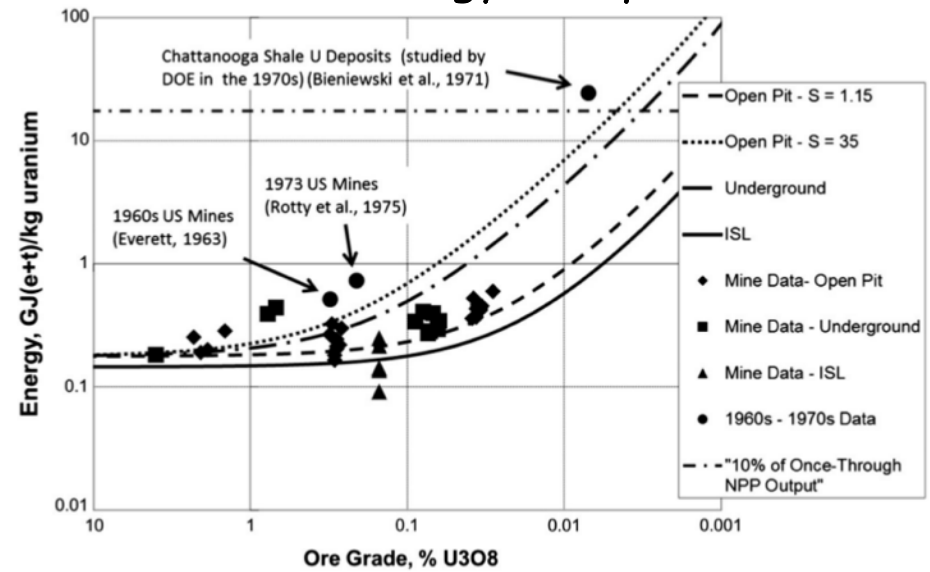

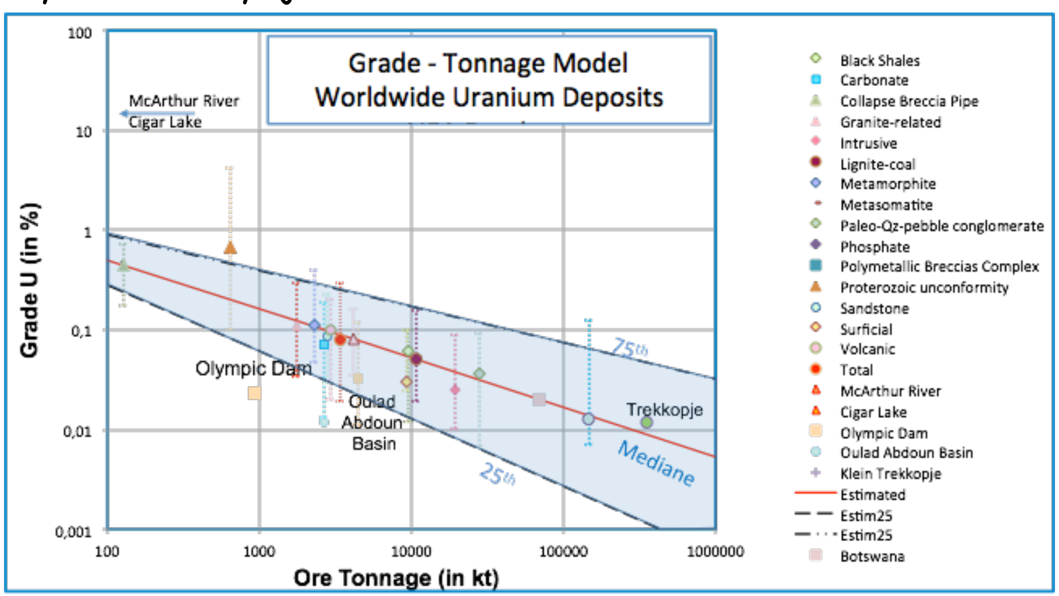

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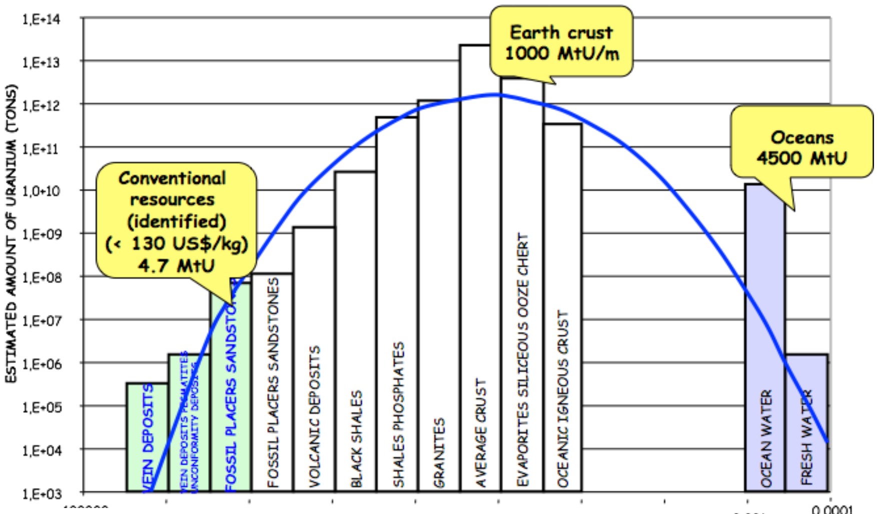

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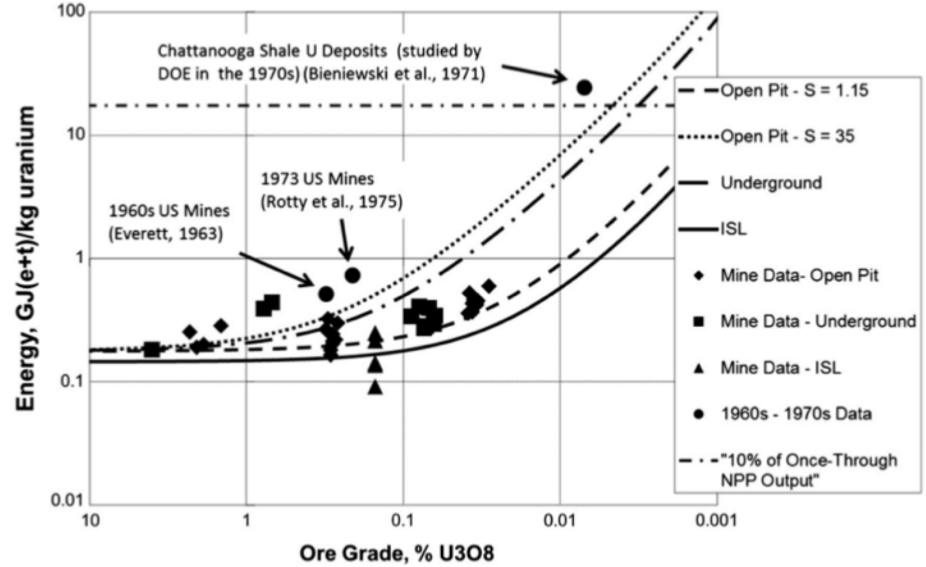

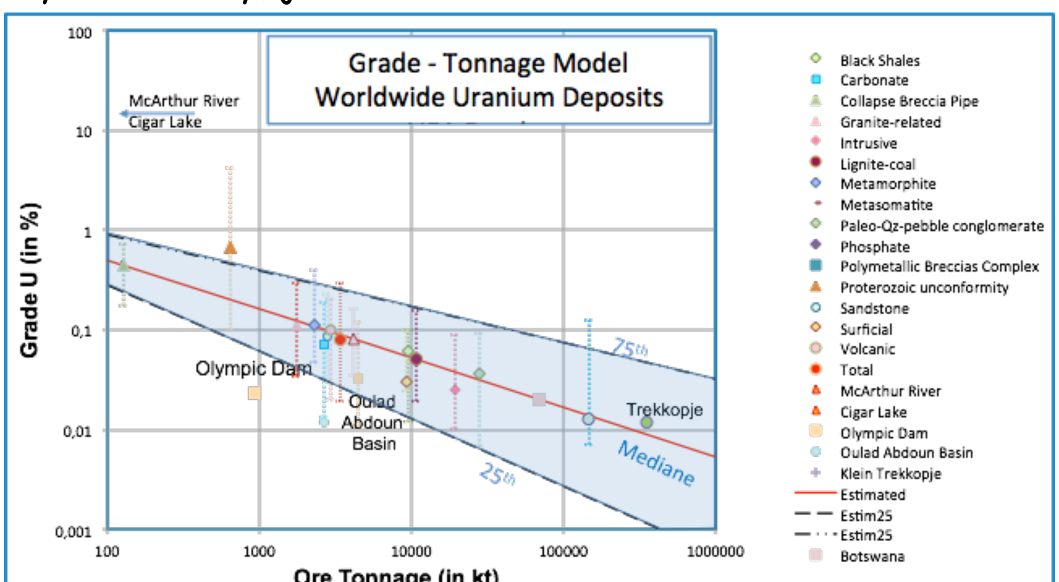

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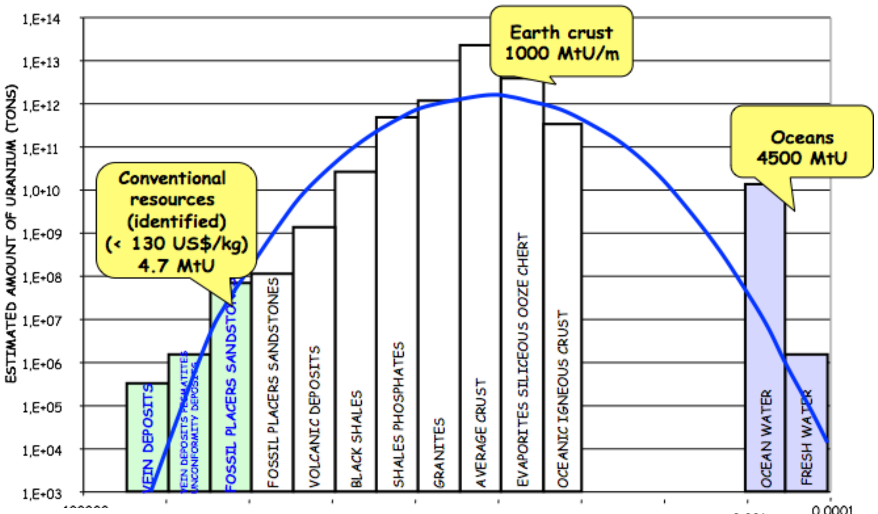

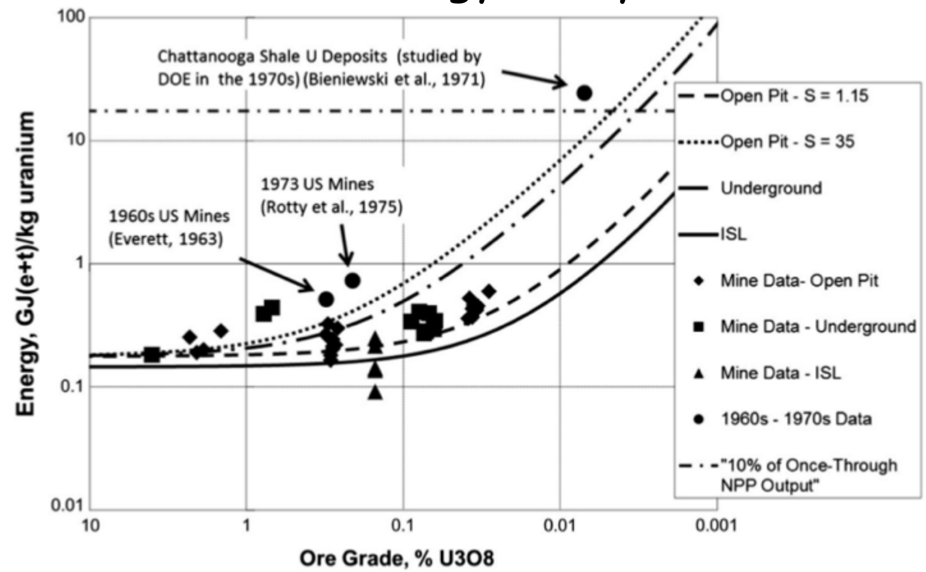

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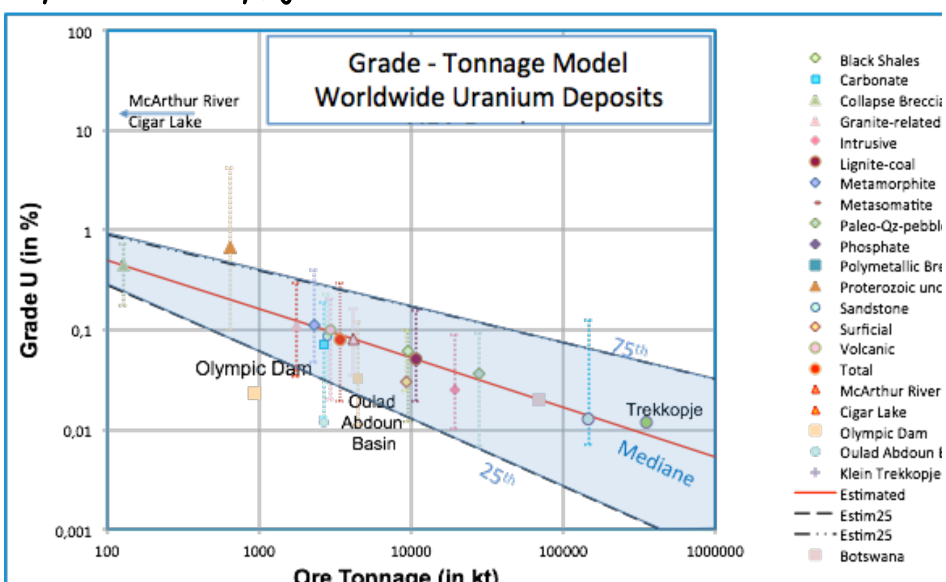

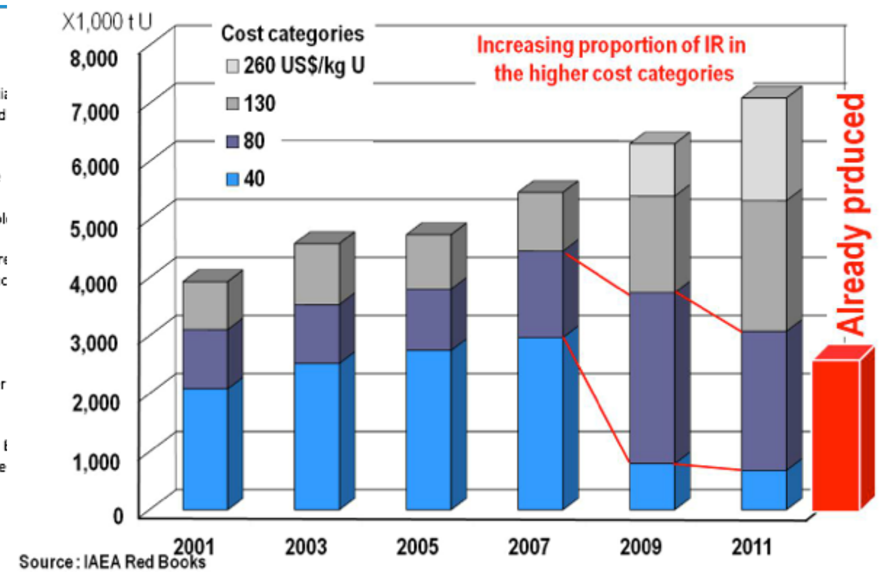

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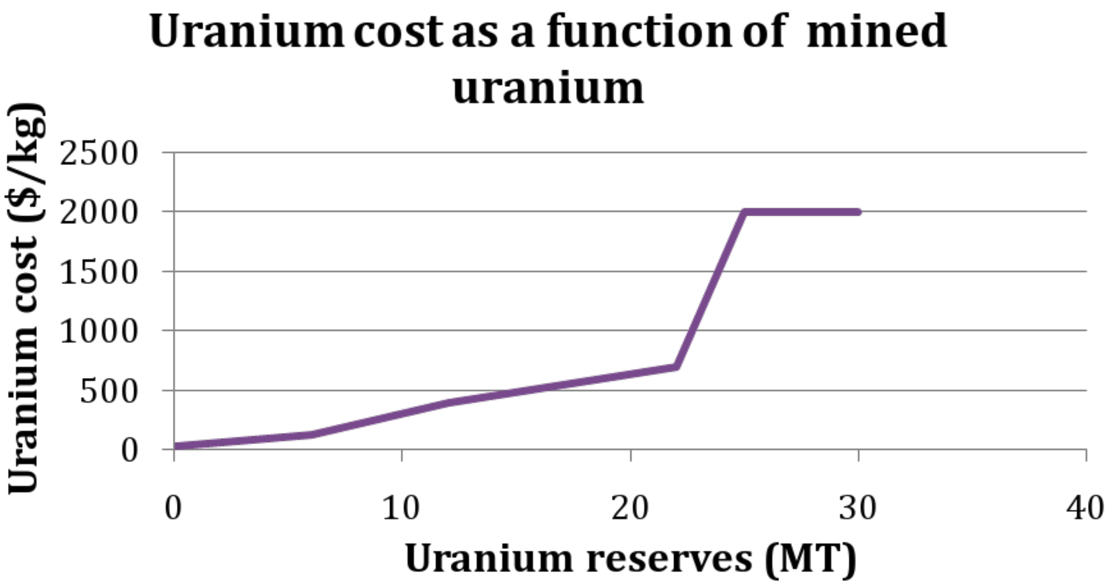

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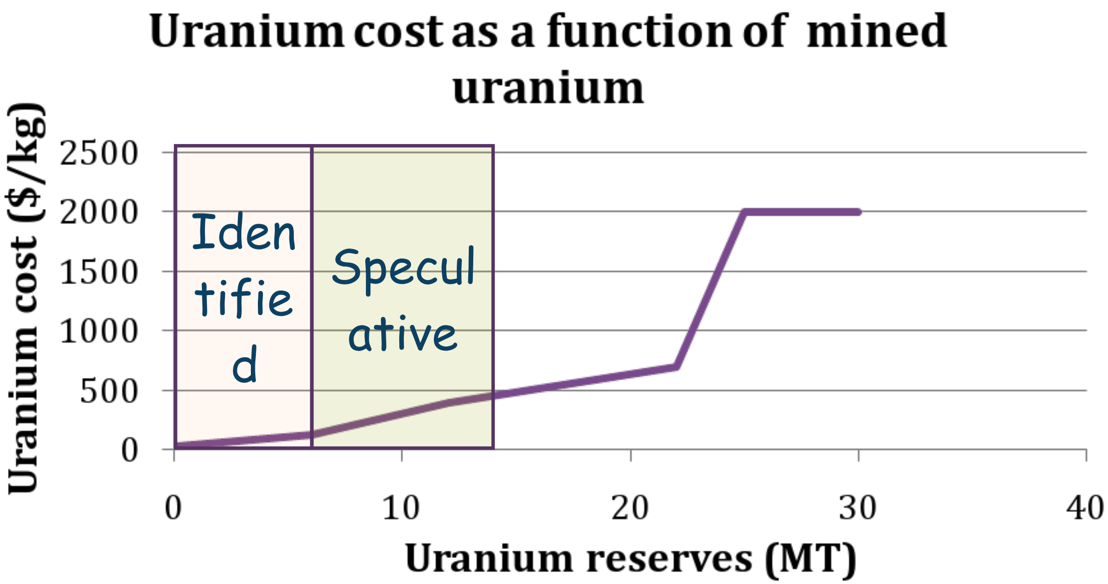

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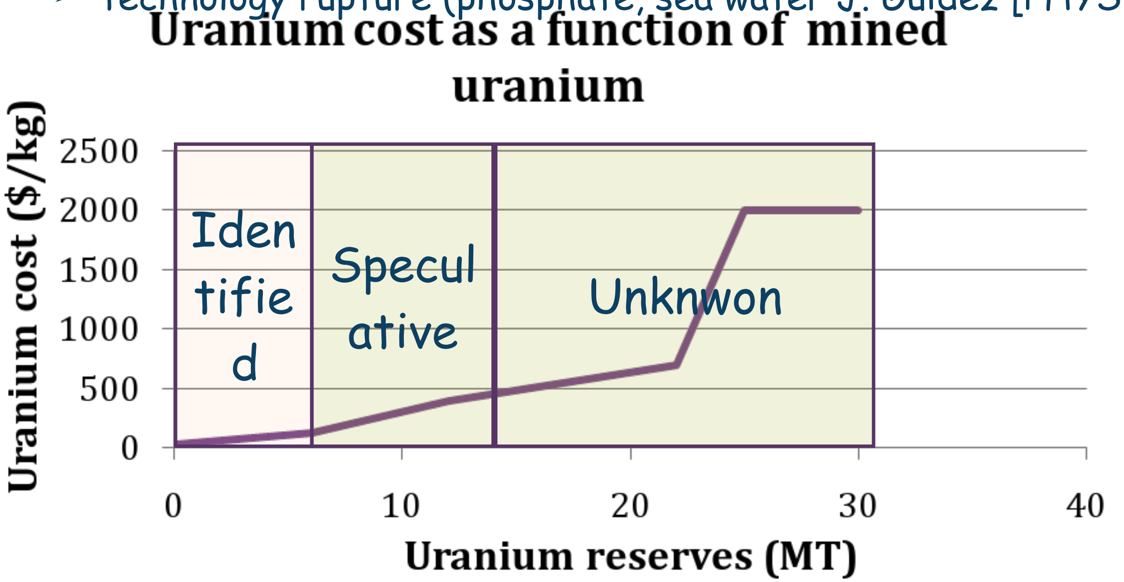

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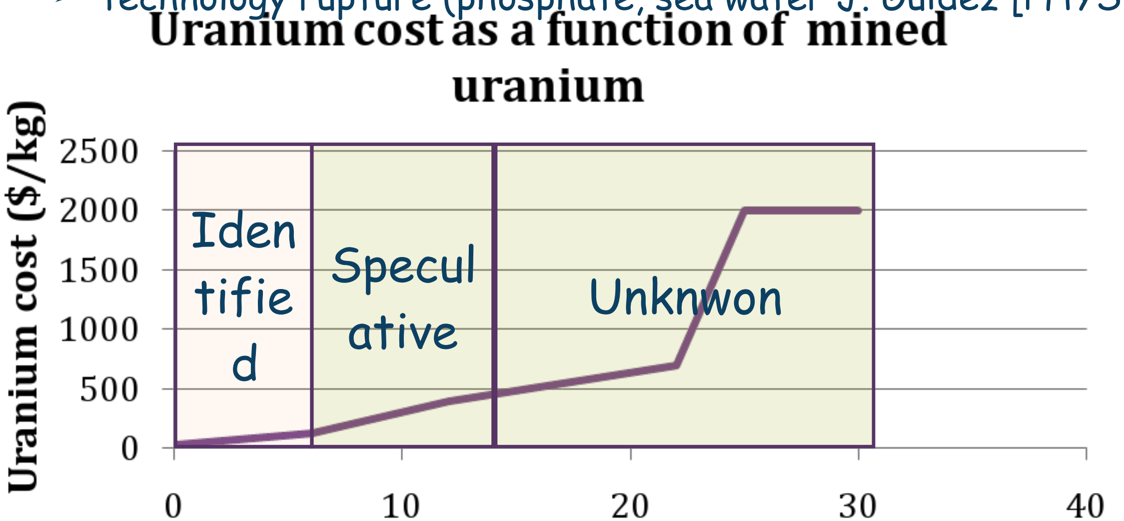

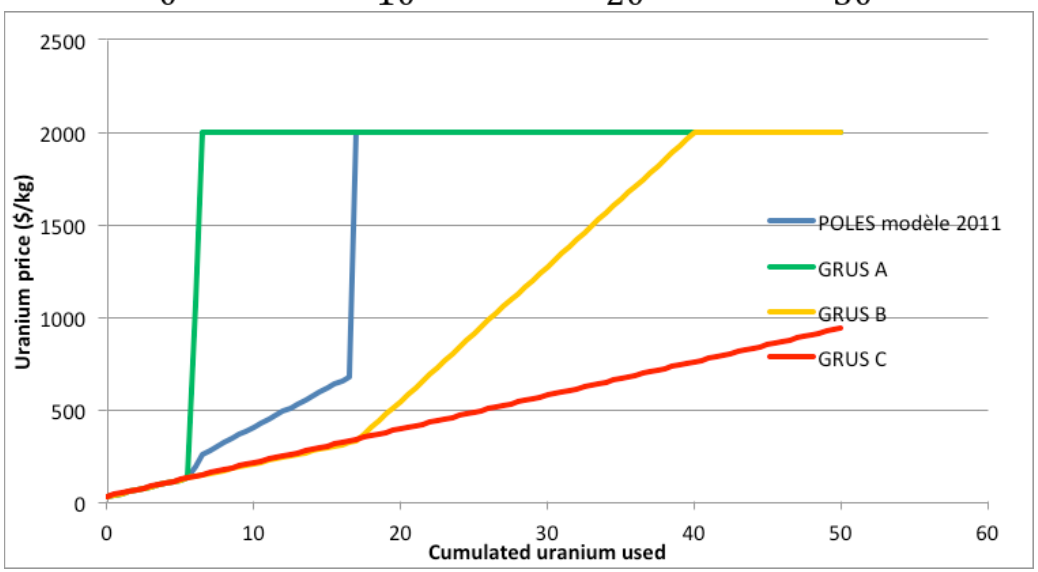

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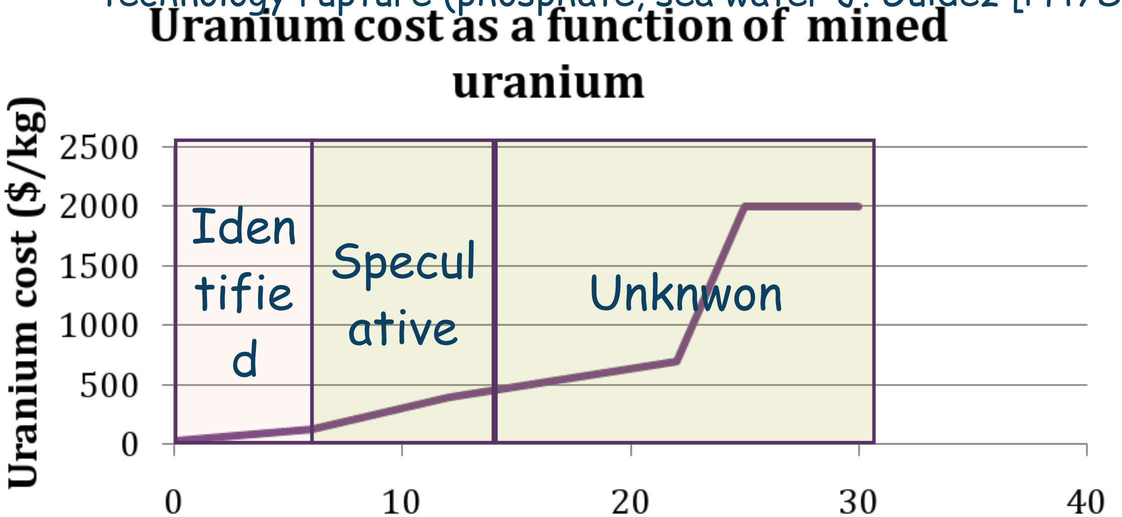
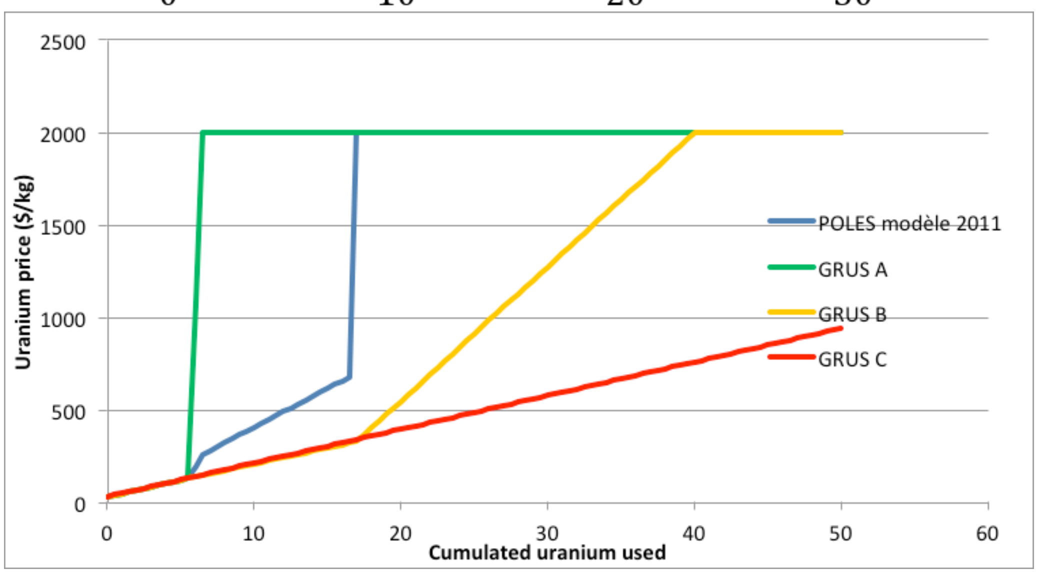


What lies beyond the little red book ?

At what speed could those (non conventional) resources be developed ?



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Phosphates.
But uranium contained in phosphate flows < 10kt Unat/y (cf AIEA, I-TESE).
Coal mines < 1kt/y
Others…

==> uranium price should become dependent on annual production volumes

Cost category	Conventional			Unconventional (minimum)
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	Total	co-product (%)		
Unassigned			5 609	7 260
<USD 260/kgU	7 635	28%	4 702	
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Low production rates : uranium cost= separation of uranium from raw material flows
High production rates (> primary co products), uranium price must cover most of mine costs

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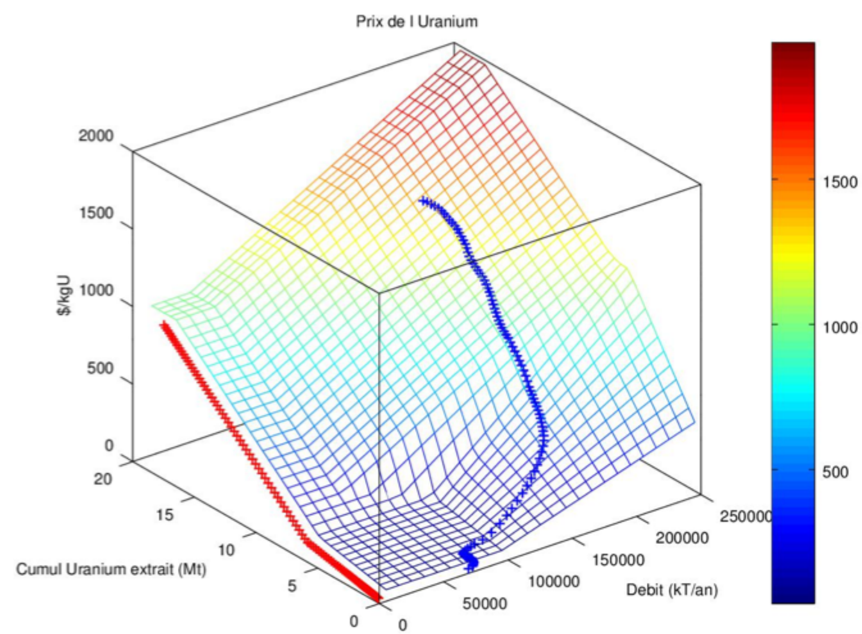

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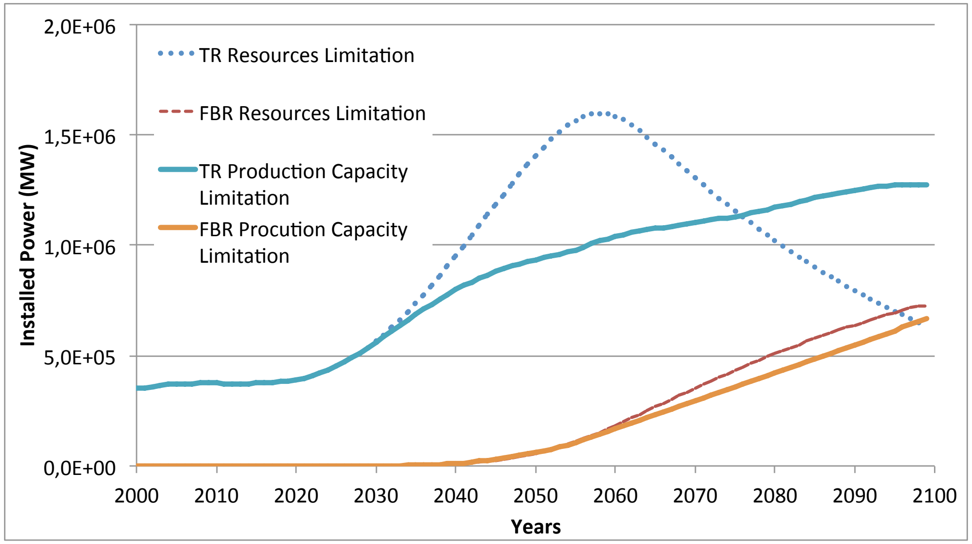

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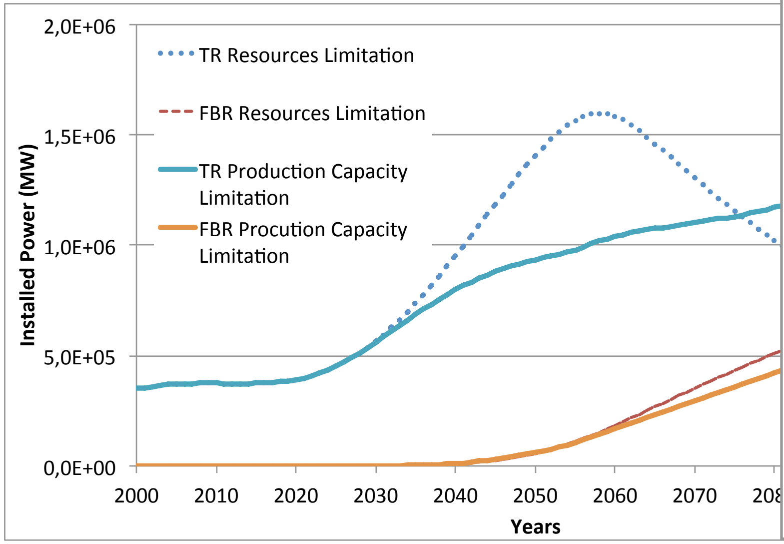

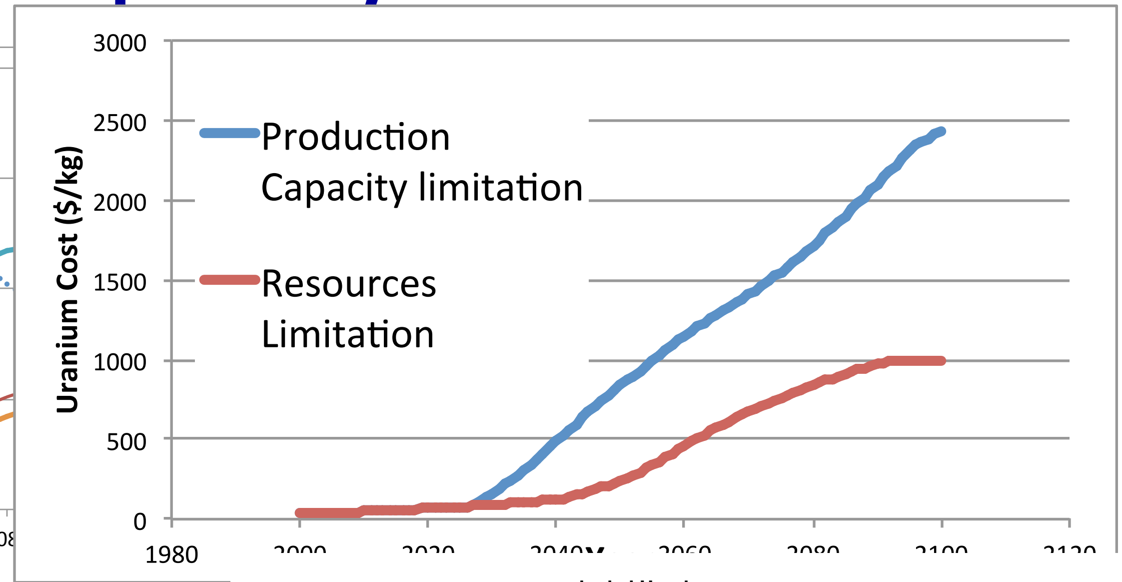

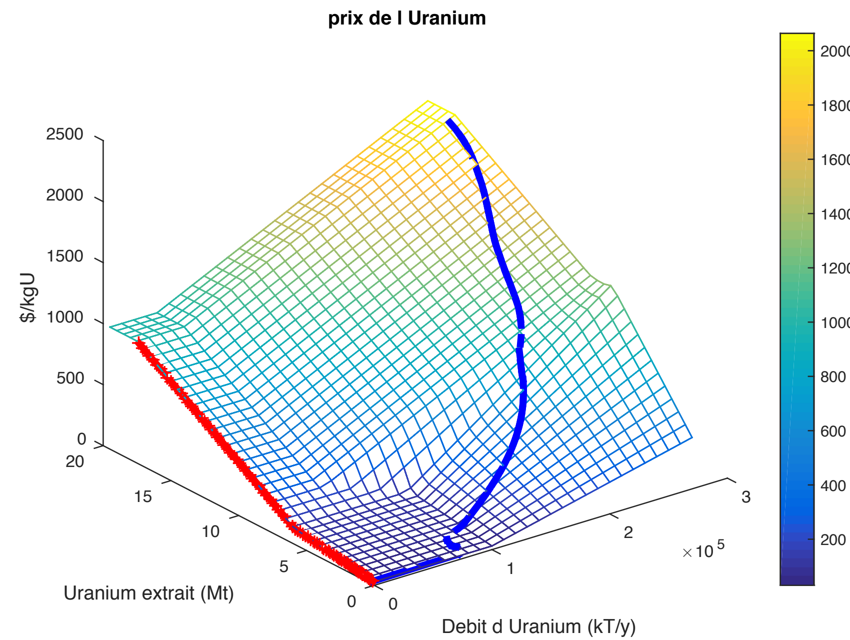

No more Uranium Peak

No Ultimate resources definition

- Higher Uranium costs
- Equivalent FR development

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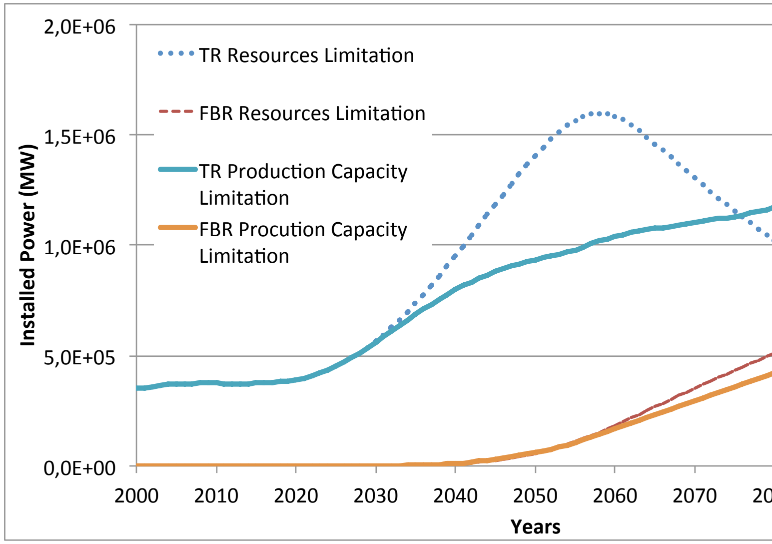

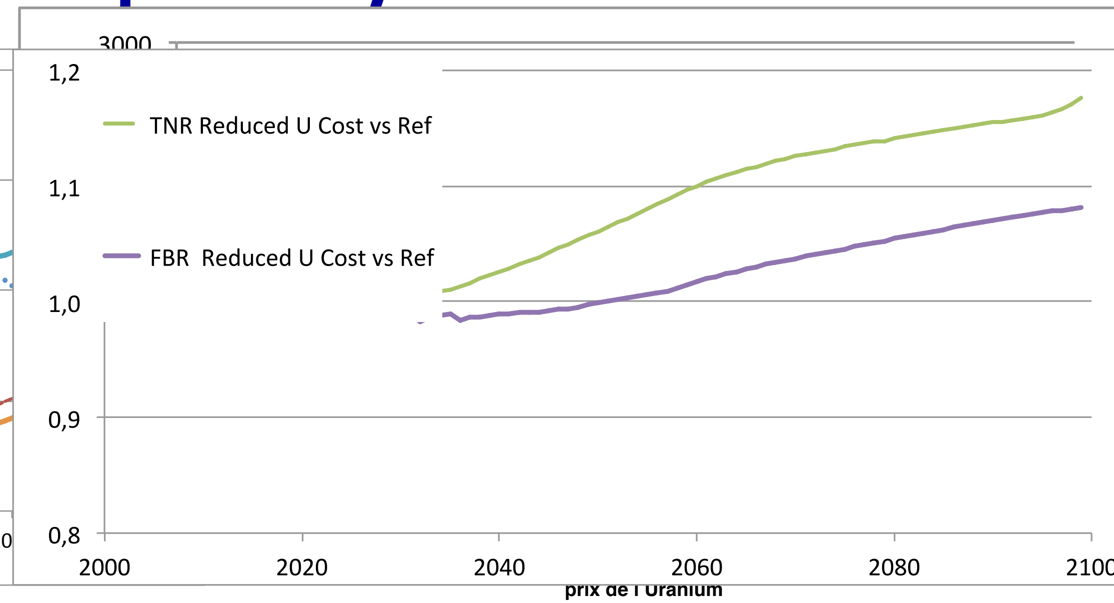

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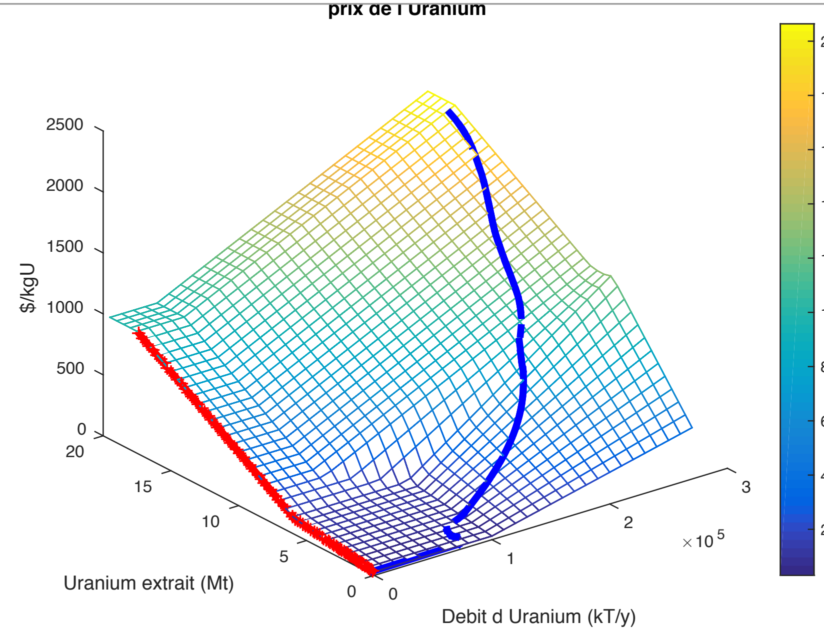
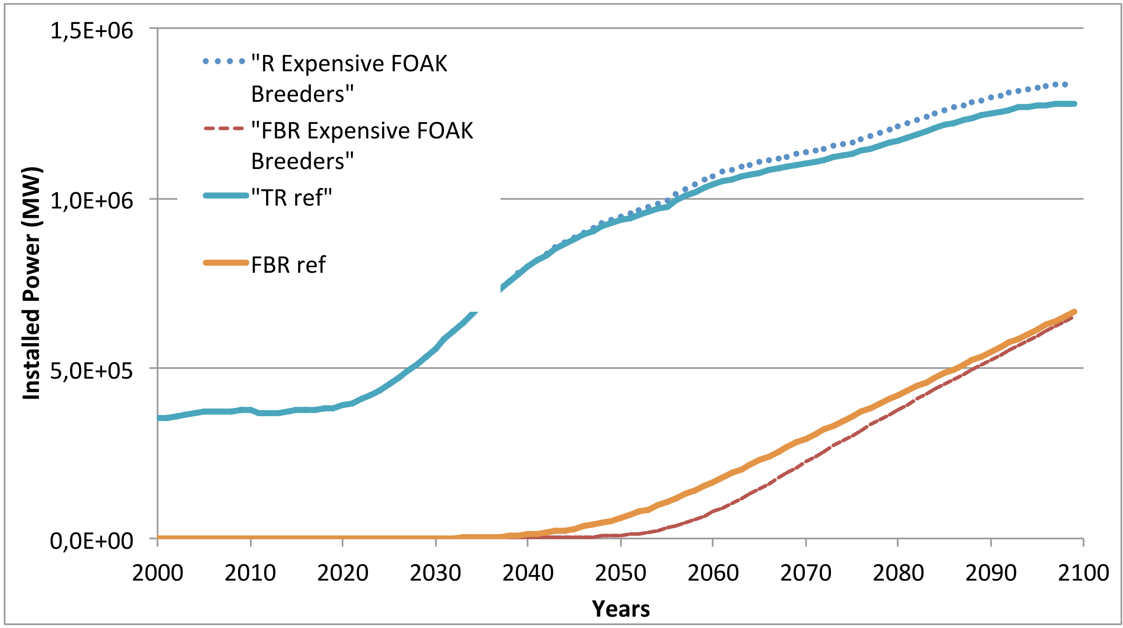
Reduced Uranium costs (-20%)

- Increase of TR
- Increase of FR !



Sensitivities to FR costs

- +50 % First Of A Kind (FOAK) Reactors costs
  - ➢ Delayed FR startup and equivalent long term deployment
  - ➢ Very late extra TR (learning curve effects)



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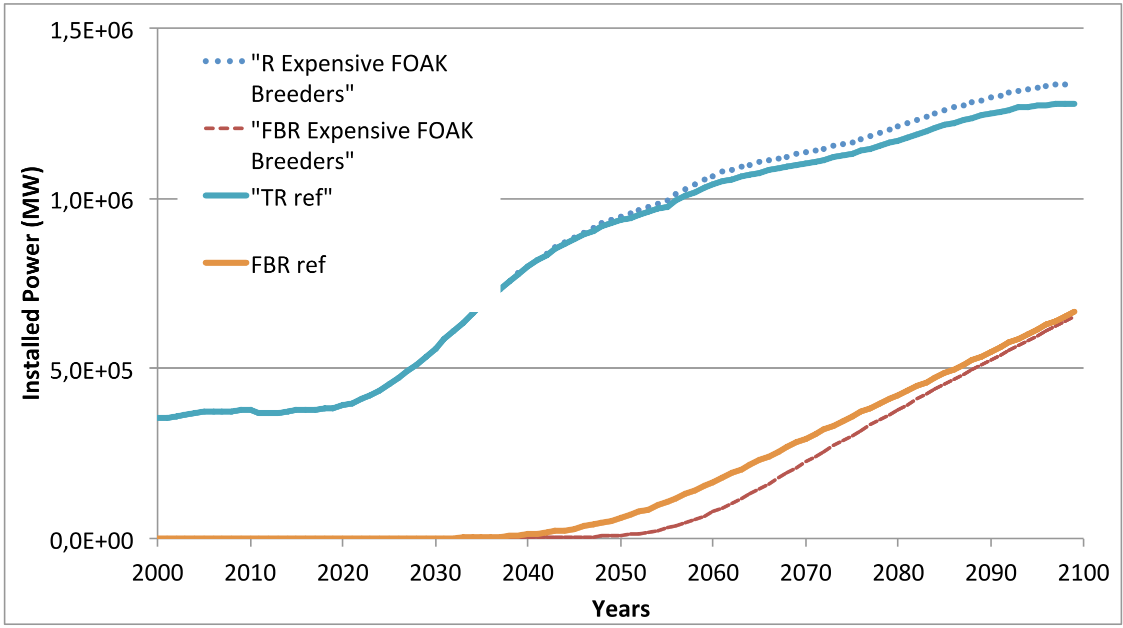

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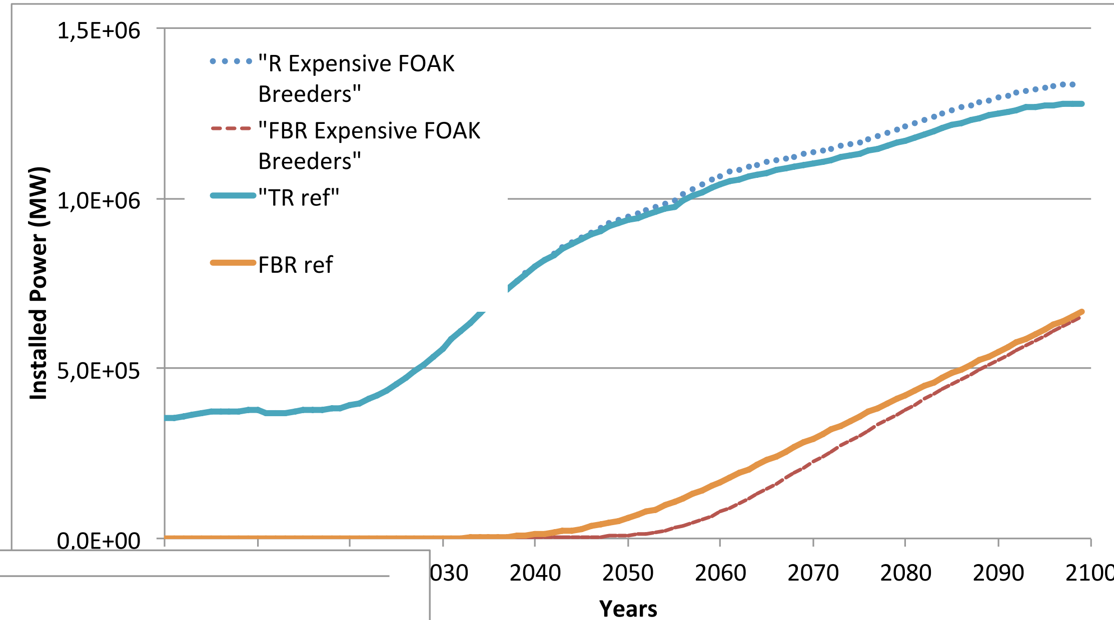
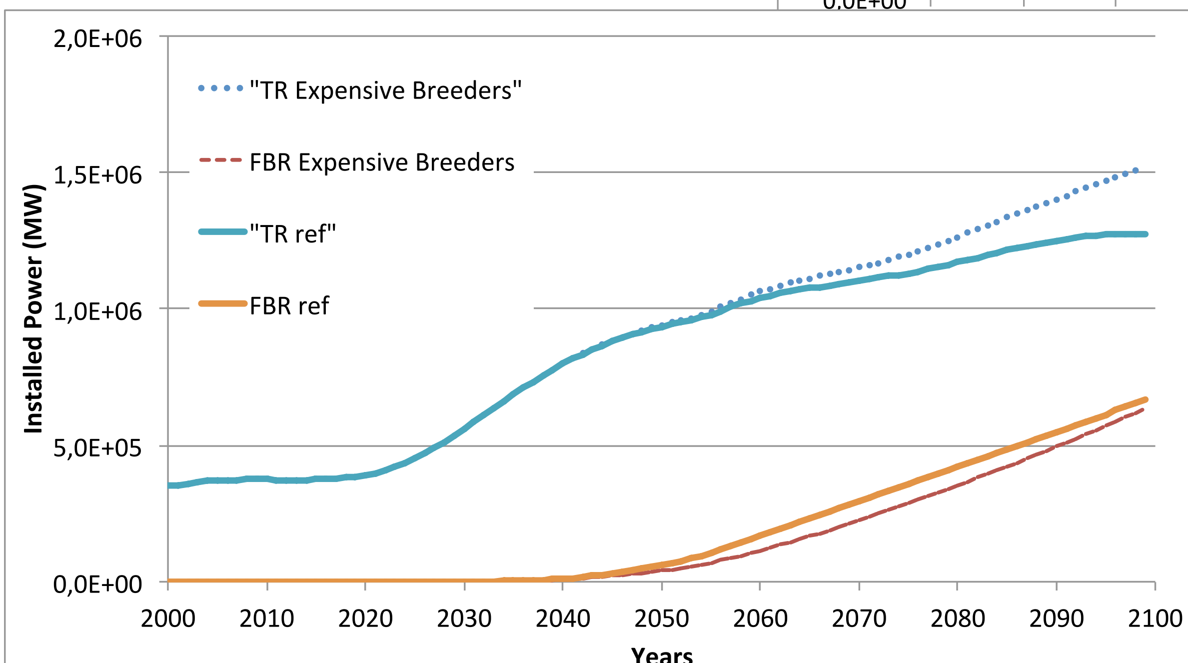
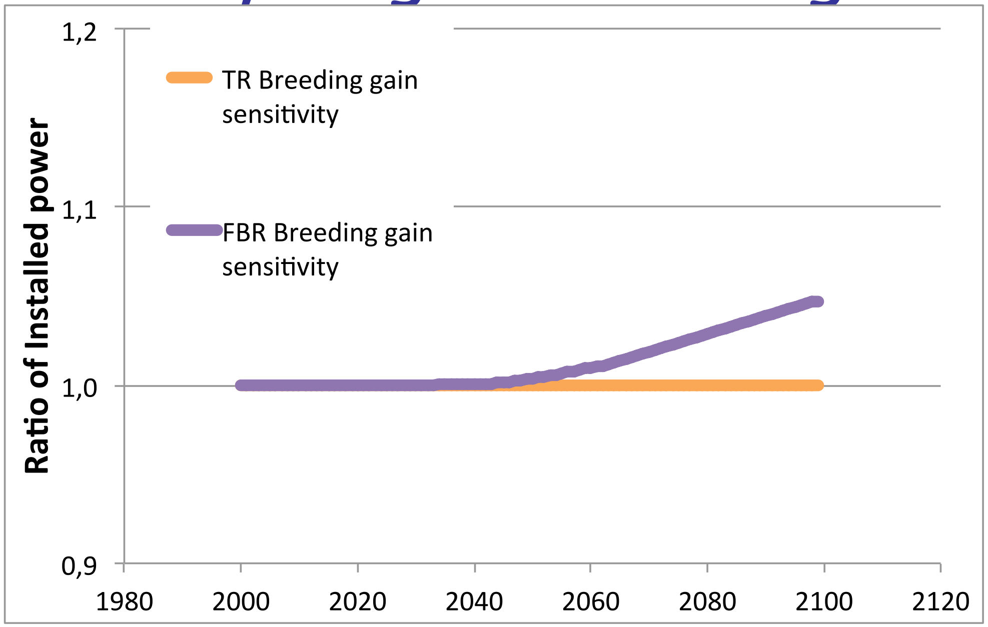




+30 % long term FR (floor costs)

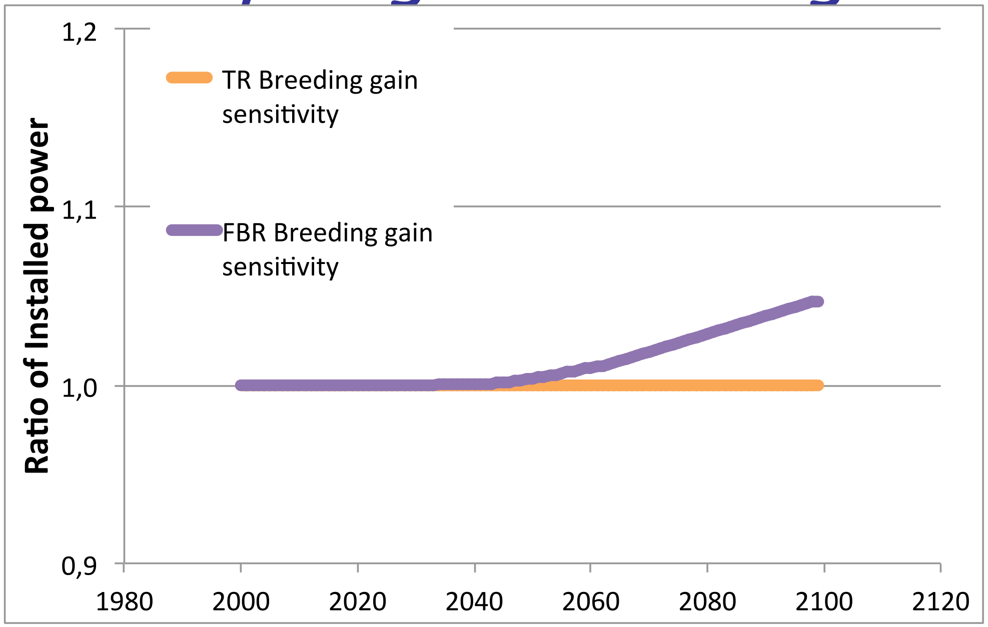
- Strong long lasting n reduction of FR deployment
- Very late extra TR

FR physical parameters and synergetic strategies



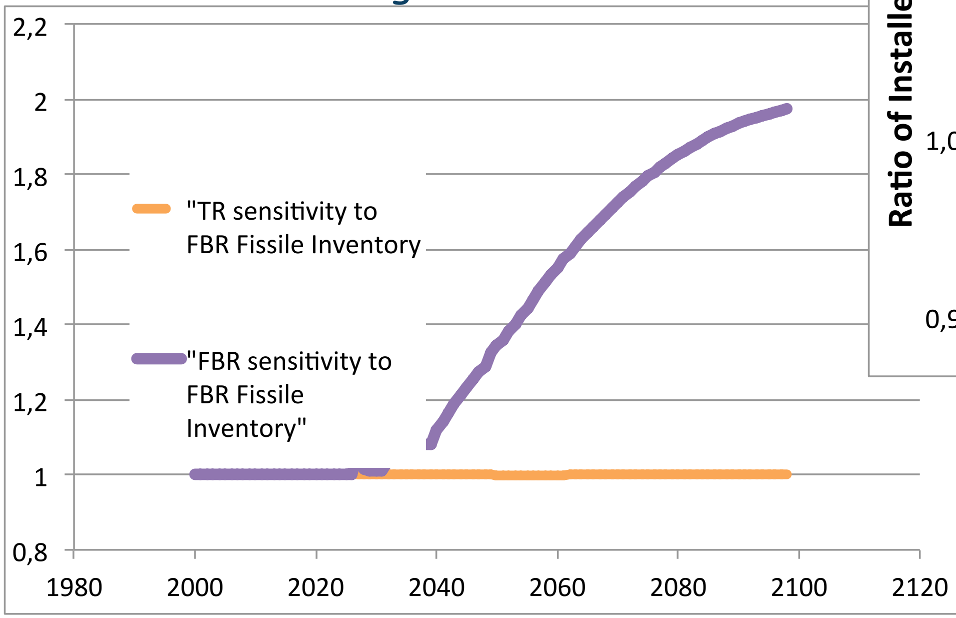
FR physical parameters and synergetic strategies

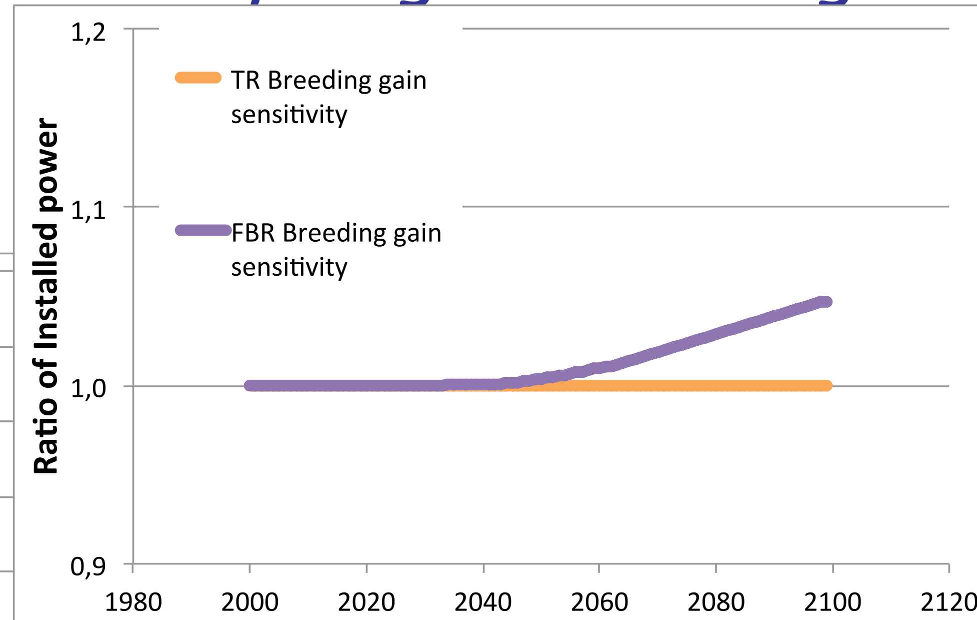
❖ FR initial inventory halved => FR doubled



FR physical parameters and synergetic strategies

- FR initial inventory halved => FR doubled
- Breeding gain + 5% => FR + 5 %
- TR almost unchanged





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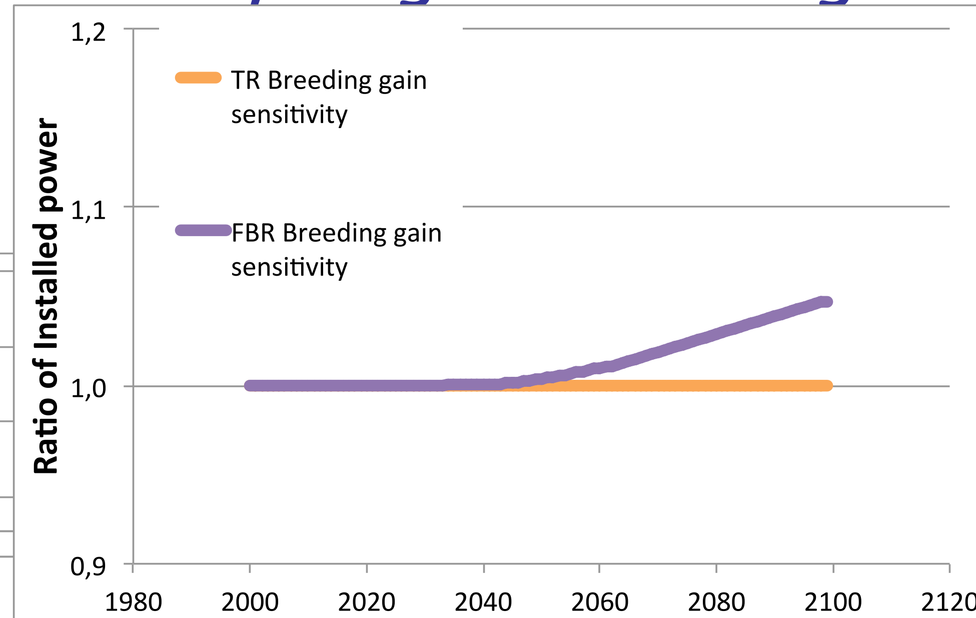

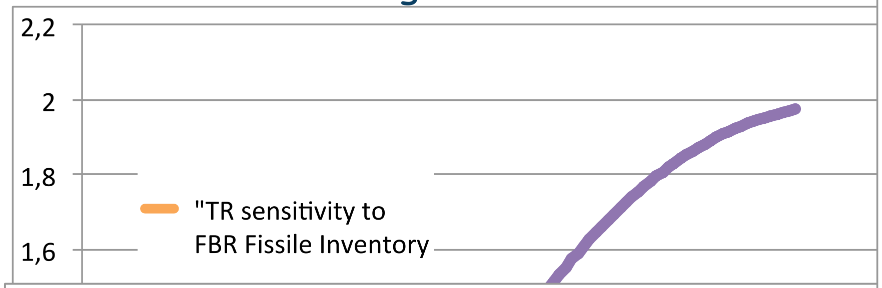

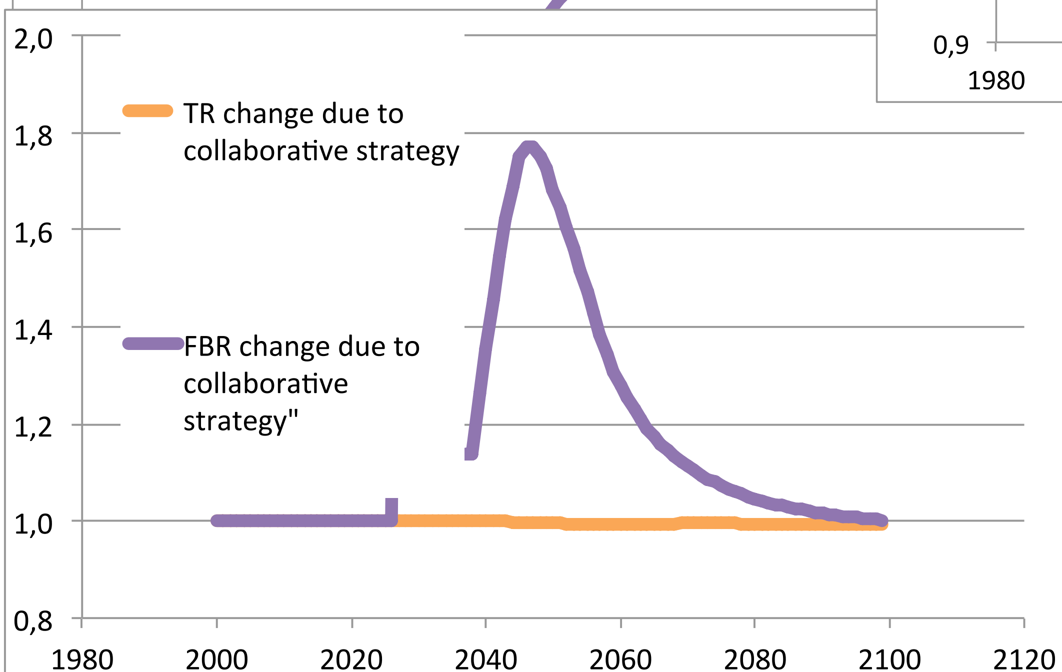

- Synertic scenario : FR have access to a « world TR used fuel bank »
- FR growth rate almost doubled during early deployment phase
- TR almost unchanged

Nuclear Generations fight together ?

Nuclear Generations fight together ?

Investment = f(LCOE)

- Nuclear (New build > 60%)
- Variable Renew (80-100 %)

LCOE = Levelized Cost of Electricity

Nuclear Generations fight together ?

Investment = f(LCOE)

Nuclear (New build > 60%)

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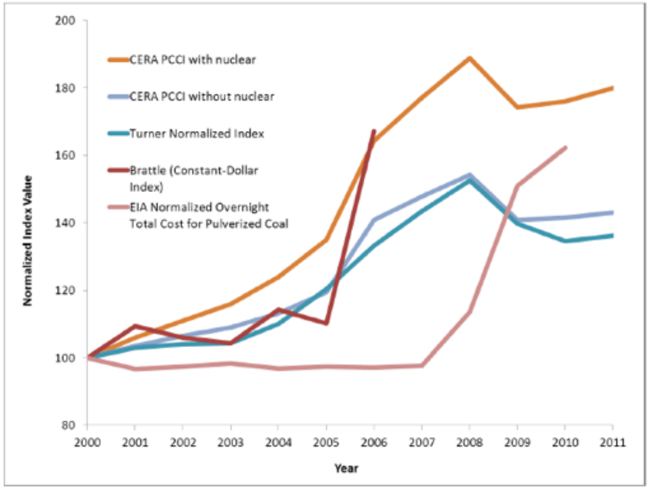
Union of Concerned Scientits



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Note: We used a GDP deflator to express all indices in constant dollars.

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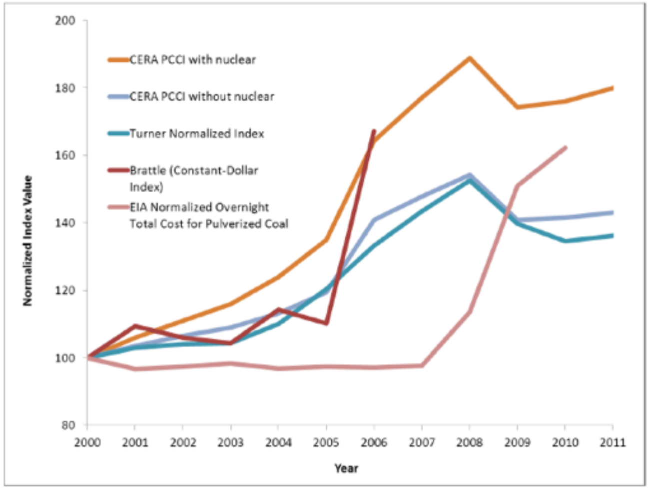

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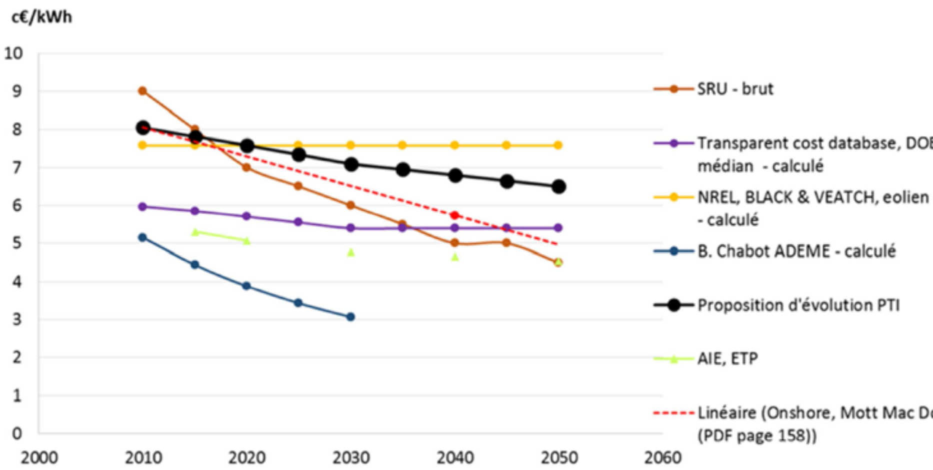

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Expected evolution of Wind energy LCOE ADEME 100% renewable scenario study (2015)

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Operation based on marginal cost

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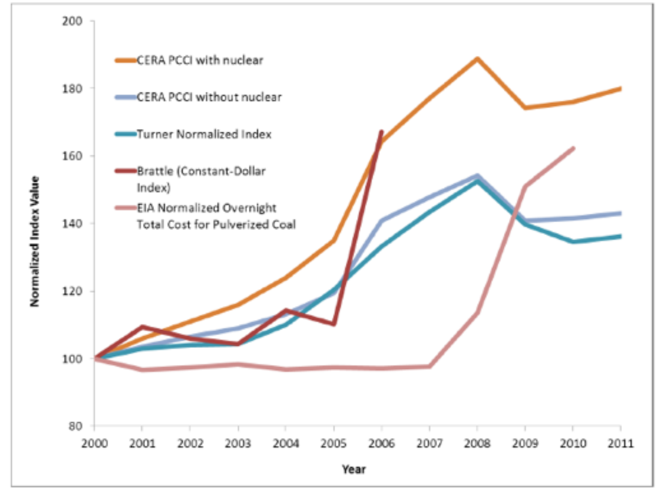
Union of Concerned Scientits



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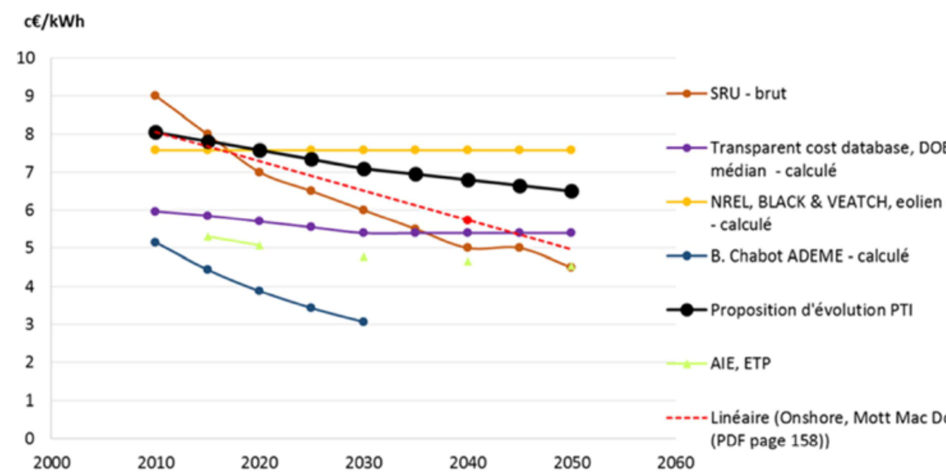

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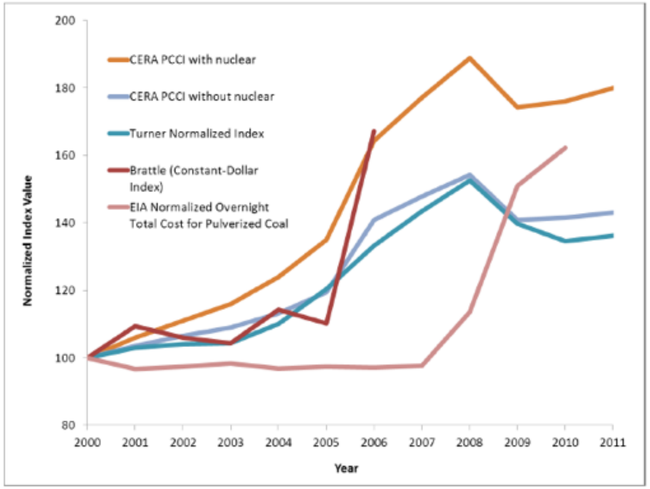
Even without priority access, new renewables may force base load techs like nuclear, out of the market

Union of Concerned Scientits



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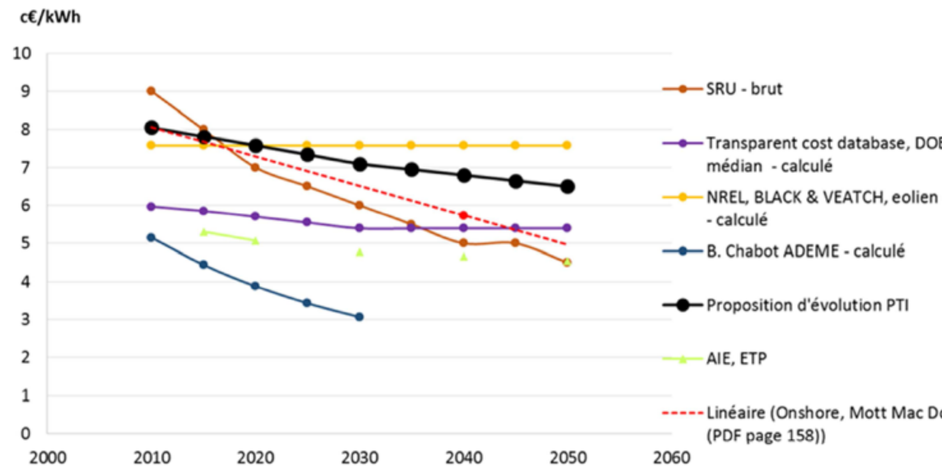

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Expected evolution of Wind energy LCOE   ADEME 100% renewable scenario study (2015)

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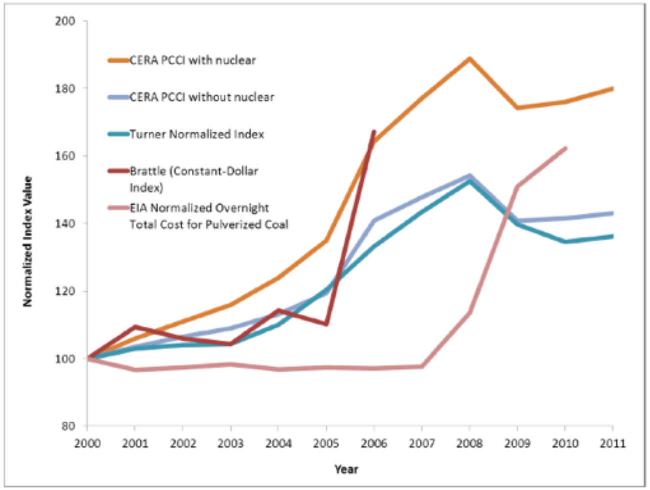
Even without priority access, new renewables may force base load techs like nuclear, out of the market

(at least for some sunny / windy hours)

Union of Concerned Scientits



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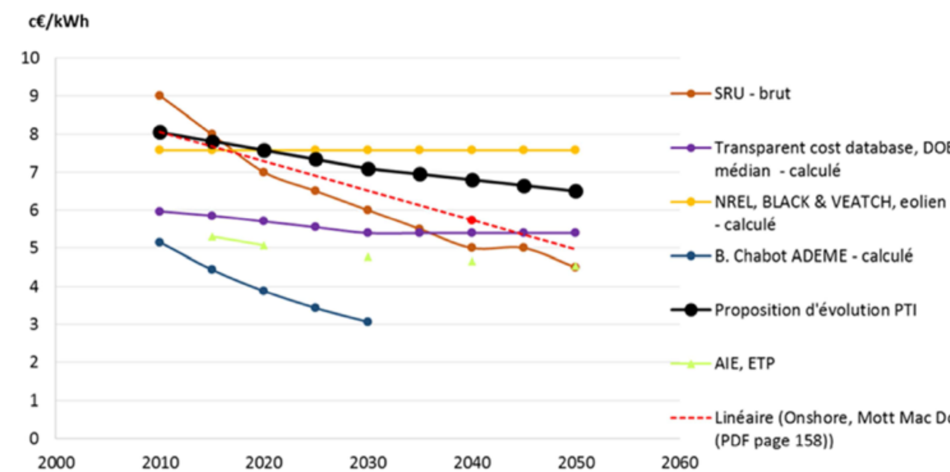

LCOE = Levelized Cost of Electricity

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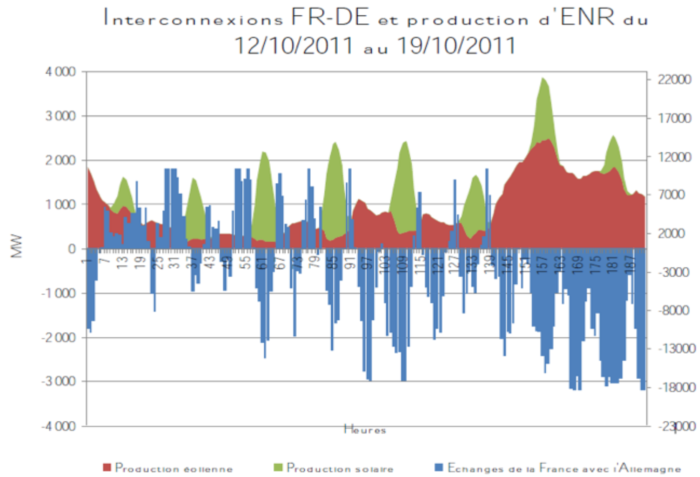
Nuclear Load Following capacity

Nuclear Load Following capacity

- Dispachable units need to cope with variable demands and renewable productions at ALL time scales (season, week, day, hours, minutes, seconds)
- Large interconnections are helpful



RTE (French TSO) 2014 Annual report

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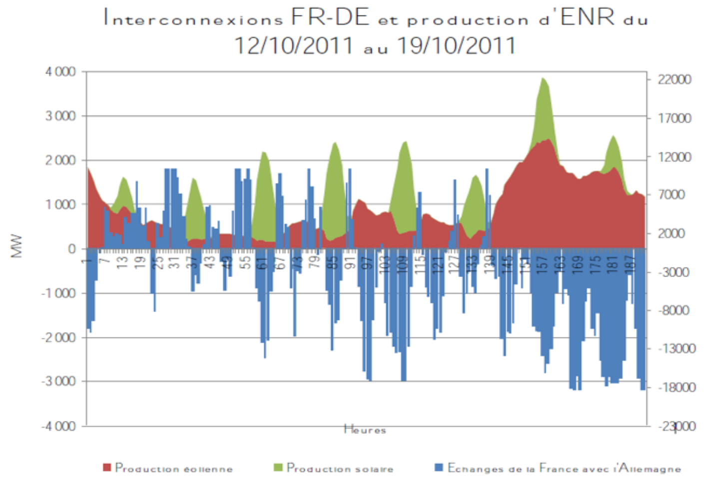
French Nuclear fleet do it !



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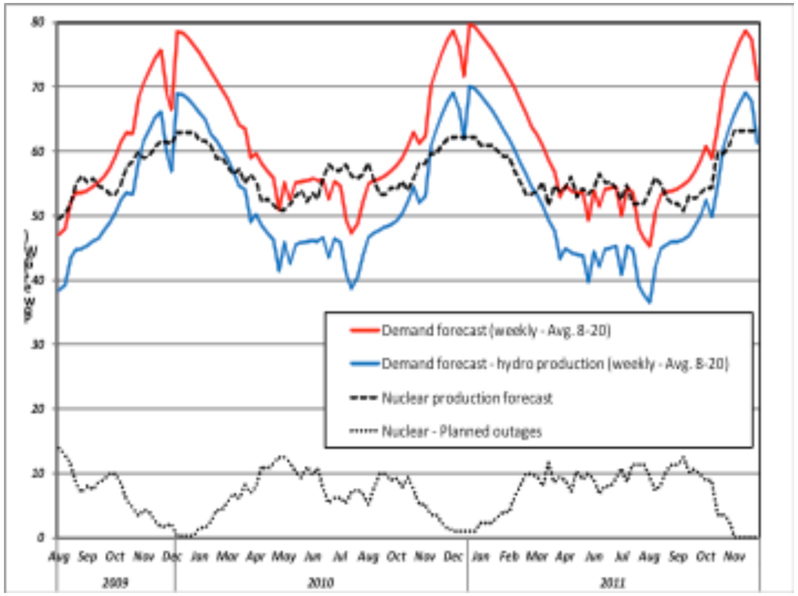

Fleet's seasonal adjustment to demand by adapted outage planning

OECD NEA Nuclear and Renewables

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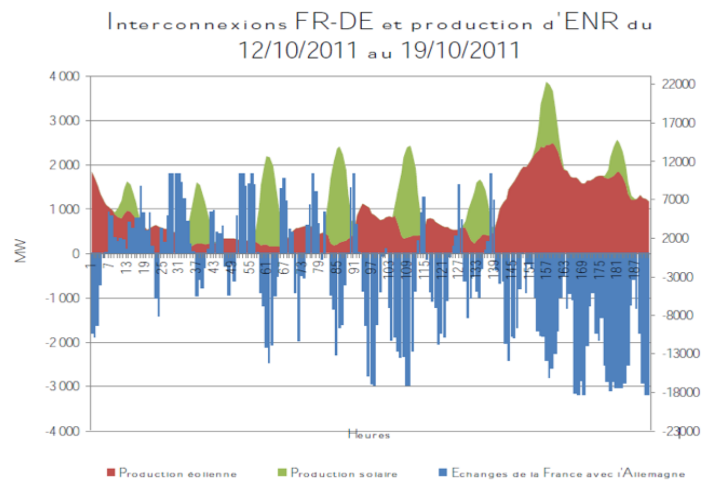

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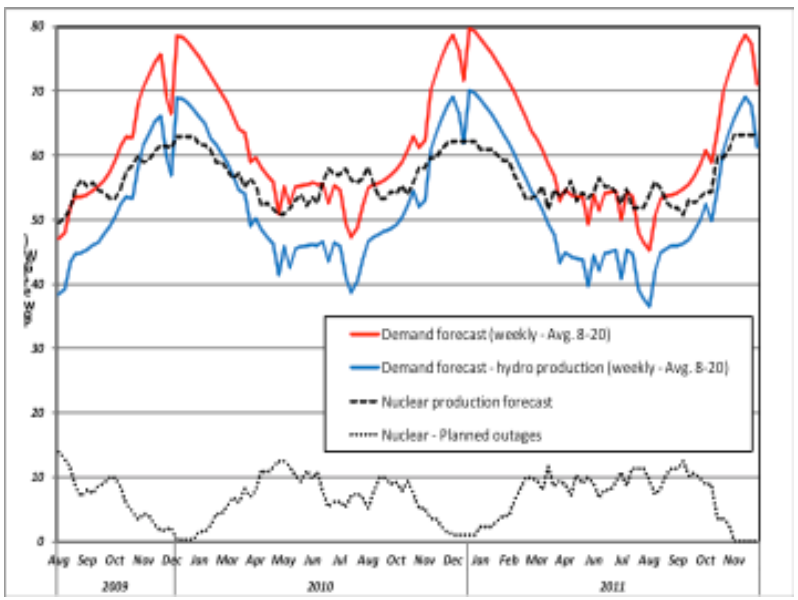

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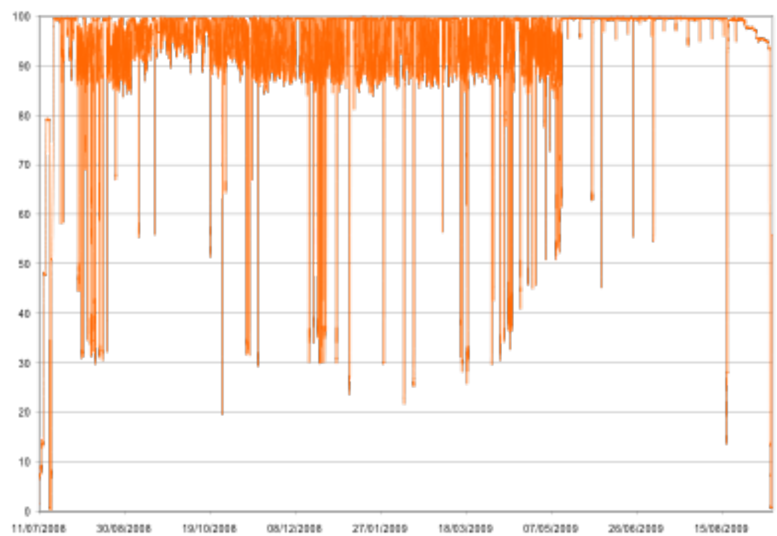

1 NPP production history

OECD NEA Nuclear and Renewables

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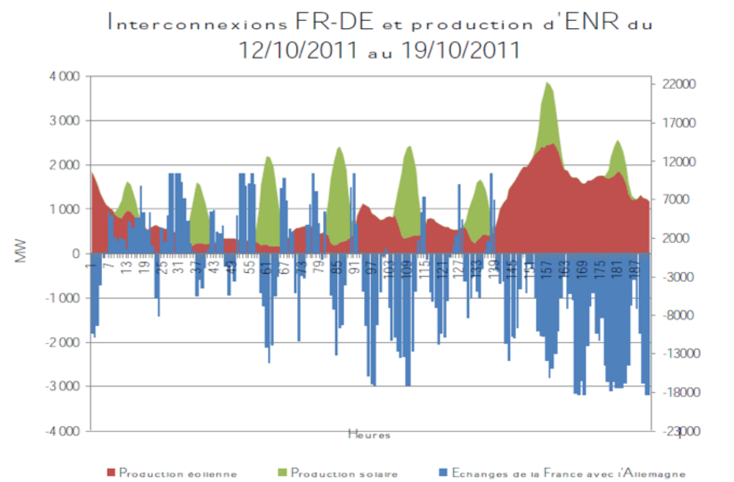

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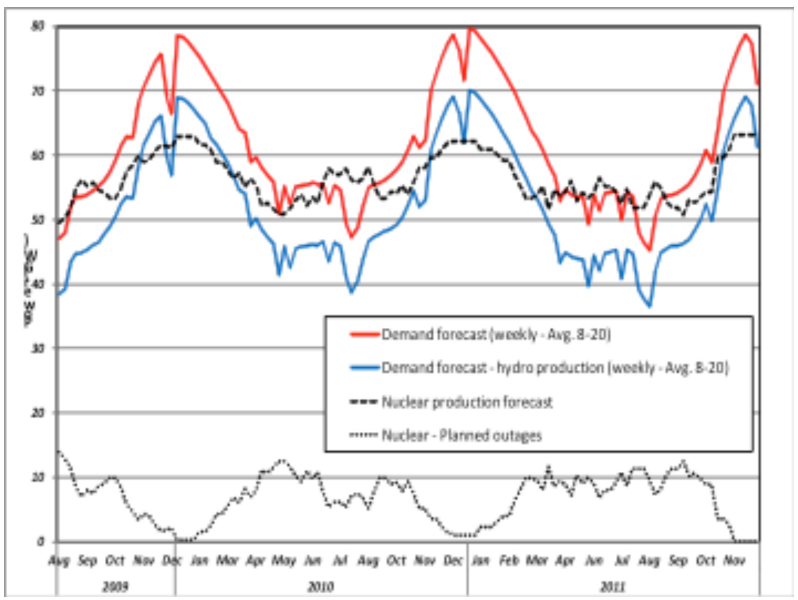

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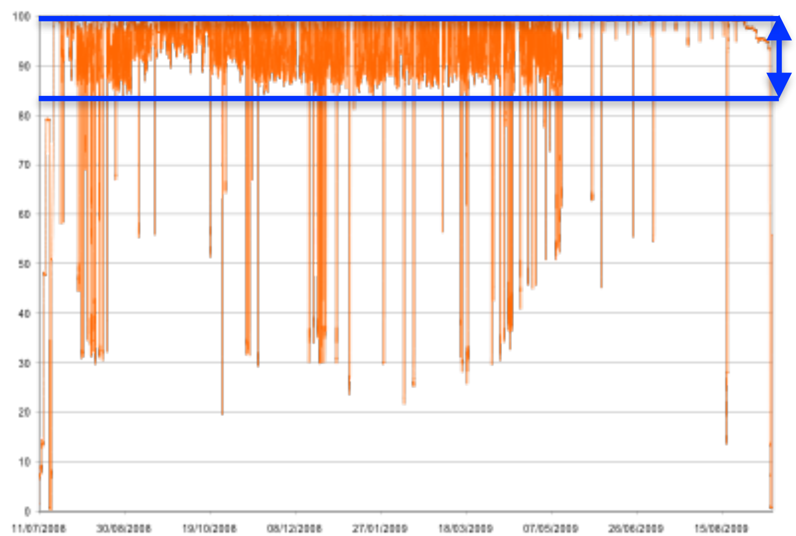

+- 7%
Frequency control
rotating reserve

1 NPP production history

OECD NEA Nuclear and Renewables

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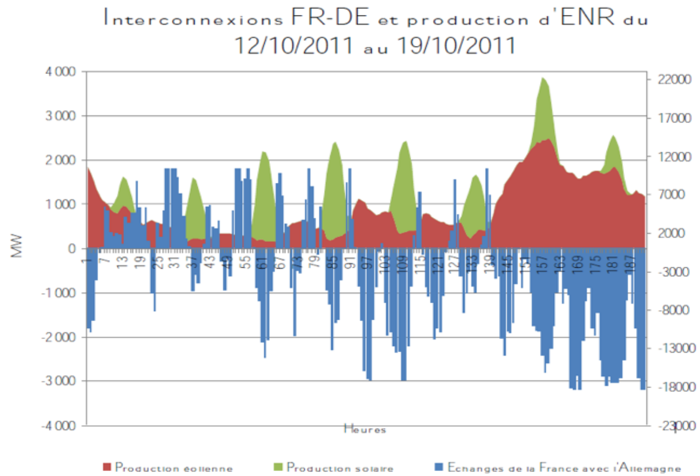

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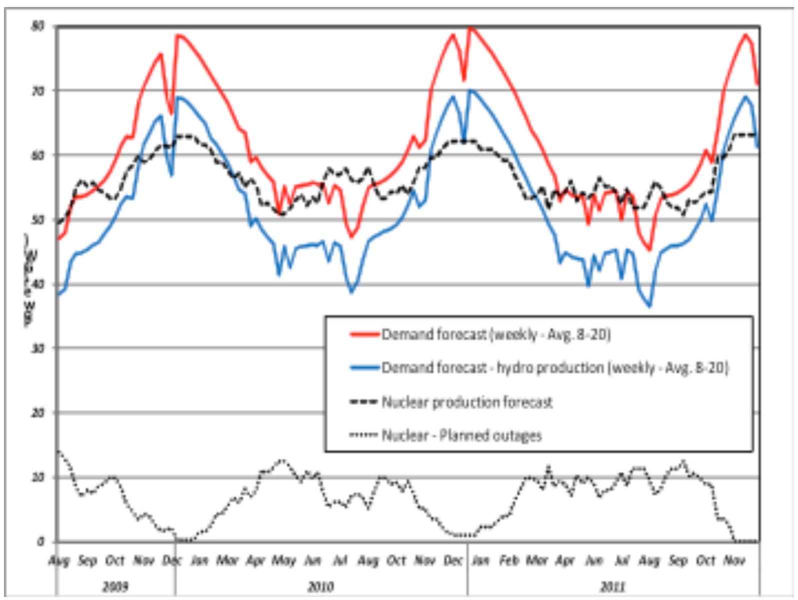
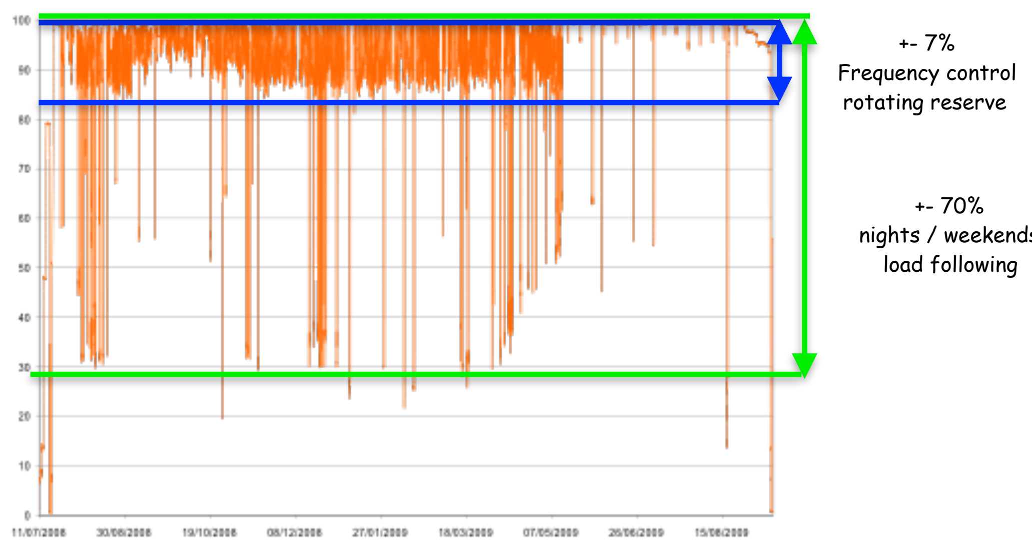


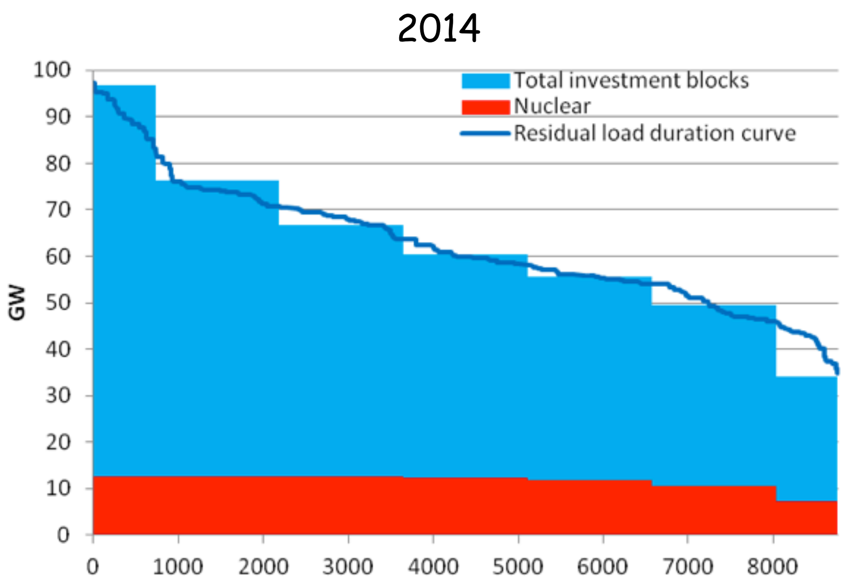


1 NPP production history

Fleet's seasonal adjustment to demand by adapted outage planning

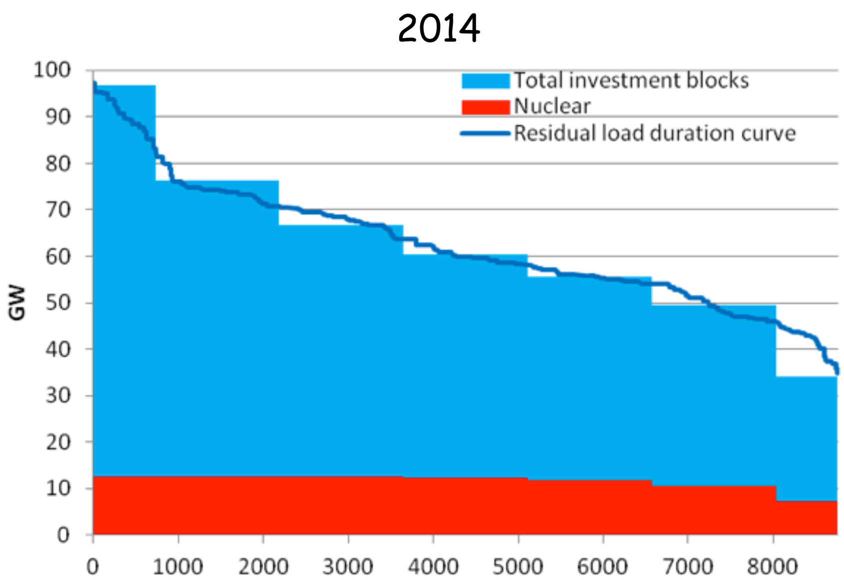
OECD NEA Nuclear and Renewables

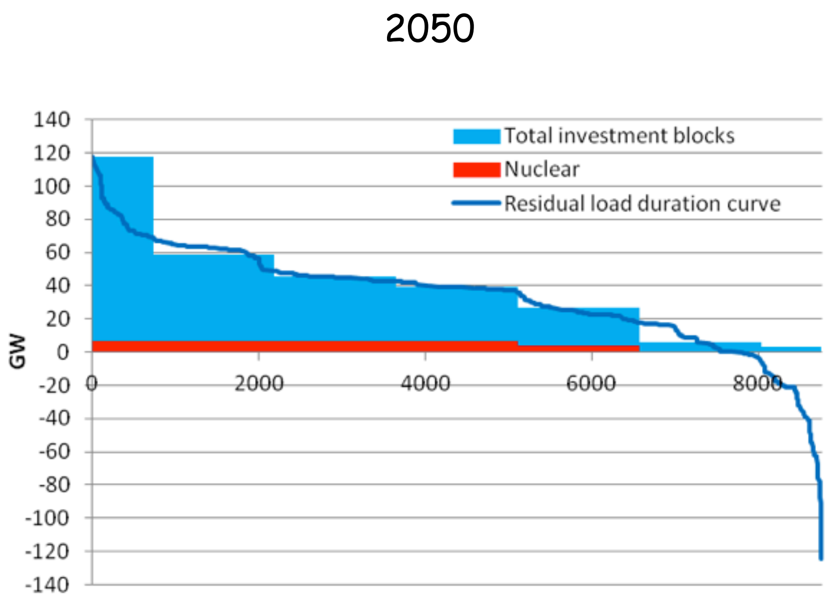
Duration curve evolution (ex : France)



Projected nuclear fleet reduced (higher construction costs now than in the 80's)

Duration curve evolution (ex : France)



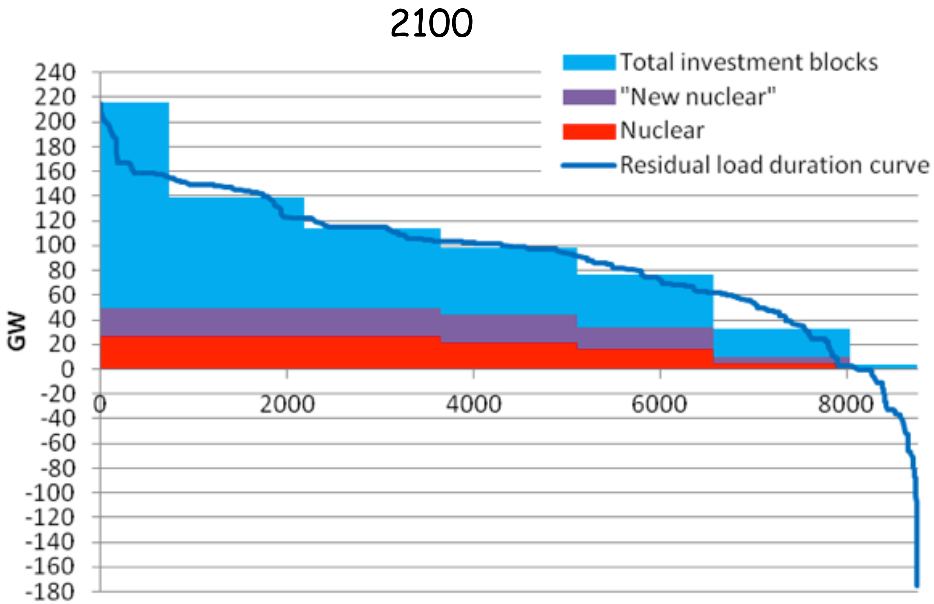


Projected nuclear fleet reduced (higher construction costs now than in the 80's)

Massive evolutions:

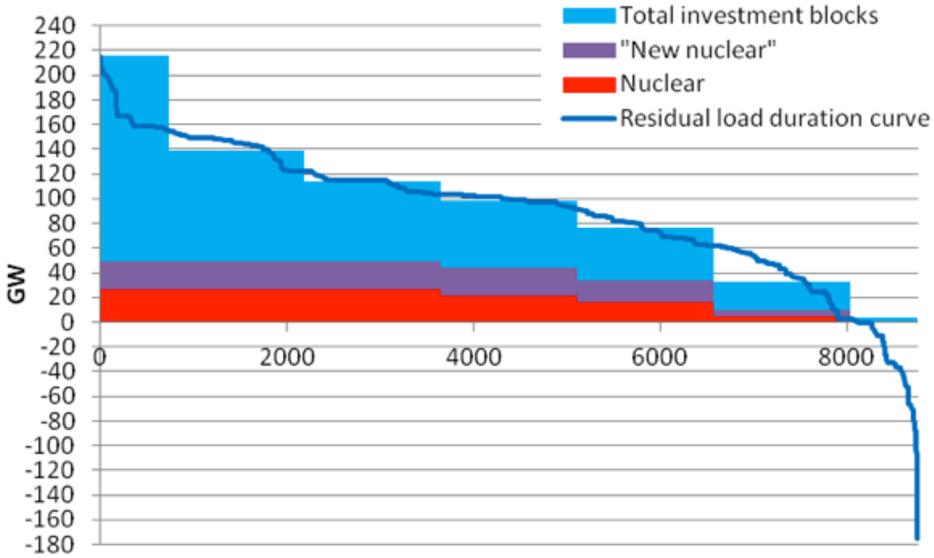
- disapearence of base load !
- increase in peak capacities (half the dispatchables)
- disapearence of Nuclear ?

Load following capacity extension



Load following capacity extension

2100

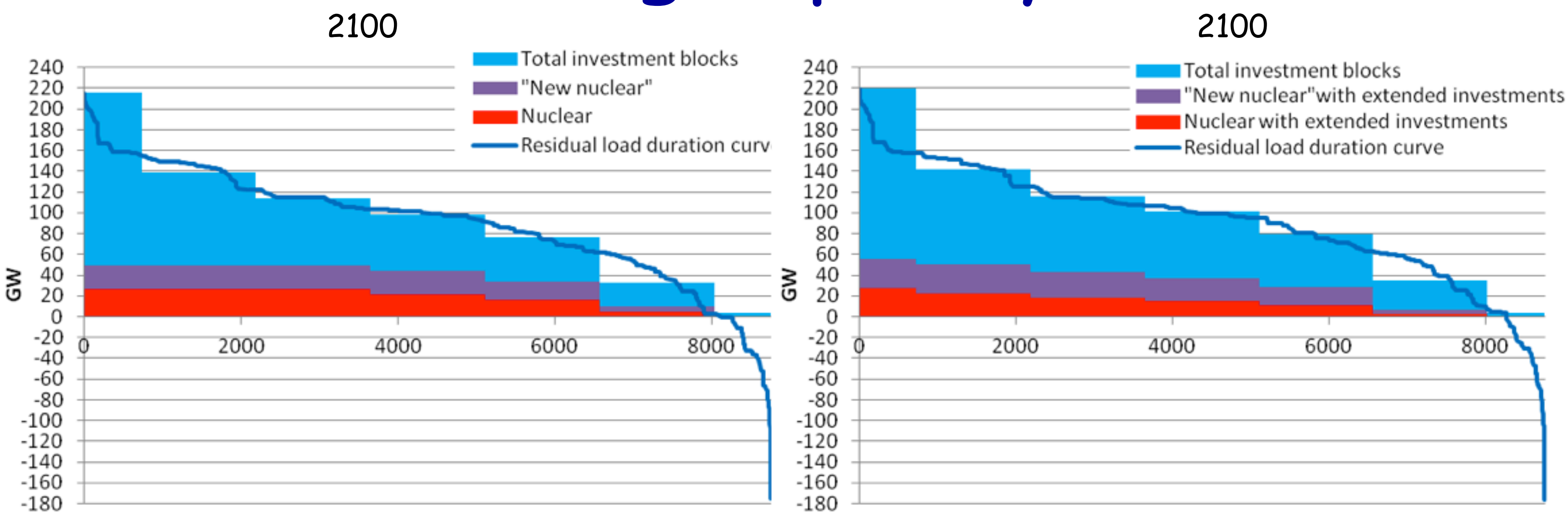


« Electricity is the future »

-> massive increase in global electricity consumption in 2100

-> need for dispatchable sources still very strong (incl. Nukes)

Load following capacity extension



« Electricity is the future »

-> massive increase in global electricity consumption in 2100

-> need for dispatchable sources still very strong (incl. Nukes)

-> If nuclear can contribute to lower hours investments blocks.
+10GW of nuclear capacity !

Scenario studies

Scenario studies

4 main scenarios

- No policy
- 2°C Climate policy
- Climate policy, No CCS
- Climate policy, No CCS, no new electricity storage

Scenario studies

4 main scenarios

No policy

2°C Climate policy

Climate policy, No CCS

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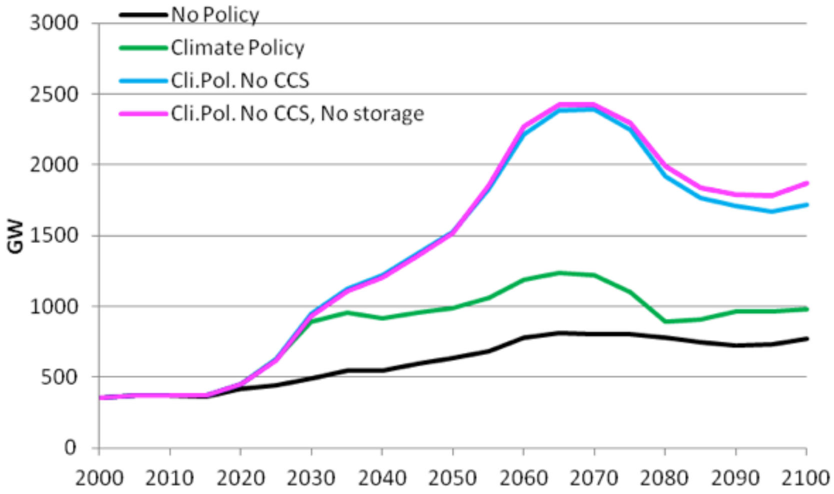

World nuclear installed power (WR + FR)

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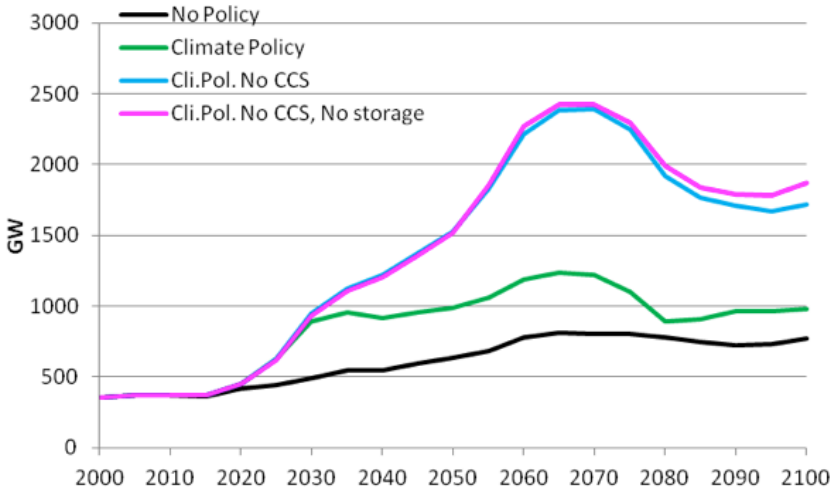

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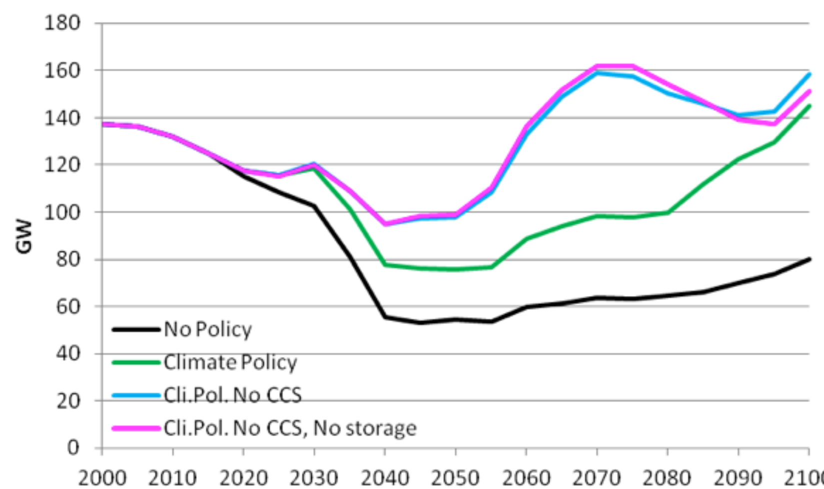

Europe nuclear installed power (WR + FR)

Country specific paths (« know your enemy »)

Scenario studies

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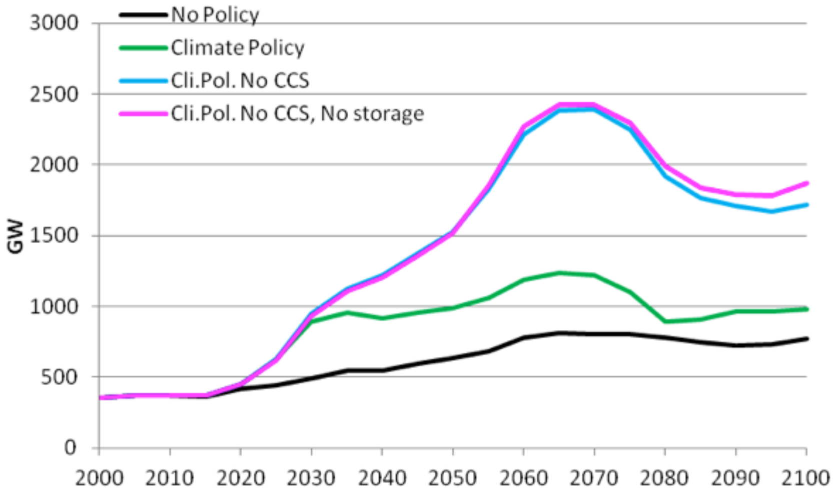

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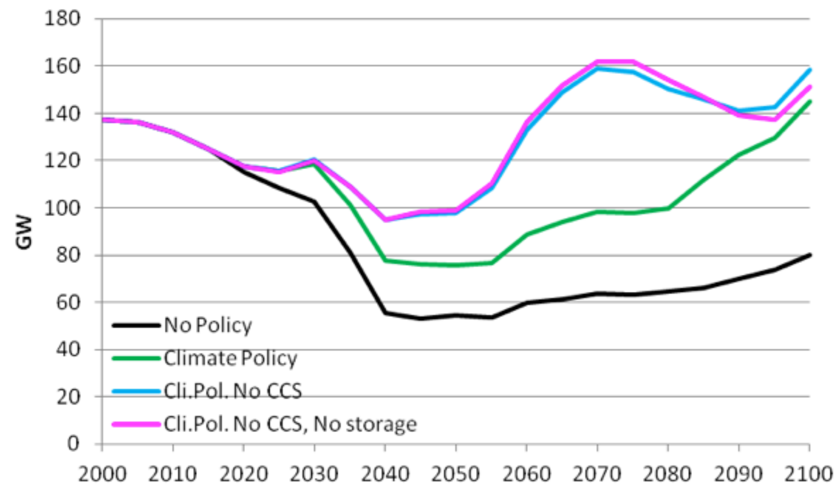

Europe nuclear installed power (WR + FR)

Country specific paths (« know your enemy »)

No « fixed » demand, strong sensitivity to learning curves

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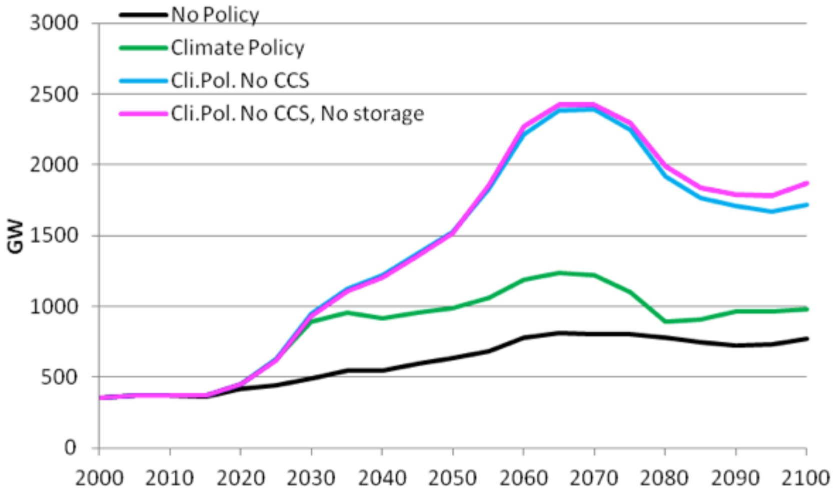

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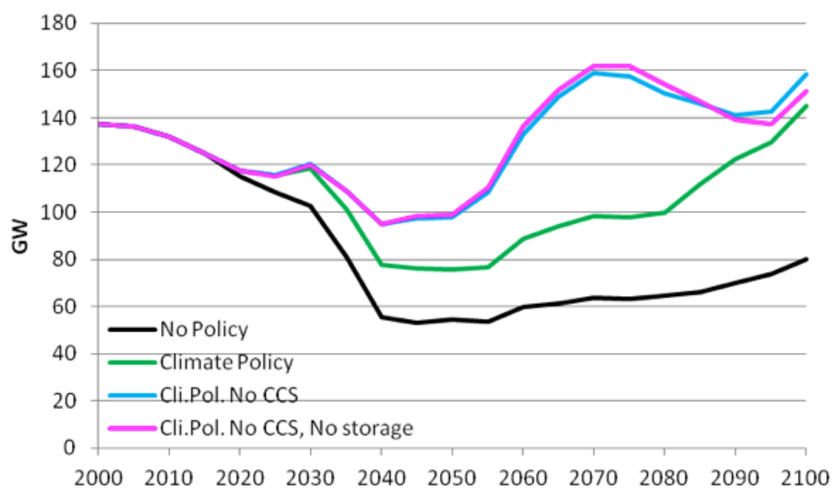

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Country specific paths (« know your enemy »)

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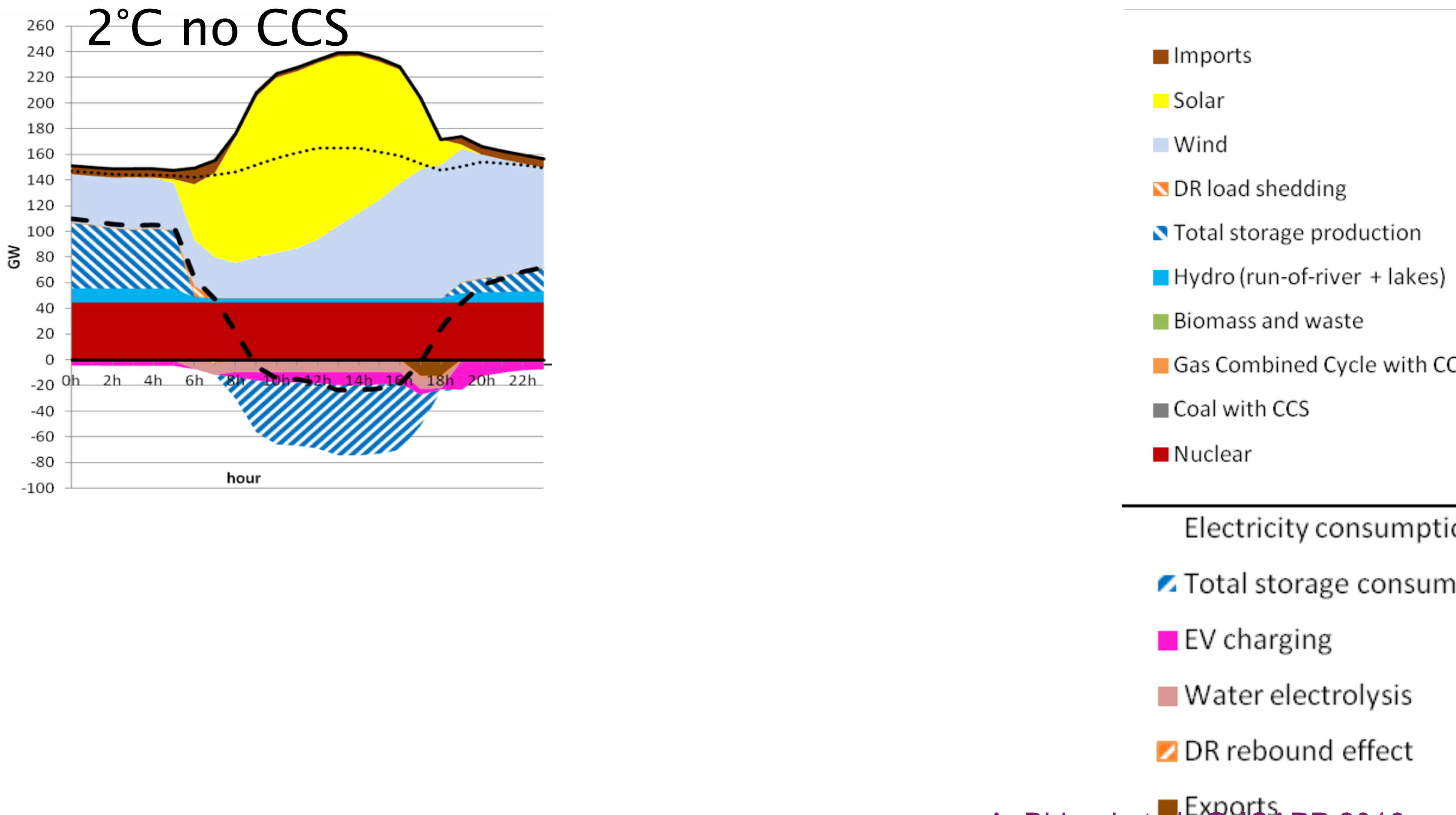
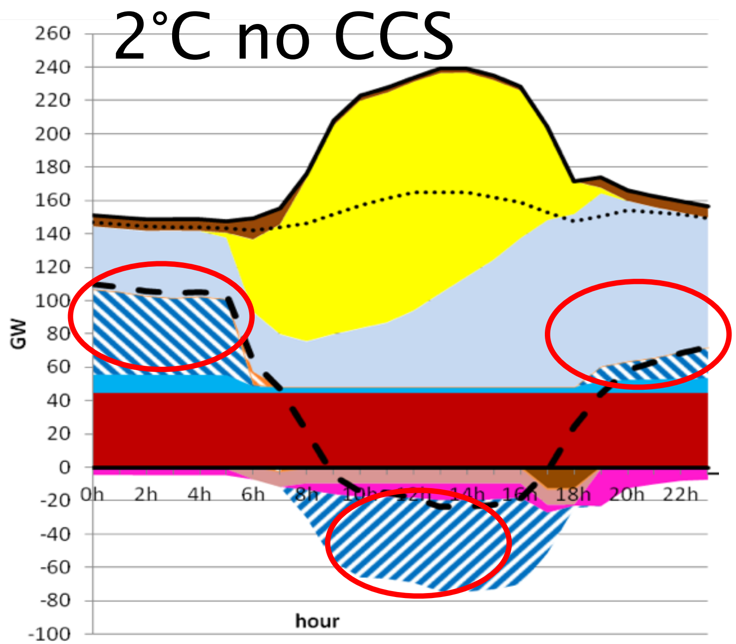
Uranium resources limits

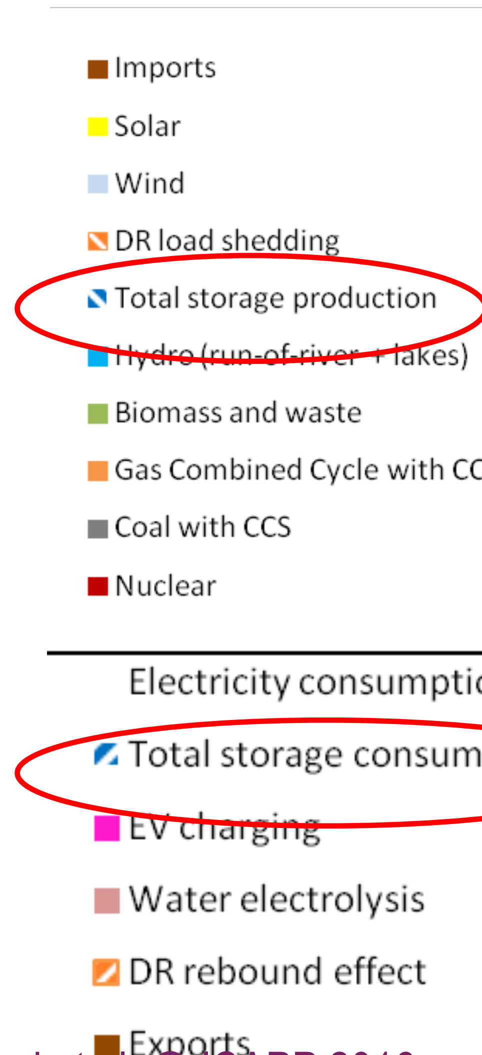
Typical daily profiles



A. Bidaud et al. @ ICAPP 2016

Typical daily profiles





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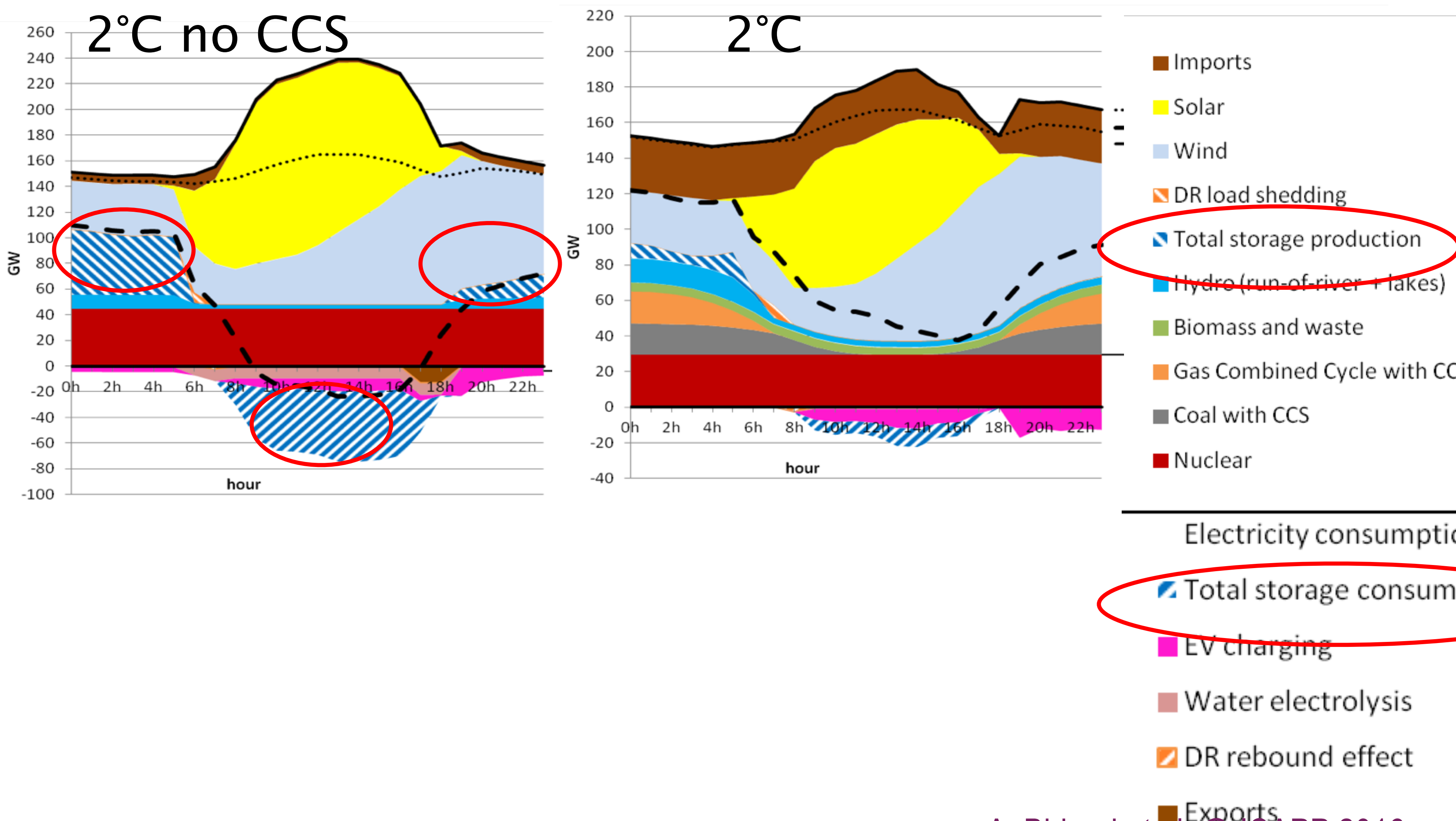

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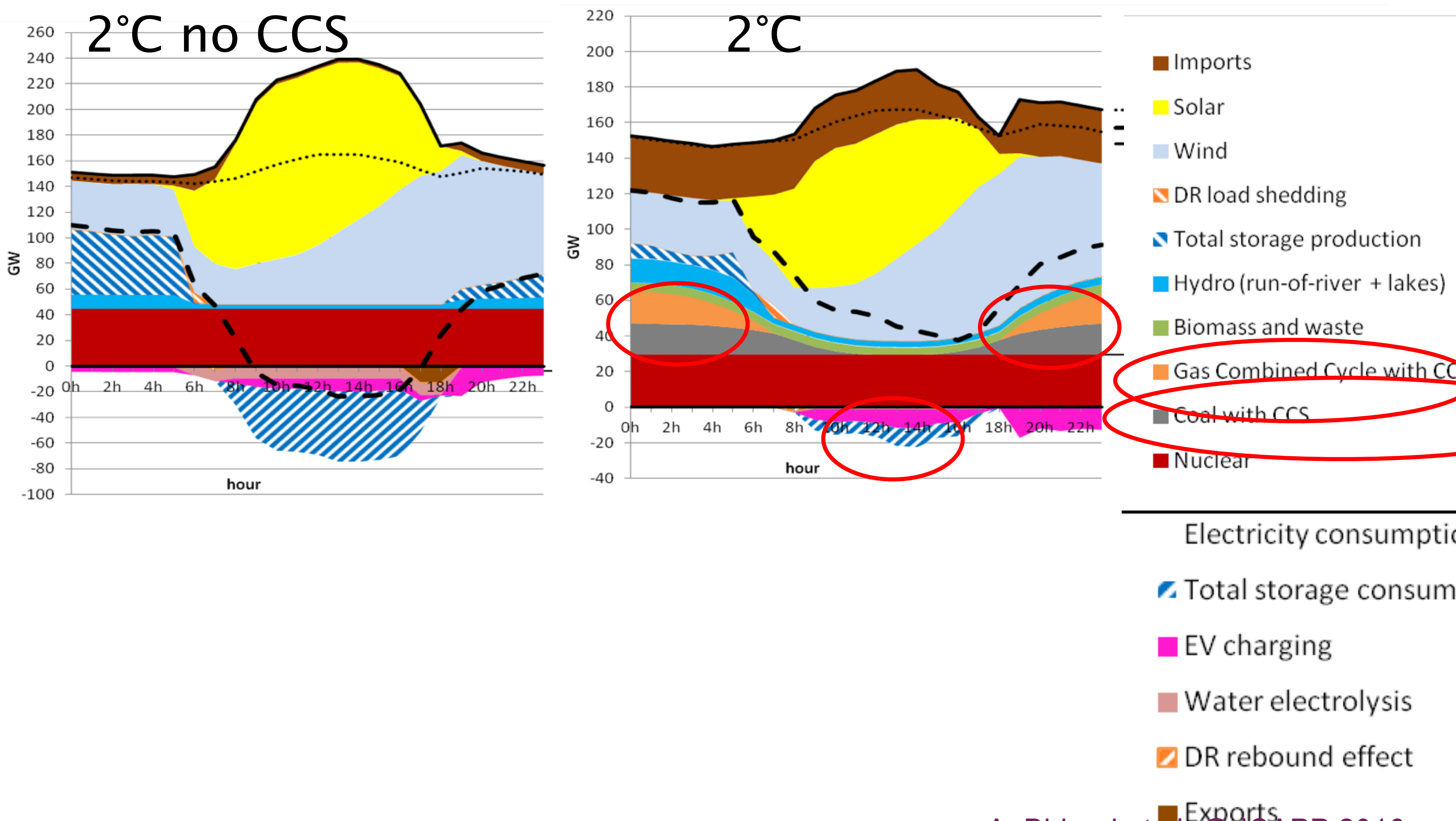

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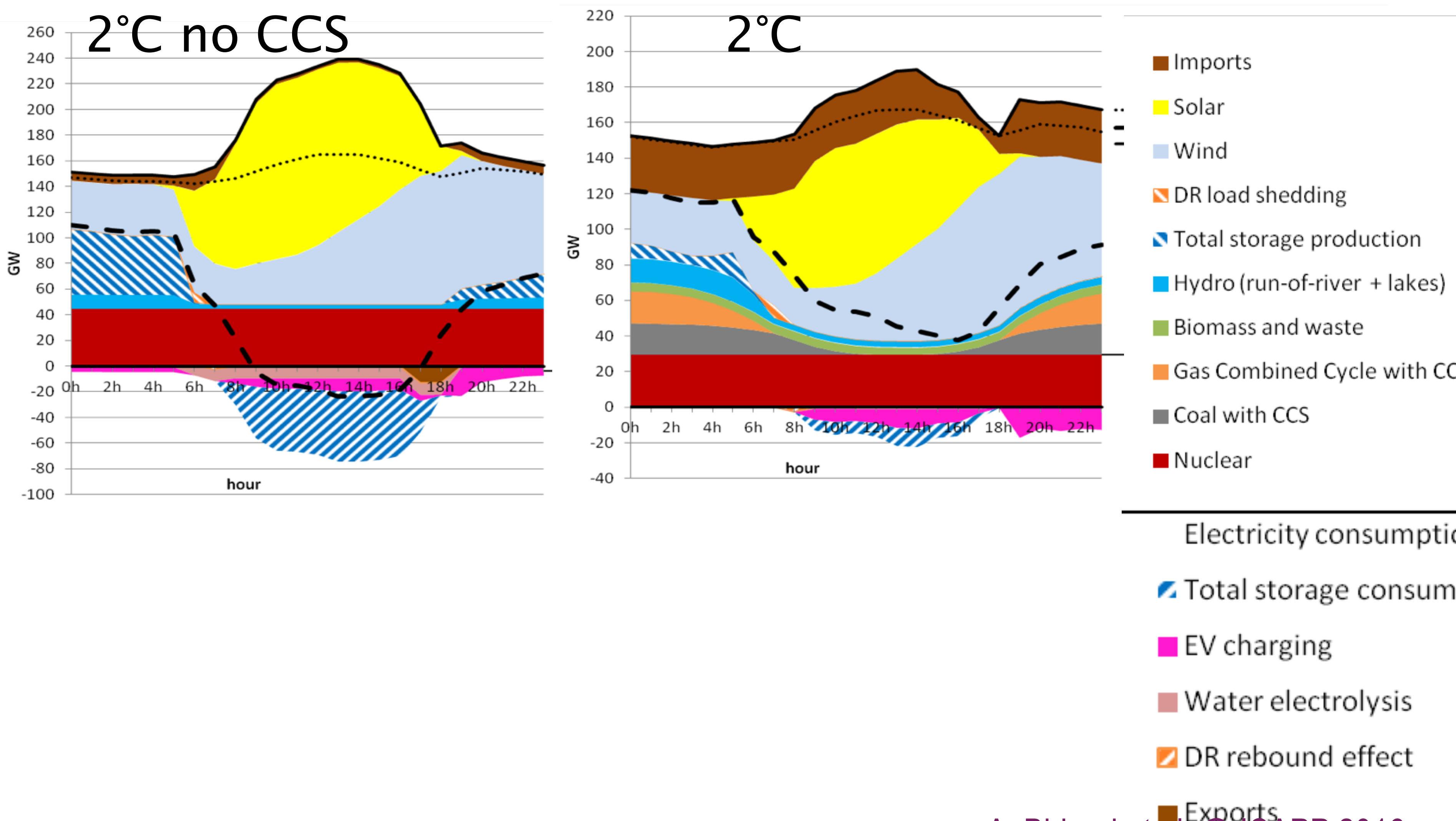

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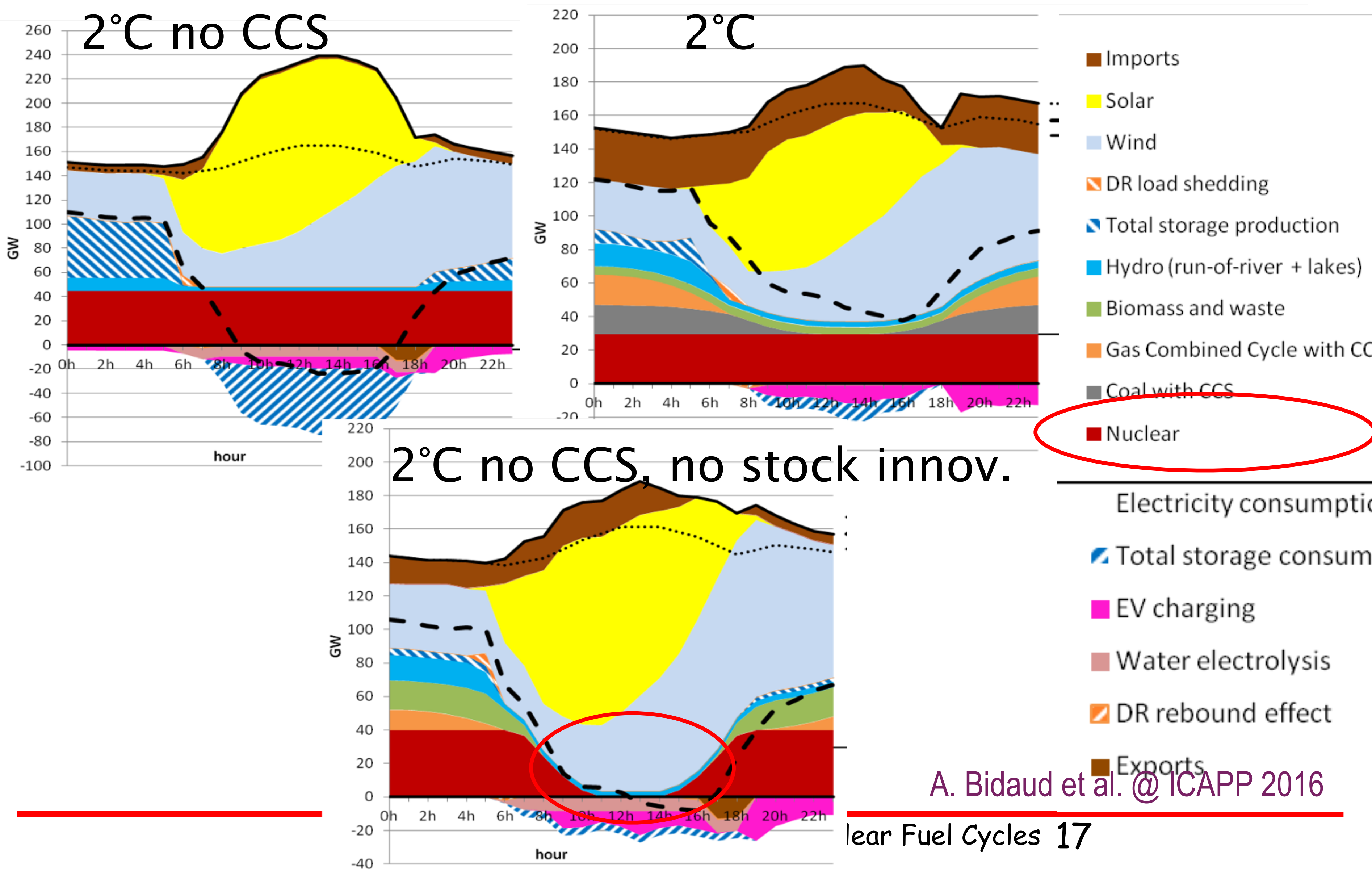

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Extension of Load Following Capacities

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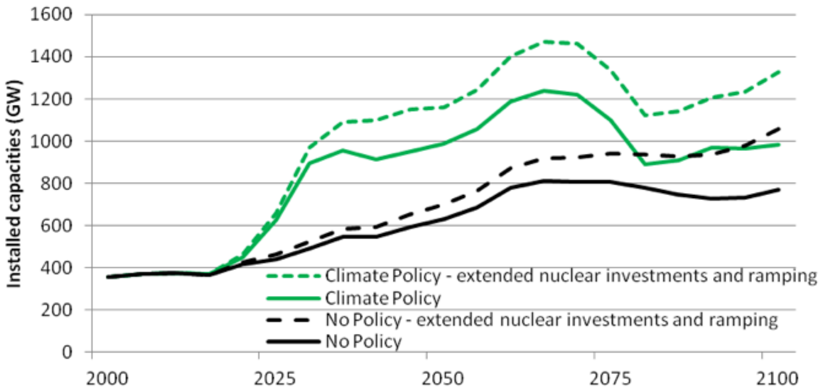

World nuclear installed power (WR + FR)

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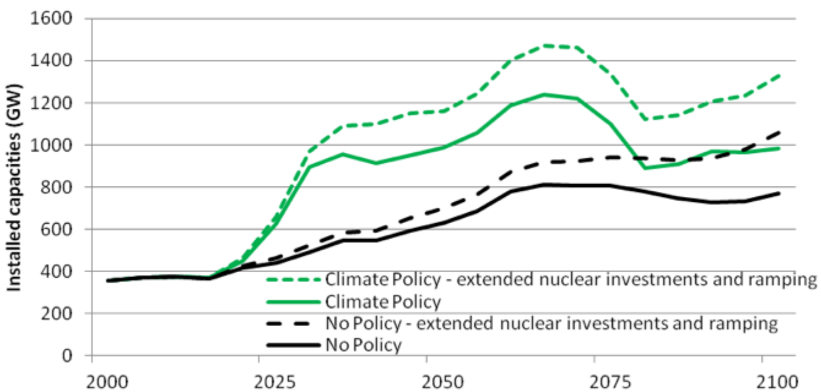

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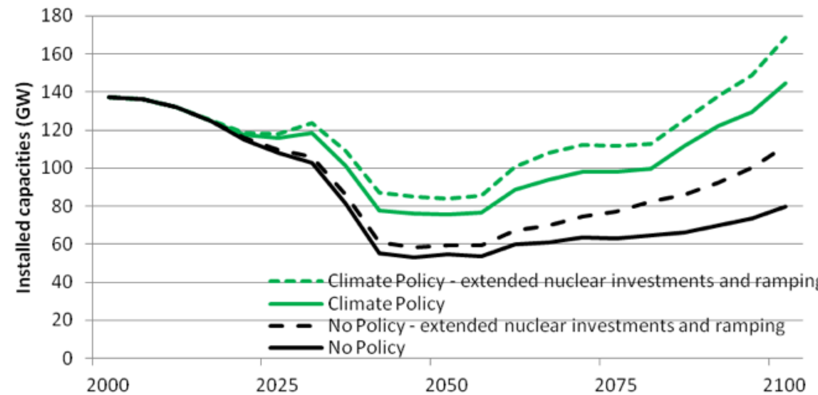
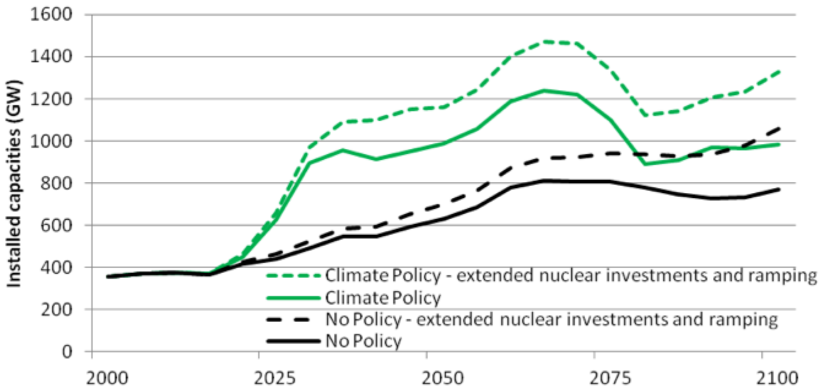


Europe nuclear installed power (WR + FR)

Extension of Load Following Capacities



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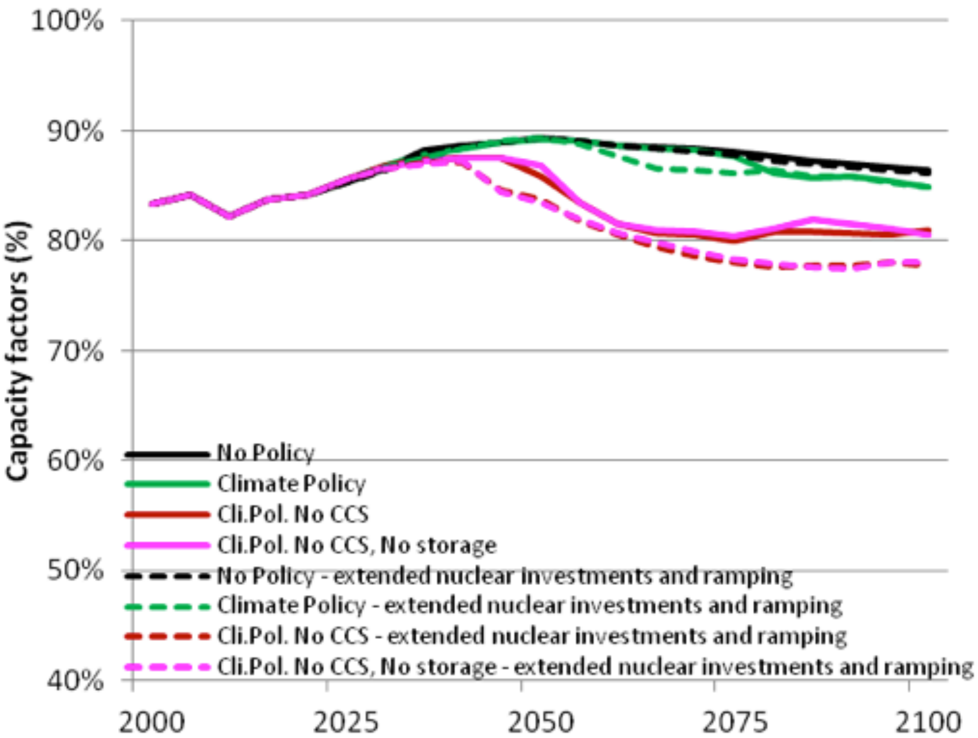

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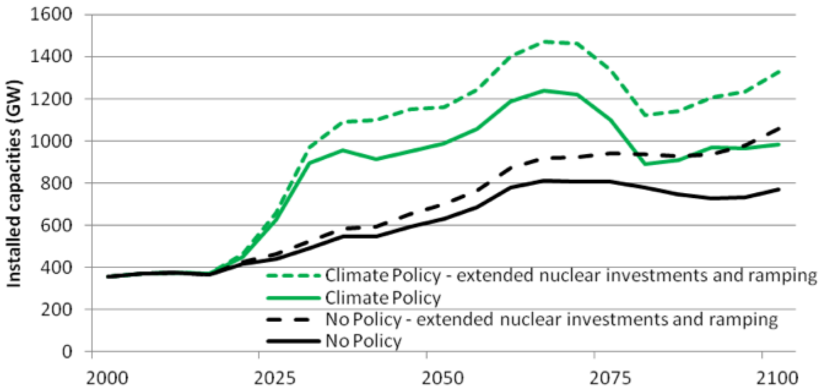

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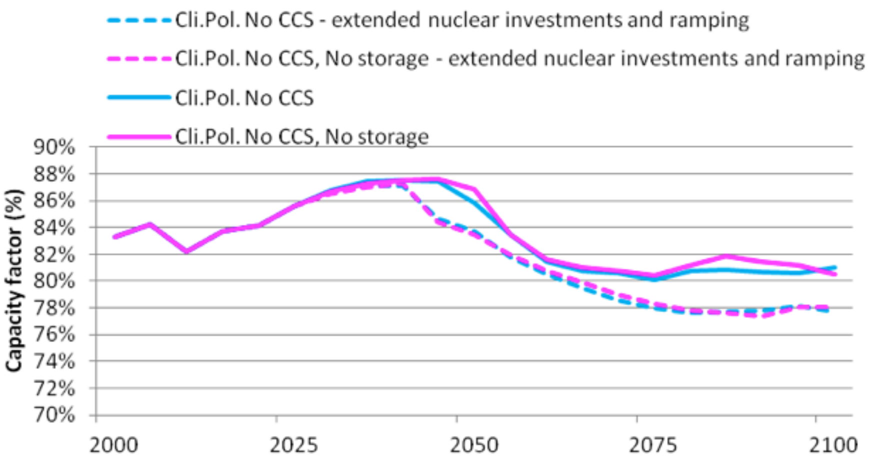
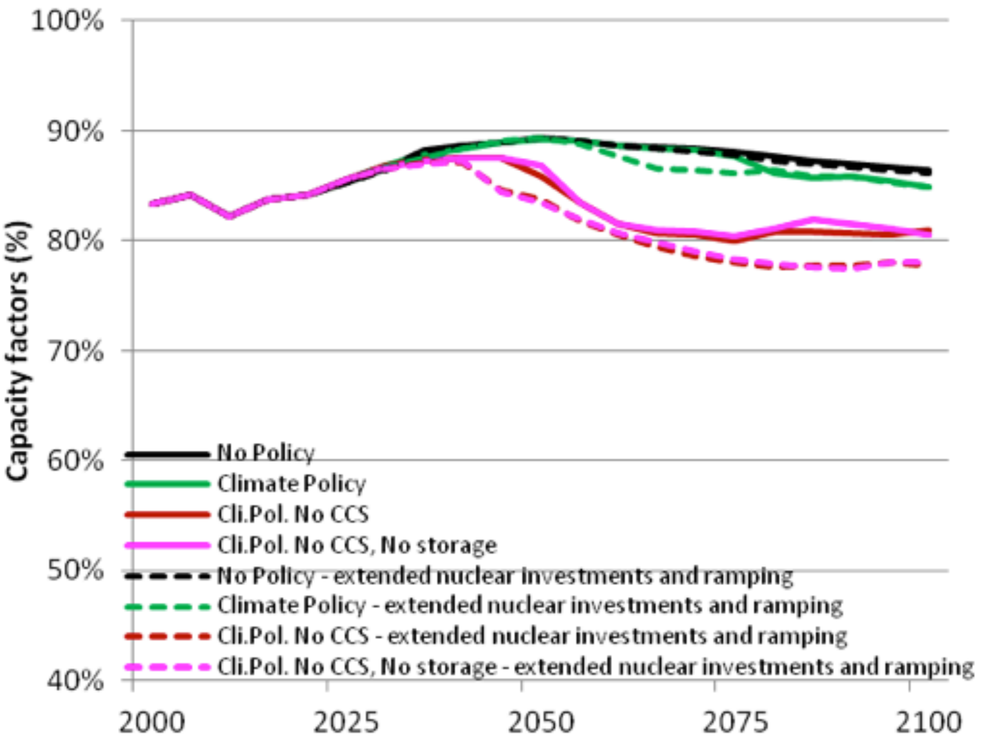


World nuclear Load Factors (WR + FR)



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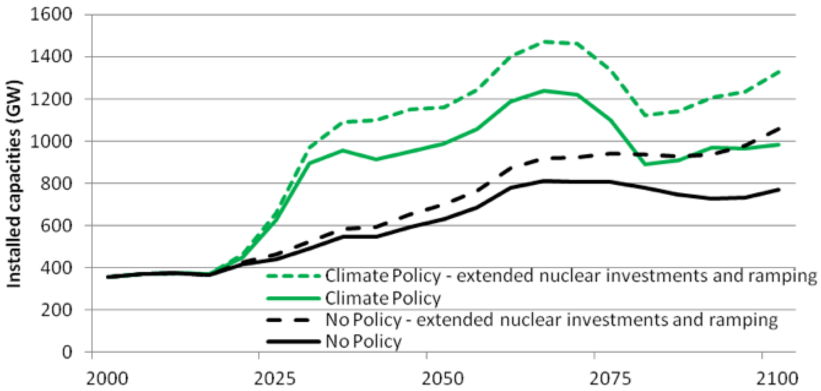

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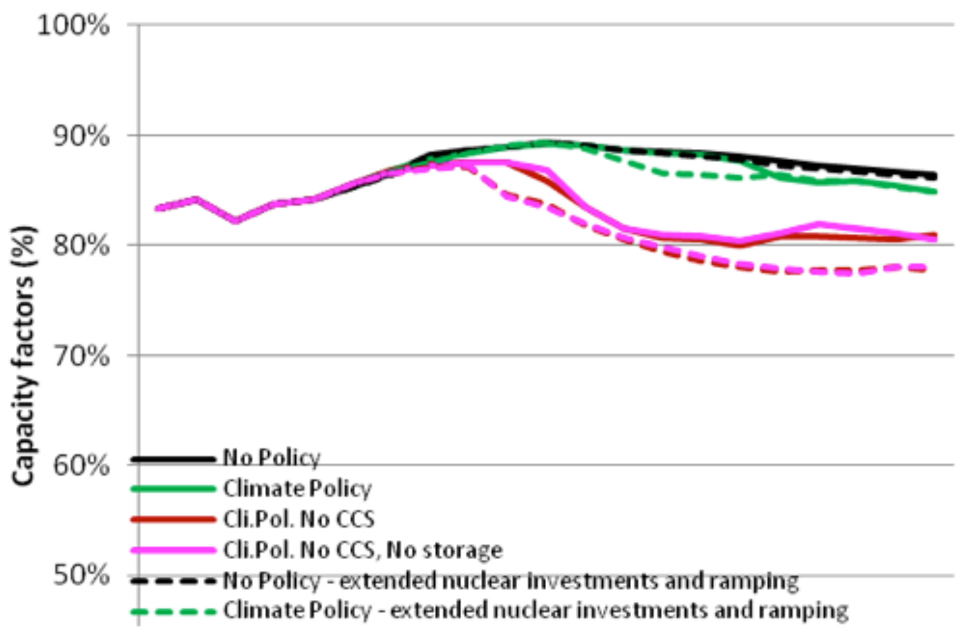

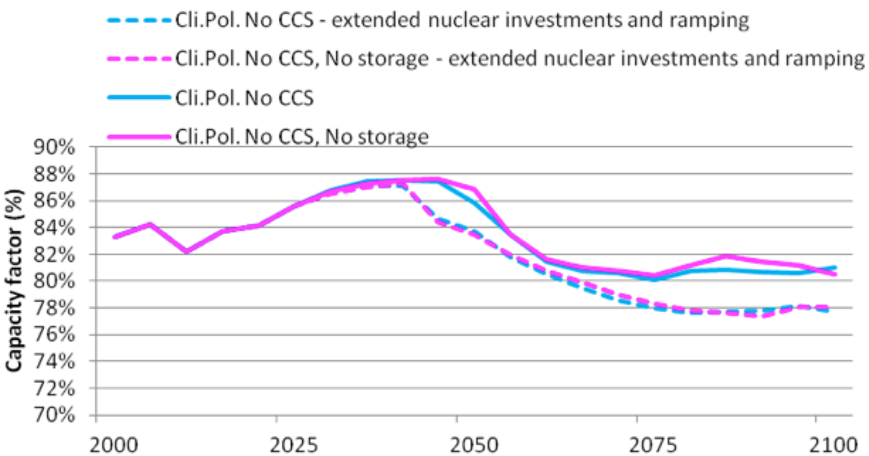

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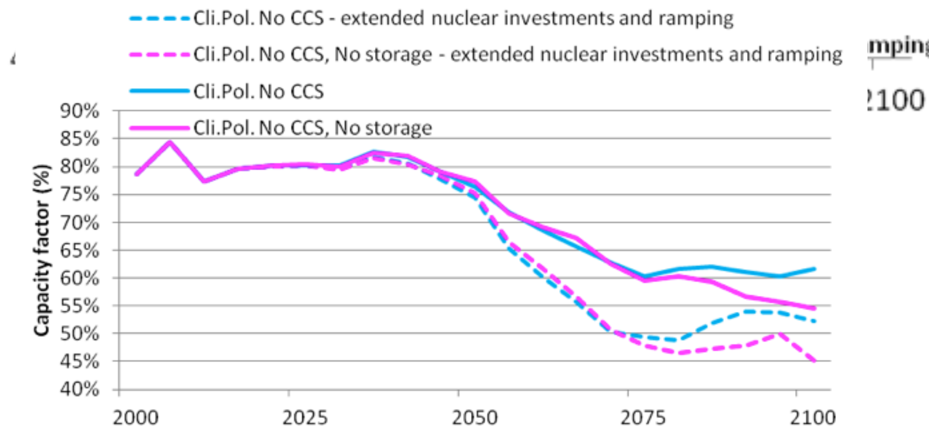

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Perspectives

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Merci de votre attention !

Thank you !