Power System Economics
Generation and consumption

Master Energy – Master 2

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Nicolas Omont

nicolas.omont@rte-france.com

The views expressed are personal and do not necessarily represent the views of RTE

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Definitions

- **Energy** is the property that must be transferred to an object in order to perform **work** on, or to **heat**, the object. In physics, **work** is defined as a force causing the movement—or displacement—of an object. The SI unit of energy is the **joule** (J) or newton-meter (N * m). The joule is also the SI unit of work.
  - **Heat** is the amount of energy that flows spontaneously from a warmer object to a cooler one ☹.
- **Power** is the rate of doing work. The SI unit of power is the joule per second (J/s), known as the watt.

Units

- The electric power grid (almost) does not store energy $\Rightarrow$ The main unit used is the megawatt.

	Power systems	Gas systems	General analysis
Power	MW, MVAr	MW *(or BTU/h)*	
Energy	MWh, MVArh	MWh *(or BTU)*	Mtoe

- 1 MWh = 3600 MJ
- 1 Mtoe = 11.63 MWh
- 1 MW = 1 MVAr from the unit point of view. *MVAr is used for only "reactive power" in Alternating Current systems. This power changes direction twice per cycle so that the average energy transmitted per cycle is 0. As for "active power", it follows a conservation law.*

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The electrical power system in the energy system: example of France

Primary energy consumption:
266.4 Mtoe (Millions of tons of oil equivalent) / 3090 TWh

~130 Mtoe
1508 TWh

~49%

~51%

Electrical system
Efficiency: 31%

Storage
~1 hour of consumption

Storage ~several months of consumption

Other systems (gas, oil…)
Efficiency: 85%

~40 Mtoe
464 TWh

~25%

~75%

Final energy consumption *(mixing energies with different abilities to produce work)*:
155.6 Mtoe / 1805 TWh

Source : bilan énergétique de la France pour 2011 (CGDD)

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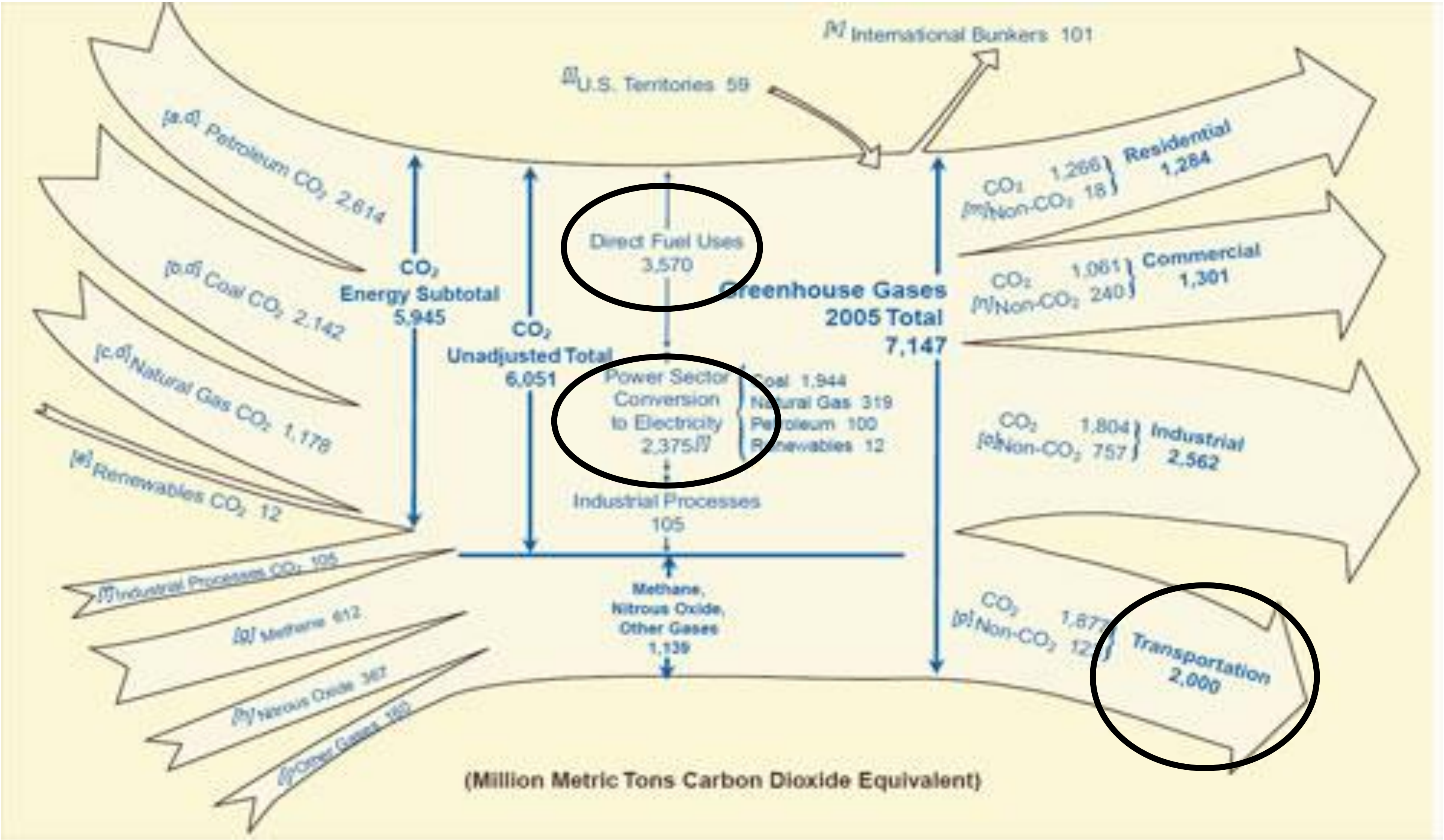
Example of the US: CO2 flows

CO2: 2375mmt Electric, 2000mmt Transportation



Direct fuel use includes auto & home heating

Source: James D. McCalley (Iowa State University)

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What do consumers of power grids need?

- Mainly, energy **(in MWh)** at a given time and a given location
  - Mainly withdrawal (and, optionally, injections for a “prosumer”)

  ➢ *A “good”, even if it has no weight (it is transmitted at speed of light, and not transported)*
- But also:
  - The right to connect to the grid
    - Initial connection cost
    - Annual connection fee
  - Insurances and financial products
    - Seasonal capacity payment **(in MW)** to be able to inject/withdraw a given power at a given time in the future.
    - Futures to secure their purchases and sales.
- And more and more, access to markets on which to trade various products (energy, reserve, and capacity).

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Value for consumer

- How much energy are consumers ready to pay and at which price?
  - Consumers are expected to use given amount of energy for their “reference” activity.
  - The concept of “Value of Lost Load”, “Unserved energy”
- Many studies to differentiate between the use, the duration, the period of notice…
- On the short term and for captive uses, generally assumed to be high: 3 000 – 30 000 €/MWh
- On the long term for non captive uses (heating), depending on the cost of alternatives for the consumers: 30 – 300 €/MWh.

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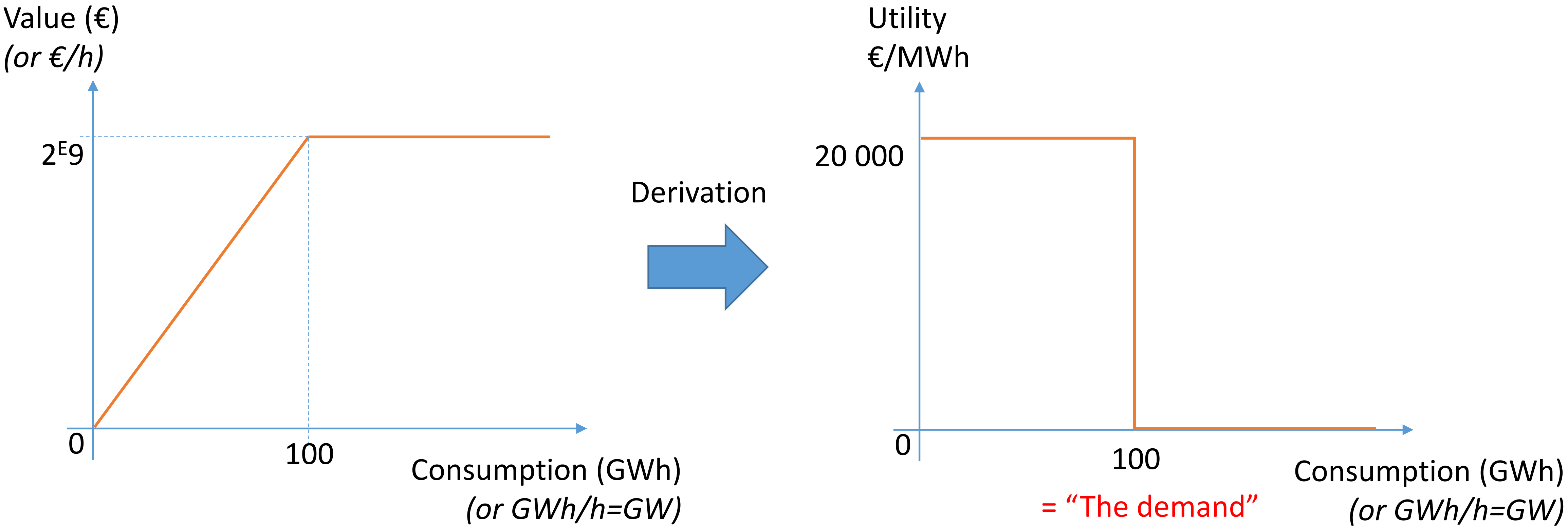
Aggregated utility curve

Example for a very cold day in France for one hour around noon (Demand: 100 GW)

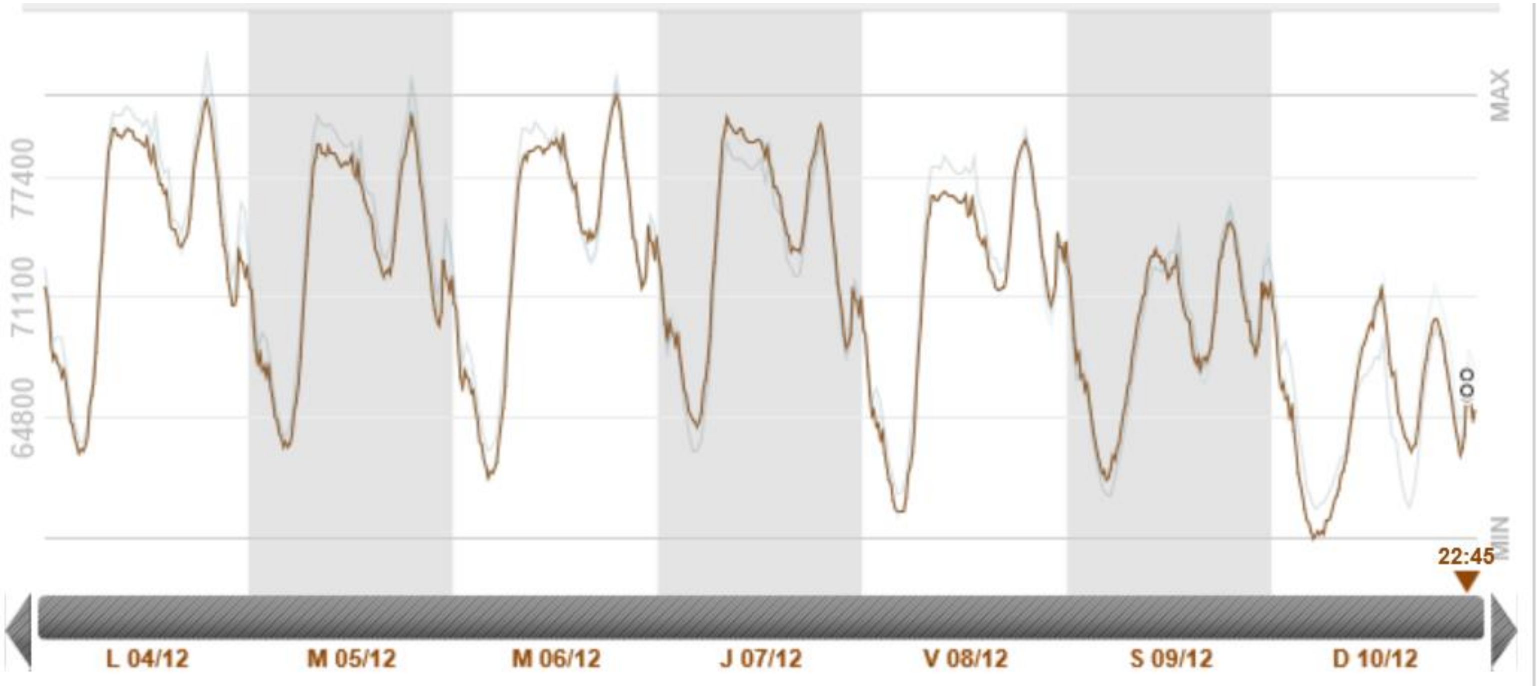


The utility curve changes from hour to hour (consumption is lower in summer –in cold countries- and at night).

The demand

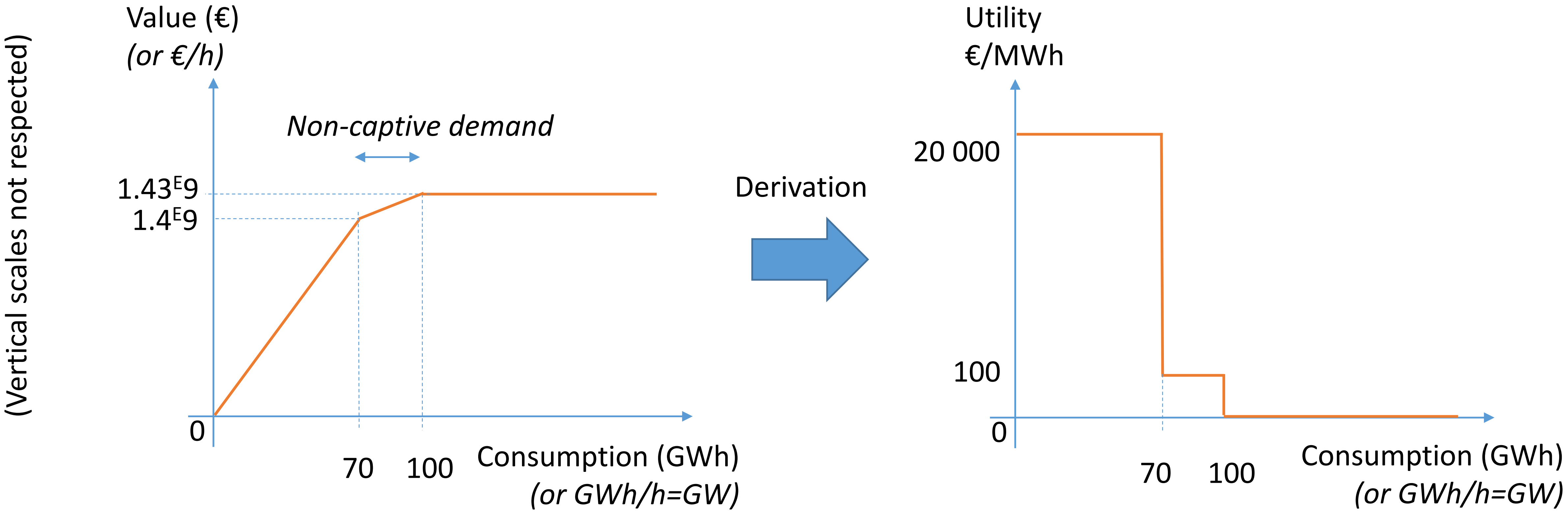
- Demand changes according to economic cycle and weather.
- Demand = consumption, except if some customers are not served.

http://www.eco2mix.fr



Aggregated utility curve (long term)

Example for a very cold day in France for one hour around noon



⇒ As consumers can change the source of heating, the utility of the heating part of the demand is lower.

Production – long-term (decades)

- A central planner wants to satisfy the demand at the lowest generation cost. A private company wants to sell energy in order to maximize its profit
  - Under some (unrealistic) assumptions, both solve a similar problem.
- He/she has to decide which amount to produce for every time step of the planning horizon (several decades) and decide how to produce it. He/she makes decisions:
  - Investment: which kind of power plant to build?
  - Operation: which kind of power plant to use at a given time step?
- Each decision has a cost:
  - Fixed costs (investment decision): Cost to build <u>and</u> to keep able to run <u>and</u> to dismantle the generation plant = CAPEX (Capital Expenditure)
  - Variable costs (operation decisions): Cost to run the plant = OPEX (Operational Expenditures) or Operation & Maintenance costs.
  - Rule of thumb: the variable costs = <u>the money saved by not running a generating unit during a given period</u>.

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Producer – mid-term (years)
Example of a thermal unit

- Investments have been done. The producer can:
  - Keep the power plant able to run, and decide, for each time step to produce or not.
  - Anticipate the closure before the expected life duration (to spare the cost of keeping the power plant able to run).
  - “Mothball” the power plant for several years, waiting for better time…
- Therefore:
  - Fixed costs (Mothball decision)= Cost ~~to build and~~ to keep able to run ~~and to dismantle the generation plant~~
  - Variable costs (Operation decision)= Cost to run the plant.

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Production – short-term (day)
Example of a thermal unit

- Investment and mothball decision have been made. The producer can decide:
  - To start the plant or to keep it stopped
  - If it is started, to produce a given amount of power
- Therefore:
  - Fixed costs = start-up costs, human resource costs…
    - Sometimes referred to as “pseudo-fixed costs”
  - Variable costs = combustible costs, wear and tear costs,…

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Other decisions: dispatch and storage

- Definitions:
  - Dispatchable technology = controllability of the output. Ability to follow a given power set point schedule
  - Limited storage technology can produce a limited amount of energy per period of time.
- Fuel-based technologies are considered dispatchable.
  - In addition, fuel storage is usually considered infinite.
  - Some exception exists: biogas generation, combined heat&power generation…
- Reservoir hydro is also considered dispatchable, but it is storage-constrained.
  - Pumped hydro only give back previously consumed energy
- PV and wind technologies are not dispatchable:
  - Unproduced energy is lost (short-term variable costs are close to 0 €/MWh), maximum output is time varying $\Rightarrow$ Units are usually run to max.
  - Coupling with storage restores (some) dispatchability.

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Long Term Marginal Cost (Or LCOE Levelized Cost of Energy)

LTMC = (Fuel Cost + Carbon Price * Emission Factor) / Efficiency + Variable O&M costs
+ (Fixed O&M costs + Annuity) / (Capacity Factor)

Variable	Unit	Definition
LTMC	€/MWhe	Long Term Marginal Cost: The cost of the decision to develop the system with a given technology per electrical unit of energy. The constant lifetime remuneration for the supplier of electricity.
Fuel Cost	€/MWht	Fuel cost per thermal unit of energy
Carbon Price	€/tonne	Price of CO_2 emission
Emission Factor	tonne/MWht	Quantity of CO_2 emission per thermal unit of energy consumed
Efficiency	%	Electrical conversion efficiency
Variable O&M costs	€/MWhe	Variable part of the operation and maintenance costs
Fixed O&M costs	€/MWe.year	Fixed part of the operation and maintenance costs
Annuity	€/MWe.year	Annual cost of capital (Reimbursement of loan)
Capacity Factor	%	Proportion of the time the technology is running

Heavily depends on the remaining of the system (other generation technologies, shape of consumption..)

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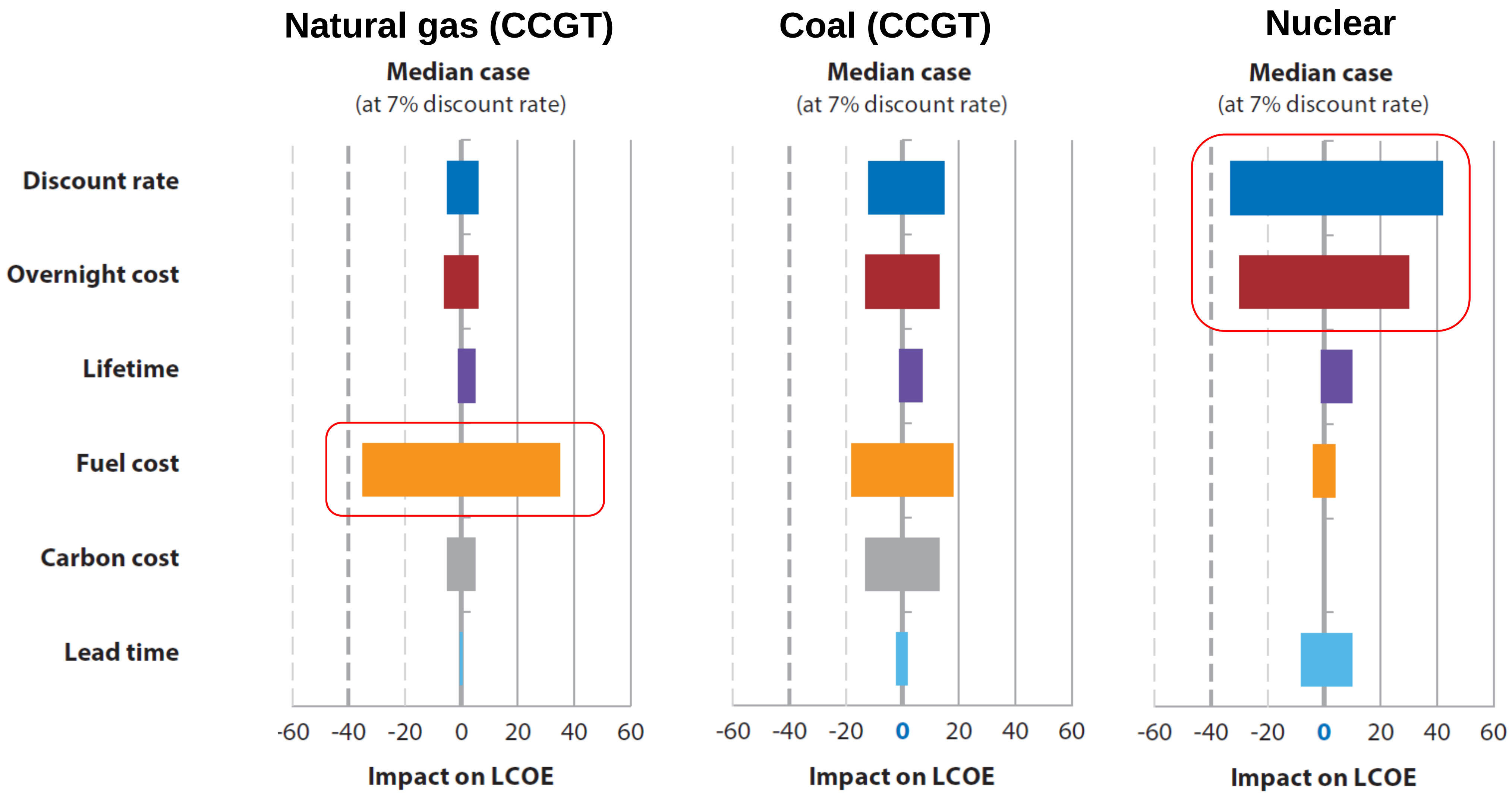
		Natural Gas		Coal	Nuclear	PV		Wind		Hydropower
		OCGT (extrapolated)	CCGT			Residential	Large	Onshore	Offshore (extrapolated)	run-of-the-river (source Irena)
Data	Net capacity (MWe)	150	475	772	1 300	0	3	20	50	
	Electrical conversion efficiency (%)	40%	59%	45%	33%					
	Overnight cost (USD/kWe)	691	1 014	2 264	4 896	2 297	1 436	1 804	4 037	5 000
	Lifetime	30	30	40	60	25	25	25	20	80
	Fixed O&M cost (USD/MWe)	29 435	29 435	34 542	68 800	28 333	26 667	45 475	58 611	100 000
	Variable O&M cost (USD/MWhe)	0,7	2,7	3,4	6,9	0	0	5,9	7,6	
	Carbon emission factor (kg/GJt)	56,1	56,1	94,6						
	Fuel costs (USD/MWht)	37,87	37,87	14,54	3,08					
	Carbon price (USD/Tonne)	30	30	30						
	Capacity factor (%)	85%	85%	85%	85%	13%	15%	28%	43%	90%
	Interest rate (%)	7%	7%	7%	7%	7%	7%	7%	7%	7%
Computations	Annuity (USD/MWe.year)	55 685	81 715	169 821	348 738	197 107	123 224	154 802	381 088	351 568
	Fuel cost (€/MWhe)	95	64	32	9					
	Carbon price (€/MWhe)	15	10	23						
	Total variable cost (USD/MWhe)	111	77	58	16	0	0	6	8	0
	Total fixed cost (USD/MW.year)	85 120	111 150	204 363	417 538	225 440	149 891	200 277	439 700	451 568
	Total fixed cost (USD/MWh)	11	15	27	56	198	114	82	117	57
	LCOE (Levelized Cost of Energy, Long Term Marginal Cost, USD/MWh)	**122**	**92**	**86**	**72**	**198**	**114**	**88**	**124**	**57**

Source: IEA 2015 median case and IRENA 2015

Example of "typical" Long Term Marginal Costs

Sensitivity to parameters



Source: IEA 2015 median cases

The vertical axis indicates the median case LCOE value, while the horizontal bars present the increase or decrease in LCOE (in percentage terms) after the parameter has been adjusted by ±50%.

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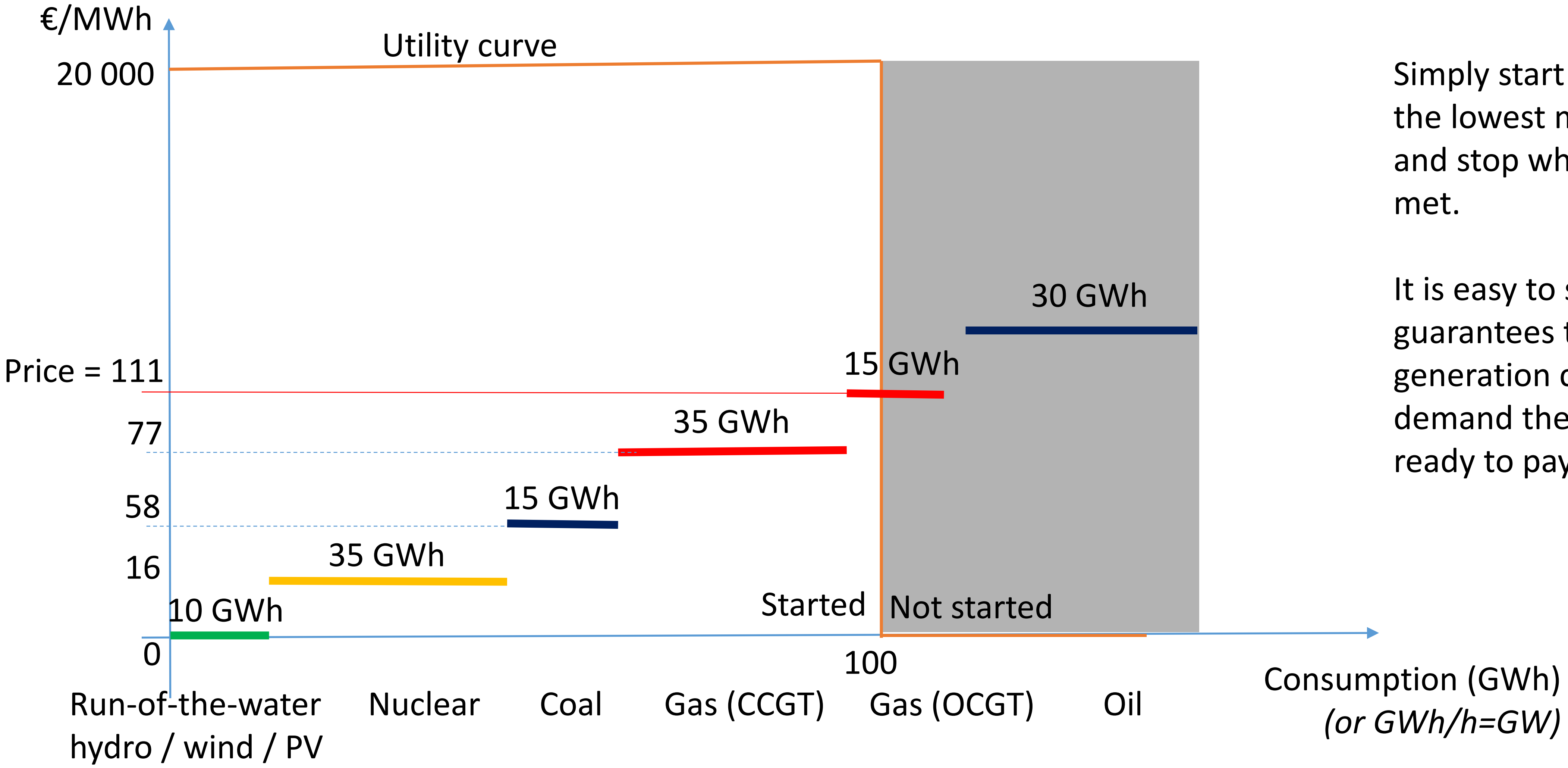
Balancing supply and demand

- We have described:
  - A traded good: “electricity”
    - Energy exchanged during a given short period (5 mn-1 h)
  - The demand characteristics
    - Fixed demand and high “unserved energy” price on the short term.
    - Sensitivity to price due to non-captive.
  - The generation characteristics
    - High long term fixed costs.
    - Depending on technology, high fixed costs goes with low variable costs and vice-versa.
- But how to match demand and generation?
  - And at which price should transactions be made?

Balancing supply and demand without fixed costs: the **“merit order”** for a central planner



Simply start the units with the lowest marginal cost first and stop when demand is met.

It is easy to show that this guarantees the lowest generation cost for the demand the consumers are ready to pay.

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The "merit-order" for a market designer: The neo-classical theory of markets

- Assuming electricity is traded on a market, under the following assumptions ("pure and perfect competition"):
  - Homogeneity of product: OK
  - Atomicity of market (many small players): NOK but the regulator takes care that no market power is exercised.
  - Transparency: perfect and free information for all
  - Mobility of production factors: work and capital go to most efficient uses. NOK for capital (ex.: subsides for renewable energy)
  - Free entrance on the market (NOK because of economies of scales)
  - Anticipation according to the same economical modelling
- Only one price for each product
- No shortages and no production in excess
- Nobody thinks he/she is able to manipulate the price so that everybody offer goods at a price that reflects its costs.

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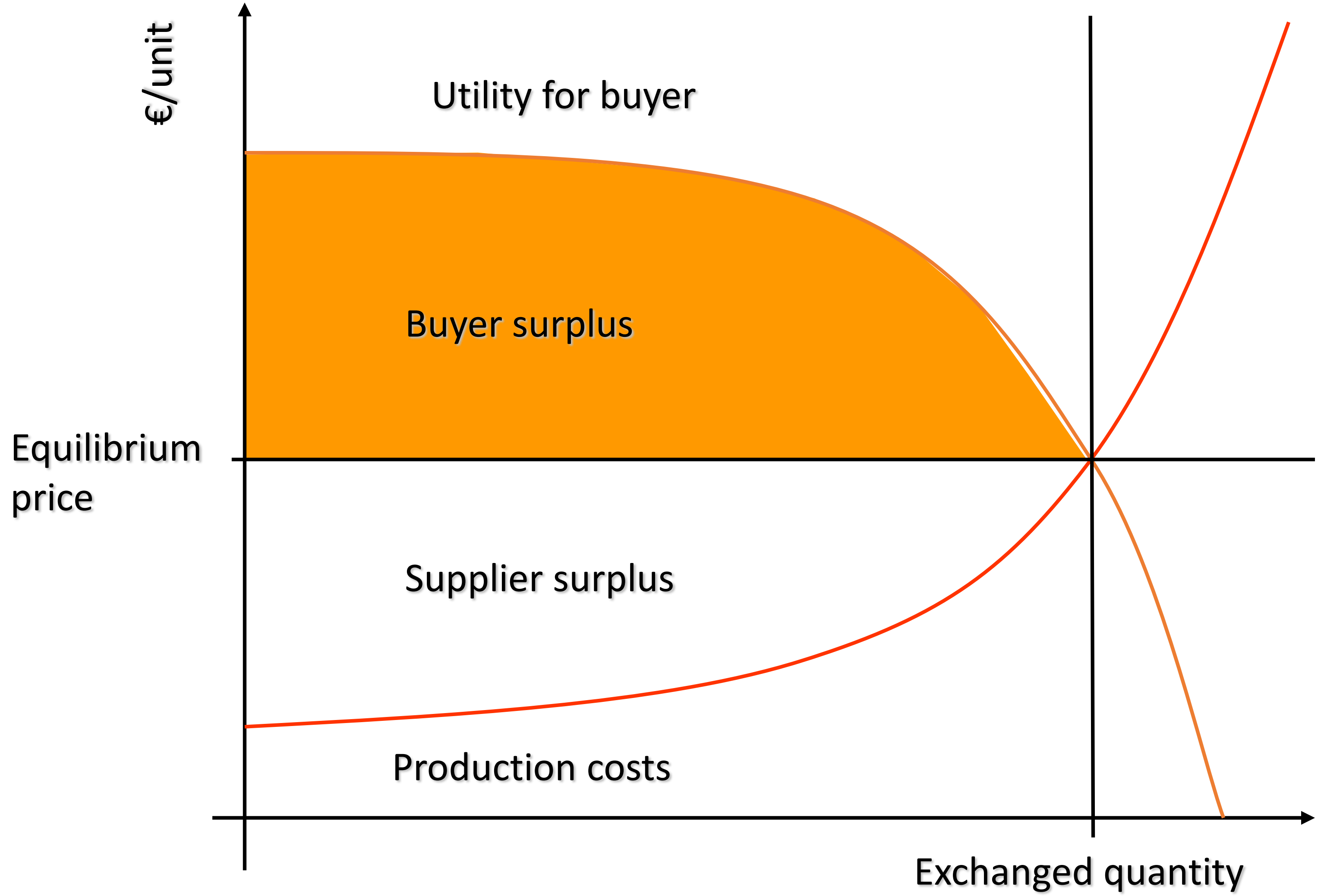
Price formation: supply/demand curve



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Price formation: properties

- The price is fair for all agents in that no trading opportunity remains.
- The equilibrium corresponds to a maximum of the social welfare.
  - It corresponds to a minimization of costs (for example, it satisfies to the “merit-order” rule) as the central planner could have done it. **The market and the central planner deliver the same optimal solution.**
  - It is unique if marginal costs are increasing and marginal utilities decreasing.
- Therefore the price is said to be both “fair” and “optimal”..

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Merit order and neoclassical theory

- Reminder:
  - **Cost** refers to **decision** making.
  - **Price** refers to **transaction** making.
- Theoretically (see later), the “best” price for all transactions is the marginal cost of the most expensive running unit.
  - (Price, Volume) determined by the intersection of the demand and supply curve.
- The most expensive running unit is called the **marginal unit.**
  - It is partly loaded (It does not run at maximum)
  - The price is equal to its short-term marginal cost
  - Therefore, the price is also called the **short-term marginal price** because it is the price to be paid to buy one more MWh (it will be produced by the marginal unit)

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The infra-marginal rent

Numerical values of slide 22	
Price	111 €/MWh
Volume	100 GWh
Value of Lost Load	20 000 €/MWh
OCGT marginal cost	111 €/MWh
CCGT mc	77 €/MWh
Coal mc	58 €/MWh
Nuclear mc	16 €/MWh

- Transaction (for one hour):
  = Price * Volume
  = 100 GWh * 111 €/MWh = 11.1 M€
- Buyer/Consumer surplus per unit
  = Value of lost load – price
  = 20 000 €/MWh – 111 €/MWh = 19 889 €/MWh
- Seller/Producer surplus per unit
  = Price – Marginal cost
  - **For the marginal unit, the surplus is 0 €/MWh**
    - OCGT: = 111 – 111 = 0 €/MWh
  - **For the other units, the additional positive benefit is the infra-marginal rent**
    - CCGT: = 111 – 77 = 34 €/MWh
    - Coal: = 111 – 58 = 53 €/MWh
    - Nuclear: = 111 – 16 = 95 €/MWh

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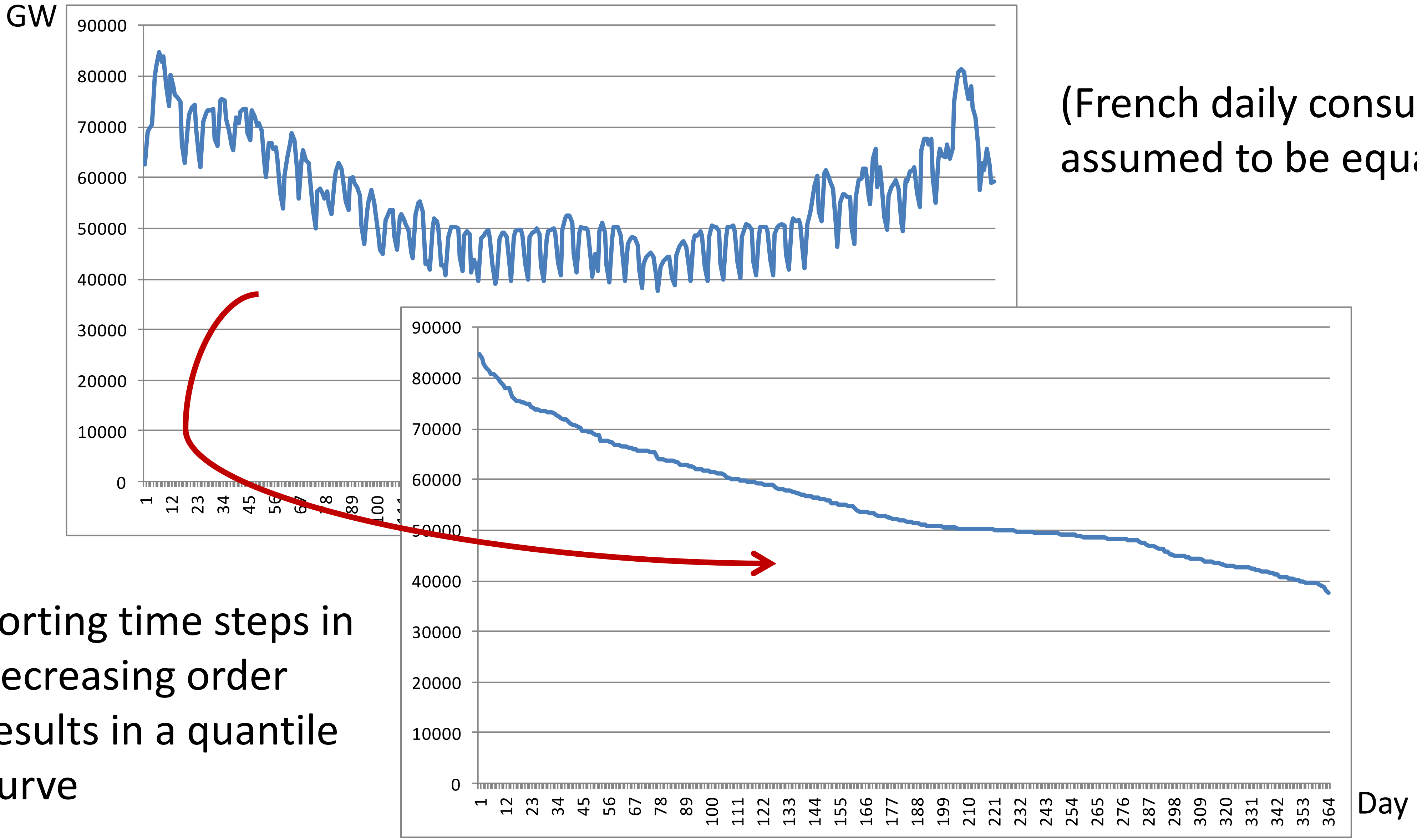
Balancing supply and demand with fixed costs: **the "optimal mix"**

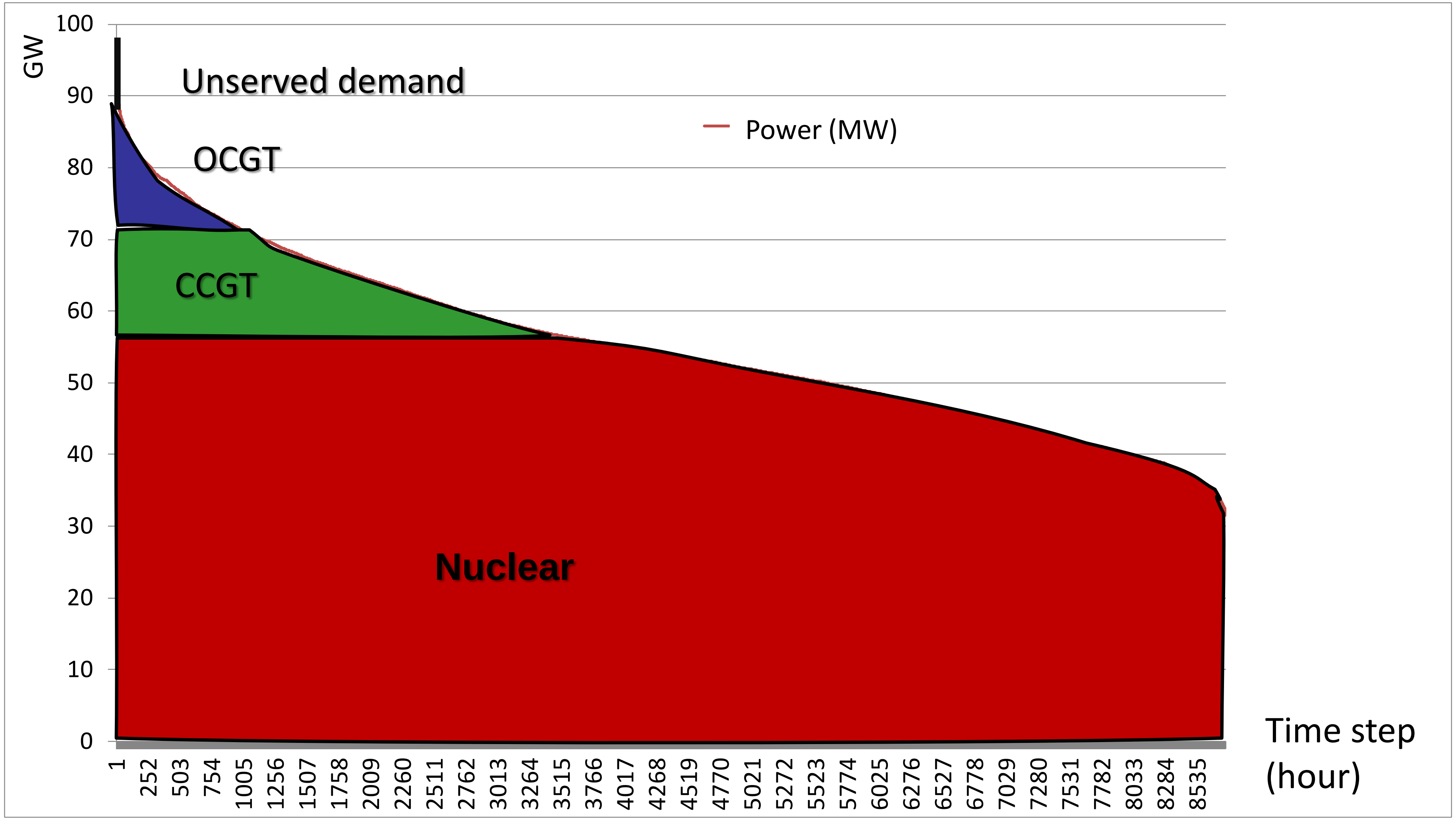
The demand distribution curve: definition



(French daily consumption, assumed to be equal to demand)

Sorting time steps in decreasing order results in a quantile curve

Visualization of the “merit order”



Assuming capacity of each technology is know, the merit order rule allows to dispatch generation for each hour of the distribution curve

But what are the best capacities to choose?
And what should be the transaction price for each hour?

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The optimal mix

- Graphical example with 2 (dispatchable with infinite storage) technologies and a demand insensitive to price:

Technology	Fixed costs (€/MW.year)	Variable costs (€/MWh)
Base technology	400 000	16
Peak technology	80 000	111
Unserved demand/ Curtailment	0	20 000

- Break-even running duration
  - Base/Peak: 400 000 + 16*d = 80 000 + 111*d ⇒ d = 3368 h/year = 38.45%
  - Peak/Unserved: 80 000 + 111*d = 20 000 d ⇒ d = 4 h/year = 0.04%

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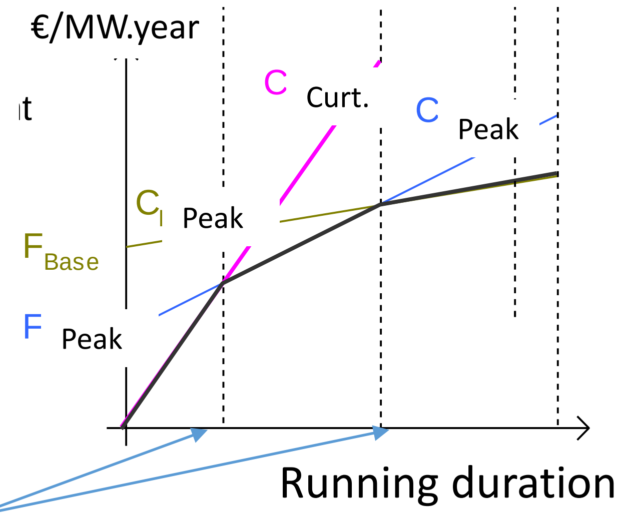
The optimal (lowest cost) mix

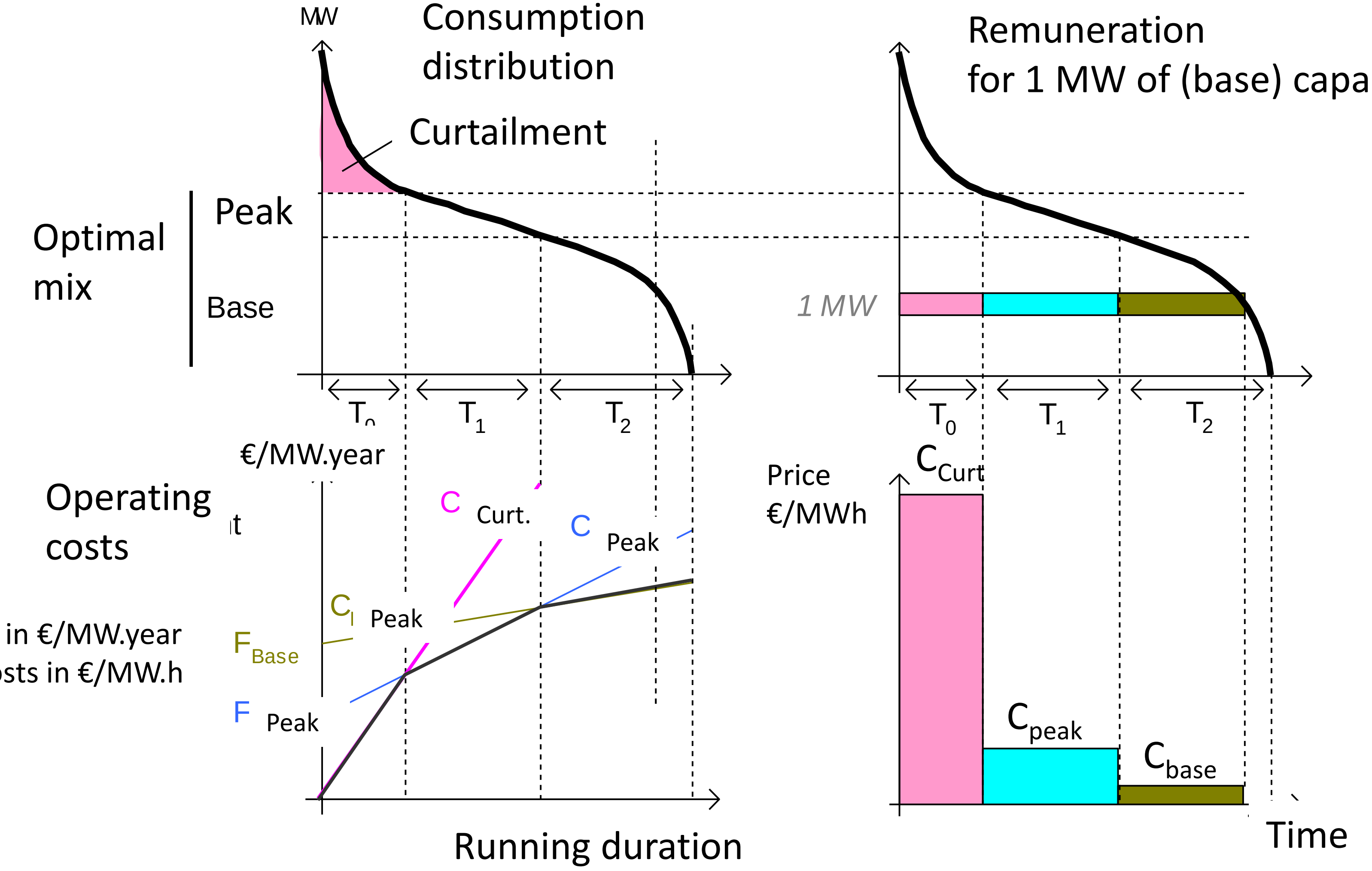
Operating costs

F = Fixed costs in €/MW.year
C = Variable costs in €/MW.h



Break-even durations

The optimal (lowest cost) mix (print version)



F = Fixed costs in €/MW.year
C = Variable costs in €/MW.h

The optimal mix

- Marginal surplus for base technology

$$= T0 * Price(T0) + T1 * Price(T1) + T2 * Price(T2) - (T0+T1+T2) * C(base) - F(base)$$

$$= T0 * C(curt.) + T1 * C(peak) + T2 * C(base) - (T0+T1+T2) * C(base) - F(base)$$

$$= \underbrace{T0 * C(curt.) + T1 * C(peak) - (T0+T1) * C(base)}_{\text{Inframarginal rent}} - \underbrace{F(base)}_{\text{Fixed costs}}$$

= 0 if the mix is optimal

- Consequence:

Nature of the mix	Financial consequences
Optimal mix	Natural compensation of the fixed costs by the inframarginal rent.
Excess of capacity for a given technology	Revenues are not enough to cover investment costs ⇒ Expect some power plants to be mothballed/closed.
Lack of capacity for a given technology	Revenues higher than fixed cost (scarcity rent) ⇒ Expect new investors to build new power plants.

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Bibliography

- Energies Economies et Politiques, Jean-Pierre Hansen and Jacques Percebois (in French).
- Fundamentals of Power System Economics, Daniel S. Kirschen and Goran Strbac (in English)

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An equivalent problem: car renting

- Problem:
  - A renting company knows how many cars it needs to fulfill the demand during the year to come:
    - 60 cars during 330 days (« blue » period).
    - 100 cars during the 32 days (« white » period).
    - 120 cars during the remaining 3 days (« red » period).
  - Cars with 2 different technologies can be bought:
    - Diesel: 3000 €/year whatever the use + 200 €/day of use
    - Gasoline: 1000 €/year + 250 €/day of use.
  - Consumers find an alternative if the price of the service is above 500€ per day and per car.
- Questions:
  - *Which cars should the company buy?*
  - *At which price should the company rent the cars during each period?*

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Which cars should the company buy?

- For long period of use, diesel cars are better than gasoline. For short period of use, gasoline cars are better. *Compute the threshold (in days) above which diesel cars are more economical.*

  3000 € + 200 €/d * #t = 1000 € + 250 €/d * #t

  #t = 40 days

- *What is the average cost per day of a car used only 3 days in the year?*

  Average cost(3 days) = (1000 € +250 €/d * 3 d) / 3 d = 583.33 €

- Conclusion: to minimize the costs, the company should buy:
  - 60 diesel cars to be used 365 days
  - 40 gasoline cars to be used 35 days
  - In addition:
    - No cars will be available to serve 20 customers during 3 days, because the average cost is above what they are ready to pay.
    - The overall cost is 4 950 000 €

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At which price should the company rent the cars?

- Remarks:
  - The costs already include a margin so that a 0€ benefit is OK.
  - Other companies may buy cars in order to try to capture the demand, so that high prices are impossible.
- Indications:
  - No car should be rent below its daily cost.
  - To pay the fixed cost, there should be at least some periods where the price is higher than the daily cost.

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Price computation

- « Red » period *(all cars rent):*
  - 500 €/car.day is OK
  - More: customers will not come
  - Less: why? The company seeks to maximize its profit, and no company will rent it for less.
- « White » period *(all cars rent):*
  - Cost of a gasoline car to be recovered during the « white » period:

    1000 + 250 * 35 – 500*3 = 8250 €

    Cost per day = 8250 € / 32 d = 257.81 €/d
  - More: someone will rent for lower. Less: the company would lose money.
- « Blue » period *(only diesel cars are rent):*
  - Cost of a diesel car to be recovered during the « blue » period:

    3000+200*365-500*3-257.81*32=66250 €

    Cost per day = 66250 € / 330 d = 200,76 €/d
  - More: someone will rent for lower. Less: the company would lose money.
- Revenue:

  = 500 * 3 * 100 + 257.81 * 32 * 100 + 200.76 * 330 * 60

  = 4 950 000 €

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Conclusions

- The long term **marginal cost** : the cost of serving one more customer, including the « capacity cost ».
- The **optimal price** (if one can still choose which cars to buy) is the long term marginal cost.
- Profit = Cost – Revenue= 0 €

  $\Rightarrow$ No other company can do better.

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Bonus

- What would happen if the price of company A is below 500€ during the « red » period?
  - The price during the « blue » and « white » period would be increased.
  - The company B setting the prices « optimally » would price lower than company A during the « blue » and « white » period and would be able to enter the market.
  - The company B would price higher during the « red » period, but without impact on its ability to sell because there is unserved demand.

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Is the theory adequate?

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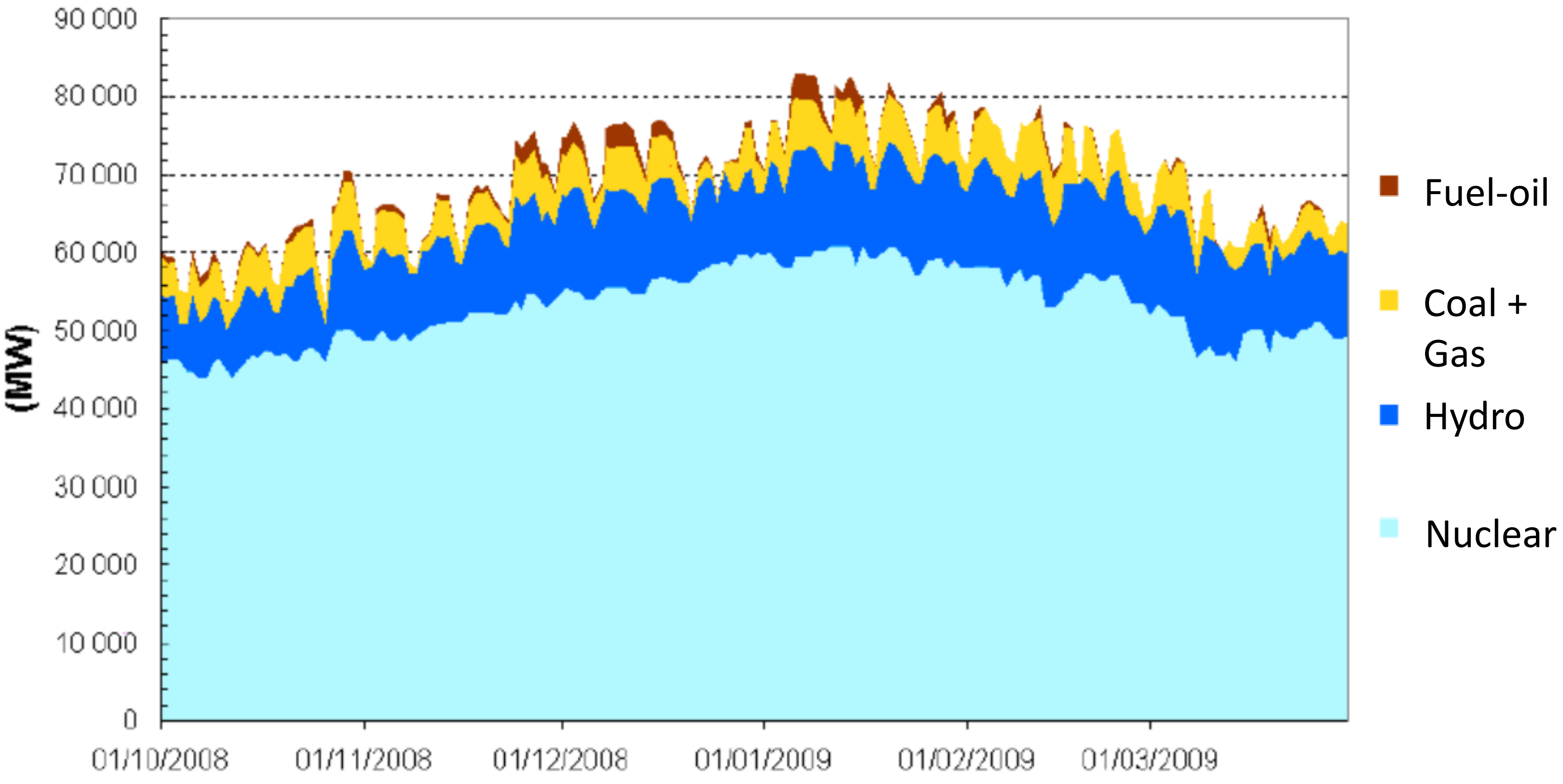
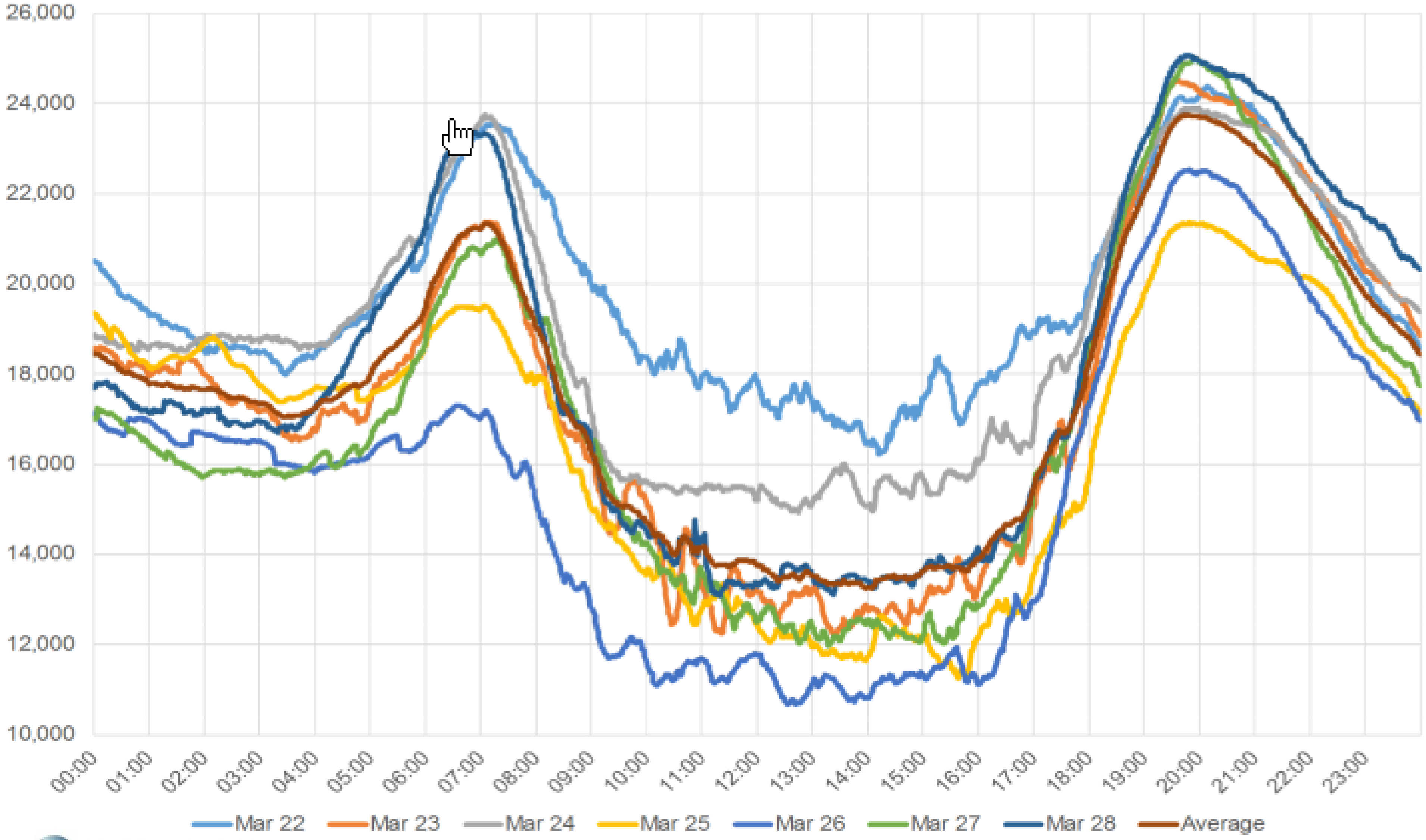
The merit order: a simple but useful assumption



French daily average consumption(MW)

- Dynamics of power plant is more complex:
  - Minimum power
  - Start-up costs
  - Minimum running time
  - Ramps, increasing yields…
- Units with steep ramps can also be remunerated to face real-time uncertainties and not only to deliver energy (reserves).

Net load varies significantly day-to-day and minute-to-minute



California ISO

CAISO 2018 - Public

CA Market Evolution – The People, Technology, and Markets Needed for High Renewable Energy Scenarios, Amber Motley, 2018-03-14, UVIG Spring Technical Conference

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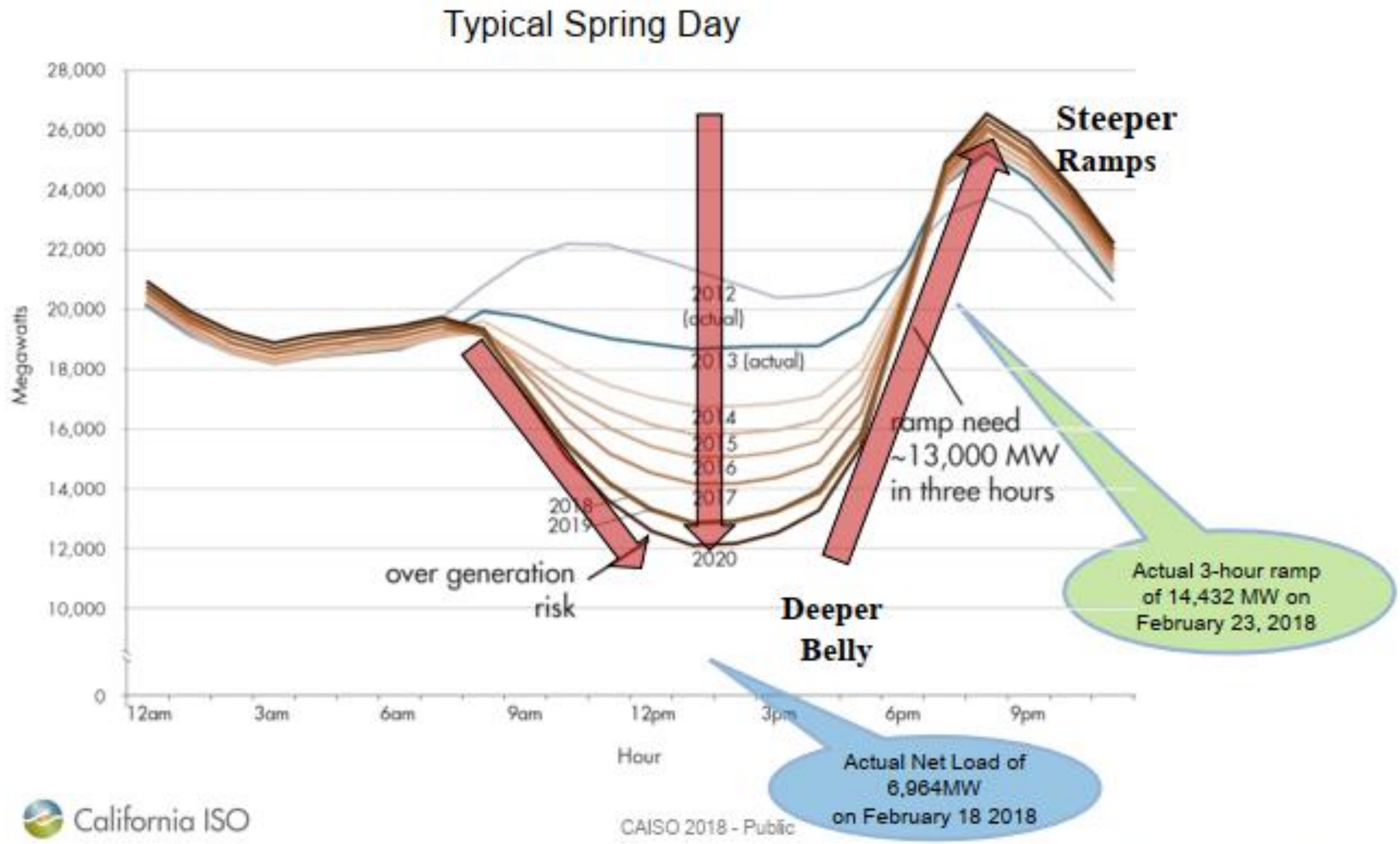
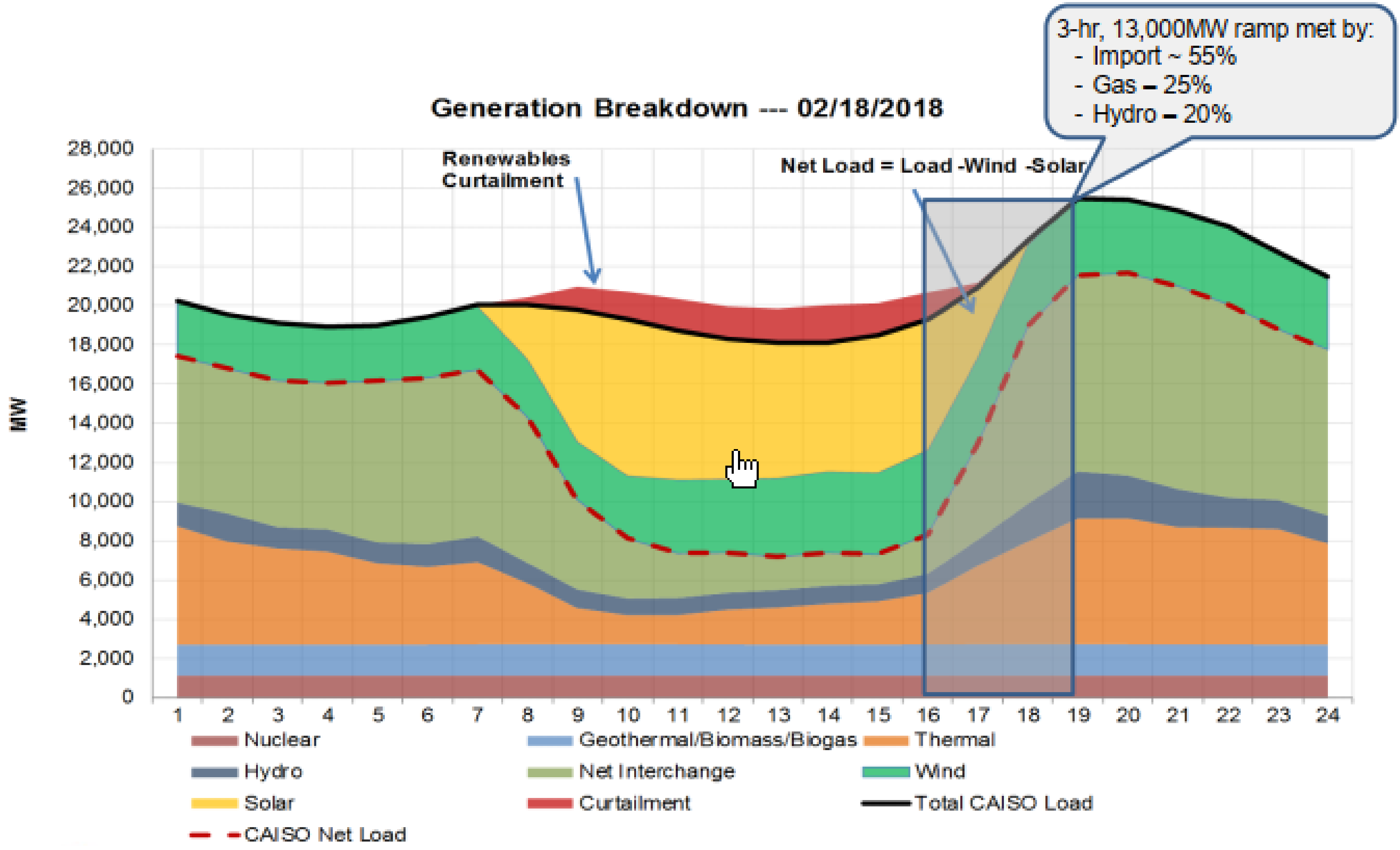
Actual net-load and 3-hour ramps are about four years ahead of ISO's original estimate



During February 18, 2018 renewables met 71% of load



The optimal mix: a useful framework

- Limited economic model:
  - Some developments are impossible (large dams): permanent scarcity rent.
  - Economies of scale (“series” effect for nuclear power plant) also lead to uncovered fixed costs or scarcity rent.
  - Flexibilities (requiring timeseries representation) become more important with REN.
- Very useful to analyse the present but future is uncertain…
  - Useful to analyse deviation of the current mix to the optimal mix
  - Planning has always been difficult because of uncertainties:
    - On Long Term Marginal Cost values (it is known only after decommissioning…)
    - On demand evolution (and on market/regulatory conditions).
- Difficulties are amplified by the end of growth:
  - With 10% demand growth, today’s power plants will represent only 38% of the park in 10 years.

  $\Rightarrow$Plenty new investment decision allow to aim for an optimal mix in 10 years.
  - With 0% growth, in ”steady state” with 40 years life time, 75% of today’s assets will still be there in 10 years.

  $\Rightarrow$2.5 times less degrees of freedom to reach the optimal mix.

  $\Rightarrow$Worse: Excess capacity can be used only after a 2.5 times longer period.

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On the central planning vs. market equivalence:

- From the origins to ‘90s, monopoly was the usual organization
  - On the short-term, the dispatcher collects all the costs and the demand and provides the volumes to be produced to each power plant thanks to the merit order procedure.
  - On the long-term, the central planner forecasts long term marginal costs and demands and computes the investment to make.
- Since the ‘90s, states organized market in many parts of the world
  - On the short-term, generation capacity owner trade power with consumers.
  - On the long-term, private companies anticipate the possibility to make benefits out of new investments.
  - ➢ Contrary to other markets (oil, wheat…), electricity markets have never risen naturally.

➢ No general conclusion: there were well run and badly run markets and monopolies.

- ➢ Current technologies (CCGT, wind and PV) have lower economies of scale than before suggesting that the deoptimization of having many small companies is now lower.

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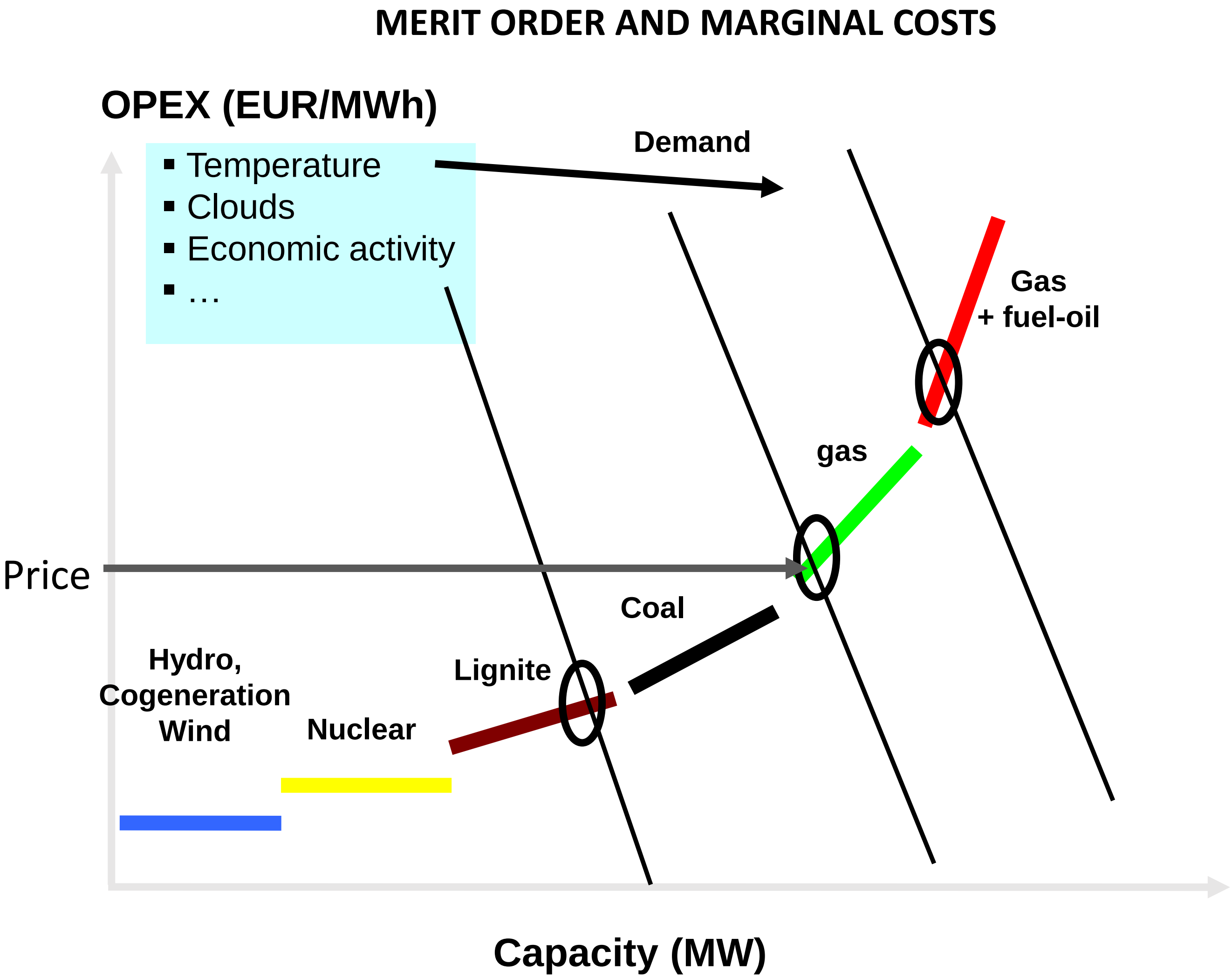
Some analysis of current situations relying on the theory

Prices and merit order: examples

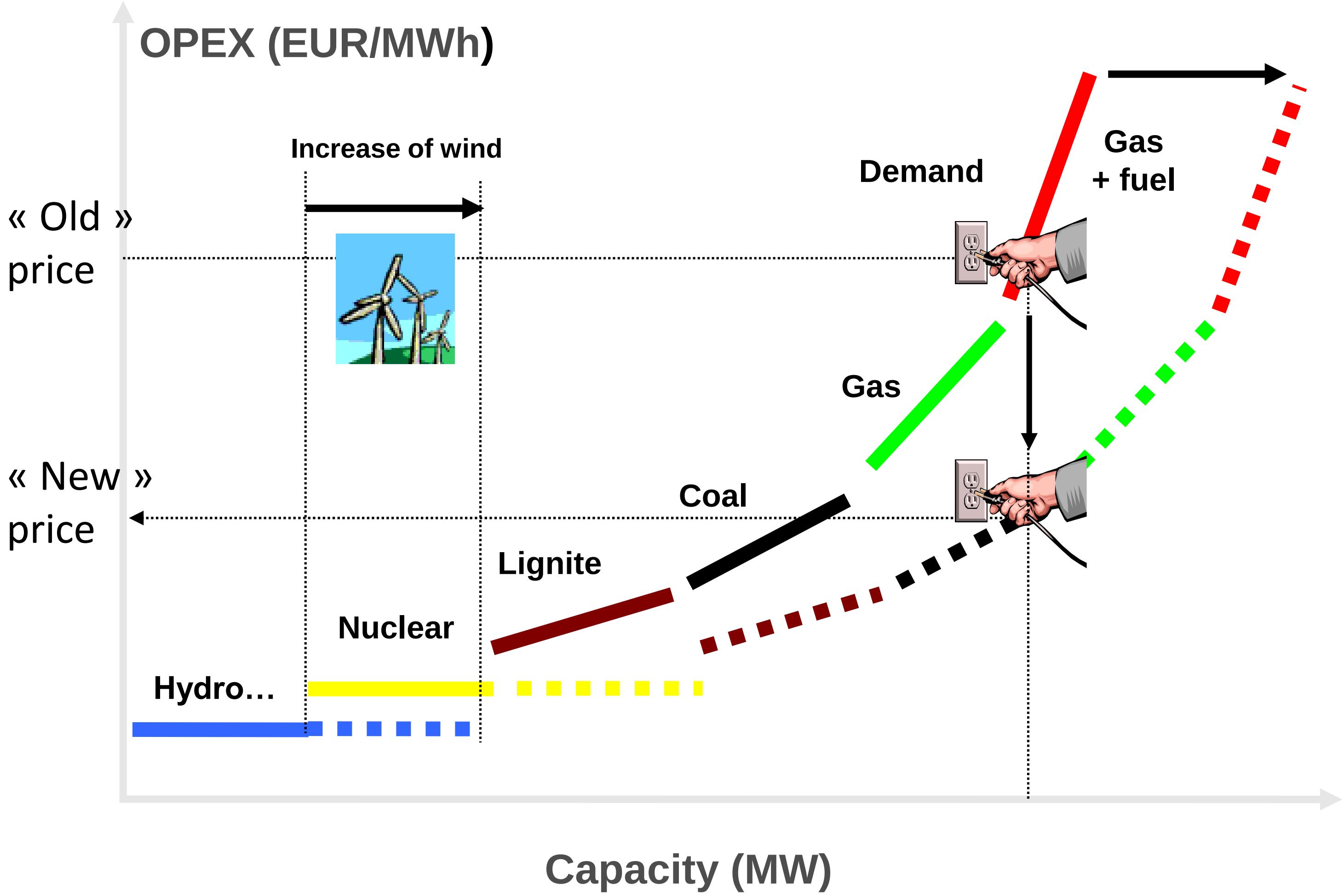


In a competitive market
with enough capacity:

Price = Variable cost (OPEX)
of the marginal producer

Fuel costs are the most
important part of it

Prices: wind generation impact



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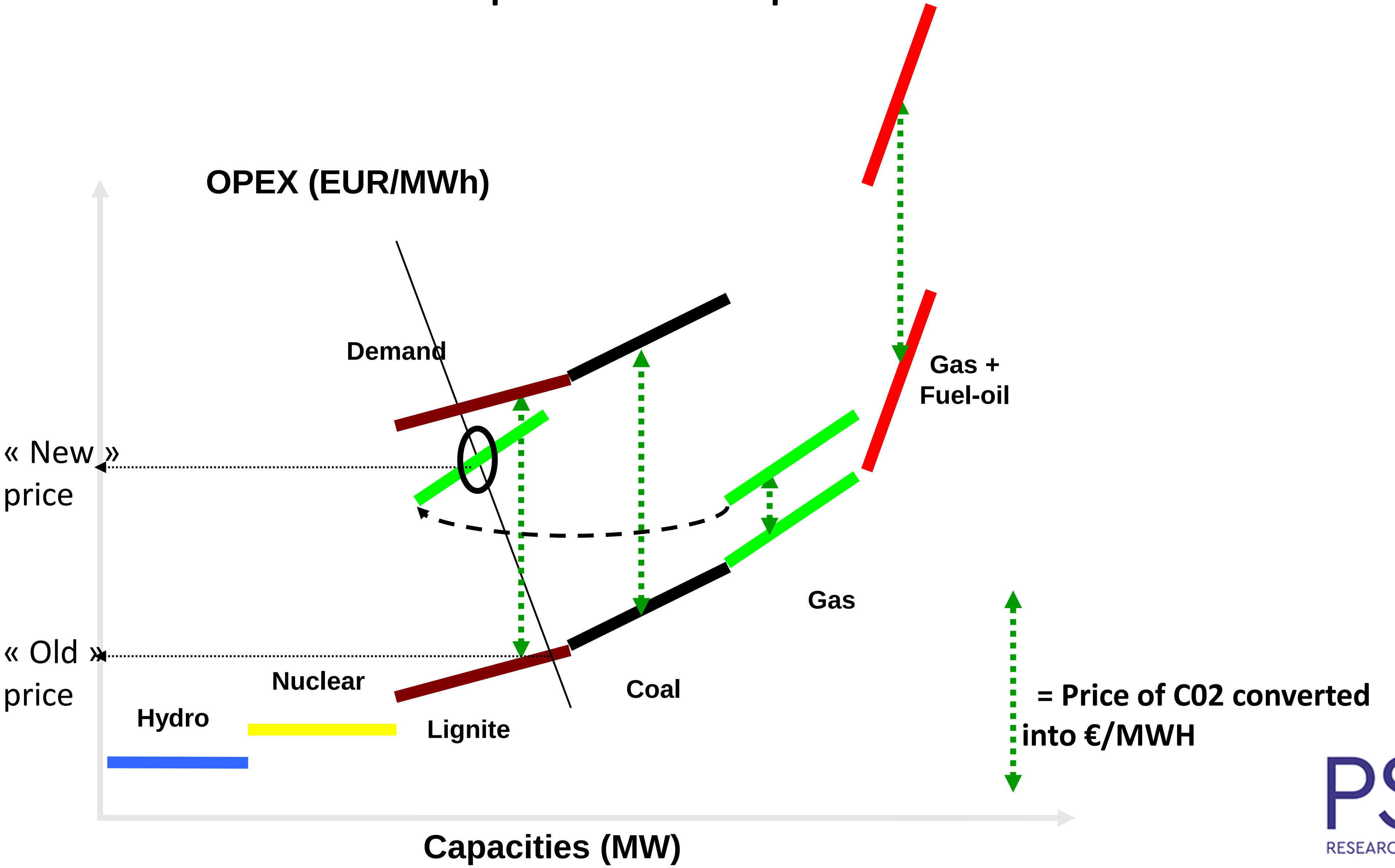
Prices: CO2 price impact



Prices: aggregated offer and demand curve for October 19th 2009

October 19th 2009 - 14h

Prix : 87,3 €/MWh & volume = 6,2 GWh

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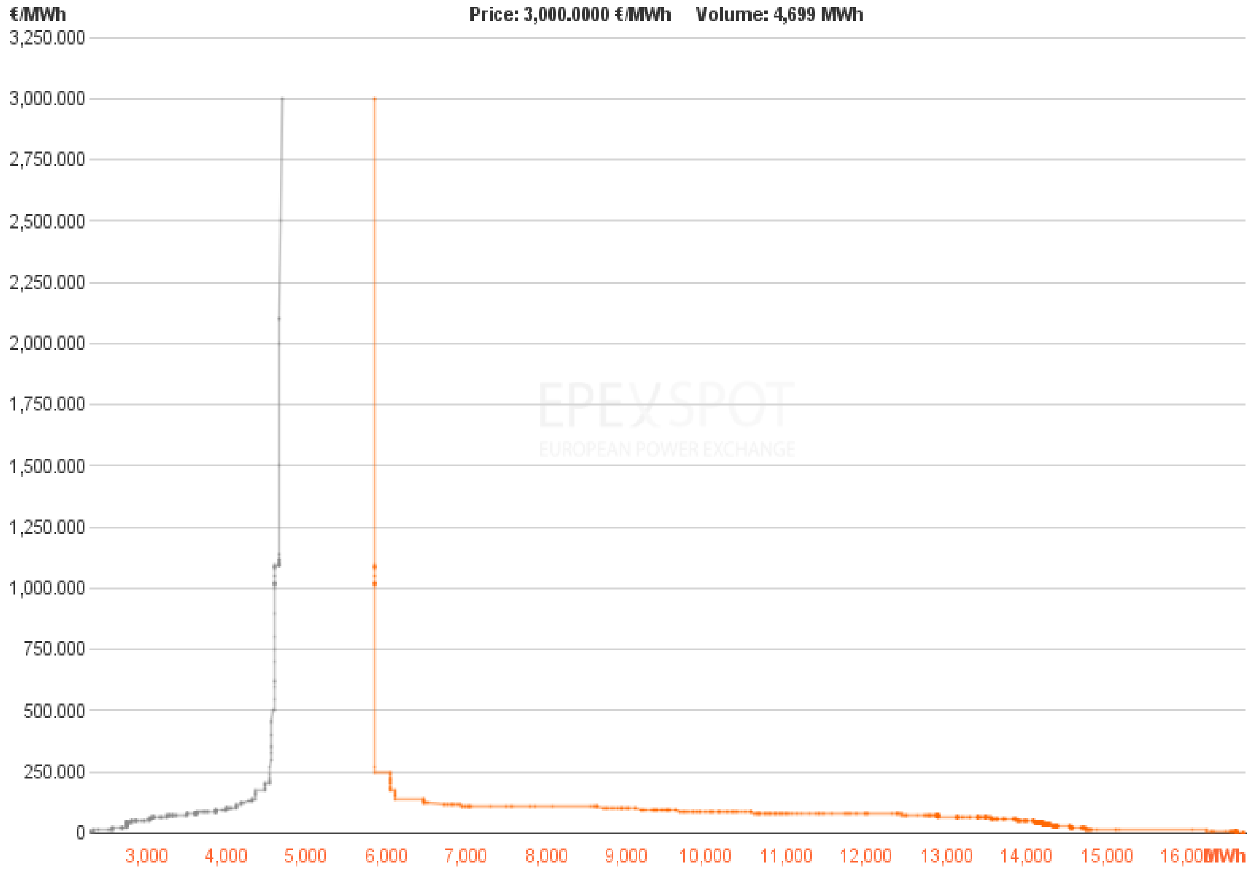
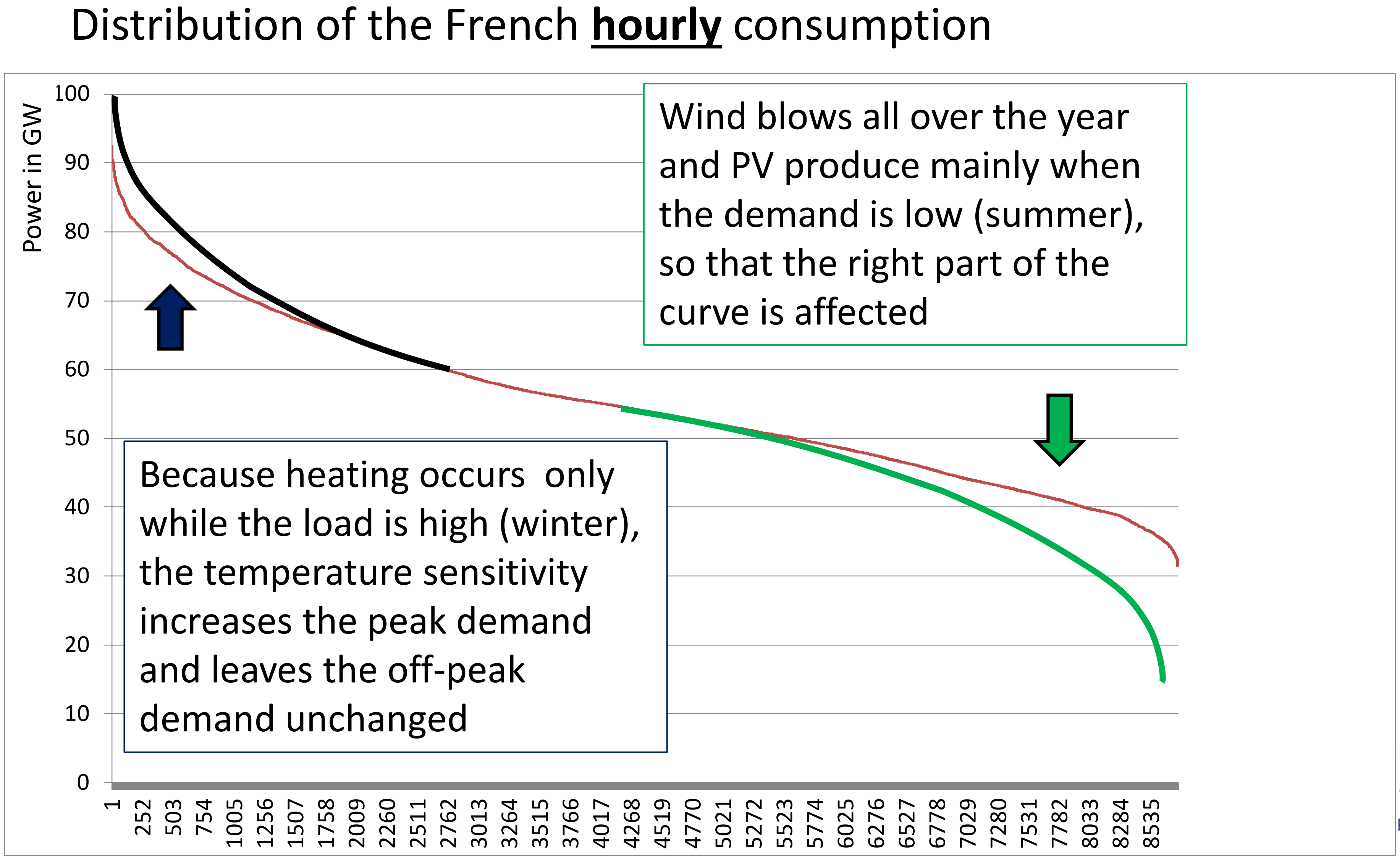
Prices: aggregated offer and demand curve for October 19th 2009

October 19th 2009 - 8h

Prix = 3000 €/MWh - Volume = 4,7 GWh



The distribution curve: French example



FOSSIL FUELS

Europe Mothballs 20GW of Gas Plants in 2013, With More to Come

And that figure could spike to 110 gigawatts by 2017.

KATHERINE TWEED | MARCH 28, 2014

Europe Mothballs 20GW of Gas Plants in 2013, With More to Come

Photo Credit: Statkraft

https://www.greentechmedia.com/articles/read/europe-mothballs-20gw-of-gas-plants-in-2013-with-more-to-come#gs.v4lwxOg

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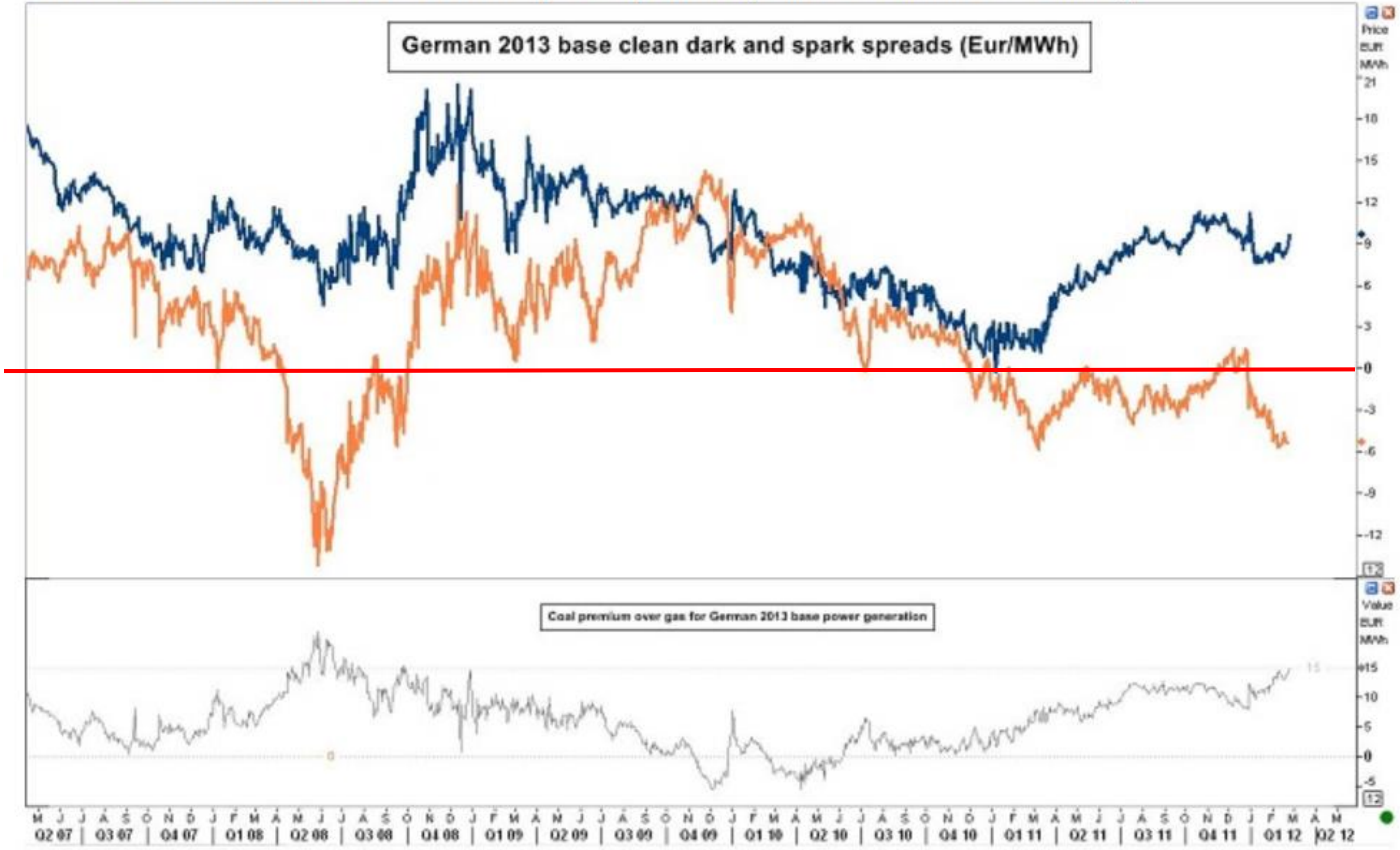
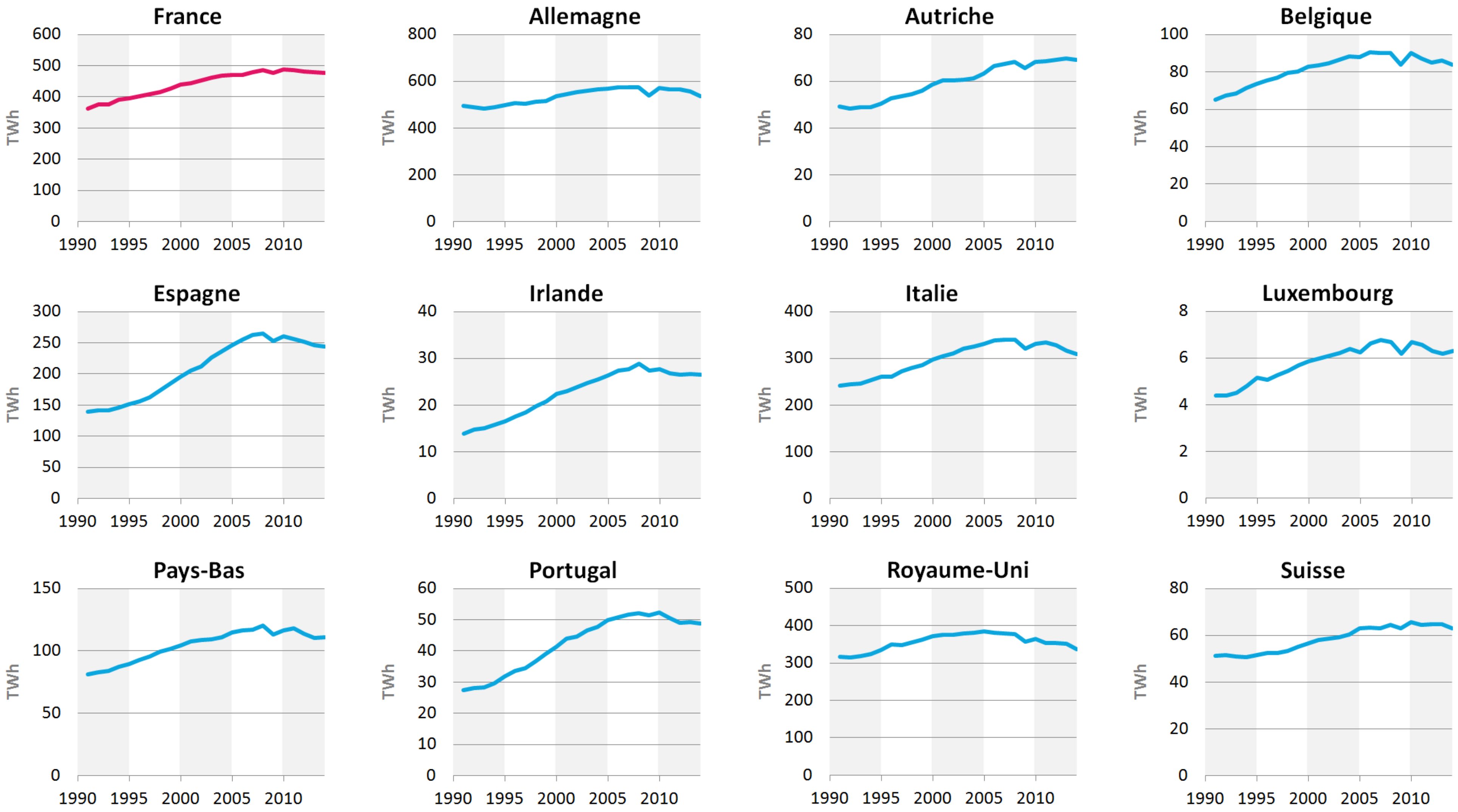
“A tough spread environment” (2012-03-05)

Chart 1: **German clean dark and spark spreads** (source Thomson Reuters)



https://www.timera-energy.com/a-tough-spread-environment/

Demand has stalled all over Europe



Source: RTE BP 2015

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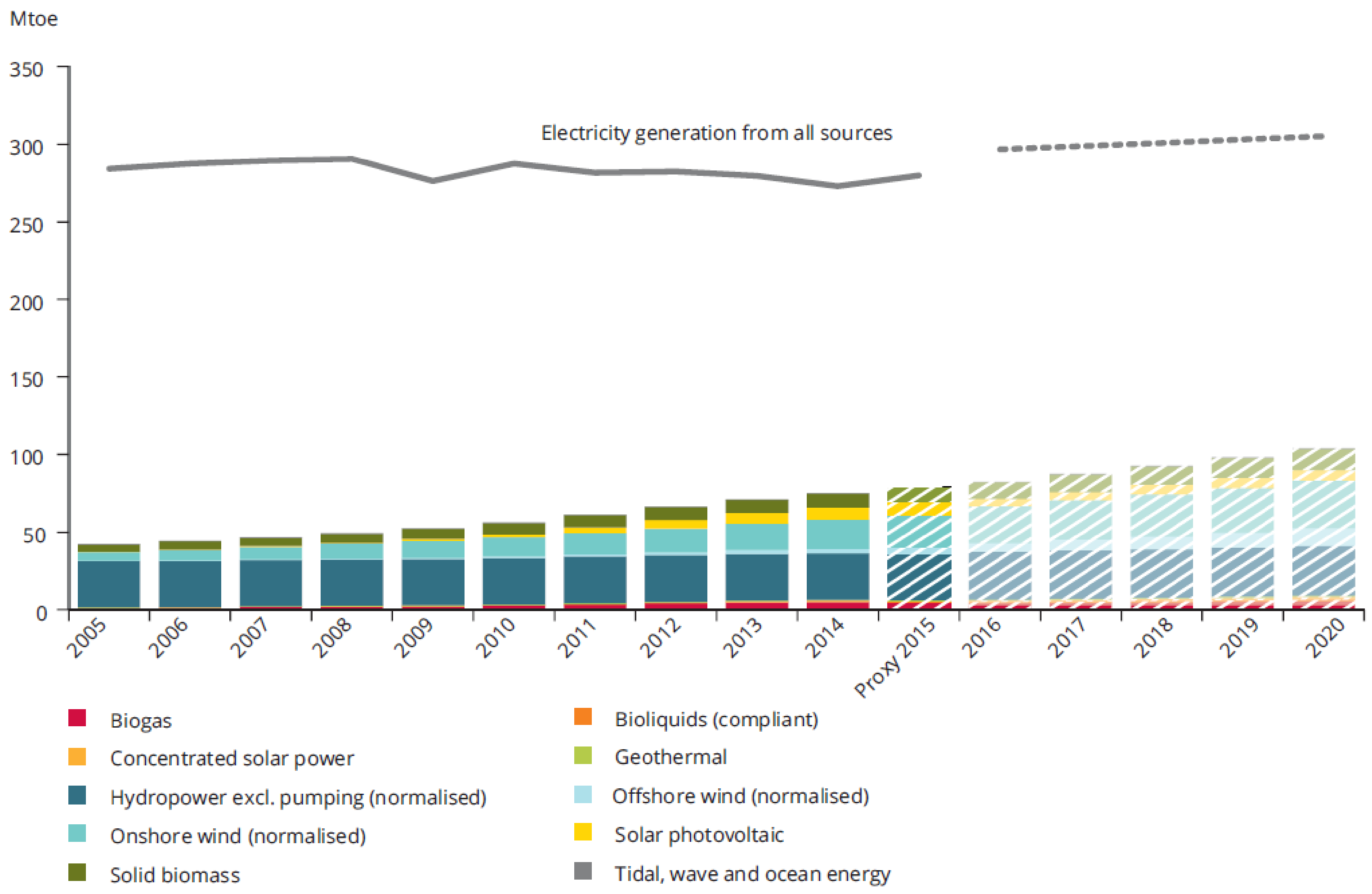
Renewable generation has increased

Figure 2.3 **RES-E in the EU-28**



Notes: This figure shows the realised final RES-E consumption for 2005-2014, approximated estimates for 2015 and the expected realisations in the energy efficiency scenario of the NREAPs for 2016-2020. Wind power and hydropower are normalised. The consumption of RES accounts for only biofuels complying with the RED sustainability criteria.

Sources: EEA; Eurostat; NREAP reports.

Source: Renewable energy in Europe 2017 (EEA report)

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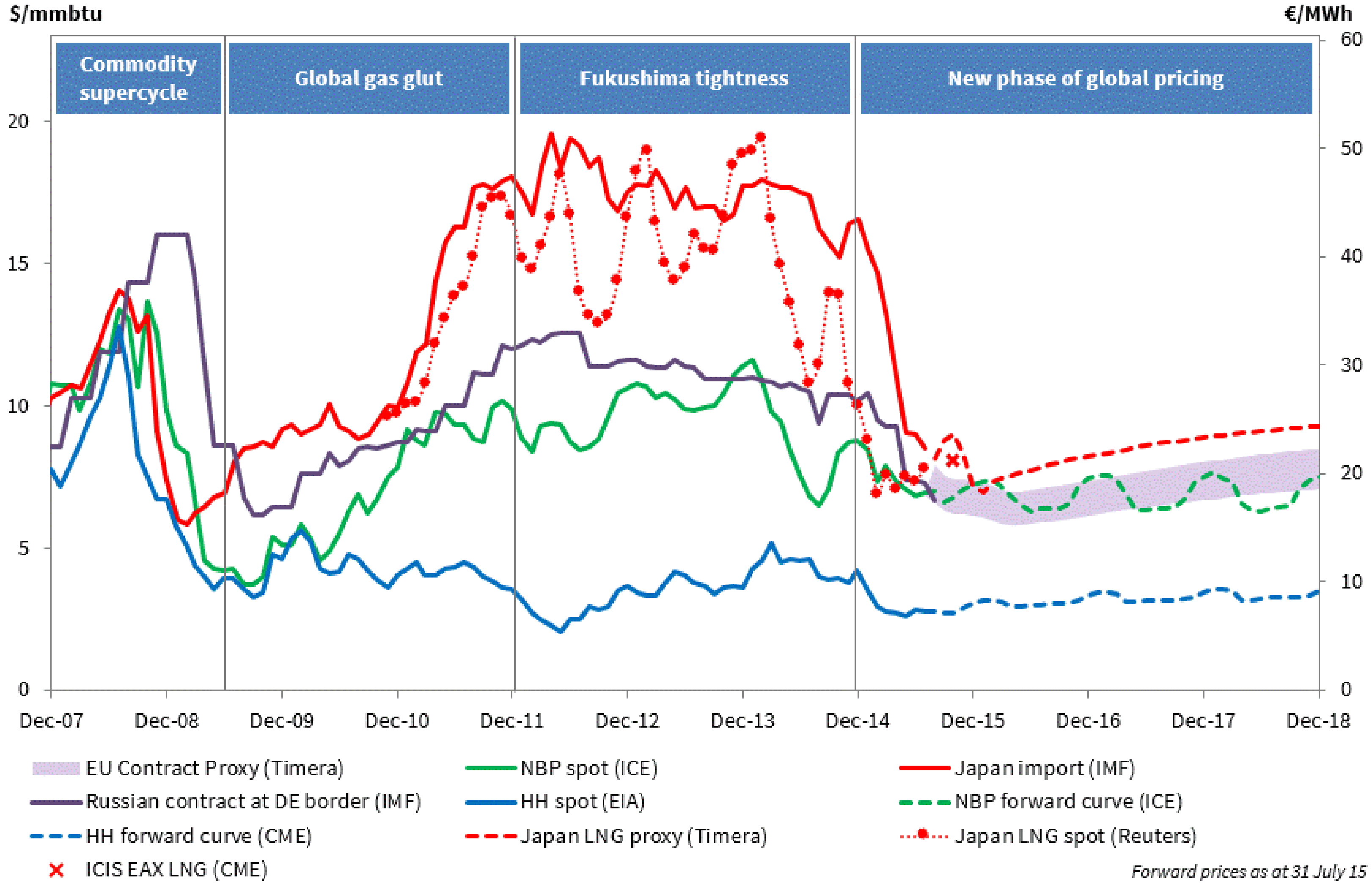
Gas price has increased



(NBP=UK)
(HH=USA)

https://www.timera-energy.com/structural-transition-in-gas-prices/

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Thermal coal price has decreased

http://www.infomine.com/investment/metal-prices/coal/all/

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The capacity issue

- Power plants were closing all over Europe because they could not run often enough…
- While they were needed to ensure adequacy (avoid lost load/curtailment)!
- The theory cannot explain it. Only “inefficiencies” do:
  - Curtailment events are rare and difficult to forecast
    - “Rolling blackouts”: never occurred in the past 30 years in France (but prepared during 2016-2017 winter).
    - Spikes on the spot market: none since 2009.
  - The curtailment price (maximum price) is too low (3 000 €/MWh) to ensure sufficient reliability.
    - And too high for some those who pay…

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INDUSTRIE

L'incroyable pic des prix de l'électricité en Bourse

LES ECHOS | LE 09/02/2012

1 / 1

La vague de froid pousse le système électrique à sa limite. Hier à 19 heures, la France a battu un nouveau record de consommation, à 101,7 gigawatts, dépassant celui de 100,5 atteint la veille. Conséquence de cet emballement, le marché de l'électricité est de plus en plus tendu. Sur la Bourse Epex Spot, le prix du mégawattheure pour livraison le lendemain entre 10 et 11 heures s'est littéralement enflammé hier, à 1.938 euros. A comparer à un cours de 100 à 200 euros dans une journée d'hiver normale. Face aux températures de 10 degrés inférieures aux normales saisonnières, tous les moyens d'EDF sont mobilisés, sans compter les importations et les efforts d'économies demandés aux grands clients. *« Ce pic de prix traduit la rareté de l'offre »*, juge un opérateur.●

Page 24

https://www.lesechos.fr/09/02/2012/LesEchos/21120-002-ECH_l-incroyable-pic-des-prix-de-l-electricite-en-bourse.htm

The “right” price cap

- By the French law, the curtailment expectancy should be 3 h/year.
- Therefore, the installed unit with the most expensive marginal cost will run only 3h/year on average (more realistically 30 h every 10 years given the French peak is linked to infrequent cold waves).
- Therefore, its revenue will be 3 * price cap and should pay for its costs. Assuming an OCGT cost of 60 k€/year, the price cap should be 20 k€/year.
- Some countries have higher price caps:
  - Australia: 14 200 AUS/MWh = 9 230 €/MWh

https://en.wikipedia.org/wiki/National_Electricity_Market

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Capacity mechanism

- A mechanism was set up so that consumers directly pays producers for the capacity that will be able a few years ahead.
- An auction was made in December 2016 for the year 2017.

EPEXSPOT

EUROPEAN
POWER
EXCHANGE

PRESS RELEASE

EPEX SPOT successfully launches first auction of French capacity market

Capacity guarantees were traded for 999,98 Euros on 15 December 2016

Paris, 15 December 2016

- It adds to the other revenues of the capacity owner (spot market, reserve markets…)

https://www.epexspot.com/document/36737/2016-12-15_%20Launch%20of%20French%20capacity%20mechanism.pdf

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RTE’s adequacy report

- Named “Bilan Prévisionnel” (BP) in French.
- A mission of RTE as part of its public service.
- Assess the adequacy of the supply to the demand between 5 and 20 years ahead.

Method

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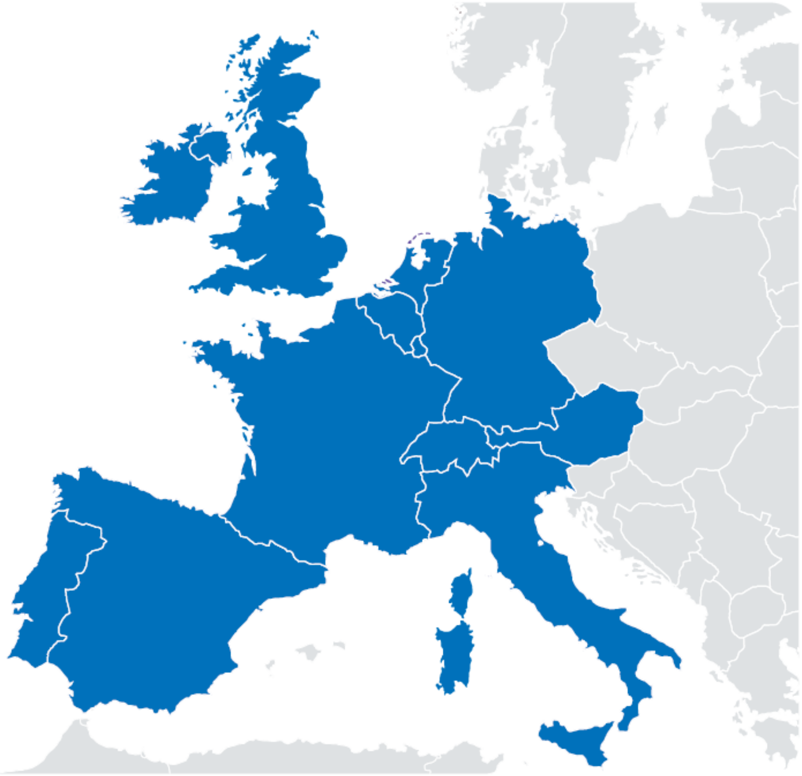
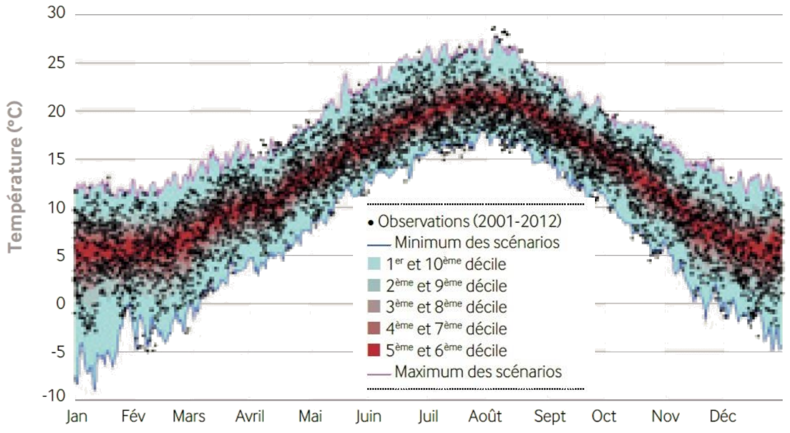
A European, transparent, probabilistic model

Study perimeter of the 2015 adequacy study

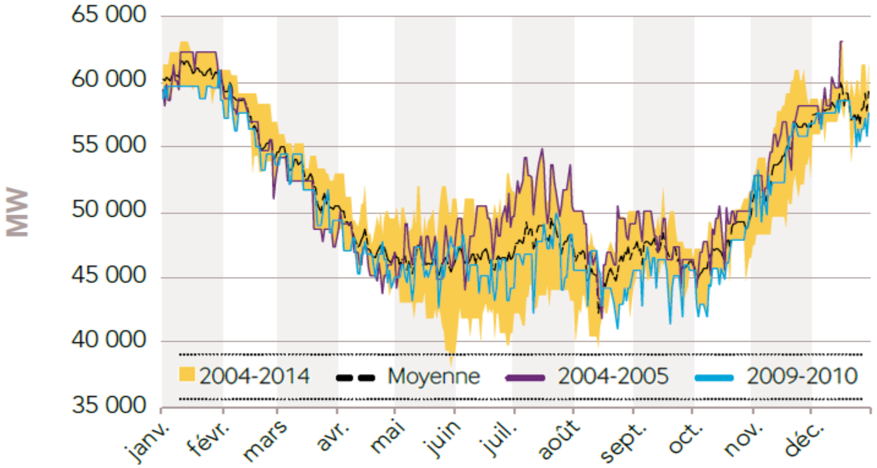


- Explicit modelling of European countries

Daily temperatures: simulations and observations



Availability of nuclear generation



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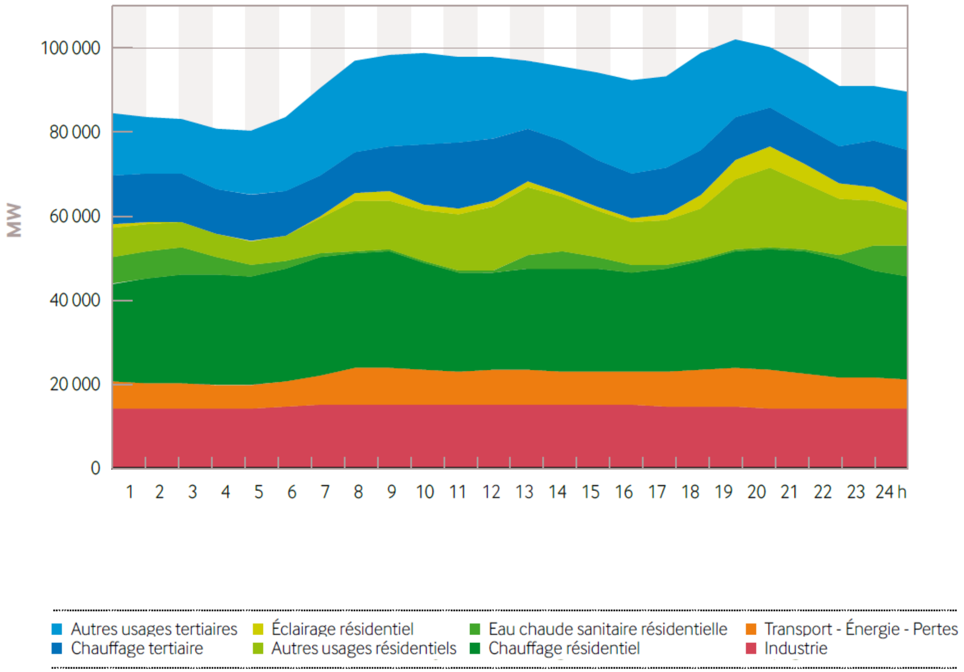
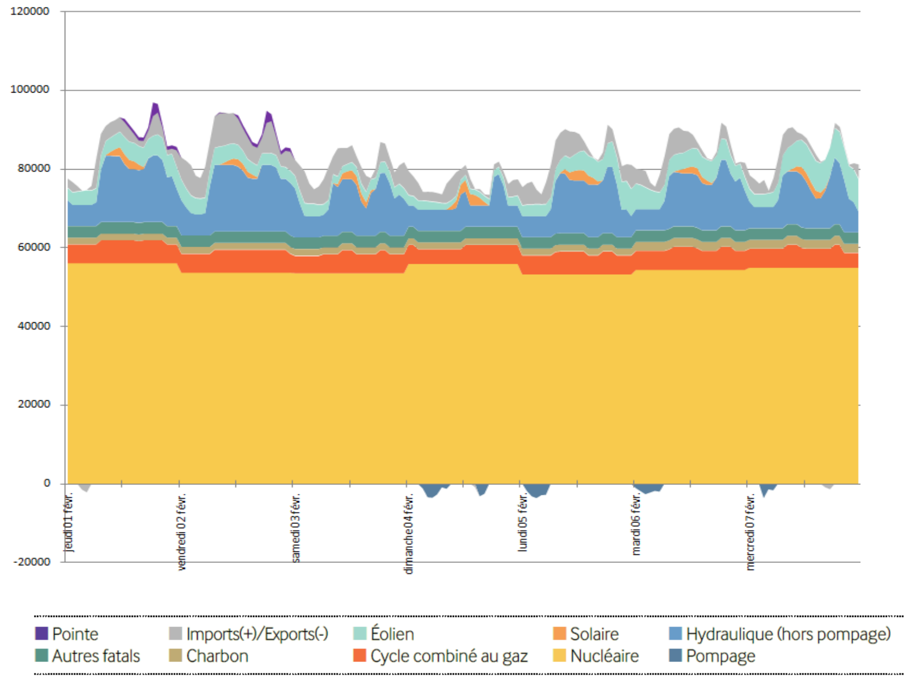
A technical and economical modelling by stacking

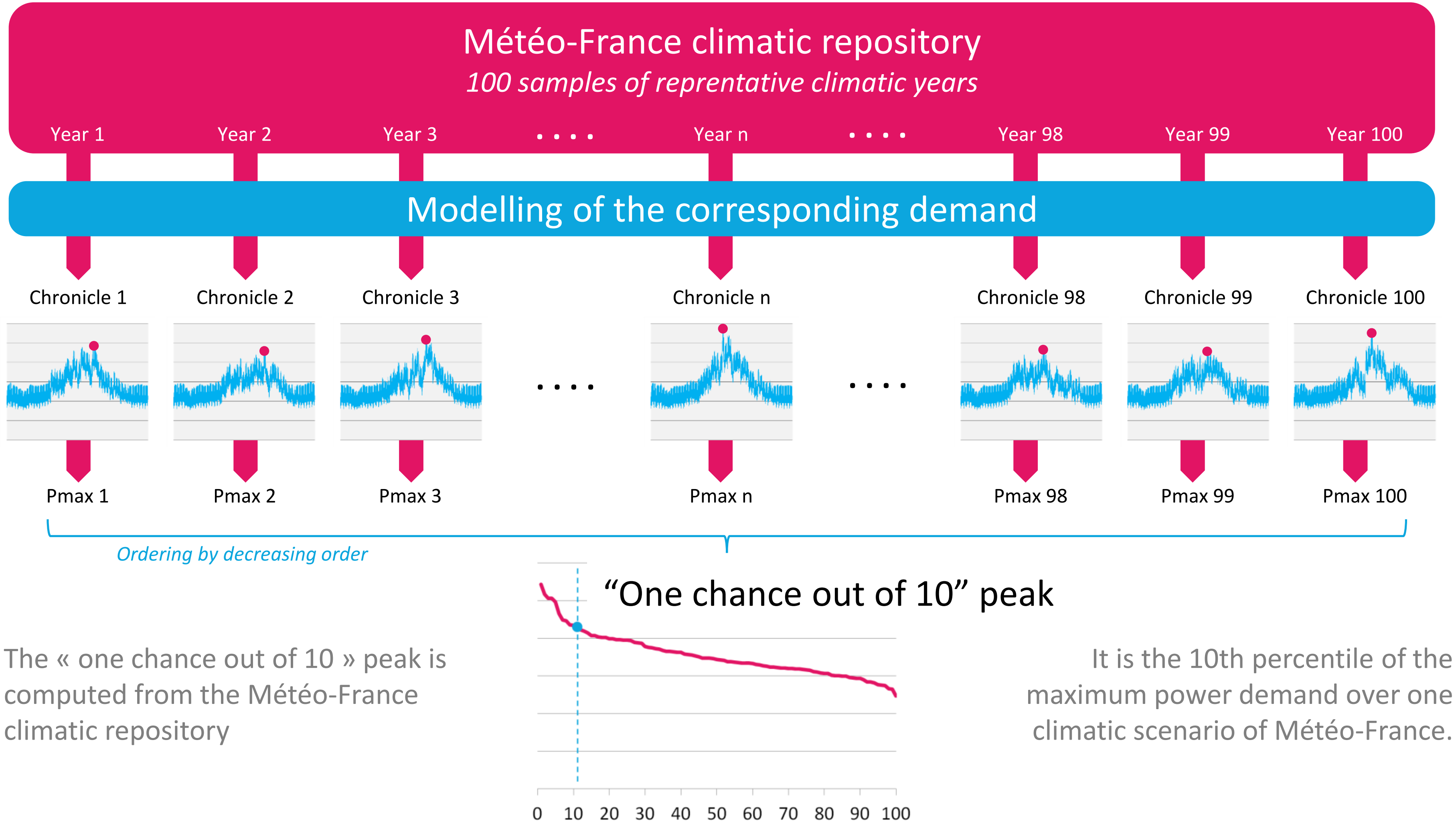
Estimated decomposition of the load curve for a very cold working day of 2012



Example of a generation mix for a winter week of 2017-2018 seen from 2015 Scenario with a closure of Fessenheim in 2016



“One chance out of 10” peak computation



The « one chance out of 10 » peak is computed from the Météo-France climatic repository

It is the 10th percentile of the maximum power demand over one climatic scenario of Météo-France.

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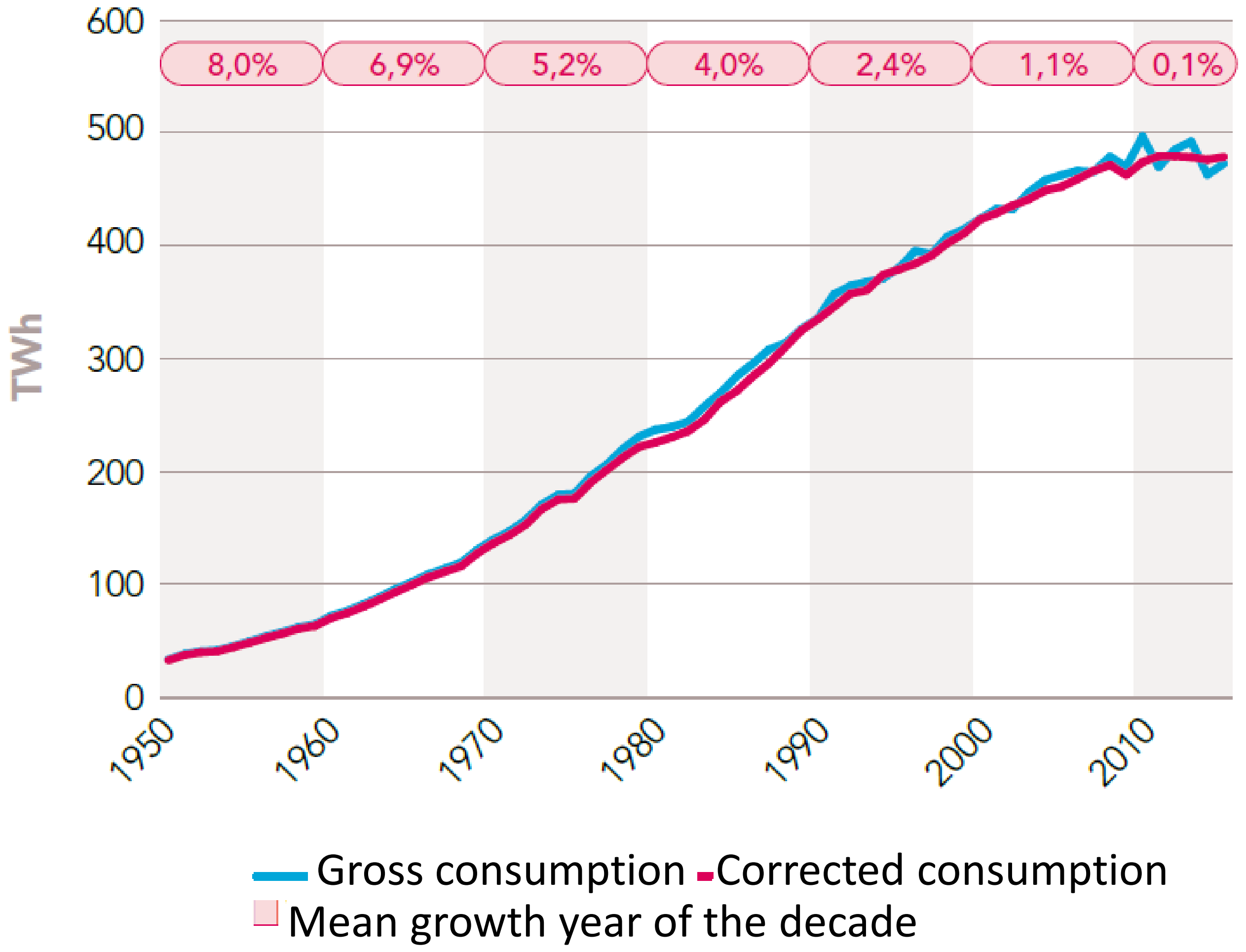
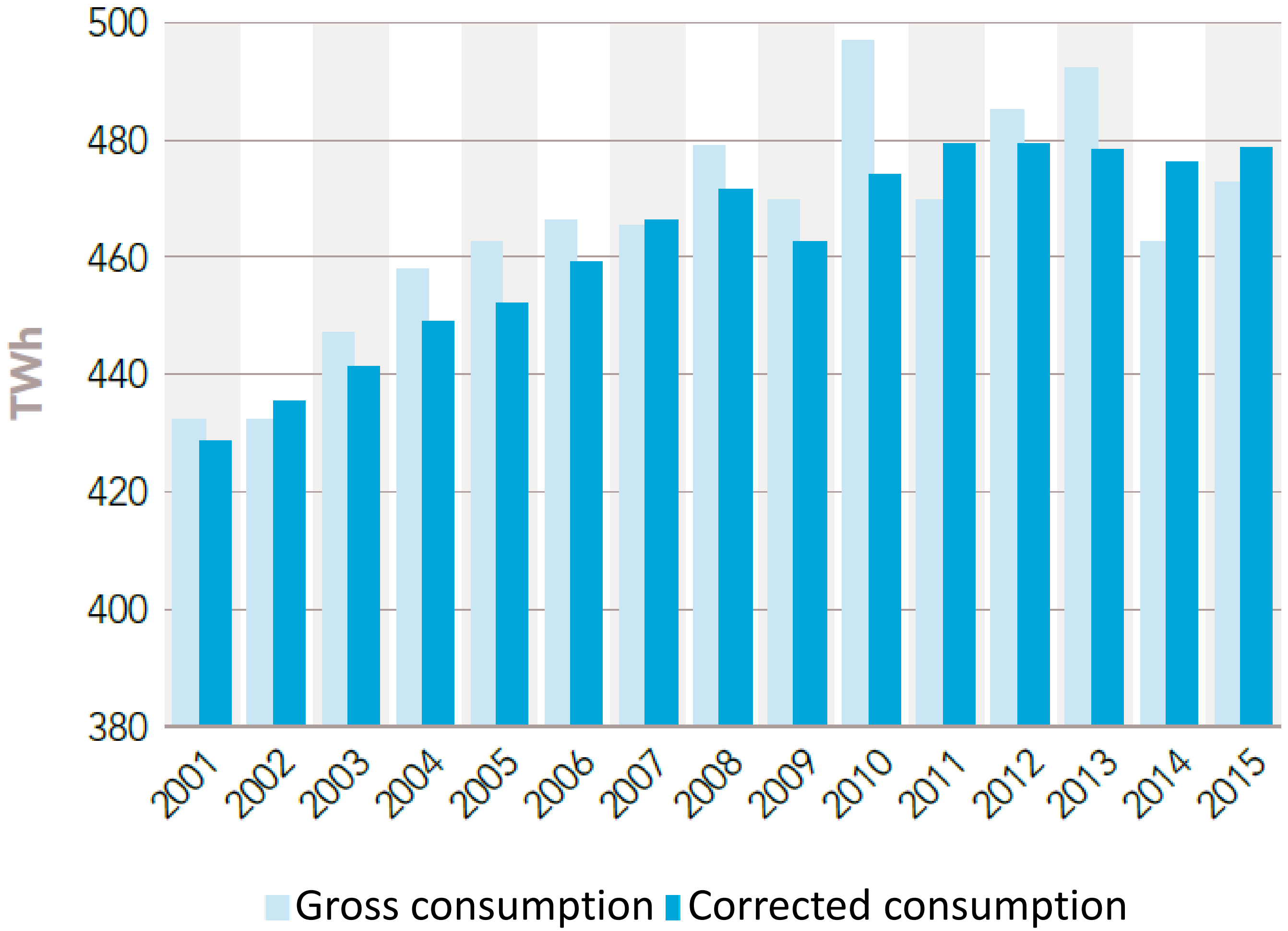
Evolution of demand

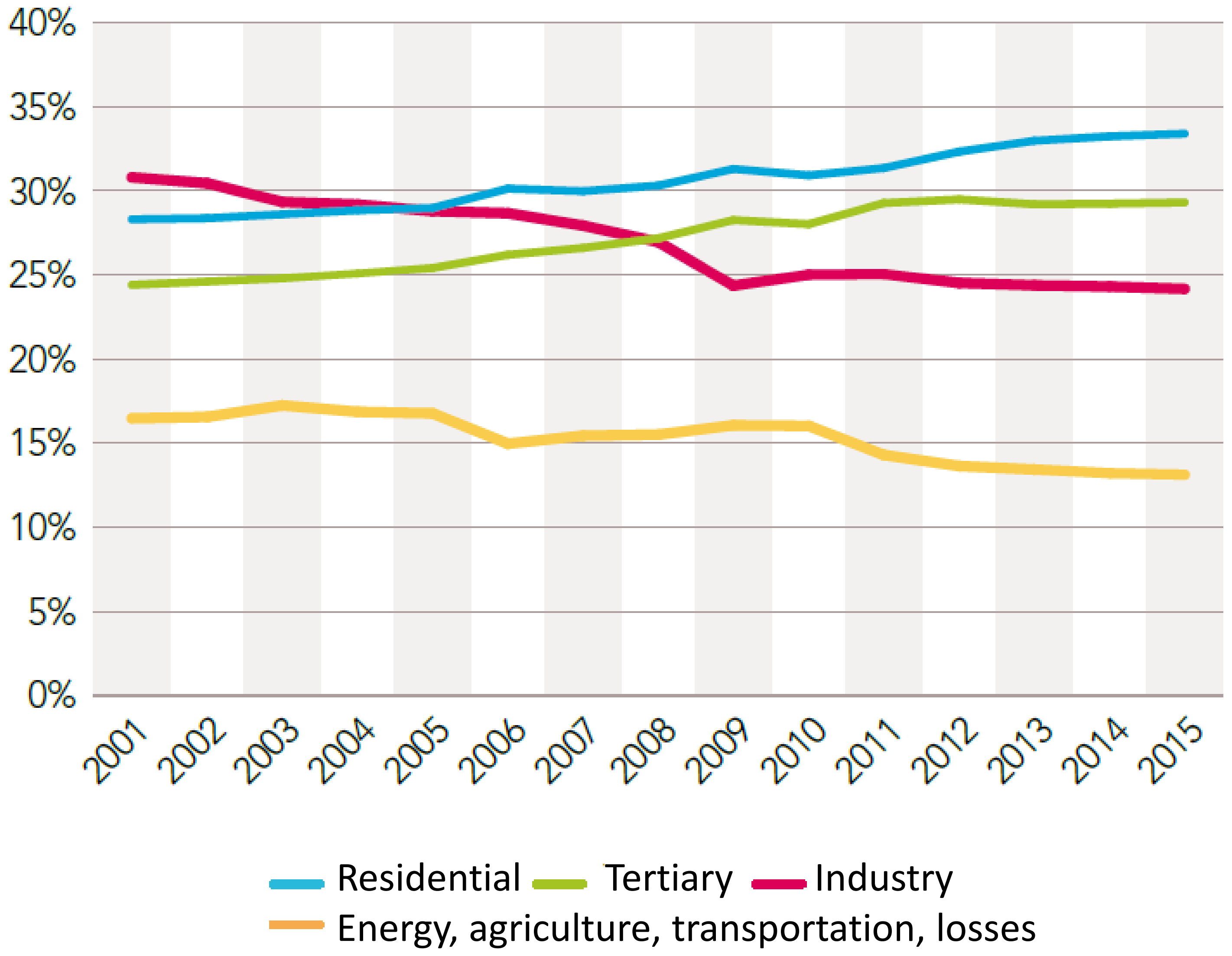
Growth of demand is slowing



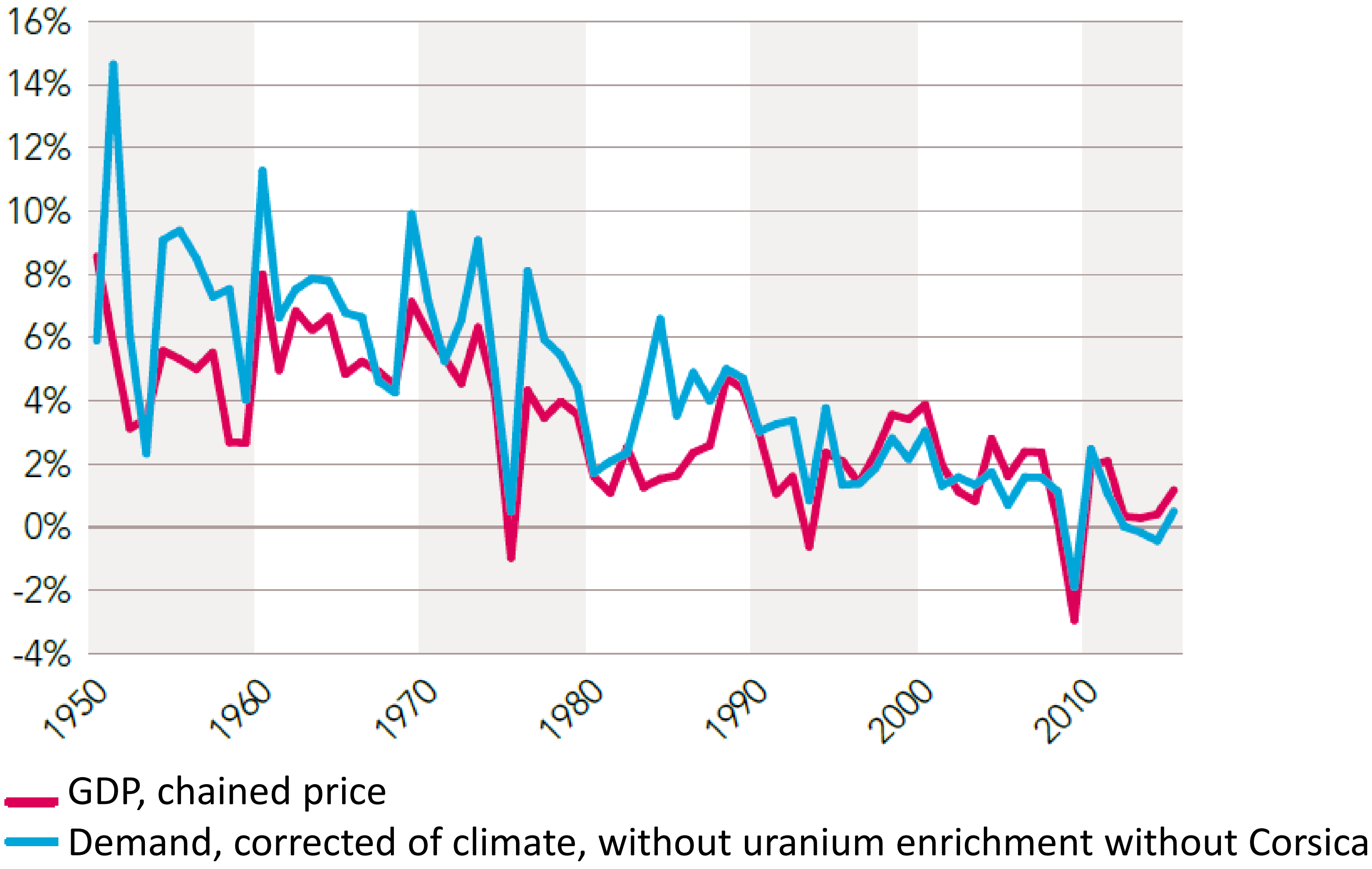
And is even stabilizing



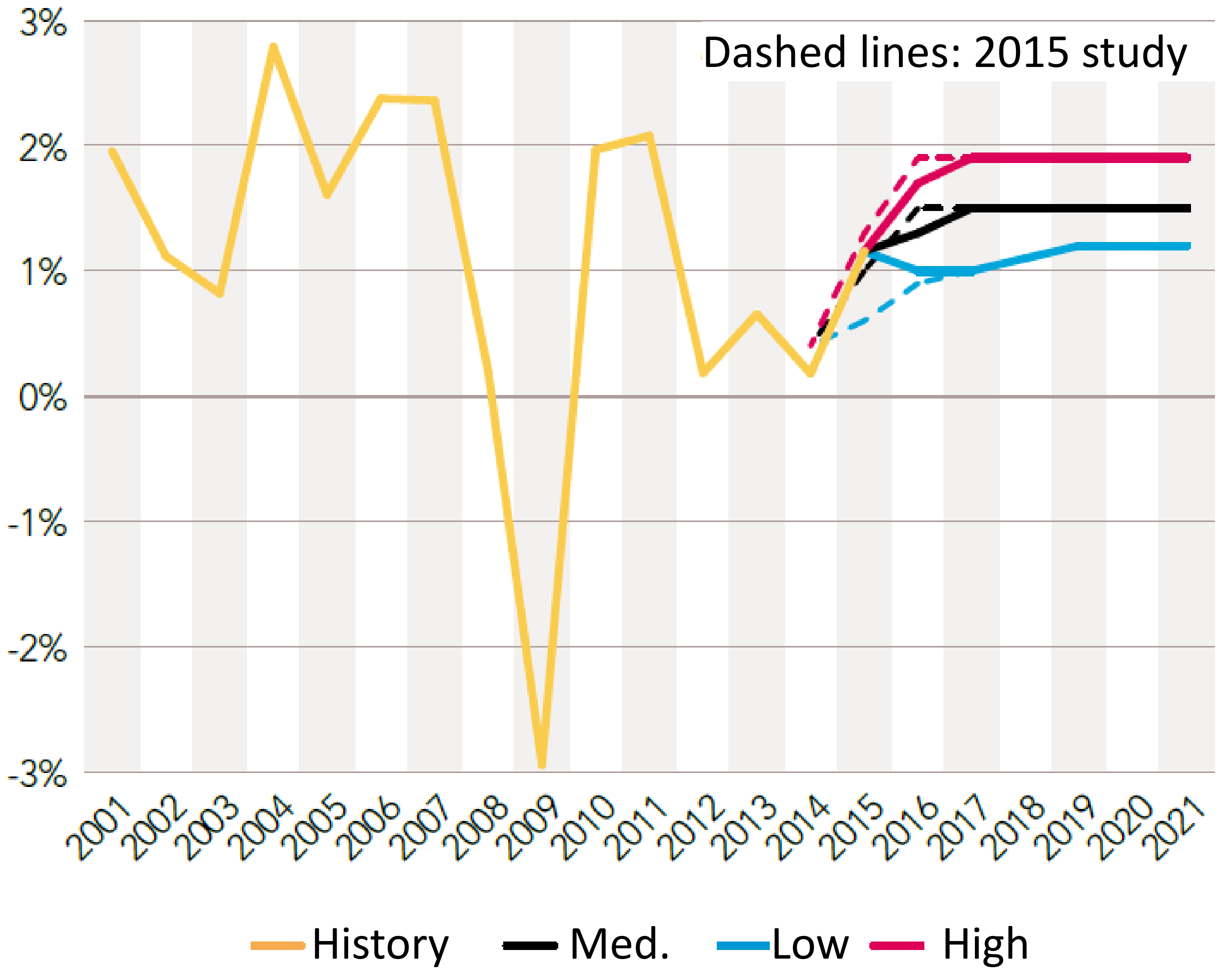
The structure is evolving



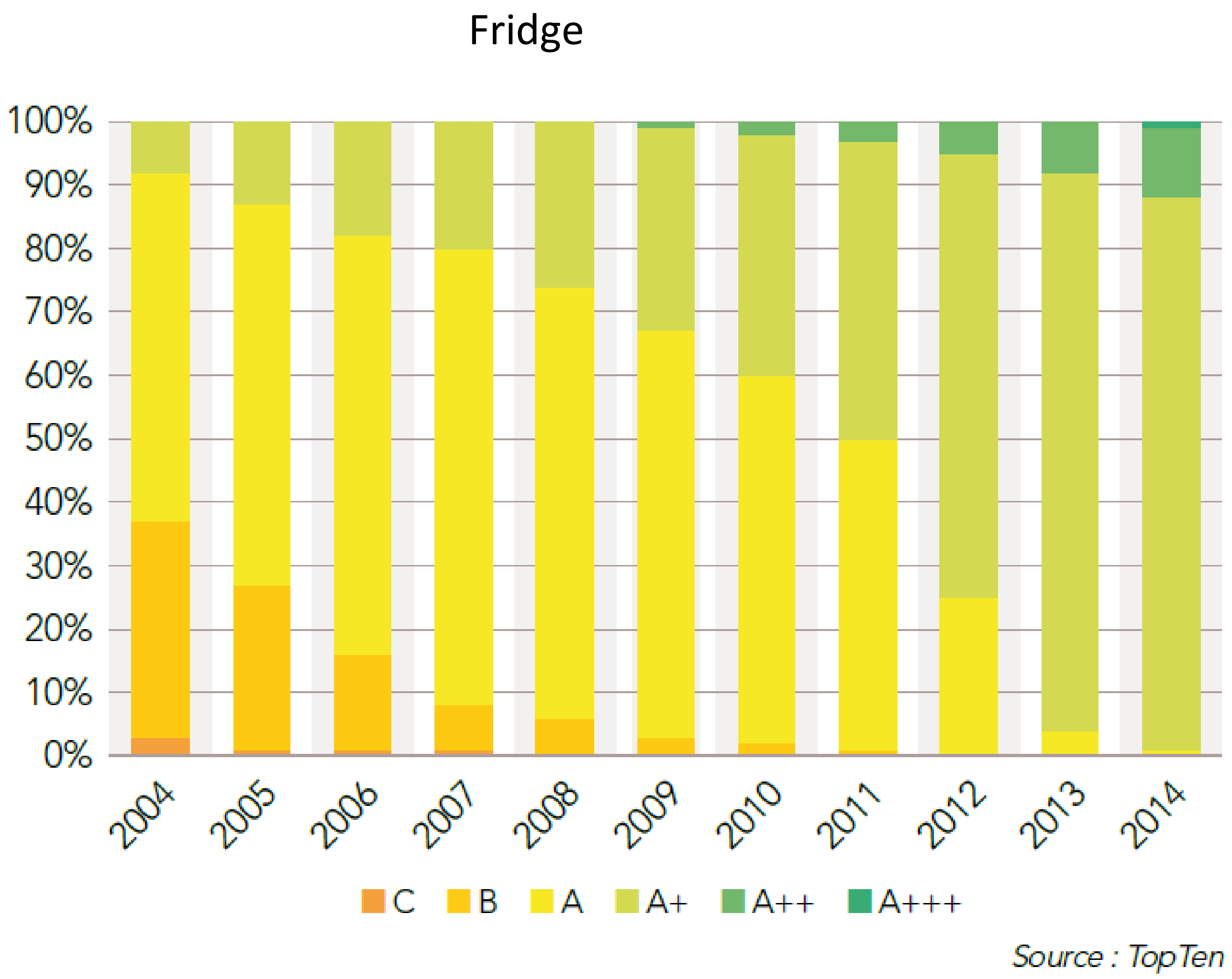
The economic activity is a major driver of the demand



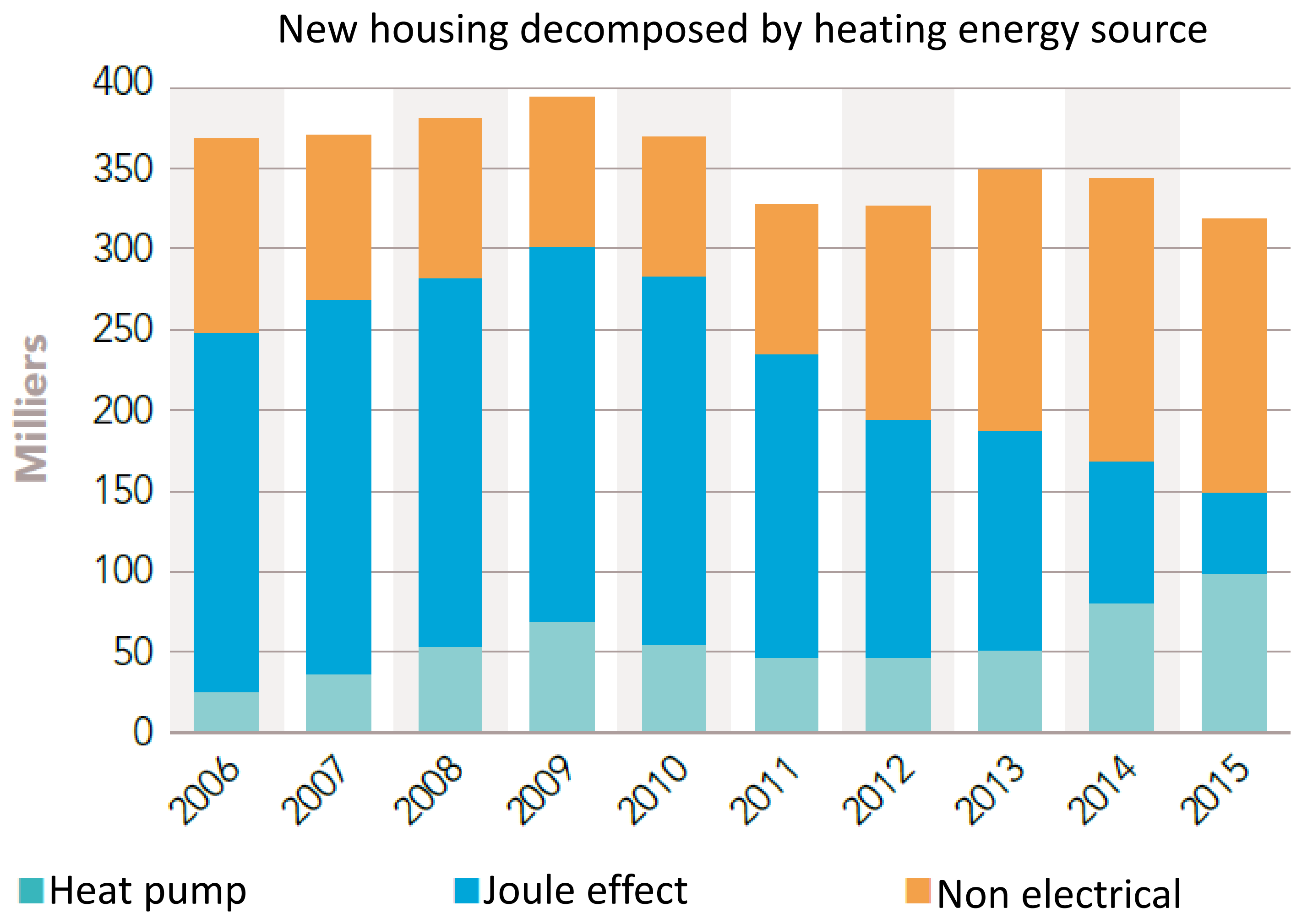
And is the major medium term uncertainty source



Energy efficiency improvement is decreasing the demand

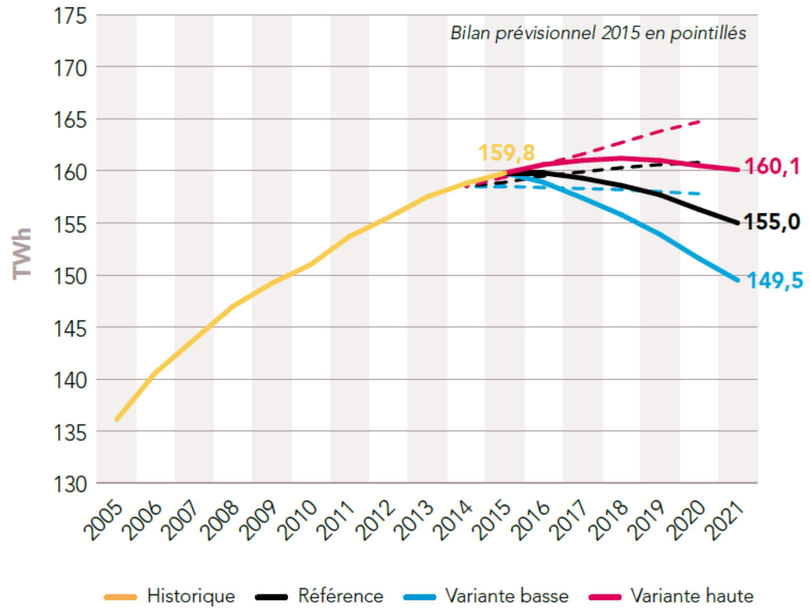


Energy efficiency improvement is decreasing the demand

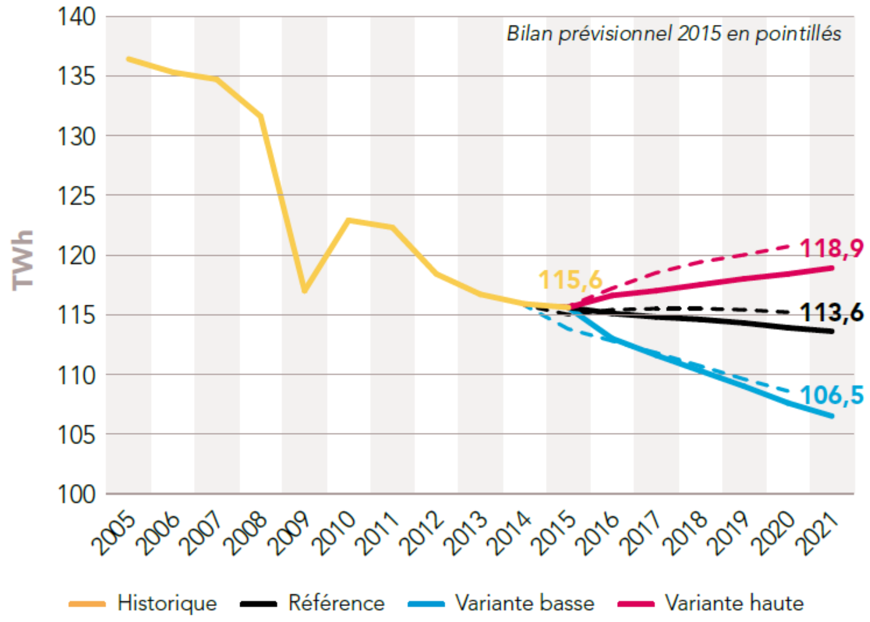


Various dynamics depending on the sector, but low growth.

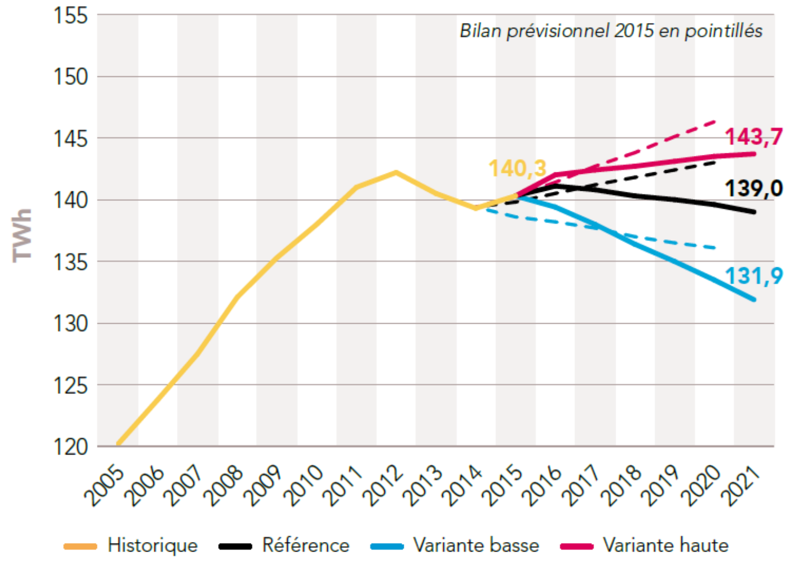
Residential



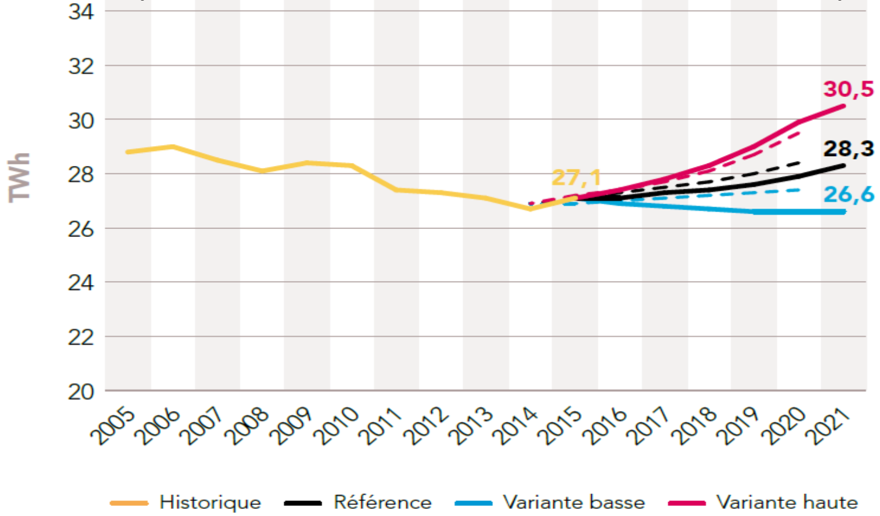
Industry



Tertiary



Transportation, agriculture (without losses and uranium enrichment)



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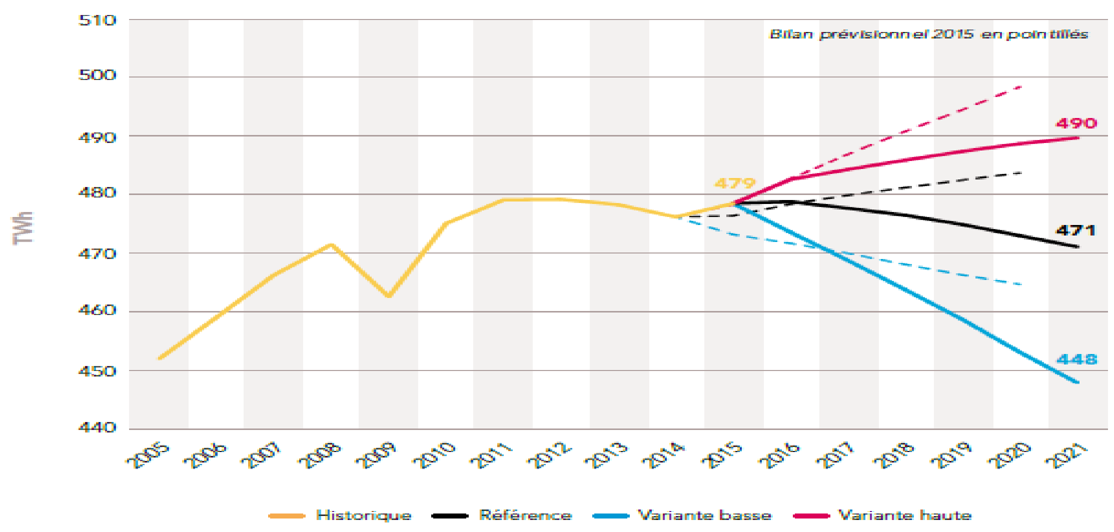
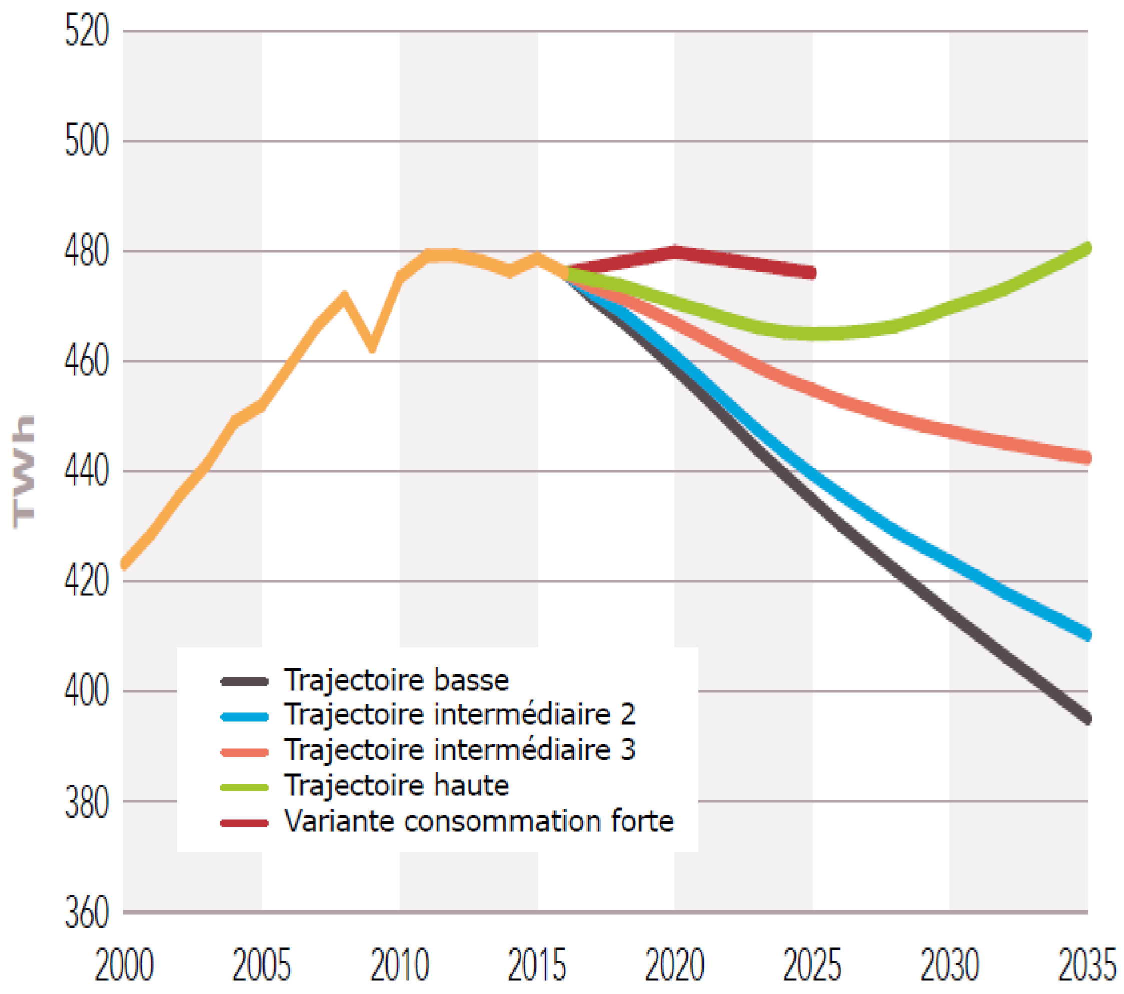
Overall low growth of demand.
In 2017 (right), no growth scenario!





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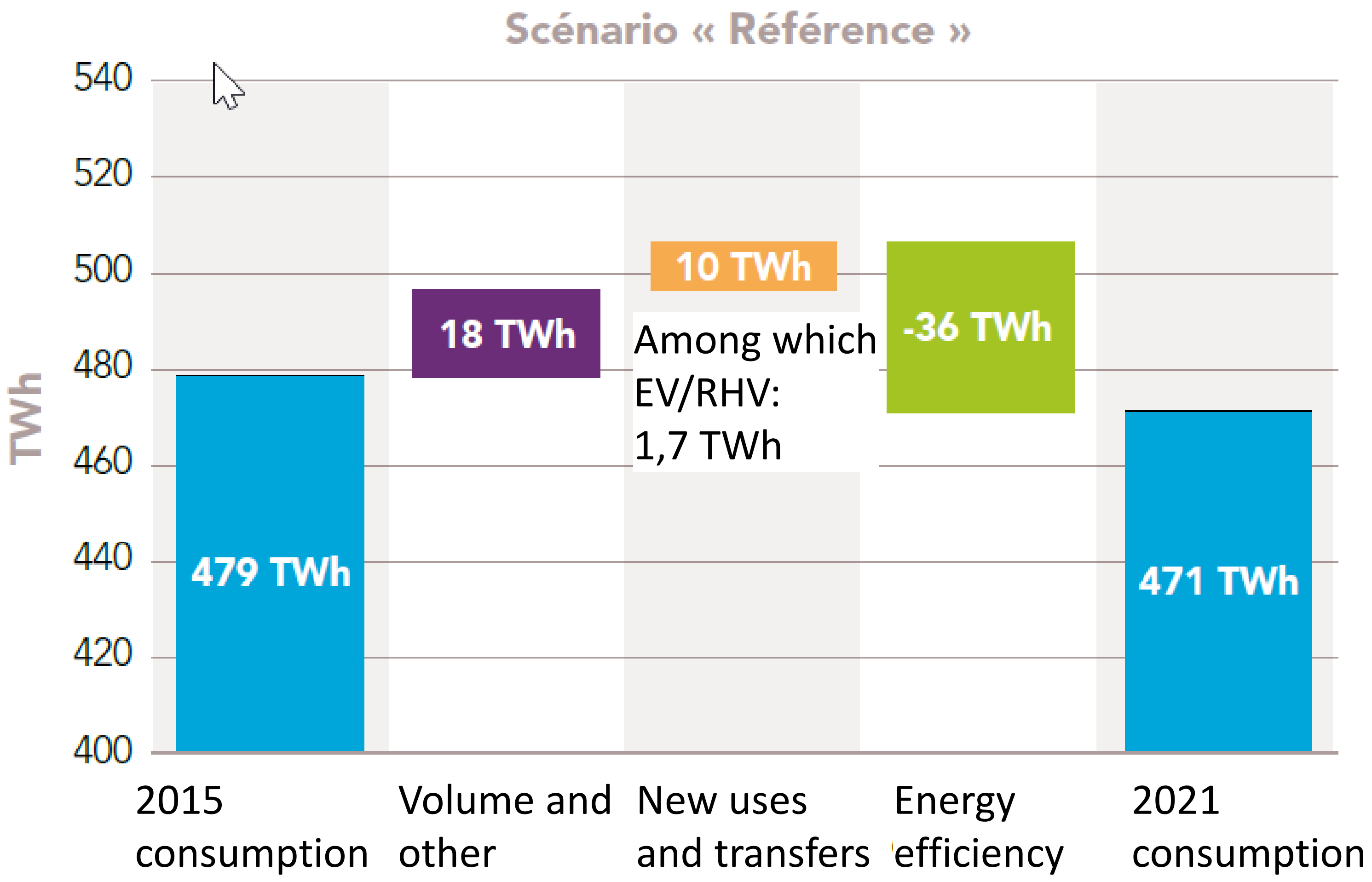
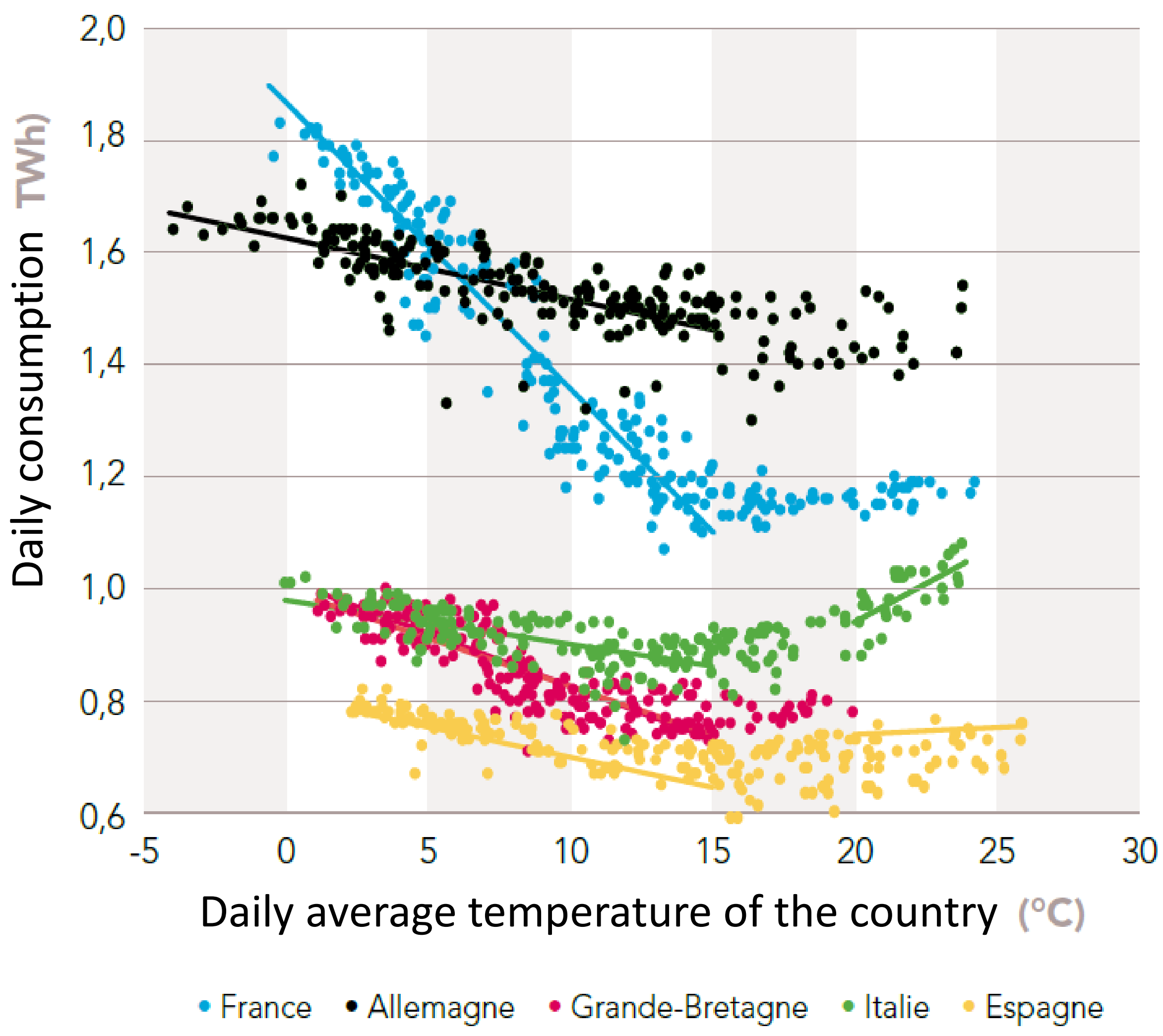
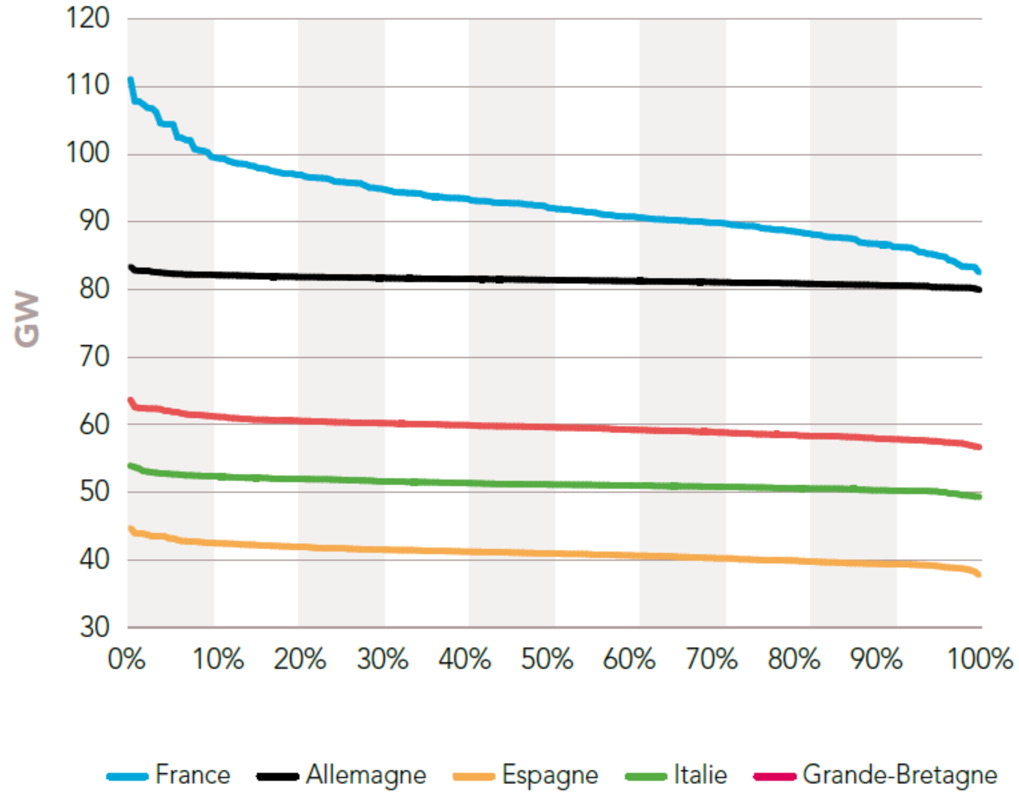
Because of energy efficiency



French thermosensitivity: an exception

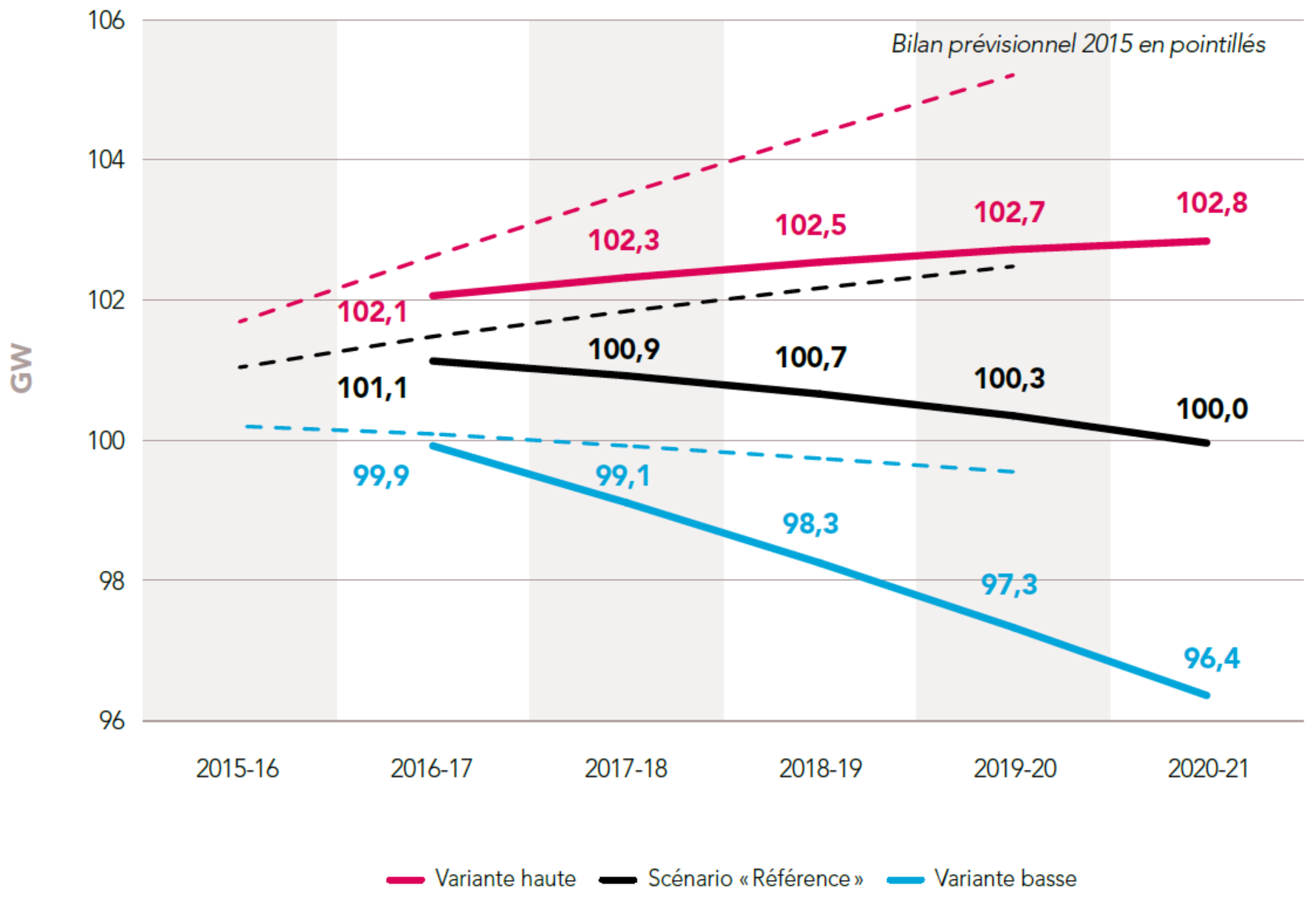


Cumulated distribution of the yearly maximum consumption



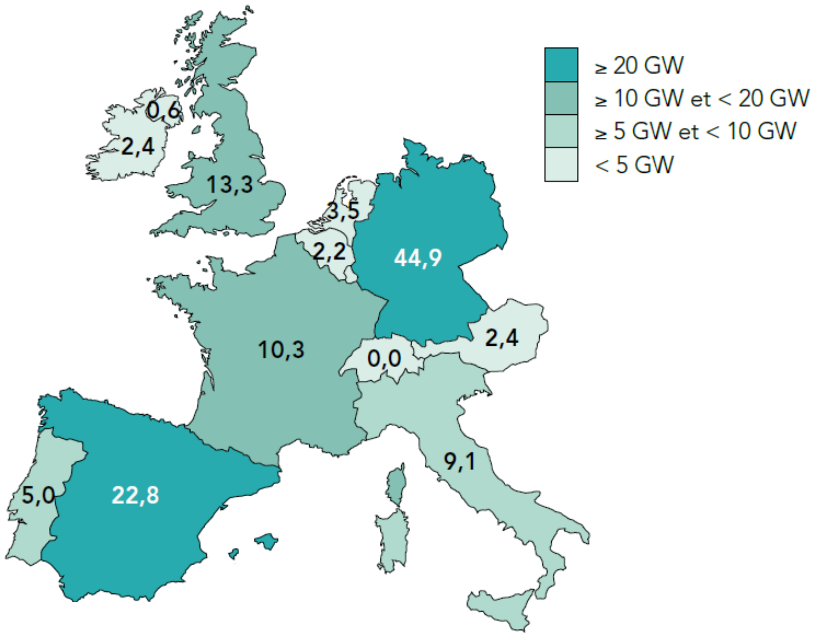
The peak demand growth is also limited by the efficiency

Evolution of the “one chance out of 10” winter peak



Evolution of supply

Wind continues to grow

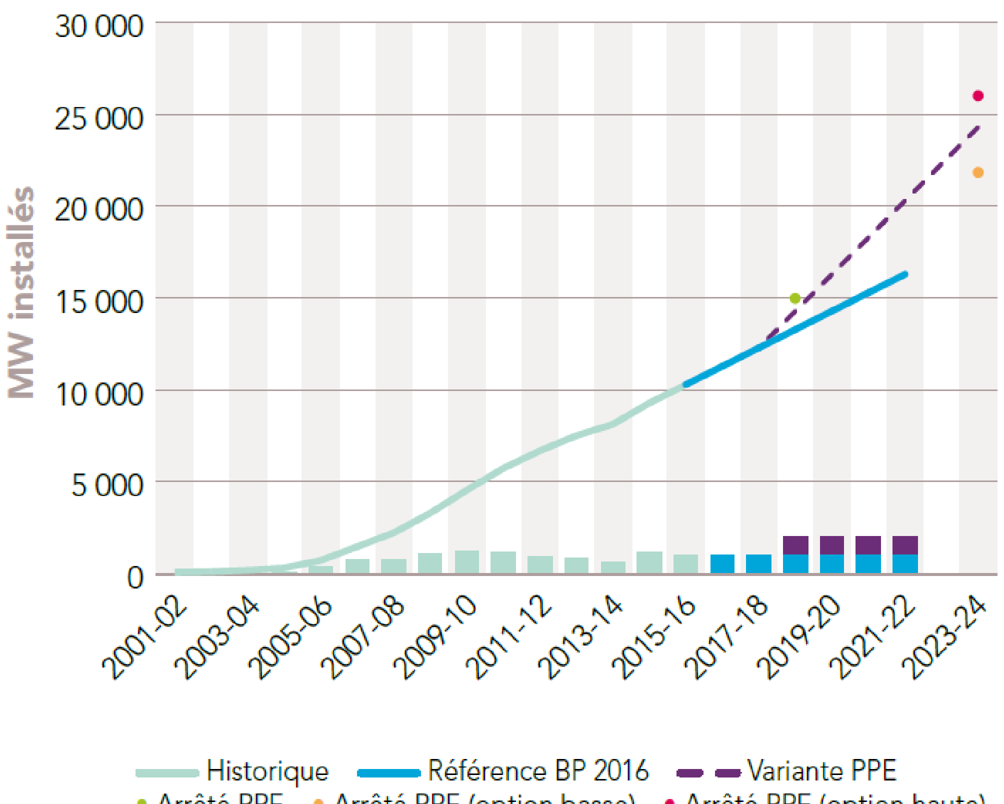


Wind start growing again

- Tariff and reglementary stabilization
- Procedure simplification
- Instruction delays shortening

+1 000 MW/an
On middle term

Wind park evolution hypothesis



Offshore wind is coming on the middle term.

1 000 MW installed
for winter 2019-2020

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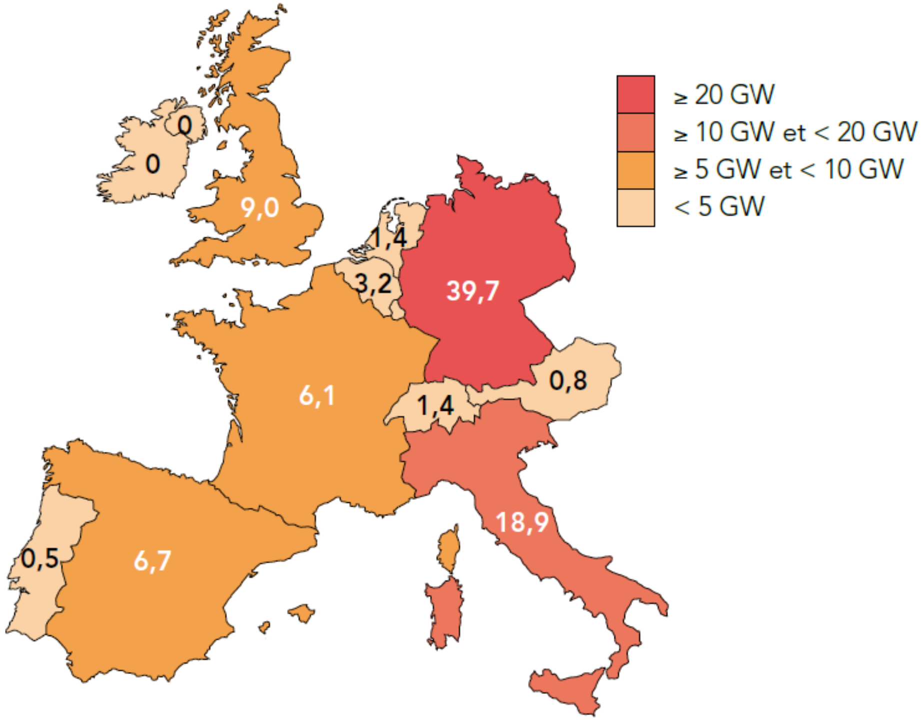
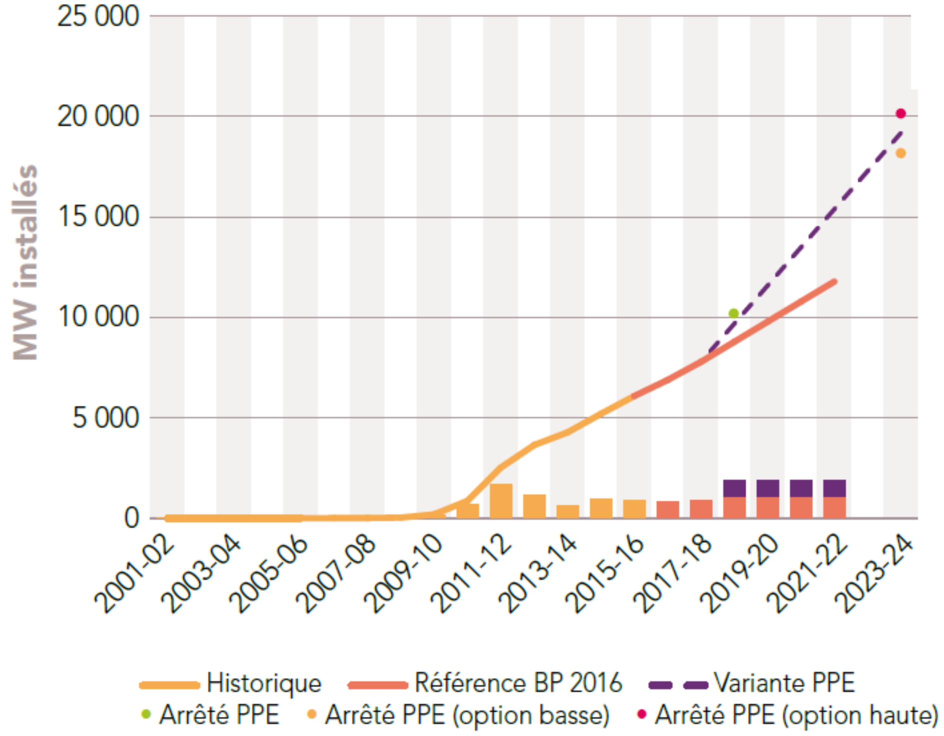
PV continues to grow



+1 000 MW/an
On middle term

PV park evolution hypothesis



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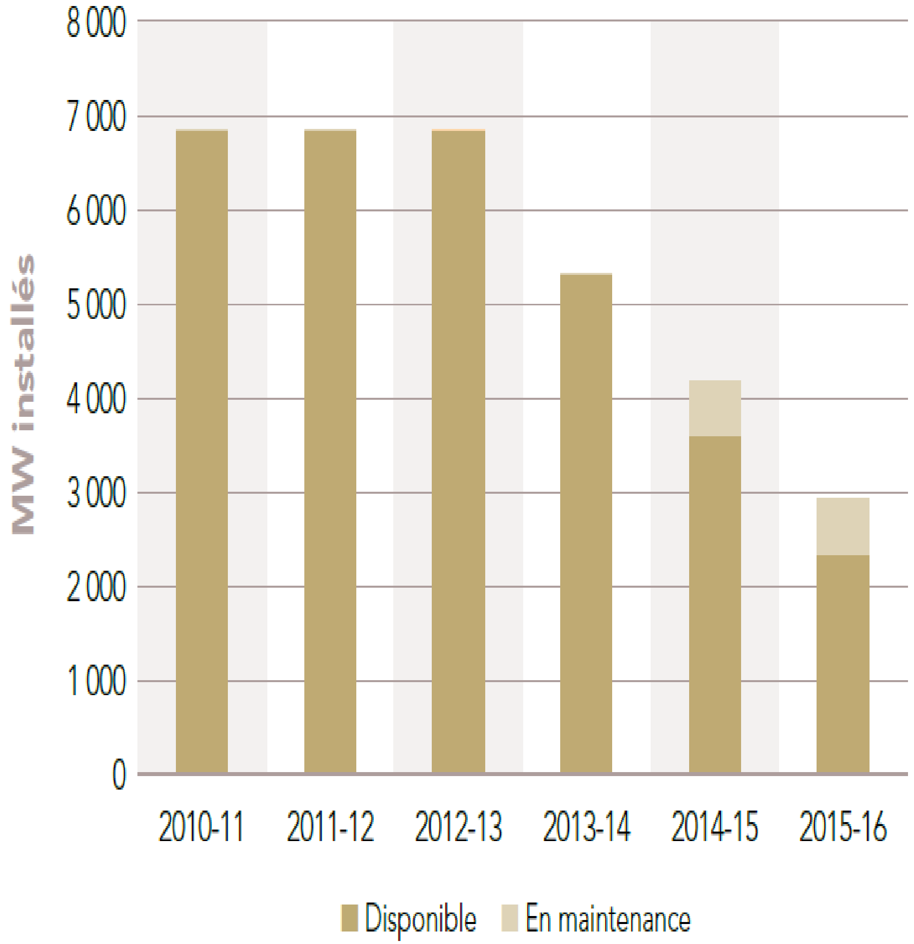
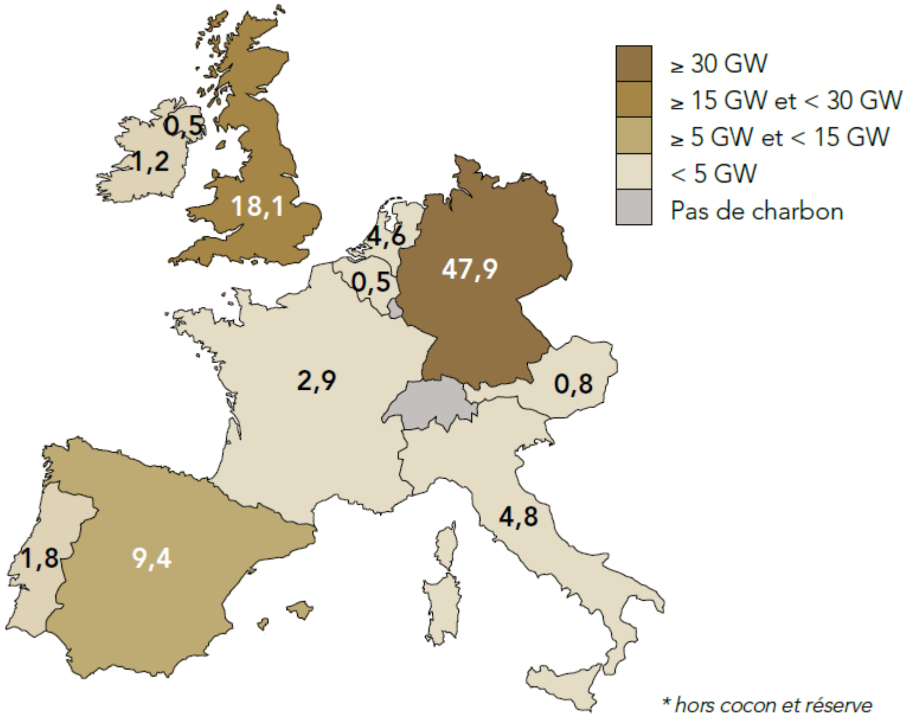
Coal is declining

Closure because of environmental regulations

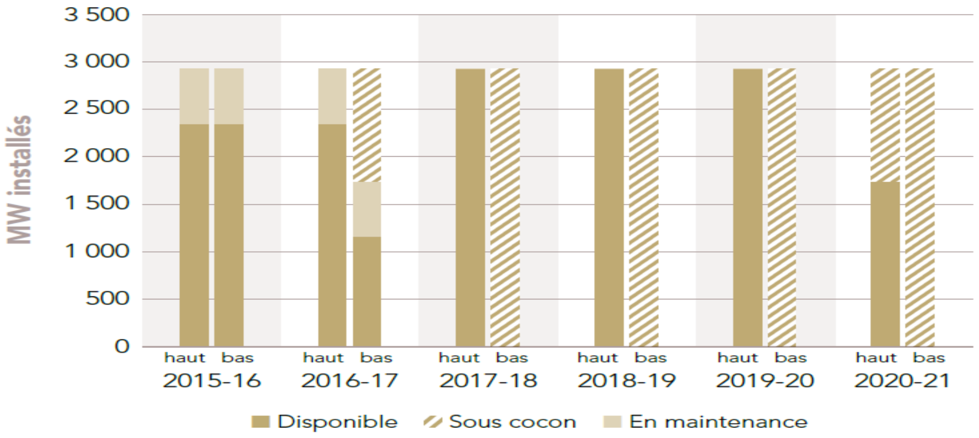
- Nearly 4 GW closed between 2013 and 2015
- A reduced capacity because of heavy maintenance

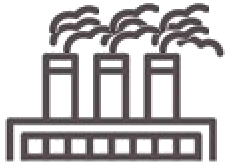
Coal historical capacity





Coal park evolution hypothesis





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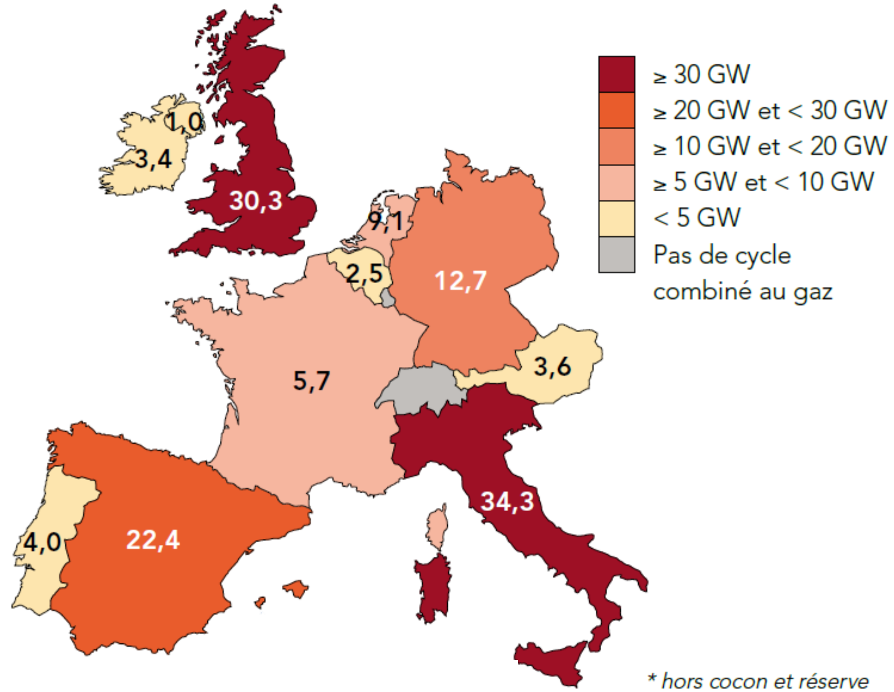
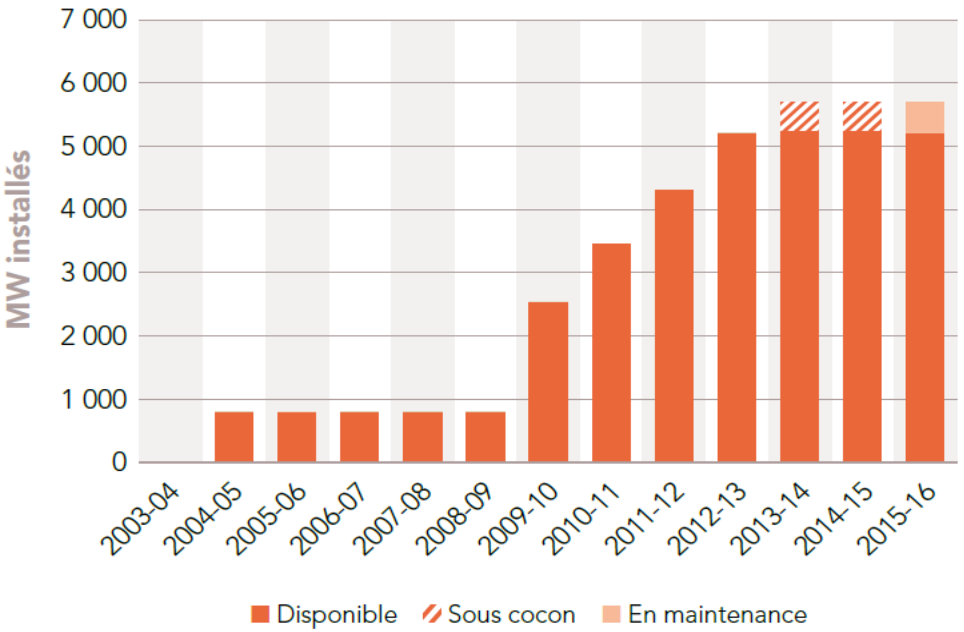
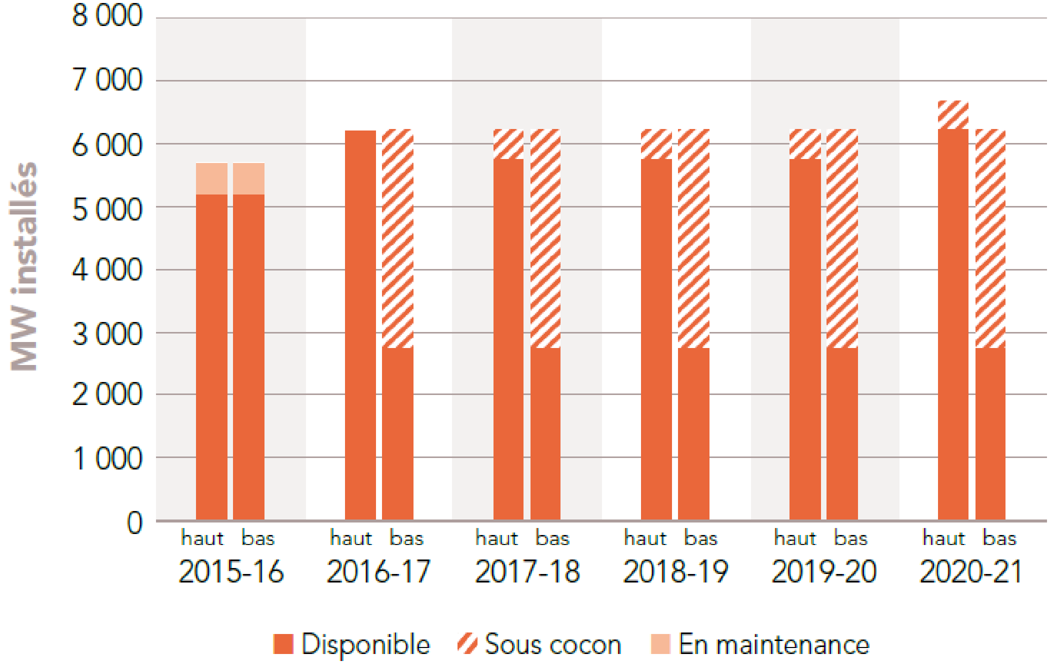
Still mothballed CCGT units





CCGT park evolution hypothesis



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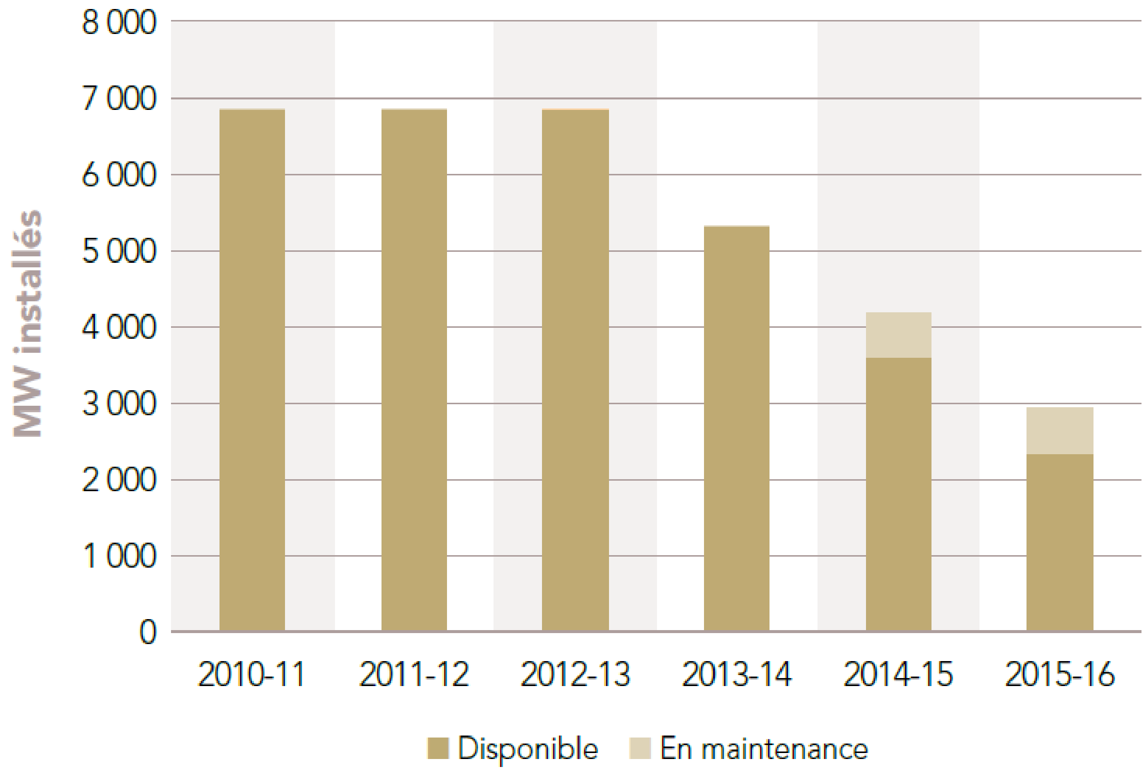
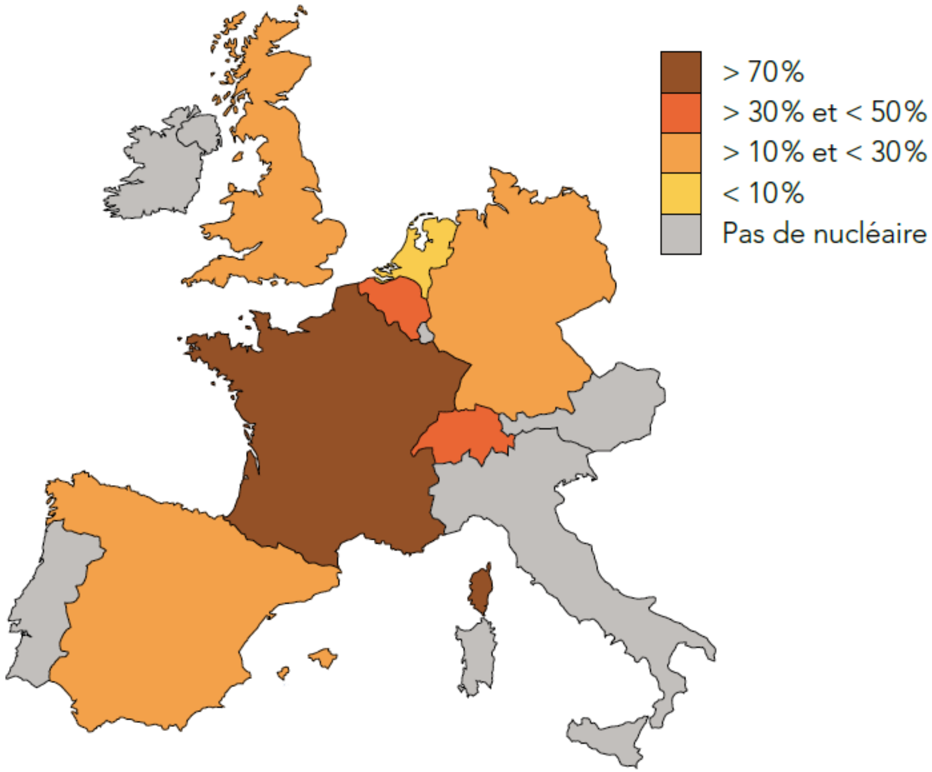
Fuel-oil is disappearing

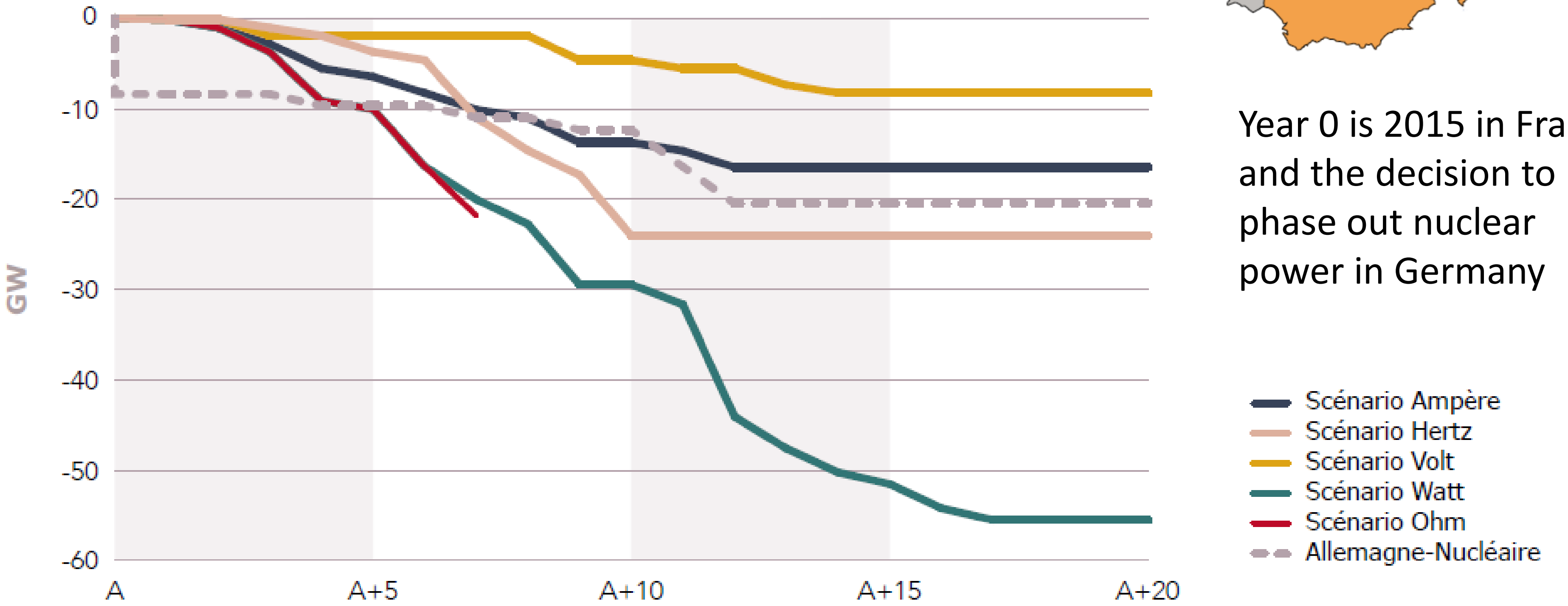


The last fuel-oil unit will close in 2018

Nuclear (BP 2017)



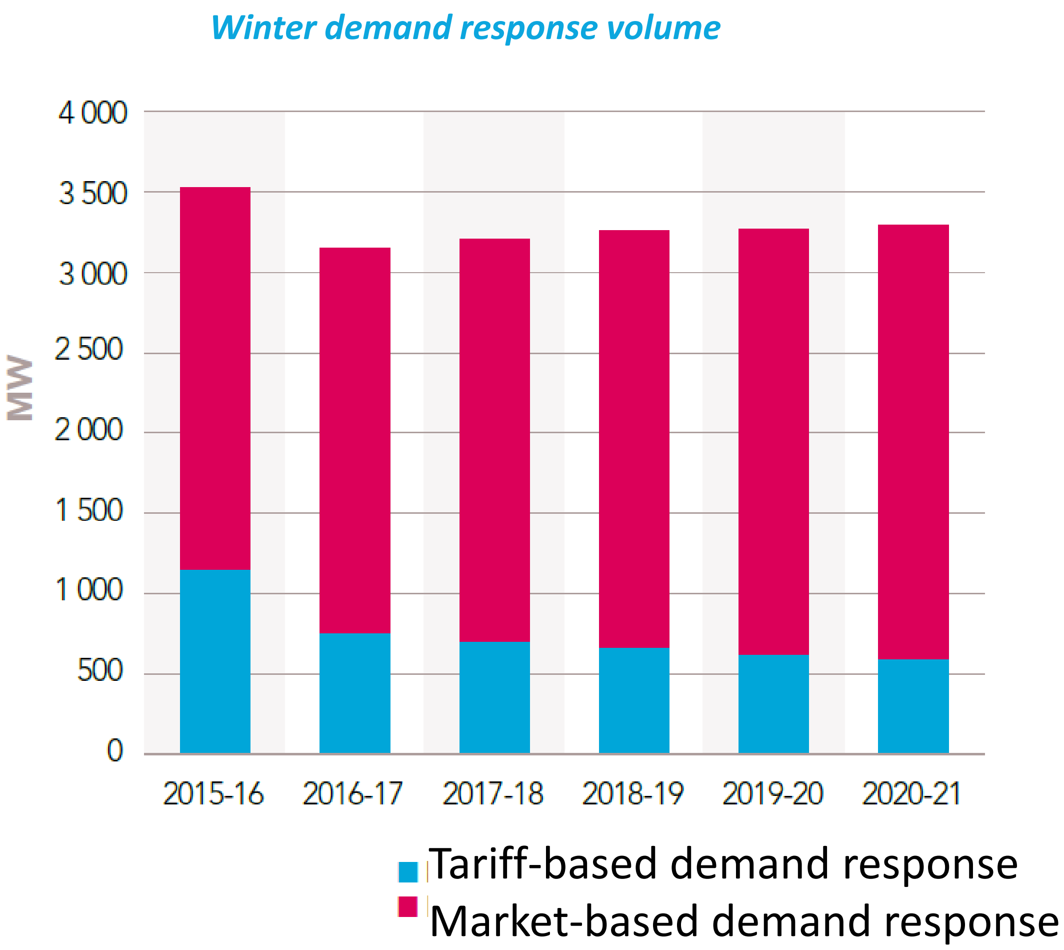
Reduction rythm of the nuclear installed capacity in the various scenarios and in Germany



Year 0 is 2015 in France and the decision to phase out nuclear power in Germany

Demand response

- **The market mechanisms of RTE allowed to stabilize the volume on the middle term**



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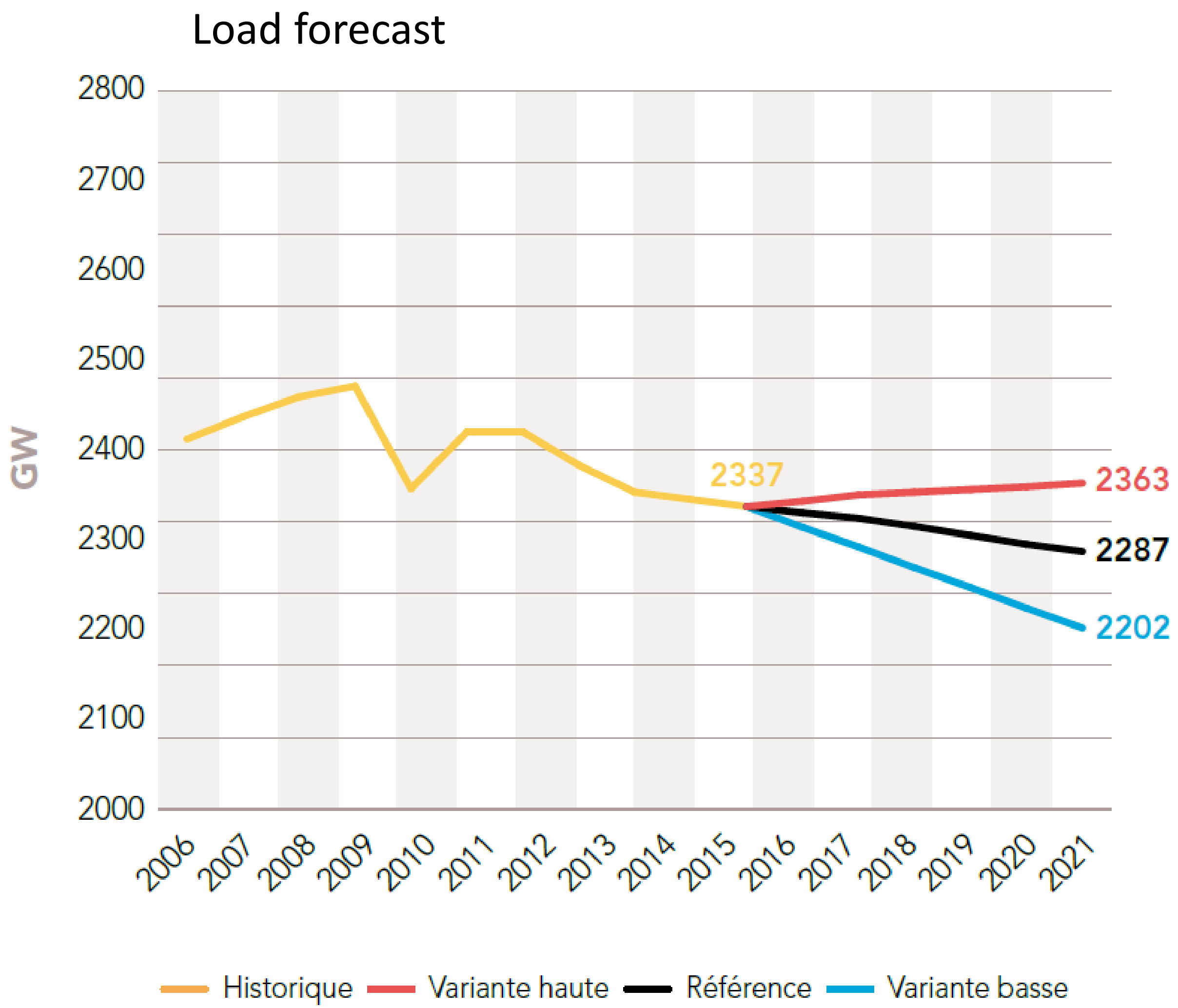
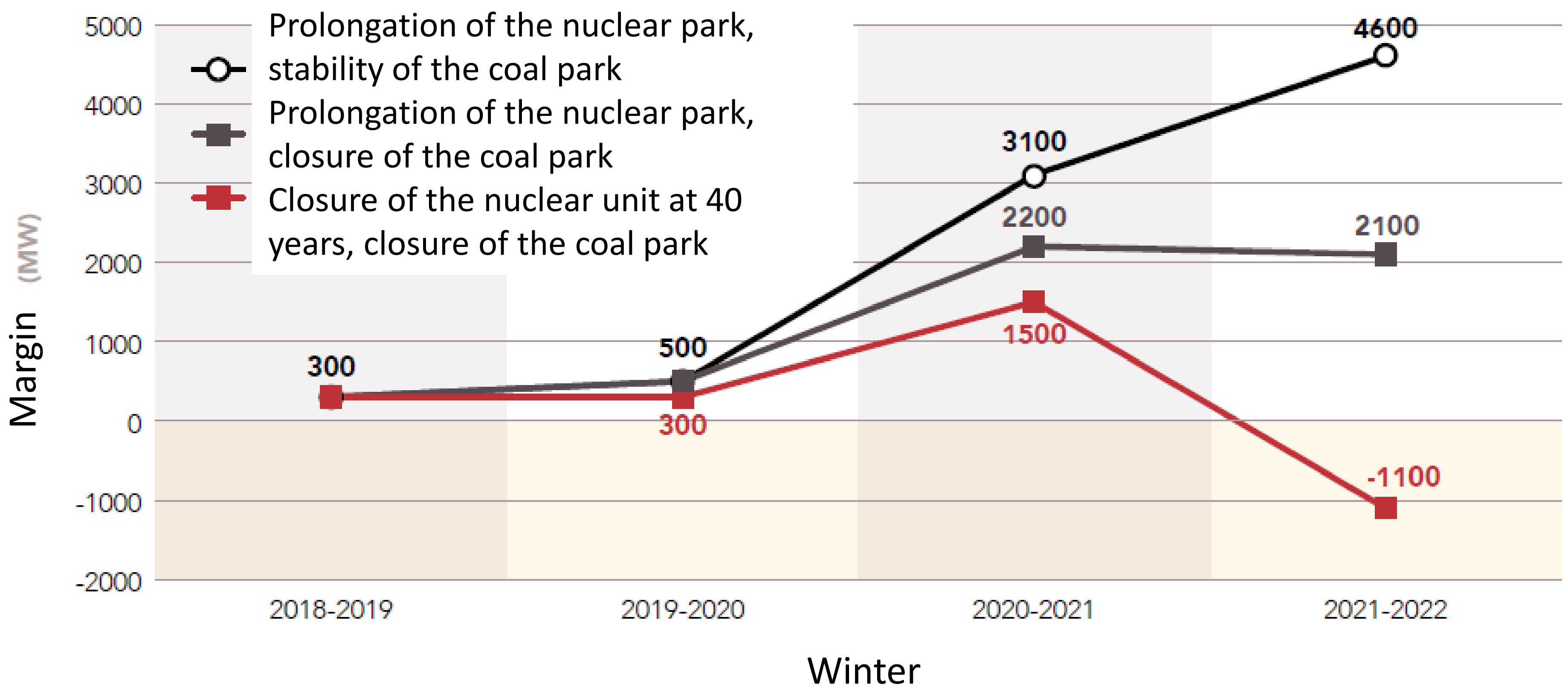
European model

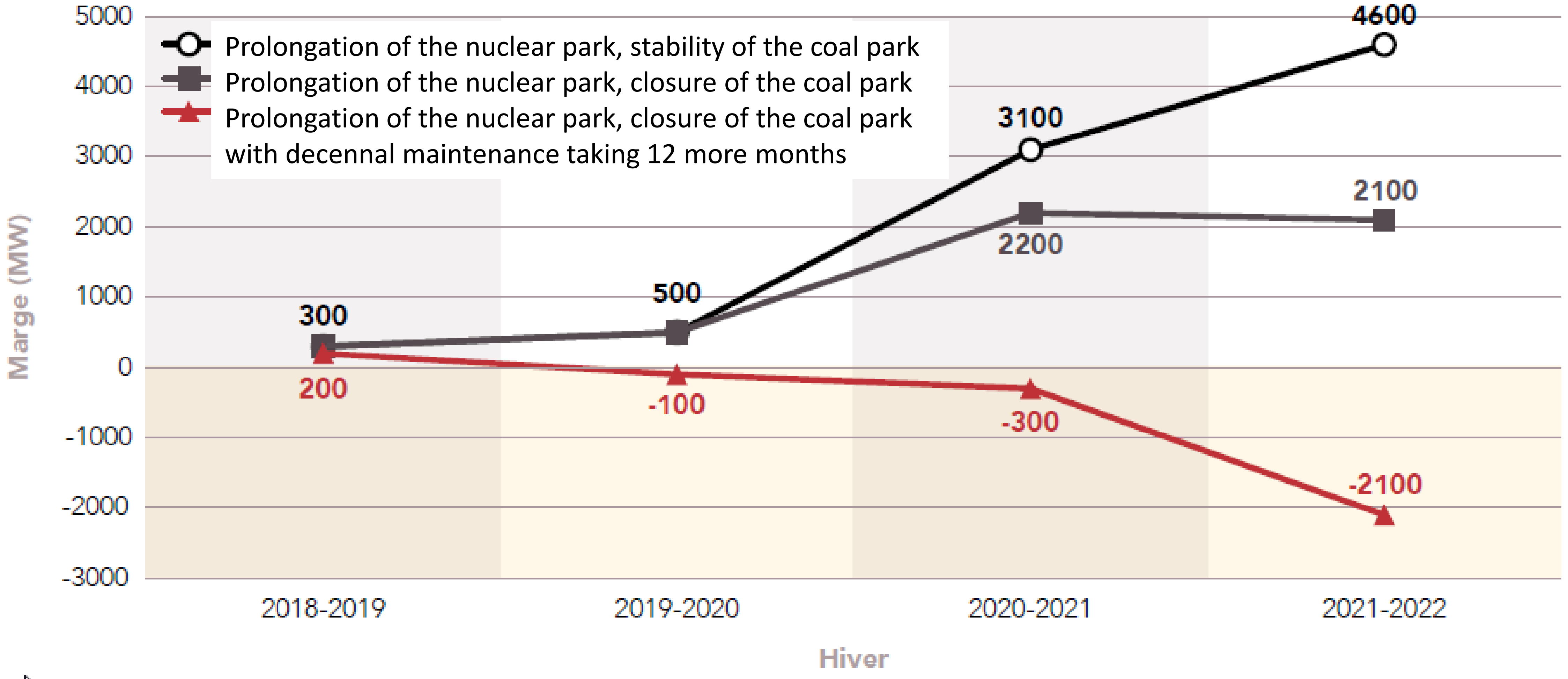


The 5 year adequacy study (BP 2017)

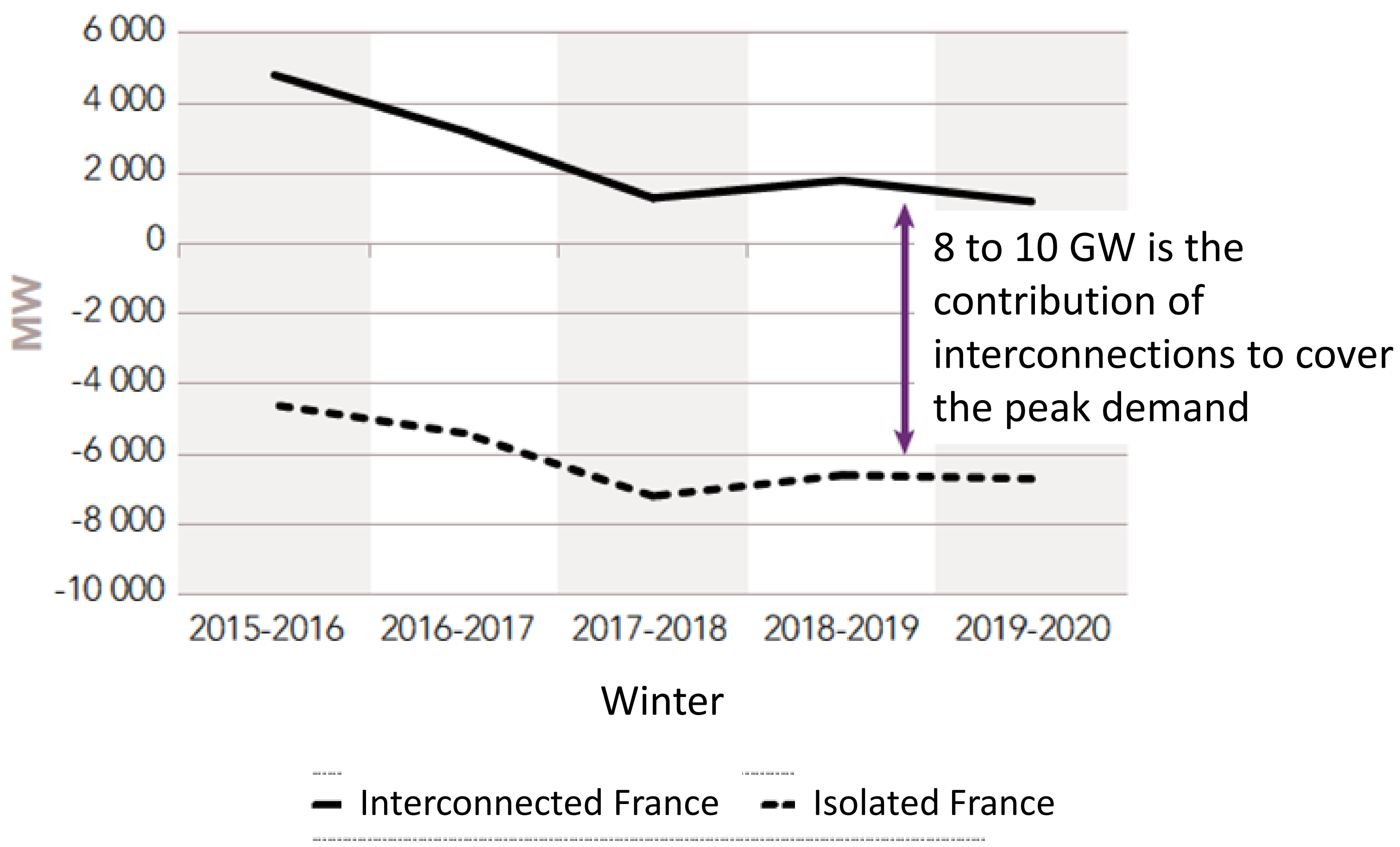


The safety criterium is OK if the margin is positive

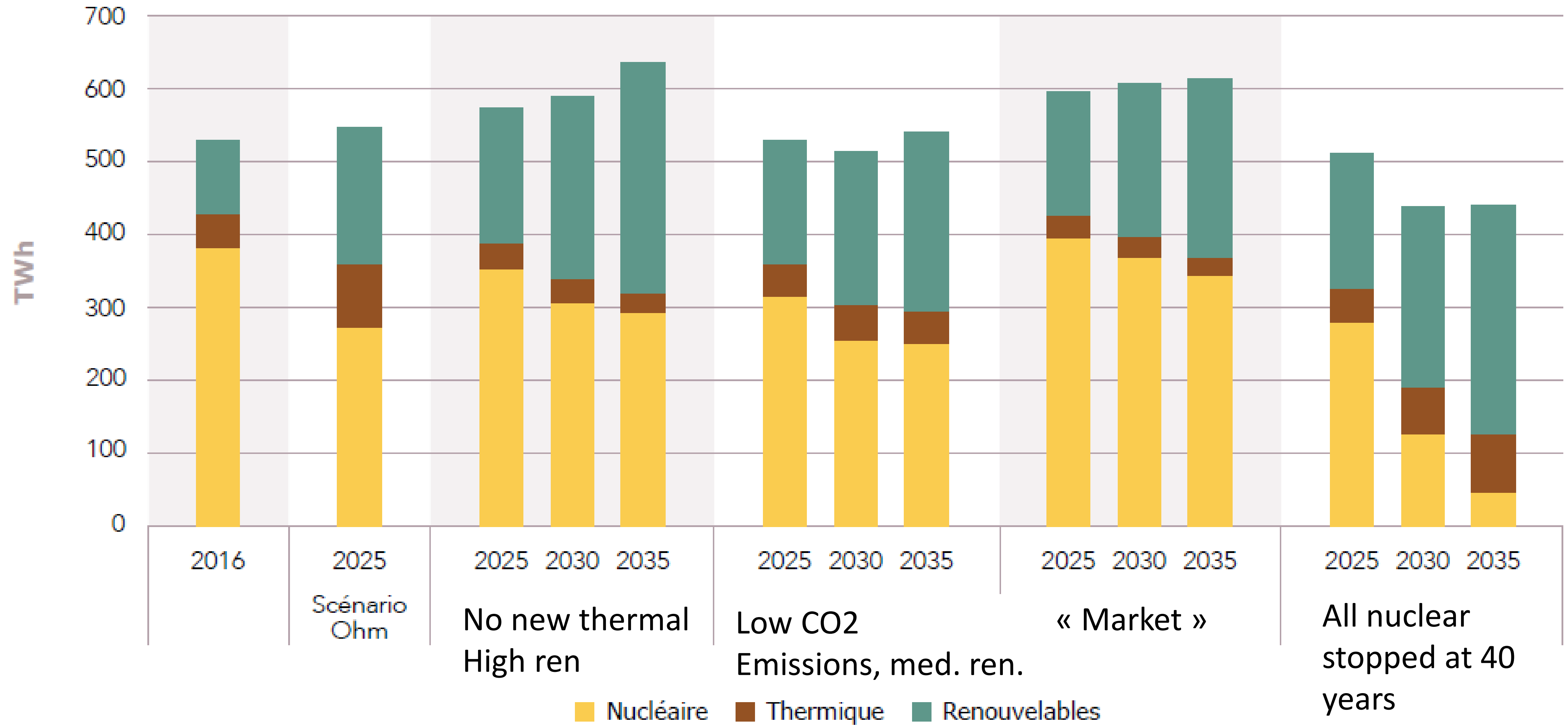
The 5 year adequacy study (BP 2017)
Sensitivity to maintenance



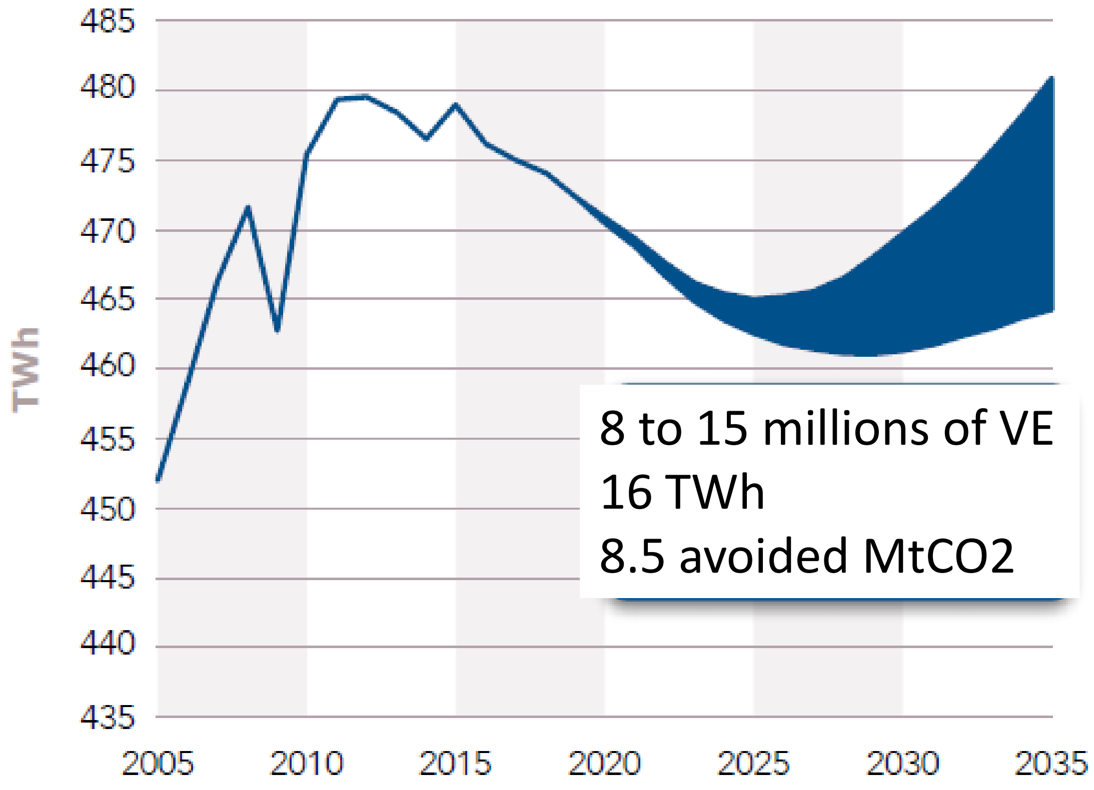
Without interconnections, the safety criterium would not be met (BP 2015)

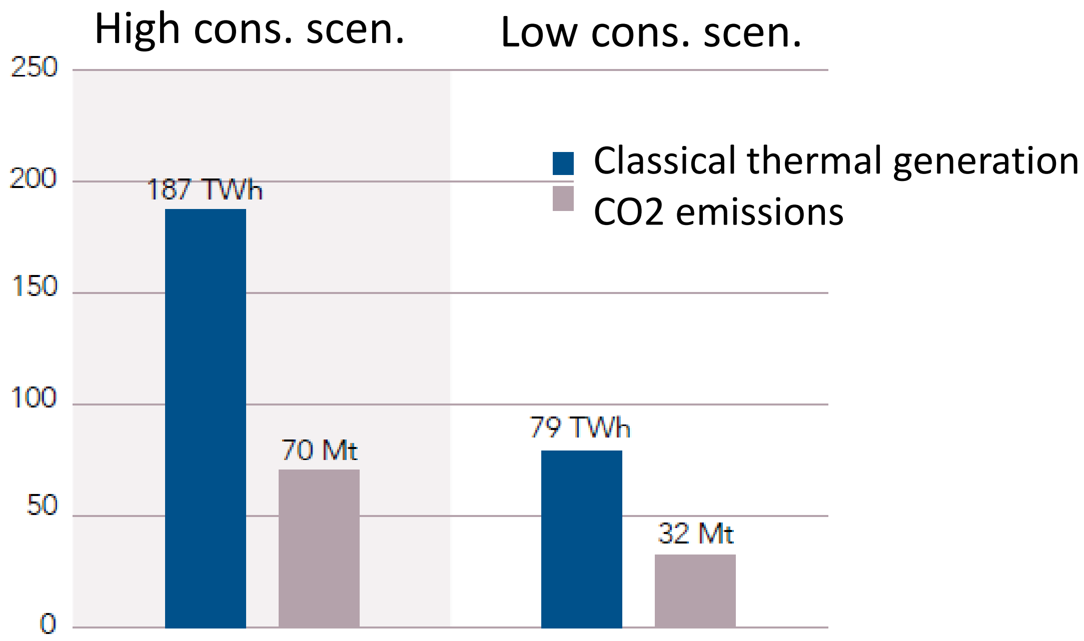


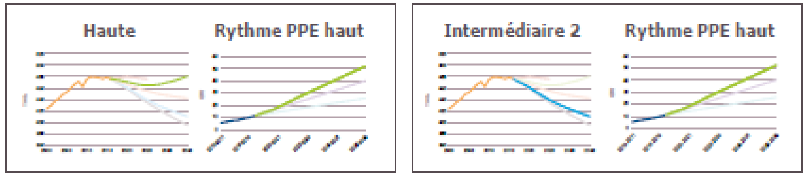
The 2035 target (BP 2017)



The 2035 target: opportunities created by the perspective of consumption reduction

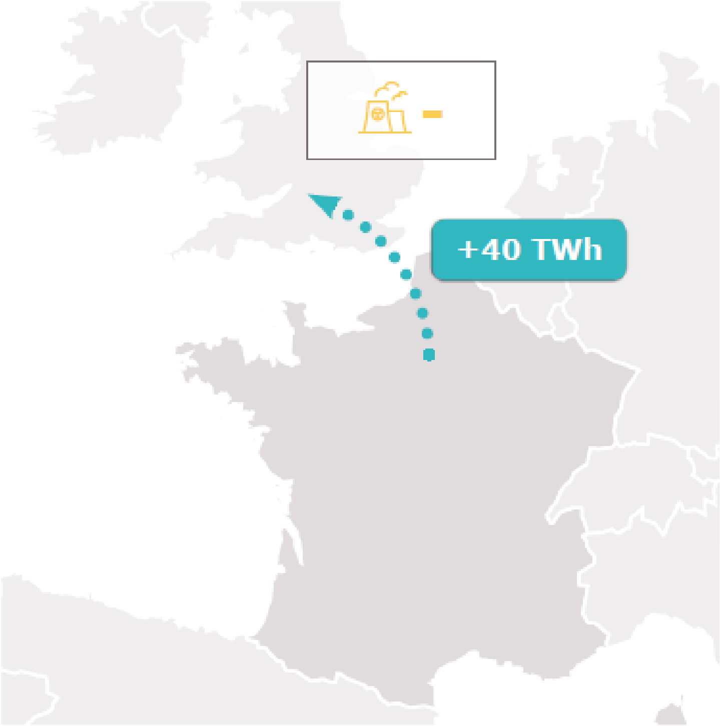


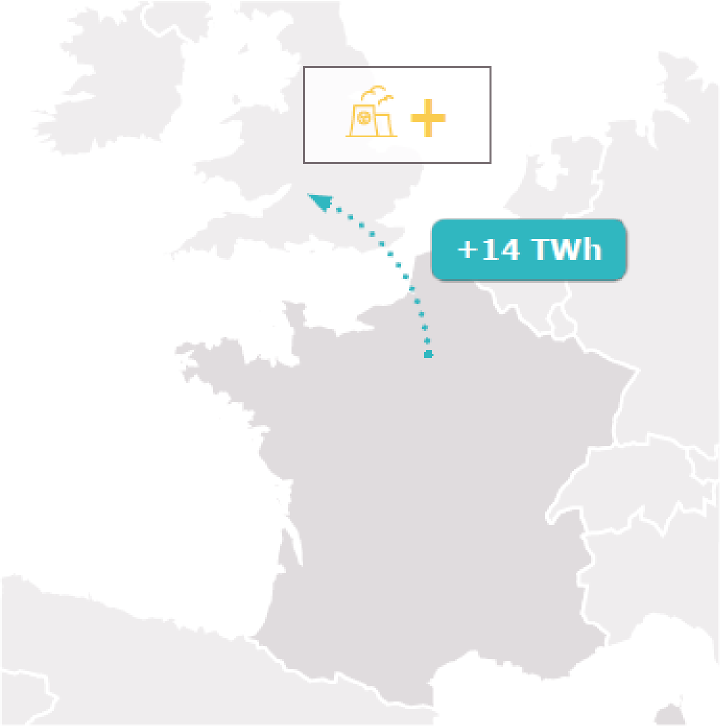




Limiting CO2 emissions while closing nuclear power plant

The 2035 target: Foreign energy policy have an impact





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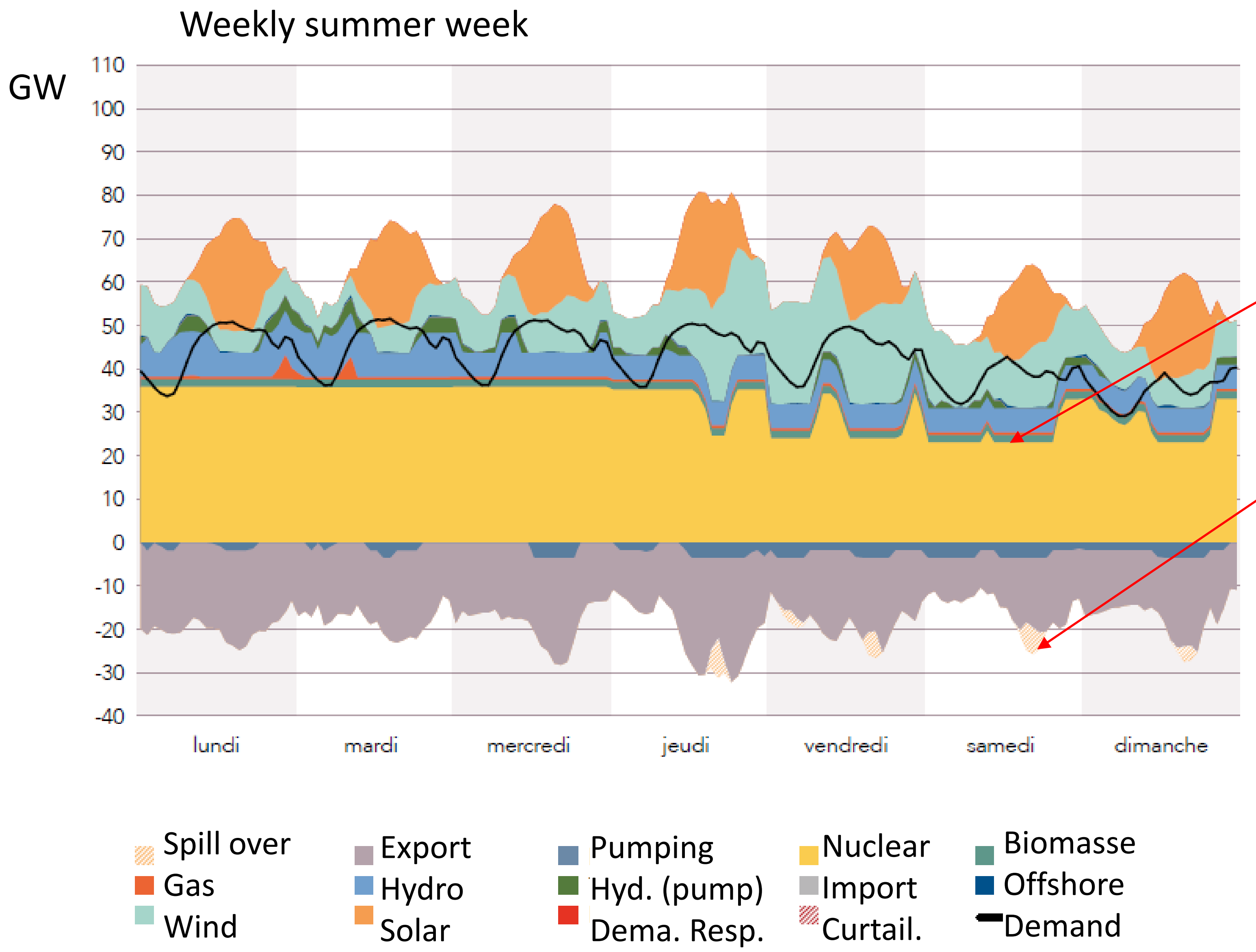
The 2035 target: flexibility needs



Nuclear does not always run at maximum power

Despite this and export, spilled energy appears

Generally, there is no thermal generation

Conclusion on RTE’s adequacy study

- Confrontation of generation and demand forecast 5 to 20 years ahead
- Requires:
  - Probabilistic load forecast and scenarios (100 climatic years)
  - Modelling of the generation
  - For 15 European countries
  - A software tool to compute the generation schedules (a boosted version of the short-term merit order)
- Allows to check the safety margin for France for the 5 next years.
- In 2017, allowed to propose 5 scenarios of nuclear capacity reduction.

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