CO2 Policy Uncertainty and Plant Investments

A proof of concept of Stochastic Programming

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- The Challenge
- Methodology
- Stylised Example
  - Setup
  - Solution
- Conclusion

The Challenge – investments in an uncertain World

- How will the world change?
  - demand uncertainty
  - demand volatility (wind)
  - input costs (CO_2, gas and oil prices)

scenario trees

- Policy uncertainty – regime changes
  - CO_2 reduction targets
  - nuclear exit?

incorporating into tree

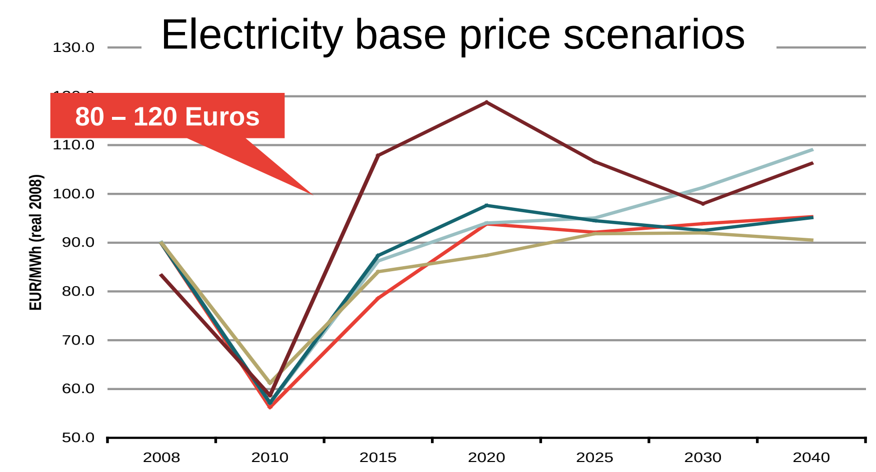
- Peak load pricing – merit order logic
  - varying demand, limited storage and L shaped cost functions – **scarcity rents**
  - lead to strongly varying prices

capacity constraints, price duration curve

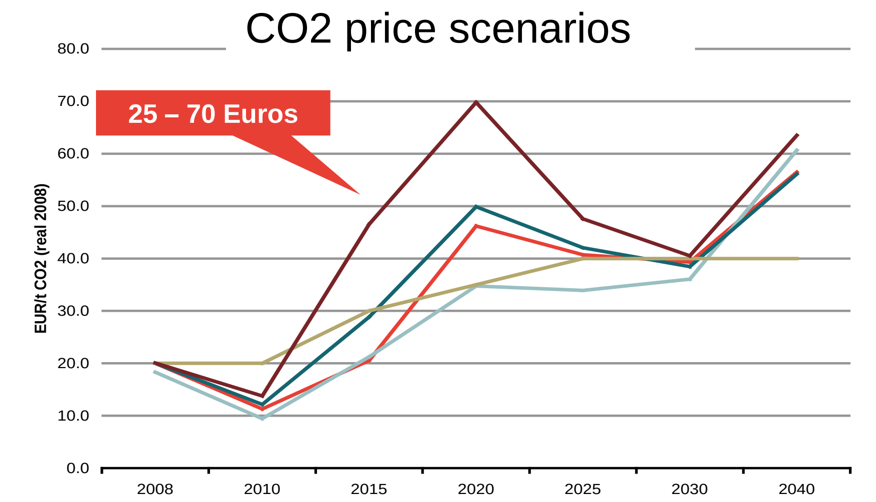
- capacity constrained
- multi stage optimization model
- under uncertainty

Focus on electricity price and CO2

- Depending on factors like:
  - demand development
  - GDP growth
  - market developments
  - world market prices for fuel
- Potential for variation is huge



- Depending on factors like:
  - CO2 quotas
  - policy
- Potential for variation is huge



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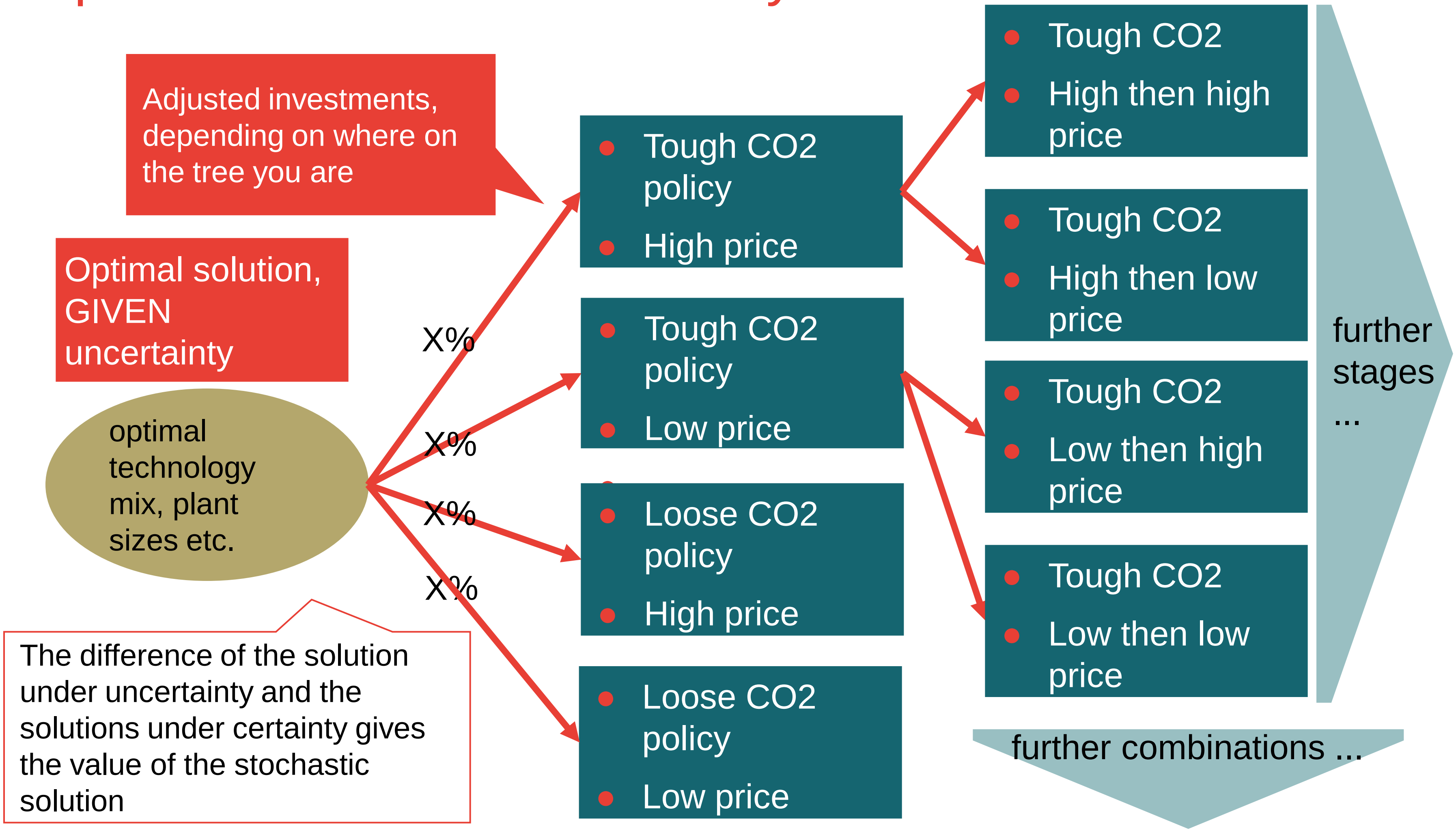
Optimisation under uncertainty



Coming up with the scenarios and probabilities is one of the main challenges. Normally, econometric VAR models are used. In anticipation of regime changes we also propose judgement and fundamental approaches like the Frontier dispatch model and price forecast.

Core model

Relatively simple formulation of the problem

Profit maximised

Investment cost

For all technologies (k), market states (m) and possible future scenarios (s)

Discount factor

Margins

$$\max \pi(q_{k,m,s}, Inv_{k,s}) = \sum_{k \in K} \sum_{s \in S} [\phi_s INV_{s,k} IC_k] + \sum_{k \in K} \sum_{m \in M} \sum_{s \in S} [\phi_s q_{k,m,s}(c_{k,s} - p_{k,m,s})]$$

Choosing vector of quantities – set optimally for every state of the market

Simultaneously choosing optimal investment, given possible future scenarios

s.t.:

$$\text{rest. Stage1: } q_{s1,k,m} - K_k \leq 0;\ \forall k, m$$

$$\text{rest. Stage2: } q_{s2,k,m} - K_{i,k} - INV_{s1} \leq 0;\ \forall s1, k, m$$

$$\text{rest. Stage3: } q_{s3.1,k,m} - K_{i,k} - INV_{s1} - INV_{s2.1} \leq 0;\ \forall s2, k, m$$

....

$$q_{s,k,m} \geq 0;\ \forall s, k, m$$

Capacity constraint in Stage 1

Investments increase capacity

In later stages, investments depend on which path on the probability tree I took

Stylised example

	investment cost	production cost	CO2 exposure
coal	medium	low	high
CCGT	low	high	medium
coal CCS	high	medium	none
CCGT CCS	medium	high	none

choice of technology

25%

- Tough CO2 policy
- High price

CO2 price of 70

electricity prices 10% higher

25%

- Tough CO2 policy
- Low demand

CO2 price of 70

electricity prices 10% lower

25%

- Loose CO2 policy
- High demand

CO2 price of 10

electricity prices 10% higher

25%

- Loose CO2 policy
- Low demand

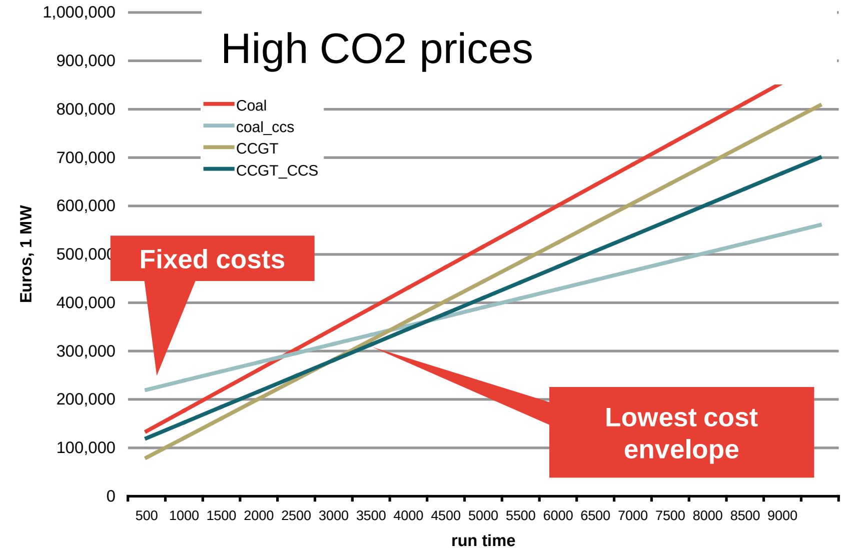
CO2 price of 10

electricity prices 10% lower

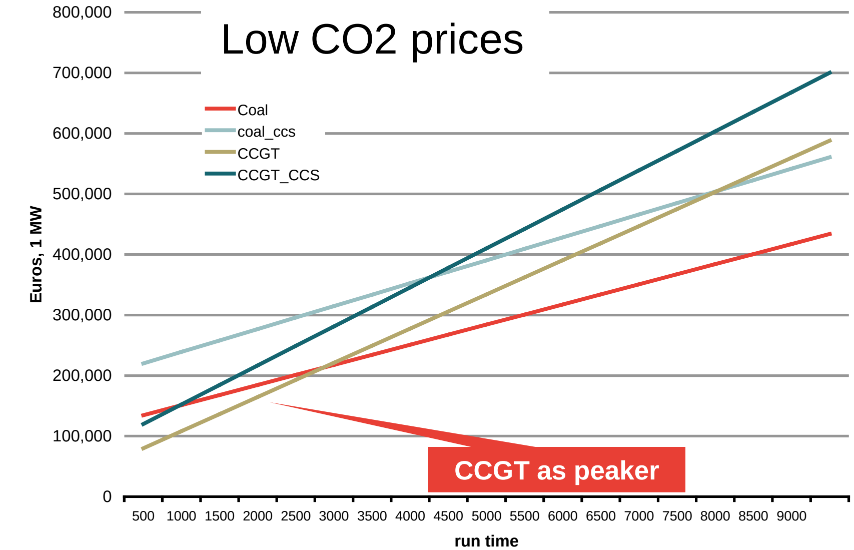
Probabilities chosen for simplicity, normally correlation should be considered

Costs of combustion power plants

- With a CO2 price of 70 …
  - conventional coal is completely dominated
  - coal CCS is the cheapest base–load plant
  - potential for CCS CCGT in upper mid-merit
  - conventional CCGT for peak-load



- With a CO2 price of 10 …
  - conventional coal dominates the base-load segment
  - CCS CCGT is completely dominated
  - conventional CCGT for peak-load



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Stylised example

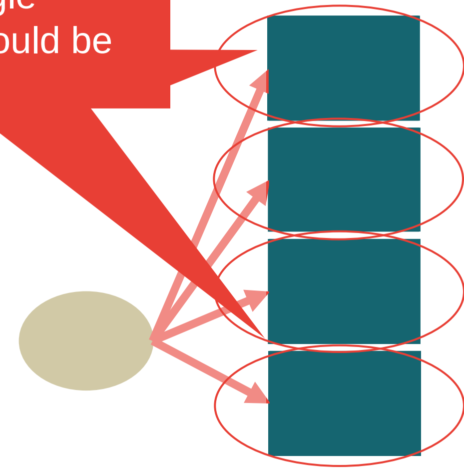
Solution

Possibilities of solution - I

Single scenario solution

Solving every single scenario as it it would be cerain

	Prices 10% higher		Prices 10% lower	
	CO2 price 70	CO2 price 10	CO2 price 70	CO2 price 10
Coal		1,909,181		900,630
CCGT		284,422	-134,757	
Coal CCS		1,846,459		
CCGT CCS	534,388	534,388		

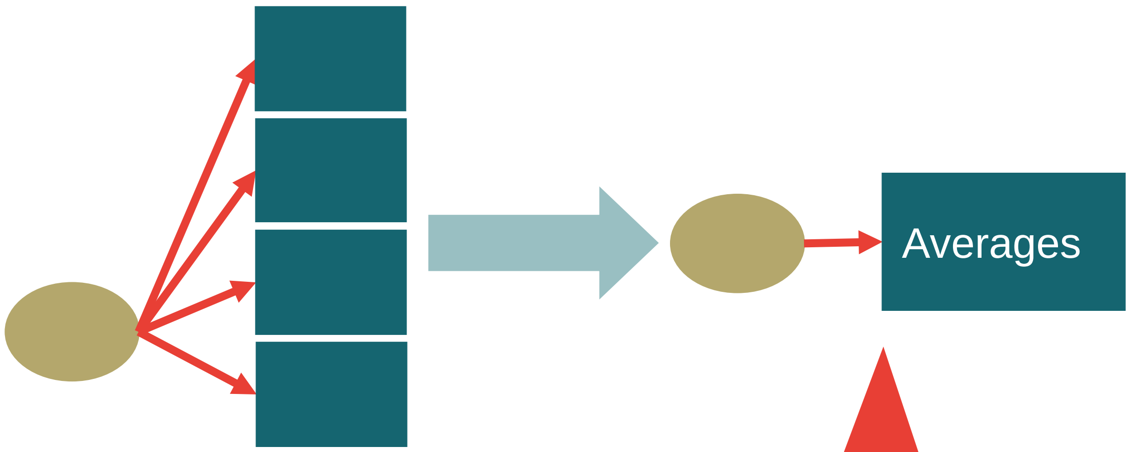


- Solving the model under certainty, in the high demand and high CO2 price scenario gives CCGT CCS as preferred option.

  Please note: in a model with more realistic scenario probabilities, CCGT CCS will usually never be a good choice.

- The other scenarios have their own ideal solution
- Coal dominates the low carbon scenario
- CCS technologies dominate the high carbon scenarios

Possibilities of solution - II



Expected values

Expected prices

CO2 price 40

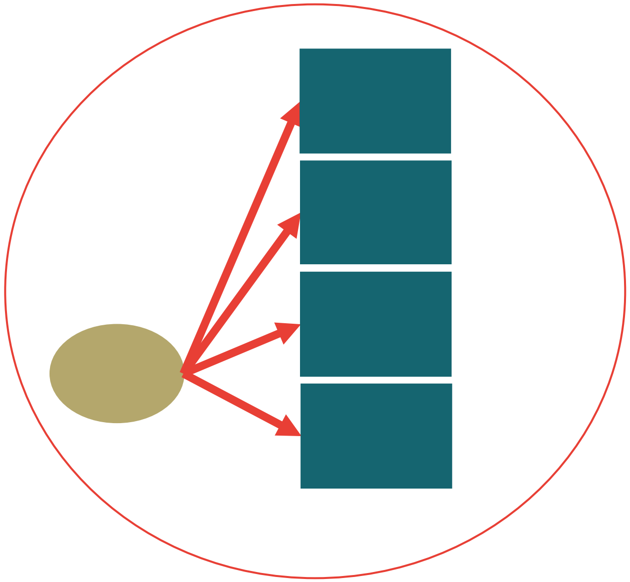
36,870
74,833
73,336
45,487

Calculating solution using expected values as inputs and solving as if they were certain

A solution that seems reasonably hedged:

- Not much exposure to CO_2
- Still running in low price scenarios

Possibilities of solution - III



Proper stochastic solution, considering all the upsides and downsides

Expected values	Scenario based
Expected prices	4 scenarios, as above
CO_2 price 40	
36,870	
74,833	
73,336	395,558
45,487	

- MUCH higher expected value
- Value of stochastic solution about 320,000 Euros
- Reason: simple model in averages could not “see” considerable upsides

Full enumeration - I

	Single scenario solution					Expected values	Scenario based
	Prices 10% higher		Prices 10% lower			Expected prices	4 scenarios, as above
	CO2 price 70	CO2 price 10	CO2 price 70	CO2 price 10	Average	Expected CO2 price of 40	
Coal	-490,708	1,909,181	-775,248	900,630	385,964	36,870	
Coal CCS	284,422	284,422	-134,757	-134,757	74,833	74,833	
CCGT	34,49[illegible]	1,846,459	[illegible]571,167	272,445	395,558	73,336	395,558
CCGT CCS	534[illegible]	534,388	[illegible]2,239	-402,239	66,[illegible]	45,487	

- Coal has the biggest upside in case of low CO2 prices
- But, its vulnerability to CO2 price makes it a bad choice overall

- Coal CCS has no exposure to CO2 and is therefore very stable
- But, the high investment costs cannot be recovered if demand is too low

- CCGT offers a high upside, to which the solution using average inputs is blind
- Because of less exposure to CO2, the return is also more stable than coal

Full enumeration - II

	Single scenario solution					Expected values	Scenario based
	Prices 10% higher		Prices 10% lower			Expected prices	4 scenarios as above
	CO2 price 70	CO2 price 10	CO2 price 70	CO2 price 10	Average	Expected CO2 price of 40	
Coal	-490,708	1,909,181	-775,248	900,630	385,964	36,870	
Coal CCS	284,422	284,422	-134,757	-134,757	74,833	74,833	
CCGT	34,496	1,846,459	-571,167	272,445	395,558	73,336	395,558
CCGT CCS	534,388	534,388	-402,239	-402,239	66,074	45,487	

Full enumeration of possibilities shows that using average inputs fails to capture the upside of the investment opportunities

Full enumeration is only possible because:

- Decision variables are discrete
- No second stage (real option, later adjustments, value to wait)
- Small example

Without full enumeration, Stochastic Optimisation is the ONLY way to capture the value of the stochastic solution

Conclusion

What we did:

- We demonstrated, with a simple example that simplistic approaches to deciding on investment strategies are potentially misleading
- A structured approach and detailed modelling of risk offers:
  - Better decision making
    - Hedging against downsides
    - Capturing upsides
  - Better justification for decision making – the potential risks are accounted for in a scientific and disciplined way

Further improvements:

- Scaling the model up to a realistic size
- Coming up with consistent scenarios, by using:
  - Frontier high resolution dispatch models and price forecast models
  - Econometric analysis (time series and VAR models)
  - Industry knowledge and judgement
- This is not trivial, given that the future will involve not only uncertainty but regime changes