Measuring performance of long-term power generation portfolios

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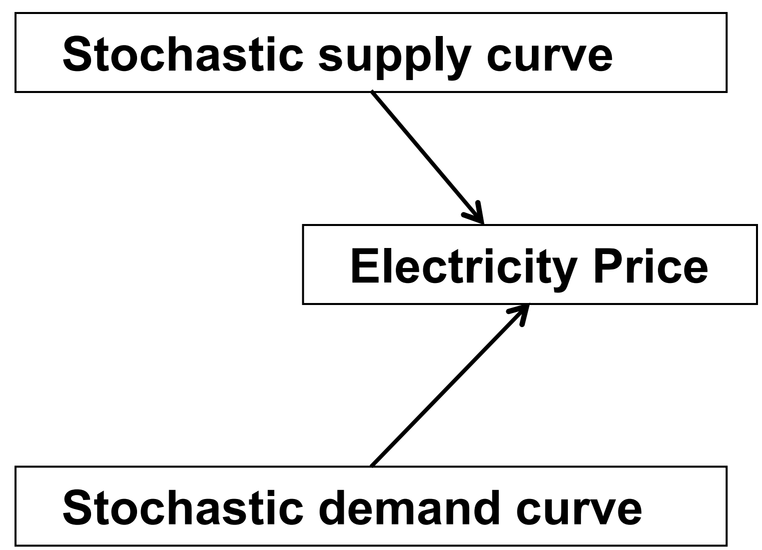
Background

- Investments in power generation entail two types of effects: portfolio effects and option value effects → risk/return trade-off in static and dynamic perspectives.
- Mean Variance (MV) theory: the efficient frontier.
- Real Options (RO) approach: valuation of flexibility, management options.
- **Focus**: assess the performance of dynamic generation mixes in a MV context:
  - coal, natural gas, nuclear, wind, and hydro power plants under carbon restrictions
  - natural gas stations are the marginal units
- **Sources of risk**:
  - Physical: load, power plant contingency
  - Economic: coal price, natural gas price, carbon price
- **Methodology:** Optimal dispatch, Monte Carlo simulation, risk-neutral valuation
- **Example:** UK future energy scenarios up to 2032 with a floor carbon price.
- **Output**: expected price of electricity, price volatility, carbon emissions.
- Others: measurement of diversity and concentration of capacity and generation.

Model features

- Stochastic price models
  - Coal
  - Natural gas
  - CO_2 emissions (floor)
- Stochastic contingencies
  - Power plants
  - Renewable generation
- Operational characteristics:
  - Power plant efficiency
  - New plants; decommissionings
- Financial margins

- Stochastic (seasonal) demand



Physical and economic environment

- Load : $d = D + P$

- Power generation:

$$S_c^i = \begin{Bmatrix} 0, \text{'off' state with probability } 1 - \Lambda_c dt \\ 1, \text{'on' state with probability } \Lambda_c dt \end{Bmatrix},$$

$$S_g^i = \begin{Bmatrix} 0, \text{'off' state with probability } 1 - \Lambda_g dt \\ 1, \text{'on' state with probability } \Lambda_g dt \end{Bmatrix},$$

$$S_n^i = \begin{Bmatrix} 0, \text{'off' state with probability } 1 - \Lambda_n dt \\ 1, \text{'on' state with probability } \Lambda_n dt \end{Bmatrix}.$$

- Demand-side costs: $(d - s) \times VOLL$

- Supply-side costs:

$$c(x) = x_c (M_m + \frac{C + 0.34056A}{H_C}) +$$

$$+ x_g (M_m + \frac{G + 0.20196A}{H_G}) + x_p 1.1(M_m + \frac{0.20196A}{H_G})$$

Economic dispatch

$$\min_{\{x_c, x_g, x_p, s\}} c(x_c, x_g, x_p) + (d - s) \times VOLL$$

$$0 \le x_f \le a_f \bar{x}_f, \;\; f = \{c, g, n, w, h, p\};$$
$$0 \le s \le d;$$
$$dD = a(D,t)dt + b(D,t)dV; \;\; D = \{D\};$$
$$dR = a(R,t)dt + b(R,t)dY; \;\; R = \{W, H, P\};$$
$$dX = a(X,t)dt + b(X,t)dZ; \;\; X = \{C, G, B\};$$
$$A_t = floor(t) + \max(B_t - floor(t);0).$$

Stochastic Optimal Control (Monte Carlo simulation + optimization)

- 750 simulations. Each simulation: 1,200 steps.
- 60 steps per year → 20 years.
- 900,000 optimizations with:
  - Minimization:
    Total Cost = Generation cost + Unserved load cost (VOLL)
  - Linear restrictions:
    Generation limits
    Power supplied $\leq$ Power demanded
  - Non-linear restrictions:
    Demand: seasonal and stochastic
    Stochastic load factor of renewables
    Stochastic commodity prices
    Exogenous floor carbon price
- Output variables: power generated, load served. Hence: total cost, generation costs, unserved load, electricity price, CO_2 emissions, emissions costs, …
- Application to future generation mixes: absolute performance
- Comparisons between them: relative performance.

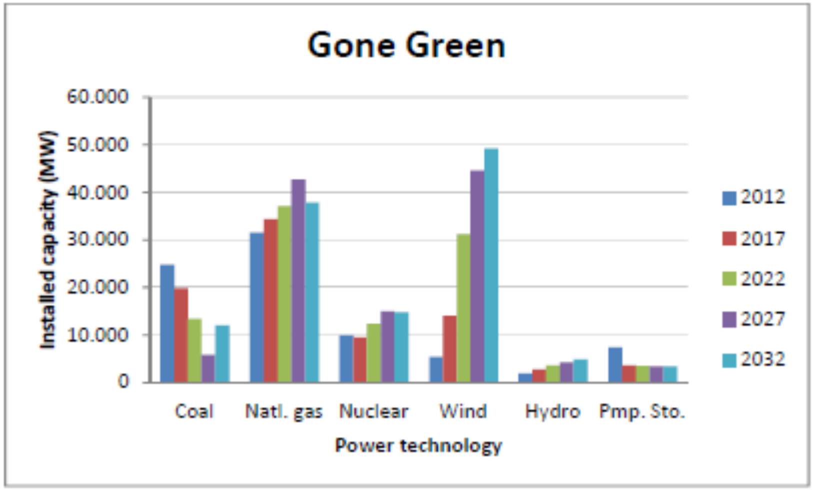
A heuristic application in GB

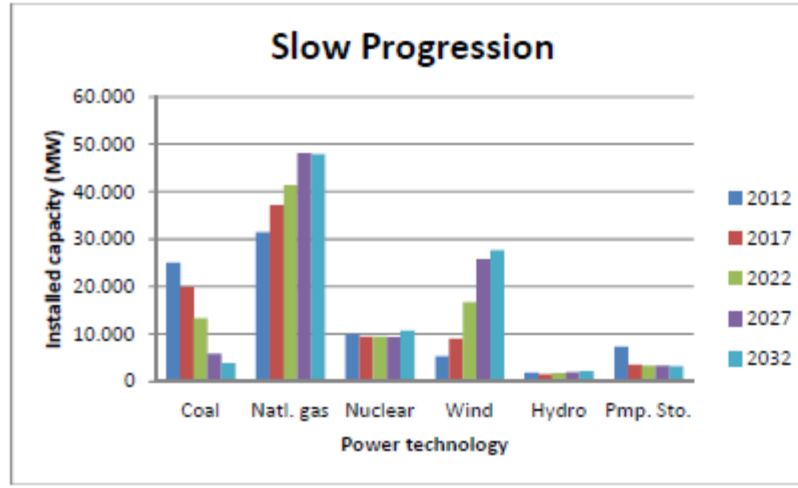
Table 1 GB electricity generation mix as of 2012 (National Grid, 2012; Background)

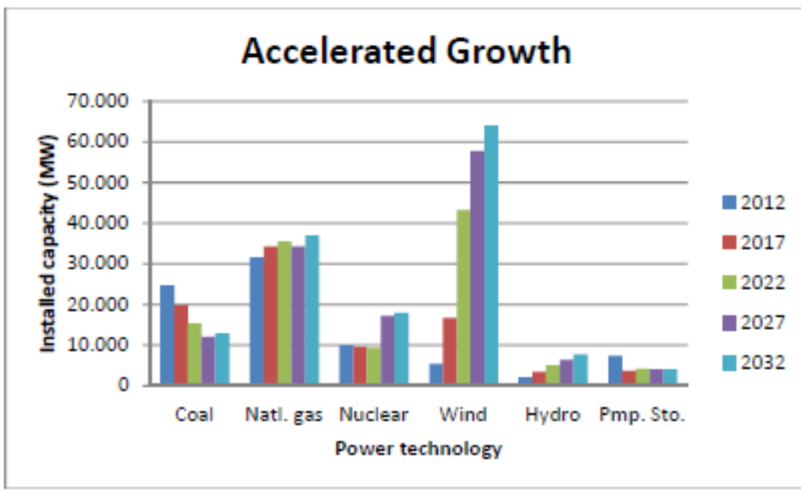
	TEC (MW)[*]	*MPP stations*	*Thermal eff.*	*Availability*
Coal	27,571	22	0.360	0.75
Natural Gas	33,769	79	0.477	0.95
Nuclear	10,561	10	0.398	0.77
Wind	6,910	71		
Hydro	1,626	79		
Pumped Storage	6,380	4		

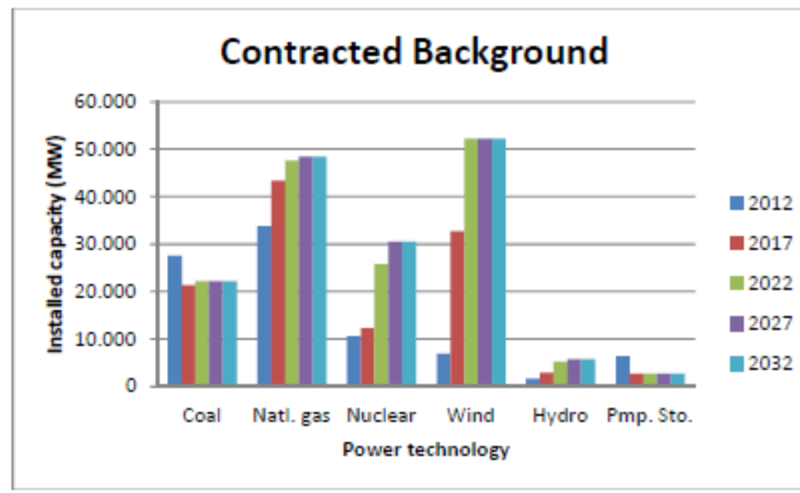
- VOLL: 2,500 ₤/MWh interrupted (2,904 € /MWh).
- Gas plants' profit margin: 6.56 € /MWh (from ICE London, 01/12/09 - 30/11/10)
- Drift & volatility of demand: Jan 2002 – Aug 2013 (DECC)
- Drift & volatility of load factor for wind (Apr 2006 – Dec 2010), hydro (Jan 1998 – Aug 2013), and pumped storage (Jan 1998 – Aug 2013)
- Price processes: futures prices of coal & gas (EEX Leipzig), CO_2 (ICE London).

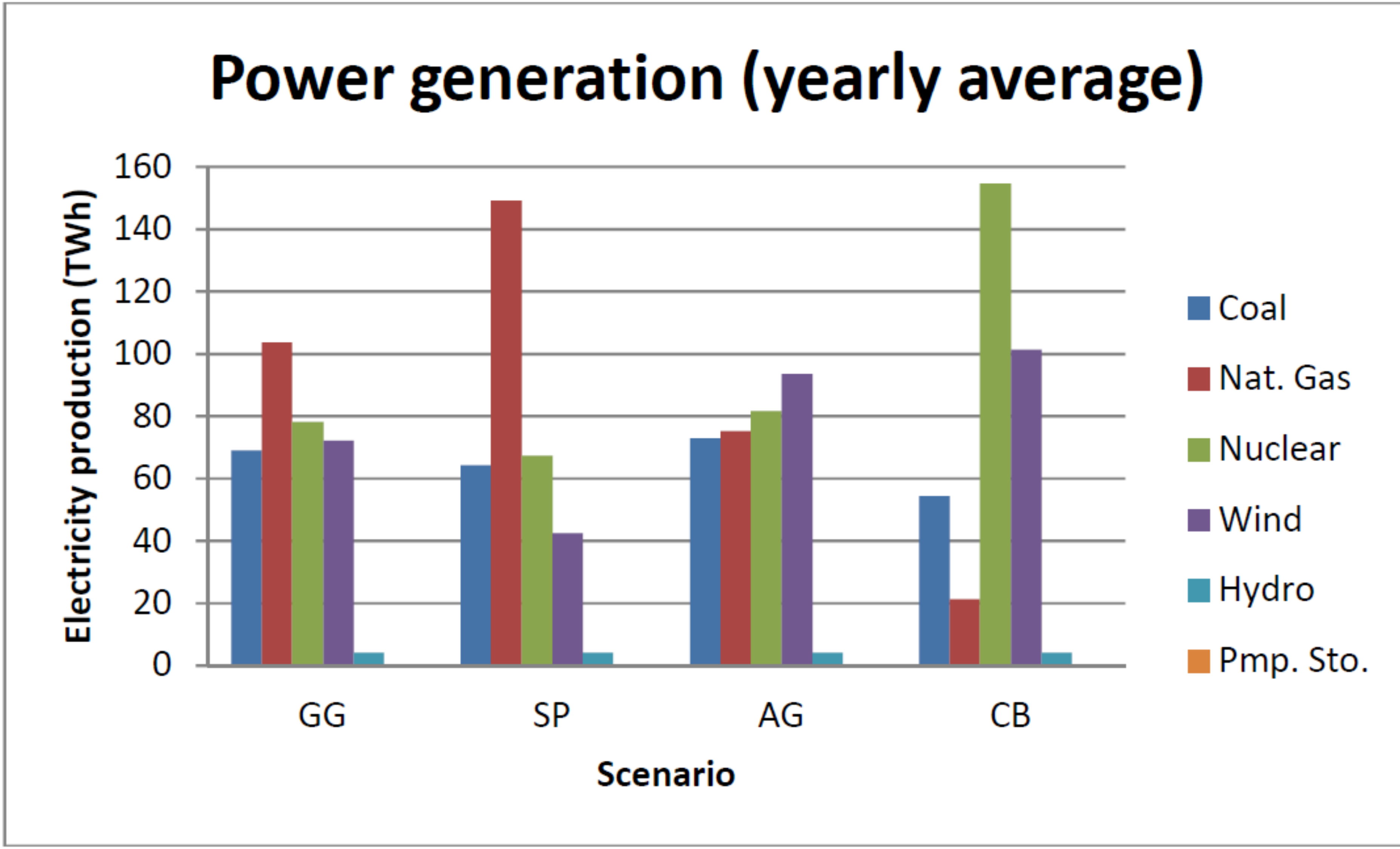
Future energy scenarios 2012-2032

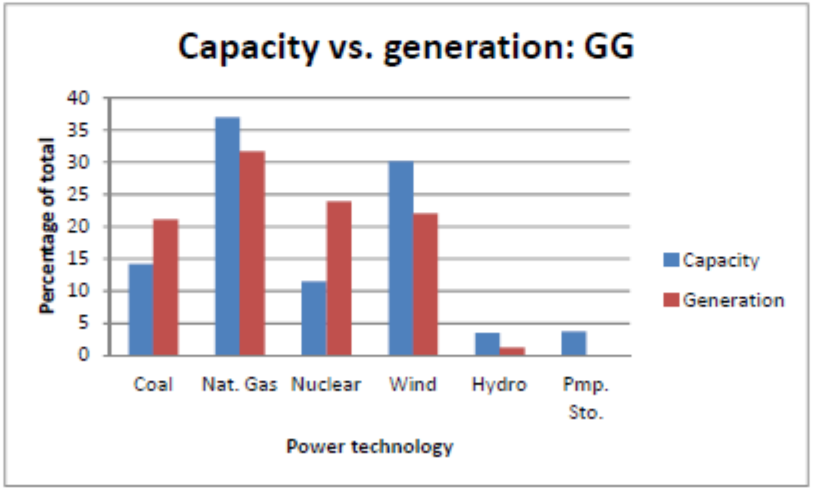


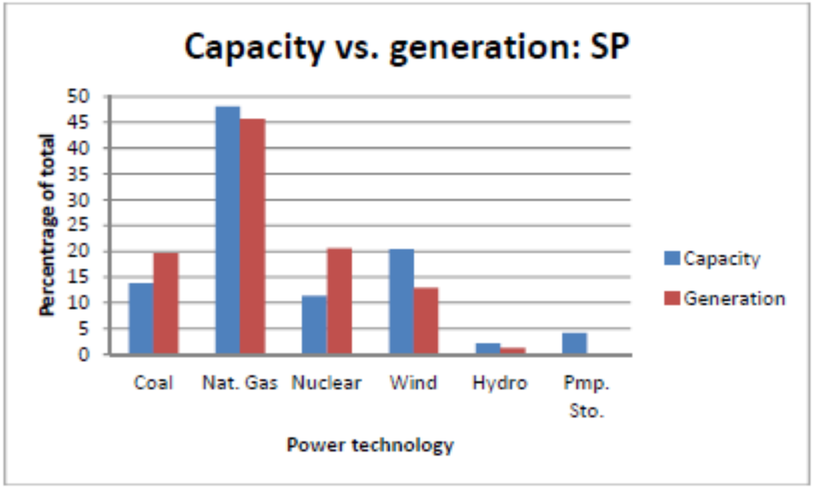


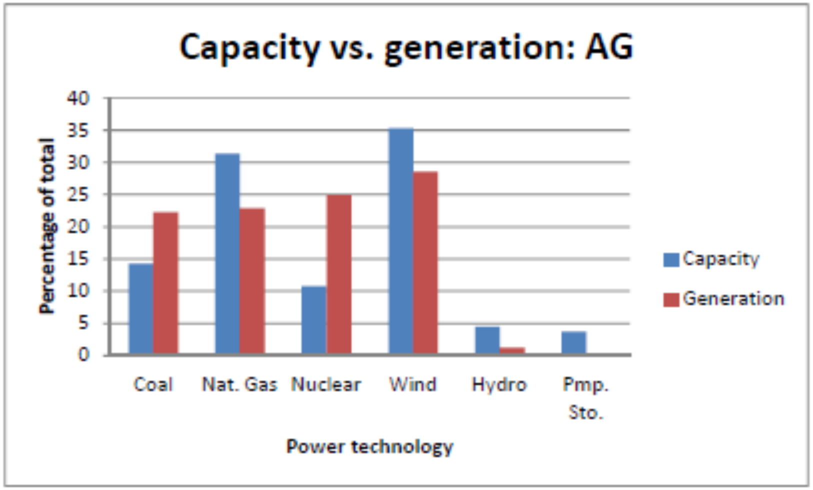


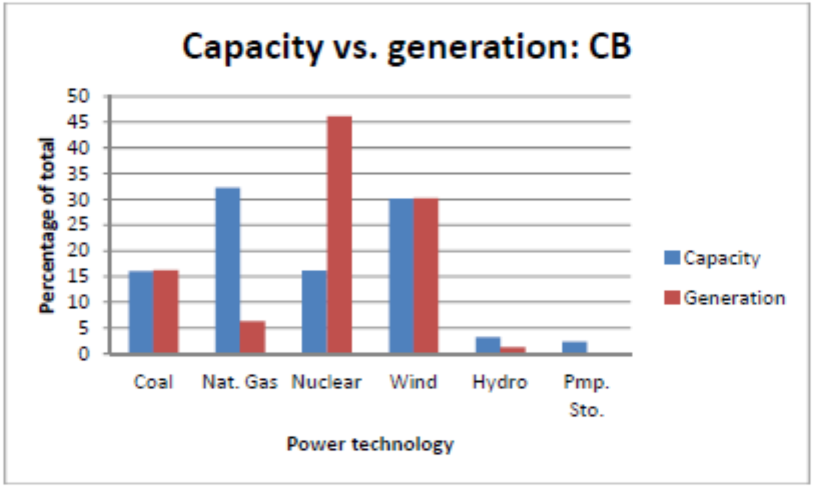


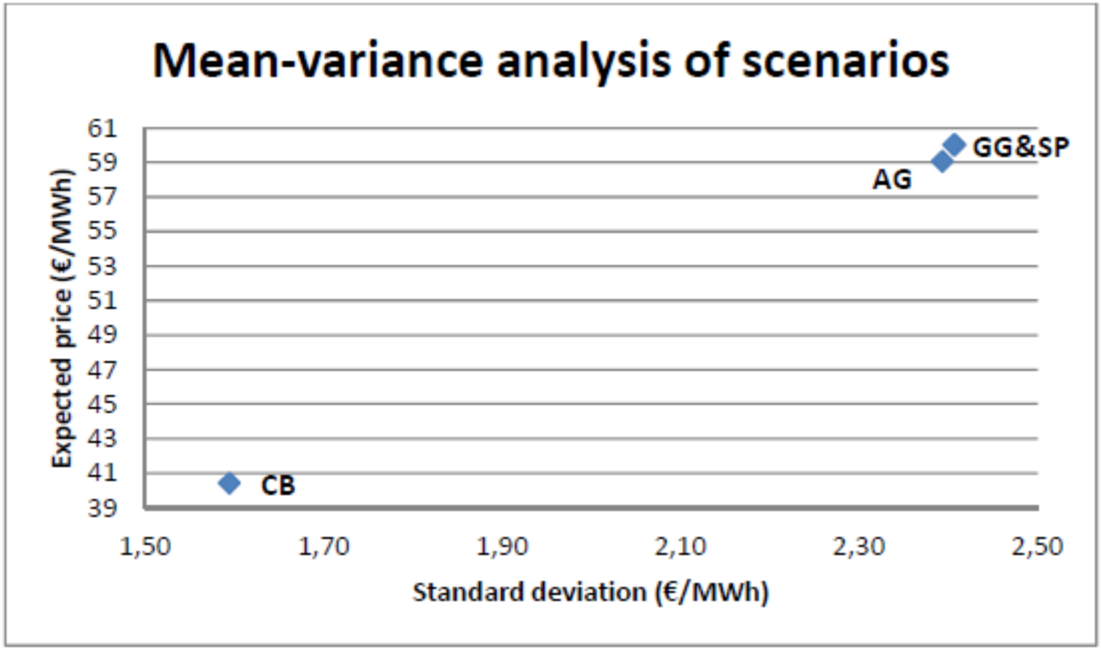

Power generation (yearly average)
Electricity production (TWh)
160
140
120
100
80
60
40
20
0
GG
SP
AG
CB
Scenario
Coal
Nat. Gas
Nuclear
Wind
Hydro
Pmp. Sto.

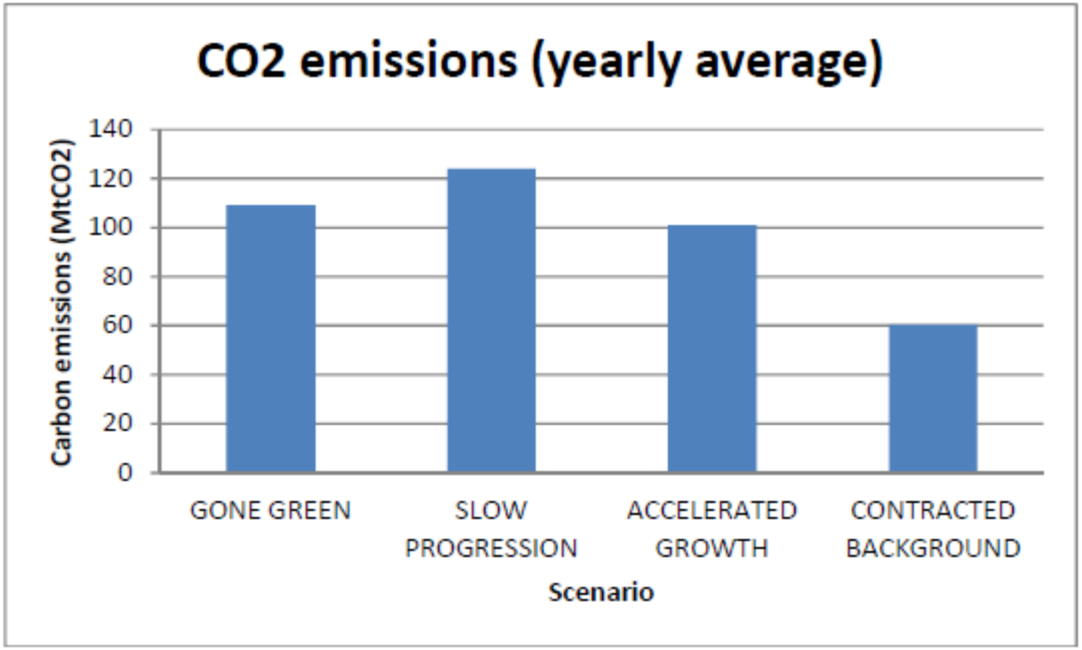

Capacity vs. generation: GG
Percentage of total
Power technology
Coal
Nat. Gas
Nuclear
Wind
Hydro
Pmp. Sto.
Capacity
Generation

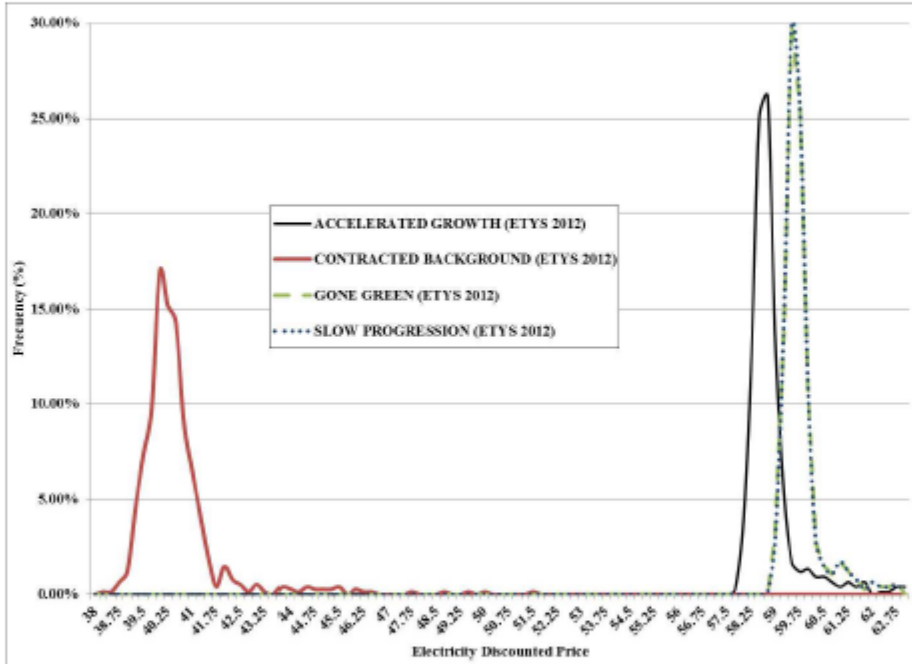

Capacity vs. generation: SP
Percentage of total
Power technology
Coal
Nat. Gas
Nuclear
Wind
Hydro
Pmp. Sto.
Capacity
Generation

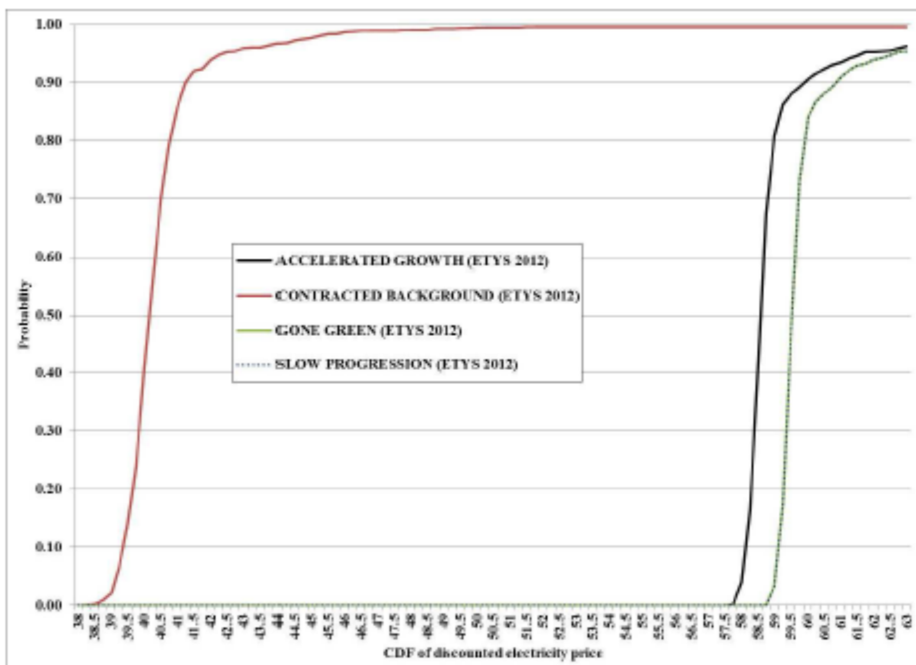

Capacity vs. generation: AG
Percentage of total
Power technology
Coal
Nat. Gas
Nuclear
Wind
Hydro
Pmp. Sto.
Capacity
Generation


Capacity vs. generation: CB
Percentage of total
Power technology
Coal
Nat. Gas
Nuclear
Wind
Hydro
Pmp. Sto.
Capacity
Generation


Mean-variance analysis of scenarios
Expected price (€/MWh)
61
59
57
55
53
51
49
47
45
43
41
39
GG&SP
AG
CB
1,50
1,70
1,90
2,10
2,30
2,50
Standard deviation (€/MWh)


CO2 emissions (yearly average)
Carbon emissions (MtCO2)
140
120
100
80
60
40
20
0
GONE GREEN
SLOW PROGRESSION
ACCELERATED GROWTH
CONTRACTED BACKGROUND
Scenario


ACCELERATED GROWTH (ETYS 2012)
CONTRACTED BACKGROUND (ETYS 2012)
GONE GREEN (ETYS 2012)
SLOW PROGRESSION (ETYS 2012)
Frecuency (%)
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
Electricity Discounted Price


ACCELERATED GROWTH (ETYS 2012)
CONTRACTED BACKGROUND (ETYS 2012)
GONE GREEN (ETYS 2012)
SLOW PROGRESSION (ETYS 2012)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
CDF of discounted electricity price

Concentration and diversification of generation mixes

- Efficiency could come at the expense of diversity and flexibility.
- MV theory assumes price shocks are stochastic: not so under market power.
- Shannon-Wiener diversity index: $SW = \sum_{i=1}^{I} -p_i \ln(p_i)$
- Herfindahl- Hirschman concentration index: $HH = \sum_{i=1}^{I} p_i^2$

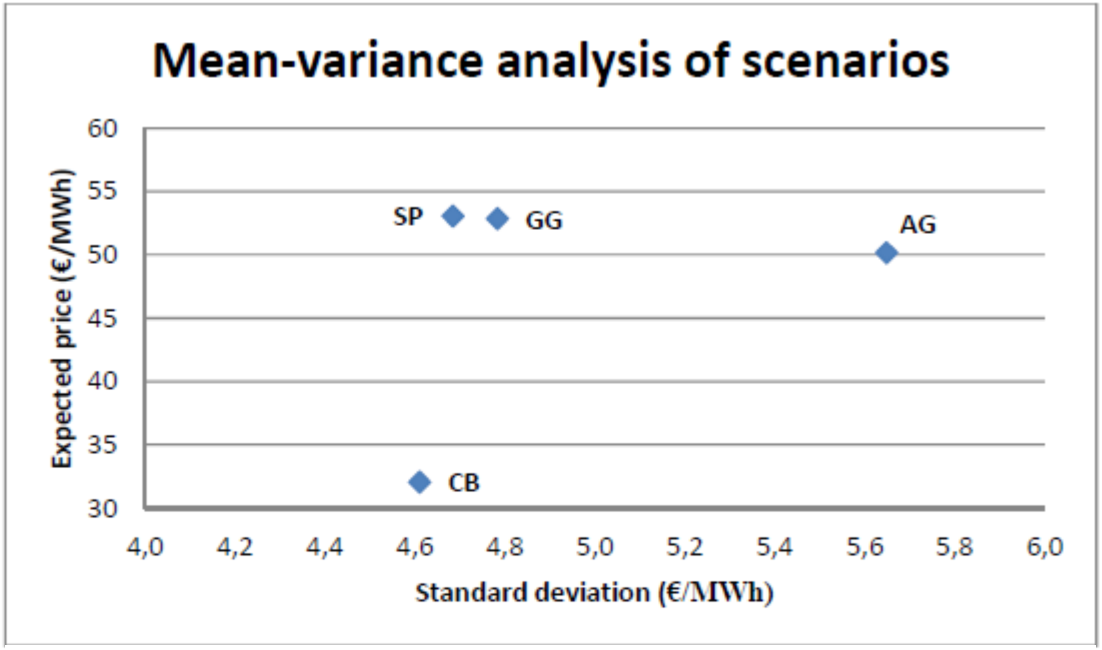
Table 2 Diversity and concentration indexes of GB installed capacity from 2012 to 2032

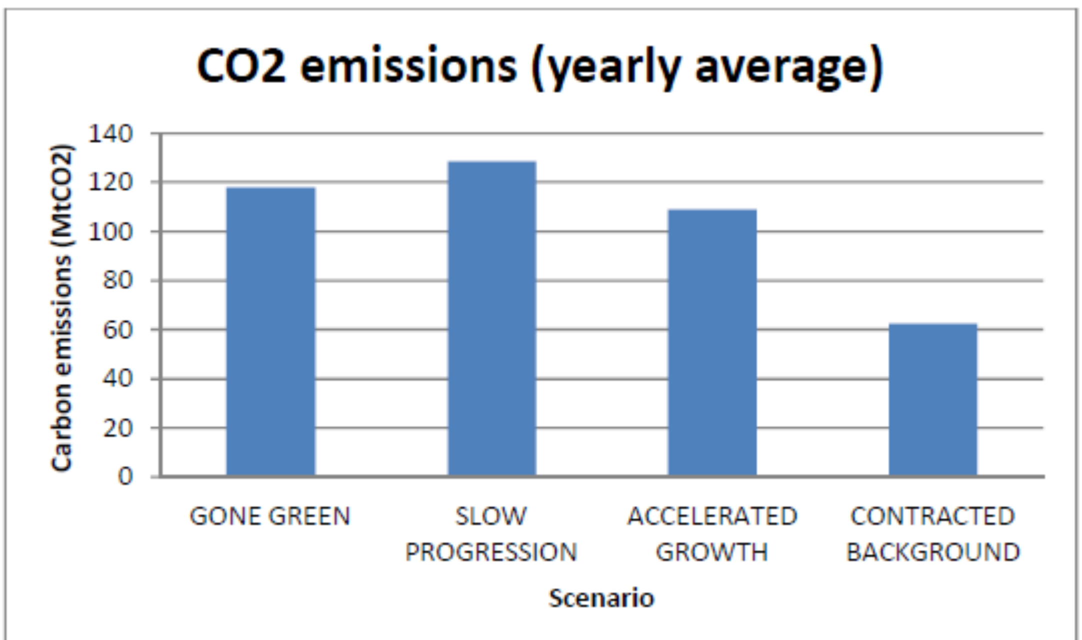
	Installed capacity (2012)	Gone Green (2032)	Slow Progrs. (2032)	Accelerated Growth (2032)	Contr. Bckgrnd (2032)
SW	1.455	1.440	1.281	1.441	1.500
HH	4,161	4,096	3,464	4,004	4,556

Table 3 Diversity and concentration indexes of GB installed capacity from 2012 to 2032

Index	Gone Green	Slow Progression	Accelerated Growth	Contracted Background
SW: Capacity	1.494	1.412	1.510	1.511
SW: Generation	1.422	1.322	1.431	1.242
HH: Capacity	2,634	3,070	2,588	2,477
HH: Generation	2,508	3,057	2,463	3,336

Sensitivity analysis: No floor carbon price





Conclusions

- Investments in power generation call for addressing the risk/return tradeoff in both a static and dynamic perspective.
- Uncertainty all around: physical facilities, load, commodity prices.
- Valuation model that accounts for physical and economic uncertainties.
- Model combines optimization with simulation. Use of prices on futures markets enables risk-neutral valuation.
- Demonstration by example: four time-varying generation mixes in Great Britain.
- We assess their performance in terms of electricity price and risk alongside other metrics (among them carbon emissions).
- Base case (floor carbon price): the GG and SP portfolios are almost indistinguishable from each other, and AG is very close. CB outperforms them.
- The CB portfolio is the most diversified regarding installed capacity, but the least so concerning power generation.
- The four portfolios are problematic in terms of exposure to supply risk because of concentration issues.

Some references

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