Optimal generation mix under strong carbon constraints

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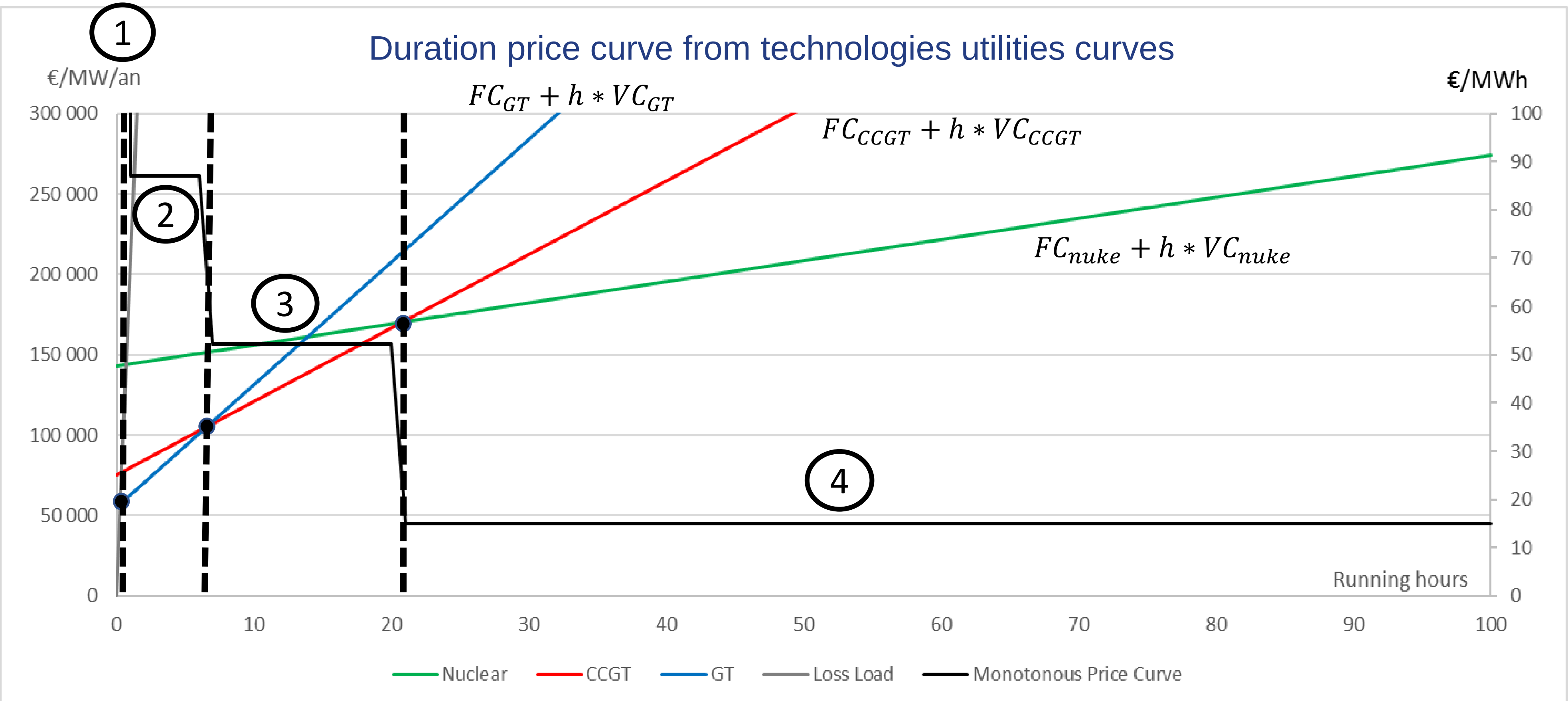
Agenda

- Review of theoretical approach of an energy only optimum
- Modelling long term investment strategy through dispatch model
- Study of EO only optimum’s sensitivities facing carbon constraints

Theoretical approach of EO optimum from marginal hours

- **One simple approach to demonstrate the Energy Only (EO) optimum is to used power plants' utility curves denoting which technology fulfill the best the demand constraint, according to their features (peak, semi-baseload, baseload)**

- **Thus, definition of the monotonous price curve can be deducted direclty from utility curves**



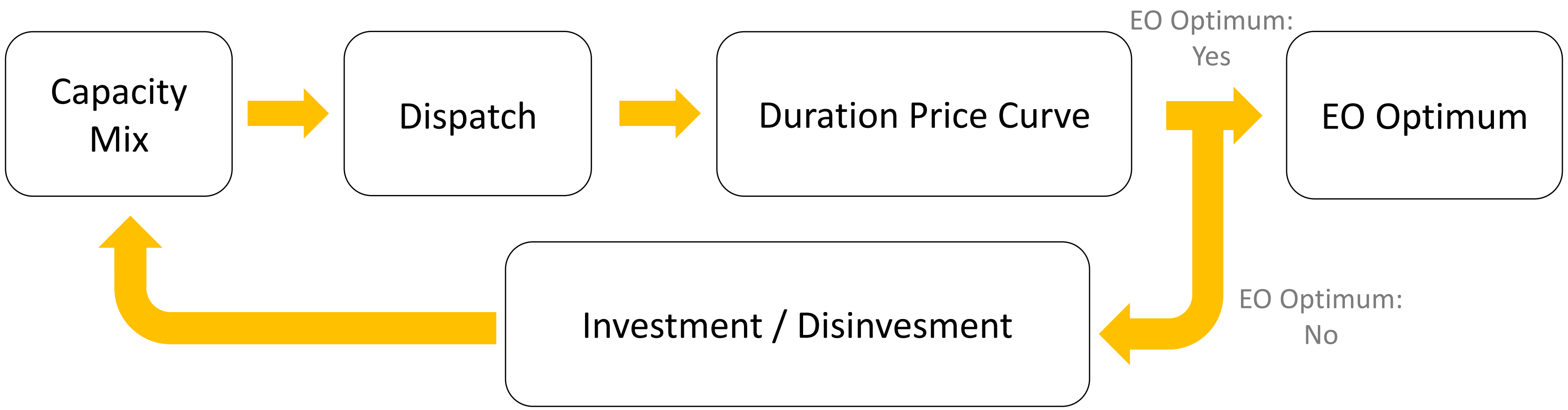
Empirical approach from dispatching model

- **EO Long term optimum is defined as equilibrium where each power plant i covers its annual cost during the year :**

$$Revenue_i = Fixed\_Cost_i + Variable\_Cost_i * H_{running} + OPEX_i$$

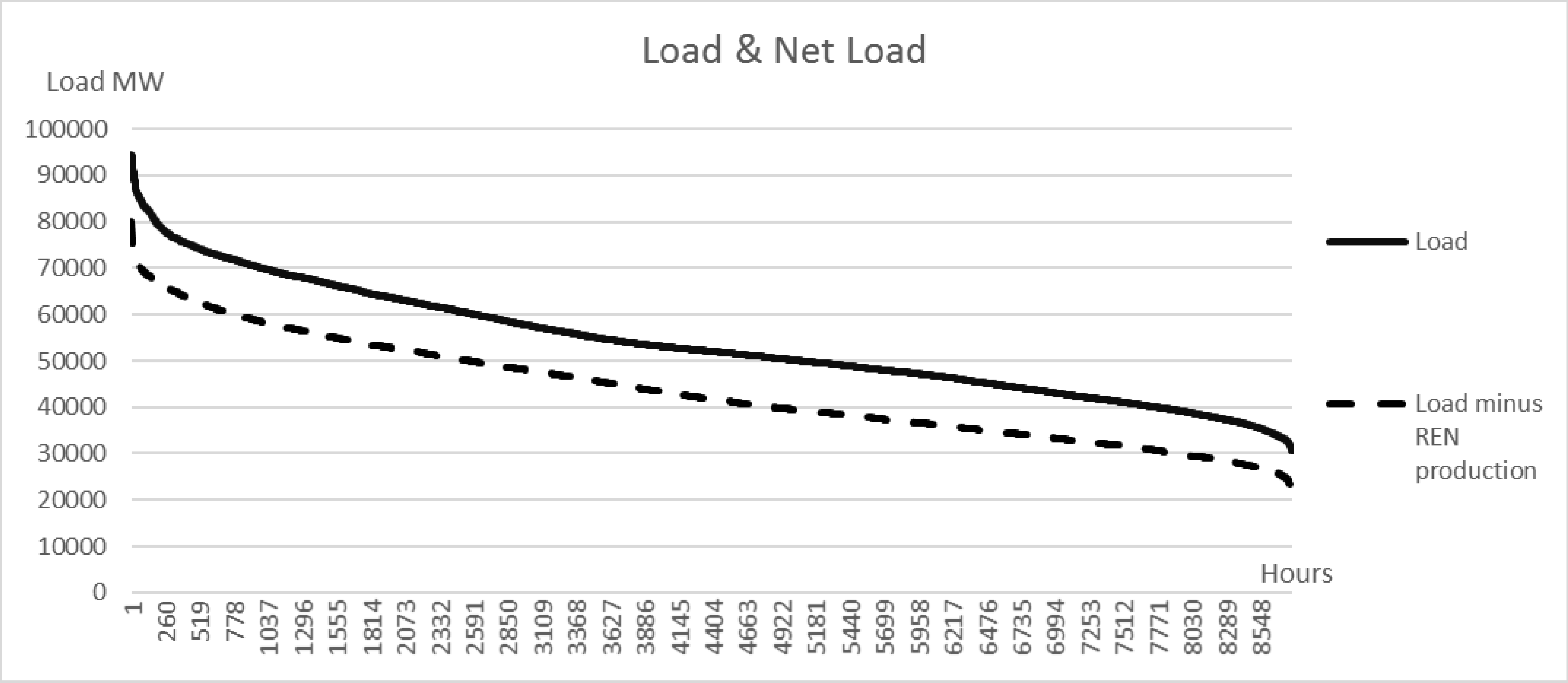
- **Theoretical approach :**

- **Modelling approach – optimal Energy Mix through investment :**



Dispatch modelling : Renewables Management

- **Data Load (France RTE - 2018), with non-merchant renewables**
- **Hydro production is substracted directly to the load in order to simplify the dispatch problem**



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Optimal Mix Modelling

- **Assumptions & problem formulation :**
  - Each one of the N power plants bids at its marginal cost (MC)
  - Fixed Cost (FC) and OPEX are estimated from RTE data (2018)
  - Only thermal power plants are considered as dispatchable (Nuclear, Coal, Gas)
  - All power plants are supposed available and reliable
  - Start-up costs are not modelled
  - Price (P) is equal to the marginal cost of the last power plant satisfying the demand constraint, following the merit order (perfect competition model)

- **Optimum in EO market is reached when revenue covers OPEX and capital cost for each power plant. Then for a power plant i :**

$$\text{Net } Revenue_i\ (€/kW/an) = FC_i\ (€/kW/an) + OPEX_i(€/kW/an)$$

- **Net Revenue :**

$$\text{Net } Revenue_i\ (€/kW/an) = \sum_{t=0}^{8760} (P_t - MC_i)^+$$

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Dispatch modelling : Data & assumptions

	Nuclear	Coal	CCGT	GT
Lifetime (year)	60	50	25	30
Discount rate (%)	5	5	5	5
Investment Cost (€/kW)	2000	860	600	150
Fixed OPEX (€/kW.an)	75	80	36	26
Annuity (€/kW.an)	106	47	43	10
TOTAL (€/MW.an)	181	127	79	36

France Energy Mix (RTE 2018)	Installed Capacity (GW)
Nuclear	63
Coal	3
Fuel	1
CCGT	6,2
GT	2
Hydro	17
Wind	13
Solar	8
Demand Response	2

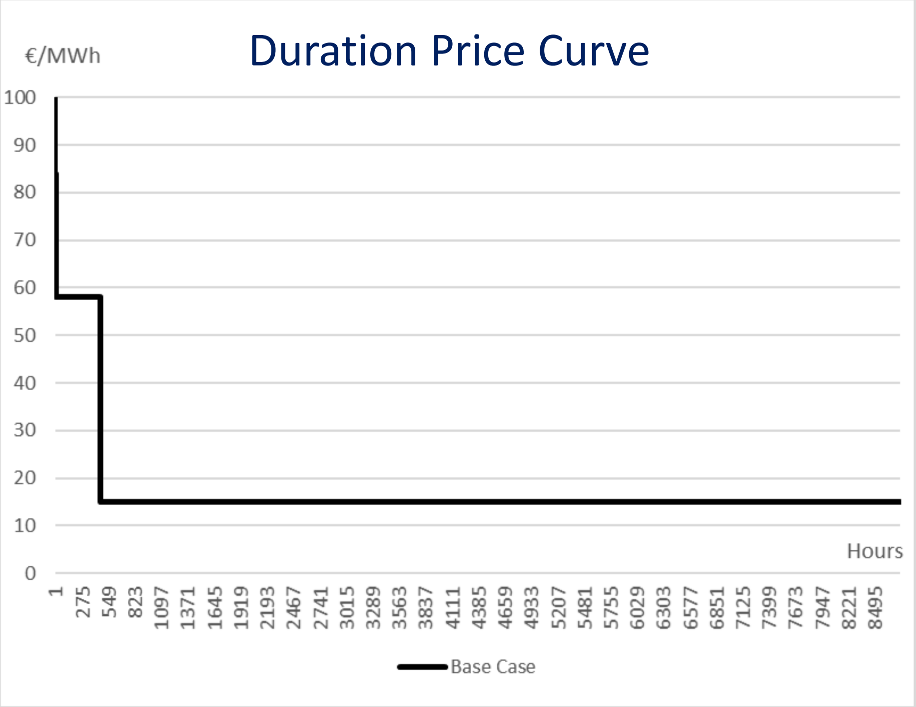
Source : https://assets.rte-france.com/prod/public/2020-06/bp2017_complet_vf_compressed.pdf

- **Loss of Load Cap @3 000 €/MWh**
- **Gas Price = 17 €/MWh**
- **CO_2 Price = 65 €/tCO_2**

First results of Energy Mix (without investment cycles)

- **Base Case :**

	Nuclear	Coal	CCGT	GT	Loss of Load
Annual Costs (€/kW)	180	130	78	36	-
Annual Revenue (€/kW)	63	30	28	0	-
Net Margin (€/kW)	-117	-100	-50	-36	-
Hours of marginality	8000	26	729	5	0



- **Over-capacity of energy mix**
- **Missing money problem**
- **0 hour of Loss of Load @3000 €/MWh**

→ Disinvestment to converge to EO optimum

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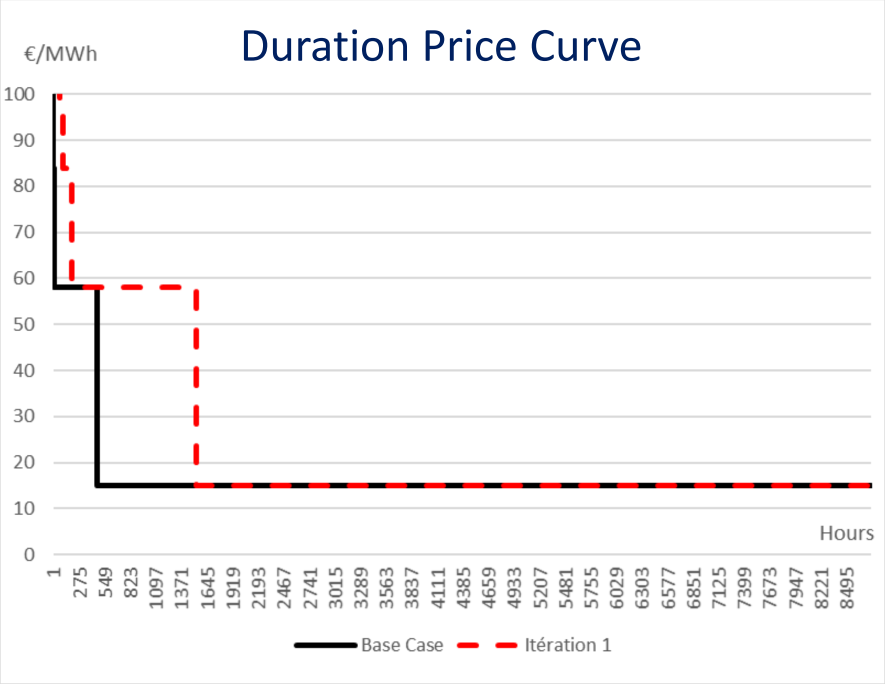
First results of Energy Mix (iteration 1 : disinvestment)

- **Base Case -5GW of nuclear power :**

	Nuclear	Coal	CCGT	GT	Loss of Load
Annual Costs (€/kW)	180	130	78	36	-
Annual Revenue (€/kW)	126	70	69	69	-
Net Margin (€/kW)	-64	-60	-9	33	-
Hours of marginality	7723	39	966	8	24



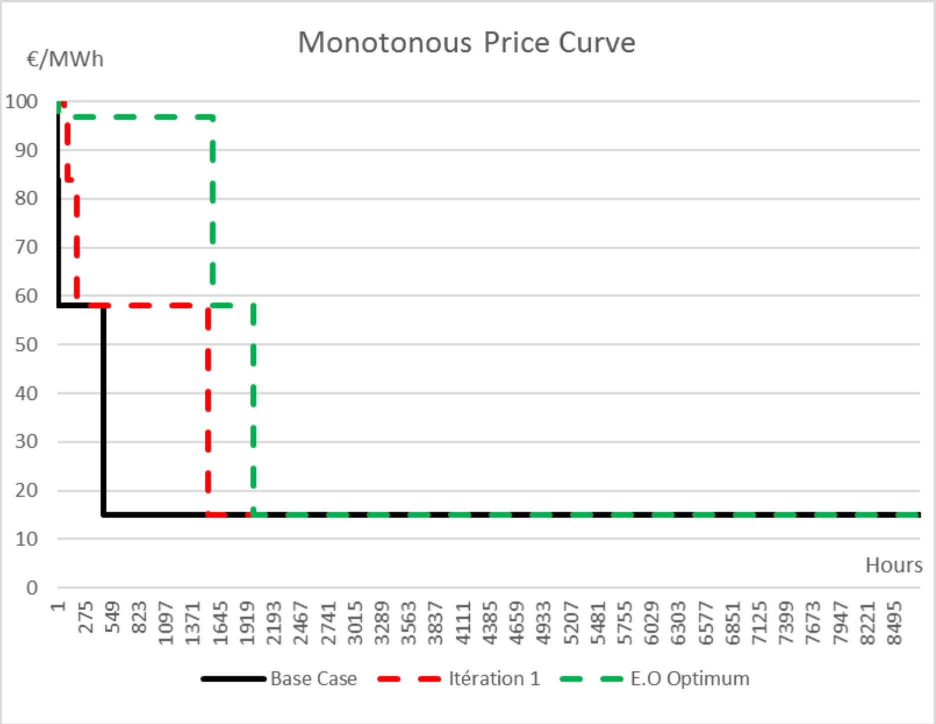
- **Under-capacity of energy mix**
- **Missing money problem + Overpayment of GT**
- **24 hour of Loss of Load**

Mix of Investment & Disinvestment to converge to EO optimum

First results of Energy Mix (Final Optimal EO)

- **EO optimal mix from base case :**

	Nuclear	Coal	CCGT	GT	Loss of Load
Annual Costs (€/kW)	180	-	78	36	-
Annual Revenue (€/kW)	180	-	78	36	-
Net Margin (€/kW)	0	-	0	0	-
Hours of marginality	6108	0	1841	798	13



- **Important Switch of capacity between GT and CCGT**

- **13 hour of Loss of Load with basecase assumptions**

- **REN Captured Price :**

Captured Price - Solar	**5,10**	€/MWh
Captured Price - Wind	**10,45**	€/MWh

Optimal EO from basecase

- **EO Optimal mix :**

	Initial Capacity (GW)	Optimal Capacity (GW)	Increment (GW)
Nuclear	63	49	-14
Coal	3	0	-1
CCGT	12	10	-2
GT	3	15	+12

- **13 hour of Loss of Load**
- **Hydro power plants are not taken into account during this simplified dispatch, this type of assets (peaker) should lower CCGT & GT capacity needs**
- **Optimal capacity depends on technology cost assumptions which need to be validated**

First results of Energy Mix (Final Optimal EO)

- **How reaching an EO Optimal mix with a security of supply criteria < 3 hours ?**
  - **13 hours are needed to cover costs of GTs in our basecase mix**
  - **Difficulty to reach an optimal EO mix without peak assets**

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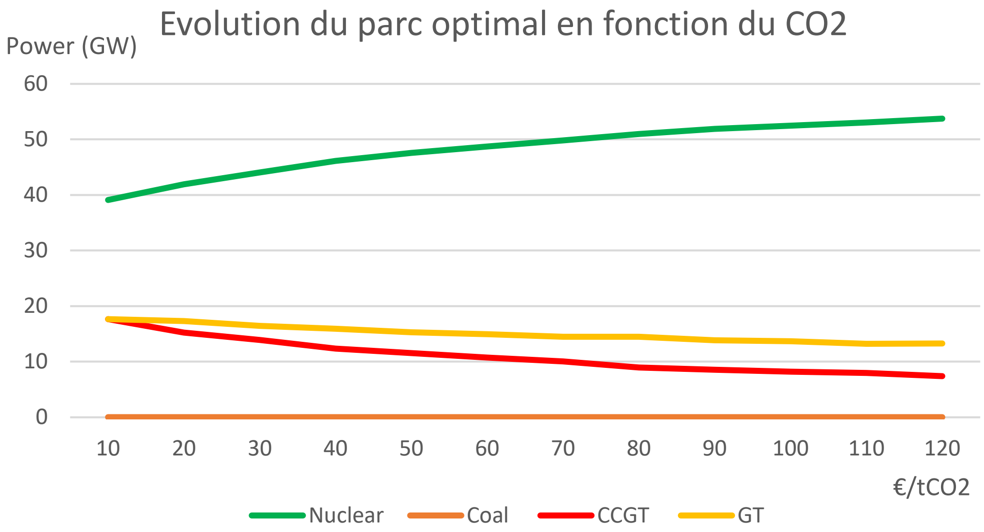
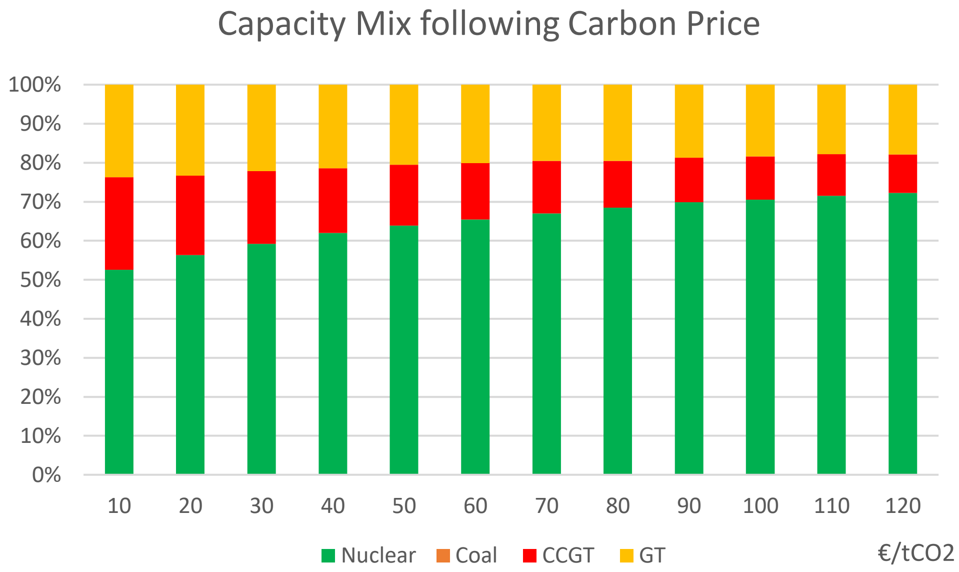
Optimal EO sensitivity to Carbon Price





- **Carbon Price leverage investment for Nuclear Power**
- **Additional capacity of Nuclear replace mainly CCGT assets**

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www.ceem-dauphine.org/assets/presentation.pdf

Tasks

- Optimal generation mix robustness facing commodities prices
  - CO2 prices
  - Gas prices

- How to converge to an optimal market design ?
  - EO (Risk revenues shared by consumers and producers : volatility, security of supply)
  - Capacity market (Lessening risks, inducing reduction in capital cost)
  - Other (specific tenders, strategic reserves, real time markets, …)

- Study of Optimal Renewables development through different market mechanism, and their consequences on social welfare :
  - Tenders
  - Capacity remuneration
  - Market signal from CO2