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Designing an electricity wholesale market for significant renewables penetration:
Adapting the EU model for the UK

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Outline

- European Union **commitments to decarbonize**
- A high RES scenario is becoming realistic
  - Falling cost of RES, storage still costly,
  - need to retain options on nuclear, CCS, …
  - improvements in interconnectors – flexibility
- Need to **modify** market design and regulation
  - six principles of good market and regulatory design
- securing flexible plant: **capacity auctions**
- auctions for renewables
  - need new auction designs for both

Principles for market/policy design

1. Correct **market failures** close to source
2. Allow cross-country variation, **not one-size-fits-all**
3. Let prices reflect the **value of all electricity services**
4. Collect regulatory revenue shortfalls with **least distortion**
5. **De-risk financing** of low-carbon investment
6. Retain **flexibility** to respond to new information

MSs have different resource/institutional constraints

The Electricity Trilemma

- **Security** of supply trumps other goals
  - Disconnections: high visibility impacts on everyone
- **Affordability**: a problem of short-run perception
  - Govt: won't raise taxes but happy to impose charges
- **Sustainability**: Investment must be low-C
  - Renewables (RES), nuclear and/or CCS
  - Each create challenges for financing and balancing

Can the liberalised electricity market deliver?

Problems of ***missing markets*** & ***missing money***

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Charging for electricity

- **Networks** are regulated natural monopolies
  - – low variable costs, high fixed costs, massive econs of scale
  - => marginal cost below average cost
  - => efficient pricing at marginal cost **fails to recover full costs**

⇒ challenge: efficient price signals ***and*** recover residual

⇒ Public finance theory: balance efficiency vs equity

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

=> challenge is to develop efficient wholesale/retail prices

- – But not normally a regulated asset
- ⇒ long-term contracts?

How to charge final consumers?

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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, …)

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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-LoLP)*SMC + LoLP*VoLL
  - reflects probabilities of **supply** or **lack of supply**

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Ancillary services for QoS

Faster more flexible responses needed with high renewables

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

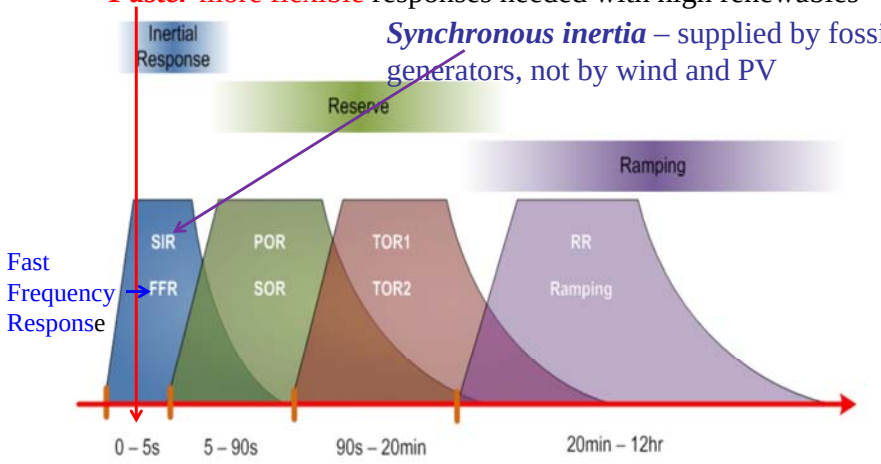

Figure 1: Frequency Control Services (Source: EirGrid)

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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
  - – 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**
- Large RES depresses prices, needs flexible reserves

⇒ hard to invest in flexible plant in policy-driven market

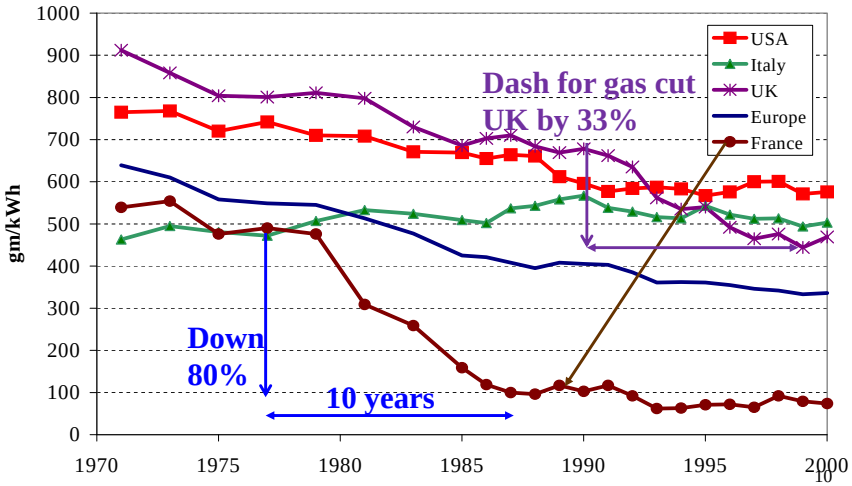
⇒ capacity auctions and new flexibility products

⇒ Increases case for interconnections paid for security

⇒ **Need better contracts for RES and capacity adequacy**

Nuclear power can cut emissions – but we have forgotten how to do it at reasonable cost

CO2 emissions per kWh 1971-2000



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Premature nuclear retirement makes no economic sense

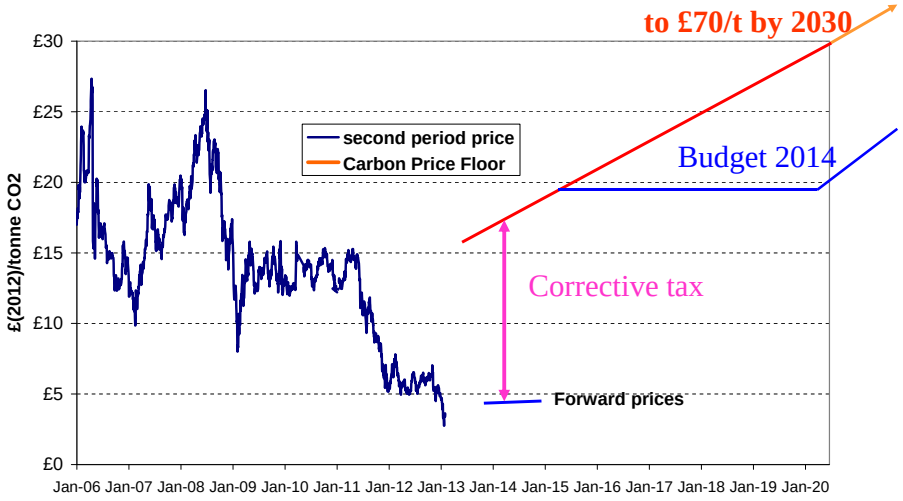
- Variable costs of nuclear << average cost
  - – But not negligible
  - – Low gas prices/ high RES lower wholesale prices

  => nuclear plants retiring early in US, phase-out in EU
- EU lacks an adequate carbon price
  - – Social cost of CO_2 > €40/tonne?
  - – At €25/tonne => raises **CCGT cost €12/MWh**
    - And € 23/MWh if coal at the margin
- But zero-carbon nuclear not adequately supported
  - – Unlike renewables

Case for a CO_2 price or price floor

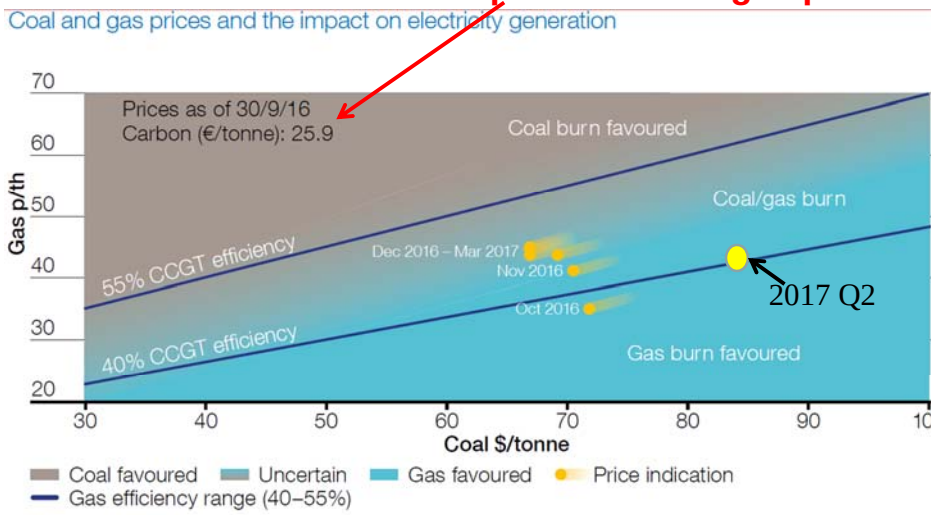
UK's Carbon Price Floor - in Budget of 3/11

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



Source: EEX and DECC Consultation

Gas displaces coal at high CO_2 price and low gas price



Data source: ICE Nat Grid Winter Outlook 2016-17

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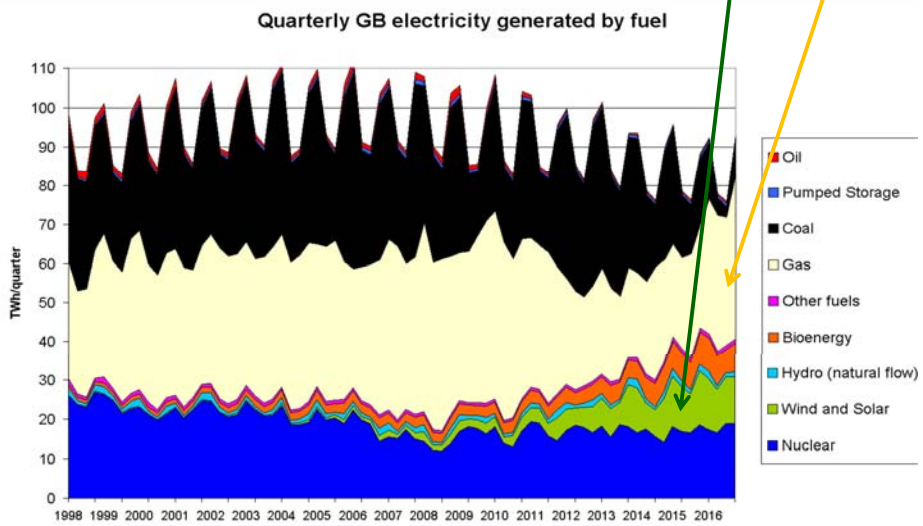
Coal displaced by RES & gas: carbon price floor working



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UK coal policy

- UK adopted a carbon price floor
  - ETS demonstrably unfit for purpose
  - Combined with an emissions performance standard
    - Impossible to meet at baseload on coal, possible on CCGT
- UK Govt: all coal to cease by 2025
  - eligible for annual capacity auction to provide low cost winter peaking capacity (and CO_2 already priced)
- Given COP21 and plans to reform ETS surely no sane utility plans new coal in EU

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Revised RES Directive

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**

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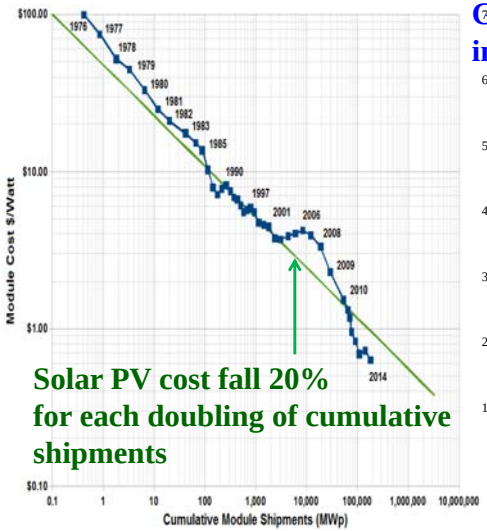
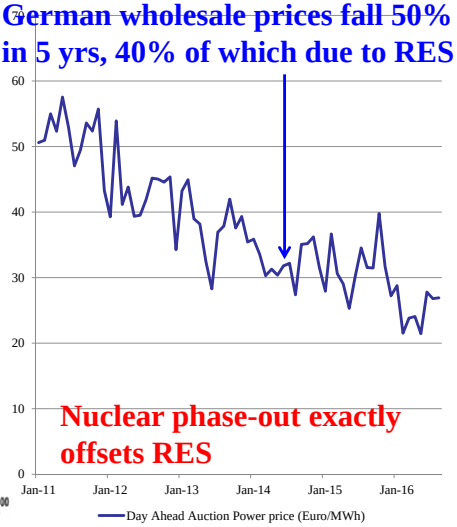
Learning justifies support but is on cumulative shipping not RES output



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

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



Nuclear phase-out exactly offsets RES

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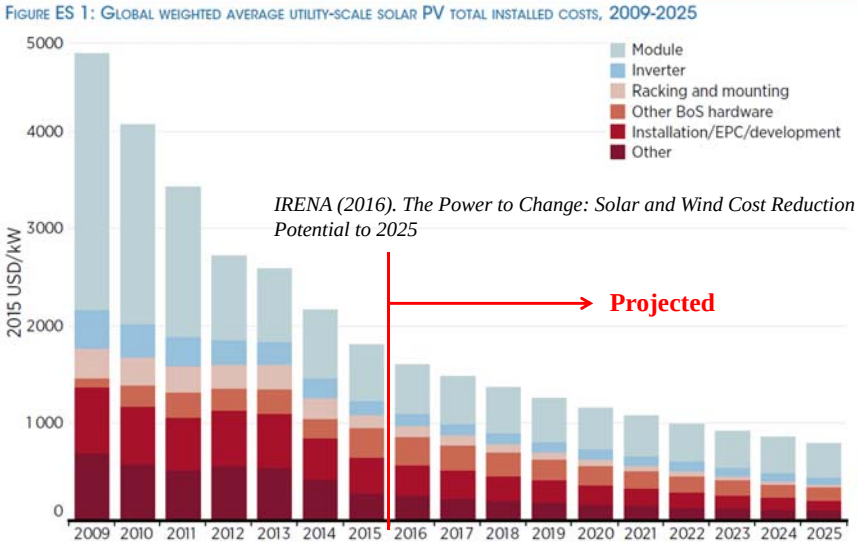
Dramatic fall in solar PV prices



IRENA (2016). The Power to Change: Solar and Wind Cost Reduction Potential to 2025

Projected

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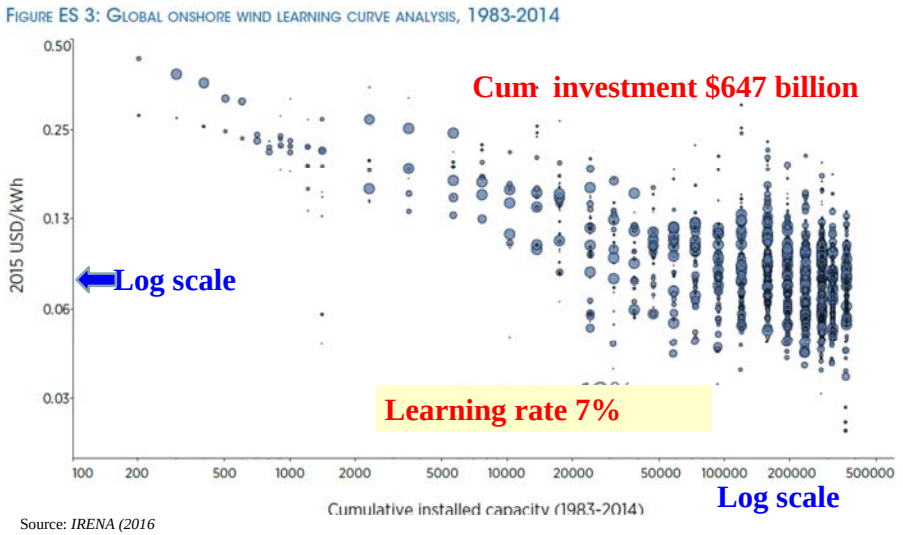
On-shore wind: taller towers give higher capacity factors



Cum investment $647 billion

Log scale

Learning rate 7%

Log scale

Source: *IRENA (2016*

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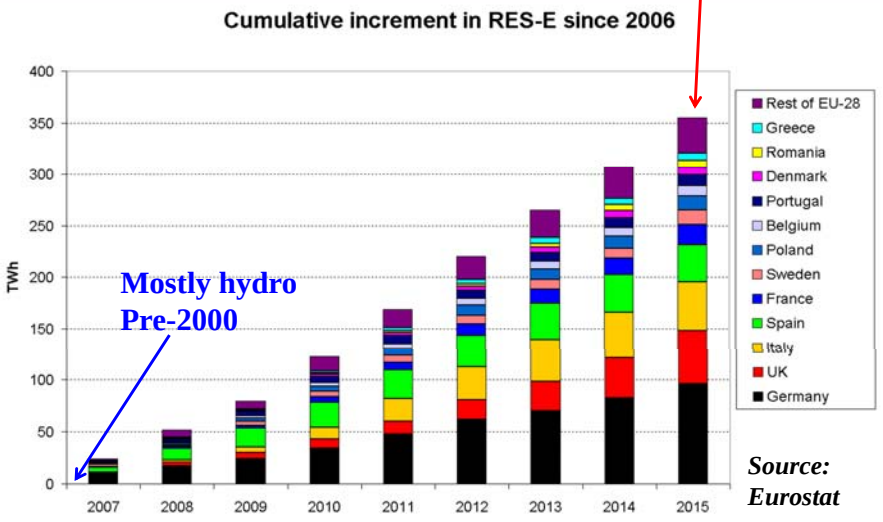
Rapid *increase* in EU renewable electricity to 29% in 2015



Mostly hydro Pre-2000

Source: Eurostat

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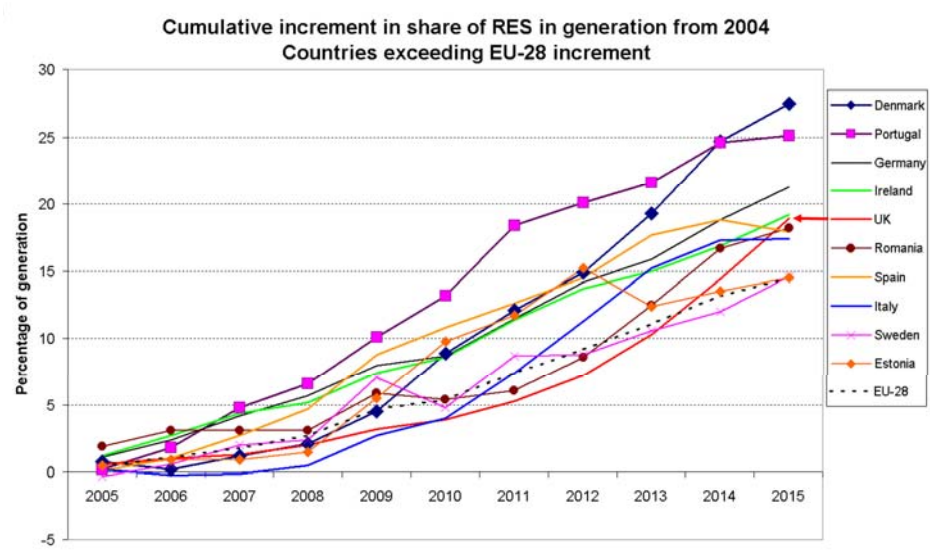
UK RES catching up rapidly



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Reforming RES-E support

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

⇒Contract €***X***/MWh for (e.g.) 30,000 MWh/MW, auction determines premium €***X***

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
  => **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

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Quantifying the spill-over benefit

					GWp cumulative		
Country	2010	2011	2012	2013	2014	2015	shares
China	0.8	3.3	6.8	19.7	28.2	43.5	19%
Germany	17.4	24.9	32.5	35.8	38.2	39.8	17%
Japan	3.6	4.9	6.6	13.6	23.3	34.2	15%
USA	2.5	4.4	7.3	12.1	18.3	25.6	11%
Italy	3.5	12.8	16.5	18.1	18.5	18.9	8%
UK	0.1	0.9	1.9	3.4	5.1	8.9	4%
France	1.2	3.0	4.1	4.7	5.7	6.6	3%
subtotal	29.1	54.1	75.6	107.3	137.2	177.5	76%
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 Spillover contributions by country					total $ million/yr			
Country	2010	2011	2012	2013	2014	2015	cumulative	share
Germany	$14,276	$5,536	$5,049	$1,964	$1,292	$737	$28,855	21%
China	$657	$1,849	$2,324	$7,681	$4,499	$7,234	$24,245	18%
Japan	$2,973	$958	$1,141	$4,142	$5,148	$5,120	$19,482	14%
USA	$2,078	$1,372	$1,918	$2,858	$3,291	$3,454	$14,970	11%
Italy	$2,878	$6,883	$2,420	$963	$205	$219	$13,568	10%
UK	$63	$612	$662	$878	$916	$1,799	$4,930	4%
France	$989	$1,309	$741	$382	$492	$438	$4,352	3%
subtotal	$23,915	$18,519	$14,255	$18,869	$15,842	$19,001	$110,402	80%
range +/-	$7,323	$5,266	$3,727	$4,480	$3,360	$3,522	$27,678	

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RES CfD 2015 auction results

Technology		admin price	lowest clearing price	2015/16	2016/17	2017/18	2018/19	Total Capacity (MW)
Advanced Conversion	£/MWh	£140	£114.39			£119.89	£114.39	
Technologies	MW					36	26	62
Energy from Waste with	£/MWh	£80	£80				£80.00	
Combined Heat and Power	MW						94.75	94.75
Offshore wind	£/MWh	£140	£114.39			£119.89	£114.39	
	MW					714	448	1162
Onshore wind	£/MWh	£95	£79.23		£79.23	£79.99	£82.50	
	MW				45	77.5	626.05	748.55
Solar PV	£/MWh	£120	£50.00	£50.00	£79.23			
	MW			32.88	36.67			69.55

Source: DECC (2015)

Foolish bid - withdrew

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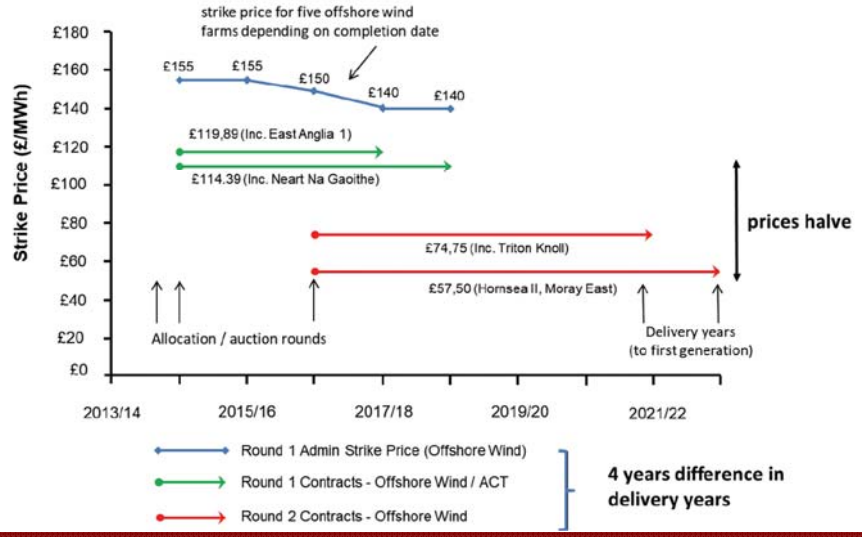
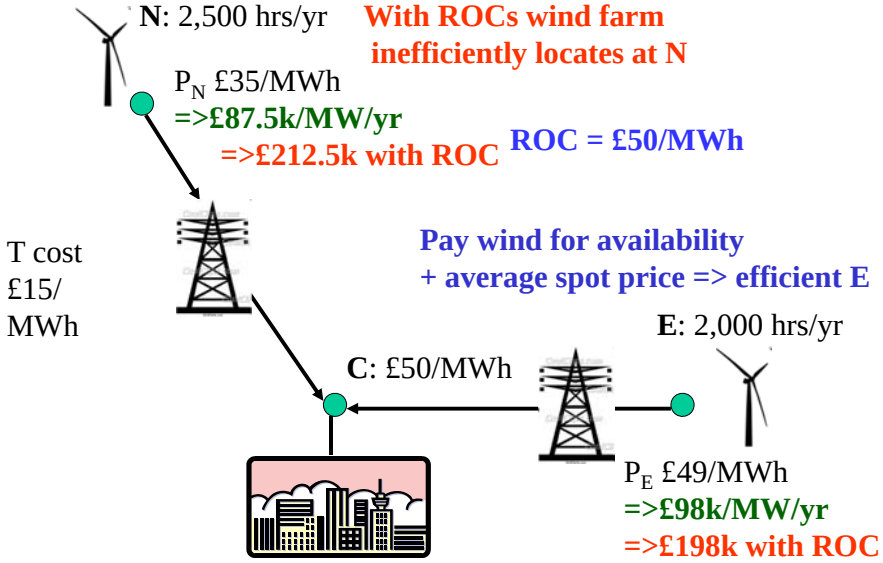
UK Off-shore wind auction prices



Location choices under LMP and spot pricing for wind



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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

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Reliability Options to replace Capacity agreements

- 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***

Trade over interconnectors efficient

No need to pay foreign generators

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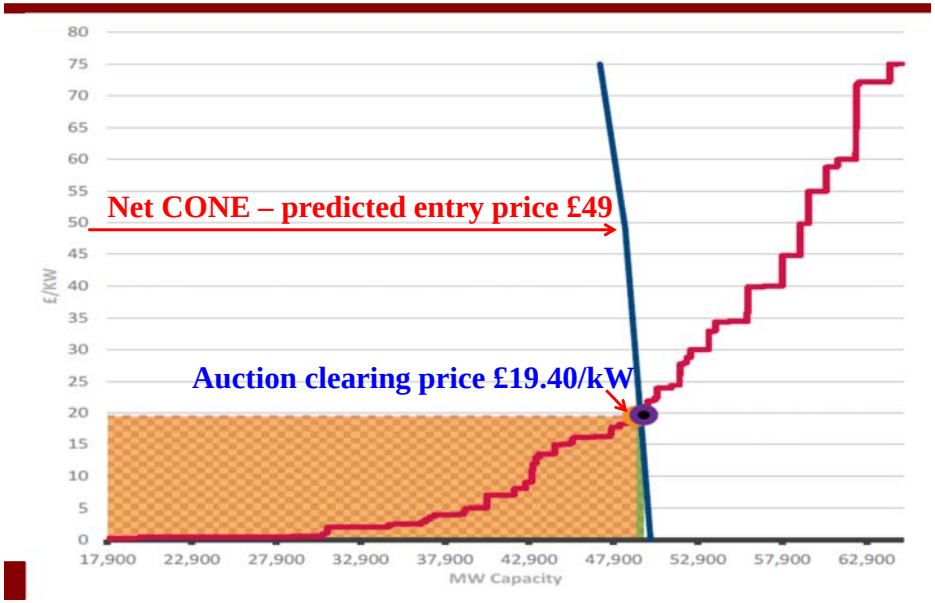
GB 2014 Capacity Auction



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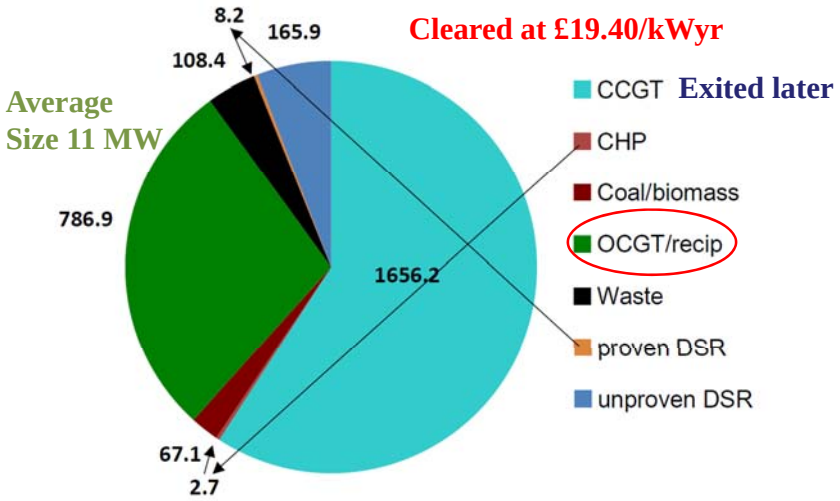
New build 2014 T-4 auction



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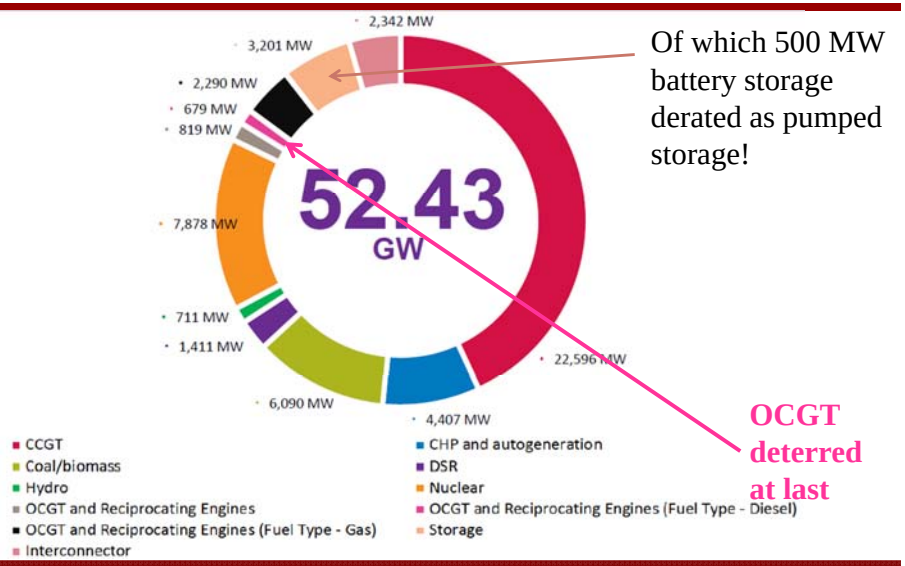
T-4 by technology Dec 2016 for 2020/21



Of which 500 MW battery storage derated as pumped storage!

OCGT deterred at last

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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

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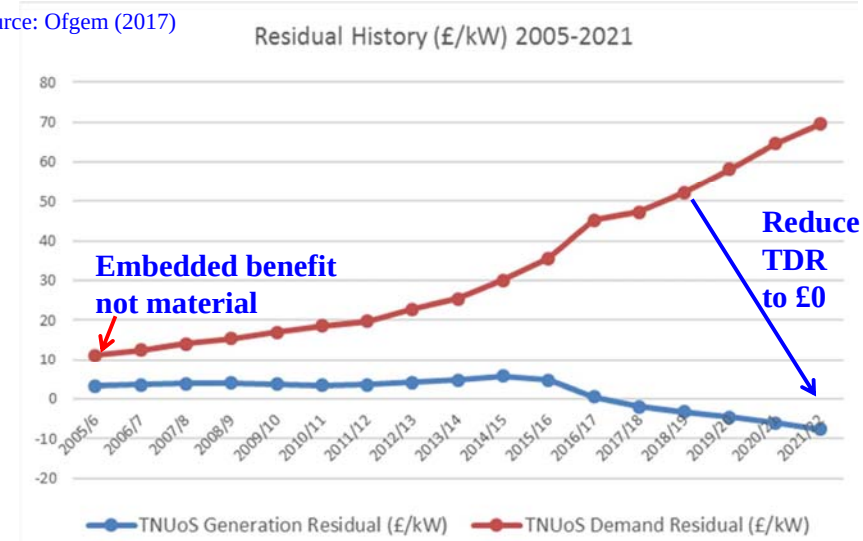
GB Transmission demand *residual – extra to DN connex*

Source: Ofgem (2017)



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Efficient tariffs

- Distinguish efficient price and short-fall in required revenue
  - Efficient peak T price is marginal expansion cost
  - At best 30% average cost, less if demand falling
- Ramsey-Boiteux pricing => "tax" inelastic demand
  - ⇒ equi-proportional reductions in all types of demand
    - incl. option to take up to *N* Kw
- Diamond-Mirrlees: tax only ***final*** consumers

⇒ T&D revenue shortfall on final consumption ***not*** net demand (at network connection)

⇒ reduces embedded G benefit from £60 to < £10/kWyr

⇒ **Regulator**s need to compute efficient T&D tariffs

⇒ and move faster. Auction in 1 day grants 15-yr contract

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Conclusions

- Support for RES needs change
  - recognise learning benefits by capacity support, CO_2 per MWh
  - needs better location and dispatch price signals => markets
  - market responsive requires auctions and good network tariffs
- Efficiently pricing externalities and system impact key for efficient entry *and* exit decisions
- Tariffs and market design need reform to guide decisions
  - **network tariffs** to avoid distorting embedded benefits
  - **reliability options** better than capacity auctions for market
- Consumers can help if they make efficient decisions
  - need to face efficient tariffs for networks – largely fixed charges
  - and efficient electricity prices => lower off-peak; higher peak
  - then can decide on PV, batteries, Electric Vehicles, etc.

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Acronyms

CfD	Contract for Difference
CONE	Cost of New Entry
CP	Capacity payment
DG	Distribution-connected Generation
DN	Distribution Network
G, L	Generation, Load
LMP`	Locational Marginal Pricing (Nodal pricing)
LoLP	Loss of Load probability
LoLE	Loss of load expectation in hrs/yr = reliability standard
Q0S	Quality of service
RES	Renewable energy/electricity supply
RO	Reliability option
ROC	Renewable Obligation (i.e. green) Certificate
SMC/P	System Marginal Cost/Price
T&D	Transmission and Distribution
TDR	Transmission demand residual
TG	Transmission-connected generation
TNUoS	Transmission Network Use of System, G =Generation, L=Load
VOLL	Value of Lost Load