## Penetration Metrics

<table>
<thead>
<tr>
<th></th>
<th>Capacity pen. (%)</th>
<th>Energy pen. (%)</th>
<th>Max. inst. pen. (no exports) (%)</th>
<th>Max. possible inst. pen. (%)</th>
<th>Söder Metric (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iberian Peninsula</td>
<td>20.88</td>
<td>15.00</td>
<td>&gt; 55</td>
<td>99.30</td>
<td>93.76</td>
</tr>
<tr>
<td>Ireland</td>
<td>16.36</td>
<td>10.00</td>
<td>&gt; 50</td>
<td>81.82</td>
<td>67.92</td>
</tr>
<tr>
<td>South Australia</td>
<td>22.06</td>
<td>20.00</td>
<td>86</td>
<td>118.63</td>
<td>67.08</td>
</tr>
<tr>
<td>West Denmark</td>
<td>34.95</td>
<td>30.00</td>
<td>&gt;100</td>
<td>195.71</td>
<td>59.05</td>
</tr>
<tr>
<td>Crete</td>
<td>16</td>
<td>15.1</td>
<td>&gt; 40</td>
<td>57.14</td>
<td>57.14</td>
</tr>
<tr>
<td>ERCOT</td>
<td>11.40</td>
<td>8.00</td>
<td>&gt; 25</td>
<td>27.43</td>
<td>26.61</td>
</tr>
</tbody>
</table>

AEMO, Australian Energy Market Operator, “Wind Integration In Electricity Grids: International Practice And Experience” WP1, October 2011
Wind and demand, dance partners?

AEMO, Australian Energy Market Operator, “Wind Integration In Electricity Grids: International Practice And Experience” WP1, October 2011
Load, wind and CO\textsubscript{2} Ireland

30% Total Energy Penetration on 22nd Jan 2012

7.5% Total Energy Penetration on 23rd Jan 2012

50% Instantaneous Wind Penetration

Wind
Load
CO\textsubscript{2}
Where does it fit into NAWEA
Educational programme & succession planning
NAWEA Research Programme

- System science and engineering
- Grid integration and management
- Interdisciplinary Research
- Social acceptance
- Policy research
- Atmospheric sciences
- Environmental science
- Market barriers
- Business and financial
- New research
Some Research Areas

- Fundamentals of power systems
  - Asynchronous generation
  - Transmission system changing

- Flexibility
  - Wind providing control
  - Optimal portfolio & tools
  - Cycling
  - Markets
Asynchronous Generation Technologies are changing the Grid fundamentally
Simple Model of the Grid

50/60 Hz

Does not add to system inertia

Synchronous generator

Doubly fed induction generator wind turbine

Fixed speed wind turbine generator
Operational Boundaries

Transmission system is expanding and changing
AC/DC?

**Electrical Transmission networks**

- **High Voltage Alternating current (HVAC)**
  - Overhead lines
  - Sea-cables (short)
  - Underground cables (short)

- **High Voltage Direct current (HVDC)**
  - Overhead lines
  - Sea-cables
  - Underground cables
Public acceptance of Transmission
<table>
<thead>
<tr>
<th>System Node</th>
<th>3</th>
<th>5</th>
<th>7</th>
<th>9</th>
<th>11</th>
<th>13</th>
<th>15</th>
<th>17</th>
<th>25</th>
<th>33</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-year dataset</td>
<td>27.3</td>
<td>29.6</td>
<td>29.7</td>
<td>29.9</td>
<td>30.3</td>
<td>31.0</td>
<td>31.9</td>
<td>31.4</td>
<td>32.4</td>
<td>33.9</td>
</tr>
<tr>
<td>1-year dataset</td>
<td>24.0</td>
<td>28.5</td>
<td>28.7</td>
<td>29.5</td>
<td>28.9</td>
<td>29.9</td>
<td>31.5</td>
<td>28.1</td>
<td>30.2</td>
<td>32.3</td>
</tr>
</tbody>
</table>

### TABLE II

**Optimal Nonfirm Wind Capacity Allocation (MW)**

<table>
<thead>
<tr>
<th>System Node</th>
<th>3</th>
<th>5</th>
<th>7</th>
<th>9</th>
<th>11</th>
<th>13</th>
<th>15</th>
<th>17</th>
<th>25</th>
<th>33</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma ) (GW)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>177</td>
<td>70</td>
<td>432</td>
<td>321</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>308</td>
<td>364</td>
<td>704</td>
<td>624</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>65</td>
<td>0</td>
<td>914</td>
<td>563</td>
<td>548</td>
<td>903</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>228</td>
<td>157</td>
<td>0</td>
<td>175</td>
<td>325</td>
<td>1087</td>
<td>553</td>
<td>523</td>
<td>952</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>730</td>
<td>376</td>
<td>0</td>
<td>338</td>
<td>543</td>
<td>1030</td>
<td>415</td>
<td>582</td>
<td>985</td>
</tr>
<tr>
<td>6</td>
<td>508</td>
<td>812</td>
<td>637</td>
<td>0</td>
<td>372</td>
<td>651</td>
<td>854</td>
<td>397</td>
<td>717</td>
<td>1051</td>
</tr>
<tr>
<td>7</td>
<td>1145</td>
<td>854</td>
<td>639</td>
<td>60</td>
<td>334</td>
<td>683</td>
<td>889</td>
<td>442</td>
<td>812</td>
<td>1140</td>
</tr>
</tbody>
</table>

Flexibility
Ramp ERCOT - 18/19\textsuperscript{th} April 2009

Wind Power Output (MW)

+3,039 MW in 1 hour

Source: http://www.nerc.com/docs/pc/ivgtf/IVGTF_Task_1_4_Final.pdf
Flexibility metrics

Wind providing control
Aggregate Emulated Inertial Response

- Potential response from wind will be stochastic - dependent on:
  - Number of turbines online
  - Operating level of wind turbines

Number of turbines above minimum speed (from wind farm data, across the island of Ireland)

Response at different operating points (GE field tests)

Frequency nadir (lowest point) can be improved

- Rate of change of frequency (ROCOF) issue may remain on small isolated systems

Optimal Portfolio & Tools
Variable Renewables and Generation Expansion

Cycling
Effects of Cycling
Impact of Dynamic Cycling Costs

Markets
The Electricity Market Design Lifecycle

- Little investment, difficult for renewables, little energy efficiency
- Regulate for low price
- Capacity Payments, Green incentives ➔ Raises Prices
- Unhappy Consumers
- Accusations of market abuse / failure
Final thoughts and direction
Convergence

- Renewable Sources
- Electric Vehicles
- Lighting Appliances & Industry
- Nuclear
- Electric Heating
International Collaboration
The Pipeline

Undergraduate

PhDs

Industry

Masters

Schools

Postdoctoral
Conclusions

- International experience
- Fundamental research areas
- Collaboration
- The pipeline is all important
Acknowledgements

- Matthew A. Lackner and NAWEA
- Jonathan Ruddy, UCD
- Funding Agencies: Department of Communications Energy and Natural Resources, Electricity Research Centre (ERC), Enterprise Ireland, EU, Irish Research Council for Science, Engineering & Technology, Science Foundation Ireland, Sustainable Energy Ireland, Teagasc, IRCSSH, PRTLI
- Current research Team: Dr. Damian Flynn, Dr. Eleanor Denny, Dr. Andrew Keane, Dr. Ciara O’Connor, Mr. Alan Taylor, Dr. Roisin Duignan, Dr. Niamh Troy, Dr. Eknath Vittal, Mr. Paul Smith, Mr. Michael Power, Mr. Batsaikhan Nyamdash, Dr. Peter Richardson, Mr. Aonghus Short, Ms. Amy O’Mahoney, Mr. Paul Cuffe, Mr. Eamonn Lannoye, Mr. David Kavanagh, Mr. Colm Lowery, Mr. Stefano Verde, Ms. Lisa Rutledge, Ms. Muireann Lynch, Mr. Eamon Keane, Mr. David Fletcher, Mr. Lasantha Meegahapola, Mr. Erik Ela, Mr. Mario Džamarija, Dr. Andrej Gubina, Ms. Ciara O’Dwyer, Mr. Olivier Neu, Mr. James Ryan, Mr. Noel Cunniffe, Mr. Hassan Wajahat Qazi, Dr. Reza Tavakoli, Ms. Ellen Diskin, Mr. Mostafa Bakhtvar, Ms. Allison O’Connell, Mr. Fabiano Pallonetto, Ms. Despiona Christantoni, Ms. Claudia Aravena, Mr. James Carroll, Ms. Fiona D’Rosario, Mr. Jonathan Ruddy, Ms. Magda Szczepanska, Ms. Grace O’Shea
- Graduated PhDs: Dr. Peter Richardson, Dr. Niamh Troy, Dr. Eknath Vittal, Dr. Daniel Burke, Dr. Aidan Tuohy, Dr. Garth Bryans, Dr. Eleanor Denny, Dr. Ronan Doherty, Dr. Meadhbh Flynn, Dr. Andrew Keane, Dr. Gill Lalor, Dr. Jonathan O’Sullivan, Dr. Michael Walsh
- Graduated Masters: Ms. Sonya Twohig, Mr. Jody Dillon, Mr. Shane Rourke, Mr. Paul Sheridan, Mr. Fintan Slye
- Collaborators: Peter Meibom, Brian Parsons, Michael Milligan, Erik Ela, Prof. Janusz Bialek, Dr. Brendan Fox, Prof. John FitzGerald Dr. Chris Dent etc.
Recent Relevant Journal Publications


Grid Integration Challenges and Solutions

Mark O’Malley
North American Wind Energy Academy
Amherst, MA, USA
August 8th, 2012

www.ucd.ie/erc
The following slides were used subsequent to the presentation at the panel session
Yearly load & 100 % Wind (Ireland)
Monthly Capacity Factor – Ireland

May 2011 – 47%
Yearly Capacity Factor - Ireland

- 2002: 32%
- 2003: 34%
- 2004: 32%
- 2005: 32%
- 2006: 31%
- 2007: 31%
- 2008: 34%
- 2009: 33%
- 2010: 22%
- 2011: 34%