The value of wind revisited: A systems-planning perspective

Council for Scientific and Industrial Research (CSIR): Energy Centre

Strommarkttreffen
Reiner Lemoine Institut, Berlin. October 2017
Agenda

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2. Results
3. Conclusions
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Methodology: Run LT least-cost expansion for increasing penetrations of wind energy in greenfield system (2017 demand & costs)

Adequacy = same for all wind penetrations; Full chronology (hourly)
Methodology: Run LT least-cost expansion for increasing penetrations of base supply energy in greenfield system (2017 demand & costs)
With no wind included as an expansion option, a particular portfolio of generators are built
Greenfield system: LT least-cost expansion without wind

Cost to supply residual load [€-billion/a]

Available wind [TWh/a]

Energy produced [TWh/a]

Wind available energy as % of annual demand

Adequacy = same for all wind penetrations; Full chronology (hourly)
With a pre-defined amount of wind allowed - a new portfolio of generators is built

Greenfield system: LT least-cost expansion with 10% available wind

Cost to supply residual load [€-billion/a]

Available wind [TWh/a]

Energy produced [TWh/a]

Wind available energy as % of annual demand

Adequacy = same for all wind penetrations; Full chronology (hourly)
The cost to supply the residual load after the pre-defined amount of wind is calculated for each penetration of wind.
Average system value is the cost difference relative to the cost to supply with no wind included (0% penetration)

Cost to supply residual load [€-billion/a]
- 15.9
- 14.4

Available wind [TWh/a]
- 0
- 25

Cost difference [€-billion]
- 1.5

Average system value of wind (10%)
- 56.7 €/MWh

Available wind [TWh]
- 25

Energy produced [TWh/a]
- 250
- 185
- 38
- 27
- 25

Adequacy = same for all wind penetrations; Full chronology (hourly)
Marginal system value is the cost difference relative to the previous penetration level

Cost to supply residual load [€-billion/a]:
- 15.9
- 14.4

Available wind [TWh/a]:
- 0
- 25

Energy produced [TWh/a]:
- 185
- 25

Wind available energy as % of annual demand:
- Biogas
- Solar PV
- Peaking
- Gas
- Coal
- Wind

Cost difference [€-billion]:
- 1.5

Available wind [TWh]:
- 25

Marginal cost difference [€-billion]:
- 1.5

Available wind Difference [TWh]:
- 25

Average system value of wind (10%): 56.7 €/MWh

System value of Marginal wind (10%): 56.7 €/MWh

Adequacy = same for all wind penetrations; Full chronology (hourly)
## Marginal system value declines quicker than average value (as expected)

### Available wind [TWh/a]

<table>
<thead>
<tr>
<th>0%</th>
<th>10%</th>
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<th>30%</th>
<th>40%</th>
<th>50%</th>
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<tr>
<td>0</td>
<td>25</td>
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### Energy produced [TWh/a]

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<th>0%</th>
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<tr>
<td>185</td>
<td>154</td>
<td>124</td>
<td>25</td>
<td>50</td>
<td>15.9</td>
<td>14.4</td>
<td>13.1</td>
<td>0</td>
<td>25</td>
<td>50</td>
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</tbody>
</table>

### Cost to supply residual load [€-billion/a]

- 15.9
- 14.4
- 13.1

### Cost difference [€-billion]

- 2.8

### Available wind [TWh]

- 50

### Average system value of wind (20%) [€/MWh]

- 55.4

### Marginal cost difference [€-billion]

- 1.3

### Available wind Difference [TWh]

- 25

### System value of Marginal wind (20%) [€/MWh]

- 54.1

---

### Adequacy = same for all wind penetrations; Full chronology (hourly)
Decline in average and marginal value as penetration level increases

Cost to supply residual load [€-billion/a]

Available wind [TWh/a]

Energy produced [TWh/a]

Cost difference [€-billion]

3.9

/..

Available wind [TWh]

74

Average system value of wind (30%)

52.5 €/MWh

Marginal cost difference [€-billion]

1.1

/..

Available wind difference [TWh]

24

System value of Marginal wind (30%)

46.6 €/MWh

Wind available energy as % of annual demand

Adequacy = same for all wind penetrations; Full chronology (hourly)
More notable degradation of wind value as soon as wind begins to be curtailed

Cost to supply residual load [€-billion/a]

Available wind [TWh/a]

Energy produced [TWh/a]

Wind available energy as % of annual demand

Adequacy = same for all wind penetrations; Full chronology (hourly)
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Initial residual portfolio is coal-based but changes as wind penetration increases where solar PV and gas-fired CCGTs/OCGTs are preferred.

Total capacity and energy of residual load for each penetration level of wind.

- Energy Produced
  - Wind available energy as % of annual demand
  - Energy produced [TWh/a]

- Capacity built to supply demand
  - Installed capacity [GW]
  - 2017 Technology costs

- 2017 Technology costs
  - Wind
  - Coal
  - Gas
  - Peaking
  - Solar PV
  - Biogas

- Wind Curtailed
- Biogas
- Solar PV
- Peaking
- Gas
- Coal
- Wind

Total capacity and energy of residual load for each penetration level of wind.
The effect of the wind profile is notable but not significant
Value of wind tested with multiple wind profiles from 2009 - 2013

Cost to supply residual load

Average system value

Wind available energy as % of annual demand

- 2011 wind profile (benchmark)
- 2010 wind profile
- 2013 wind profile
- 2009 wind profile
- 2012 wind profile
- Cost of wind

Wind available energy as % of annual demand

- 2011 wind profile (benchmark)
- 2010 wind profile
- 2013 wind profile
- 2009 wind profile
- 2012 wind profile
- Cost of wind
Marginal value of wind declines as expected but not as quickly as seen in previous literature

Value of wind tested with multiple wind profiles from 2009 - 2013

Cost to supply residual load

- System value of marginal wind
- Cost to supply residual load
- Wind available energy as % of annual demand

- 2011 wind profile (benchmark)
- 2010 wind profile
- 2013 wind profile
- 2009 wind profile
- 2012 wind profile
- 2016 Actual wind

Below 60-70%:
Value wind > current cost
With same methodology but applied for a base-supplier and no wind to isolate the effect.

Total capacity and energy of residual load for each penetration of base supply.
Average value for a base-supplier also declines but nowhere near as much as wind (as expected).

Average system value of base supply generator decreases as energy share of base supply increases.

Cost to supply residual load

Average system value

Base supply available energy as % of annual demand

Cost to supply residual load [€-billion/a]

System value of base supply [€/MWh]

Value base supply never higher than cost

Base supply available energy as % of annual demand

- Base supply (value)
- Cost of new base supply (nuclear)
- Cost of new base supply (coal)
More importantly – what is the value of wind relative to a base-supplier and what are the actual relative costs of each?

Wind value relative to base supply

**Average system value**

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<tr>
<th>System value [€/MWh]</th>
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**Value factor**

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<td>0.60</td>
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<td>0.80</td>
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<tr>
<td>1.00</td>
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<td>1.20</td>
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**Base supply/wind available energy as % of annual demand**

- 2011 wind profile
- 2010 wind profile
- 2013 wind profile
- 2012 wind profile
- 2009 wind profile
- 2016 Actual wind
- Cost factor (wind/nuclear)
- Cost factor (wind/coal)
Due to differences in profiles, wind value generally < base supply value at higher energy shares (as expected)
Example day: hourly generation for wind and base supply at 50% energy share

Residual load wind > Residual load base supply at higher energy shares as some wind is wasted
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As penetration↑ - wind value decline not as extreme as expected and wind value-factor never below relative base-supply to wind cost-factor

System-planning approach to valuing power generators for a range of penetration levels (focus on wind)

- Value of any power generator can be considered - wind and base supply presented
- As expected – average and marginal value of wind declines with increasing penetration but:
  - Value of wind greater than cost for penetration levels of up to 60-70%

Interesting outcomes:

- For a range of wind profiles - change in wind value is not too large
- Average and marginal wind value decline not as significant for all penetration levels (as seen in the literature)
- Value factor (relative to base-supply) never below cost factor of wind to base suppliers (coal/nuclear)

Going forward:

- Study based on 2017 costs. Future costs for batteries and solar PV plus uptake of electric vehicles change optimal capacity mix towards higher share of solar PV
- Apply methodology to other technologies (solar PV) and other jurisdictions
- How important is the wind resource and profile?
- Other aspects to enable richer findings and test whether fundamental findings change:
  - Cost of balancing (effect of forecast errors)
  - Relative grid-related costs
Thank you