Designing an electricity wholesale market for significant renewables penetration: Lessons from the UK

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`Clean energy for all Europeans’ package and Mediterranean Electricity Market Integration

Brussels
11th April 2018
Outline

• European Union commitments to decarbonize
  • A high Renewable scenario is becoming realistic
    – Falling cost of RES, storage still costly,
    – improve interconnectors => flexibility
    – Support RES in low-cost external countries via Mission Innovation? PV & CSP in MENA?

• Need to modify market design and regulation
  – address market failures directly

• auctions for renewables
  – need new auction designs

• securing flexible plant: capacity auctions
Decarbonising power

• **Power sector** key to decarbonising economy
  – Large, easiest, and capital **highly durable**
• Coal-fired electricity has more than **twice** the GHG emissions of gas **and** far higher air pollutants
  – Gas as transition fuel to the low carbon future
  – Deployment has dramatically lowered cost of wind, PV
  – Learning spill-overs justify **support for R&D and deployment**
• Large RES depresses prices, needs flexible reserves
  ⇒ hard to invest in flexible plant in policy-driven market
  ⇒ capacity auctions and **new flexibility products**
  ⇒ Increases case for interconnections paid for security
  ⇒ **Need better contracts for RES and capacity adequacy**
  ⇒ **Need wider support for delivering learning spill-overs**
Why support renewables?

• **Learning-by-doing** creates unrewarded spill-overs that reduce later costs
  – Justifies quite large subsidy for solar PV
  – Secured at least cost in high insolation areas = MENA

=> subsidize *installation, not output*

• Low carbon price => second best **subsidize low-C for CO₂ abated**

⇒ subsidy per MWh at marginal CO₂ displaced

⇒ Shortfall @ €20/t CO₂ => **CCGT displaced €9/MWh**

*Form coalitions for collective support of RES*

⇒ **Mission Innovation**
Electricity characteristics

- **Electricity characteristics and cost drivers:**
  - **capacity (MW):** max demand on links & generation
  - **energy (MWh):** nodal for each time period: fuel + C
  - **quality** (frequency, voltage etc.): nodal each second

- **Pay networks for access option** to take capacity
  - Drives investment in T & D
    - Some depends on system peak, some on local max. demand
  - regulated – so need careful design

- **QoS** bundled with access, energy, capacity
  - paid by final consumers to suppliers of service
  - Procured by System Operator (markets, auctions, …)
Paying for energy & capacity

• Pay for **energy** at efficient cost of **supply**
  – System marginal cost, SMC
    • variable cost of the most expensive in-merit generator
• Value/cost varies over time and space
  => locational marginal price varying every 5 mins(?)
  • the US Standard Market Design
• Pay for **capacity** = value of meeting **demand**
  – Loss of Load Probability x (Value of Lost Load - SMC)
• full price = \((1-\text{LoLP})\times \text{SMC} + \text{LoLP} \times \text{VoLL}\)
  • reflects probabilities of **supply** or **lack of supply**
Ancillary services for QoS

*Faster* more flexible responses needed with high renewables

*Synchronous inertia* – supplied by fossil generators, not by wind and PV

Figure 1: Frequency Control Services (Source: EirGrid)
GB’s Carbon Price Floor - in Budget of 3/11

EUA price second period and CPF £(2012)/tonne

to £70/t by 2030

Budget 2014

Corrective tax

Forward prices

Source: EEX and DECC Consultation
Coal and gas prices and the impact on electricity generation

Data source: ICE

Nat Grid Winter Outlook 2016-17

Gas displaces coal at high CO₂ price and low gas price

Prices as of 30/9/16
Carbon (€/tonne): 25.9

Coal burn favoured

Coal/gas burn

Gas burn favoured

55% CCGT efficiency

40% CCGT efficiency

Coal favoured

Uncertain

Gas favoured

Price indication

Gas efficiency range (40–55%)
Coal displaced by RES & gas: carbon price floor working

Quarterly GB electricity generated by fuel

- Oil
- Pumped Storage
- Coal
- Gas
- Other fuels
- Bioenergy
- Hydro (natural flow)
- Wind and Solar
- Nuclear
Revised RES Directive

16. “When designing support schemes and when allocating support, Member States should seek to minimise the overall system cost of deployment, taking full account of grid and system development needs, the resulting energy mix, and the long term potential of technologies.”

26. “…(allow) Member States to count energy from renewable sources consumed in other Member States towards their own”

- Art 3 proposes Union funds (financial instruments) to reduce cost of capital for RES projects; mandatory move towards investment aid
- Art 4: ensure RES responds to market price signals and support is granted in an open, transparent, competitive, non-discriminatory and cost-effective manner
- Art 6: Increase investor confidence: no retroactive changes
Blue, Green bad, red good

Sonneneinstrahlung 2007 (kWh/m²)

- Light blue: 601 - 650
- Blue: 651 - 700
- Light green: 701 - 750
- Green: 751 - 800
- Light yellow: 801 - 850
- Yellow: 851 - 900
- Light orange: 901 - 950
- Orange: 951 - 1,000
- Light brown: 1,001 - 1,050
- Brown: 1,051 - 1,100
- Light red: 1,101 - 1,150
- Red: 1,151 - 1,200
- Light pink: 1,201 - 1,250
- Pink: 1,251 - 1,300
- Light dark red: 1,301 - 1,350
- Dark red: 1,351 - 1,400
- Light maroon: 1,401 - 1,450
- Maroon: 1,451 - 1,500
- Light brown: 1,501 - 1,550
- Brown: 1,551 - 1,600
- Light brown: 1,601 - 1,650
- Brown: 1,651 - 1,700
- Light brown: 1,701 - 1,750
- Brown: 1,751 - 1,800
- Light brown: 1,801 - 1,850
- Brown: 1,851 - 1,900
- Light brown: 1,901 - 1,950
- Brown: 1,951 - 2,000

≈Full hrs/yr
Doubling the irradiance halves the cost

WORLD MAP OF GLOBAL HORIZONTAL IRRADIATION

Chile PV PPA
At $25/MWh

http://geosun.co.za/solar-maps/
Learning justifies support but is on cumulative shipping not RES output

German wholesale prices fall 50% in 5 yrs, 40% of which due to RES

Solar PV cost fall 20% for each doubling of cumulative shipments

Nuclear phase-out exactly offsets RES

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Dramatic fall in solar PV prices


Projected
Quantifying the spill-over benefit

<table>
<thead>
<tr>
<th>Country</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>shares</th>
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<tbody>
<tr>
<td>China</td>
<td>0.8</td>
<td>3.3</td>
<td>6.8</td>
<td>19.7</td>
<td>28.2</td>
<td>43.5</td>
<td>19%</td>
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<tr>
<td>Germany</td>
<td>17.4</td>
<td>24.9</td>
<td>32.5</td>
<td>35.8</td>
<td>38.2</td>
<td>39.8</td>
<td>17%</td>
</tr>
<tr>
<td>Japan</td>
<td>3.6</td>
<td>4.9</td>
<td>6.6</td>
<td>13.6</td>
<td>23.3</td>
<td>34.2</td>
<td>15%</td>
</tr>
<tr>
<td>USA</td>
<td>2.5</td>
<td>4.4</td>
<td>7.3</td>
<td>12.1</td>
<td>18.3</td>
<td>25.6</td>
<td>11%</td>
</tr>
<tr>
<td>Italy</td>
<td>3.5</td>
<td>12.8</td>
<td>16.5</td>
<td>18.1</td>
<td>18.5</td>
<td>18.9</td>
<td>8%</td>
</tr>
<tr>
<td>UK</td>
<td>0.1</td>
<td>0.9</td>
<td>1.9</td>
<td>3.4</td>
<td>5.1</td>
<td>8.9</td>
<td>4%</td>
</tr>
<tr>
<td>France</td>
<td>1.2</td>
<td>3.0</td>
<td>4.1</td>
<td>4.7</td>
<td>5.7</td>
<td>6.6</td>
<td>3%</td>
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<tr>
<td>subtotal</td>
<td>29.1</td>
<td>54.1</td>
<td>75.6</td>
<td>107.3</td>
<td>137.2</td>
<td>177.5</td>
<td>76%</td>
</tr>
</tbody>
</table>

Global cumulative capacity

|                   | 47.0 | 78.0 | 110.0 | 144.0 | 184.0 | 234.0 | 100%   |

Spillover per kWp

|                     | $822 | $740 | $664  | $595  | $531  | $472  |

<table>
<thead>
<tr>
<th>Table  Spillover contributions by country</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>total $ million/yr</th>
<th>cumulative</th>
<th>share</th>
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</thead>
<tbody>
<tr>
<td>Germany</td>
<td>$14,276</td>
<td>$5,536</td>
<td>$5,049</td>
<td>$1,964</td>
<td>$1,292</td>
<td>$737</td>
<td>$28,855</td>
<td>21%</td>
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<tr>
<td>China</td>
<td>$657</td>
<td>$1,849</td>
<td>$2,324</td>
<td>$7,681</td>
<td>$4,499</td>
<td>$7,234</td>
<td>$24,245</td>
<td>18%</td>
<td></td>
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<tr>
<td>Japan</td>
<td>$2,973</td>
<td>$958</td>
<td>$1,141</td>
<td>$4,142</td>
<td>$5,148</td>
<td>$5,120</td>
<td>$19,482</td>
<td>14%</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>$2,078</td>
<td>$1,372</td>
<td>$1,918</td>
<td>$2,858</td>
<td>$3,291</td>
<td>$3,454</td>
<td>$14,970</td>
<td>11%</td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>$2,878</td>
<td>$6,883</td>
<td>$2,420</td>
<td>$963</td>
<td>$205</td>
<td>$219</td>
<td>$13,568</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>$63</td>
<td>$612</td>
<td>$662</td>
<td>$878</td>
<td>$916</td>
<td>$1,799</td>
<td>$4,930</td>
<td>4%</td>
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</tr>
<tr>
<td>France</td>
<td>$989</td>
<td>$1,309</td>
<td>$741</td>
<td>$382</td>
<td>$492</td>
<td>$438</td>
<td>$4,352</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>subtotal</td>
<td>$23,915</td>
<td>$18,519</td>
<td>$14,255</td>
<td>$18,869</td>
<td>$15,842</td>
<td>$19,001</td>
<td>$110,402</td>
<td>80%</td>
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<tr>
<td>range +/-</td>
<td>$7,323</td>
<td>$5,266</td>
<td>$3,727</td>
<td>$4,480</td>
<td>$3,360</td>
<td>$3,522</td>
<td>$27,678</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Rapid *increase* in EU renewable electricity to 29% in 2015

Cumulative increment in RES-E since 2006

Mostly hydro
Pre-2000

Source: Eurostat
Reforming RES-E support

- **Learning spill-overs** need remuneration
  - Almost entirely from making and installing equipment

  \[ \Rightarrow \text{Contract } €X/\text{MWh for (e.g.) 30,000 MWh/MW, auction determines premium } €X \text{ added to local wholesale price} \]

**Reasons:**

- **Subsidy targeted** on source of learning = *investment aid*
  - Reduces cost of capital and risk via debt finance
  - Ideally associated with CO\(_2\) credit per MWh

- **Could expose RES to current locational spot price**
  - \[ \Rightarrow \text{incentivizes efficient location, connection} \]

- **Does not amplify benefits of high wind/sun**
  - Not over-reward favoured locations with same learning

- **Auction** better than bureaucrats at minimizing cost
## RES CfD 2015 auction results

<table>
<thead>
<tr>
<th>Technology</th>
<th>Admin price</th>
<th>Lowest clearing price</th>
<th>2015/16</th>
<th>2016/17</th>
<th>2017/18</th>
<th>2018/19</th>
<th>Total Capacity (MW)</th>
</tr>
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<tbody>
<tr>
<td>Advanced Conversion Technologies</td>
<td>£140</td>
<td>£114.39</td>
<td></td>
<td></td>
<td>£119.89</td>
<td>£114.39</td>
<td>62</td>
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<tr>
<td>Energy from Waste with CMHP</td>
<td>£80</td>
<td>£80</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>80.00</td>
</tr>
<tr>
<td>Combined Heat and Power</td>
<td>£140</td>
<td>£114.39</td>
<td></td>
<td></td>
<td>£119.89</td>
<td>£114.39</td>
<td>94.75</td>
</tr>
<tr>
<td>Offshore wind</td>
<td>£140</td>
<td>£114.39</td>
<td></td>
<td></td>
<td>£119.89</td>
<td>£114.39</td>
<td>1162</td>
</tr>
<tr>
<td>Onshore wind</td>
<td>£95</td>
<td>£79.23</td>
<td></td>
<td></td>
<td>£79.23</td>
<td>£79.99</td>
<td>£82.50</td>
</tr>
<tr>
<td>Solar PV</td>
<td>£120</td>
<td>£50.00</td>
<td>£50.00</td>
<td>£79.23</td>
<td>£79.99</td>
<td>£82.50</td>
<td>748.55</td>
</tr>
</tbody>
</table>

Source: DECC (2015)

*Foolish bid - withdrew*
UK Off-shore wind auction prices

- Strike price for five offshore wind farms depending on completion date:
  - £119.89 (Inc. East Anglia 1)
  - £114.39 (Inc. Neart Na Gaoithe)
  - £150
  - £155
  - £140

- Allocation / auction rounds:
  - 2013/14
  - 2015/16
  - 2017/18

- Delivery years (to first generation):
  - 2019/20
  - 2021/22

- 4 years difference in delivery years

- Prices halve
Location choices under LMP and spot pricing for wind

With ROCs wind farm inefficiently locates at N

**T cost**
£15/ MWh

**N**: 2,500 hrs/yr

**P_N** £35/MWh

=> £87.5k/MW/yr

=> £212.5k with ROC

**ROC** = £50/MWh

**Pay wind for availability + average spot price => efficient E**

**E**: 2,000 hrs/yr

**C**: £50/MWh

**P_E** £49/MWh

=> £98k/MW/yr

=> £198k with ROC
How best to integrate MENA electricity in EU?

- Compare exporting PV to EU vs local use
  - Local use displaces CO$_2$, generates same spillovers
    - Gas to displace oil as flexible lower-C balancing
    - Export surplus gas cheaper than exporting power
  - Exporting PV requires extra transmission
    - NA same time zone as CET so competes with EU PV

- MENA ideal test site for Concentrated Solar Power
  - Atacama, Chile: base-load CSP below $5.0$/kWh in 2017
    - Noor-1, Morocco, 160 MW CSP, power for 3hrs after sunset

*Indirect exports better than Desertec?*
Conclusions

• Support for RES needs change
  – recognise learning benefits by capacity support, CO₂ per MWh
  – needs better location and dispatch price signals => markets
  – requires auctions and good network tariffs
• Efficiently pricing externalities and system impacts key for efficient entry and exit decisions
• Tariffs and market design need reform to guide decisions
  – network tariffs to avoid distorting embedded benefits
  – Energy-only market not suited to high RES needing flexible backup
    • Capacity mechanisms will be needed in liberalised markets

• EU support RES in MENA as part of Mission Innovation?
Delivering flexible capacity: lessons from the GB capacity auction
Supporting flexible back-up

- Ambitious RES targets need flexible back-up
  - Normally comes from old high-cost plant = coal
    - EU Large Combustion Plant Directive 2016 limits coal
    - Integrated Emissions Directive further threat to coal
    - GB Carbon price floor + hostility to coal => close old coal
  - high (pre-2015) EU gas prices and low load factors
    - gas unprofitable, new coal prohibited by GB EPS
- Future prices now depend on uncertain policies
  - on carbon price, renewables volumes, other supports
  - on policy choices in UK, EU, COP21, …

*Without a contract new flexible back-up too risky?*

⇒ Auctions for capacity
⇒ Better still for Reliability Options
Reliability Options to replace Capacity agreements

- **RO sets** *strike price*, \( s \) (e.g. at €500/MWh)
- **Market price** \( p \) reflects scarcity (\( \text{Voll} \times \text{LoLP} \))
  - SO sets *floor price* to reflect spot conditions
  - Wholesale price signals efficient international trade
- **RO auctioned for annual payment** \( P \)
  - 7-10 yrs for new, 1 yr for existing capacity
- **Gen pays back wholesale price** \( p \)
  - less strike price if available (\( p - s \))
  - G chooses whether to be paid \( p \) or \( s + P \)
- **Suppliers hedged at strike price** \( s \) for premium \( P \)

*Trade over interconnectors efficient*

*No need to pay foreign generators*
GB 2014 Capacity Auction

Net CONE – predicted entry price £49

Auction clearing price £19.40/kW
New build 2014 T-4 auction

Average Size 11 MW

Cleared at £19.40/kWyr

- CCGT: Exited later
- CHP
- Coal/biomass
- OCGT/recip
- Waste
- Proven DSR
- Unproven DSR

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Flaws in GB Capacity Procurement

• Transmission-connected generation TG pays full G TNUoS
• Distribution-connected generation DG receives L TNUoS
  – But avoided cost at most the transmission demand residual
    = extra money to pay full cost less efficient charge of transmission
  ⇒ represents extra £50/kWyr embedded benefit in 2018/19
  ⇒ Auction cleared at £20/kWyr
  ⇒ DG gets £70/kWyr and TG gets £20/kWyr
  ⇒ Large number of small (10 MW) diesel and reciprocating engines win capacity contracts on distribution network

Over-encourages entry of costly subscale plant
GB Transmission demand
residual – extra to DN connex

Source: Ofgem (2017)

Embedded benefit not material
Reduce TDR to £0

Residual History (£/kW) 2005-2021

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<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CfD</td>
<td>Contract for Difference</td>
</tr>
<tr>
<td>CONE</td>
<td>Cost of New Entry</td>
</tr>
<tr>
<td>CP</td>
<td>Capacity payment</td>
</tr>
<tr>
<td>DG</td>
<td>Distribution-connected Generation</td>
</tr>
<tr>
<td>DN</td>
<td>Distribution Network</td>
</tr>
<tr>
<td>G, L</td>
<td>Generation, Load</td>
</tr>
<tr>
<td>LMP`</td>
<td>Locational Marginal Pricing (Nodal pricing)</td>
</tr>
<tr>
<td>LoLP</td>
<td>Loss of Load probability</td>
</tr>
<tr>
<td>LoLE</td>
<td>Loss of load expectation in hrs/yr = reliability standard</td>
</tr>
<tr>
<td>QoS</td>
<td>Quality of service</td>
</tr>
<tr>
<td>RES</td>
<td>Renewable energy/electricity supply</td>
</tr>
<tr>
<td>RO</td>
<td>Reliability option</td>
</tr>
<tr>
<td>ROC</td>
<td>Renewable Obligation (i.e. green) Certificate</td>
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<tr>
<td>SMC/P</td>
<td>System Marginal Cost/Price</td>
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<tr>
<td>T&amp;D</td>
<td>Transmission and Distribution</td>
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<tr>
<td>TDR</td>
<td>Transmission demand residual</td>
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<tr>
<td>TG</td>
<td>Transmission-connected generation</td>
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<tr>
<td>TNUoS</td>
<td>Transmission Network Use of System, G =Generation, L=Load</td>
</tr>
<tr>
<td>VOLL</td>
<td>Value of Lost Load</td>
</tr>
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</table>
References to the EU Clean Energy proposals
