Evaluating the Impact of Wind Generation on the Cost of Balancing Electricity Demand and Supply in the UK

DILIP K JENA, XIAOYI (SHAWN) MU

CENTRE FOR ENERGY, PETROLEUM AND MINERAL LAW AND POLICY (CEPMLP), UNIVERSITY OF DUNDEE

X.MU@DUNDEE.AC.UK, AND D.K.JENA@DUNDEE.AC.UK, JUNE 2021

Outline

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3. Methodology
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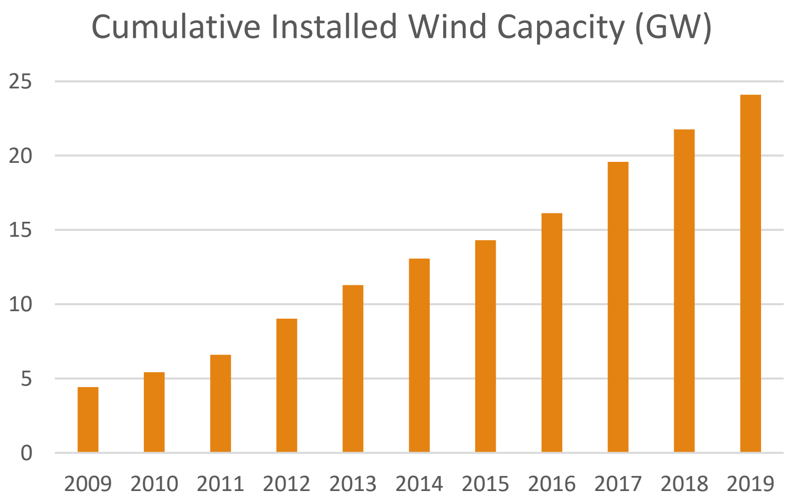
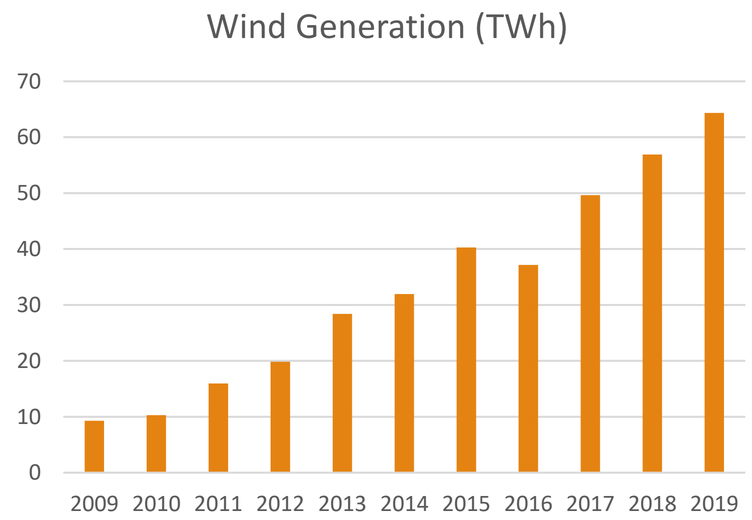
Motivation

1. Huge increase in wind power over the last decade, in terms of both the installed capacity and total generation. Renewable energy is set to play a significant role in realising the net-zero target (IEA, 2017)
2. The monthly cost of balancing have also tripled to £108 million from £35 million for the National Grid (ESO, 2020)





Key literature

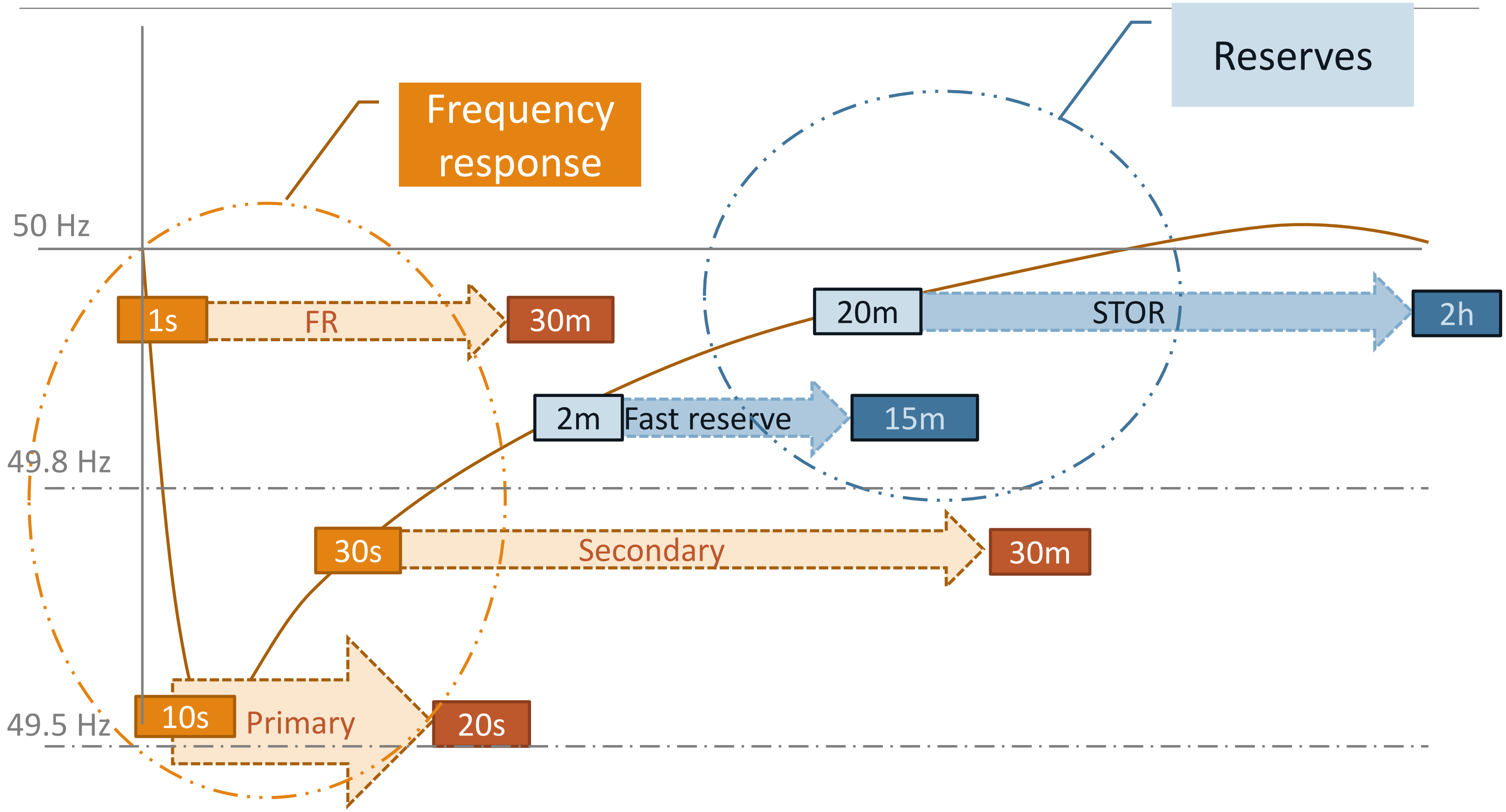
INTERMITTENCY EFFECT

1. Renewable power is deterministic but aperiodic nature (Bishop, 2017, Smith, 2007)
2. This makes the renewable power unreliable to be included in dispatch planning
3. The property is also called the intermittency effect (Oliver, 2019)
4. Bassi et al. (2012) claim an additional requirement for procuring balancing service
5. Gross et al. (2006) conclude that with penetration of 20% of renewable power in the GRID there is an incremental need for 15.2% to 22.1% of non-intermittent power

MERIT ORDER EFFECT

1. Also, Erbach (2017) asserts that the lower marginal cost of generation of renewable power
2. This property of renewable power gives it a priority for economic dispatch
3. And this effect is called the merit order effect (Oliver, 2019)
4. Per, Jacobson and Delucchi (2011), the average annualised costs of the renewable power, for all purposes viz electric power, transportation, and heating/cooling during 2020 and onwards, is comparable to conventional generations.

Deployment sequence of balancing services



Methodology

Time-series model: Econometrics

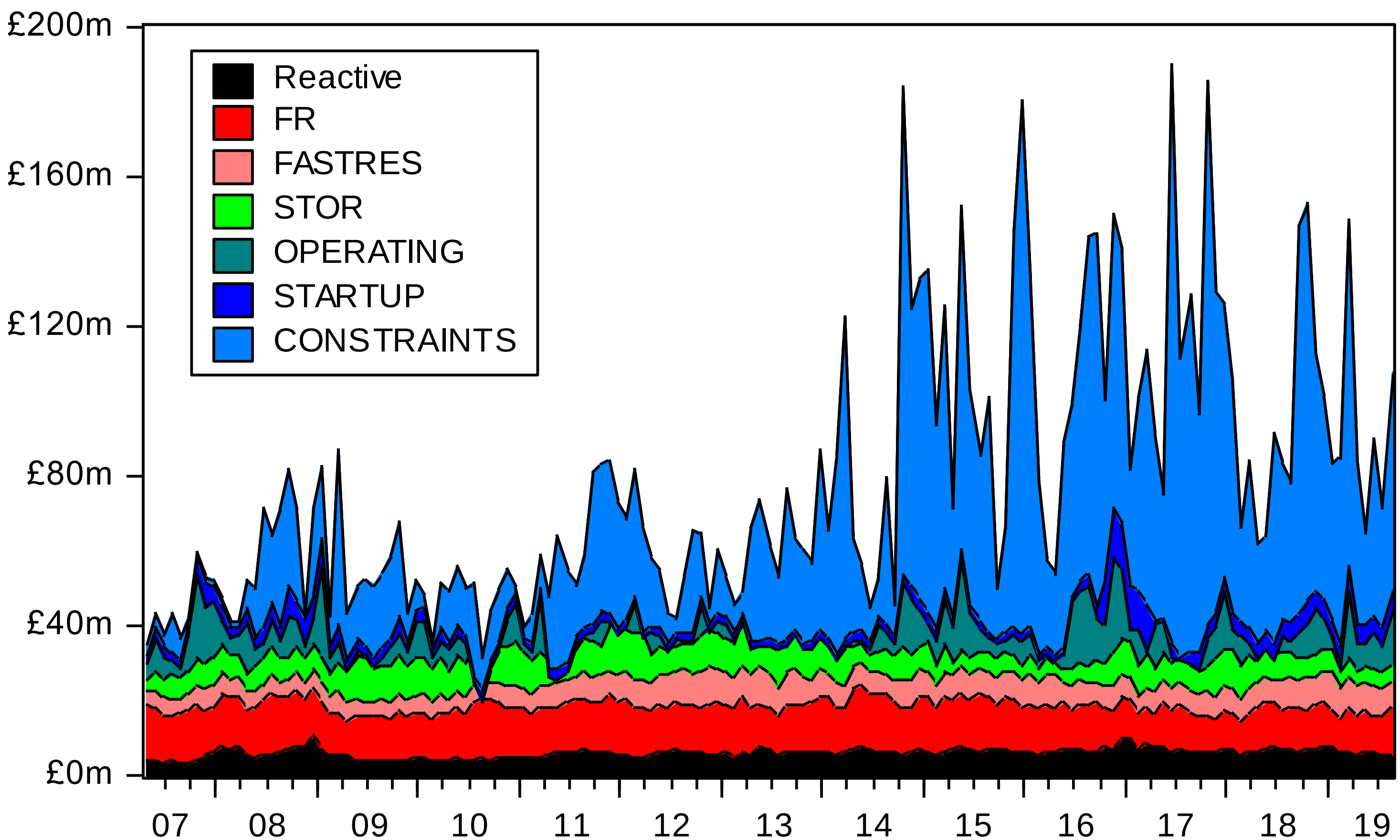
1. This is one of the first studies that uses econometrics methodology for estimating the impacts of determinants, including wind power, on the cost of procuring balancing services in the GB.

2. The impacts on voltage, frequency and reliability services are separately estimated.

3. The study covers a twelve-year period between 2007 through 2019.

Dependent variable

Sl. No.	Dependent Variable	Units	Representation
	Services for delivering voltage		
1.	Monthly average reactive services costs	£/MWh	RREAC
	Services for delivering frequency		
2	Monthly average frequency response services costs	£/MWh	RFR
	Services for delivering reliability of power supplies		
3	Monthly average fast reserve costs	£/MWh	RFAST
4	Monthly average short term operating reserve costs	£/MWh	RSTOR
5	Monthly average operating reserve costs	£/MWh	ROPERATINGRES
6	Monthly average start-up services cost	£/MWh	RSTART
7	Monthly average constraints services cost	£/MWh	RCONS



Monthly expenditure, in £ million, on different balancing services since April 2007 to August 2019

Source: National Grid ESO (monthly balancing reports)

Summary statistics: Dependent variables

Dependent variables (£ mil)	Min	Max	Std. Dev.	Mean	Obs
Reactive	3.34	10.87	1.25	6.09	149
Frequency response	8.56	16.23	1.70	12.55	149
Fast reserve	3.46	10.05	1.50	6.36	149
STOR	3.13	13.51	2.28	7.43	149
Operating	-13.85	25.30	6.54	5.17	149
Start-up	0.51	12.67	2.24	3.37	149
Constraints	0.41	154.55	32.42	36.54	149

Regressors

Data Sources:

1. BEIS
2. EIA
3. ICE
4. ONS

Sl. No	Regressors	Units
1	Biogenic electric power supplied (Bio)	TWh
2	Europe Brent Spot Prices FOB (Brent)	$/barrel
3	Coal-fired electric power supplied (Coal)	TWh
4	Gas-fired electric power supplied (Gas)	TWh
5	Heating Degree Days (HDD)	Average number of HDD
6	Hydro-electric power supplied (Hydro)	TWh
7	NBP Prices (NBP)	Index
8	Net_imports of electric power supplied (Net_Imports)	TWh
9	Net_otherpurchase of electric power supplied (Otherpurchase_Net_) (transferred from auto-generators)	TWh
10	Nuclear based electric power supplied (Nuclear)	TWh
11	Oil-fired electric power (Oil)	TWh
12	Other electric power (non-renewable waste) (Other)	TWh
13	Pumped Hydro Storage electric power (Pump)	TWh
14	Wind based electric power supplied (Wind)	TWh
15	Solar electric power supplied (Solar)	TWh

Summary statistics: regressors

Variables	Min	Max	Std. Dev.	Mean	Obs
BIO (TWh)	0.13	1.85	0.54	0.78	149
COAL (TWh)	0.04	15.47	4.16	6.64	149
GAS (TWh)	5.03	15.72	2.58	10.04	149
HYDRO (TWh)	0.08	0.78	0.15	0.33	149
NET_IMPORTS (TWh)	-0.73	2.57	0.71	1.08	149
NUCLEAR (TWh)	3.05	6.29	0.69	4.99	149
OIL (TWh)	0.02	0.64	0.12	0.11	149
OTHERGEN (TWh)	0.00	0.11	0.04	0.04	149
PUMPS (TWh)	-0.12	-0.03	0.02	-0.09	149
SOLAR (TWh)	0.00	0.55	0.15	0.09	149
WIND (TWh)	0.16	5.87	1.45	1.94	149
OTHERPURCHASE_ NET_ (TWh)	0.93	2.14	0.30	1.44	149
BRENT ($/bbl)	33.28	165.98	31.60	90.73	149
NBP (Index)	23.77	97.63	16.20	54.86	149
HDD (Avg Days)	0.00	15.77	4.13	5.49	149

Why ECM or ARDL?

1. Stationarity of variables: ADF, I(0) and I(1)

2. Dependent and independent variables are integrated of different order, therefore Bounds test is carried out to check for long run cointegration (Pesaran et. al, 2001)

3. In case of long run, cointegration – Error Correction Model (ECM) is estimated, else ARDL is estimated.

4. Generalised ARDL (p,q) model specification

$$Y_t = \alpha_i + \sum_{i=1}^{p} \beta_i Y_{t-i} + \sum_{i=0}^{q} \gamma_i X_{t-i} + \varepsilon_{it}$$

$$\text{Where, } Y_t \; is\; dependent\; variable,$$
$$X_t \; represent\; indpendent\; variables\; with\; I(0)\; or\; I\;(I),$$
$$and\; \varepsilon_{it}\; are\; error\; terms, \alpha\; is\; constant,$$
$$\beta\; \&\; \gamma\; are\; coefficients, i = 1,2 \ldots k;$$
$$p, q, where\; p\; and\; q\; are\; optimal\; lags\; \varepsilon_{it}\; is\; error\; term$$

5. The optimal lag length of a model is determined using the lag length criteria.

Total system balancing cost

ECM: D(RTOTAL)	
D(BIO)	-0.766(0.066)
D(COAL(-1))	-0.158(0.003)
D(GAS)	-0.083(0.154)
D(GAS(-1))	-0.210(0.001)
D(HDD)	-0.050(0.163)
D(HYDRO)	0.781(0.243)
D(HYDRO(-1))	-1.037(0.094)
D(NET_IMPORTS)	-0.417(0.003)
D(NET_IMPORTS(-1))	-0.196(0.183)
D(OTHERGEN(-1))	10.636(0.143)
D(OTHERPURCHASE_NET_)	-0.997(0.040)
D(PUMPS(-1))	-14.944(0.029)
D(SOLAR(-1))	3.808(0.020)
D(WIND)	1.144(0.000)
RTOTAL_ECM(-1)	-0.495(0.000)

COINTEGRATING MODEL: RTOTAL	
C	2.501(0.007)
BRENT	-0.009(0.003)
GAS	-0.085(0.024)
HDD	-0.175(0.000)
HYDRO	1.852(0.006)
NET_IMPORTS	-0.388(0.013)
PUMPS	-16.980(0.011)
SOLAR	1.731(0.029)
WIND	0.634(0.000)

Tests	Remarks on critical values	Remarks
Ljung-Box Q-statistics	P-values below 0.05, autocorrelation	For all 6 lags, p-values > 0.05, No autocorrelation
Serial correlation LM Test	P-values below 0.05, autocorrelation	0.1681, No autocorrelation
Jarque-Bera statistic	P-values below 0.05, no normal distribution	0.0000, Not a normal distribution of residuals
Ljung-Box Q-statistics for squared residuals	P-values below 0.05, ARCH	For all 6 lags, p-values > 0.05, No ARCH effect
Breusch-Pagan-Godfrey LM test	P-values, below 0.05, heteroskedasticity	0.1255, No heteroskedasticity
CUSUM Test	Robust within the critical lines	Within the lines, Robust
CUSUM of square test	Robust within the critical lines	Within the lines, Robust

RTOTAL ECM: Residual diagnosis

Constraints services

ECM: D(RCONS)	
D(COAL(-1))	-0.063(0.071)
D(GAS(-1))	-0.157(0.001)
D(HDD)	-0.090(0.000)
D(HYDRO)	1.274(0.031)
D(NET_IMPORTS)	-0.278(0.004)
D(OTHERGEN(-1))	13.145(0.073)
D(OTHERPURCHASE_NET_)	-1.043(0.021)
D(PUMPS(-1))	-15.888(0.070)
D(SOLAR(-1))	2.977(0.016)
D(WIND)	0.989(0.000)
ECT(-1)	-0.584(0.000)

COINTEGRATING MODEL: RCONS	
BRENT	-0.046(0.009)
HDD	-0.132(0.000)
HYDRO	1.895(0.002)
WIND	0.760(0.000)
WIND*WIND	-0.056(0.071)
C	2.717(0.003)

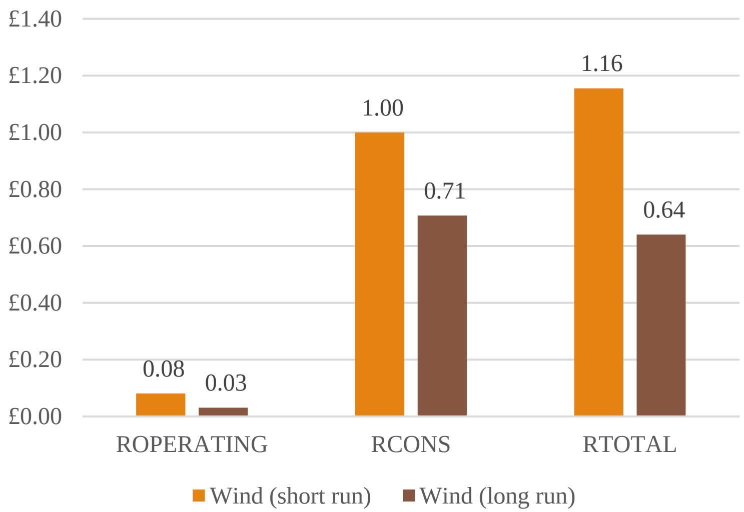
Tests	Remarks on critical values	Remarks
Ljung-Box Q-statistics	P-values below 0.05, autocorrelation	For all 6 lags, p-values > 0.05, No autocorrelation
Serial correlation LM Test	P-values below 0.05, autocorrelation	0.7198, No autocorrelation
Jarque-Bera statistic	P-values below 0.05, no normal distribution	0.0000, Not a normal distribution of residuals
Ljung-Box Q-statistics for squared residuals	P-values below 0.05, ARCH	For all 6 lags, p-values > 0.05, No ARCH effect
Breusch-Pagan-Godfrey LM test	P-values, below 0.05, heteroskedasticity	0.3698, No heteroskedasticity
CUSUM Test	Robust within the critical lines	Within the lines, Robust
CUSUM of square test	Robust within the critical lines	Within the lines, Robust

RCONS ECM: Residual diagnosis

Summary of results
(Impact of one stdev shock over the last 12 months)

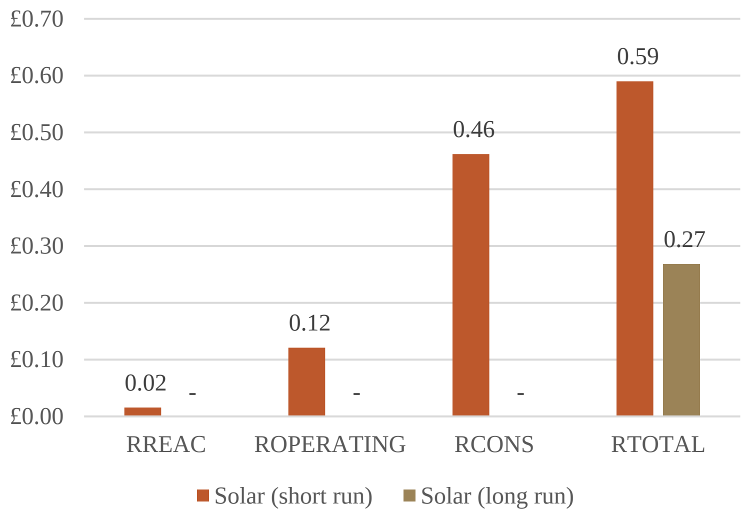
WIND

Rise in monthly average prices of electricity supplied to consumers (in £/MWh) for one unit shock in supplies of Wind Power (one standard deviation) due to the expenditure on various Balancing Services



SOLAR

Rise in monthly average prices of electricity supplied to consumers (in £/MWh) for one unit shock in supplies of Solar Power (one standard deviation) due to the expenditure on various Balancing Services



Conclusion

1. The impact of wind generation on the cost of balancing demand and supply has been assessed using ECM
2. A one stdev (1TWh/month) in the wind generation increases the average monthly price of electricity by £1.16/MWh in the short-run and £0.64/MWh in the long-run respectively, mainly due to additional expenditure towards the constraints services.
3. A one stdev increase in wind and solar together increases the total balancing cost by £1.62/MWh for the short-run and £0.91/MWh in the long-run.

Thank you!

Balancing services in GB: 1

Balancing services

Frequency response services

- Firm Frequency Response: Dynamic and non-dynamic (commercial): availability, window initiation, nomination, revision, response
  - Primary; Full response: 10S; Sustain: 20s, Min: 1MW
    - Monthly electronic tender
  - Secondary; Full response: 30s; Sustain: 30 min; Min: 1 MW
    - Monthly electronic tender
  - High; Full response: 10s; sustain: indefinitely; Min: 1 MW
    - Monthly electronic tender
- Mandatory Frequency Response: holding and response
  - Primary, Secondary, High, >10 MW
    - Monthly electronic submission
- Phase 2 Auction trial: LFS, DLW (EPEX SPOT): Monthly availability
  - Full response: 1s; Sustain: 30 mins, Min 1 MW
    - Weekly Auction
    - Monthly Availability Payment (£/MW)

Reactive power service

- Obligatory reactive power service: Utlisation (£/MVarh)
  - Rated power at 0.85 lag or 0.95 lead
    - Mandatory Service Agreement
    - Paid monthly
- Enhanced reactive power service (commercial services): Availability (£/Mvar/h) and Utlisation (£/MVarh)
  - Reach targeted Mvar in 2m
    - Tendered every six monthly for atleast 6 months
    - Paid Monthly

Balancing services in GB: 2

Balancing services

Reserve services

BM Startup and hot standby: Starup (£/h) and stanby payments (£/h)	Demand Turnup: Fixed and optional	Fast reserve: Availability, nomination and utilisation payments	STOR: Committed (availability and utilisation) and Flexible services (optional utilisation payment outside the availability windows)	Super SEL (footroom service)	Replacement reserve (Trans European Replacement Reserve TERRE)
Ready for synchronisation at 89 min	Min 1MW but can be fraction of 0.1 above it, average notice: 6 hours	Delivery rate: 25 MW/Min; Sustain for 15 min; Active power delivery with 2 mins	Min 3 MW, respond 20min to 4 hours of instruction, Sustain 2 hours	10 MW reduction, 12 hours notice	1 MW, response time: less than 30 mins; sustain: 15 mins; Primary or Secondary BMU
Bespoke agreement Price change once a week	Twice a week for windows: Friday-Monday & Tuesday to Thursday	Sign Framework Agreement Monthly competitive tendering process	STOR Framework Agreement: one season to two financial years Three tenders for 6 seasons	Bespoke agreement through expression of interest Monthly payments of arrears (£/MW/h)	Through NG BM: uptill gate closure

Balancing services in GB:3

Balancing services

System security services

- **Intertrips: disconnects the generators within 100 millisecond**
  - Service through bilateral contract while setting up connection agreement or through commercial arrangements on ad hoc basis
  - Available all times during contracting
- **SO to SO service: direction of electricity flow**
  - Offered by the interconnectors
  - Used only once or twice in a month based on agreement between the Sos and the interconnector
- **Black Start: to recover the system from total or partial shut down**
  - Procured thought the year
- **Transmission constraint management: manage congestion**
  - Purchase on ad-hoc or tender (in case of competition) or through bilateral contracts
  - Paid on monthly basis through standard settlement for balancing services
- **Maximum generation: Additional short term generation**
  - Outside of generator's operating range
  - No additional contracting