"Integration of Wind Power into Electricity Grids: Economic and Reliability Impacts"

Quantifying the System Costs of Additional Renewables in the UK

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Content

- Overview of the issues
- Complexity of the problem
- Capacity question
- Balancing question
- A few numbers

….it is about managing demand-supply balance (security of system operation)

- Conventional approach to managing demand-supply balance
  - Supply side provides management facilities (flexibility)
  - Capacity margin needed to manage uncertainty in generation availability and demand
- Impact of intermittent sources
  - Need for more flexibility
  - Need for backup
- Backup options
  - Conventional generation (traditional measure)
  - Storage and DSM (emerging measures)

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Key messages

- Intermittency question can be dealt with in two parts:
  - Capacity (back up)
  - Balancing
- Costing intermittency: comparing the total costs of complete alternative systems:
  - Capacity cost
  - Fuel cost
  - Balancing cost
  - Network cost

Alternative systems should have similar security performance

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How much does it cost after all?

- Not easy to compare various studies as the assumptions are not often clear
- Methodology may be more important than the numbers themselves
- Relevant factors may be system specific
- A system with 20% of wind generation cost 0.3p/kWh more than a conventional system (Power UK, April 2003)
  - Allocated to wind only: 1.5p/kWh

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A complex multi-disciplinary subject

- Methodologies for quantifying technical impact
  - Diversity of criteria for evaluation
  - Many interrelated factors to be considered
  - Need to extend existing modelling capability
- Interpretation, costing and environmental impact
- Evaluation of the impact of existing and alternative market arrangements and rules
- Energy policy

Questions addressed

- How is the capacity question defined?
- What are the key drivers?
- How to deal with rare events?
- What are the alternatives in backing up intermittent sources other than conventional generation?
- What are the alternative approaches to quantifying the corresponding cost?

Two approaches of formulating the capacity question

- How much conventional generation can be displaced by intermittent sources? (What is the contribution of intermittent sources to system security?)
  - What is the benefit of intermittent sources?
- How much conventional generation capacity is required to back up intermittent sources?
  - What is the penalty of intermittent sources?

What is the relationship between these two questions?

Example 1

- **System A**

  25 GW of Demand

  – 32 GW of (CC)GT

  - LOLP = 9%

- **System B**

  25 GW of Demand

  – 25 GW of wind

  – 27.5 GW of (CC/OC)GT

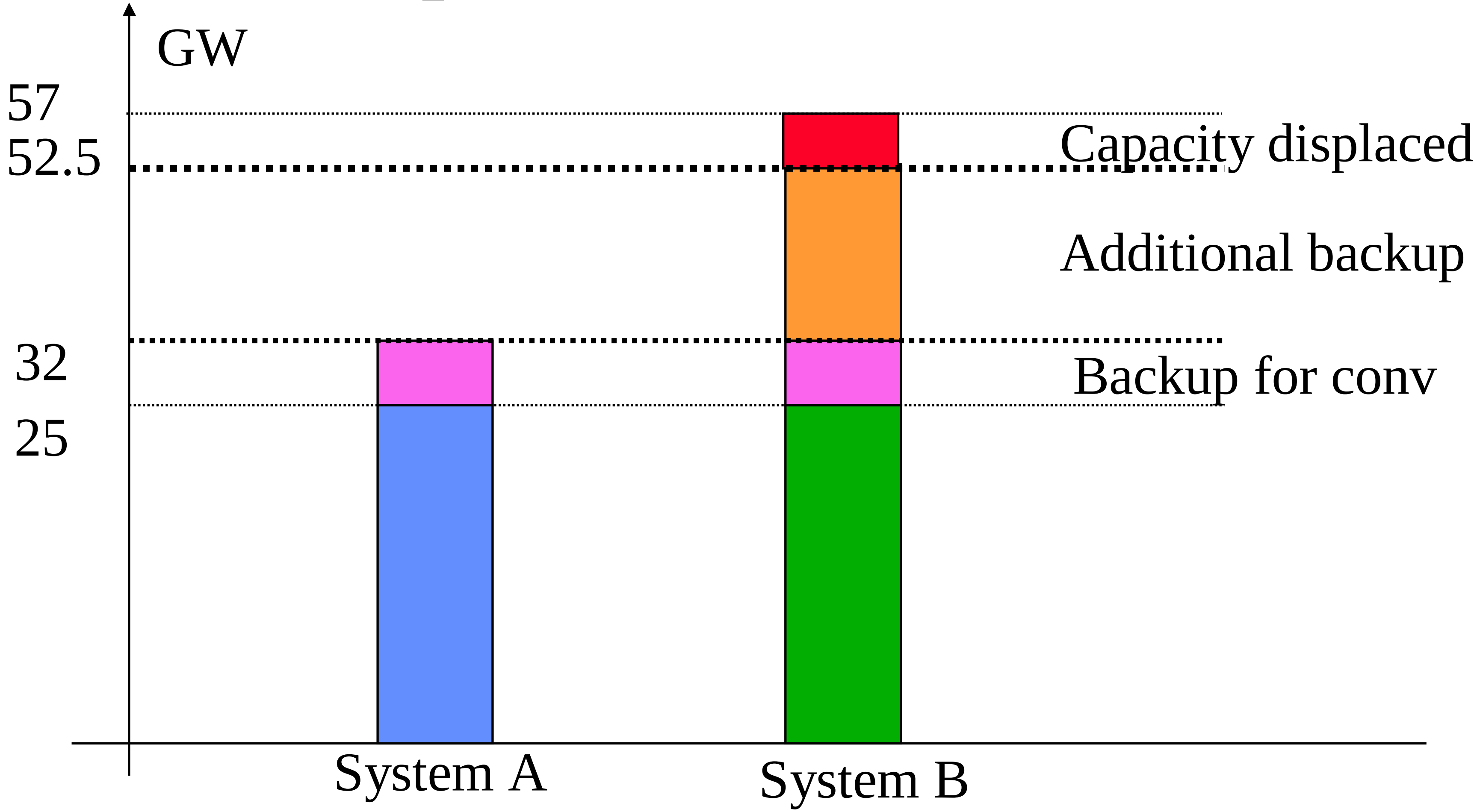
  – LOLP = 9%

Observations /1-1

- System A:
  - 25 GW of conventional plant need backup of 7GW of conventional plant
- System B:
  - 25GW of wind needs backup of 27.5GW of conventional plant (or 27.5 GW of conventional plant needs backup of 25 GW of wind)
  - 25 GW of wind displaces 4.5GW of conventional plant

All of these are true

Interpretation of the terms



Additional backup + Contribution to capacit

= Wind capacity installed

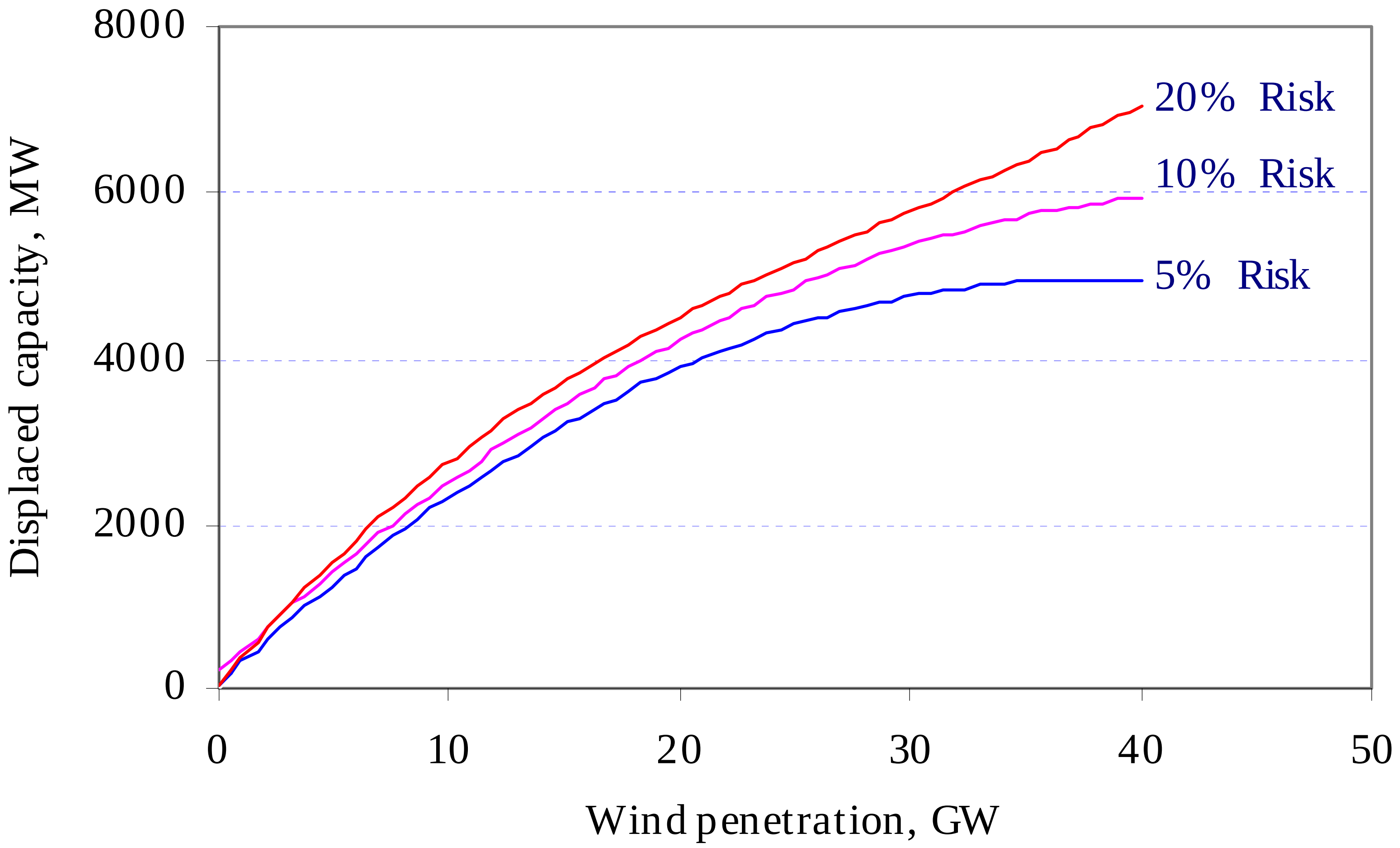
Alternative capacity questions

- What are the risk of interruptions in an electricity system with significant penetration of intermittent sources?
- How should this risk be measured, quantified and managed?
- What are the costs and benefits of alternatives?

Measuring generation adequacy

- Security standards (CEGB)
  - Probability of peak demand exceeding available generation should be less than 0.9. (LOLP = 0.9)
  - This required 24% generation margin
- Similar criteria used by other utilities
  - LOLP based
  - LOLE based

Displaced conventional capacity by wind generation



Problems with the present approaches /1

- Can only deal with the back up in the form of conventional generation
- LOLP and LOLE reliability indices do not provide sufficient information for risk of interruptions to be quantified:
  - How frequently will interruptions occur?
  - How long will these last?
  - What magnitudes of shortages should we expect?
- Information about frequency, duration and magnitudes of interruptions is critical for evaluating the viability of DSM and storage based backup options.

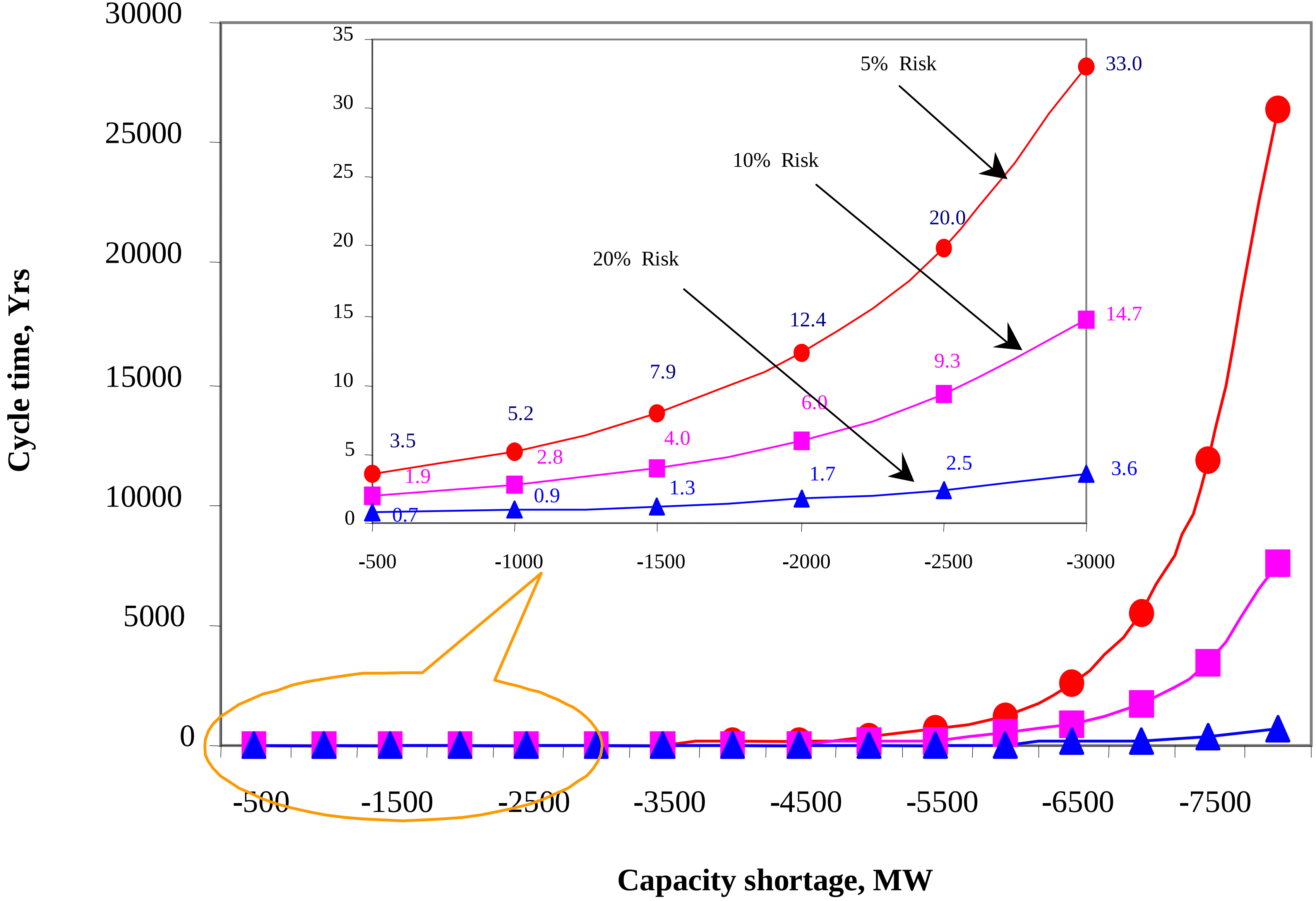
Problems with the present approach /2

- Cannot deal with with rare events, such as high-pressure weather conditions.
  - What is the contribution of wind to security if:
    - there will be 3 days with little or no wind every 5 years?
  - How important is the correlation with peak demand?

- What are appropriate levels of risk?
  - Information about frequency, duration and magnitudes of interruptions is necessary (balance between costs of interruptions and costs of generation capacity)

Review of approaches

- Conventional generation planning tools WASP (based on LOLP approach, does not deal with intermittent generation)
- Simple analytical approach, LOLP & LOLE based concept
  - Majority of existing work based on this approach
- Complex analytical approaches
- FORM/SORM (sensitivity analysis, contribution factors)
- Simulation approaches (detailed simulation of the operation of the system over many years)



Cycle time, Yrs
30000
25000
20000
15000
10000
5000
0
-500
-1500
-2500
-3500
-4500
-5500
-6500
-7500
Capacity shortage, MW
35
30
25
20
15
10
5
0
-500
-1000
-1500
-2000
-2500
-3000
5% Risk
10% Risk
20% Risk
33.0
20.0
12.4
7.9
5.2
3.5
14.7
9.3
6.0
4.0
2.8
1.9
3.6
2.5
1.7
1.3
0.9
0.7

Drivers of capacity

- Correlation between peak load and output of intermittent sources
- Load factor of intermittent sources
- Diversity of intermittent sources
- Variations across years

Balancing

- Issue:
  - Managing fluctuations and uncertainty in generation and demand over time horizons from several seconds to several hours and days
- Impact:
  - Balancing task reduces the contribution that intermittent sources make to reduction of fuel consumption

Balancing task

- Characterise uncertainty and fluctuations
  - Forecast errors across various time horizons to be quantified
- Allocate appropriate resources: reserves
  - Response – frequency sensitive
  - Reserve – frequency non-sensitive
    - Synchronised and standing (storage and DSM)
- Quantify costs and environmental impact
  - Wind curtailment

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Drivers of balancing cost

- Penetration level
- Fuel cost and plant efficiency
- Diversity
- Frequency of dispatch instructions
- Quality of forecast
- Flexibility of generation system
- Correlation of demand and generation output
- Robustness of intermittent generation

Impact of intermittent generation on continues frequency regulation

- Forecast errors over very short time (seconds) horizons are negligible.However, increased dispatch errors will require more continuous regulation.

Capacity of wind installed [GW]	Expected increase in continuous regulation [MW]	Per unit increase [MW/GW]	Annual additional cost [m£]	Additional energy cost [£/MWh]
0	0	0	0	0.0
5	44	9	3	0.2
10	159	16	10	0.3
15	320	21	21	0.5
20	505	25	33	0.5
25	706	28	46	0.6

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Impact of intermittency on reserve

- Demand for reserve driven by uncertainty in demand and generation (orthogonally, as demand and generation forecast errors are not correlated)
- Need for reserve will increase with increased penetration of intermittent resources

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Fluctuations in wind power output (25 GW of wind capacity)

Lead Time [Hours]	Standard Deviation [MW]	Likely maximum change [MW]	Extreme change [MW]
0.5	350	1,050	2,500
1	680	2,040	3,800
2	1,300	3,900	6,300
4	2,320	6,960	13,000

Managing intermittency through reserves

- Reserve provided by synchronised plant
  - Cost driven by loss of efficiency of part loaded plant
  - Additional plant operating to compensate for running part loaded
  - Additional start up cost
- Reserve provided by standing reserve
  - Start new plant with higher cost if and when needed
  - Use storage
- Balance between the synchronised and standing reserve
  - Cost of running synchronised reserve (loss of efficiency) against cost of running storage (efficiency losses)

Indicative additional reserve cost

Capacity of wind installed [GW]	Expected increase in reserve [MW]	Per unit increase [MW/GW]	Annual additional cost [m£]	Additional energy cost [£/MWh]
0	0	0	0	0.0
5	433	19	87	1.2
10	1444	63	144	2.1
15	2702	118	180	2.6
20	4060	178	203	2.9
25	5470	240	219	3.1

Wind curtailment

- As penetration of wind power increases there will be occasions, that all wind power will not be possible to accommodate
- This is generally the case when low demand conditions coincide with high wind power output.
- Drivers
  – Wind penetration
  – Flexibility of generation system
  – Balance between standing and synchronised reserve critical

Review of approaches to quantifying balancing costs

- Simple analytical approach - Dillon Farmer
  - Majority of existing work based on this approach – limited in dealing with plant flexibility and chronology
- Complex analytical approaches, based on frequency & duration concept with some ability to deal with chronology
- Simulation approaches
  - Ability to deal with plant flexibility
  - Ability to deal with storage and DSM

How much does it cost after all?

- Not easy to compare as the assumptions are not often clear
- Methodologies and assumptions may be more important than the numbers themselves
- A system with 20% of wind generation cost 0.3p/kWh more than a conventional system (Power UK, April 2003)
  - Allocated to wind only: 1.5p/kWh
- Sensitivity studies important

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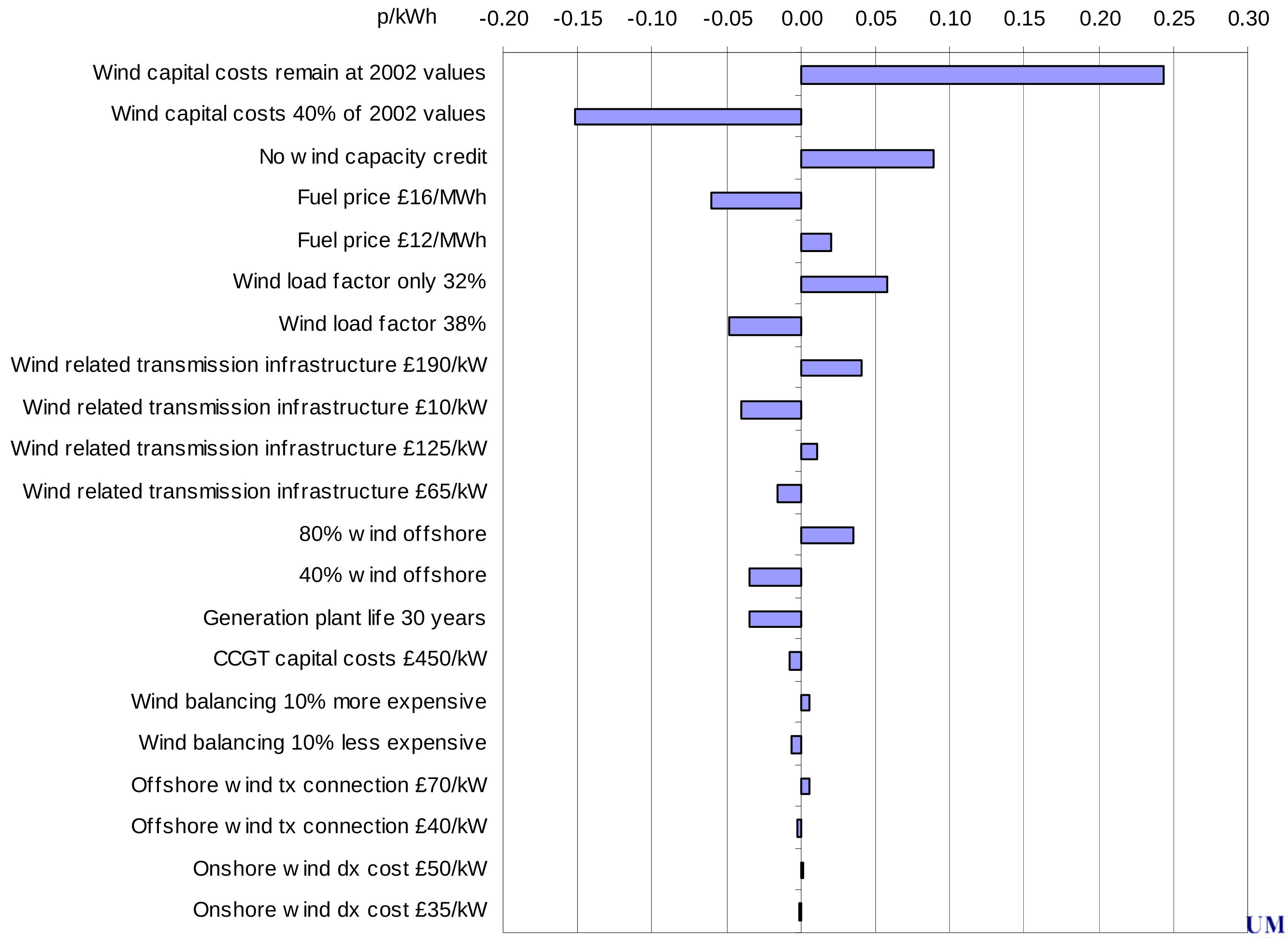
p/kWh
-0.20
-0.15
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Wind capital costs remain at 2002 values
Wind capital costs 40% of 2002 values
No w ind capacity credit
Fuel price £16/MWh
Fuel price £12/MWh
Wind load factor only 32%
Wind load factor 38%
Wind related transmission infrastructure £190/kW
Wind related transmission infrastructure £10/kW
Wind related transmission infrastructure £125/kW
Wind related transmission infrastructure £65/kW
80% w ind offshore
40% w ind offshore
Generation plant life 30 years
CCGT capital costs £450/kW
Wind balancing 10% more expensive
Wind balancing 10% less expensive
Offshore w ind tx connection £70/kW
Offshore w ind tx connection £40/kW
Onshore w ind dx cost £50/kW
Onshore w ind dx cost £35/kW

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