Wholesale market designs for future low-carbon electricity systems

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http://www.eprg.group.cam.ac.uk
• Decarbonising power needs a new market design
  – reconciling security of supply with renewables (RES)
• Nuclear, CCS or RES?
  – high capital cost, low variable cost
  – intermittent RES connected to distribution networks
• Criteria for charging and market design
  ⇒ Capacity payments, long-term contracts, auctions
  ⇒ new flexibility services required
  ⇒ Better contracts for RES
• Challenges for network regulators

* Based on joint work with Michael Pollitt and Robert Ritz, Supported by CISL
• **Electricity** is 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
  – But there is lots of coal ⇒ **CCS a long-run priority**
• Deployment has dramatically lowered cost of wind, PV
  – justifies **support for R&D and deployment**
• **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
Nuclear power can cut emissions – but we have forgotten how to do it at reasonable cost

CO2 emissions per kWh 1971-2000

- USA
- Italy
- UK
- Europe
- France

Down 80% 10 years
Rapid increase in EU renewable electricity to 29% in 2015

Cumulative increment in RES-E since 2006

Source: Eurostat

Mostly hydro Pre-2000
EU-28 doubled its RES-E share from 2004-2015

Cumulative increment in share of RES in generation from 2004
Countries exceeding EU-28 increment

Source: Eurostat
GB: RES & gas displace coal

Quarterly GB electricity generated by fuel

- Oil
- Pumped Storage
- Coal
- Gas
- Other fuels
- Bioenergy
- Hydro (natural flow)
- Wind and Solar
- Nuclear
Solar PV cost fall 20% as capacity x2

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

- **Networks** are regulated natural monopolies
  - marginal cost pricing fails to recover full costs
  - efficient grid pricing may recover < 30% of cost

=> challenge is to give efficient price signals and recover balance from optimal taxes (*efficiency vs equity*)

- Low carbon *generation* has similar cost characteristics
  - Low variable costs, high capital cost

=> challenge is to develop efficient wholesale/retail prices
  - But not normally a regulated asset
  ⇒ long-term contracts?

*How to charge final consumers?*
Electricity characteristics

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

- Pay for access option to take capacity
  - Drives investment in T & D
    - Some depends on system peak, some on local max. demand
  - Pay for energy at efficient price (SMC)
  - Pay for capacity at LoLP x (VoLL-SMC)
  - QoS bundled with access, energy, capacity
    - paid by final consumers to suppliers of service
Ancillary services for QoS

Figure 1: Frequency Control Services (Source: EirGrid)
Criteria for market design

- **Least system cost** to meet reliability and CO₂ targets
  - Coordinate generation, transmission, distribution
  - Generation: timely delivery at right place, size, technology
  - Transmission: built, sized and used for efficient dispatch
  - *Challenging with unbundled liberalised structures*

- Liberalized markets need good price signals
  - *Many of which are regulated (transmission, distribution)*

- Benchmark efficient spot prices
  - Wholesale price = **SMC + CP** at each node (LMP)
  - **CP** = LoLP*(VoLL – SMC); ∑LoLP=LoLE
  - Ancillary service prices to incentivise efficient quality

- Location signals: **long-term** financial contract on LMP

- **Revenue shortfalls: Ramsey pricing on final consumer**

- Targeted subsidies, efficient risk sharing
Revised RES Directive

16. “When designing support schemes and when allocating support, Member States should seek to minimize 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
Learning spill-overs driven by cumulative global capacity

<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>cum. value</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>$22,060</td>
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<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>
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<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>$17,653</td>
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<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>$13,508</td>
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<td>Italy</td>
<td>3.5</td>
<td>12.8</td>
<td>16.5</td>
<td>18.1</td>
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<td>18.9</td>
<td>$11,863</td>
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<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>$4,492</td>
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<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>$3,851</td>
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<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>$98,611</td>
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<tr>
<td>Global</td>
<td>47.0</td>
<td>78.0</td>
<td>110.0</td>
<td>144.0</td>
<td>184.0</td>
<td>234.0</td>
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<tr>
<td>spillover per kWp</td>
<td>$705</td>
<td>$644</td>
<td>$587</td>
<td>$535</td>
<td>$487</td>
<td>$443</td>
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</table>

80% of total

Source: Newbery EPRG Working Paper 1706
Learning spill-overs need remuneration
  – Almost entirely from making and installing equipment
⇒ Contract €X/MWh for N MWh/MW, Auctioneer sets N
⇒ Auction determines X – not left to bureaucrats
Reasons:
• Subsidy targeted on source of learning = investment aid
  – Reduces cost of capital and risk via debt finance
  – Addresses failure to set right CO₂ price
• Exposes RES to current locational spot price
  => incentivizes efficient location, connection
• Does not amplify benefits of high wind/sun
  – Not over-reward favoured locations with same learning
• Pay zero-C generation shortfall in social cost of carbon

If marginal displaced generation CCGT = €10/MWh?
Location choices under LMP and spot pricing for wind

N: 2,500 hrs/yr

With ROCs wind farm inefficiently locates at N

$P_N = £35/MWh$

$=>£87.5k/MW/yr$

$=>£212.5k$ with ROC

$ROC = £50/MWh$

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

T cost
$£15/MWh$

C: £50/MWh

E: 2,000 hrs/yr

$P_E = £49/MWh$

$=>£98k/MW/yr$

$=>£198k$ with ROC
### 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>
</thead>
<tbody>
<tr>
<td>Advanced Conversion Technologies</td>
<td>£140</td>
<td>£114.39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>62</td>
</tr>
<tr>
<td>Energy from Waste with</td>
<td>£80</td>
<td>£80</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>80</td>
</tr>
<tr>
<td>Combined Heat and Power</td>
<td>£140</td>
<td>£114.39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>94.75</td>
</tr>
<tr>
<td>Offshore wind</td>
<td>£140</td>
<td>£114.39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1162</td>
</tr>
<tr>
<td>Onshore wind</td>
<td>£95</td>
<td>£79.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>748.55</td>
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<tr>
<td>Solar PV</td>
<td>£120</td>
<td>£50.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>69.55</td>
</tr>
</tbody>
</table>

- **Source:** DECC (2015)
Capacity auctions

- 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, …

Long-term contracts the solution?
⇒ Auctions for Reliability Options
Reliability Options: the I-SEM proposal

- RO sets strike price, $s$ (e.g. at €500/MWh)
- Market price $p$ reflects scarcity (Voll x 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 $P$
Efficient tariffs

- Distinguish **efficient price** and resulting short-fall in required revenue
  - Efficient peak T price is *marginal* expansion cost
  - At best 30% average cost, less if demand falling
- Ramsey-Boiteux prices => cut demand *equi-proportionally*
- Diamond-Mirrlees: **tax only final consumers**
  ⇒ T&D revenue shortfall on final consumption *not* net demand reduces embedded G benefit from £60 to < £10/kWyr
  ⇒ **Regulators** need to compute efficient T&D tariffs
  ⇒ and move faster. Auction in 1 day grants 15-yr contract

*Ofgem alerted to adverse effects Dec 2014, decides June 2017 to reduce to zero by 2020/21*
GB Transmission demand residual – extra to DN connex

Source: Ofgem (2017)

Embedded benefit not material

Reduce TDR to £0
Conclusions

• The priority is to **decarbonise electricity**
  – To avoid long-term lock-in
  – **EC Clean Energy Directive** identifies **good principles**
    => clear guidance for good policy instruments

• Low-Carbon electricity has **high capital, low variable costs**
  – Distinguish prices for **access, capacity, energy, quality**

• Support for RES needs change
  – recognise **learning benefits** by capacity support, CO₂ per MWh
  – needs better **location** and dispatch price signals => markets
  – **network tariffs** need reform
  – **reliability auctions and contracts** avoid trade distortions

• Countries can learn from experiences elsewhere
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<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>BOS</td>
<td>Balance of system (cost)</td>
</tr>
<tr>
<td>BSUoS</td>
<td>Balancing Services Network Use of System ≈ €2-5/MWh</td>
</tr>
<tr>
<td>CCS</td>
<td>Carbon Capture and Storage</td>
</tr>
<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>EPS</td>
<td>Emissions Performance Standard</td>
</tr>
<tr>
<td>ETS</td>
<td>Emissions Trading System</td>
</tr>
<tr>
<td>EUA</td>
<td>EU Emissions Allowance Price (per tonne CO₂)</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse gas</td>
</tr>
<tr>
<td>G, L</td>
<td>Generation, Load</td>
</tr>
<tr>
<td>I-SEM</td>
<td>Integrated Single Electricity Market of island of Ireland</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>MS</td>
<td>Member State</td>
</tr>
<tr>
<td>QoS</td>
<td>Quality of service</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
</tr>
<tr>
<td>RES-E</td>
<td>Renewable energy supply in electricity</td>
</tr>
<tr>
<td>RO</td>
<td>Reliability option</td>
</tr>
<tr>
<td>ROC</td>
<td>Renewable Obligation (i.e. green) Certificate</td>
</tr>
<tr>
<td>SMC/P</td>
<td>System Marginal Cost/Price</td>
</tr>
<tr>
<td>T&amp;D</td>
<td>Transmission and Distribution</td>
</tr>
<tr>
<td>TG</td>
<td>Transmission-connected generation</td>
</tr>
<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>
</tbody>
</table>

• Clean Energy For All Europeans, COM/2016/0860 final at http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1481278671064&uri=CELEX:52016DC0860

• Ofgem (2017) Impact Assessment and Decision on industry proposals (CMP264 and CMP265) to change electricity transmission charging arrangements for Embedded Generators at https://www.ofgem.gov.uk/system/files/docs/2017/06/cmp264265.docx.pdf

Spare slides

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Dramatic fall in solar PV prices

Figure ES 1: Global weighted average utility-scale solar PV total installed costs, 2009-2025

On-shore wind: taller towers give higher capacity factors

Source: IRENA (2016)
GB 2014 Capacity Auction

Source: National Grid (2014)
Flaws in GB Capacity Procurement

- Transmission-connected generation TG **pays** G TNUoS
  - And 50% of BSUoS
- Distribution-connected generation DG **receives** L TNUoS
  - And avoids BSUoS
- TNUoS G + L charge **roughly constant** across zones
  - Rapidly rising from £20/kWyr to £66/kWyr

=> represents **extra** £53/kWyr embedded benefit in 2018/19

=> DG gets £73/kWyr and TG gets £20/kWyr

=> **efficient** locational charge = <10% total charge?
  - Rest is revenue levy to pay for grid

=> should be levied on gross not net final consumption

*Massive distortion*

Newbery
• **Good**: Auctions can dramatically reduce costs
• Each jurisdiction is facing similar problems
  – *and trying out a variety of solutions*
• **Learning** from elsewhere and experimenting essential
  ⇒ *challenge funds* to try new ideas and test regulations
  ⇒ *copy Ofgem’s Network Innovation Competitions*
• **Bad**: Auctions + new technology ⇒ rapid irreversible decisions
  – need smarter, quicker responses to ensure tariffs are suitable
• **Ugly**: tension between efficient and “fair” pricing can lead to inefficient *and* inequitable outcomes