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Demand Forecasting

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National Grid

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National Grid Overview

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National Grid Overview

50:50

US

UK

Transmission

Distribution

Electricity

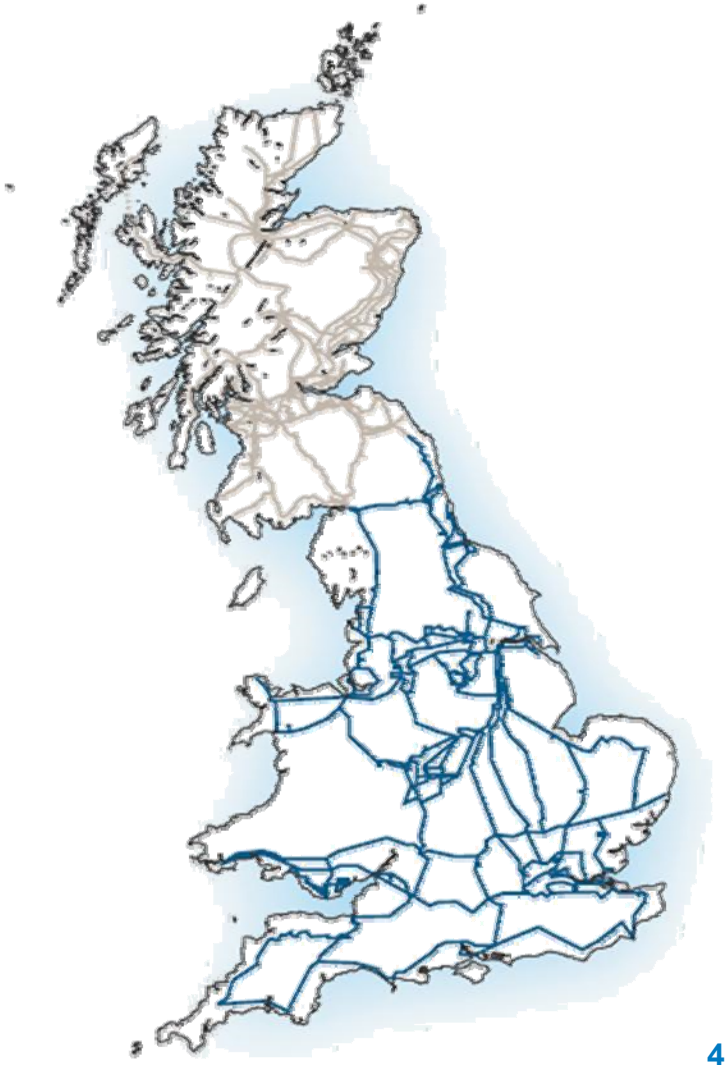
Gas

Facts:

- Total employees - 24,000
- Largest UK utility
- 2nd largest US energy utility
- FTSE 25 company

Transmission

- 7,200 km overhead line
- 1500 km underground cable
- 336 substations



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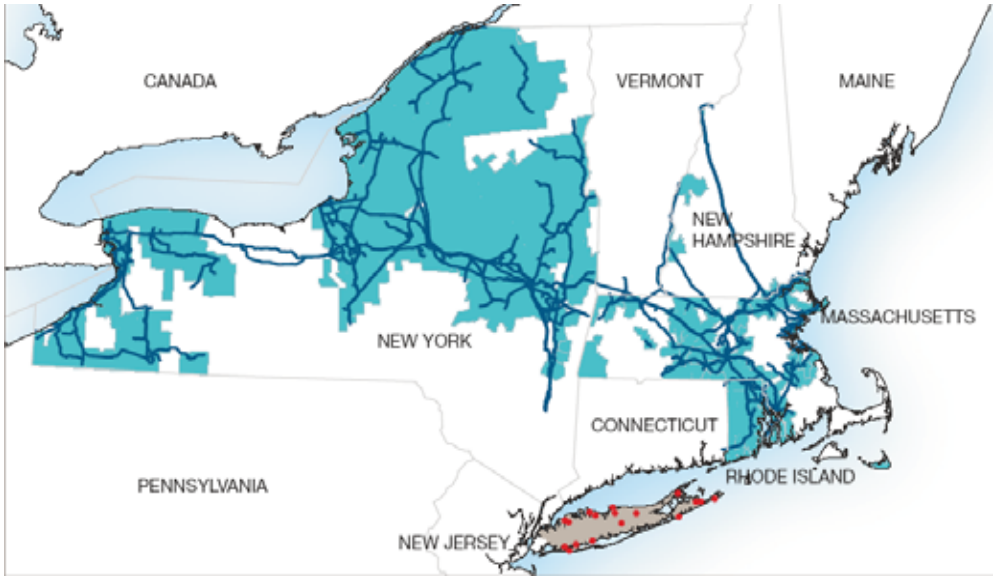
National Grid – US – Electricity

Transmission

- 14,355 km line
- 169 km cable
- 520 substations



Distribution and Generation

- 116,636 km circuit
- 644 substations
- 3.5 million customers
- 50 generation plants

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Electricity National Control Centre

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Electricity Operations - who is responsible for what?

GBSO

- Balances the GB System
- Configures the GB Transmission System
- Operational planning
- Connection and Use of System Agreements with Generators, Suppliers and Distribution companies
- GB charging and billing

GBSO

OFFTO's

TO

TO

TO/SO

Transmission Owner (TO)

- Owns, builds and maintains assets

System Operator (SO)

- Operates the system
- Provides customer interface

TO/SO Code to define interfaces such as outage planning and investment decisions

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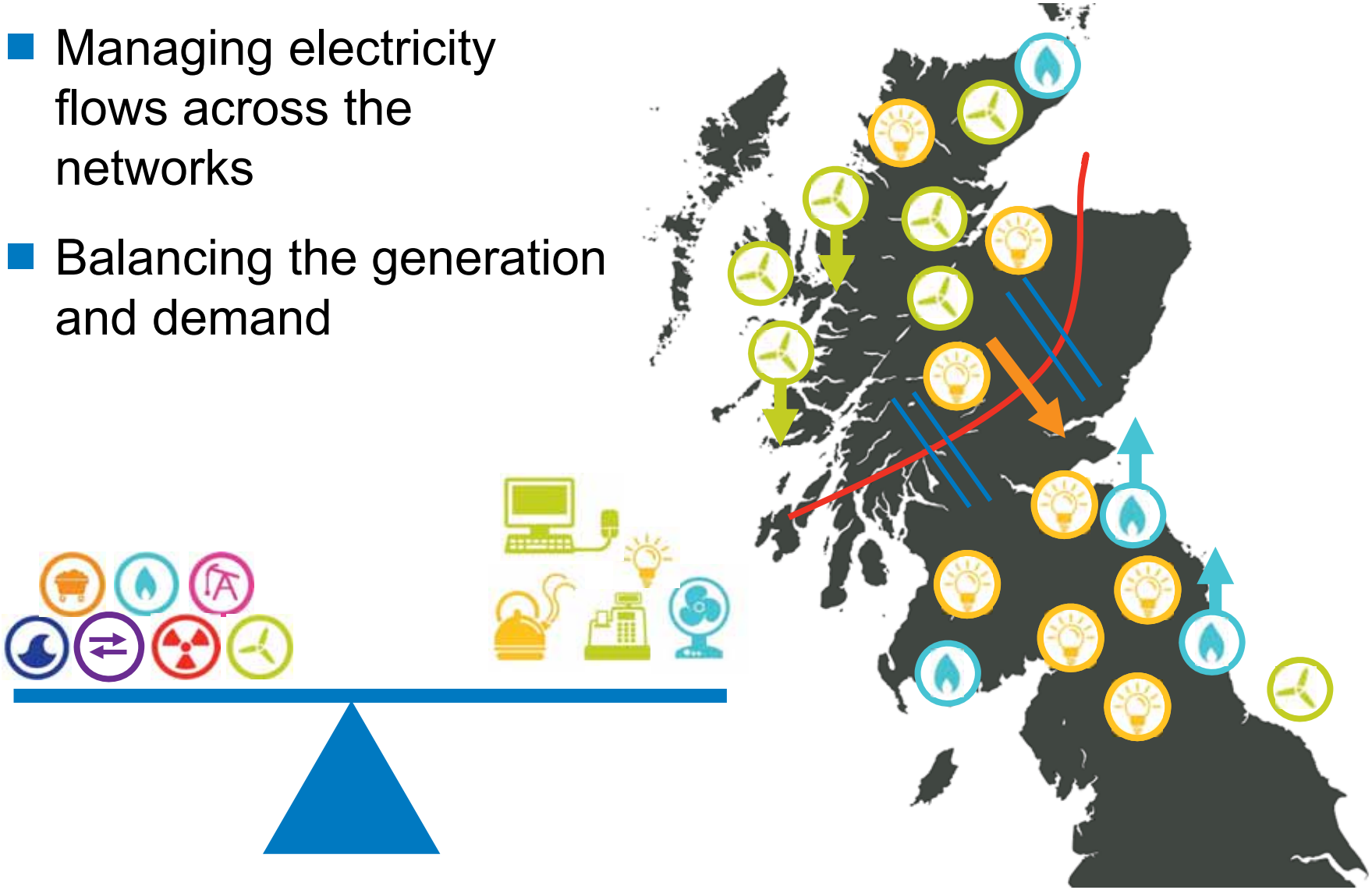
System Operator – Two key roles

- Managing electricity flows across the networks
- Balancing the generation and demand



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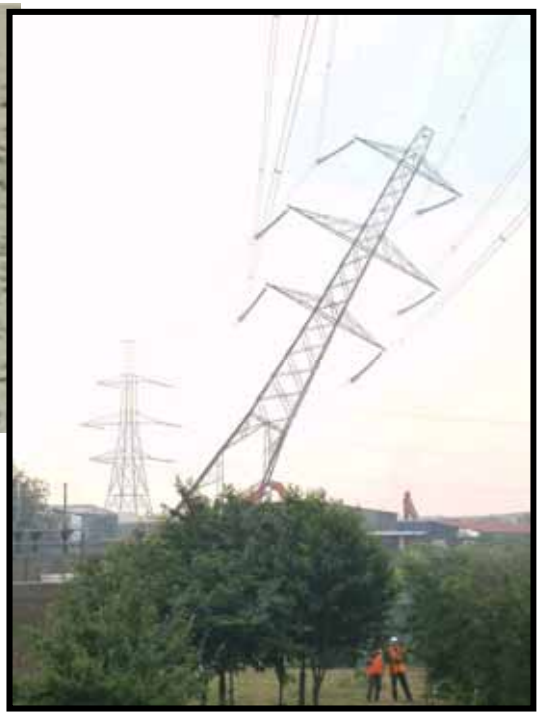
Managing uncertainties



- Demand
- Generation forced outages / trips
- Transmission circuit faults
- Market participants positions
- Weather events

Whilst ensuring

- Security
- Equipment ratings
- Voltage and frequency tolerance
- Cost minimisation

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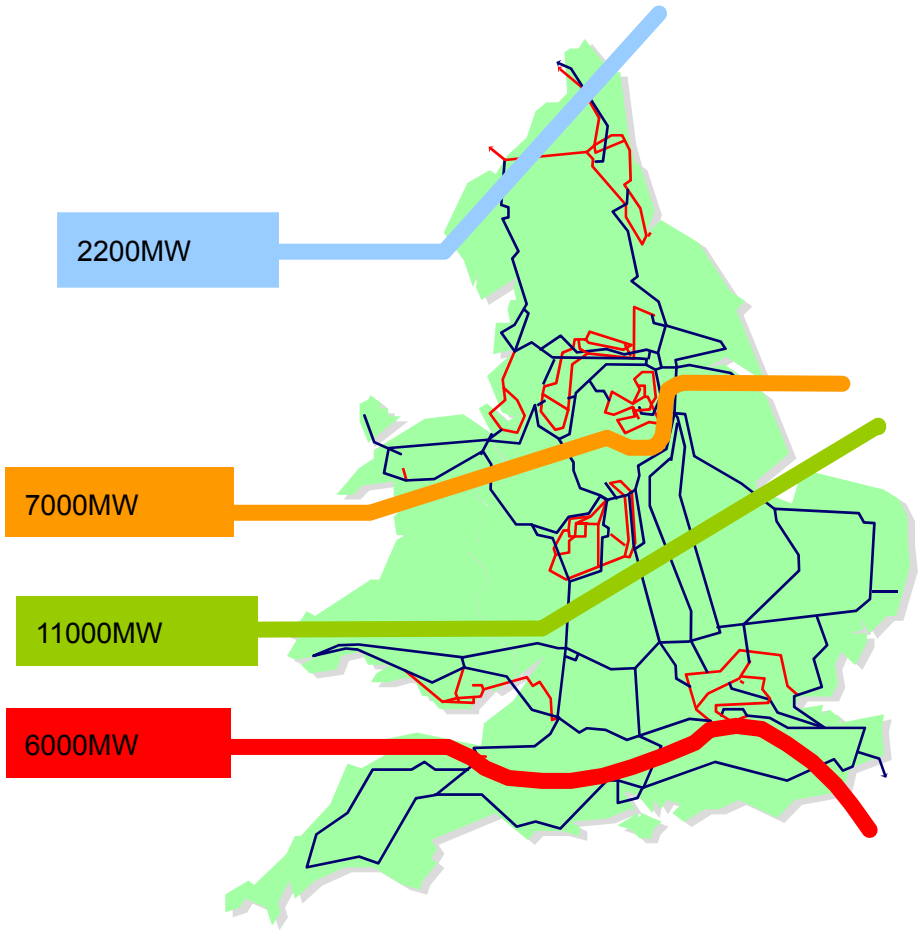
Outage Planning and Co-ordination



- System not geographically balanced for generation and demand.
- Bottle-necks arise that requires power flow to be “constrained”.
- Solutions include demand transfers, intertripping, re-switching, QB tapping etc.

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Energy Forecasting

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Energy Forecasting

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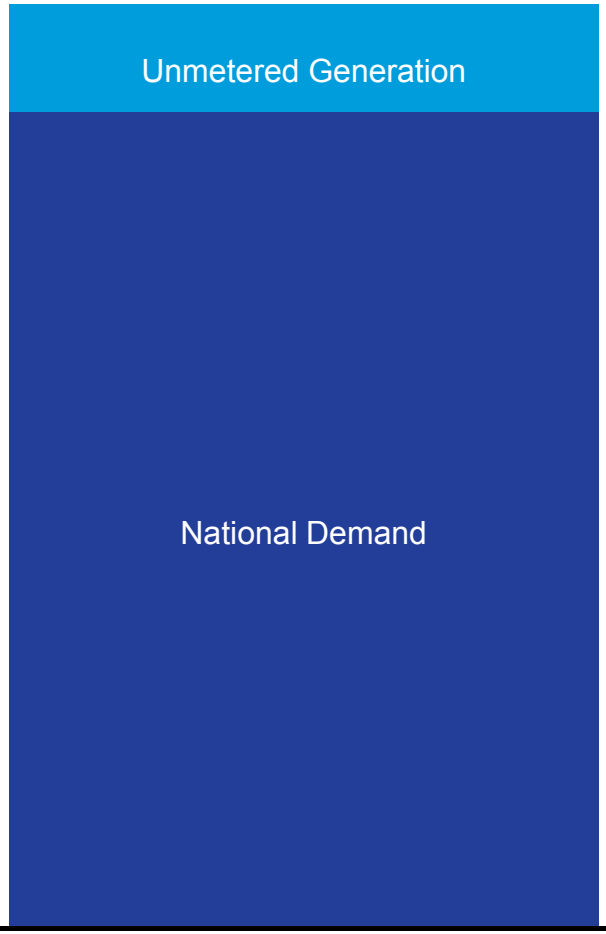
What is Demand



- National Demand = $\Sigma\, GB\ generation + net\ IC\ import - station\ load - pump\ storage\ pumping$
- National Demand only includes metered generation.
- The true GB Demand is higher but is suppressed by unmetered generation which is invisible to National Grid
- An increase in more volatile technologies means it is significant effect

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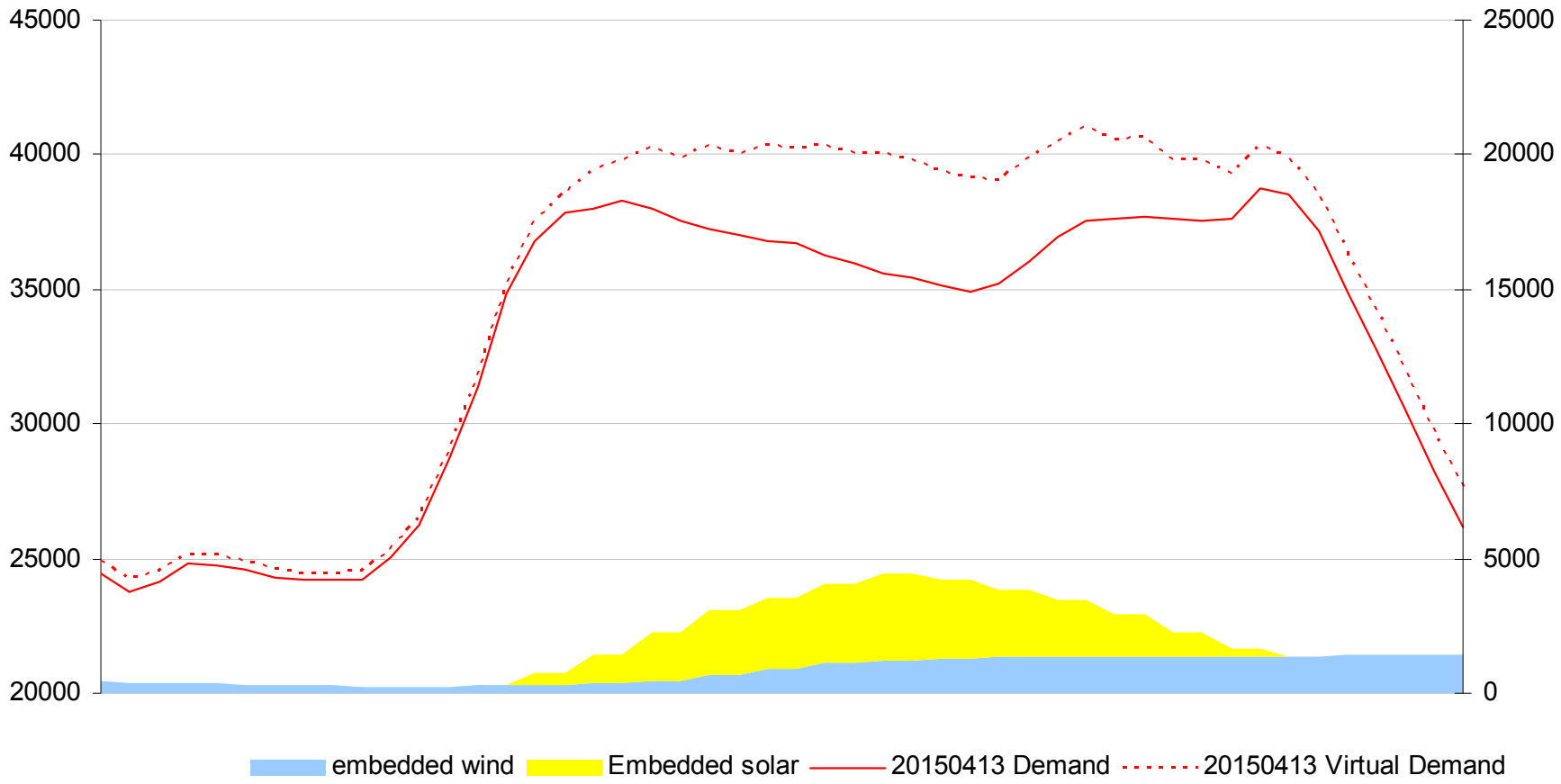
National Demand suppressed by unmetered generation



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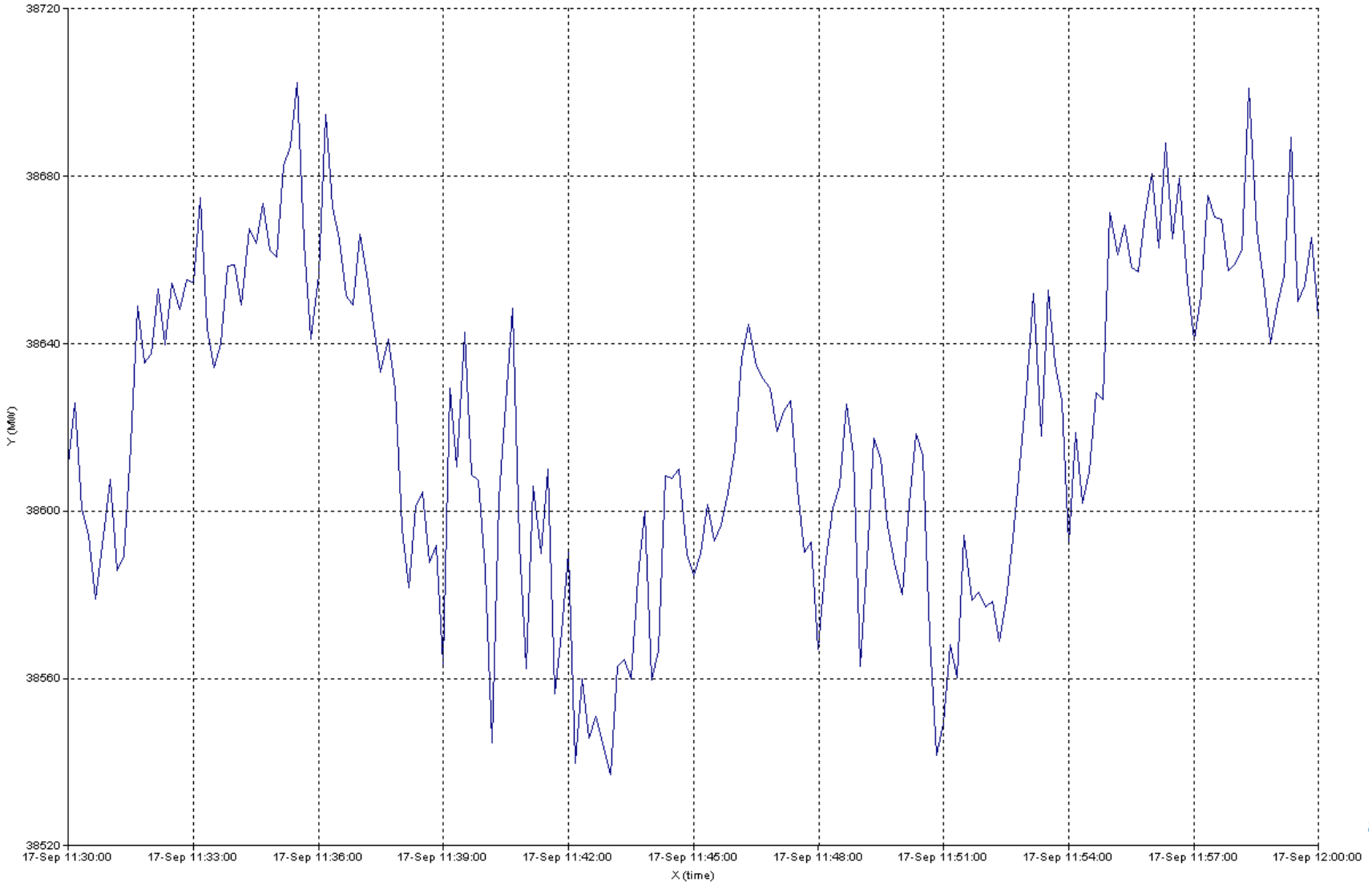
National Demand: min by min fluctuations



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What Affects National Demand?

- Time of Year
- Time of Day
- Day of Week
- Weather
- Unmetered Generation
- Bank Holidays
- School Holidays
- TV
- Special Events
- Reaction to power price
- Connection charge minimisation

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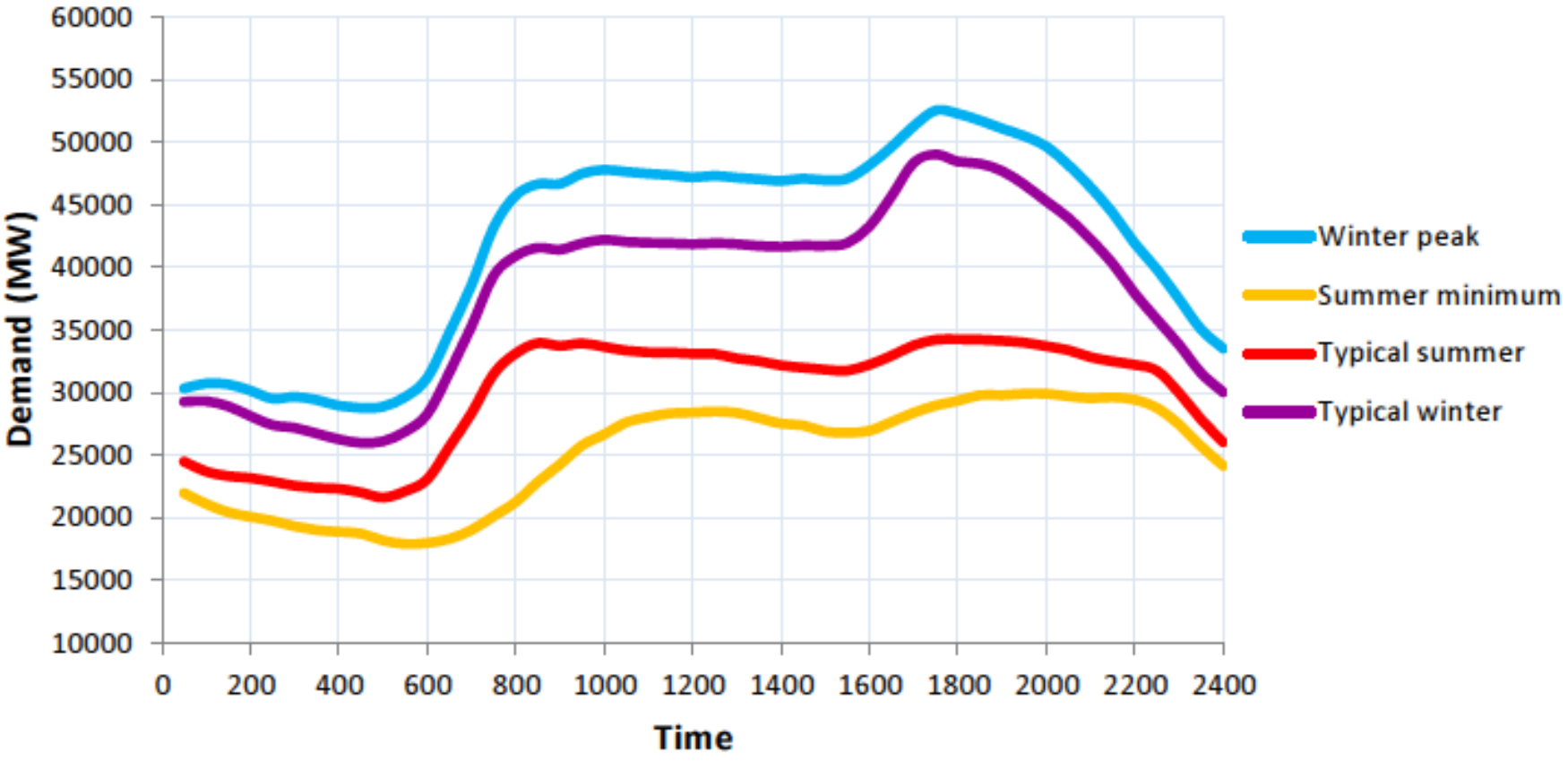
National Demand: time of year effect



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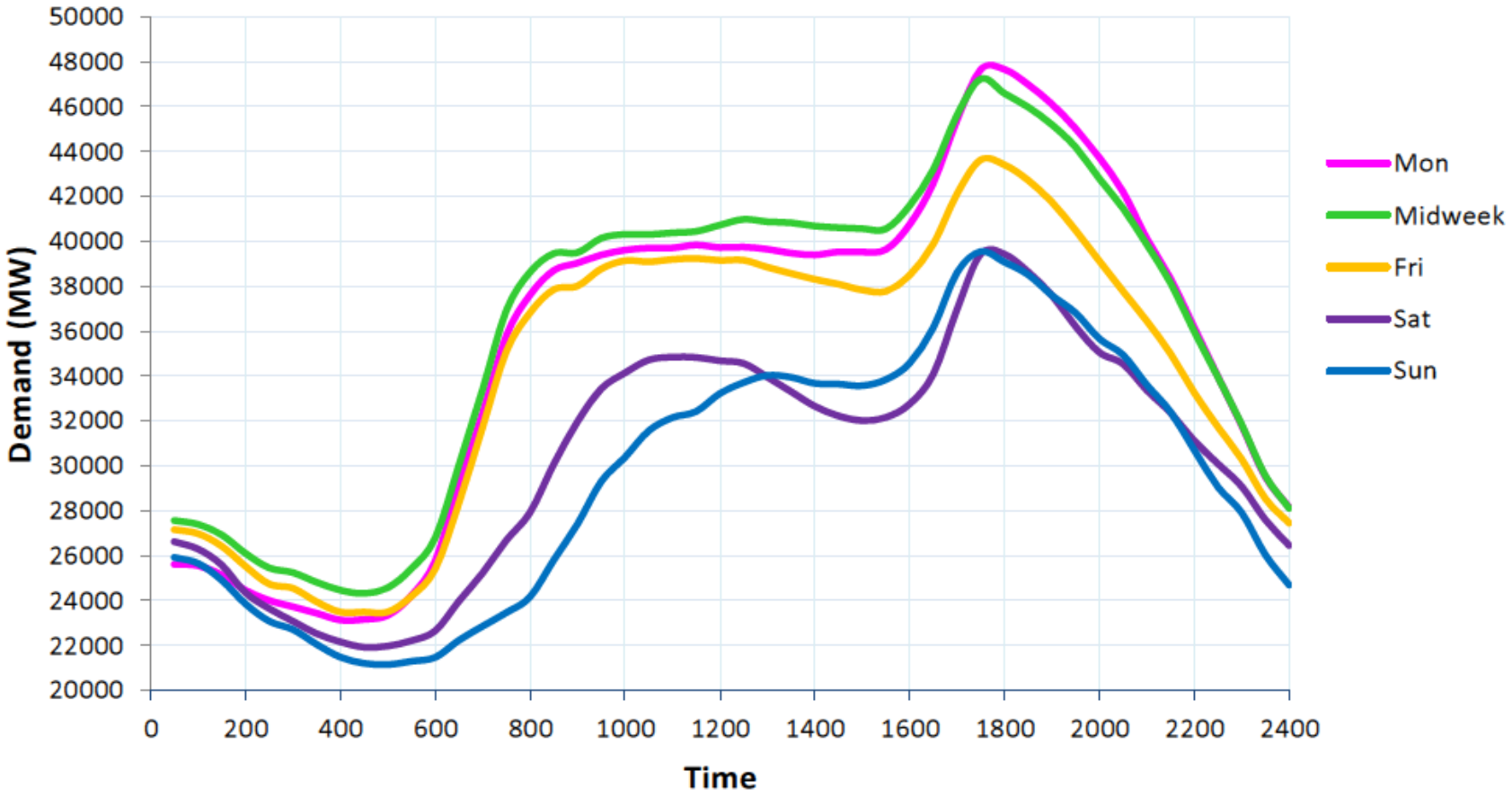
National Demand: variability during a week (GMT)



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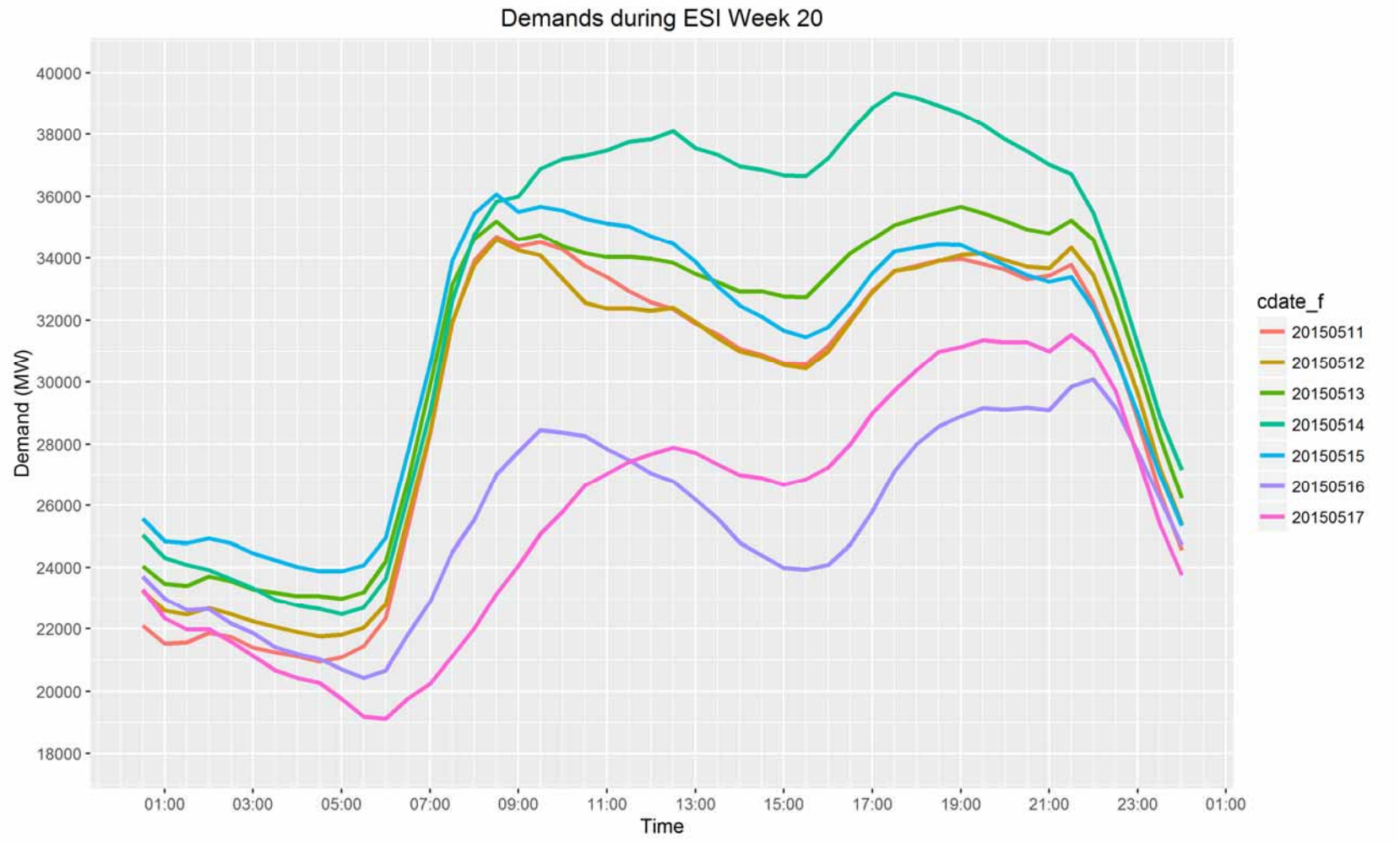
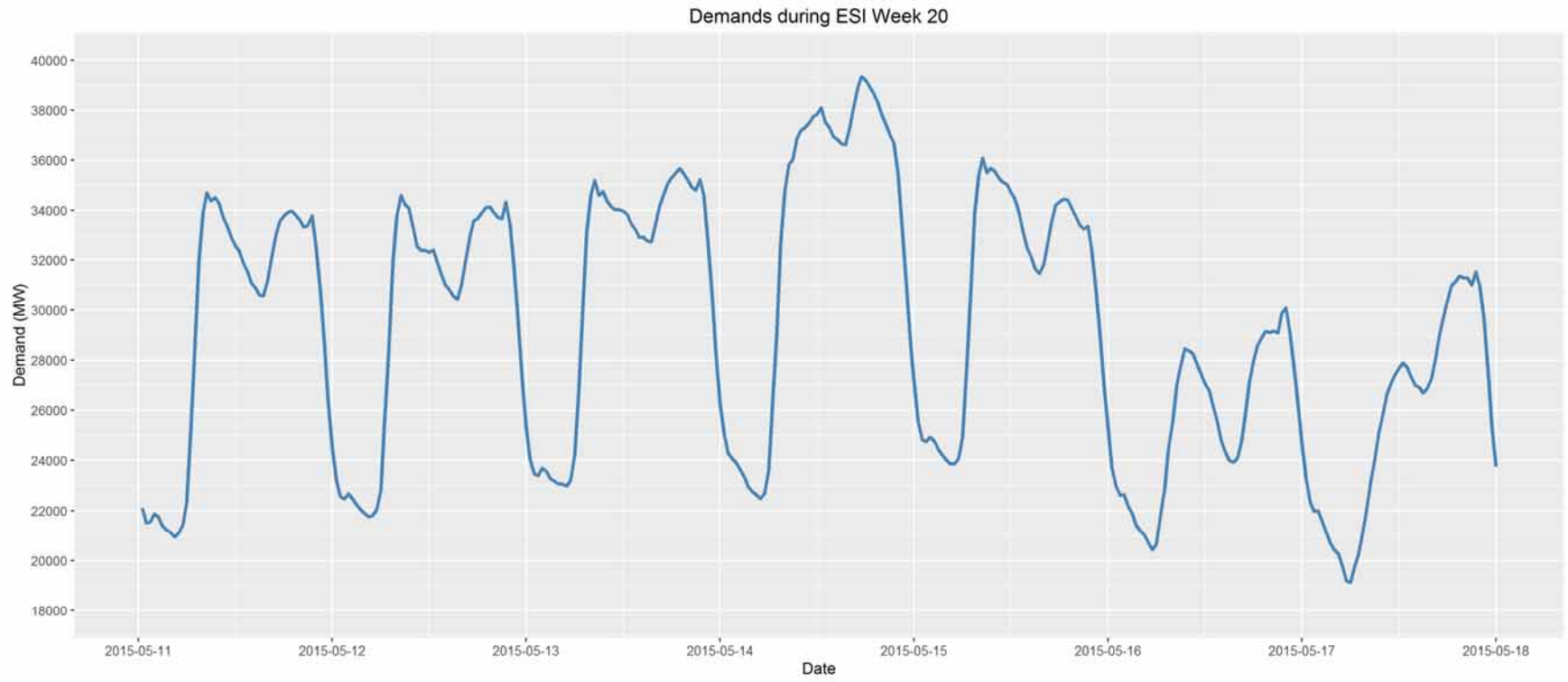
National Demand: variability during a week (BST)



National Demand: variability during a week (BST)



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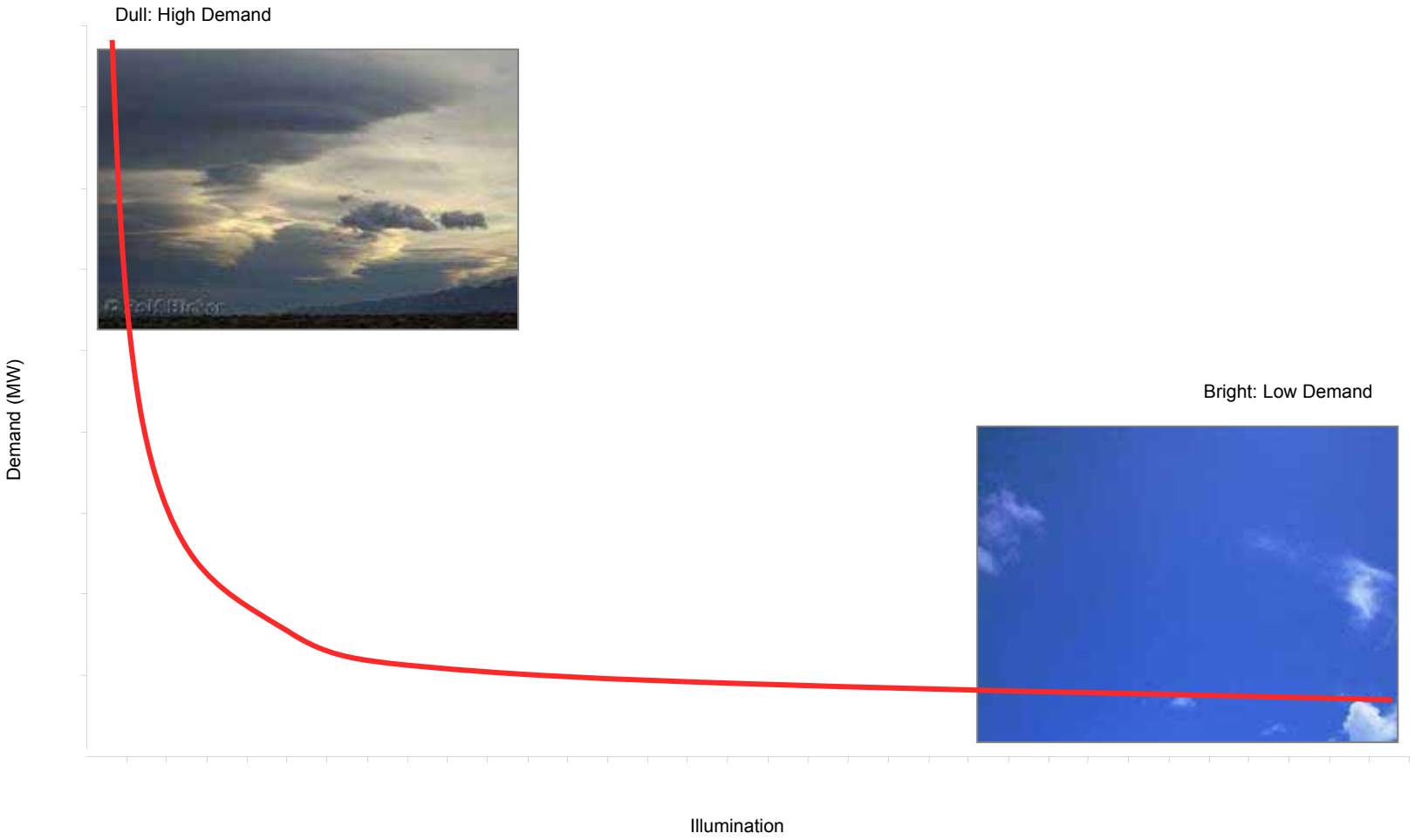
The Impact of Weather: Illumination



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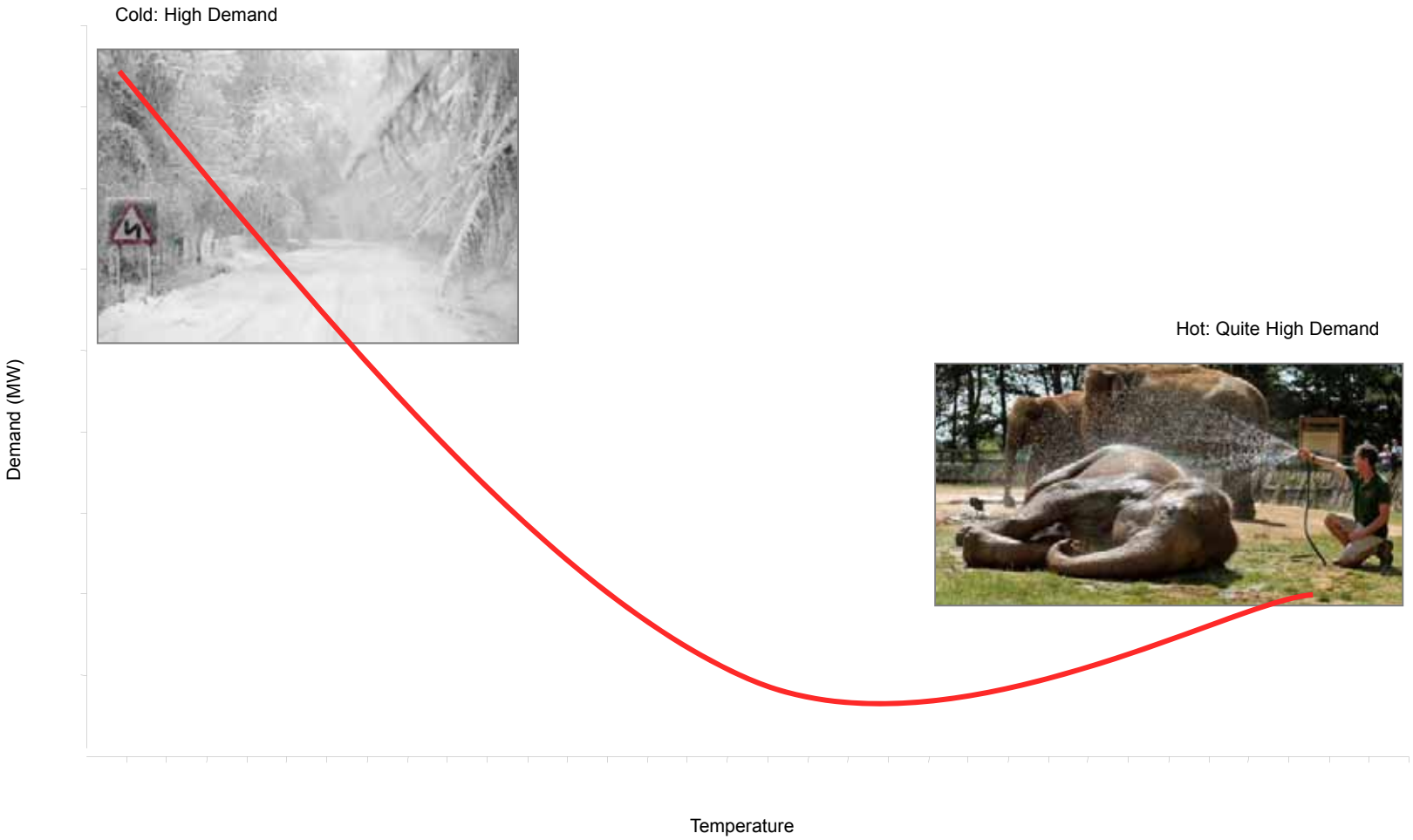
The Impact of Weather: Temperature



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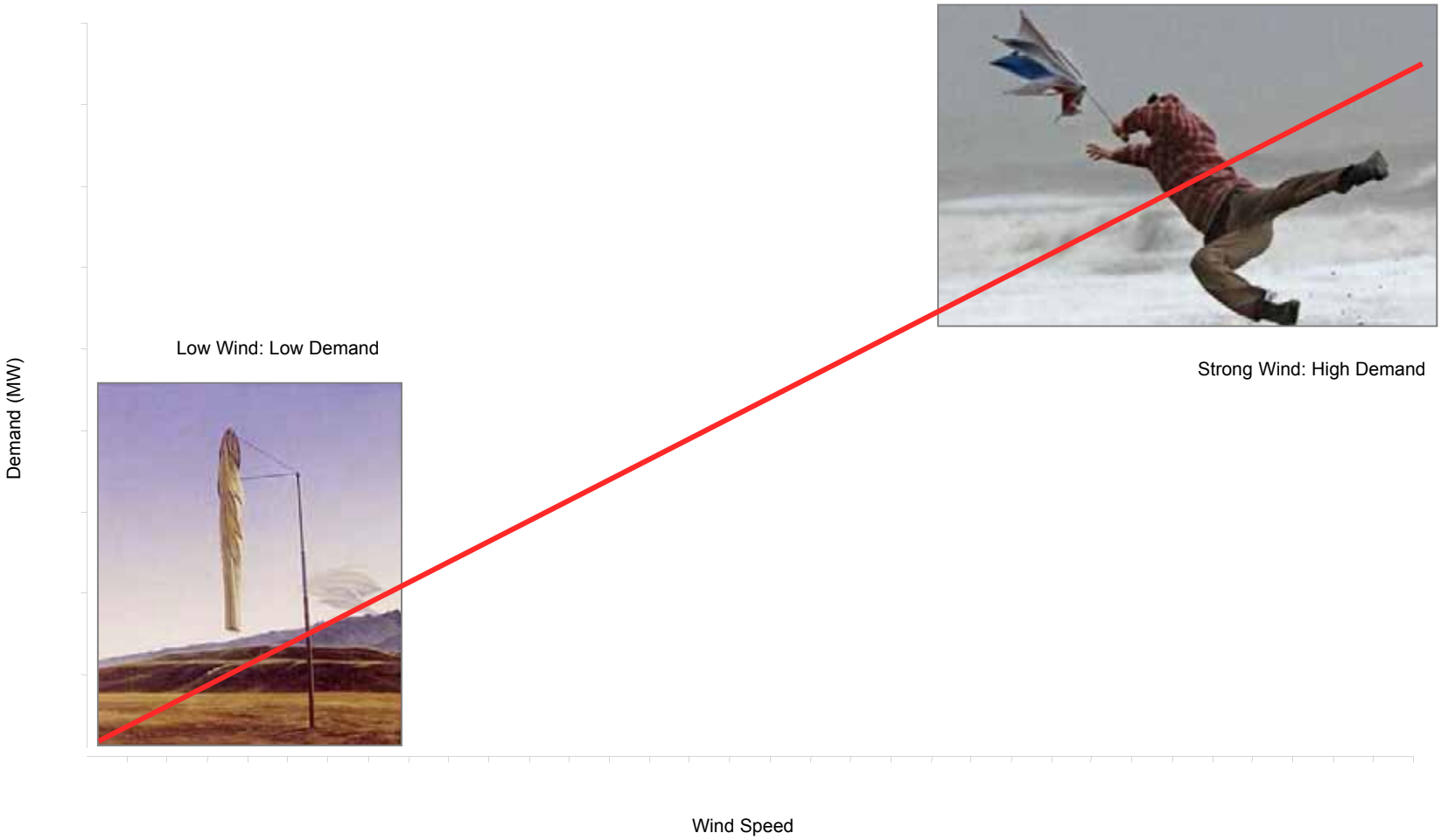
The Impact of Weather: Cooling Power of the Wind



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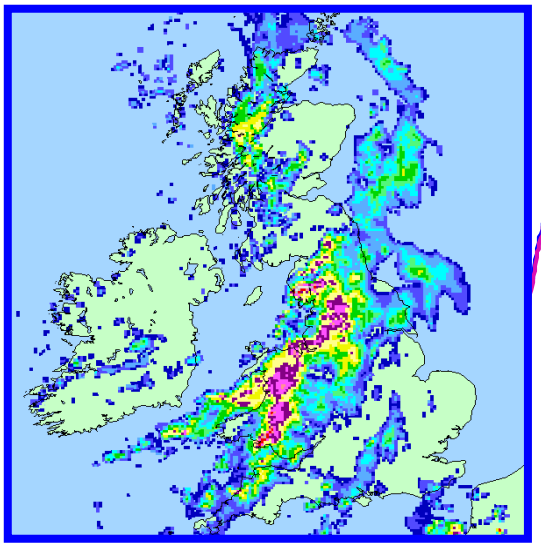
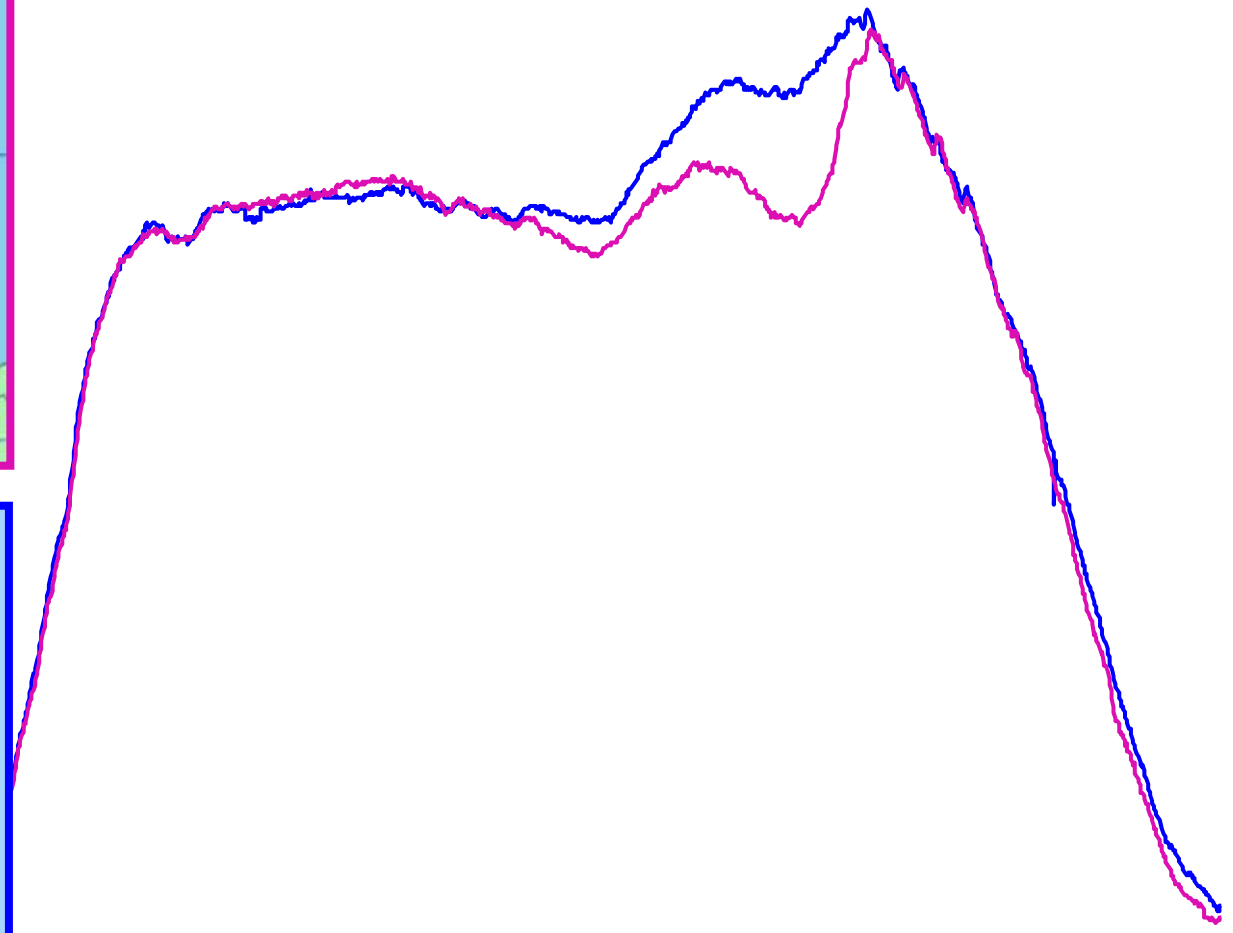
The Impact of Weather: Rain





The Impact of Weather
Some Numbers

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Temperature
(1° C fall in cold conditions)

Cloud cover
(clear sky to thick cloud)

Precipitation
(no rain to heavy rain)

Temperature
(1° C rise in hot conditions)

Cooling power
(10 mph rise in cold conditions)

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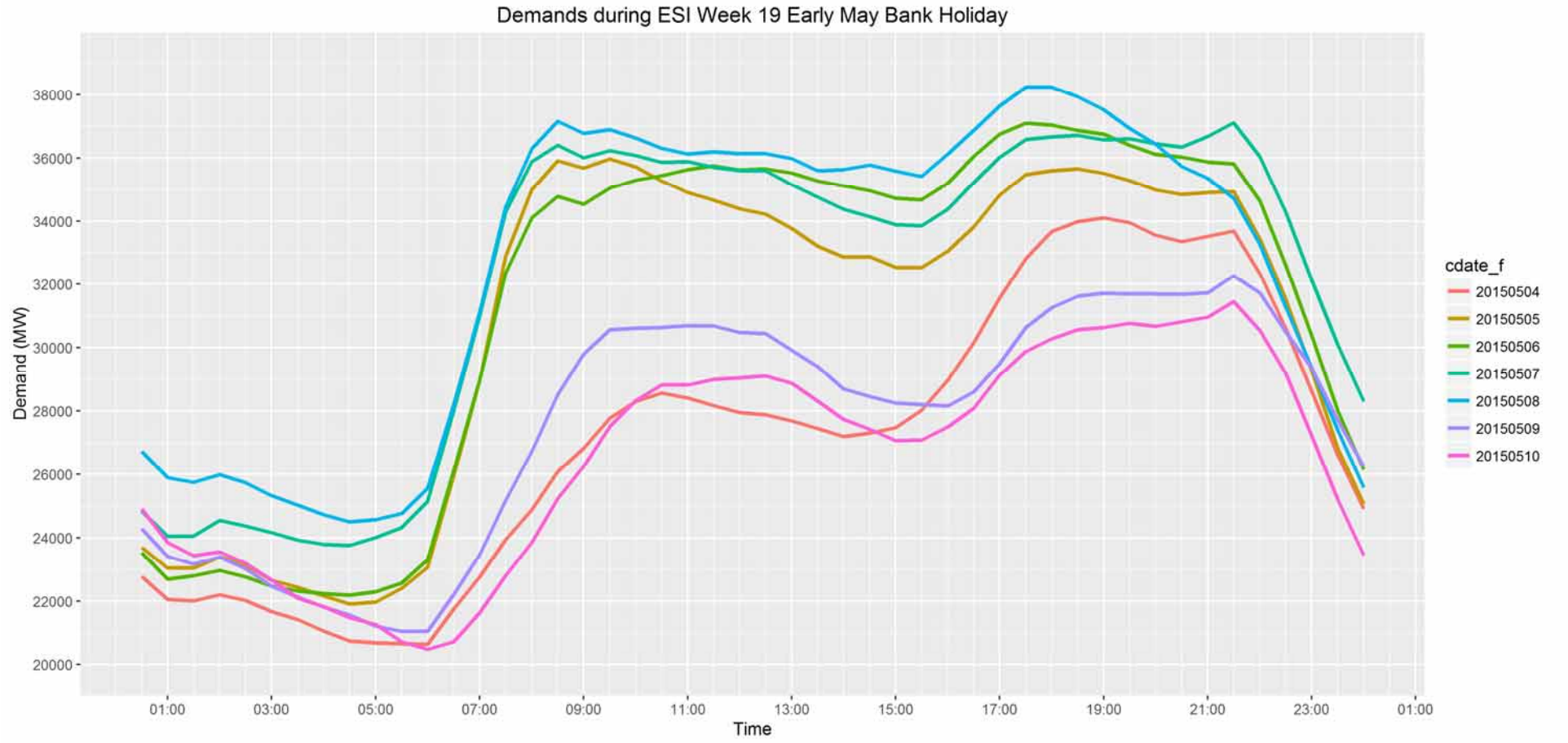
GB National Demand: Bank Holiday effect



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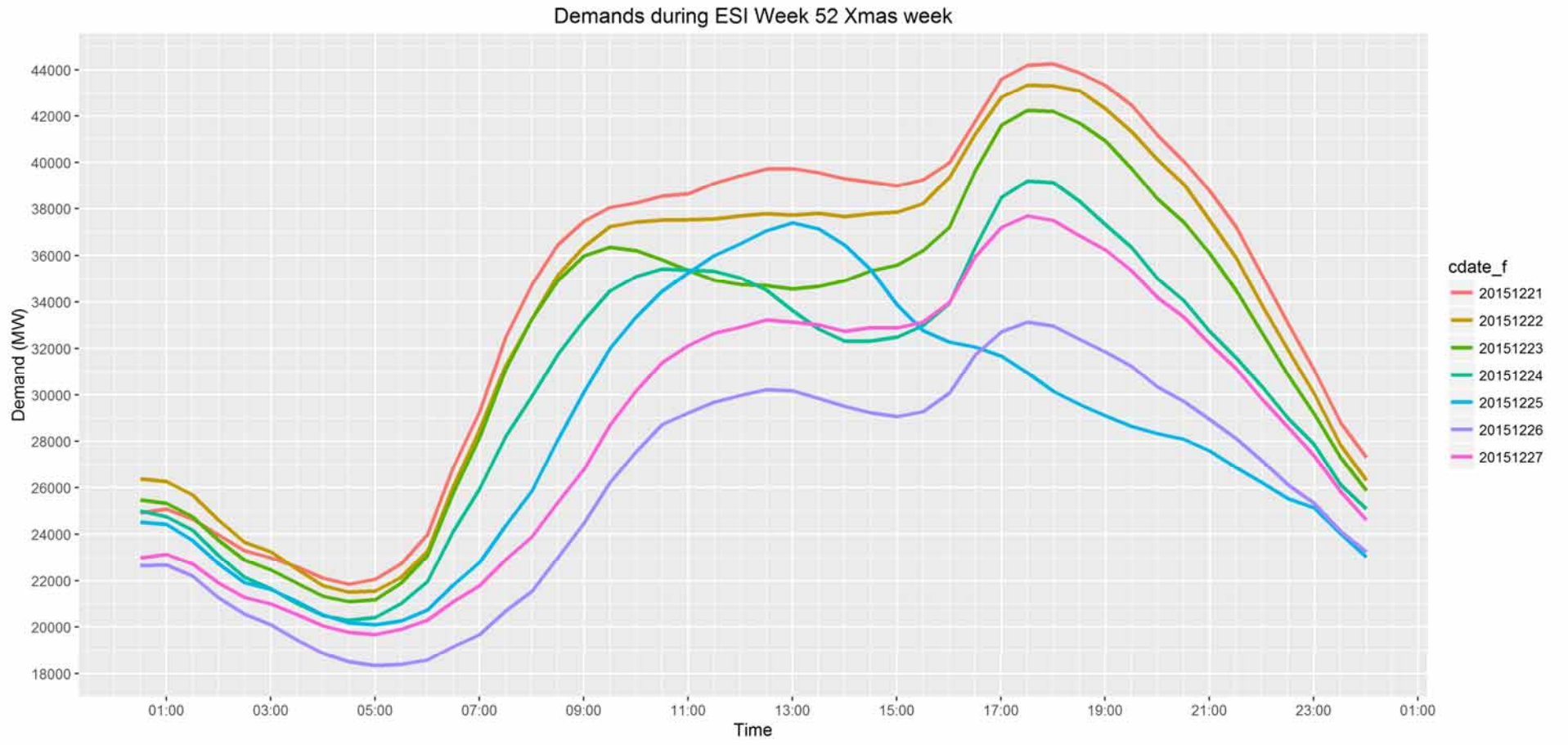
GB National Demand: Xmas effect



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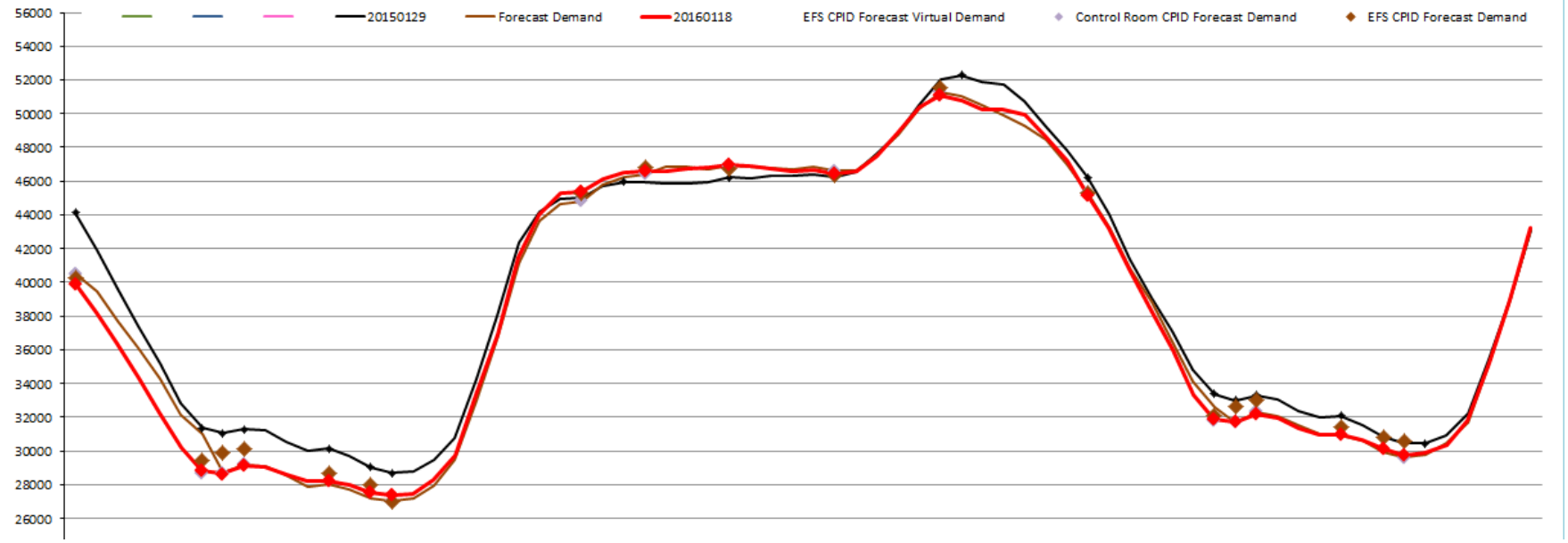
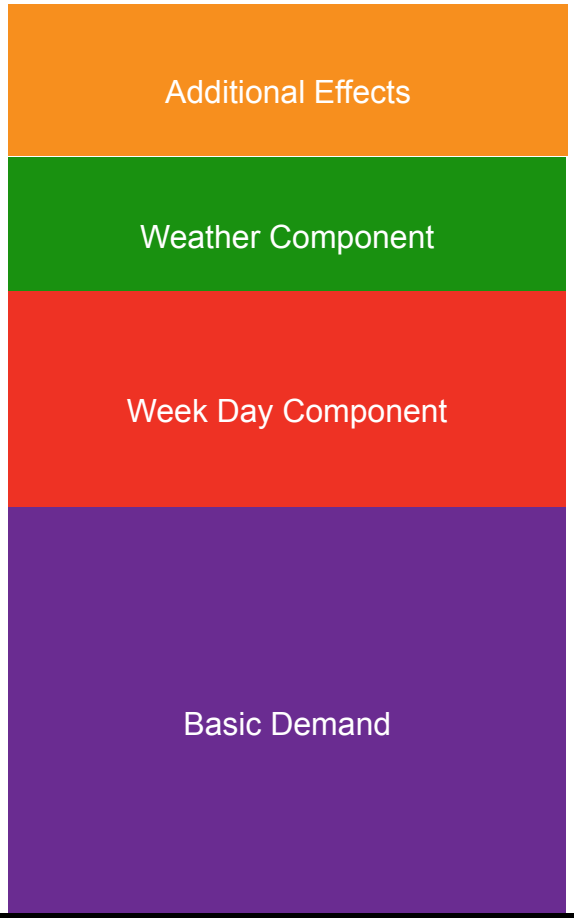
GB National Demand: Triad avoidance / CDM

	1B	2F/2A/2B	3B	DP/3C	4B	4C	1B	2F/2A/2B	3B	DP/3C	4B	4C	1B	2F/2A/2B	3B	DP/3C	4B	4C
	20160118						20160119						20160120					
Forecast Date: 20160118	27,365	46,974	46,427	51,102	45,170	31,877		47,103	44,532	50,947	45,814	32,484		47,208	43,938	50,443	45,574	31,985
	Historic Day + 0						Historic Day + 1						Historic Day + 2					
Historic Dates: 20150129 ☑ 700	27,991	45,512	45,508	51,598	45,512	32,695	29,743	46,043	43,210	50,047	42,696	31,959	27,580	40,896	38,792	45,506	38,826	30,085
☐																		
☐ 0																		
☐ 0																		



NG National Demand forecast models



- Statistical Models (standard linear regression)
- Updated twice a year
- Separate models for each Cardinal Point
- Historical data used to build models:
  - Historic Demands
  - Day of week effect
  - Historic Weather
  - Additional effects – School Holidays, Time of Year

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Weather variables used in modelling

- Weather variables used in Forecast Models represent
  - Temperature
    - TE and TO
  - Illumination
    - EI and related ID
  - Wind Speed
    - WS
  - Cooling Power of Wind (Chill Factor)
    - CP

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Met Office Forecast Data

- Data source is Met Office
- Forecast data for ~ 106 locations
- Forecast arrives 4 times a day. Each forecast is for the next 14 days ahead and at hourly resolution

Met Office weather files timestamps	Files processed & ready to use by		Goal run weather file used for
	GMT	BST	
YYYYMMDD 02:30	03:30	04:30	04:00, 09:00, Nominal (D+1)
YYYYMMDD 08:30	09:30	10:30	12:00, BPS (D+1), Pre-Nom (D+2)
YYYYMMDD 14:30	15:30	16:30	19:30
YYYYMMDD 20:30	21:30	22:30	23:00

- Weather variables that come through: temperature, solar radiation, wind speed and wind direction

Met Office Forecast Data

- Renewable generation calculations: the data for the nearest weather station to the generator is used

- Demand calculation: Forecast data for 7 main stations are used, weighted by population, to give National Average

Weather station name	Station code	Station number	Station weighting (% of Nat. Avg.)
Heathrow	LN	772	**28**
Bristol Filton	BR	628	**18**
Birmingham C/H	BM	535	**16**
Hawarden	MN	321	**14**
Glasgow	GW	134	**10**
Leconfield	LF	382	**7**
Leeming	LM	257	**7**

Met Office Actual Data

- We receive actual weather data for 45 Met Office weather stations
- Rest of the forecast stations are “Virtual MetMast” stations with no actual recorded data
- Data is received for every hour
  - arrives at 30 minutes past the hour

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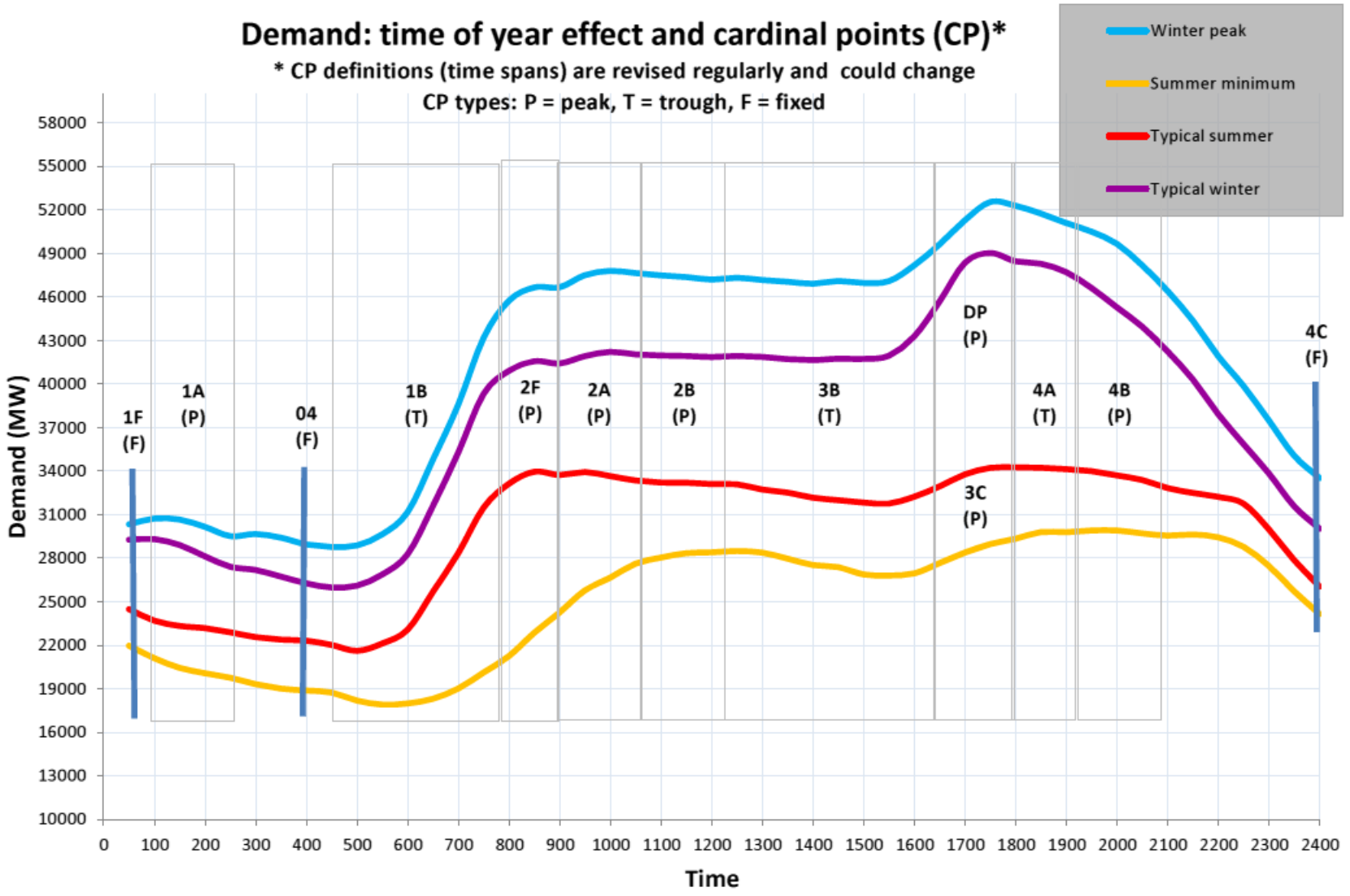
GB National Demand: Cardinal Points



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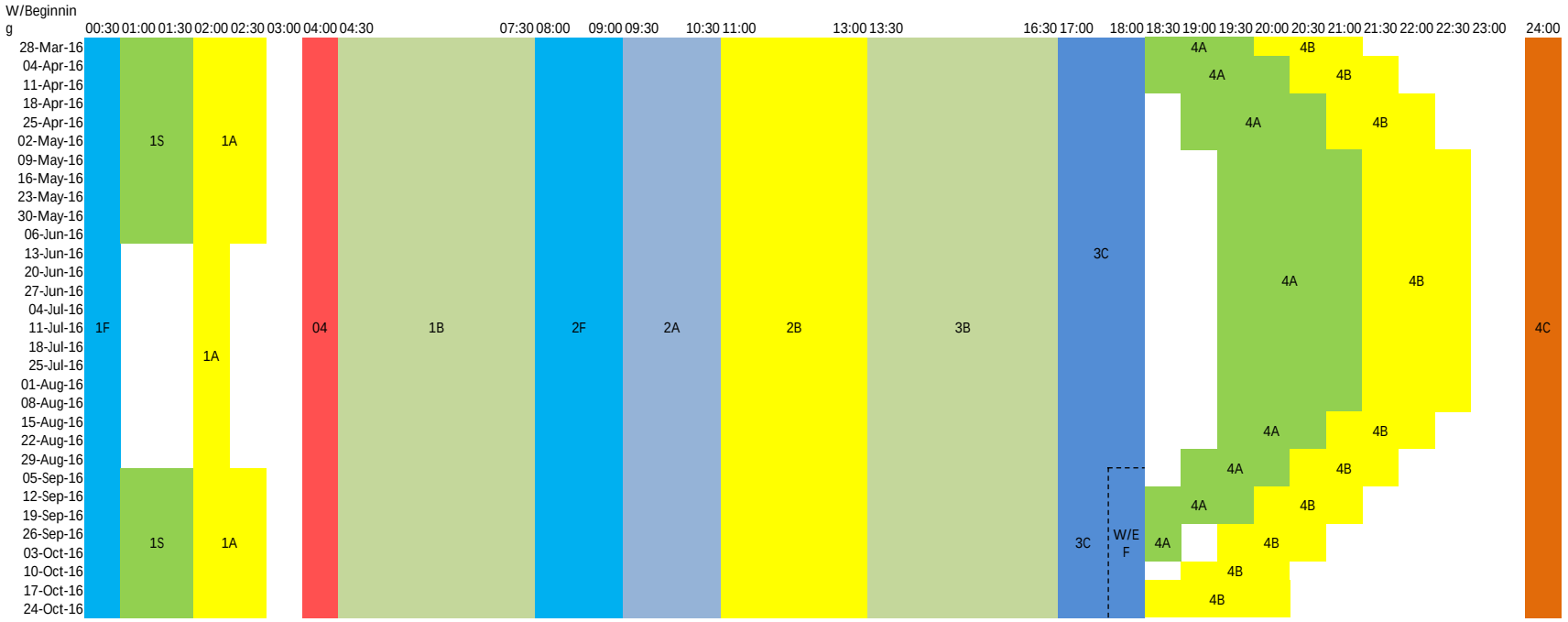
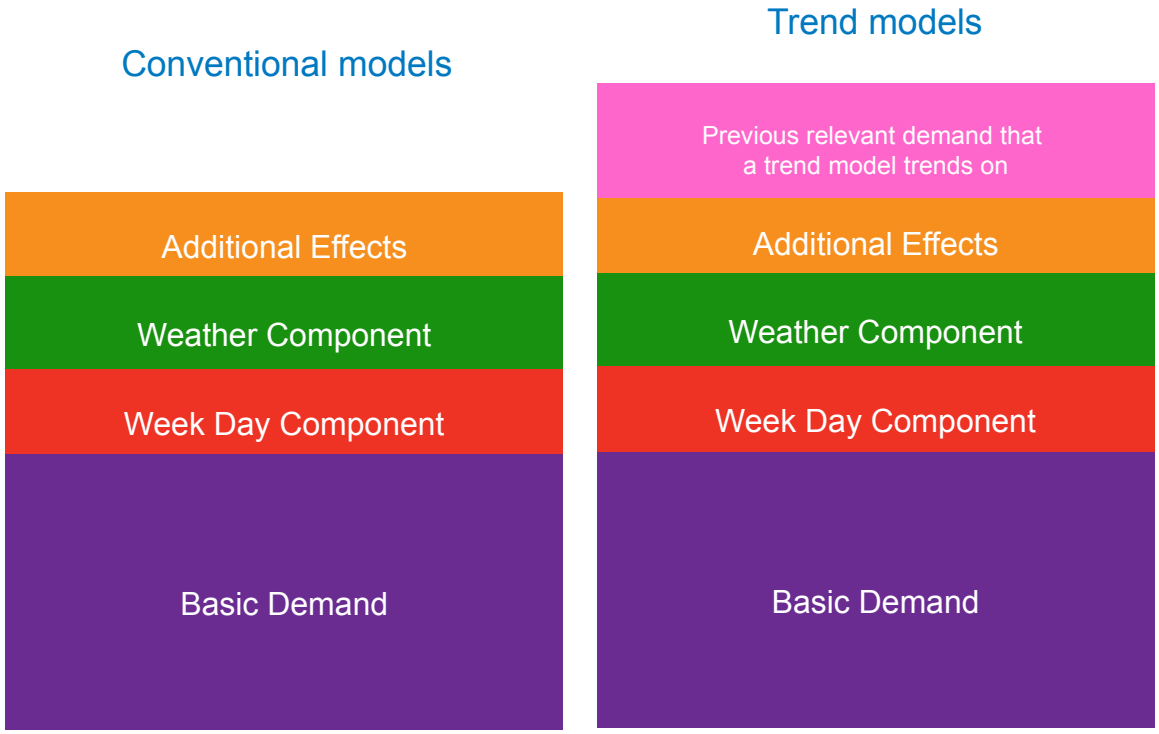
BST 2016 CP chart



NG National Demand forecast models

- Each Cardinal Point has a minimum of two forecast models:
  - At least one conventional model
  - At least one trend model
- Difference between conventional and trend models:



CP	Trend model trends on:
1F	previous day 1F
1A	previous day 1A
1B	previous day 1B
2F	in day 1B
2A	in day 1B
2B	in day 1B & in day 2A
3B	in day 1B & in day 2A
3C / DP	in day 1B & in day 2A
4B	in day 1B & in day 2A
4C	in day 1B & in day 2A

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NG National Demand forecast models

- Example of the 3B statistical model equations for the conventional and trend models:

3B conventional model

```
53501.31 + 633.29 * Y12 + 24.05 * R + -0.17 * R*R + -1211.94 * Fri + -6189.44 * Sat + -5772.22 * Sun + -
702.67 * TE15_0 + -17.05 * (EI12_0 + EI15_0) + 48.32 * WS15_0
```

3B trend model trending on 1B in day demand

```
32803.04 + 0.71 * L1B_0 + -1108.77 * Tue + -1319.84 * (Wed + Thu) + -2326.37 * Fri + -6238.73 * Sat + -
5023.05 * Sun + -274.39 * T015_0 + -23.78 * (EI12_0 + EI15_0) + 47.26 * WS15_0
```

3B trend model trending on 2A in day demand

```
16004.87 + 0.74 * L2A_0 + -1079.74 * Fri + -2176.56 * Sat + -0.02 * R*R + -196.6 * T015_0 + -14.03 *
(EI12_0 + EI15_0) + 57.34 * WS15_0
```

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Wind Generation

Wind Generation

Wind Power Forecasting

- Feb 17
- Metered Wind Capacity ~ 10,100 MW
- Unmetered ~ 4,800 MW
- Mar 16
- Metered Wind Capacity ~ 9,200 MW
- Unmetered ~ 4,200 MW

Metered Wind Farms

Unmetered Wind Farms

Metered Wind Power Forecast

National Demand Forecast

Load Curve Optimisation Using Actual Wind Speed Data

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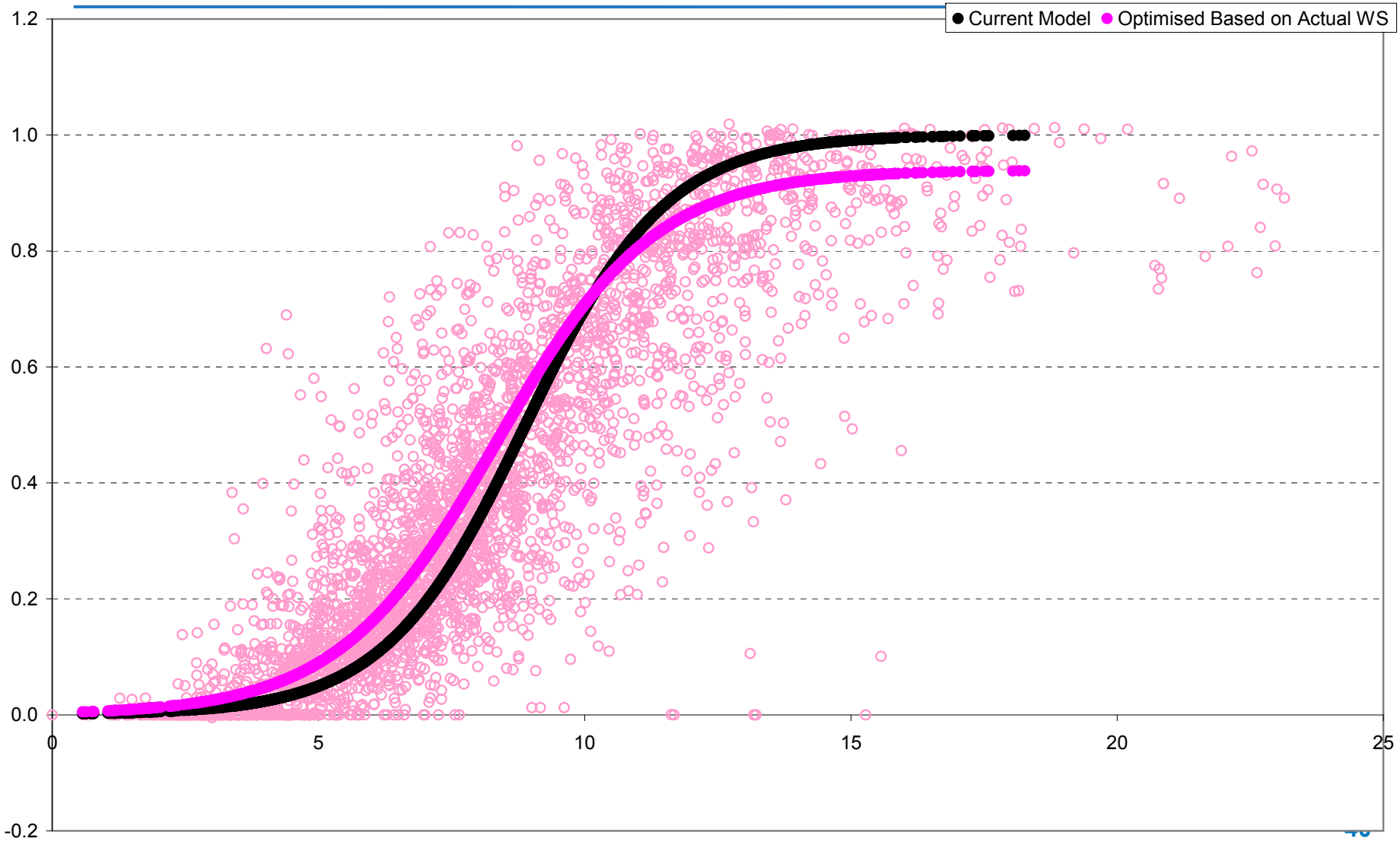

Load Curve Optimisation Using Forecast Wind Speed Data to Remove Bias

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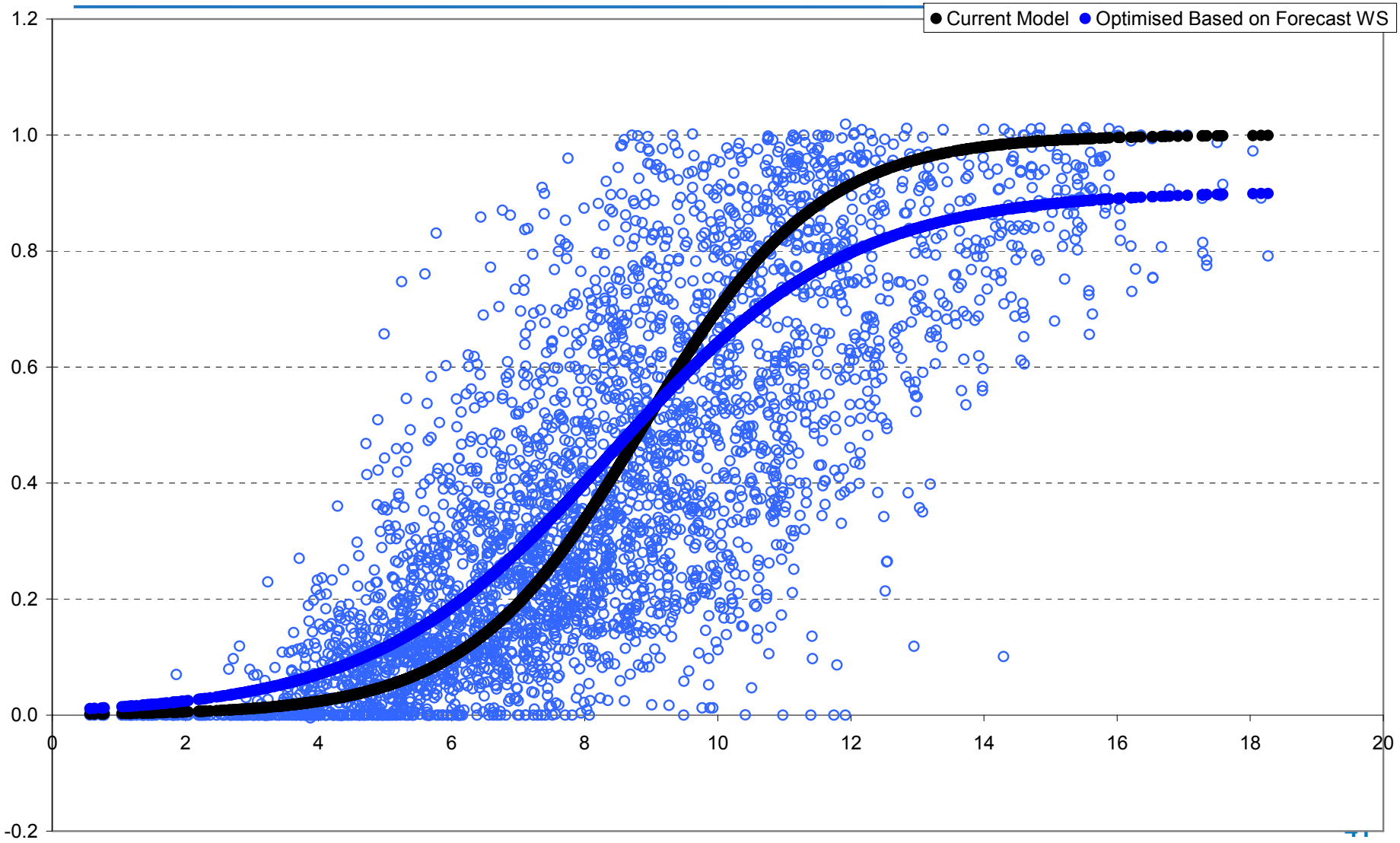

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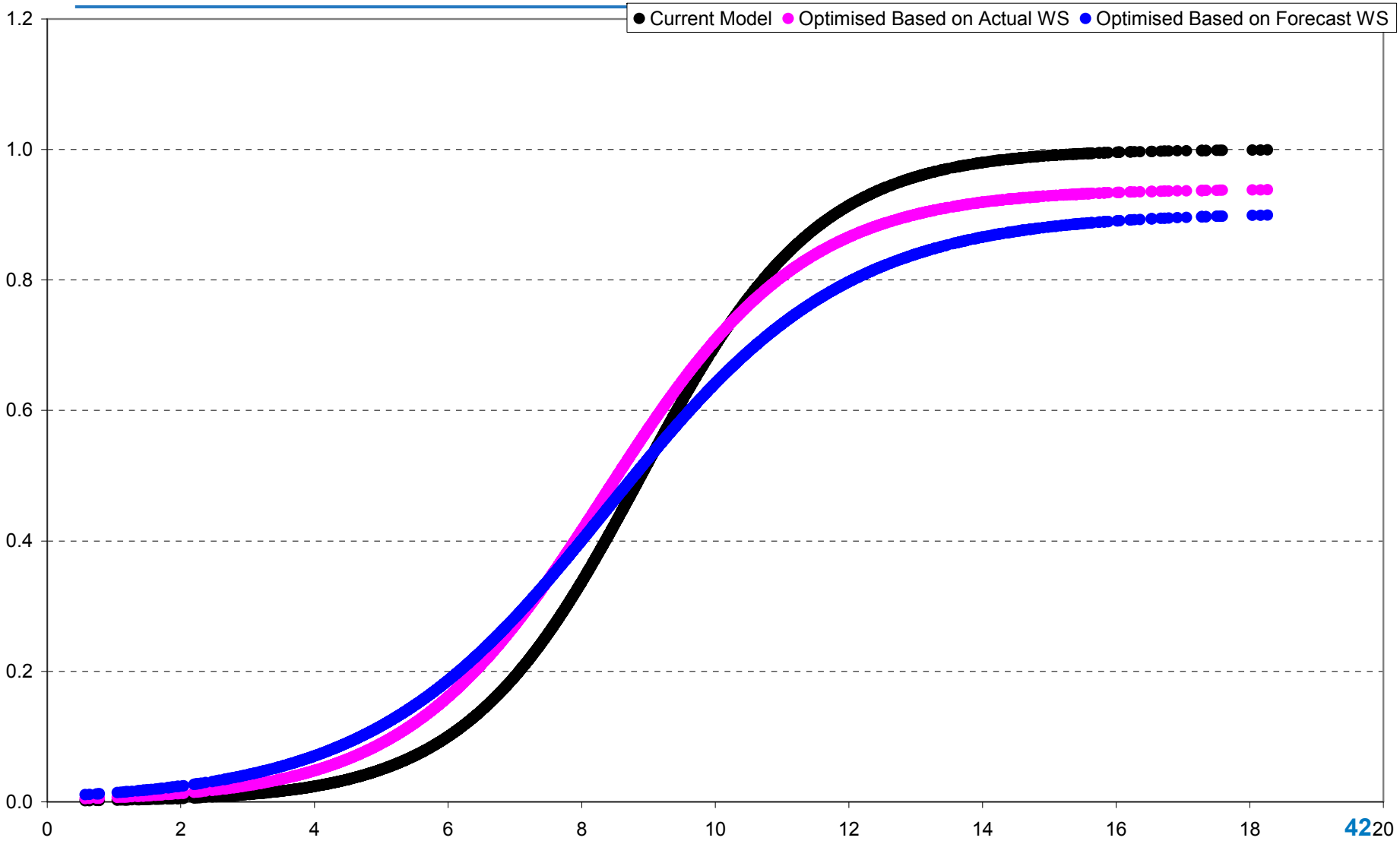
Alternative Load Curves



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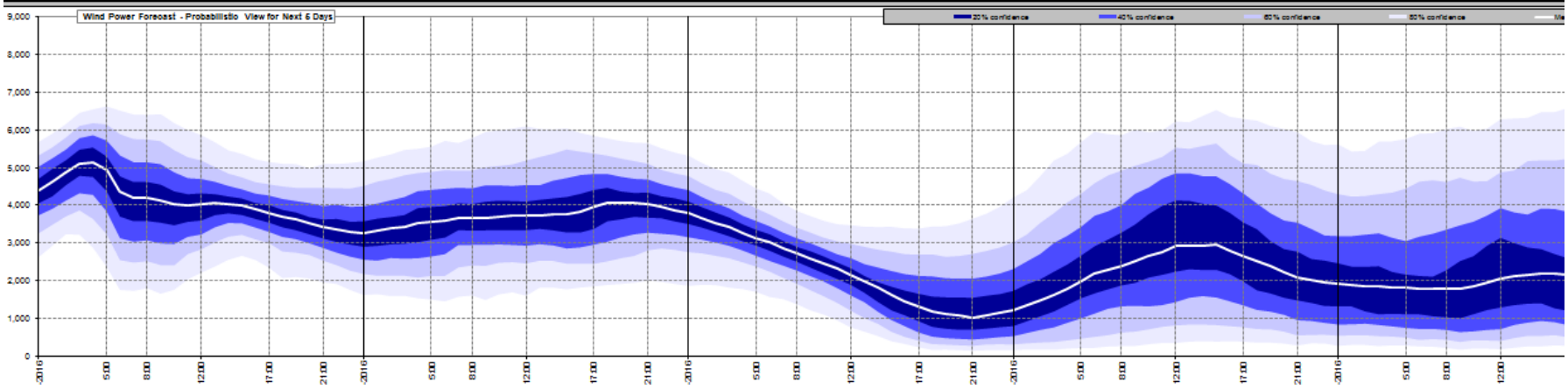
Metered Wind Generation

Wind Power Forecast — Contact: Jac

Great Britain Windpower Forecasts based on forecast timestamp: 04-MAR-2016 08:30:00

Region	Capacity	Fri	04-MAR-2016					Sat	05-MAR-2016					Sun	06-MAR-2016					Mon	07-MAR-2016					Tue	08-MAR-2016					09-MAR-2	10-MAR-2	11-MAR-2	12-
		00:00	05:00	08:00	12:00	17:00	21:00	00:00	05:00	08:00	12:00	17:00	21:00	00:00	05:00	08:00	12:00	17:00	21:00	00:00	05:00	08:00	12:00	17:00	21:00	00:00	05:00	08:00	12:00	17:00	21:00	05:00	17:00	05:00	17:00	05:00
CUMBRIA	370	714	532	546	1001	1015	933	849	775	630	600	555	453	331	156	83	39	40	75	104	139	204	309	337	264	193	205	241	363	397	530	806	513	645	330	355	726	6
Capacity at risk of Cut-off																																					
NORTH WALES	727	484	437	329	378	523	514	486	454	437	363	333	275	231	138	81	46	26	36	55	66	99	169	188	161	135	123	122	128	124	216	337	244	242	468	381	238	1
Capacity at risk of Cut-off																																					
SOUTH WEST	66	24	8	5	13	12	15	19	23	23	27	24	21	17	13	10	14	7	4	5	11	10	14	10	6	4	4	7	13	13	17	27	17	16	25	16	13	
Capacity at risk of Cut-off																																					
ANGLIA	1406	1132	1171	636	213	46	40	66	345	529	697	1046	1244	1270	1259	1194	374	534	314	322	525	600	618	559	463	538	419	333	267	247	506	1032	607	419	308	781	513	4
Capacity at risk of Cut-off																																					
HUMBER	429	231	362	259	60	22	68	155	321	347	349	351	353	348	330	306	219	139	99	135	193	208	223	195	193	188	128	100	74	92	193	278	177	156	285	265	195	1
Capacity at risk of Cut-off																																					
KENT	930	846	726	365	108	28	20	12	37	87	129	429	740	792	810	777	658	316	144	124	230	297	266	275	251	252	266	211	162	153	306	739	398	239	554	445	290	2
Capacity at risk of Cut-off																																					
ENGLAND & WALES	4528	3433	3237	2204	1773	1647	1531	1586	1954	2111	2165	2738	3085	2983	2707	2451	1949	1063	672	744	1164	1418	1599	1564	1343	1310	1152	1014	1007	1027	1828	3273	1955	1717	3223	2843	1975	15
Capacity at risk of Cut-off																																					
Argyll	20	18	16	10	5	2	1	1	2	5	7	12	17	17	17	17	16	11	7	6	9	11	10	10	10	10	10	9	7	7	10	17	12	9	14	11	8	
Capacity at risk of Cut-off																																					
SSENV	1307	215	338	435	586	711	694	632	529	482	449	414	322	281	166	106	88	110	155	223	400	472	549	419	275	239	278	318	388	384	330	489	406	504	819	511	416	3
Capacity at risk of Cut-off																																					
LOTHIAN	482	74	228	289	284	237	170	165	192	227	256	190	166	141	72	38	22	23	35	45	89	113	154	137	128	102	90	104	142	159	146	211	181	201	357	280	173	1
Capacity at risk of Cut-off																																					
ARGYLL	482	130	192	159	193	188	174	176	156	138	118	95	77	64	31	18	12	19	30	36	74	89	106	93	62	49	59	73	85	92	102	138	102	133	234 61	123	88	
Capacity at risk of Cut-off																																					
AYRSHIRE	602	134	237	316	363	276	196	172	164	157	165	105	78	63	35	22	19	27	37	39	50	60	104	98	62	49	55	64	104	114	128	176	127	154	300	173	112	1
Capacity at risk of Cut-off																																					
CENTRAL	1342	345	670	786	839	739	599	538	552	548	558	397	296	229	105	61	48	62	90	110	195	234	389	336	213	147	160	194	330	368	337	520	419	509	876	515	333	2
Capacity at risk of Cut-off																																					
SCOTLAND	4234	315	1682	1996	2269	2152	1835	1685	1595	1557	1554	1213	956	795	428	261	205	252	354	460	818	979	1312	1093	750	595	652	763	1056	1123	1174	1550	1247	1509	2539 61	1613	1130	10
Capacity at risk of Cut-off																																					
Embedded Total	3881	1306	1388	1435	1531	1388	1315	1291	1399	1455	1694	1548	1366	1259	1023	894	804	534	504	628	853	959	1192	1044	844	761	773	834	1019	1000	1162	1460	1234	1220	1706	1376	1125	9
Capacity at risk of Cut-off																																					
Metered Total (SOF	8762	4408	4313	4201	4042	3799	3426	3271	3548	3668	3719	3952	4042	3783	3134	2713	2155	1315	1026	1204	1982	2398	2911	2657	2093	1905	1804	1777	2063	2150	3001	4829	3202	3226	5828 61	4456	3105	25
Capacity at risk of Cut-off																																					
All	12643	5713	6307	5635	5573	5187	4741	4562	4947	5123	5413	5499	5407	5042	4158	3607	2959	1849	1531	1832	2834	3357	4103	3701	2937	2667	2577	2611	3082	3150	4164	6289	4437	4446	7534 61	5832	4229	35
Capacity at risk of Cut-off																																					



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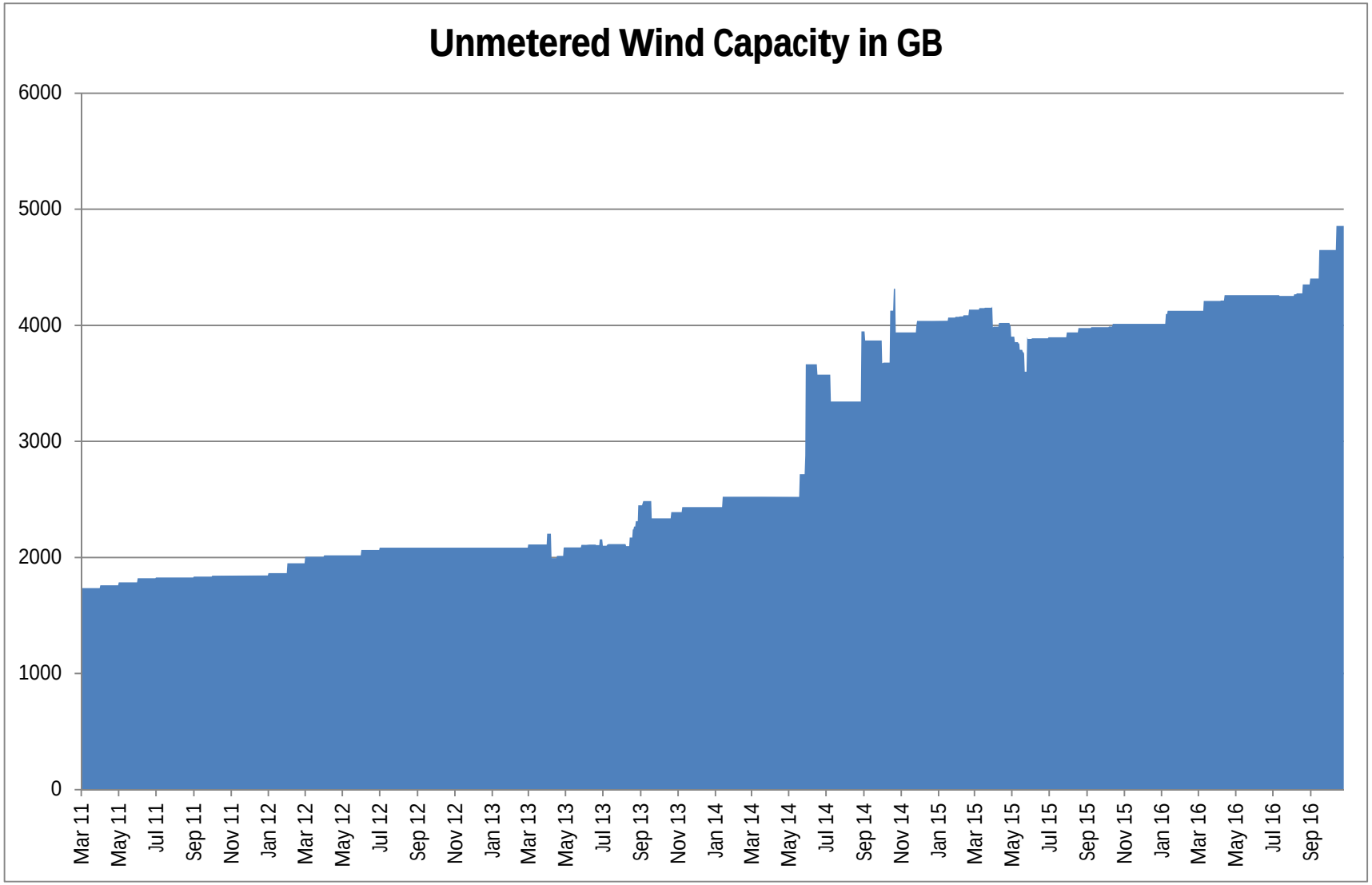
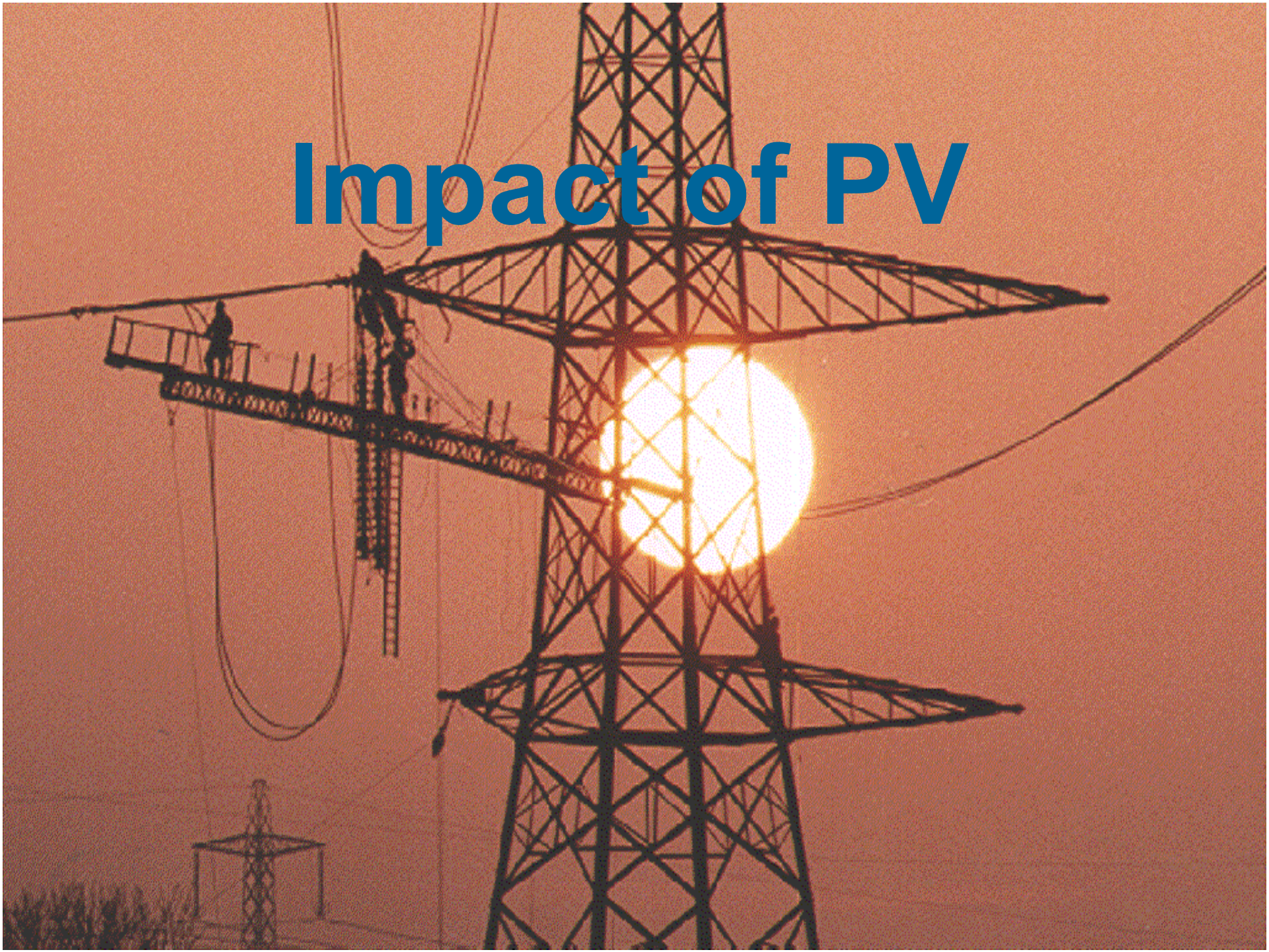
Unmetered Wind Generation (estimate)



Impact of PV



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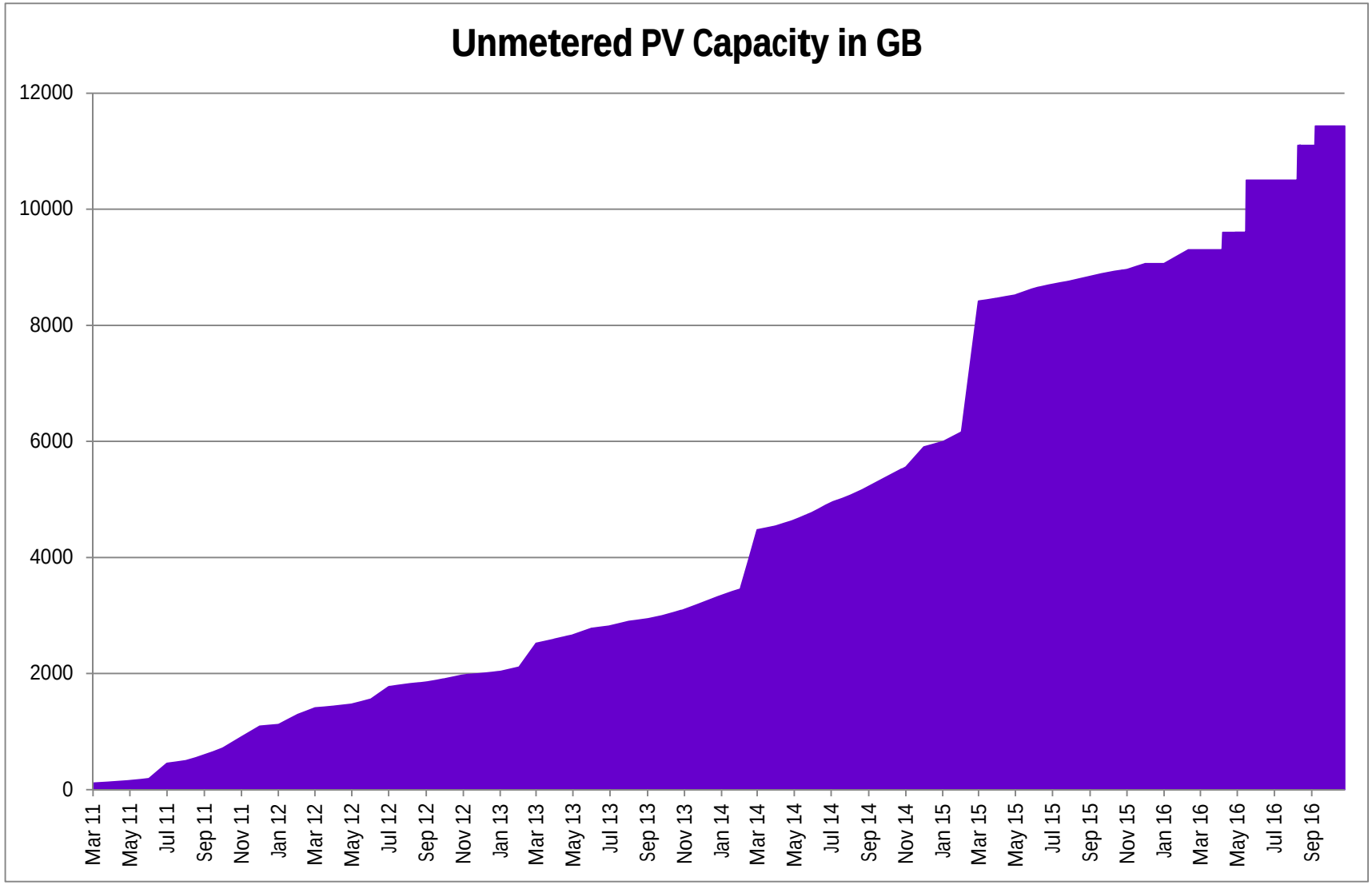
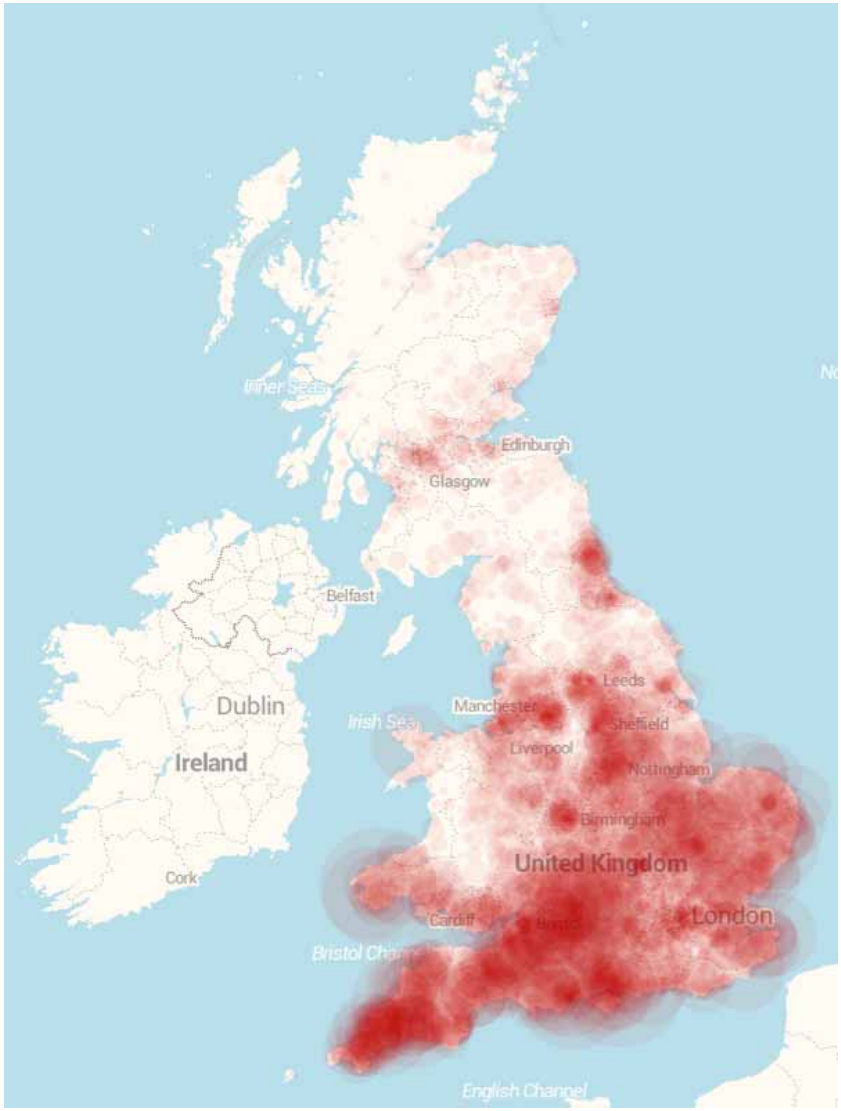
Unmetered solar generation (estimate)



Location of individual PV sites



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Increasing Volatility

Two consecutive Saturdays in June

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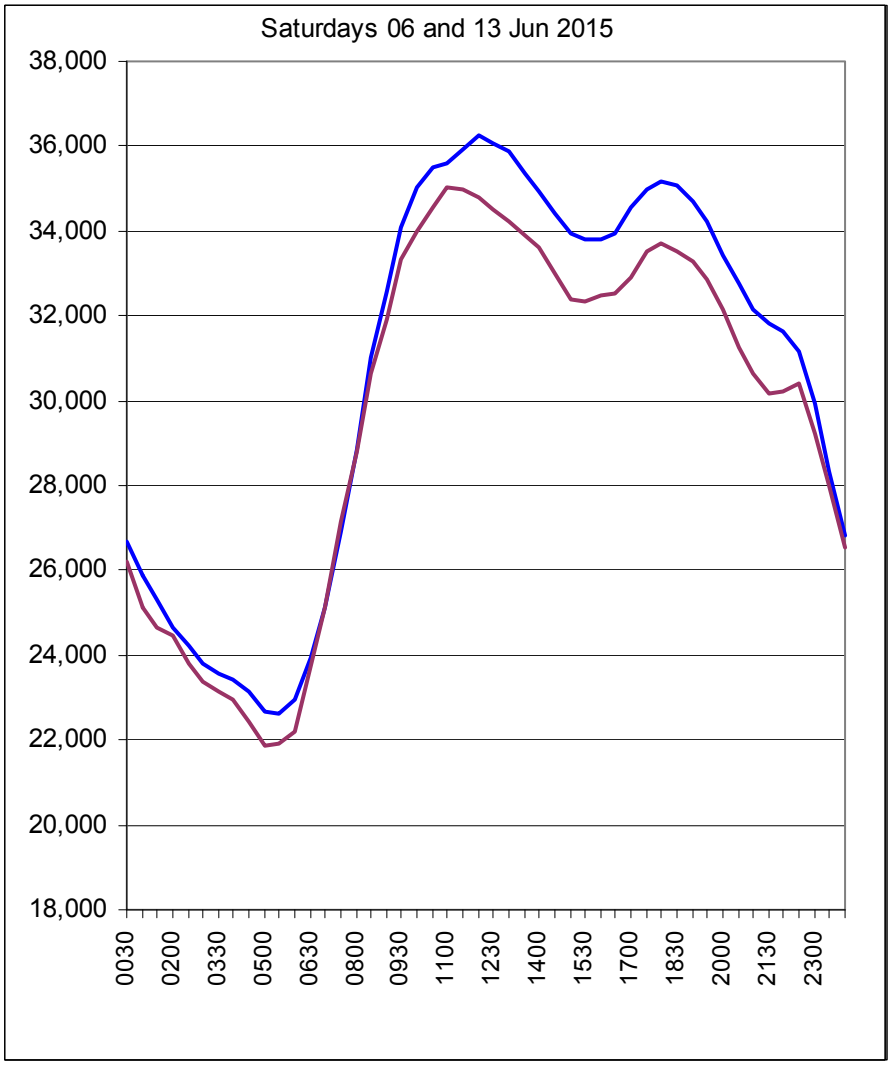
Difference between sunny and cloudy Saturdays

Saturday
6th June

- Sunny
- Windy



Saturday
13th June

- Overcast
- Still

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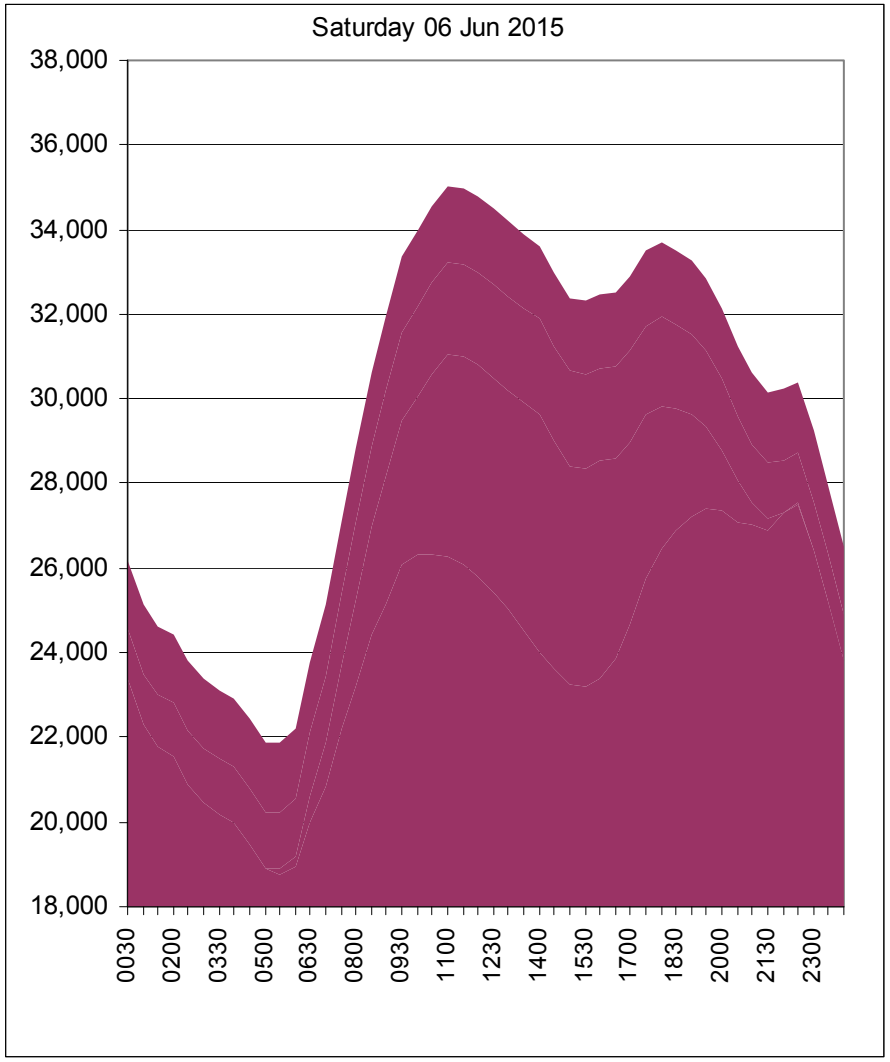
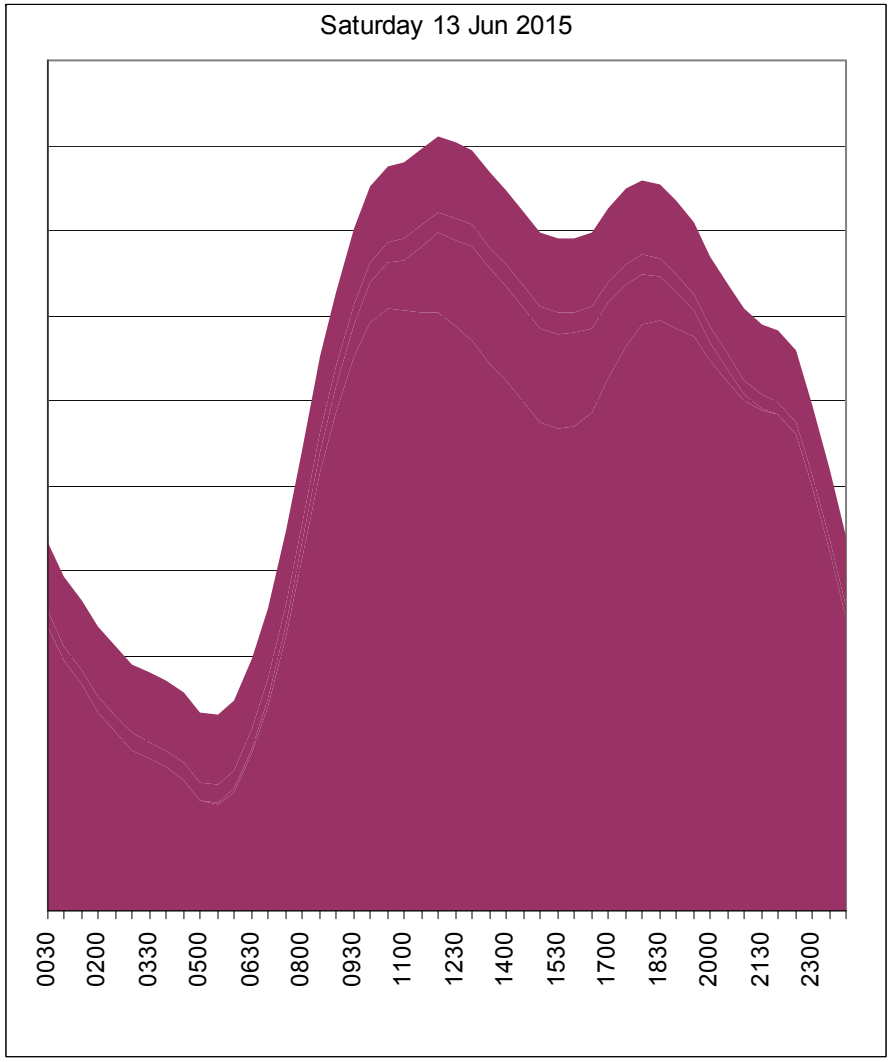
Difference between sunny and cloudy Saturdays





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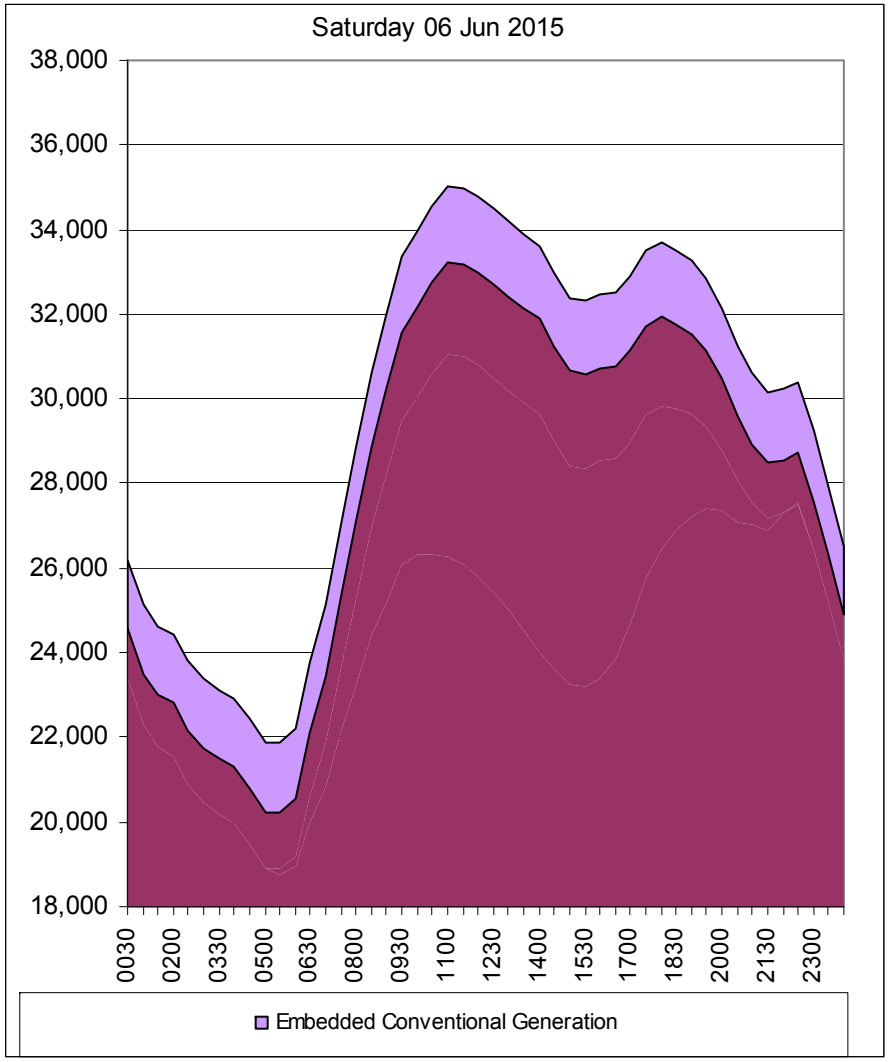
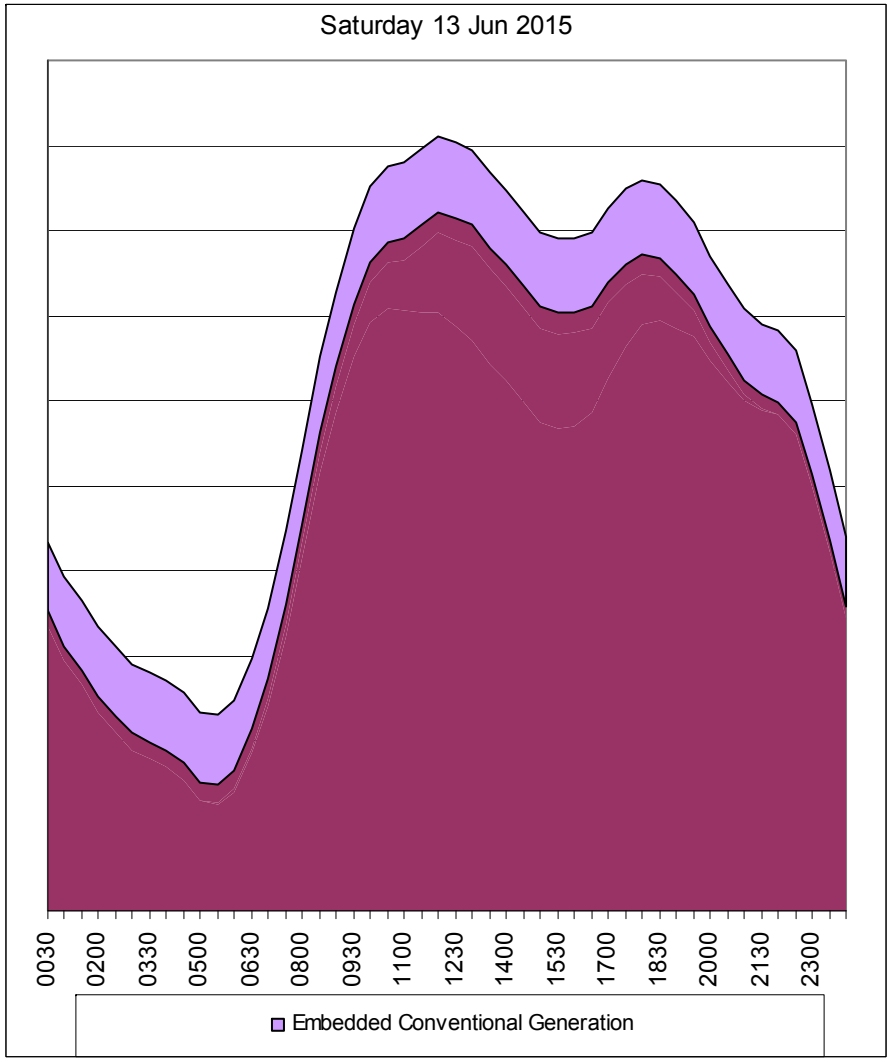
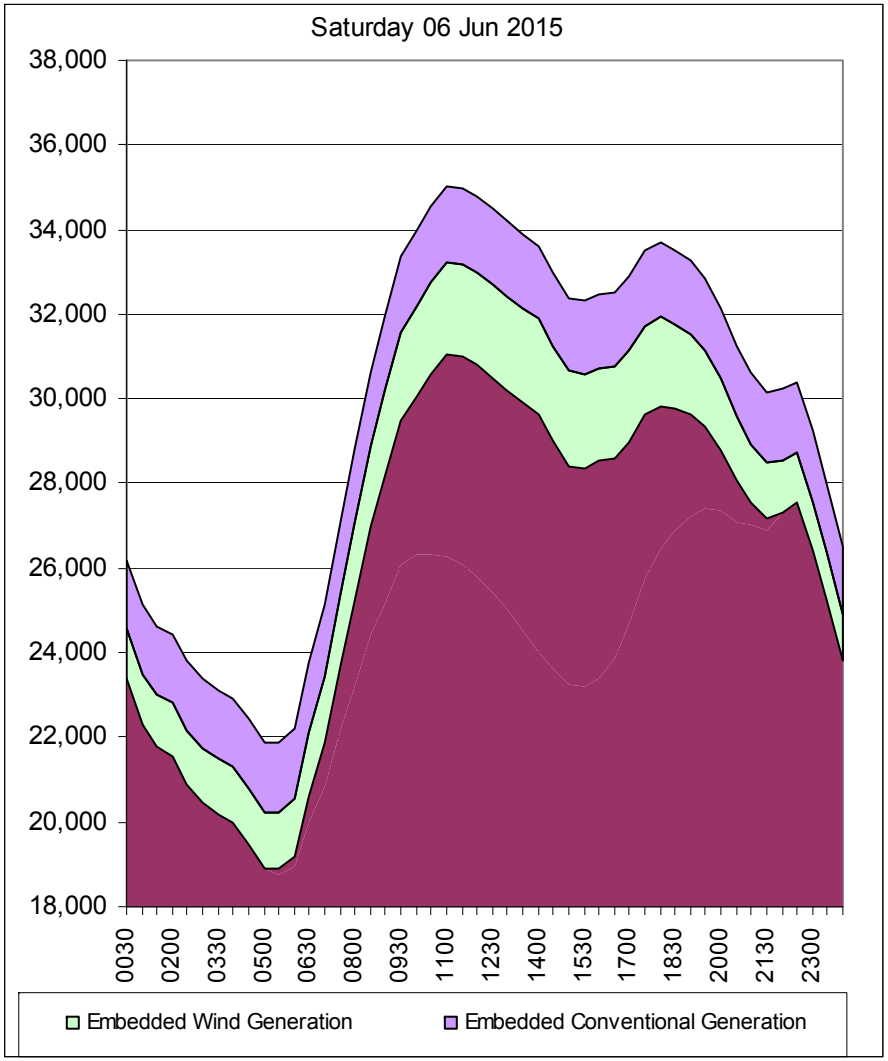
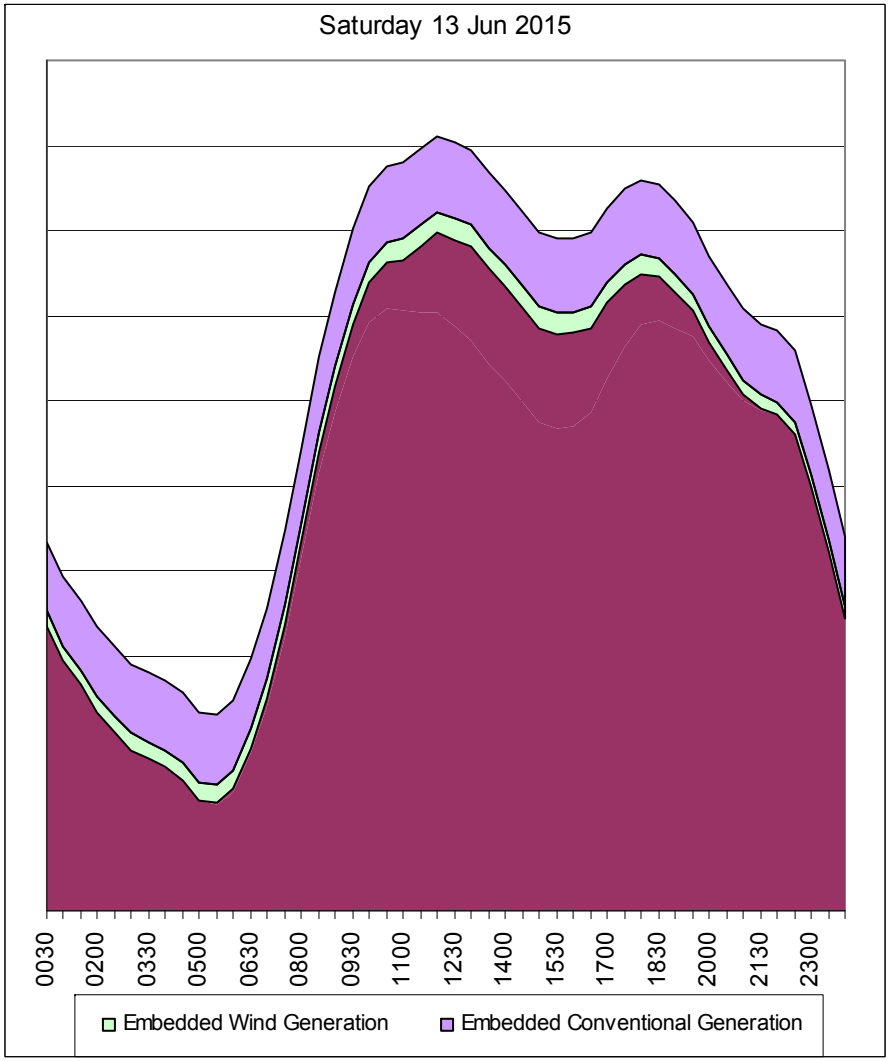
Difference between sunny and cloudy Saturdays





Difference between sunny and cloudy Saturdays





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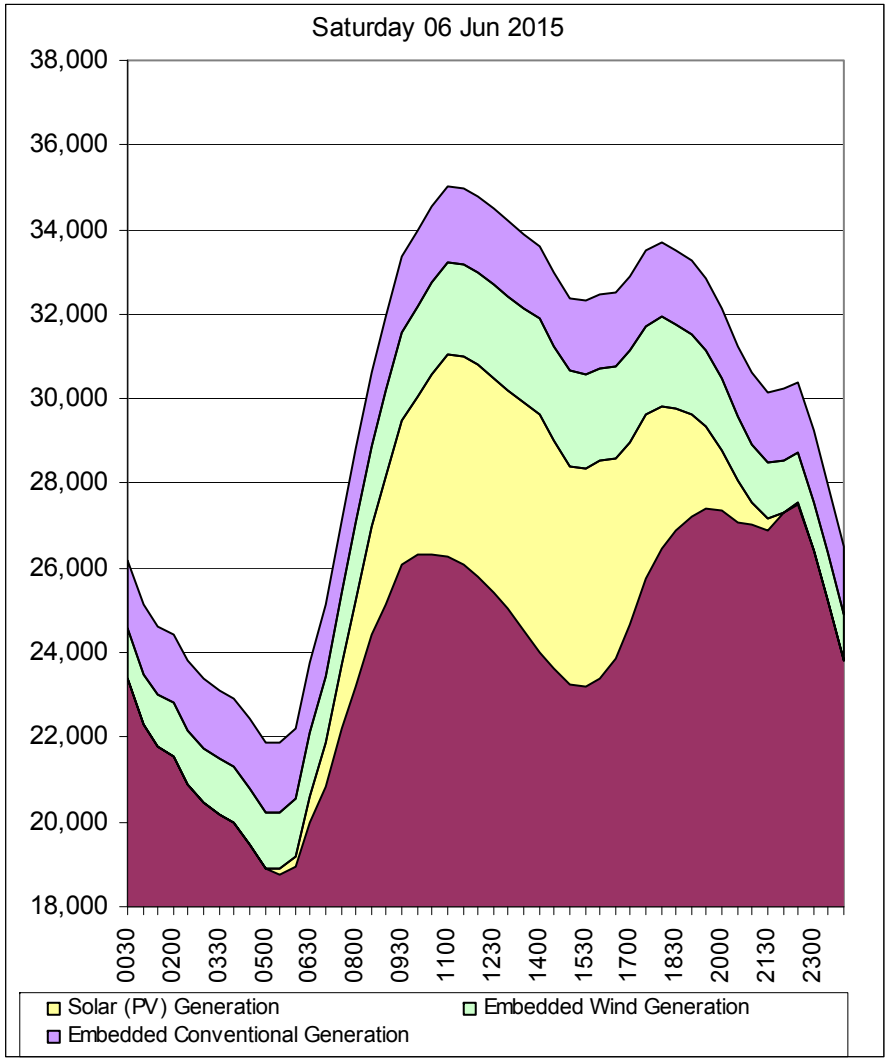
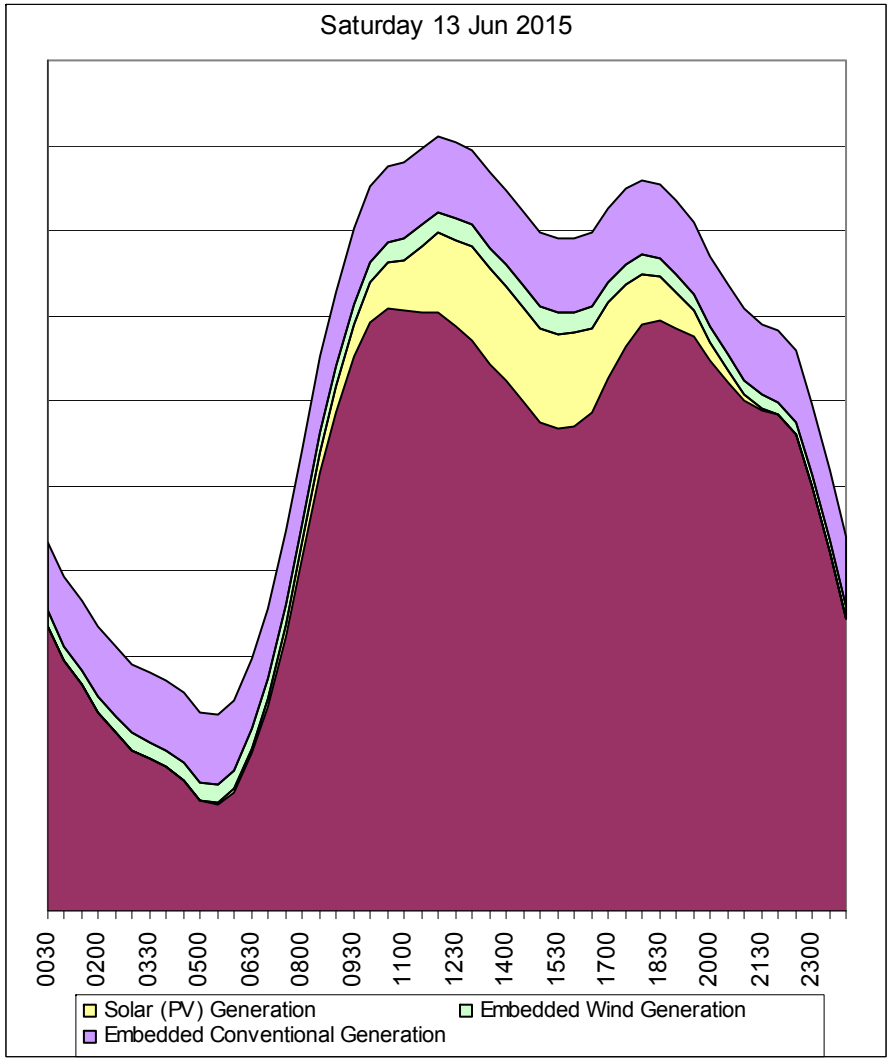
Difference between sunny and cloudy Saturdays





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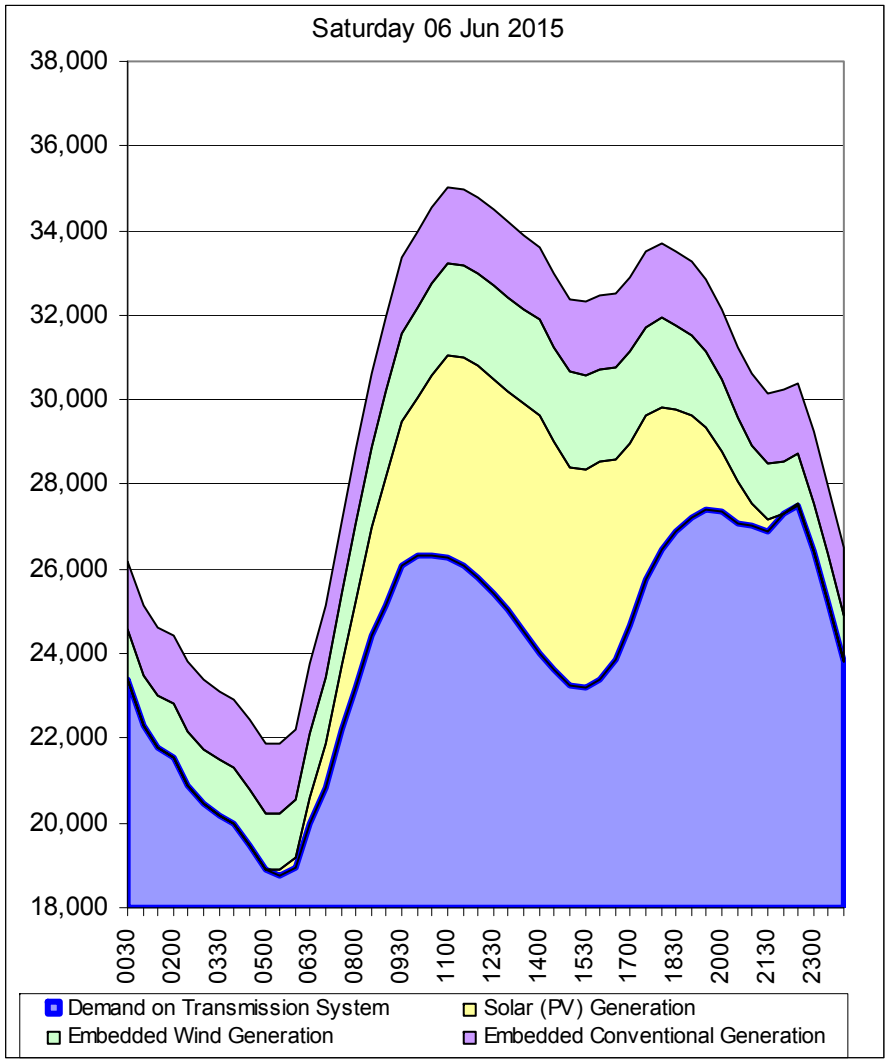
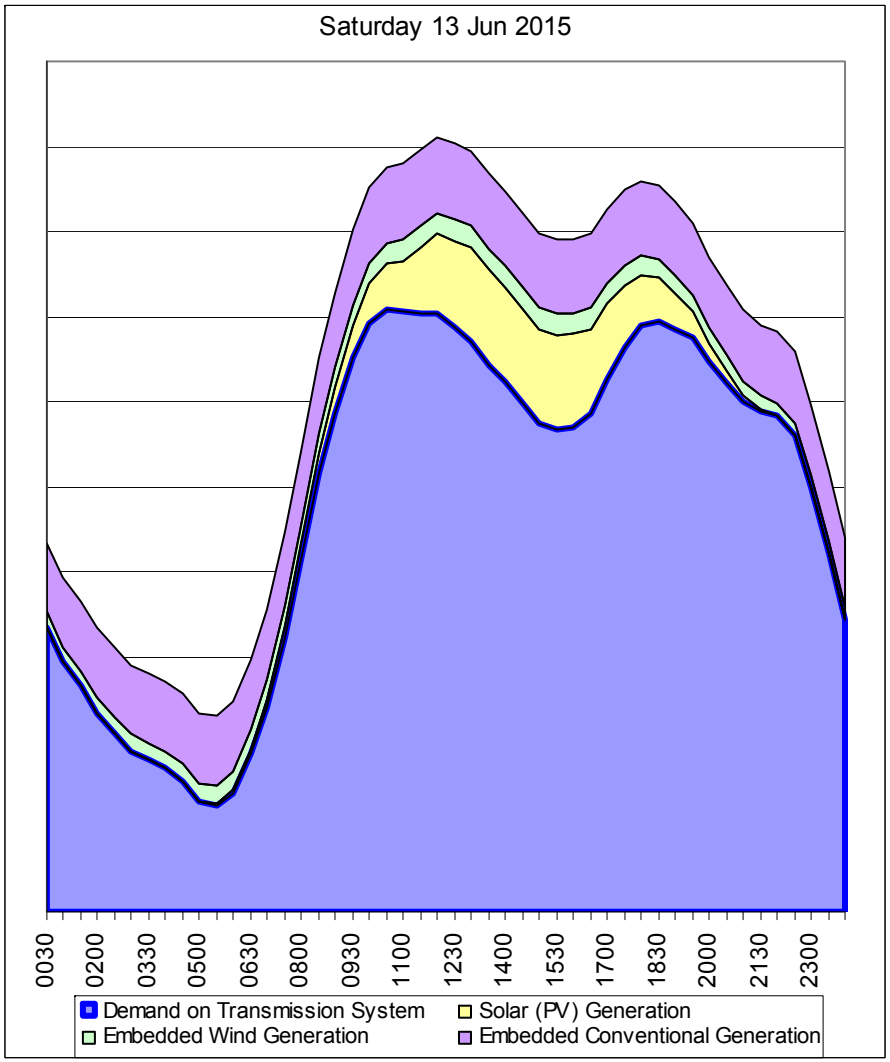
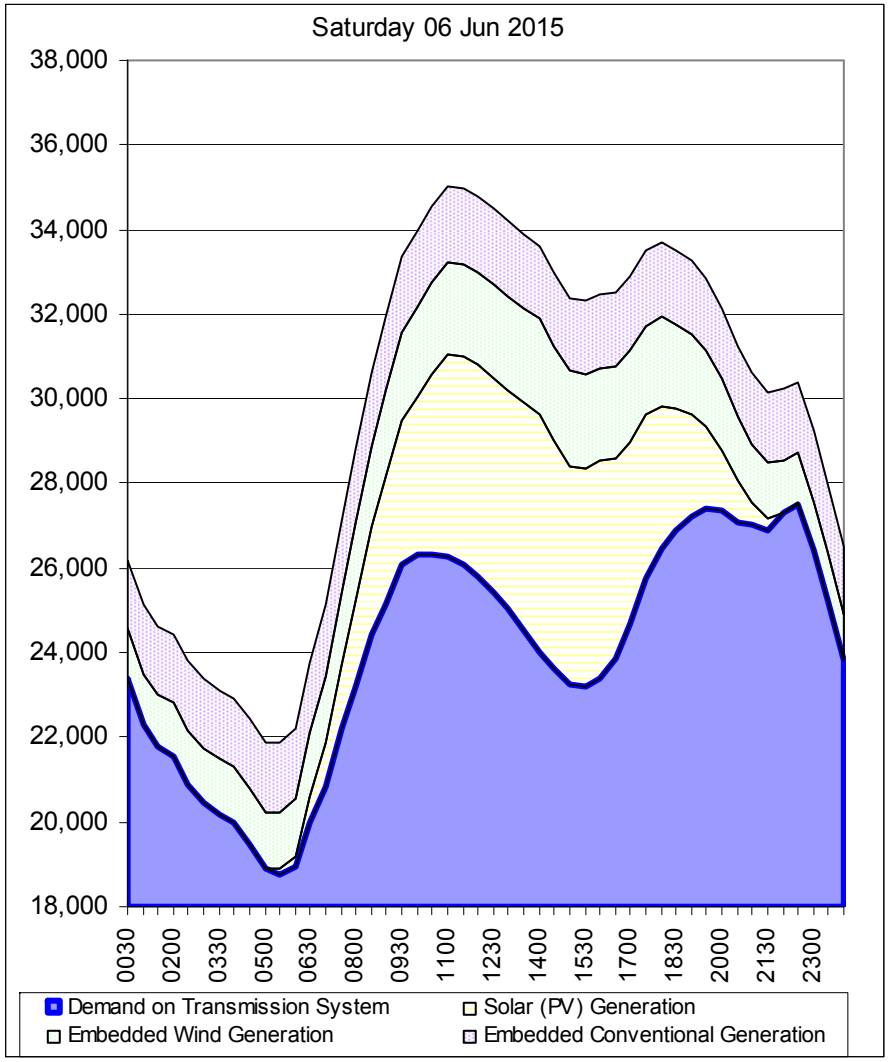
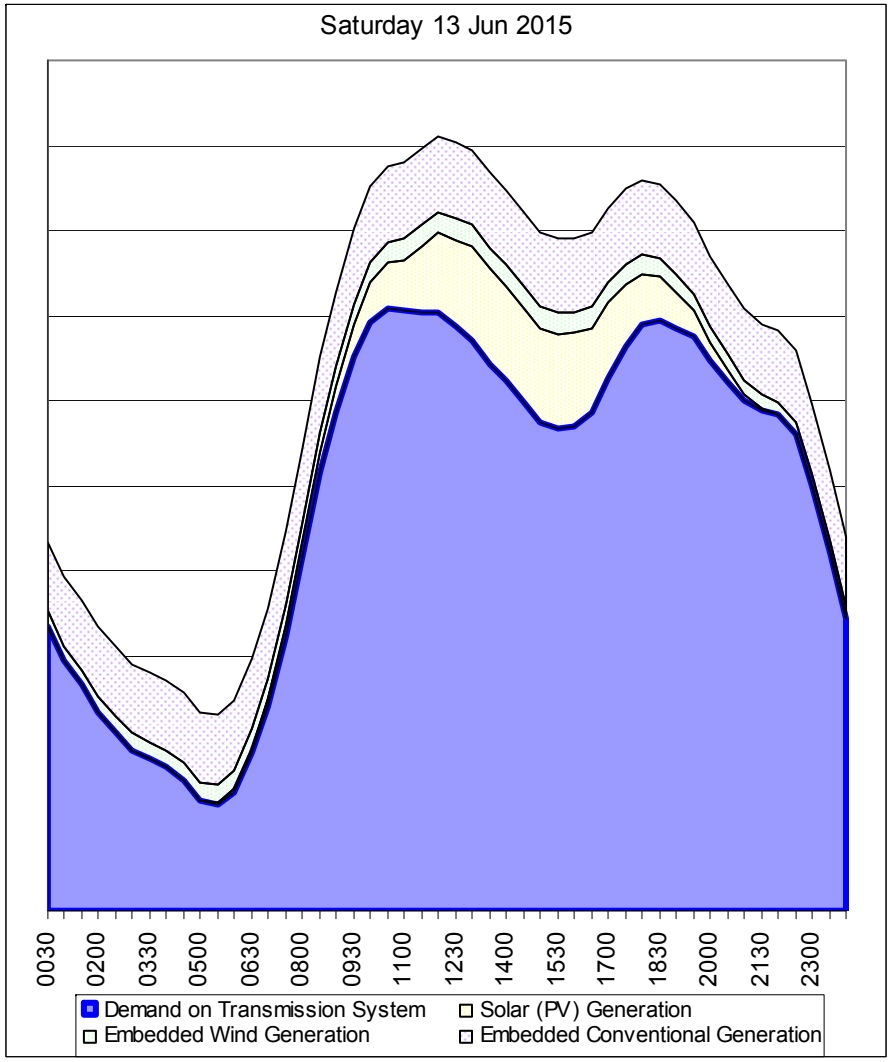
Difference between sunny and cloudy Saturdays





Difference between sunny and cloudy Saturdays





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Increasing Reliance on Weather Forecasts

- Solar Radiation is hard to forecast
- Physics of cloud formation highly complex
- Some metrological conditions particularly challenging
- Can see large errors – particularly when clouds form or clear unexpectedly

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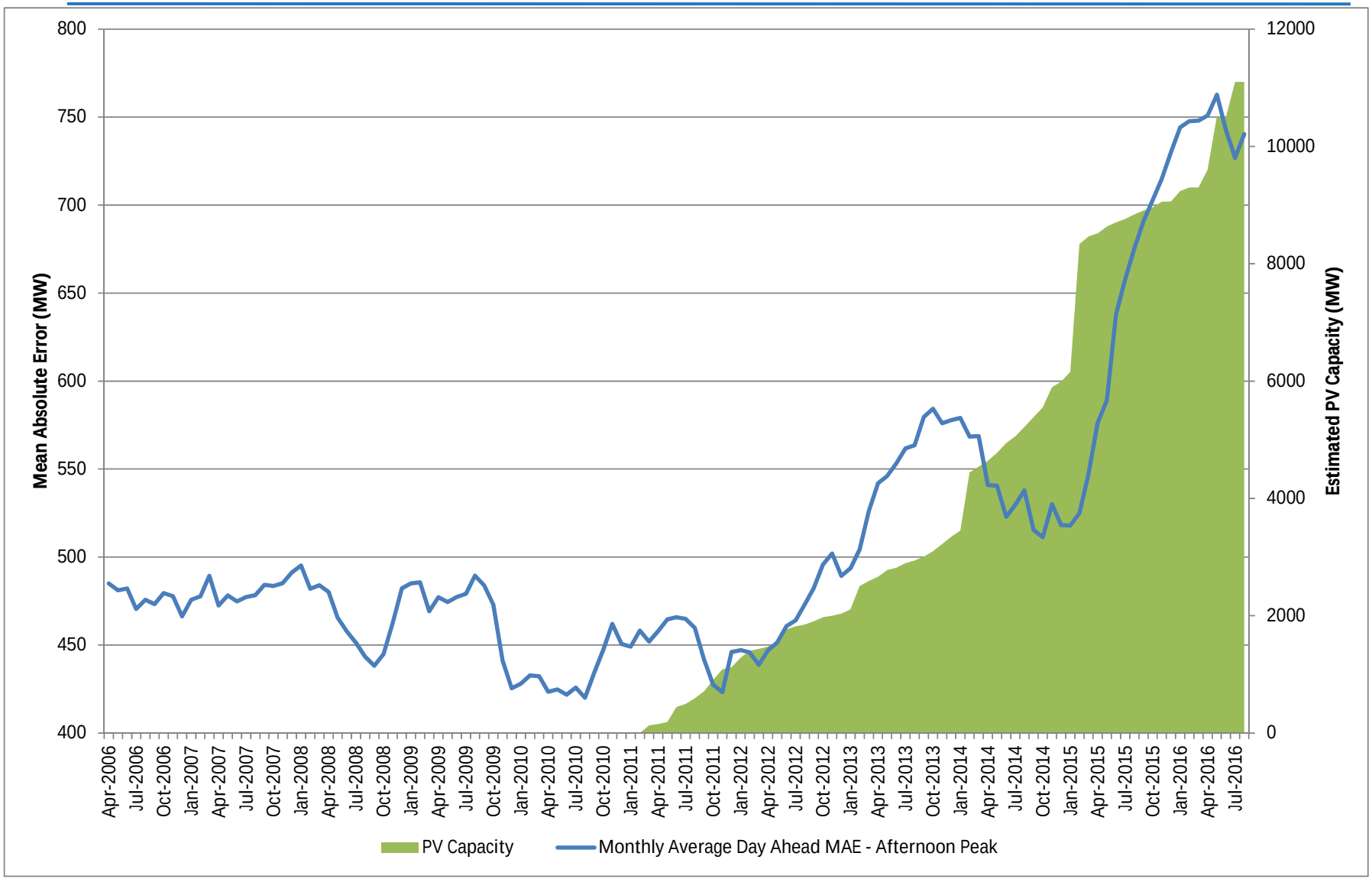
Impact of PV Growth on Forecast Error



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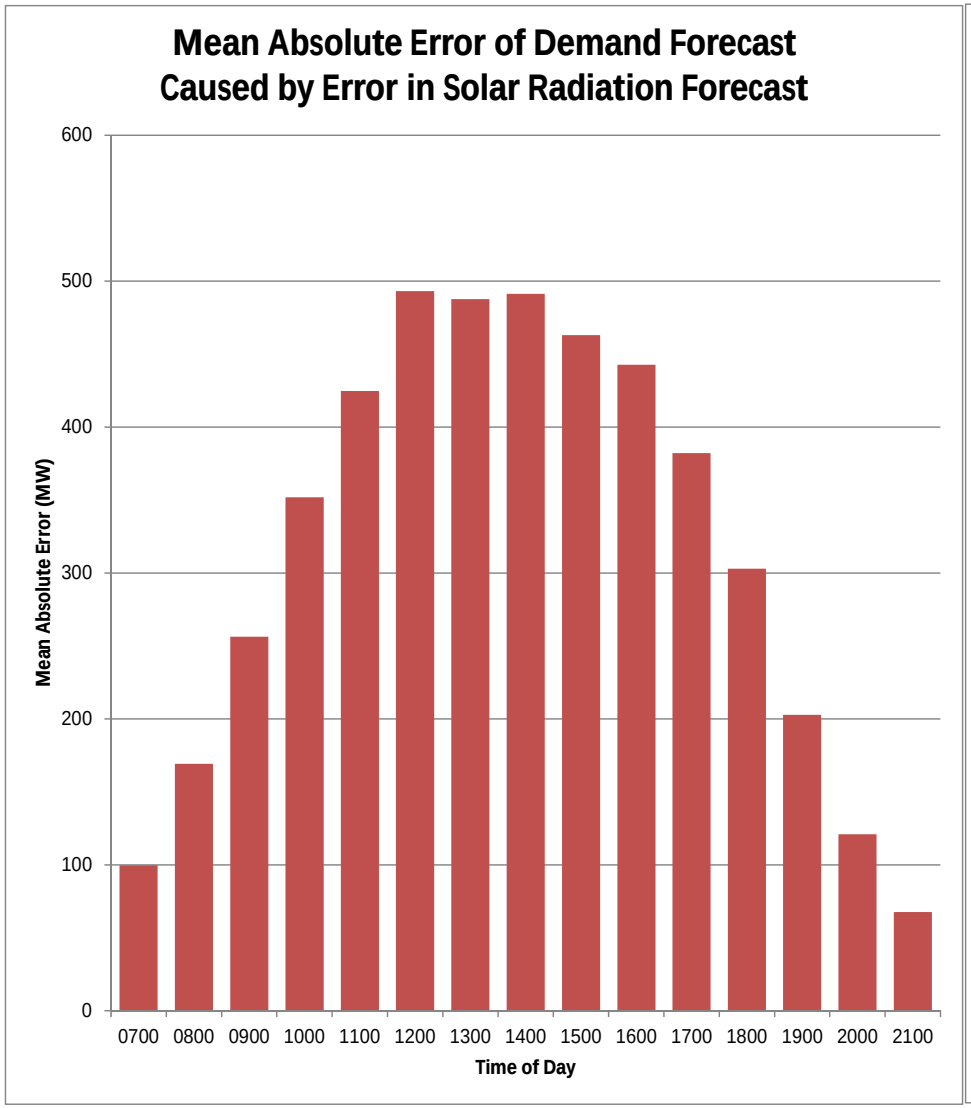
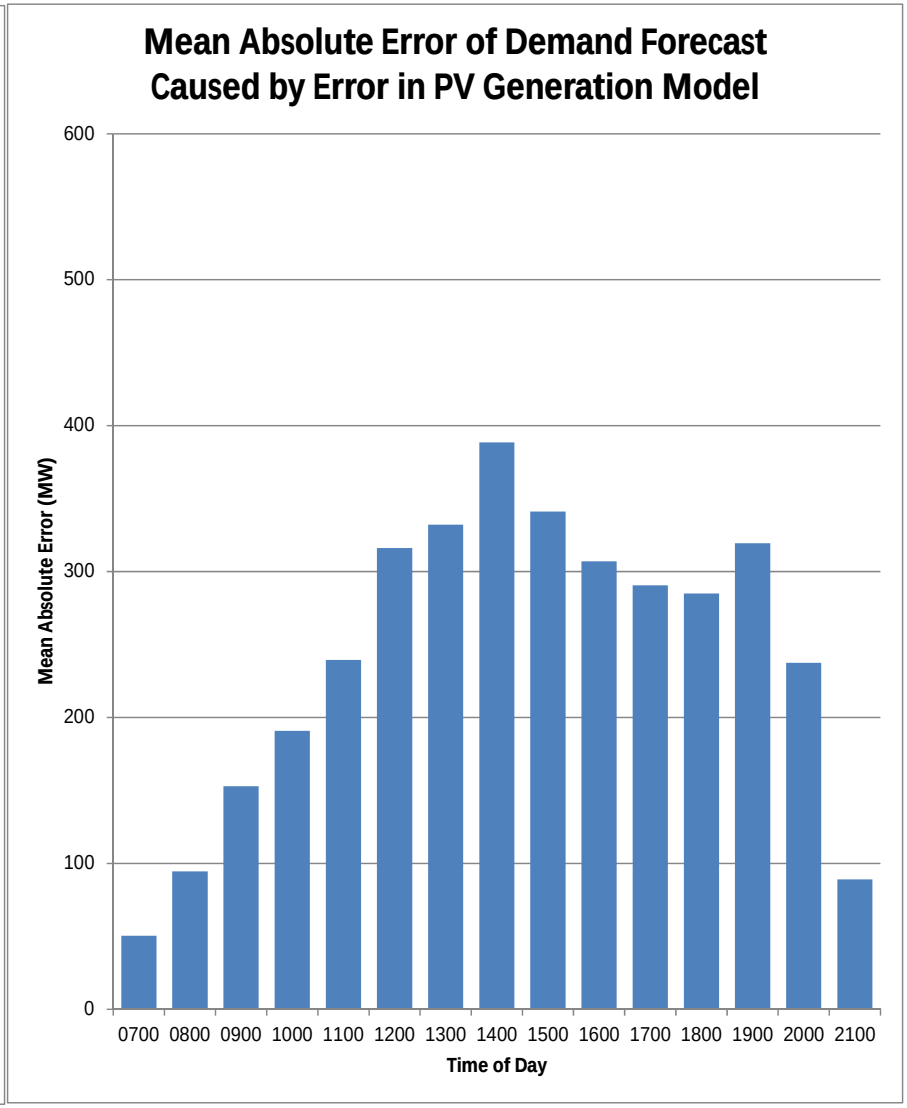
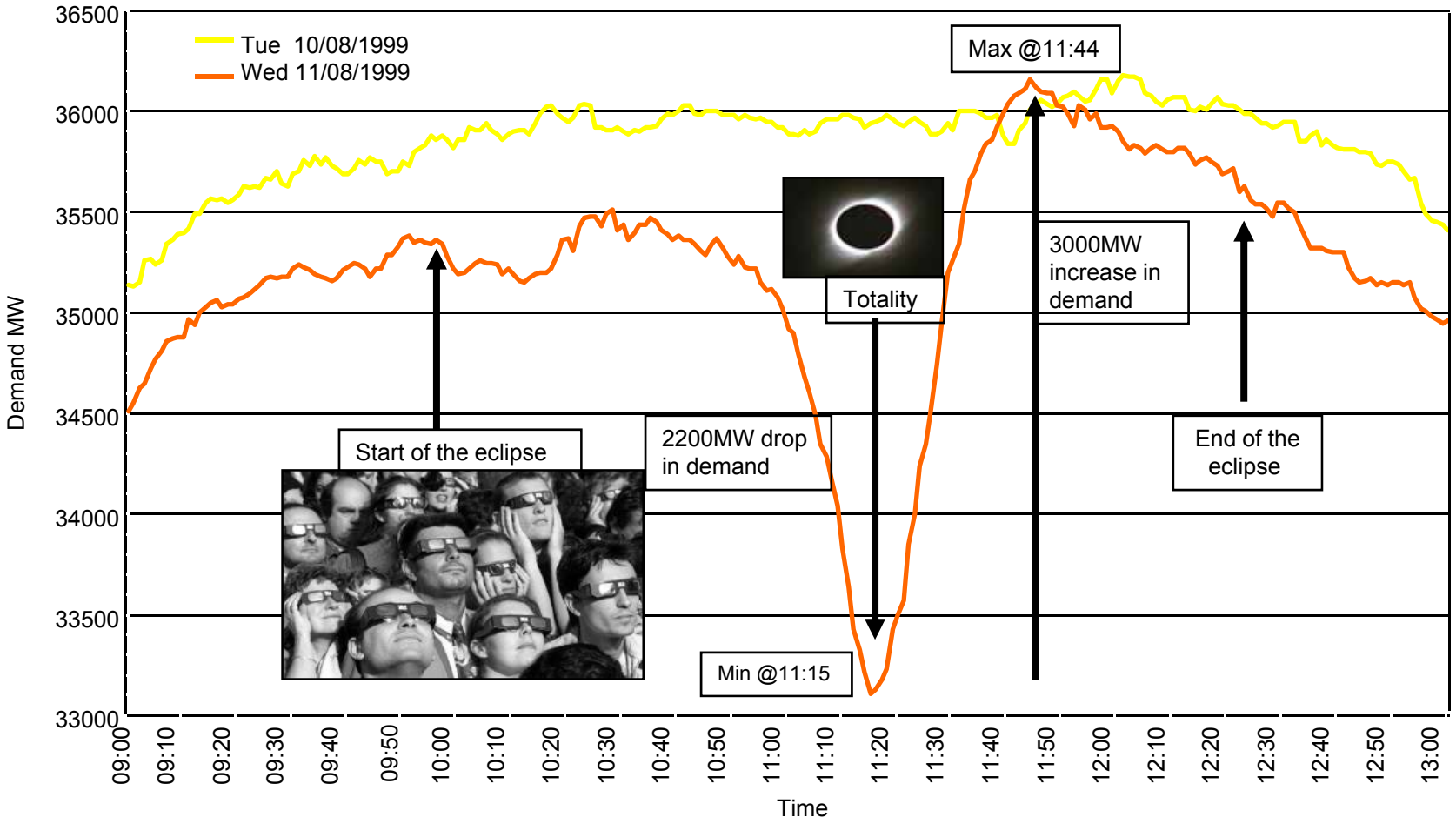
Impact of Solar Radiation Forecast





Effect of Solar Eclipse on Demand - 11 August 1999



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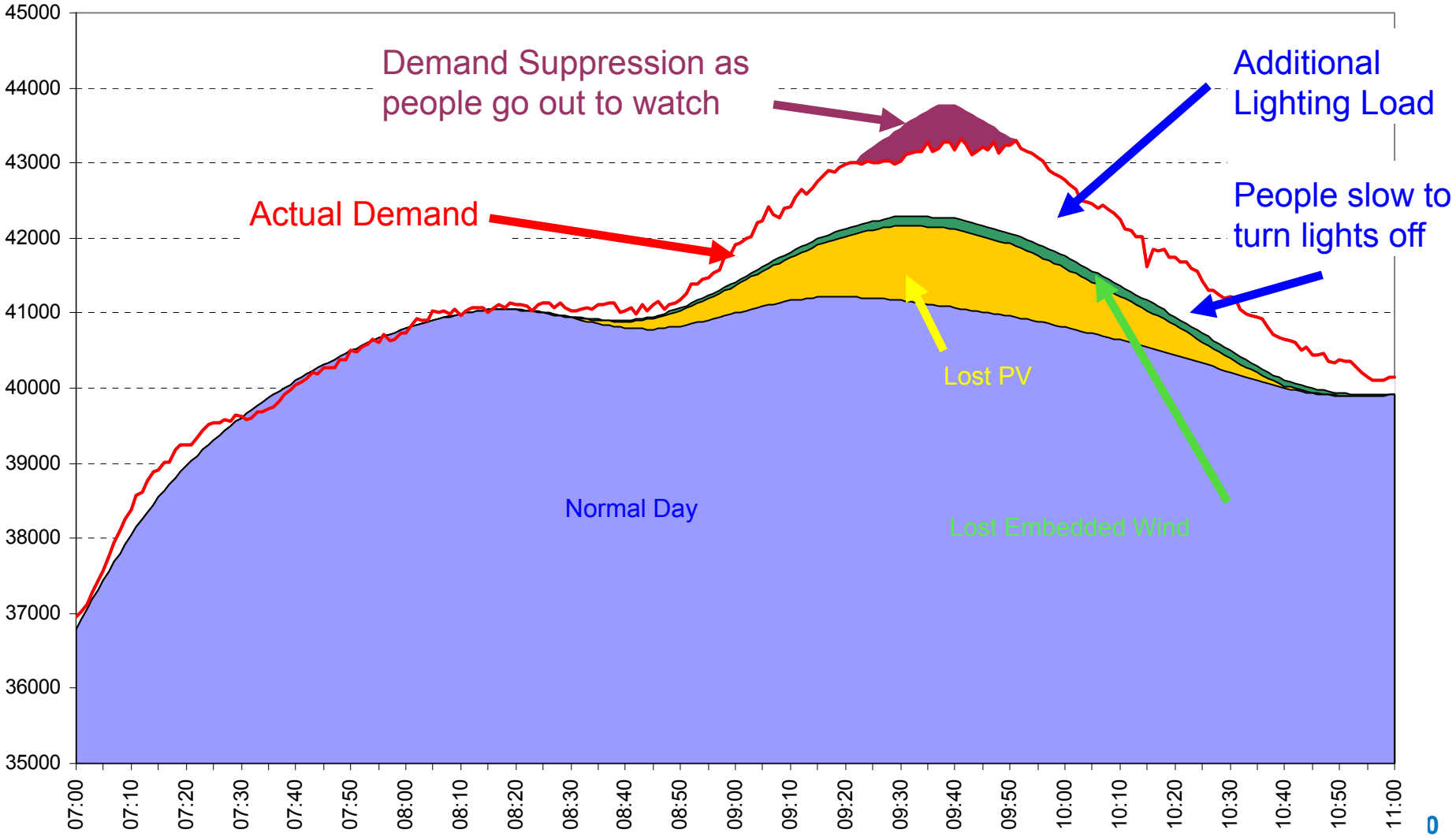
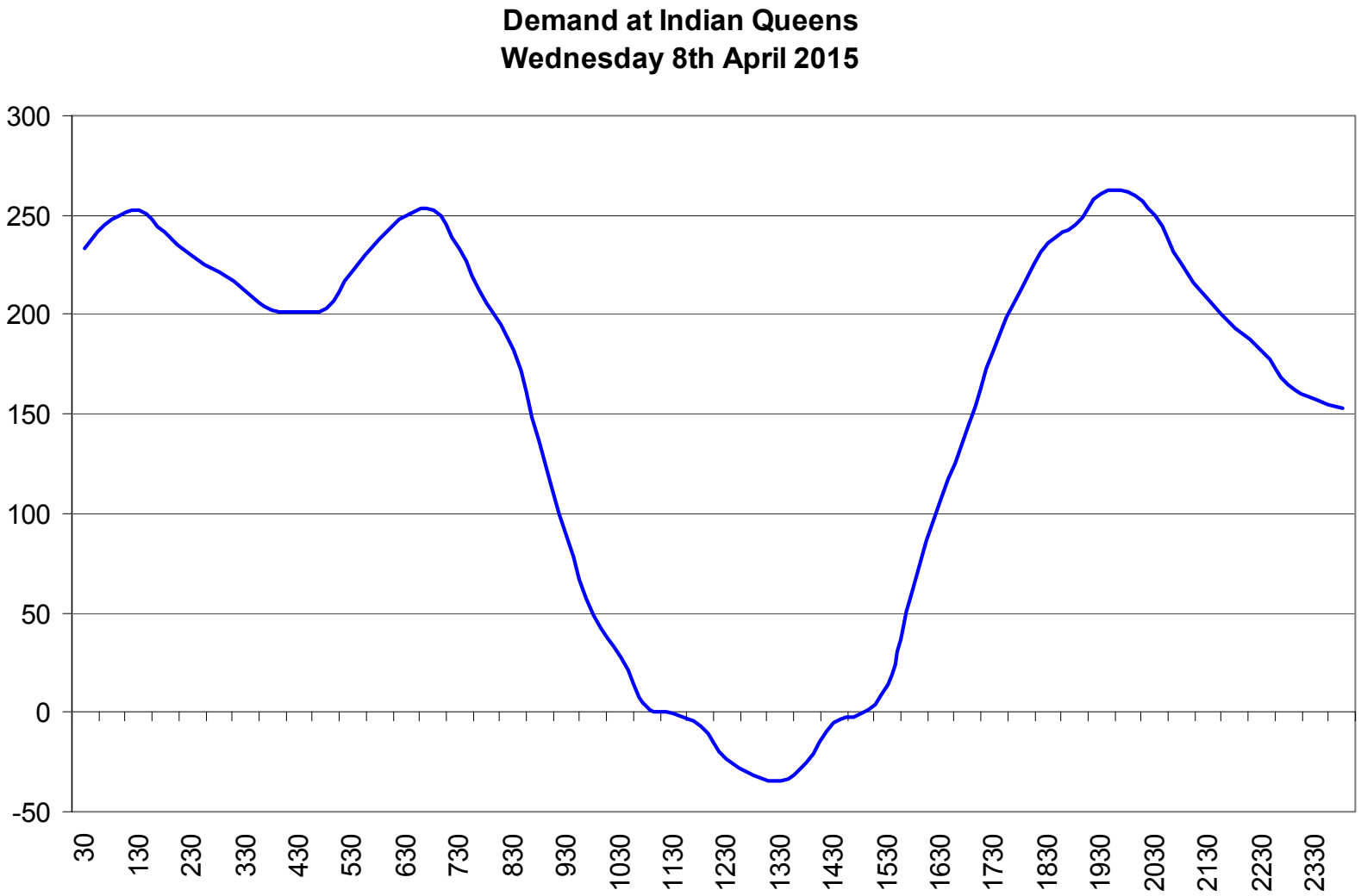
Effect of Eclipse



Effect of Embedded PV



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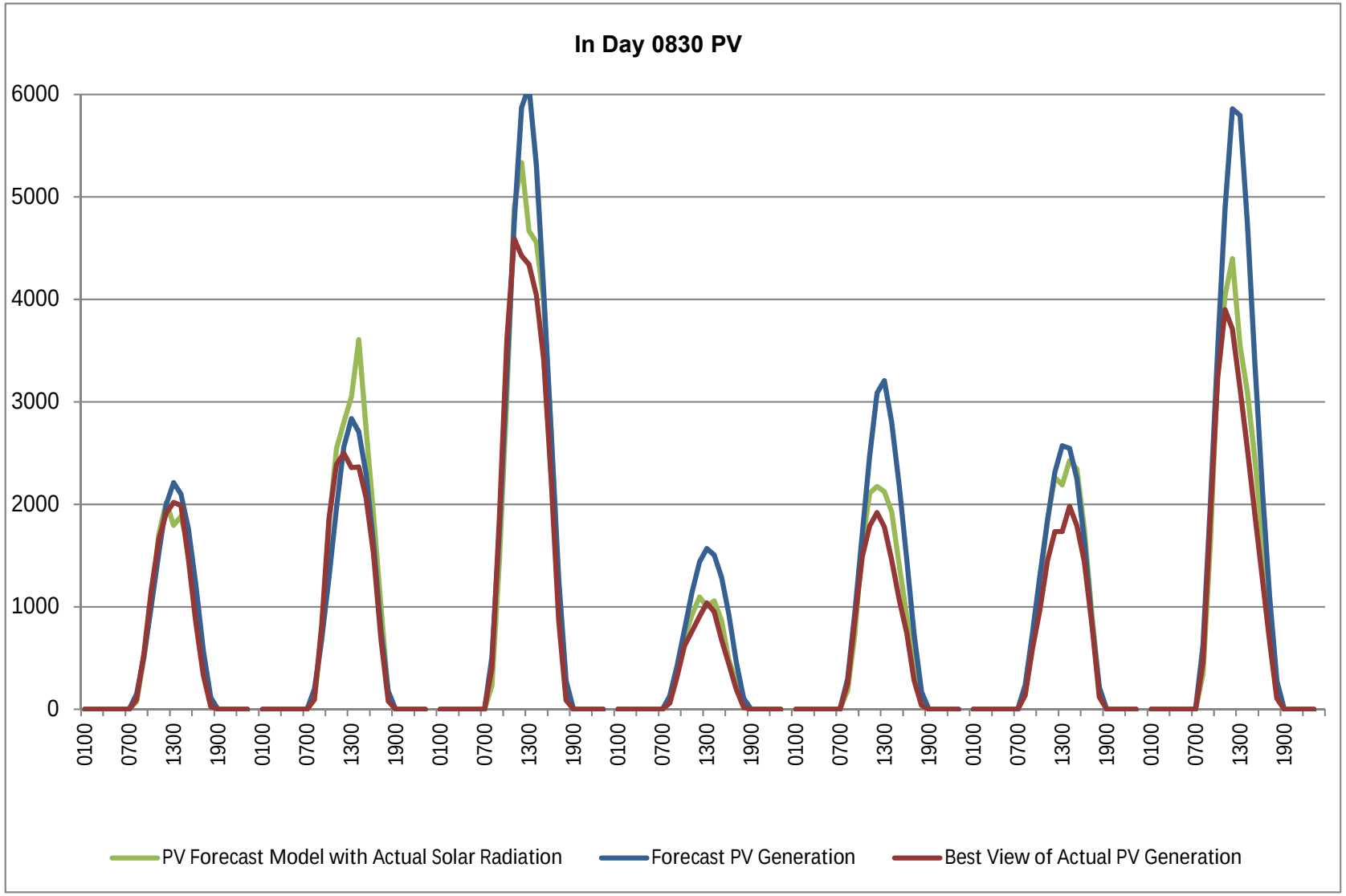
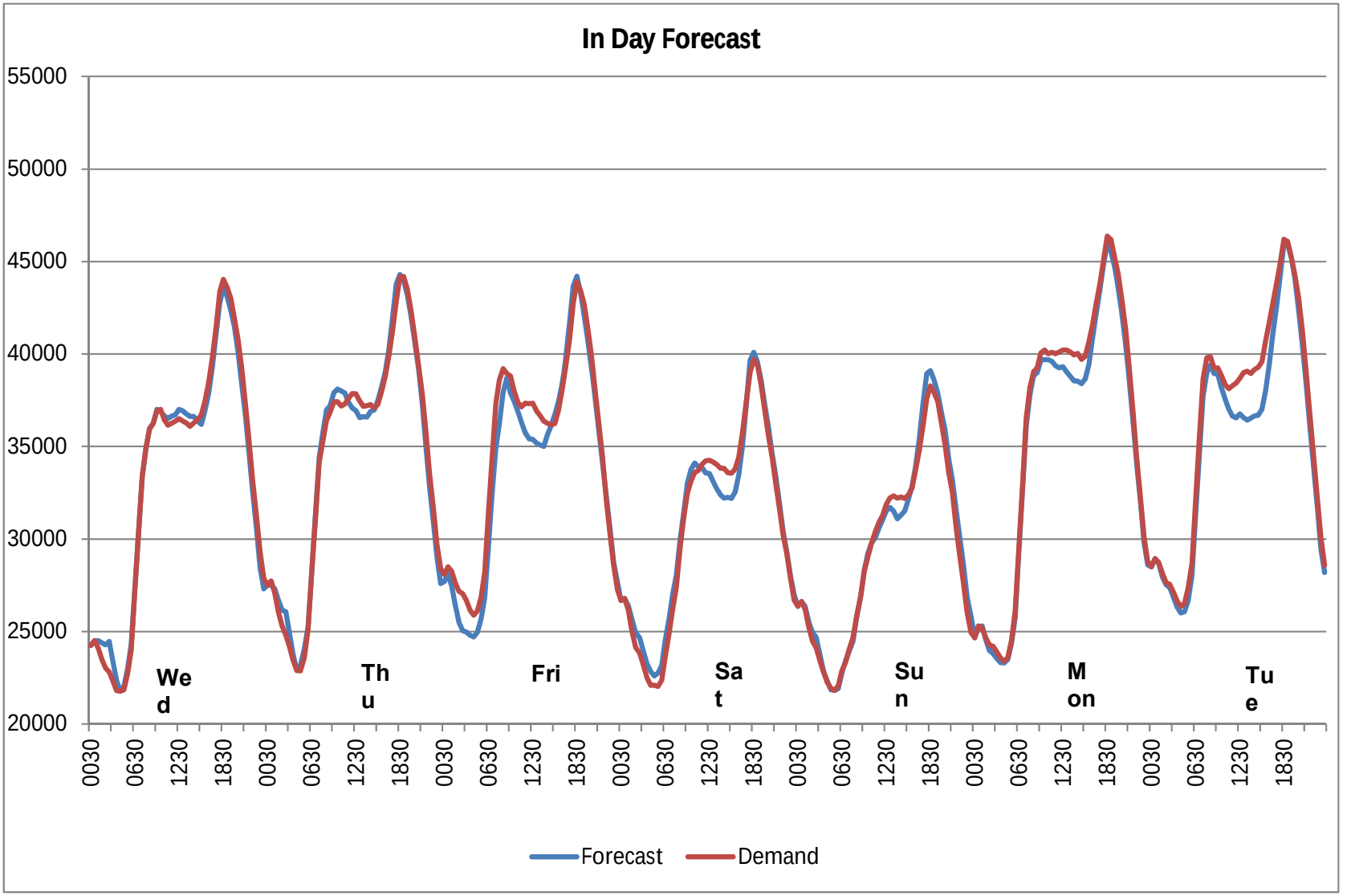
How Good Are We – PV Forecast 21-28 Feb 17



National Demand Forecast 21-28 Feb 17



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Current Energy Forecasting projects

- Sheffield Solar in partnership with the University of Sheffield
  - Better view of the live out-put of PV generation in GB
- Met Office
  - Improving the methodology of forecasting solar radiation
- University of Reading
  - Improve the conversion of solar RA into generated MW
  - Provide historical time series of renewables load factor
  - Investigate use of satellite and radar data to modify the solar RA forecast
- Modelling Embedded Non-Weather Variable Generation
- Improved modelling of PV at substation level
- Improved Embedded Wind modelling
- Improved PV Power Curves
- Live display of estimated PV output in Control Room
- Short term PV forecast based on current observations
- New methods to estimate current PV capacity