Matching Renewable Electricity Generation with Demand

Gareth Harrison

November 2006
Comments

• “One of the most obfuscating pieces of research.” - Prof. James Lovelock (“Gaia” theory)
• “Misleading and effectively meaningless. Not worth the paper it is written on.” - Prof. David Simpson (“Tilting at windmills”)
• “It’s appalling. They are trying to fudge [the target].” - Bob Graham (Highlands Against Windfarms)
The Scottish Challenge

- Supply
  - 1.5 GW hydro
  - 1.5 GW wind (existing, consented)
  - 0.5 GW biomass (estimated)
  - Wave & tidal current?

- Demand
  - 41 TWh demand
  - 7.3 GW peak

Network

2020
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UNESP Presentation
Nov 2006

Contents

Constraints GIS Mapped

Constraints

GIS

Project costs

Selection criteria

Generator locations

Resource time series

Macro

Scenarios

Network

Key figures

Results

Converter

Renewable generation

Demand
Study Area

- Spatial resolution: 1 km$^2$
- Use of British National Grid coordinates

Source: Ordnance Survey
Political

- International limit (200 nmi, 12 nmi)
- National limit
- Fishing limit (6 nmi)
- Planning authorities
- Local regulations

Sources: OS, UKHO
Physical

- Water depth
- Slope
- Lakes
- Rivers
- etc.

Example:
Average slope > 15% in a 1 km by 1 km square.

Sources: OS, BGS, BODC, SRTM
Environment

• Recreation interests (high sensitivity)
  - National Scenic Area
  - National Park
  - Regional park

• Biodiversity interests (high sensitivity)
  - Natura 2000, SSSI, ...

• Medium sensitivity areas
  - AGLV, LNR, ...

Sources: OS, SNH, SEGIS
Aviation Interests

- Civil radars
  - 15 km exclusion zone
  - 30 km consultation zone
  - NATS high impact
  - NATS lower impact
- Military radars
- Met Office radars
- Low Flying System
  - Tactical Training Area

Sources: OS, DTI, CAA, BWEA
Further Constraints

- Urban areas
  - Cities, towns, villages

- Navigational risk
  - very high
  - medium
  - very low

- Seismological measurements
  - Eskdalemuir

- Ammunition dumping

- Distances, etc.

Sources: OS, DTI, CAA, BWEA
Constraints

Example:
Onshore wind

- absolute
- consultation (10% used)
Long-Term Resource

Contents

- Constraints
- GIS
- Long-term resource
- Project costs
- Selection criteria
- Generator locations
- Resource time series
- Scenarios
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- Converter
- Network
- Demand
- Renewable generation
- Key figures
- Results
- Network
- Macro
- Converter

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Onshore Wind Resource

Average wind speed at 80 m height agl.

4  10  16 m/s

Meteorological station (21 + 3)

Abbreviations:
Au – Aultbea
Av – Aviemore
D – Dunstaffnage
K – Kinloss
Sa – Salsburgh
Sk – Skye, Lusa
St – Strathallan
T – Tulloch Bridge

Sources: OS, Met Office

Onshore Wind Resource

Average wind speed at 80 m height agl.

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Au – Aultbea
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Sources: OS, Met Office
Offshore Wind Resource

Average wind speed at 80 m height asl.

4     10     16 m/s

Water depth, 5 km offshore

- 0 ... 30 m
- 30 ... 40 m
- 40 ... 50 m

+ Met Office Simulation Point (11)

Sources: OS, DTI, Met Office
Wave Resource

Wave power per metre crest length

<table>
<thead>
<tr>
<th>Wave Power (kW/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>55</td>
</tr>
</tbody>
</table>

Water depth, 5 km offshore

- 50 ... 100 m

Met Office Simulation Point (84 + 11)

Sources: OS, DTI, Met Office
Tidal Current Resource

Average spring tide velocity (surface)

- 0.5 m/s
- 1.5 m/s
- 2.5 m/s

Water depth
- 30 to 50 m

Sources: OS, DTI, Robert Gordon Univ.
Future Generator Locations

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Long-term resource

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Renewable generation

Demand

Macro
Project Costs

Example:
Estimated onshore wind project costs including connection to existing network

- low cost
- medium cost
- high cost

- “no go” zone

Assumptions:
- 3 x 2.5 MW per km²
- 80 m hub height
- 20 years, 8 % discount rate
Creating Power Time Series

Contents
- Creating Power Time Series
- Constraints
  - Long-term resource
  - GIS
- Project costs
- Selection criteria
- Generator locations
- Resource time series
- Scenarios
- Key figures
- Network
- Results
- Macros
- Converter
- Renewable generation
- Demand
Energy Converters

On/Offshore Wind

- 3-bladed horizontal axis turbine with pitchable blades
- 80 / 120 m diameter
- 2.5 / 5 MW
- 80 m hub height
- Offshore: < 40 m water depth

Waves

- Semi-submerged articulated structure
- 180 m long
- 1.5 MW
- 50 ... 150 m water depth

Tidal Currents

- Twin-rotor horizontal axis turbine with pitchable blades
- 20 m rotor diameter
- 2 x 500 kW
- 30 ... 50 m water depth

Source: Nordex, OPD, MCT

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Contents

Generation vs. Demand

Constraints

Long-term resource

Project costs

GIS

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Generator locations

Macro

Resource time series

Scenarios

Macro

Converter

Renewable generation

Network

Key figures

Results

Demand
Demand - Daily

Source: SP and SSE 2003 Seven Year Statements

Example: 2002/03

Scottish Power
Scottish and Southern Energy

Source: SP and SSE 2003 Seven Year Statements
Demand - Annual

Example: 2002

Source: SP 2002 and 2003 Seven Year Statements
Orkney with existing & new generation
Demand Matching January, July 2003

- Tidal current
- Wave
- Onshore wind (a) new (b) existing

0 25 50 75 100 MW
20 Jan 21 Jan 22 Jan 23 Jan 24 Jan 25 Jan 26 Jan 27 Jan
0 25 50 75 100 MW

40%, 100% demand

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Matching Renewable Electricity Generation with Demand

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Nov 2006
Key Figures and Results

Contents

- Key figures
- Results

Constraints
- Long-term resource

Project costs
- GIS

Selection criteria
- Macro

Generator locations

Resource time series

Scenarios
- Network

Converter

Renewable generation

Demand

Macro

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Simulation Scenarios

• **Resource**: 2001-2003 hourly data
• **Generation**: Renewable expansion by 2020
• **Demand**: 2001-2003 hourly demand scaled for 2020
• **Network**: ideal
Findings

• After application of constraints it could be possible to develop at least
  – 6 GW of onshore wind,
  – 3 GW of offshore wind,
  – 3 GW of wave, and
  – 1 GW for tidal current,

• or any combination of these technologies.
Plant Capacity Factors

- **Exceeding 30%** for wind, wave and tidal current

- **Seasonal values** for wind and wave are significantly higher in winter than in summer.

<table>
<thead>
<tr>
<th>Plant capacity factor (%)</th>
<th>3 GW</th>
<th>6 GW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onshore-wind</td>
<td>33.9</td>
<td>32.7</td>
</tr>
<tr>
<td>Offshore-wind</td>
<td>35.8</td>
<td>-</td>
</tr>
<tr>
<td>Wave</td>
<td>31.7</td>
<td>-</td>
</tr>
<tr>
<td>Tidal-current (750 MW)</td>
<td>(30.0)</td>
<td>-</td>
</tr>
<tr>
<td>75-10-10-5% mix</td>
<td>34.7</td>
<td>33.5</td>
</tr>
</tbody>
</table>

Incl. 1.5 GW optimally dispatched hydro
Long-Term Matching

- **3 GW** of onshore wind, offshore wind or wave would on average meet 20% of Scottish demand.

- A **renewable mix** of about **6 GW** could meet, on average, **40%** of Scottish demand.

<table>
<thead>
<tr>
<th>Long-term local matching (%)</th>
<th>3 GW</th>
<th>6 GW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onshore-wind</td>
<td>21.8</td>
<td>41.5</td>
</tr>
<tr>
<td>Offshore-wind</td>
<td>23.0</td>
<td>-</td>
</tr>
<tr>
<td>Wave</td>
<td>20.4</td>
<td>-</td>
</tr>
<tr>
<td>Tidal-current (750 MW)</td>
<td>(4.8)</td>
<td>-</td>
</tr>
<tr>
<td>75-10-10-5% mix</td>
<td>22.3</td>
<td>42.7</td>
</tr>
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</table>

Incl. 1.5 GW optimally dispatched hydro
Conclusions

• Scotland could, in 2020, meet on average 40% of its demand for electricity from renewable resources with a total renewable capacity of around 6 GW.

• It does not mean that the aspirational demand target is reached during each hour of a year.

• There will be periods of shortfall and periods of excess.
Exceeding 40% of Demand

- Time when 40% of demand is exceeded was estimated.
- 3 GW renewable mix would achieve this for about 15% of the time.
- 6 GW renewable mix would achieve this for about 45% of the time.

48% incl. 1.5 GW optimally dispatched hydro, 58% with 750 MW pumped storage

<table>
<thead>
<tr>
<th>Hourly exceedance of 40% target (%)</th>
<th>3 GW</th>
<th>6 GW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onshore-wind</td>
<td>17.1</td>
<td>44.6</td>
</tr>
<tr>
<td>Offshore-wind</td>
<td>17.8</td>
<td>-</td>
</tr>
<tr>
<td>Wave</td>
<td>12.1</td>
<td>-</td>
</tr>
<tr>
<td>Tidal-current (750 MW)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>75-10-10-5% mix</td>
<td>14.5</td>
<td>46.4</td>
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Hours of Coincidence

- Coincident hours describe hourly match between generation and demand.

- Hours in a year with shortfall (import, balancing) and excess (export, curtailment) of renewable energy can be estimated.

<table>
<thead>
<tr>
<th>Coincident hours for demand &gt; 90% and production &lt; 10% (h/year)</th>
<th>3 GW</th>
<th>6 GW</th>
</tr>
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<tr>
<td>Onshore-wind</td>
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</tr>
<tr>
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<td>14</td>
<td>-</td>
</tr>
<tr>
<td>Wave</td>
<td>19</td>
<td>-</td>
</tr>
<tr>
<td>Tidal-current (750 MW)</td>
<td>(22)</td>
<td>-</td>
</tr>
<tr>
<td>75-10-10-5% mix</td>
<td>18</td>
<td>20</td>
</tr>
</tbody>
</table>

7 h incl. 1.5 GW optimally dispatched hydro,
19 h with 750 MW pumped storage
Conclusions

• **Sufficient renewable resources** exist to meet governmental target (of supplying 40% of electricity from renewable sources by 2020).

• 6 GW of mixed renewables are **on average** required.

• Diversification and dispersion improve matching.

• **Balancing** is needed (dispatchable plant, storage, interconnectors).
Case Study

• Apply renewable time series in AC power flow analysis.
• Examine marine/wind energy delivery to the demand centres with changes in
  – weather patterns
  – demand
  – network
Case Study - Area

• Orkney and Northern Highlands

• Wind, wave and tidal current resources.

• Existing wind farms, EMEC test centres.
Case Study - Constraints

- Development constraints influence the selection of renewable generation sites.
- Same parameters as for “matching study” used.
Case Study - Power System

- Existing and new generation mapped.
- Time series of power (hourly, one year) created.
- Network modelled.
Orkney with existing & new generation

Demand Matching  January 2003

Unconstrained

Tidal current

Wave

40%, 100% demand

Outage of one undersea cable

Onshore wind
(a) new
(b) existing
Case Study - Line Loading

**Orkney – Mainland undersea cable**

- 23.4 MVA
- 1E
- 1N

**Selected Orkney undersea cables**

- Stronsay - Shapinsay
- Sanday - Stronsay
- Eday - Spurness
- 12 MVA
- 1E, 1N

**Selected overhead line**

- 17.1 MVA
- 13.7 MVA
- 16.3 MVA
- 1N
- 1E

**Scenarios:** 1 Orkney - Mainland undersea cable, 1E = existing generation, 1N = existing + new generation
Case Study - Results

- **Power flows** (in PSS/E) can be run with 26,280 time steps instead of just 2 annual simulations.

- **Line loading**, voltage levels, reactor usage and required diesel backup can be examined.

- **RE generation curtailment** due to network issues can be estimated.
Comments (cntd.)

“ Fucking brilliant piece of work!”

Dr. Robin Wallace (co-author)