Offshore cost of energy: Forecasts based on the European Story so far…

NREL 3rd WESE Workshop
Boulder
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14 January 2015
Cost of Energy calculation
EU CAPEX trend to date
  • Reported
  • Modelled
  • Differences
  • Causes
EU LCOE trend to date
Future
  • The Crown Estate study and beyond
  • System engineering opportunities

Contents

Selected clients

BVG Associates

• Market and supply chain
  • Analysis and forecasting
  • Strategic advice
  • Business and supply chain development

• Economics
  • Socioeconomics and local benefits
  • Technology and project economic modelling
  • Policy and local content assessment

• Technology
  • Engineering services
  • Due diligence
  • Strategy and R&D support
Cost of energy

Basics

LCOE

\[
LCOE = \frac{\sum_{i=m}^{n} \left( (C_i + O_i + D_i) / (1+W)^i \right)}{\sum_{i=m}^{n} \left( E_i / (1+W)^i \right)}
\]

Where:
- \( LCOE \) Levelised cost of energy in £/MWh
  - = revenue needed (from whatever source) to obtain rate of return \( W \) on investment over life of the wind farm (tax, inflation etc. not modelled)
- \( C_i \) Capital expenditure in £ in year \( i \)
- \( O_i \) Operational expenditure in £ in year \( i \)
- \( D_i \) Decommissioning expenditure in £ in year \( i \)
- \( E_i \) Energy production in MWh in year \( i \)
- \( W \) Weighted average cost of capital in % (real)
  - = (cost of debt x % dept ) + (return on equity x equity portion)
- \( n \) Operating lifetime of wind farm (baseline 20 years)
- \( m \) Years before start of operation when expenditure first incurred
- \( i \) \( i \) year of lifetime (\(-m, \ldots, 1, 2, \ldots n)\)

LCOE breakdown – for specific US site; FID in 2020

- Project development and permitting up to FID: 1%
- Project management and contingencies from FID to WCD: 2%
- Nacelle: 20%
- Rotor: 15%
- Tower: 5%
- Foundation supply: 11%
- Array cables: 2%
- Foundation installation: 5%
- Array cable installation: 2%
- Turbine installation: 1%
- Transmission charges: 20%
- Unplanned service: 8%
- Operation and planned maintenance: 5%
- Other: 2%
- Decommissioning: 1%

CAPEX: 64%
Balance of plant supply: 13%
Operation, maintenance and service: 35%
Turbine supply: 39%
Installation: 8%
Project: 4%

EU Sites

33 projects across Northern Europe

Significant variation, but upward trends in difficulty and turbine size
CAPEX

33 projects across Northern Europe

Average reported CAPEX
- Little logic in trends between bubbles – wide scatter
- Sensitivity about the use of bubbles - confidentiality
- Averaged over 5 years
- Derived a smoothed ±1SD range
- Slope due to changes in site conditions and other effects
- Not sure reached point of inflection

Average calculated CAPEX
- Used in-house spatial, multi-variable module-based LCOE model
- Assumed 2011 technology, costs and 4MW turbines (selectable)
- Difference with reported should remove effect of site conditions
- Average matches to 2%
- Period of widest variation in CAPEX matches
- Gradient quite different

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Much steeper increase in CAPEX than modelled

- Change in site conditions only explains about 25% of change in CAPEX
- Still £1.4m/MW gap

6 main causes of the £1.4m/MW gap?

- Steel price
- Cost of capital (SC)
- Profiteering / risk
- Underpricing
- Inflation
- Exchange rate
Cost of Energy

Raw trend could have levelled off

Normalised LCOE for 33 projects

- Combines reported CAPEX with modelled OPEX and AEP
- All in 2011 terms; constant WACC
Forecast 1: to 2020

The Crown Estate Offshore Wind Cost Reduction Pathways study

Technology

- LCOE for wind farm with FID in 2011
- Increase in turbine power rating
- Optimisation of rotor diameter, aerodynamics, design and manufacture
- Introduction of next generation drive trains
- Improvements in jacket foundation design and manufacturing
- Improvements in aerodynamic control
- Improvements in support structure installation
- Greater level of array optimisation and FEED
- About 30 other innovations
- LCOE for wind farm with FID in 2020

Source: BVG Associates

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Methodology

Robust cost model and industry-supported baselines

Cost Model

- Models changes in risk, with resulting impact on financing cost
- Numerous other stated assumptions, agreed with industry

Baselines

Wind turbines

<table>
<thead>
<tr>
<th>Turbine MW-Class</th>
<th>Nominal range of power rating (MW)</th>
<th>Typical range of rotor diameter (m)</th>
<th>Diameter modelled (m)</th>
<th>Example current and future turbines</th>
</tr>
</thead>
<tbody>
<tr>
<td>4MW</td>
<td>3 to 6</td>
<td>up to 145</td>
<td>120</td>
<td>AREVA M5000-116 and 135, REpower 5M and 8M, Siemens SWT 3.6-107 and 120, Vestas V112-3.0</td>
</tr>
<tr>
<td>6MW</td>
<td>6 to 7</td>
<td>145 to 162</td>
<td>147</td>
<td>Alstom Haliday 150-6MW, Siemens SWT-6.0-154</td>
</tr>
<tr>
<td>8MW</td>
<td>7 to 9</td>
<td>162 to 180</td>
<td>169</td>
<td>MPSE Sea Angel, Samsung S7 0-171 Vestas V164-8 0MW</td>
</tr>
</tbody>
</table>

Wind farm sites

<table>
<thead>
<tr>
<th>Site Type</th>
<th>Average water depth (MSL) (m)</th>
<th>Distance to nearest construction and operation port (km)</th>
<th>Average wind speed at 100m above MSL (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>25</td>
<td>40</td>
<td>9</td>
</tr>
<tr>
<td>B</td>
<td>35</td>
<td>40</td>
<td>9.4</td>
</tr>
<tr>
<td>C</td>
<td>45</td>
<td>40</td>
<td>9.7</td>
</tr>
<tr>
<td>D</td>
<td>35</td>
<td>125</td>
<td>10</td>
</tr>
</tbody>
</table>

Impact of innovations

- Maximum technical potential impact of innovation under best circumstances
- Relevance to turbine size & site type
- Commercial readiness
- Market share

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## Figure 0.1 Anticipated Impact of all innovations by Turbine Size and Site Type with FID in 2025, compared with a wind farm with the same MW-Size Turbines on the same Site Type with FID in 2014.

<table>
<thead>
<tr>
<th>Impact on CAPEX</th>
<th>Impact on OPEX</th>
<th>Impact on net AEP</th>
<th>Impact on LCOE</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>5%</td>
<td>0%</td>
<td>-5%</td>
</tr>
<tr>
<td>5%</td>
<td>-10%</td>
<td>-15%</td>
<td>-20%</td>
</tr>
<tr>
<td>0%</td>
<td>-15%</td>
<td>-20%</td>
<td>-25%</td>
</tr>
<tr>
<td>-5%</td>
<td>-20%</td>
<td>-25%</td>
<td>-30%</td>
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<tr>
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<td>-35%</td>
<td>-40%</td>
</tr>
<tr>
<td>-20%</td>
<td>-35%</td>
<td>-40%</td>
<td>-45%</td>
</tr>
</tbody>
</table>

- **4 MW-Size**
- **8MW-Size**

- Site Type A
- Site Type D
Forecast 3: to 2030

The Committee on Climate Change (May 2015)

Technology, supply chain and policy drivers

Draft: in consultation with industry

Market scale, visibility and confidence
- Confidence in future levels of own supply
- Public funded RD&D and skills development
- De-risked investment in projects
- A well-structured supply chain
- A cost-efficient support mechanism
- Availability of lower cost of energy sites
- Strategic transmission planning

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Future

System engineering approach

Systems engineering opportunities with largest remaining potential LCOE impact (to 2030)

- Turbine rating, rotor diameter and drive train (concept) 6%
- Turbine reliability and OPEX (component level) 6%
- Aerodynamics and control inc. inflow measurement 6%
- Turbine float-out installation methods 4%
- Standardisation of interfaces 2%
- Multi-variable wind farm layout design 2%

Plus:
- Operations management with advanced weather forecasting
- Holistic tower and foundation design
- FEED geophysical geotechnical studies
- …
Thank you