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Mathematics and economics of electricity markets

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Outline

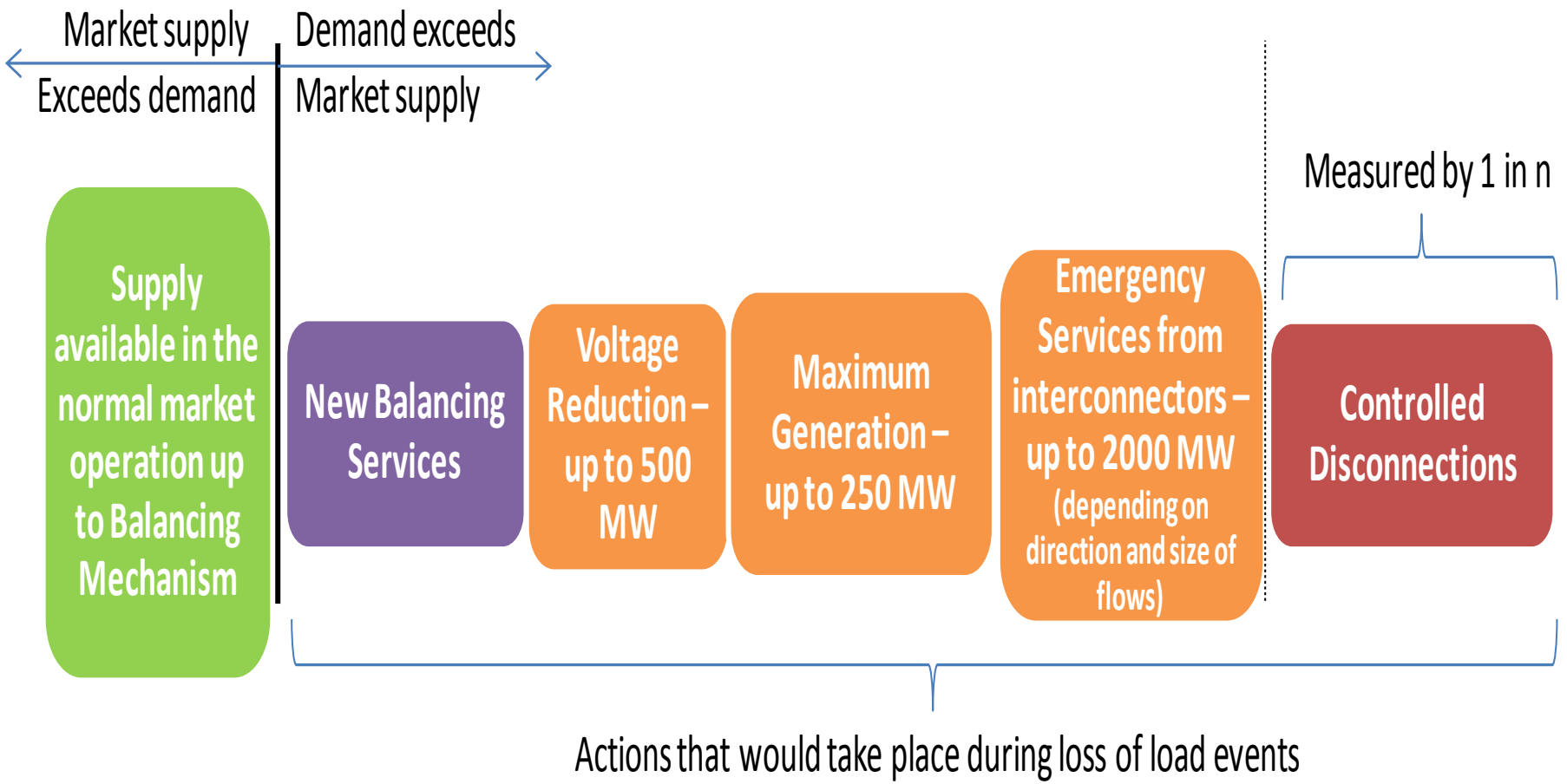
- Reliability assessments
- Capacity auctions – GB experience
- Capacity and flexibility services procurement
- Embedded benefits and efficient charging
- Balancing markets and HVDC interconnectors

Disclaimer: I was a member of the PTE advising DECC on the evidence base for the EMR and capacity auctions, but this draws only on public information and does not reflect the views of the Panel nor of DECC nor National Grid

Reliability in electricity markets

- Security of supply – ability to withstand sudden disturbances;
  - – **public good** provided by System Operator, can shed load to protect system
- Capacity adequacy – ability to supply demand allowing for plant reliability,
  - – theoretically can be left to **market**
  - – measured by **Loss of Load expectation** (GB = 3hrs/yr)
- How to determine whether a system meets the reliability standard given network constraints and interconnections to other markets?

What does "Loss of Load" mean?

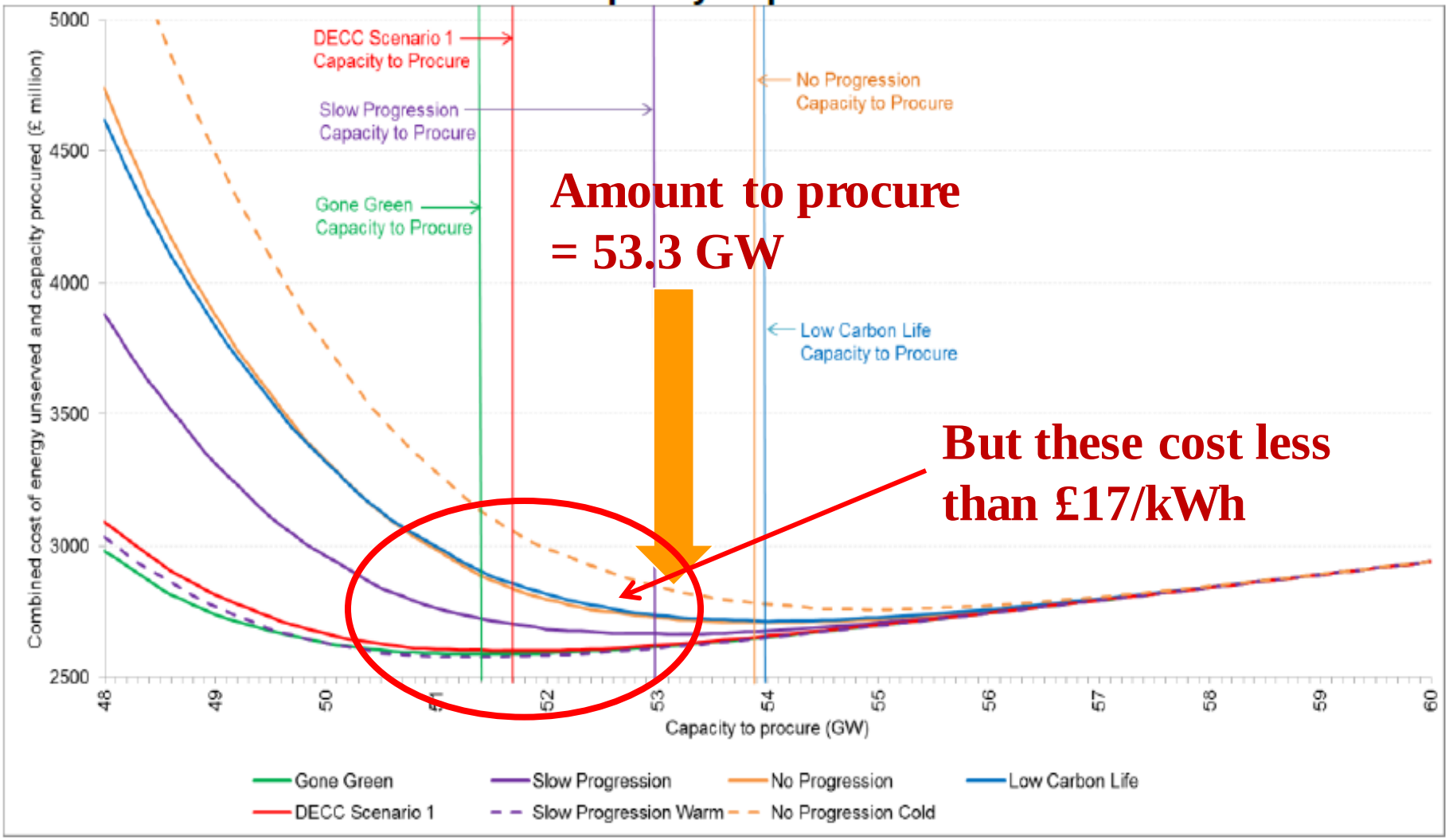


These actions have lower cost/value than £17/kWh

Source: Ofgem (2014) *Capacity Assessment 2014*

Cost of "energy unserved" = £17/kWh

Figure 12: Combined cost of energy unserved and procured capacity against capacity to procure



Source: National Grid (2014, p50)

Capacity payments: theory

Efficient price = SMC + CP

SMC = system marginal cost, CP = capacity payment

CP = LoLP*(VoLL - SMC)

LoLP = Loss of Load Probability in each hour

LOLE = ♦ LoLP over year (Loss of Load Expectation)

set at 3 hrs in GB and many EU countries

⇒ VoLL = Value of Lost Load = £17,000/MWh (**??**)

⇒ Does this require an explicit CP?

⇒ How well do energy-only markets work?

⇒ How do different market designs interact?

Capacity payments: history

- The Pool (1990-2001) had an explicit CP with VoLL = £(2013)5,000/MWh
  - (but SMP is as bid, not SMC)
- Replaced by energy-only market + Balancing Mechanism
  - 2001-2014 NETA, then BETTA
- EU Target Electricity Market is an energy-only market
  - Max price in Euphemia day-ahead = €3,000/MWh
  - Max price in France = €3,000/MWh
  - Max price in UK= £9,999/MWh (or £99,999?)
  - System Operator actions priced at £6,000/MWh
- GB now has a capacity auction and payment
- I-SEM (NI+IE) has reliability option auction

How well do these alternatives work?

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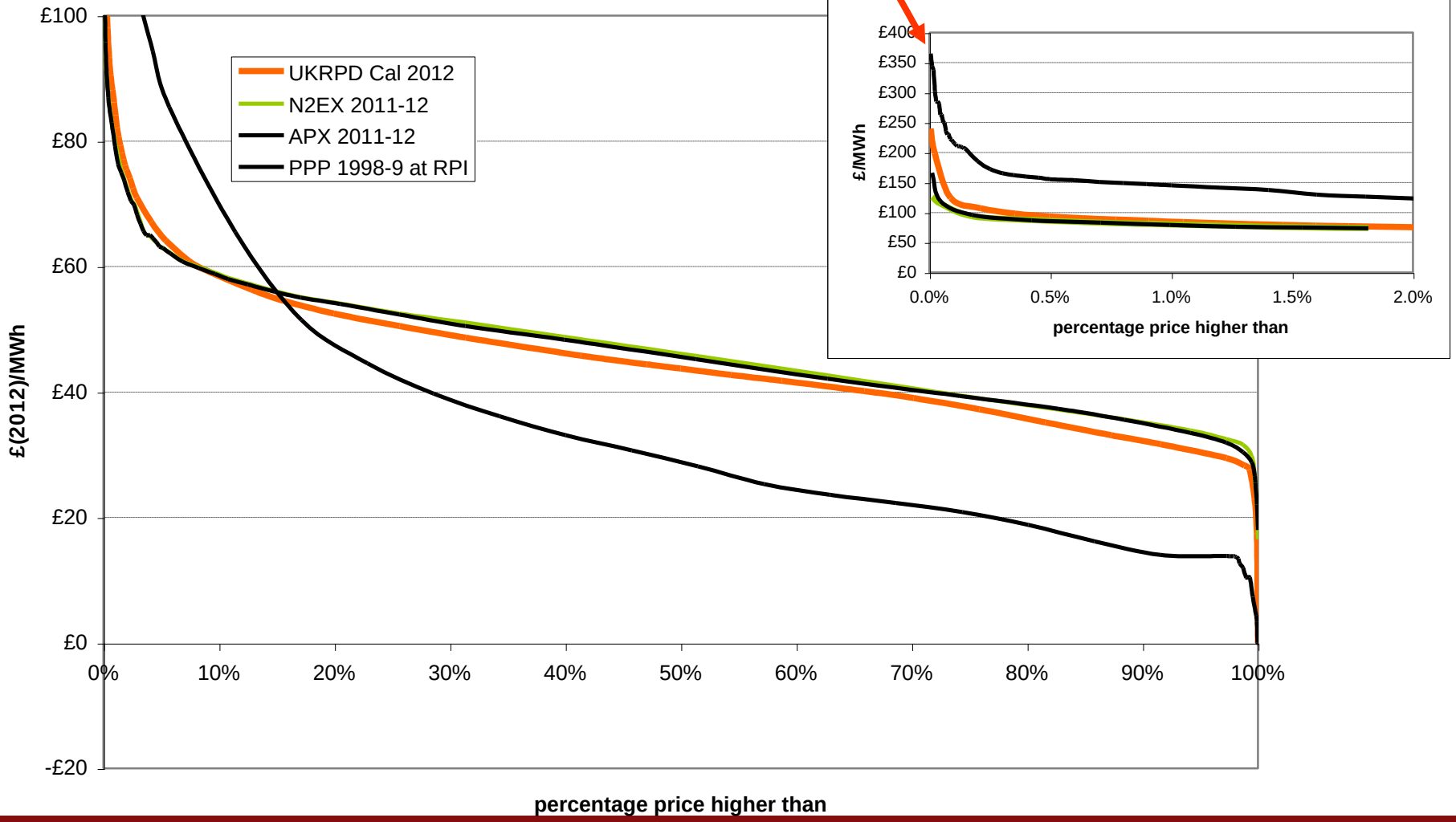
Pool prices were peakier than GB energy only market

UK price duration curves 2012 and Pool Purchase price 1998-9



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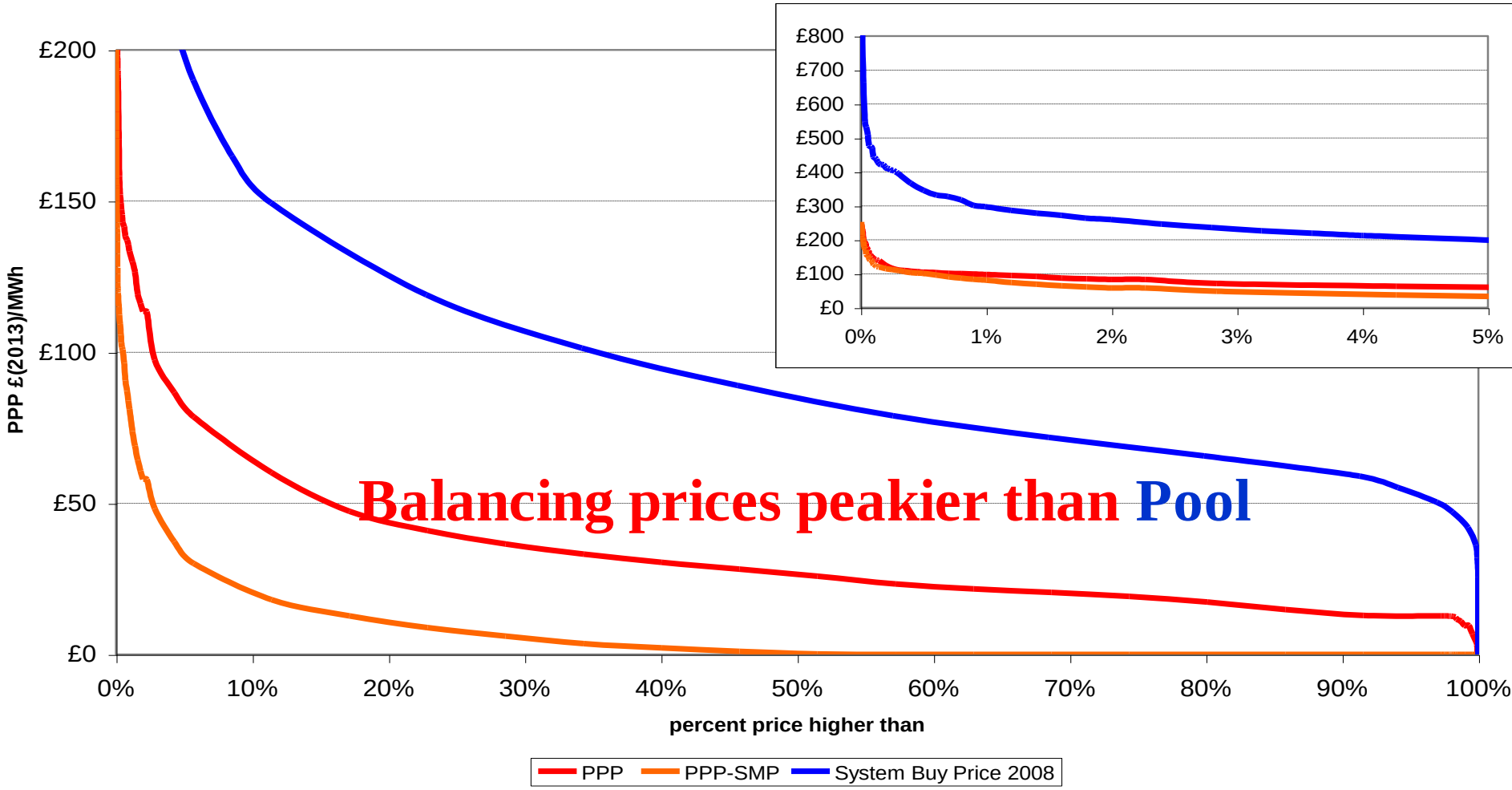
Pool prices 1998-9 and System Buy Price 2008



Case for a Capacity Revenue Mechanism (CRM)

- "Missing Money" vs "Missing Markets"
- Missing Money results from price caps

  => address via VoLL caps in markets, hedged by reliability options (ROs)
- Missing Markets
  - Future markets for financing period 15 yrs?
  - Satisfactory carbon price
  - Hedges against regulatory risk, incl price caps
  - For full range of ancillary services
    - Flexibility, fast ramping, frequency response, etc.

Ignore Missing Markets => Missing Money

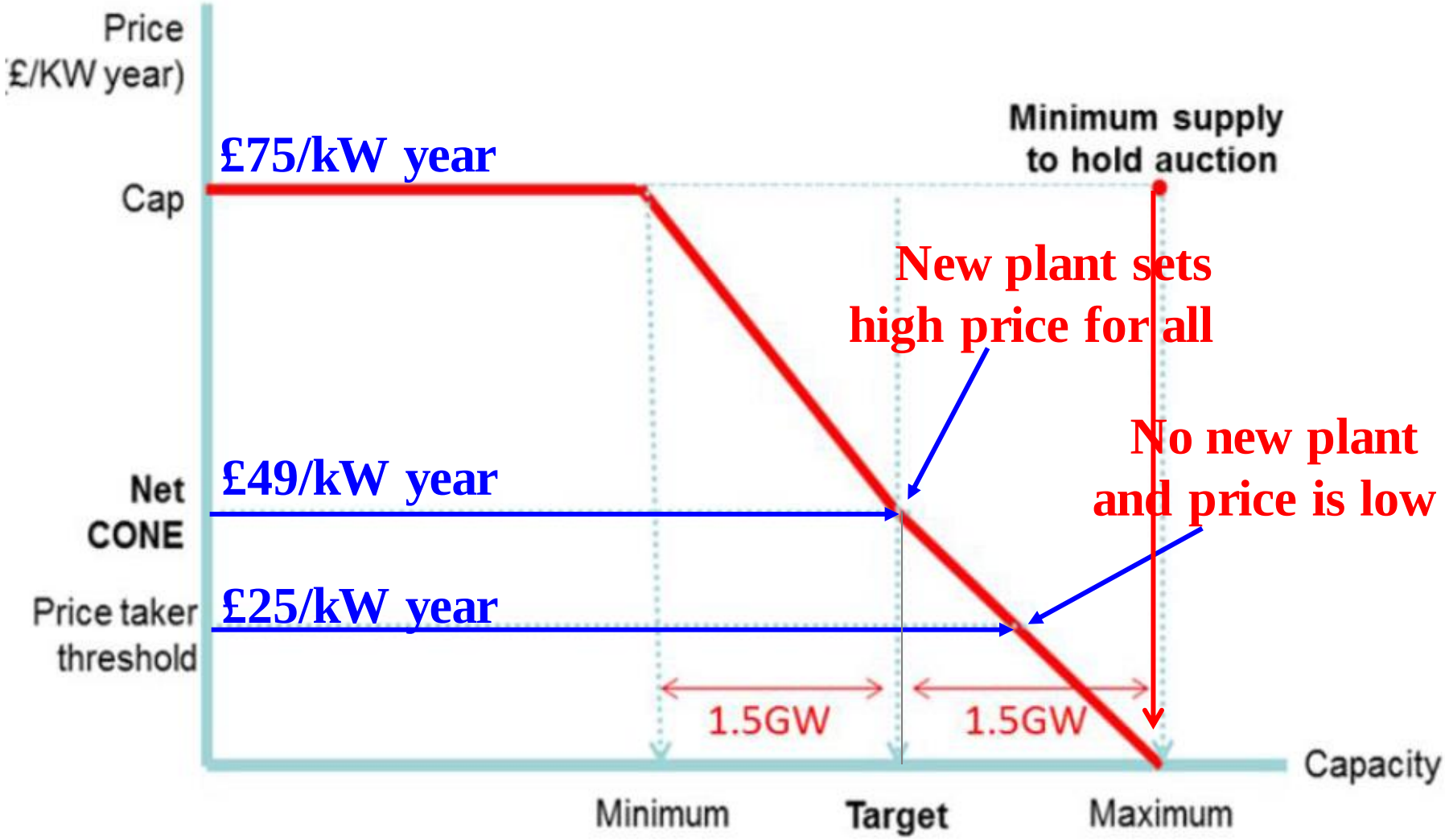
Capacity procurement

- GB has a descending clock last price single auction
- New entrants given 15-yr indexed contract £X/kWyr
- Can be called on to deliver in 4hrs, penalty for non-delivery
- Existing plant offered 1-yr contracts (to signal exit)

- Questions:
  - Does clock auction facilitate collusion?
  - Does capacity procured distort trade with other markets?
  - Should location be taken into account? If so how?
  - How do entrants decide on optimal plant characteristics (flexibility)?

EC Interim Report on Capacity Mechanisms 13/4/16

GB capacity clock auction design



Source: DECC IA

Auction results so far

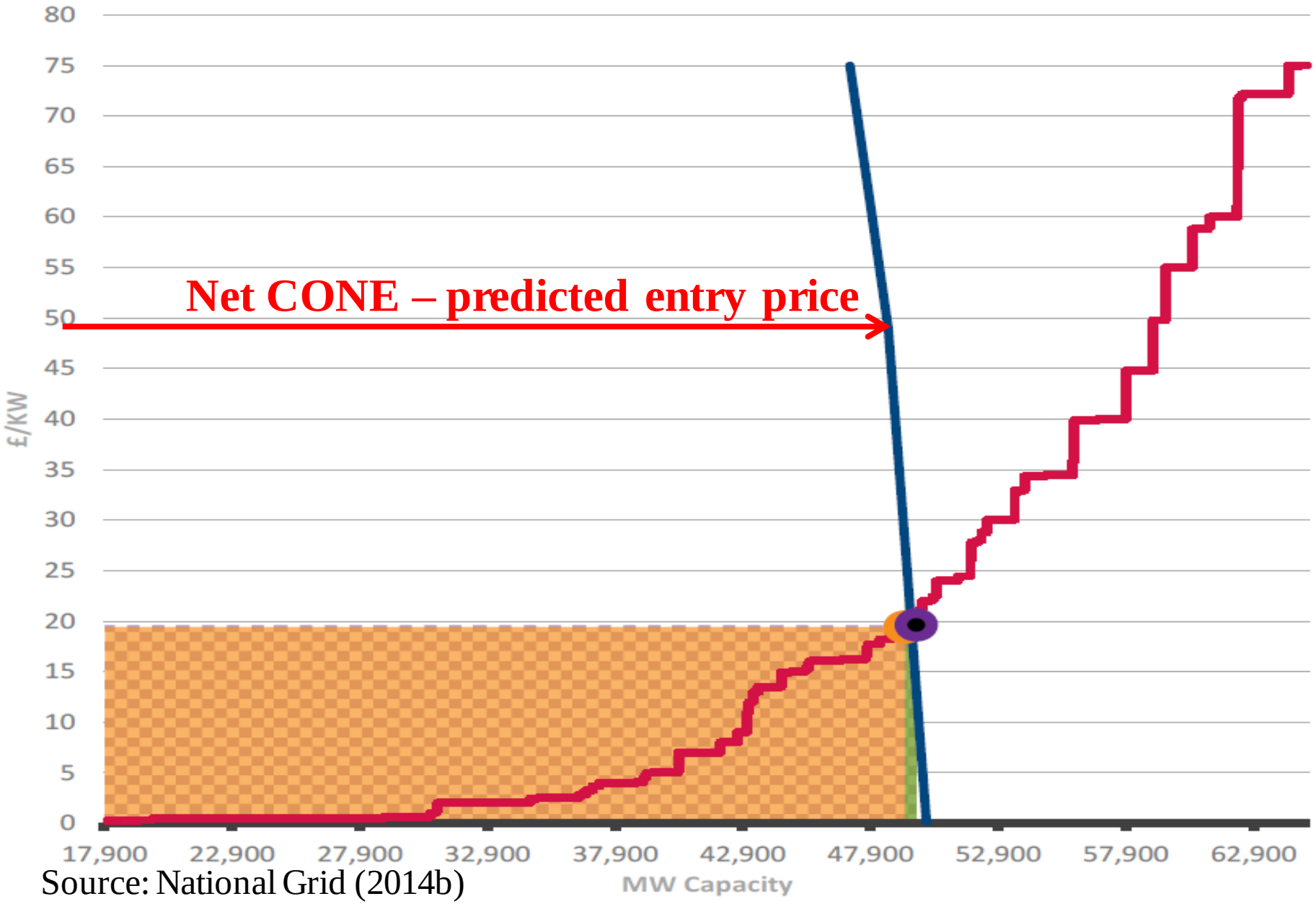
- Capacity auction December 2014:
  - PTE criticized over-cautious procurement
    - and ignoring interconnector contribution
  - New entry price predicted at £49/kWyr for CCGT
    - Could have cost £2.5 billion
- Market clearing price £19.40/kWyr, CCGT entered
- Govt concerns that auction favoured small diesel

⇒***auctions much better than bureaucrats***

⇒***Was technology neutral: deal with pollution through standards or taxes***

⇒***But transmission charging seriously flawed***

GB Dec 2014 Capacity Auction



Source: National Grid (2014b)

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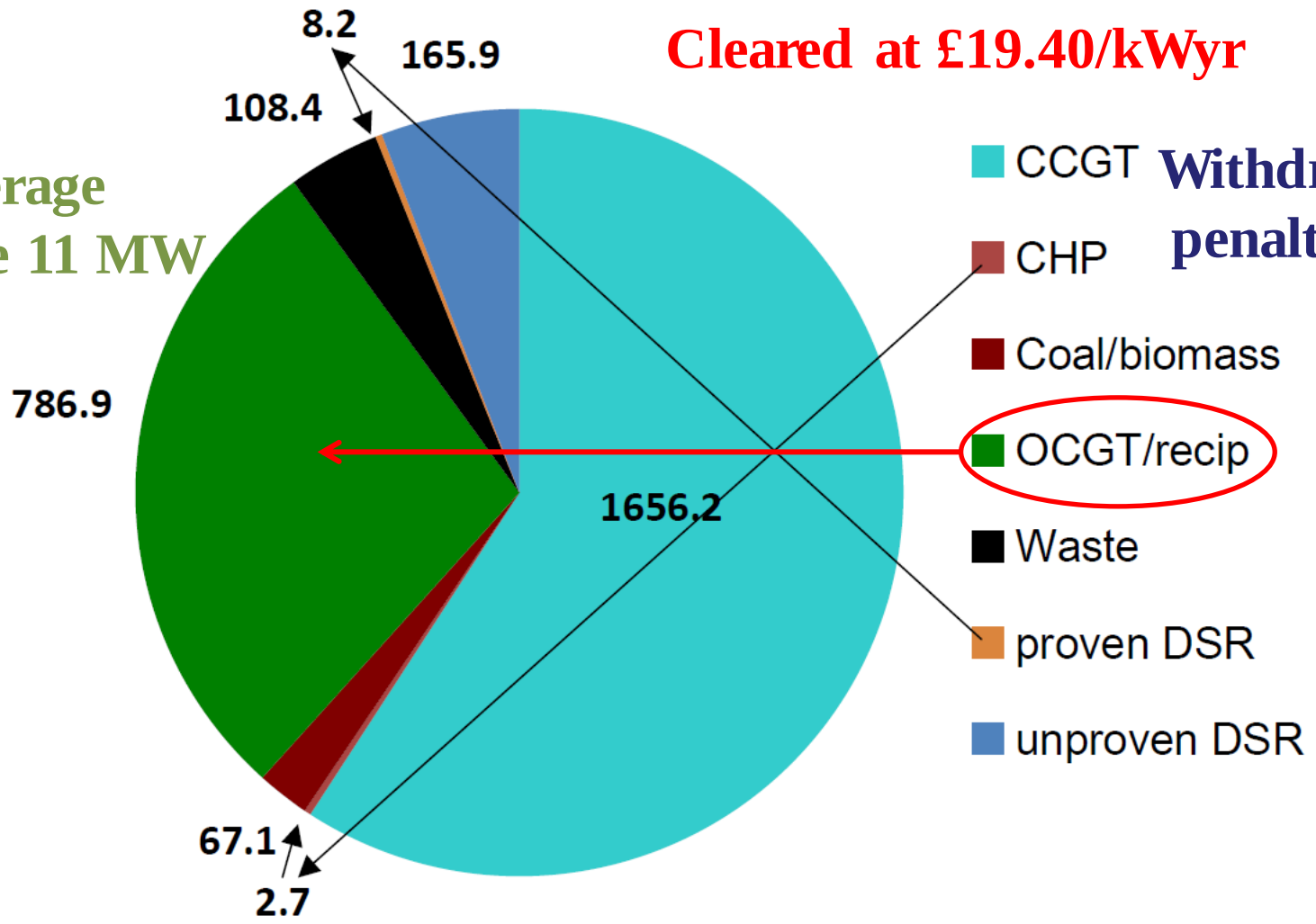
New build 2015 T-4 auction

Cleared at £19.40/kWyr

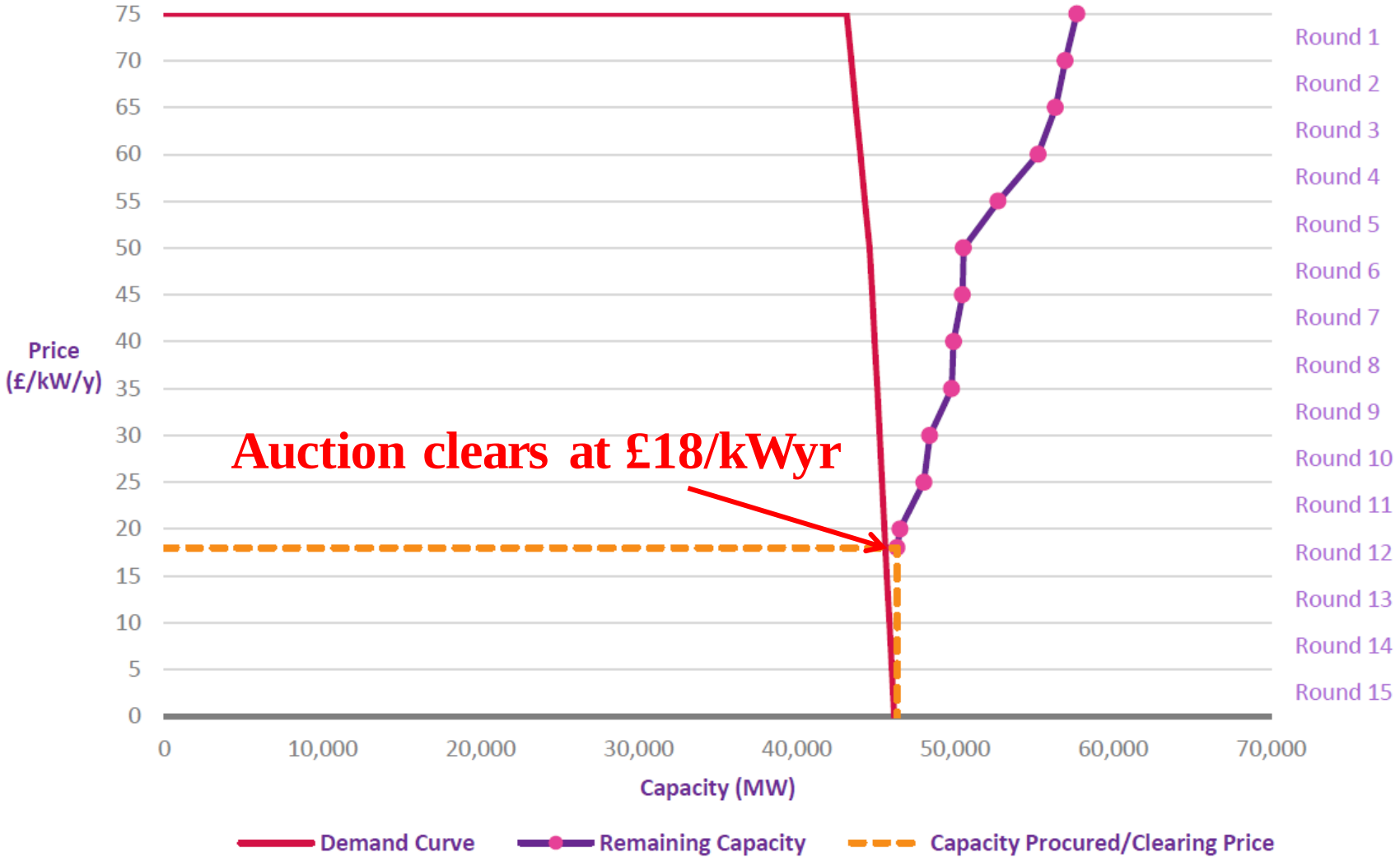
Withdrew, paid penalty

Average Size 11 MW



GB Dec 2015 Capacity Auction

Figure 1: Demand and Possible Supply Range



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Embedded benefits and tariff design

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Problems post 2014 auction

- Large coal plants exiting or **threatening to exit**
  - Some with CM agreements; penalty < expected losses
- Large volumes of sub-scale distributed generation win CM agreements

- **Ofgem needs to know how much to pay to keep *economic* coal connected– and to ensure TNUoS gives right exit signals**
- **Ofgem consults on embedded benefits**

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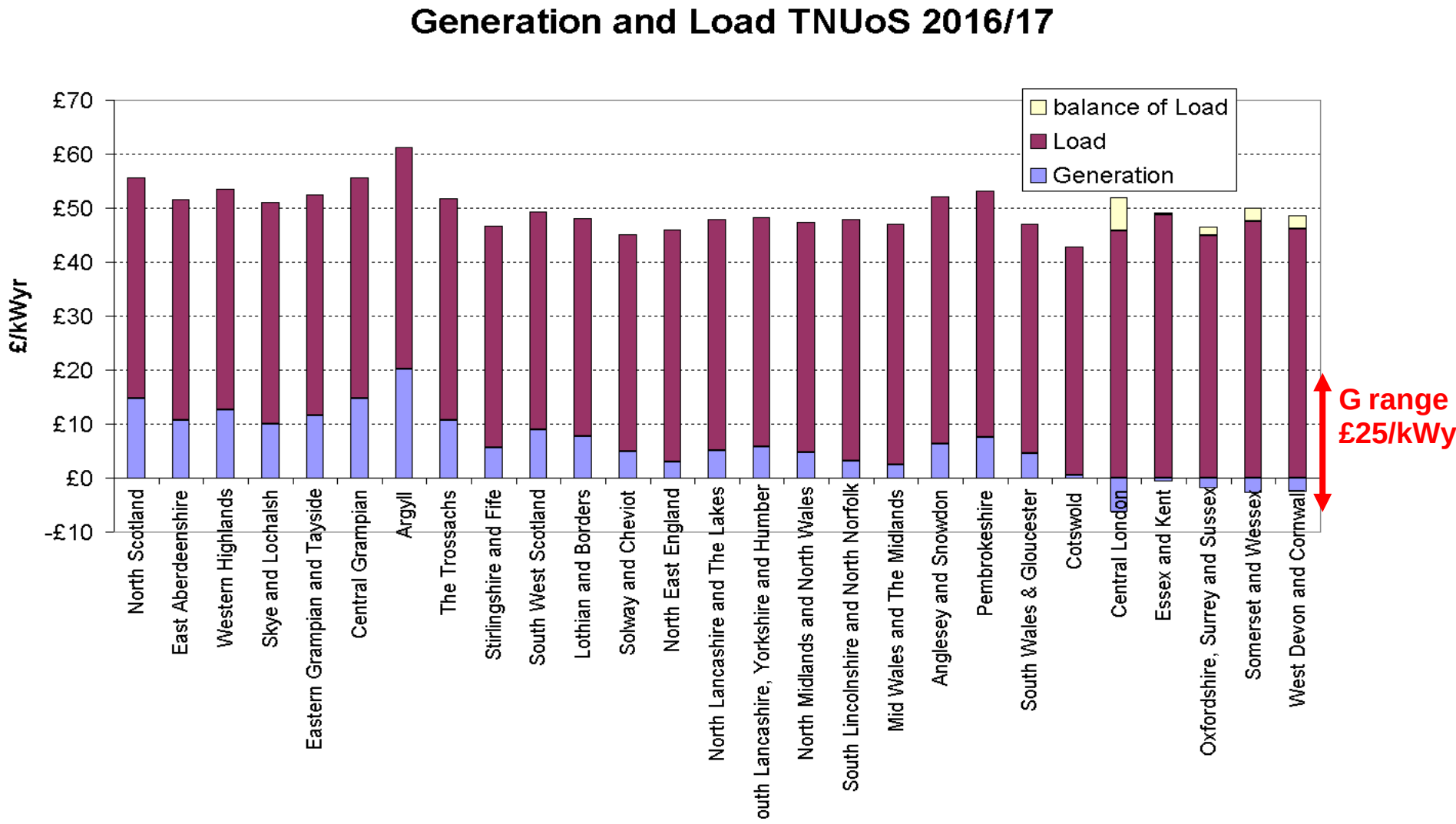
GB TNUoS (Network) charges



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 £49/kWyr to £66/kWyr

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

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

=> efficient locational charge = 10-20% total charge?

- Rest is revenue levy to pay for grid

=> should be levied on gross not net consumption

Massive distortion

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 pricing => "tax" inelastic demand
- Diamond-Mirrlees: tax only final consumers

$\Rightarrow$ T&D revenue shortfall on final consumption ***not*** net demand (at GSP or premises)

$\Rightarrow$ reduces embedded G benefit from £60 to < £10/kWyr

$\Rightarrow$ Challenge is to compute efficient T&D tariffs

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Transition from SEM to I-SEM procuring capacity and flexibility services on the island of Ireland

David Newbery

I am a SEM Committee member but this represents solely my own views

I-SEM vs GB CRMs

- **GB** interconnectors participate in capacity auction
  - 2GW of IC 80% de-rated at ≈ £20/kWyr = £32 million/yr
    - Provided flows in right way, otherwise penalized up to 100%
  - EC concerned that foreign generators excluded
- **I-SEM** proposes auctions for Reliability Options
  - One-sided CfD with strike price ≈ €500/MWhr
  - SO sets floor price in stress events, start at strike price, rise to VoLL (≈ €12,000/MWhr) when load disconnected

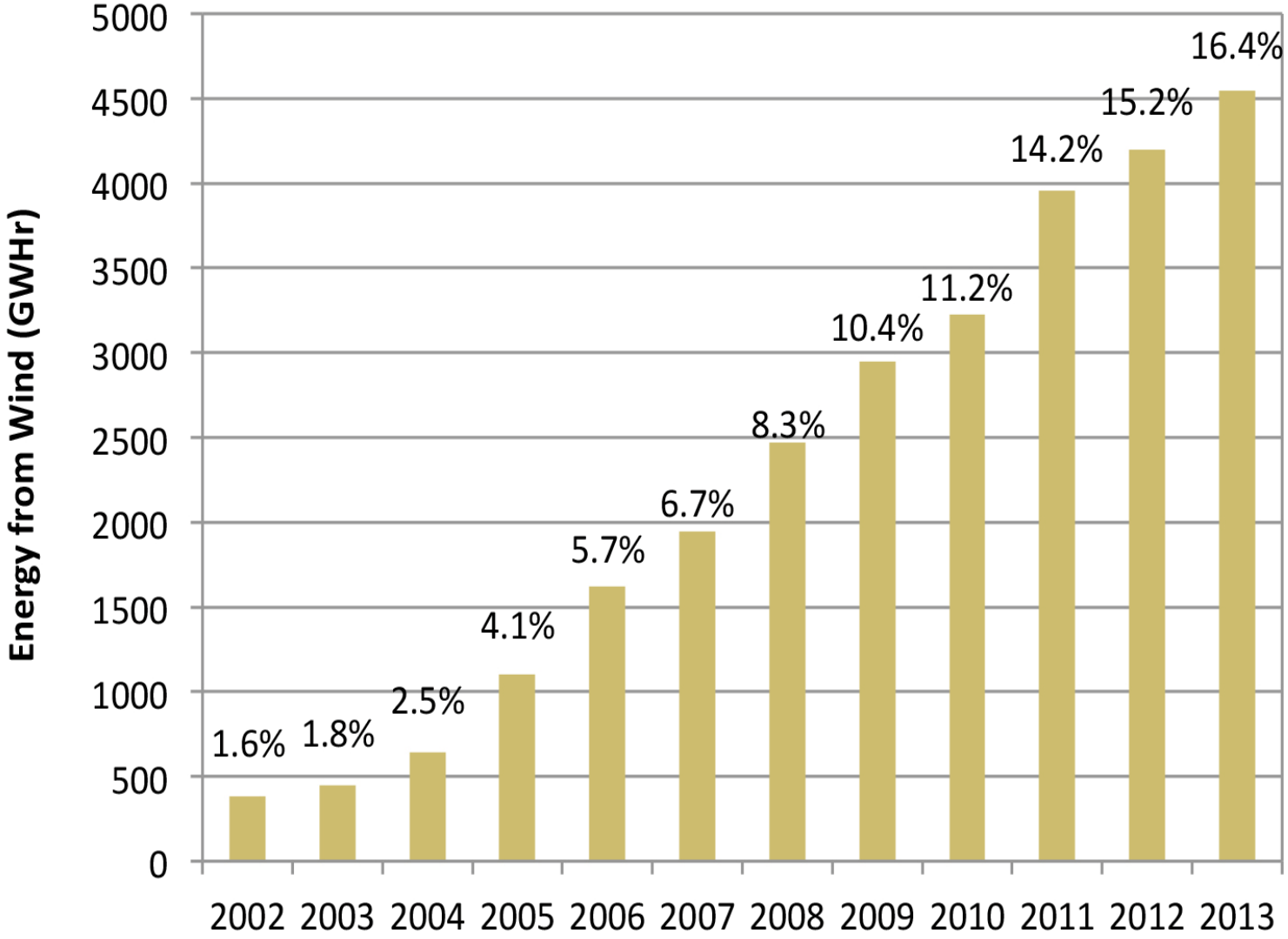
=> Spot price signals scarcity, I-SEM G & L hedged

=> No need to hedge foreigners – they can use FTRs

⇒Avoids need to harmonise CRMs across borders

⇒Avoids state aids problems (?)

Wind on the island of Ireland



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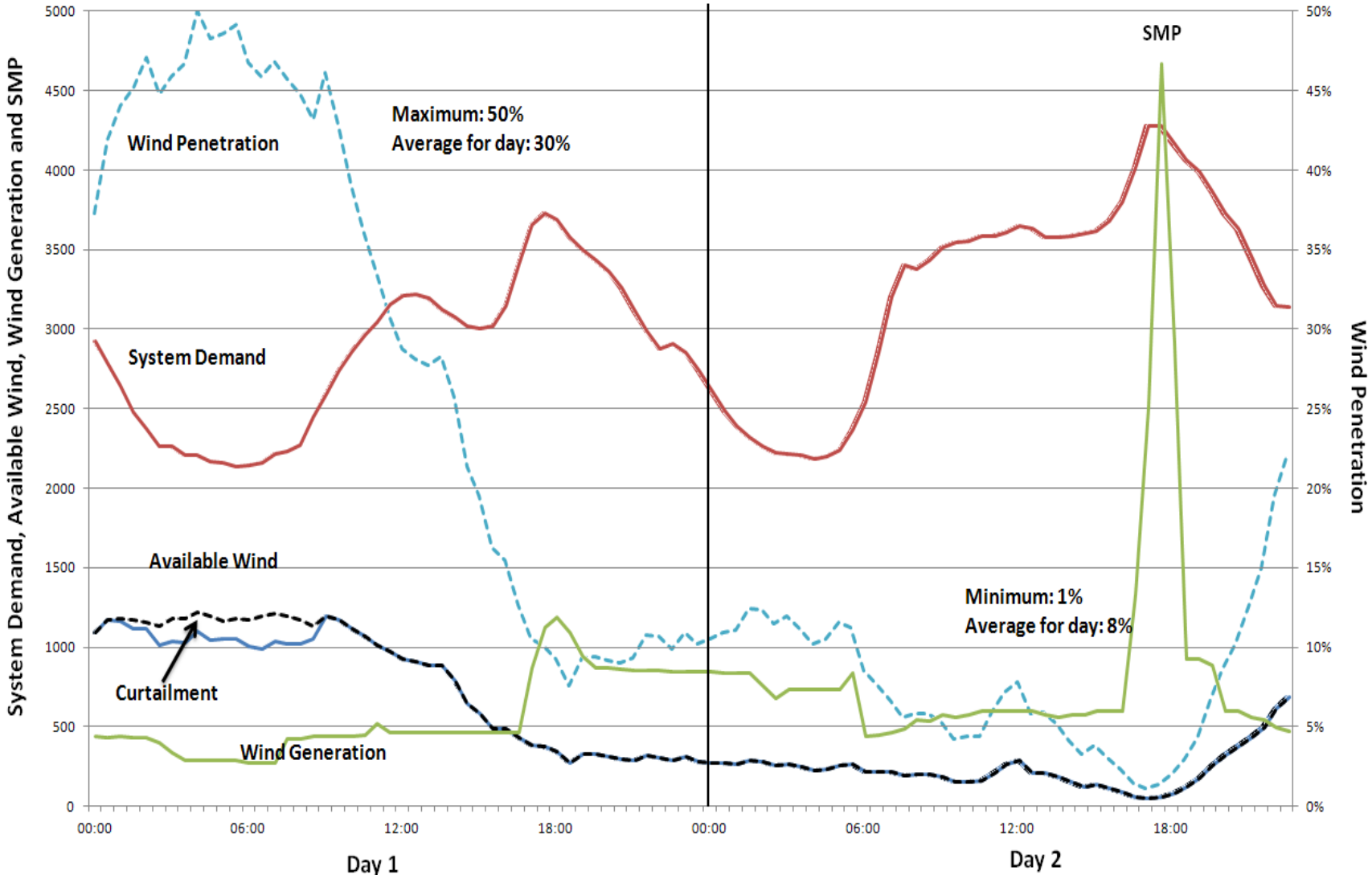
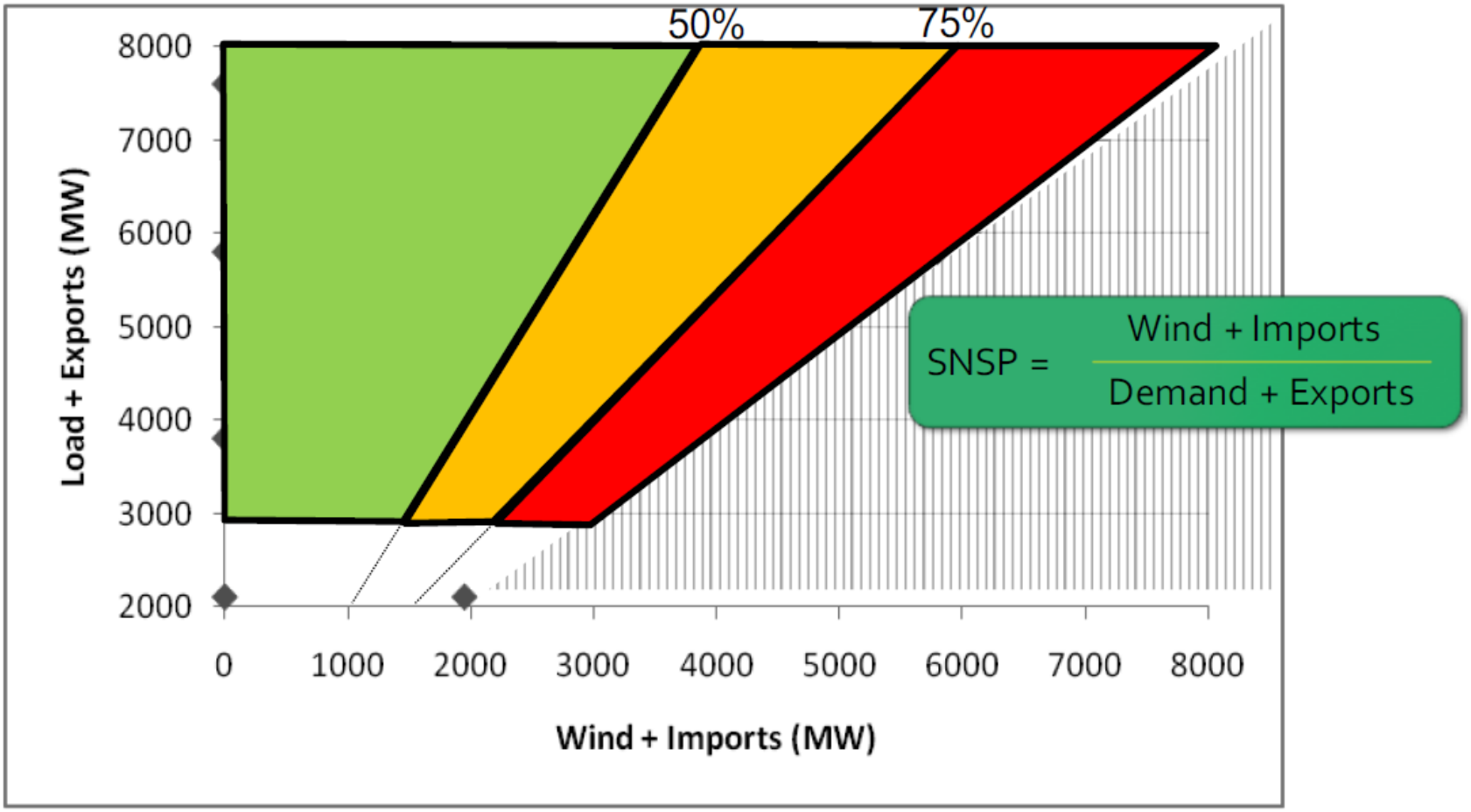
Handling high wind in SEM



Volume of SNSP is system dependent



O'Sullivan, J., Rogers, A., Flynn, D., Smith, P., Mullane, A., and O'Malley, M.J., "Studying the Maximum Instantaneous Non-Synchronous Generation in an Island System – Frequency Stability Challenges in Ireland", *IEEE Transactions on Power Systems*, Vol. 29, pp. 2943 – 2951, 2014.

I-SEM flexibility services

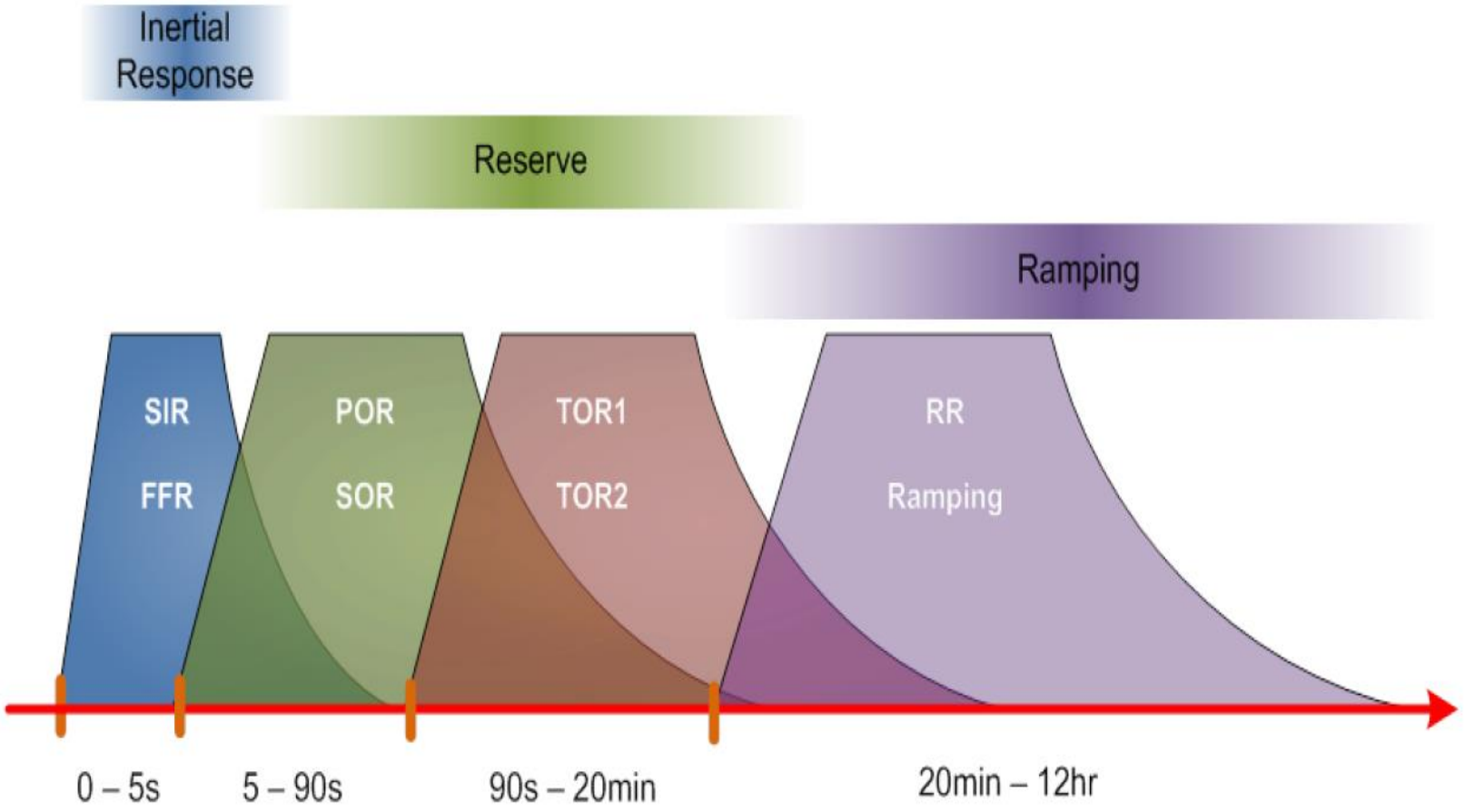


Figure 1: Frequency Control Services (Source: EirGrid)

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System services in the SEM

Table 1 Proposed new and existing System Services
Source: SEM-13-060

	New Services	Now		Existing Services	Now
SIR	Synchronous Inertial Response	65%	SRP	Steady-state reactive power	69%
FFR	Fast Frequency Response	54%	POR	Primary Operating Reserve	87%
DRR	Dynamic Reactive Response	82%	SOR	Secondary Operating Reserve	90%
RM1	Ramping Margin 1 hour	88%	TOR1	Tertiary Operating Reserve 1	91%
RM3	Ramping Margin 3 hours	88%	TOR2	Tertiary Operating Reserve 2	89%
RM8	Ramping Margin 8 hours	66%	RRD	Replacement Reserve (De-Synchronised)	83%
FPFAPR	Fast Post Fault Active Power Recovery	88%	RRS	Replacement Reserve (Synchronised)	93%

Procurement challenges

- Proposal: **auction** for capacity ROs
  - To determine missing money
- Ideally: tender auction for ancillary services (AS)
  - Provides some of the missing money
  - Hard to predict future values – depends on S vs D
  - Market power => regulated payments for some AS

=> **package auction** to determine remaining prices?

  - Capacity and ancillary services priced together?

=> can then determine optimum set of attributes for new generation and DSR

  - But **far too complicated** and prices may not be defined

Acronyms

AS	Ancillary Services
BSUoS	Balancing Services Use of System
CfD	Contract for Difference
CM	Capacity Market, CMU Capacity Market Unit
CONE	Cost of New Entry
CRM	Capacity Remuneration Mechanism
DG	Distribution-connected Generation
DSR	Demand side resources or response
EMR	Electricity Market Reform
FTR	Financial Transmission Right
G	Generation
GSP	Grid Supply Point
HVDC	High Voltage Direct Current
IC	Interconnector
I-SEM	Integrated Single Electricity Market of island of Ireland
L	Load
OCGT/recip	Open cycle gas turbine or reciprocating engine
PTE	panel of Technical Experts advising DECC on EMR
RES	Renewable energy/electricity supply
RO	Reliability Option
SMC/P	System Marginal Cost/Price
SO	System Operator
T&D	Transmission and Distribution
TG	Transmission-connected generation
TNUoS	Transmission Network Use of System, G =Generation, L=Load
VOLL	Value of Lost Load