



Electrical aspects of the energy transition

How new and emerging technology can provide solutions to support the transition

Ben Adams – Principal Associate
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Grid Event - 9 August 2019

- 1.1 million electricity customers without power for between 15 and 45 minutes.
- Major disruption to the rail network
- Impacts to Ipswich hospital and Newcastle airport



Grid Event – 27 May 2008

- Longannet and Sizewell B trip
- 2GW of embedded generation trip
- ½ million without power

British Energy

Mark Milner, industrial editor, and Graeme Wearden

Wed 28 May 2008 08.00 BST



British Energy races against time after worst power cuts in a decade



Sizewell B nuclear plant. Photograph: Guardian

British Energy today vowed to get the Sizewell B nuclear power station working again within days after Britain suffered its worst blackouts in a decade.

Half a million people were hit by unscheduled power cuts on Tuesday after seven power stations, including Sizewell B in Suffolk, unexpectedly stopped working within hours of each other.

The blackouts forced hospital operations to be cancelled at High Wycombe after an emergency generator caught fire, and also cut the lights at the town's shopping centre. Thousands of homes were left without power in south London, while in the north east the problems reportedly left eight people trapped in a lift. Cheshire, Liverpool and Lincolnshire were also hit.

Definitions



Watt = Power

W, kW, MW, GW

Watt-Hour = Energy

Wh, kWh, MWh, GWh, TWh

1 GW = 1000 MW

1 MW = 1000 kW

UK peak demand 61 GW.

Annual use = 328 TWh (average of approx. 38 GW)

Average house in England

= 2700 kWh every year

Average of 0.3 kW

MW vs MWh



10kW power
6 minute shower = 1 kWh



2 kW power
0.1 kWh to boil a litre

MW vs MWh



Hornsea 1 - 1.2 GW

Expected output – 4.1 TWh

Average output = 470MW
(40%)



Sizewell B - 1.2 GW

Output 2022– 10.4 TWh

Average output = 1.18 GW



Shotwick Park - 72 MW

Expected output– 68590 MWh

Average output = 7.2 MW
(10%)



The good old days...

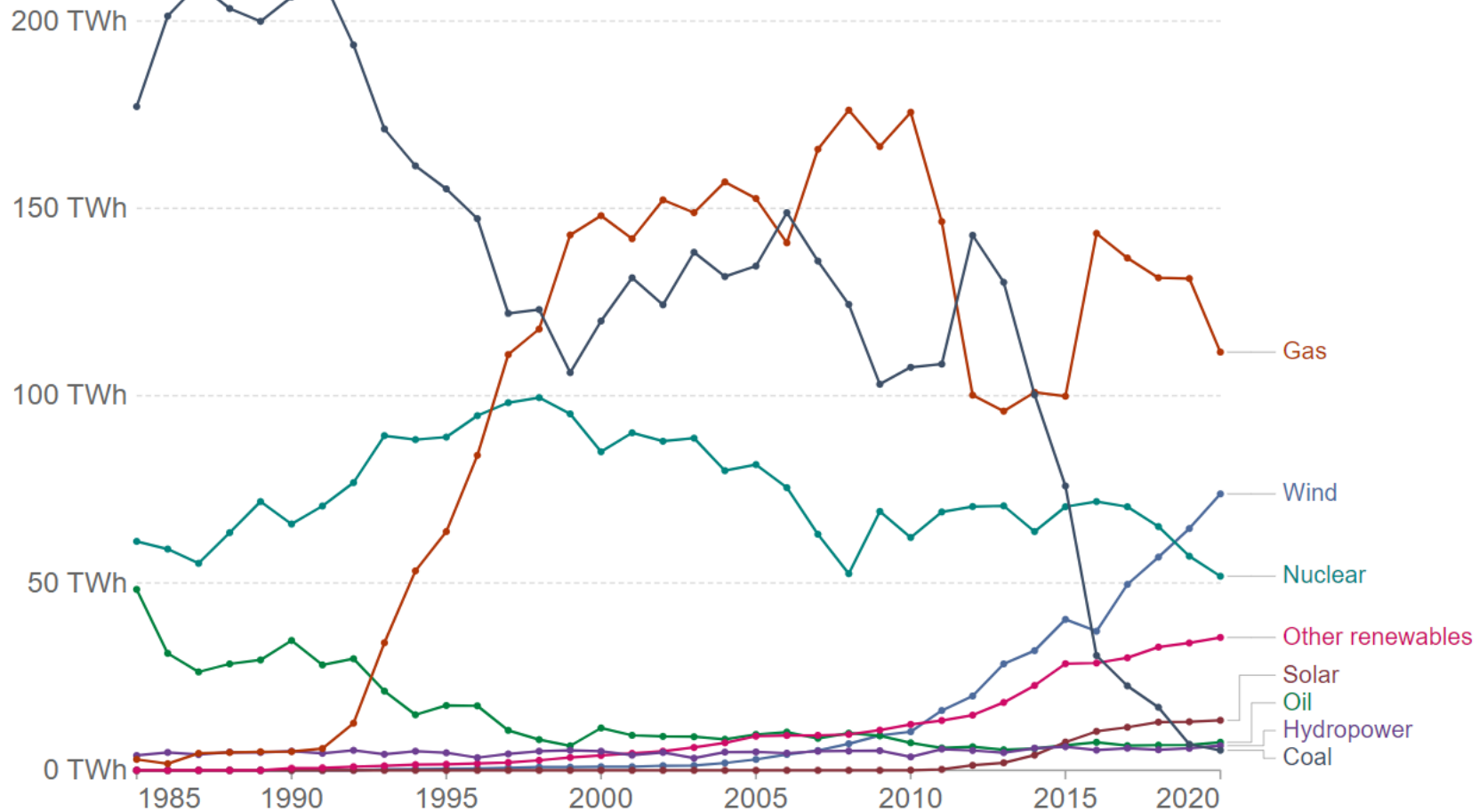
Traditional Power Plants



Generation Mix

Electricity production by source, United Kingdom

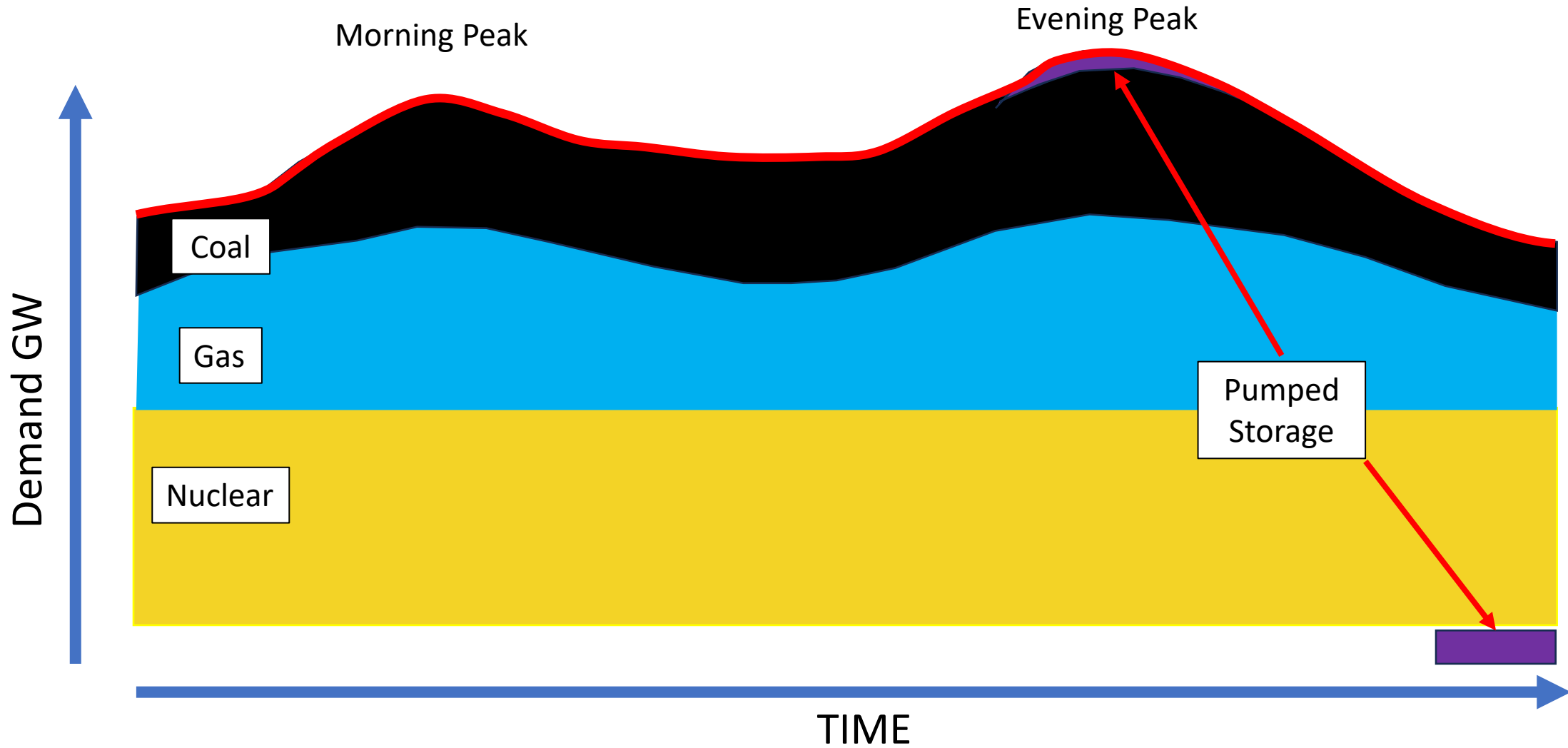
Our World
in Data



Source: Our World in Data based on BP Statistical Review of World Energy & Ember (2021)
Note: 'Other renewables' includes biomass, waste, geothermal and wave and tidal energy.

OurWorldInData.org/energy • CC BY

Generation Dispatch

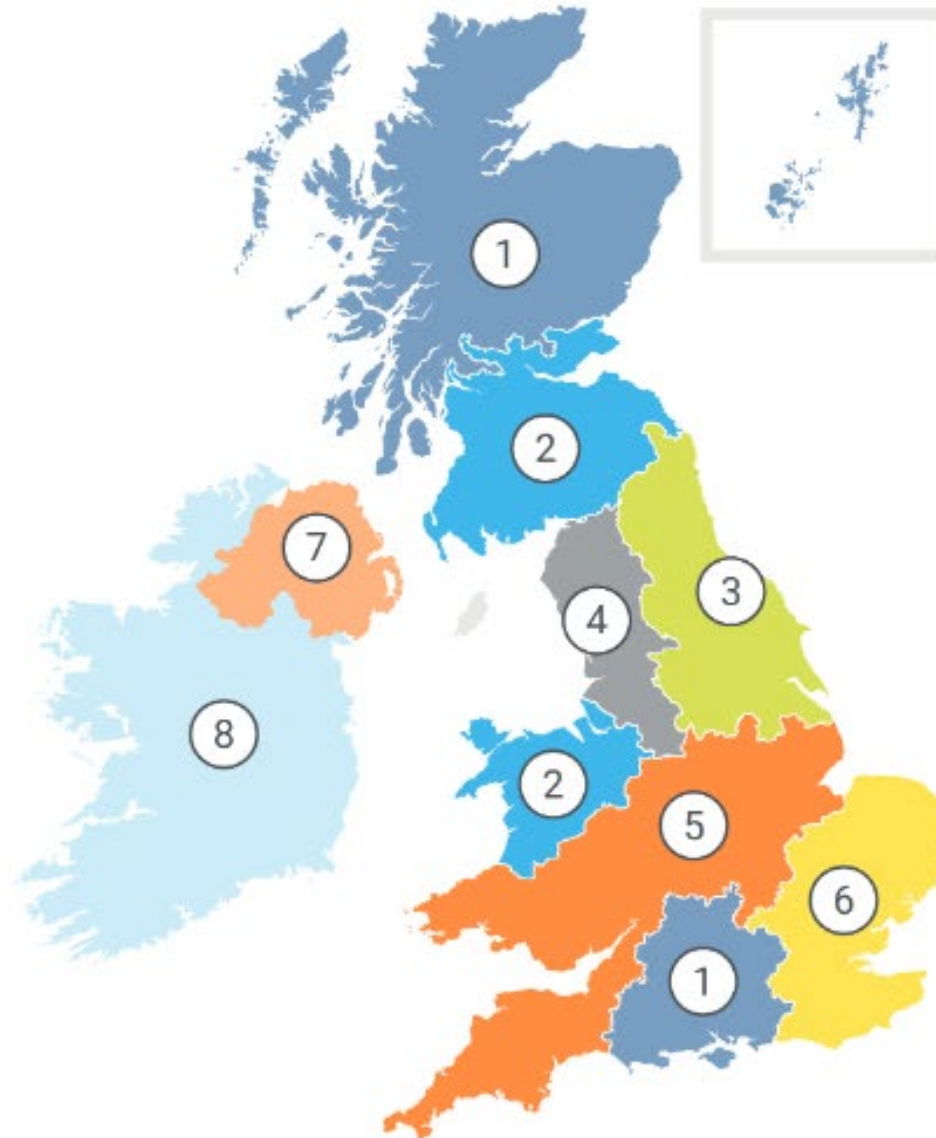


What is the grid? - Distribution

Electricity distribution



- ① Scottish & Southern Electricity Networks
- ② SP ENERGY NETWORKS
- ③ NORTHERN POWERGRID
- ④ electricity north west
Bringing energy to your door
- ⑤ nationalgrid
- ⑥ UK Power Networks
Delivering your electricity
- ⑦ Northern Ireland Electricity Networks
- ⑧ ESB NETWORKS



400 V to
132 kV

Independent distribution network operator

What is the grid? – Transmission



400 kV and
275 kV circuits

What is the grid? – TSO

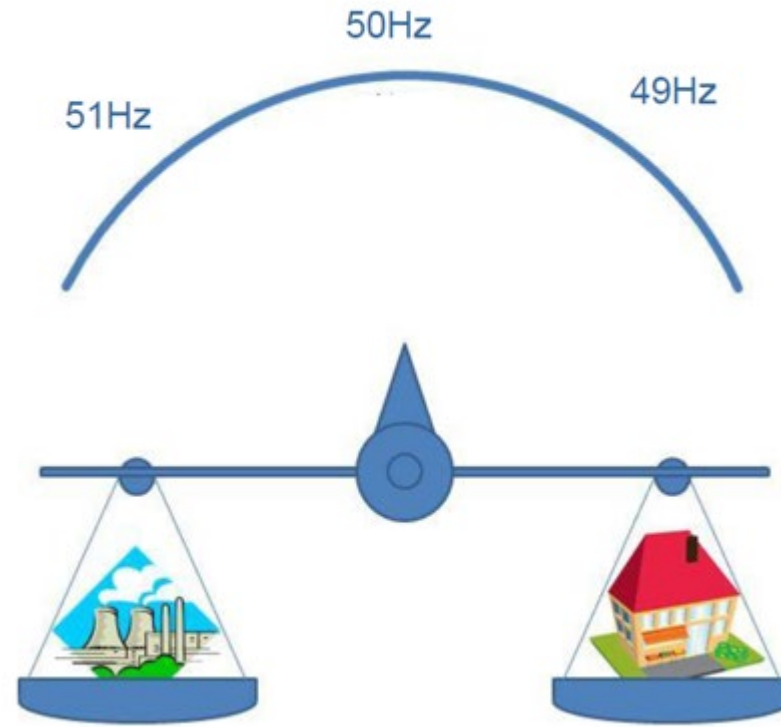


National Grid has a statutory obligation to maintain the frequency of the National Electricity Transmission System within $\pm 1\%$ of 50Hz (49.5 to 50.5Hz). The control room normally control frequency within a tighter operational limit of 49.8 to 50.2Hz.

nationalgridESO

EirGrid

Demand vs Supply



Generation VS Demand

Pick up

Pickup demand ▼	Date ◆	Programme ◆
2800 MW	4 July 1990	England v West Germany FIFA World Cup semi-final penalty shootout ^{[3][12]}
2600 MW	22 January 1984	<i>The Thorn Birds</i> ^[3] – Final episode ^[13]
2570 MW	21 June 2002	England v Brazil FIFA World Cup quarter-final ^[3]
2340 MW	12 June 2002	Nigeria v England FIFA World Cup group match ^[14]
2290 MW	5 April 2001	<i>EastEnders</i> ^[3] – "Who Shot Phil?" ^[12]
2200 MW	18 April 1994	<i>EastEnders</i> & <i>Coronation Street</i> (combined) ^[15]
2200 MW	12 May 1991	<i>The Darling Buds of May</i> ^[12]
2200 MW	28 April 1991	<i>The Darling Buds of May</i> ^[15]
2200 MW	20 July 1989	<i>The Thorn Birds</i> ^[17]
2200 MW	5 August 1985	<i>Dallas</i> ^[17]
2200 MW	16 January 1984	<i>The Thorn Birds</i> ^[15] – Episode 4/5 ^[16]

Pick up



It was revealed on 5 April 2001 that [Lisa Shaw \(Lucy Benjamin\)](#) — Phil's former girlfriend — was the culprit.^[7] The episode caused the third-largest [TV pickup](#) power surge on record^[8] and the Liverpool and Barcelona [UEFA Cup](#) semi-final was postponed for 15 minutes to accommodate a special 40 minute edition of the soap.^[9]



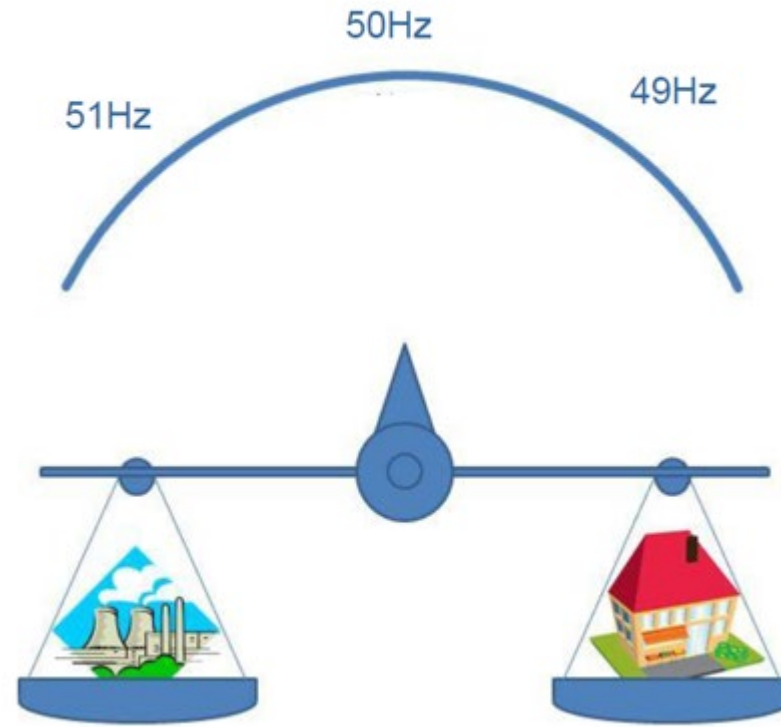
Pick up

Wind farm	Location	Coordinates	Capacity (MW)	Turbines number	Turbines model	Commissioning date	Refs
Hornsea Project Two	United Kingdom	 53°54'36.0"N 1°33'6.5"E	1,386	165	Siemens Gamesa 8.0-167 DD	2022	[2][3]
Hornsea Project One	United Kingdom	 53°53'6"N 1°47'28"E	1,218	174	Siemens Gamesa SWT-7.0-154	2019	[4][5]
Seagreen	United Kingdom	 56°35'17"N 1°44'28"W	1,075	114	MHI Vestas V164-10 MW	2023	[6]
Moray East	United Kingdom	 58°10'1.49"N 2°41'54.67"W	950	100	MHI Vestas V164-9.5 MW	2022	[7]
Triton Knoll	United Kingdom	 53°24'N 0°54'E	857	90	MHI Vestas V164-9.5 MW	2021	[8][9]
Borssele I & II	Netherlands	 51°42'10"N 3°4'34"E	752	94	Siemens Gamesa 8MW	2020	[10][11]
Borssele III & IV	Netherlands	 51°42'25.2"N 2°54'44.6"E	731.5	77	MHI Vestas V164-9.5 MW	2021	[12][13]

Pick up

Pickup demand ◆	Date ▼	Programme ◆
1800 MW	11 July 2021	England v Italy UEFA European Football Championship final ^[18]
1400 MW	7 July 2021	England v Denmark UEFA European Football Championship semi-final ^[21]
950 MW	16 April 2020	Clap for Our Carers ^[12]
1400 MW	11 July 2018	England v Croatia FIFA World Cup semi-final ^[19]
1400 MW	7 July 2018	England v Sweden FIFA World Cup quarter-final ^[20]
1200 MW	3 July 2018	England v Colombia FIFA World Cup round of 16 ^[22]

Frequency



Generation VS Demand

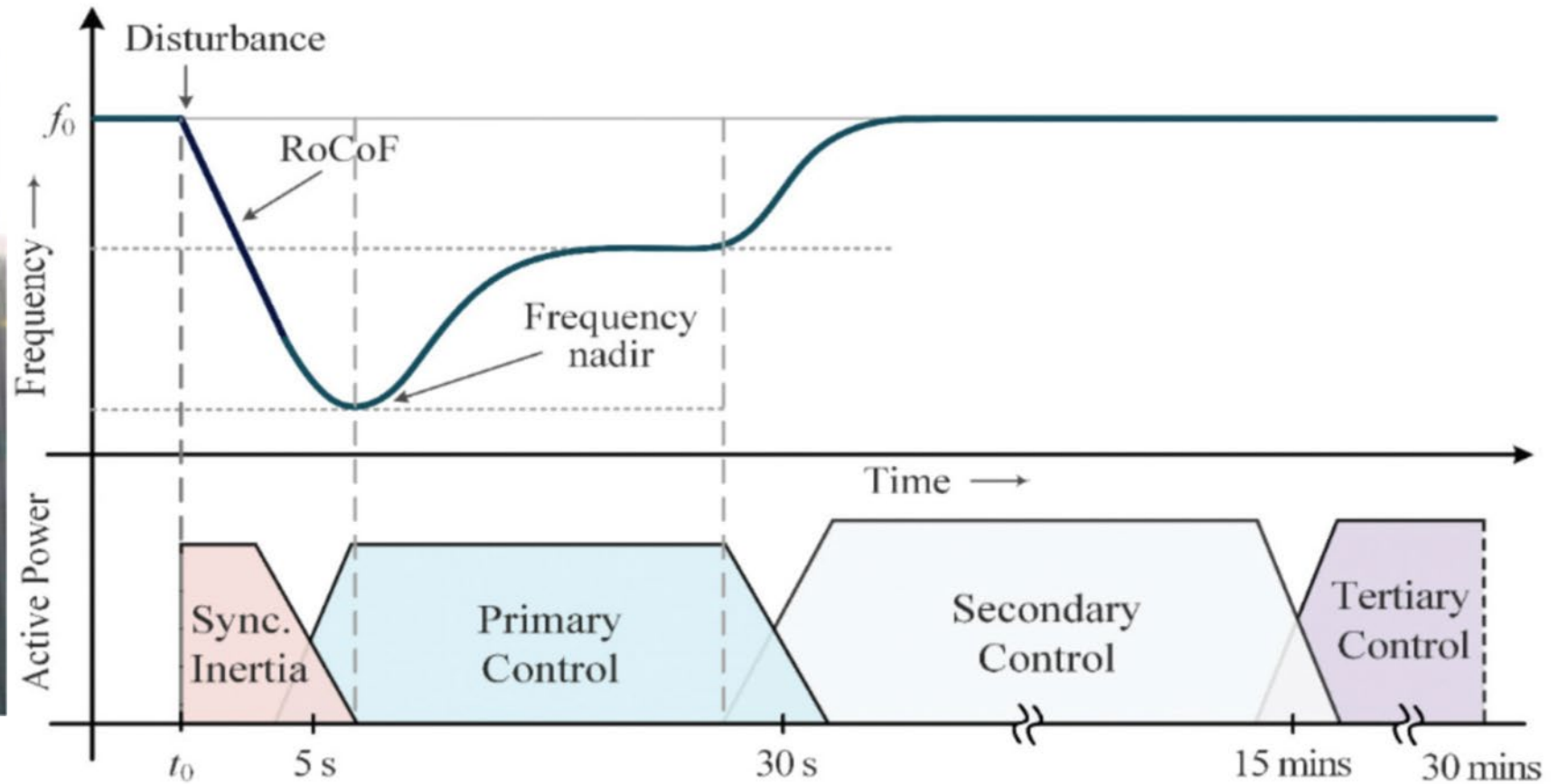
Grid system - Example



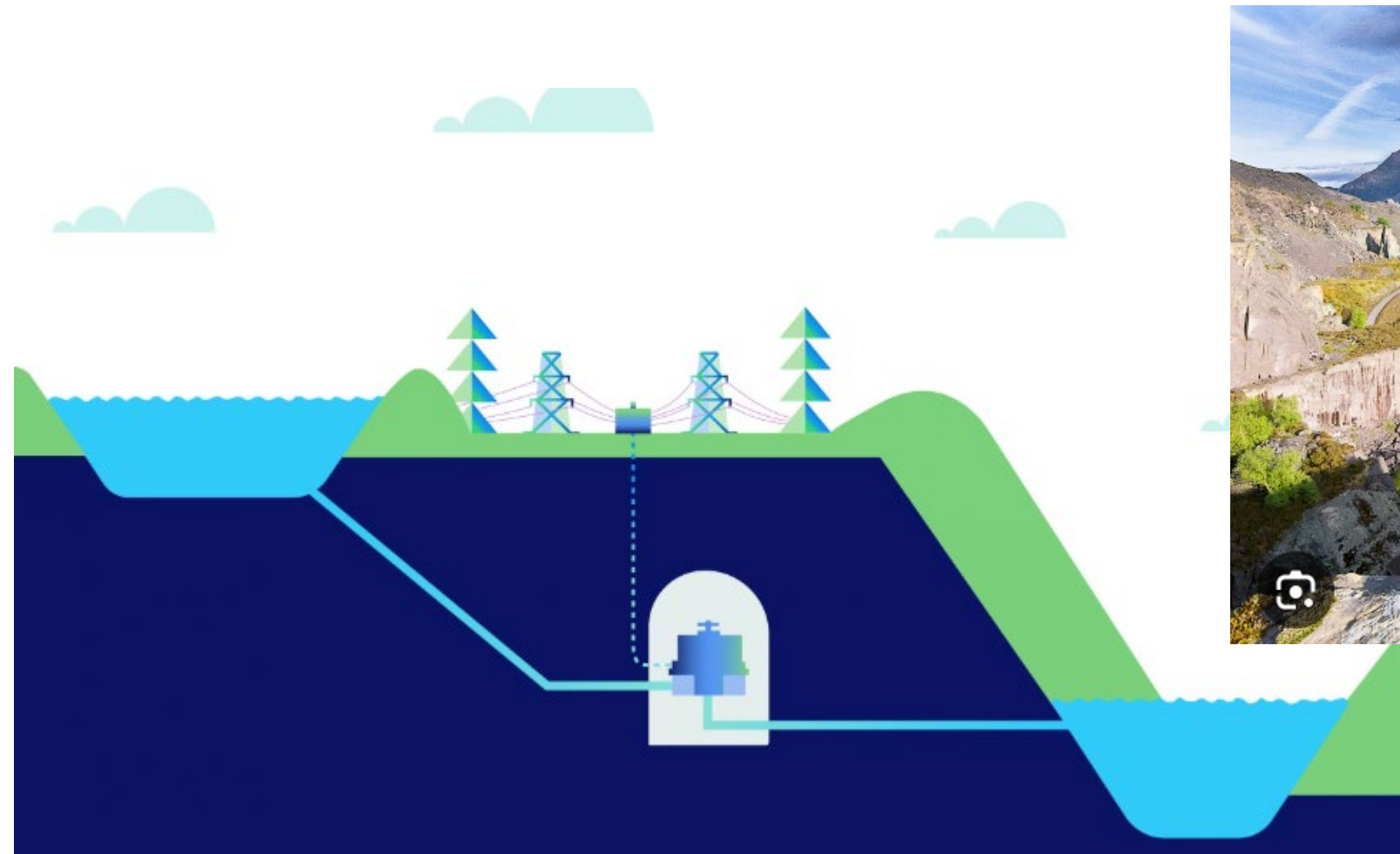
How do you control frequency...?



Fig. 1: Frequency control continuum



Pumped Storage



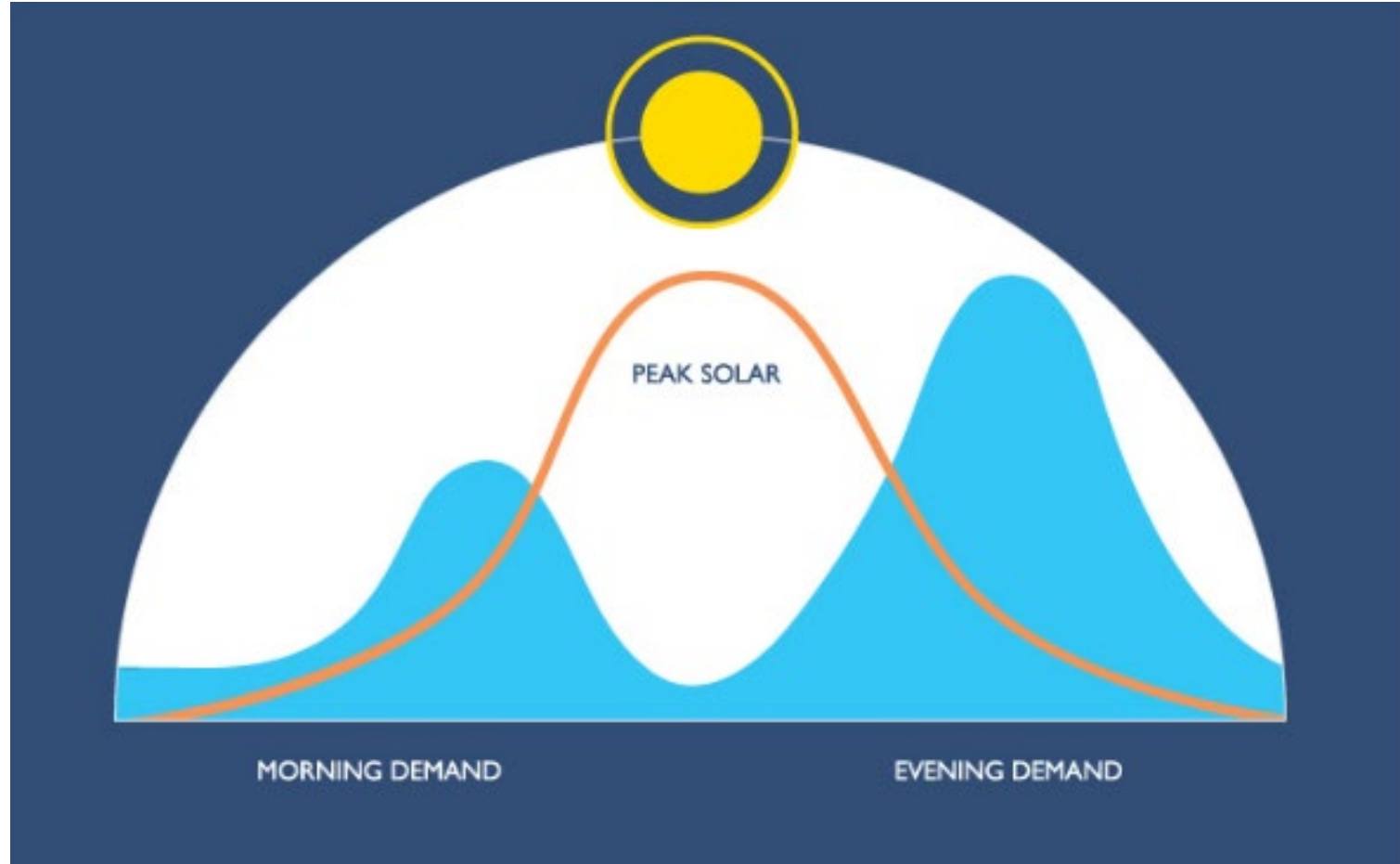
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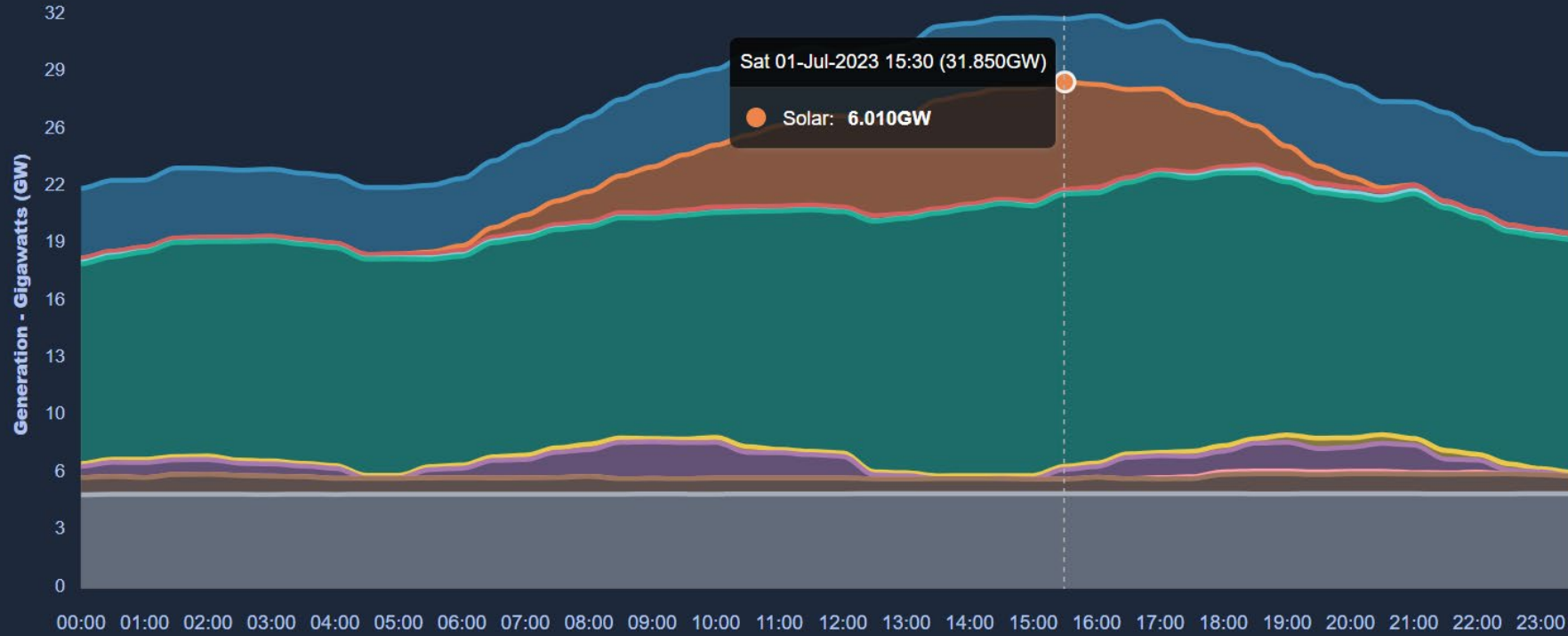
Transition to renewables

Thermal to Renewables

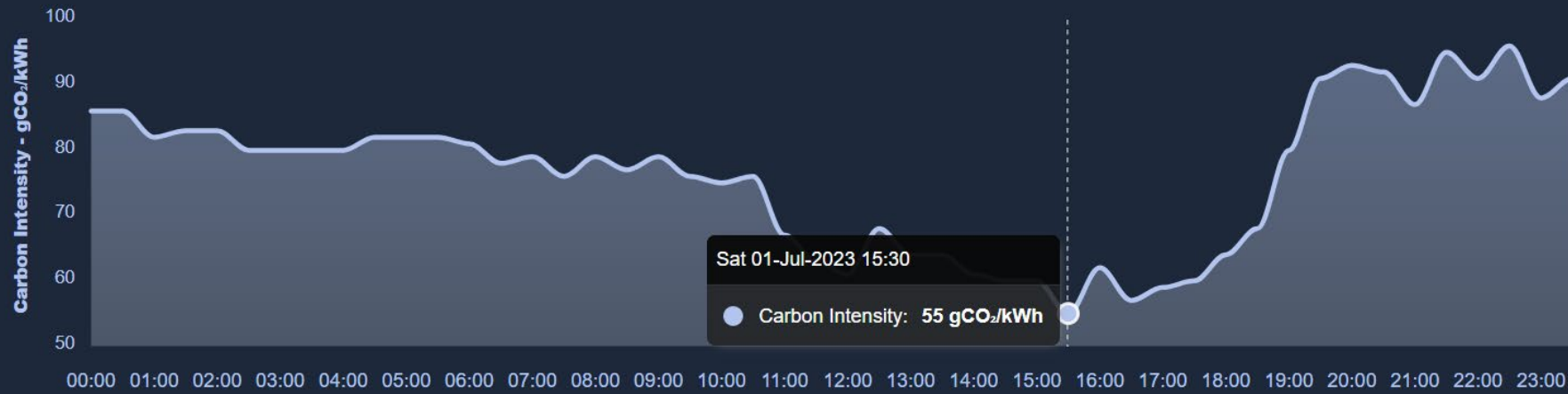


Solar Power



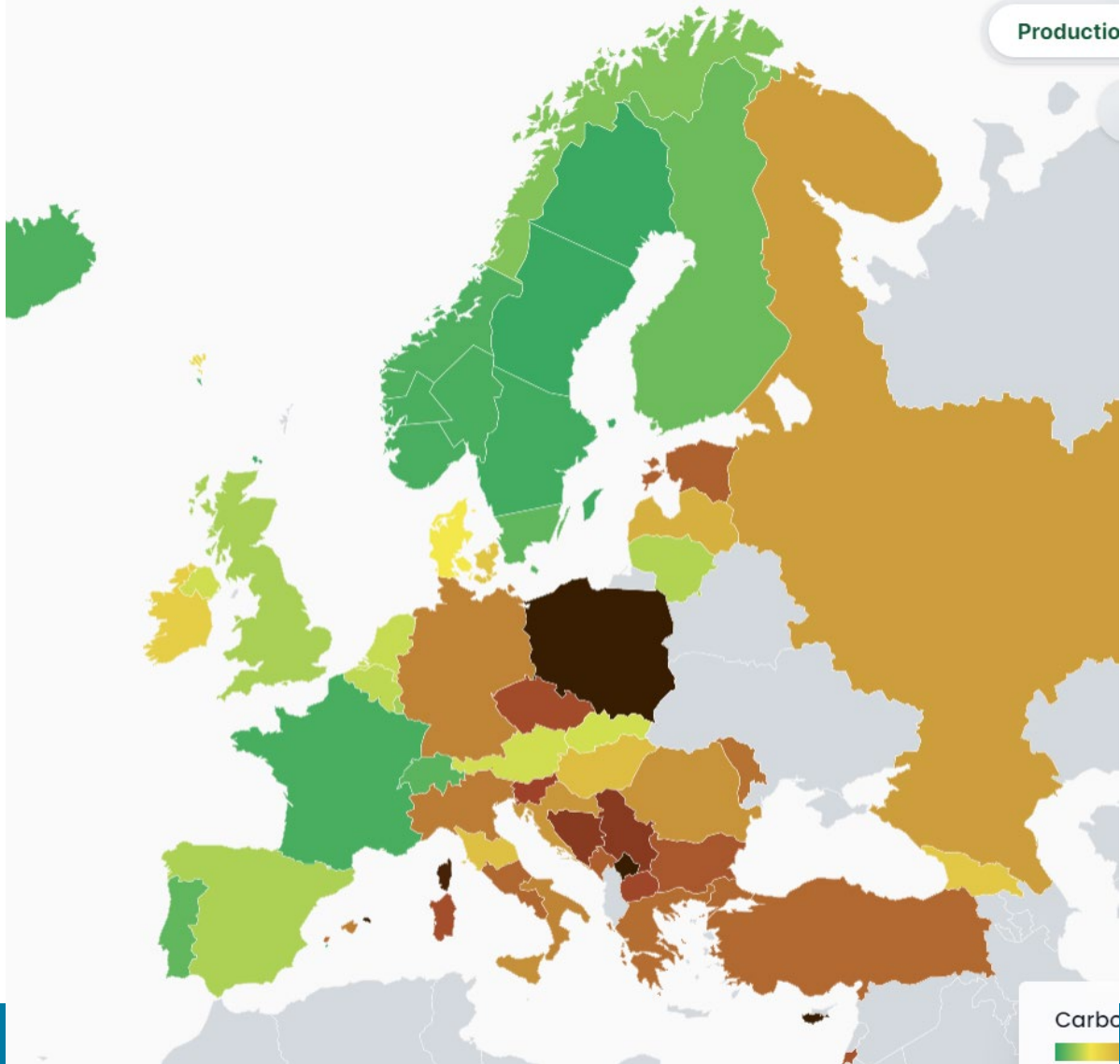


Source	GW	%	GWh
Gas	3.5	11.1	-
Solar	6.0	18.9	-
Coal	0.2	0.7	-
Hydro	0.0	0.1	-
Wind	15.2	47.8	-
Misc	0.2	0.5	-
Imports	0.5	1.7	-
PSH	0.0	0.0	-
Biomass	0.8	2.6	-
Nuclear	5.3	16.6	-
All	31.8	100	-



Source	gCO ₂ /kWh	%	CO ₂ (t)
Biomass	120	5.6	98
Coal	937	12.4	217
Gas	394	79.4	1,390
Misc	300	3.0	52
Imports	-12	-0.4	-7
All	55	100	1,752

Solar Power



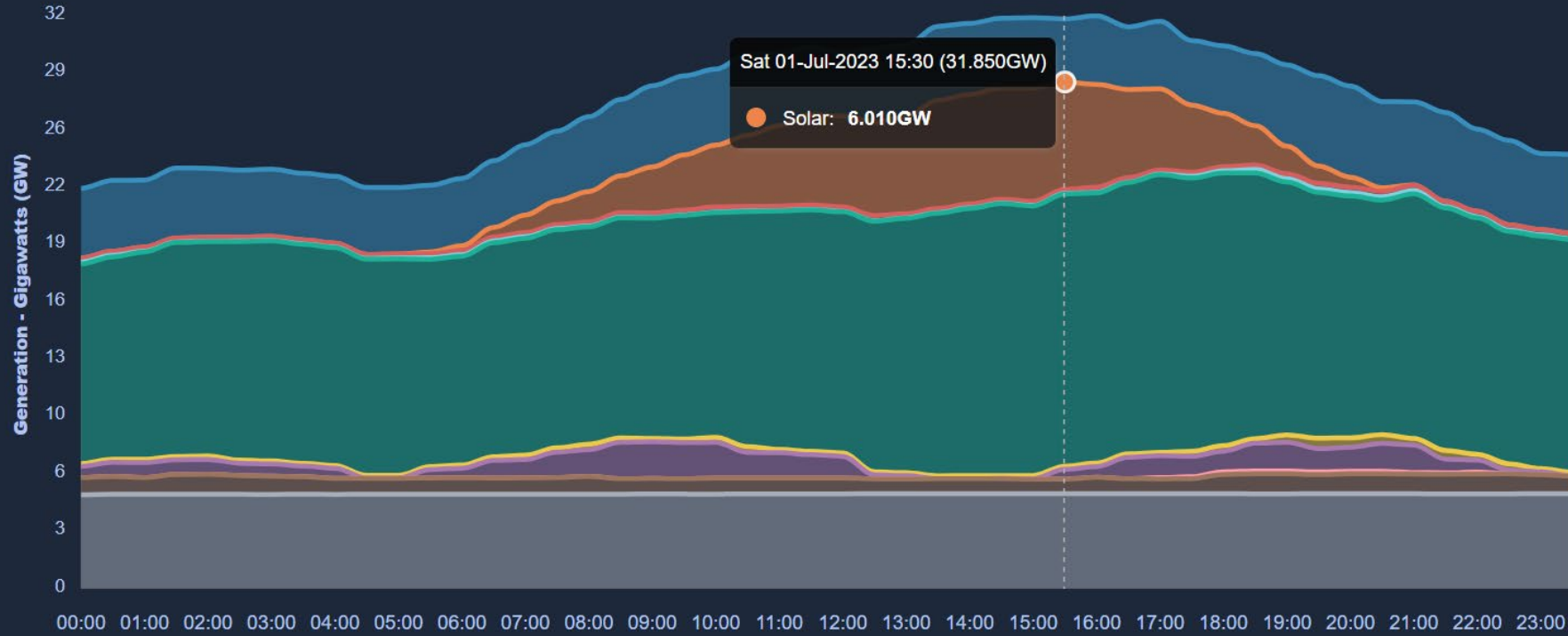
18 October

UK – 94g

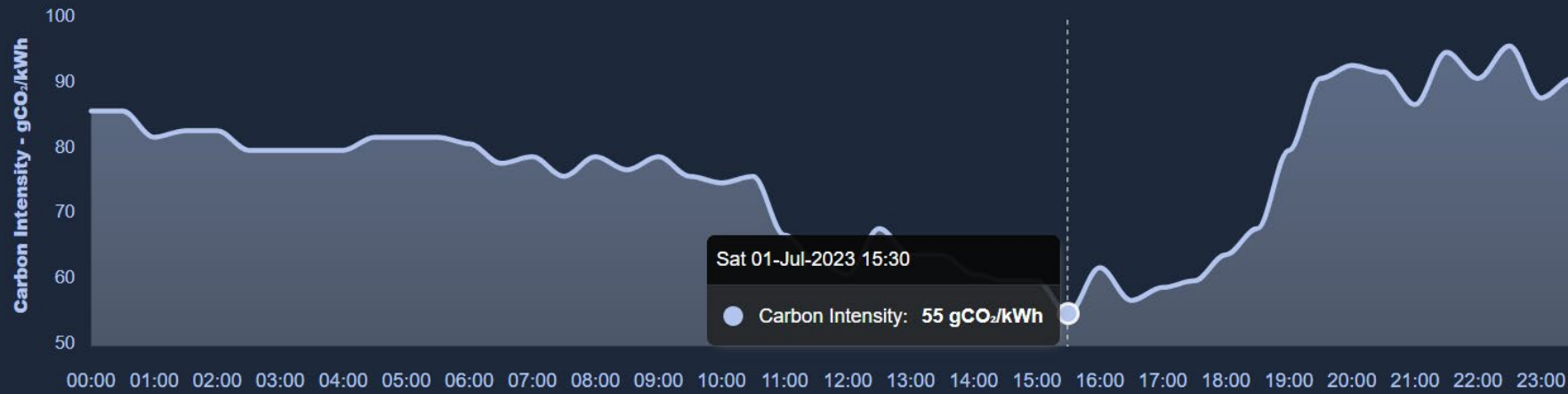
France - 24g

Germany – 425g

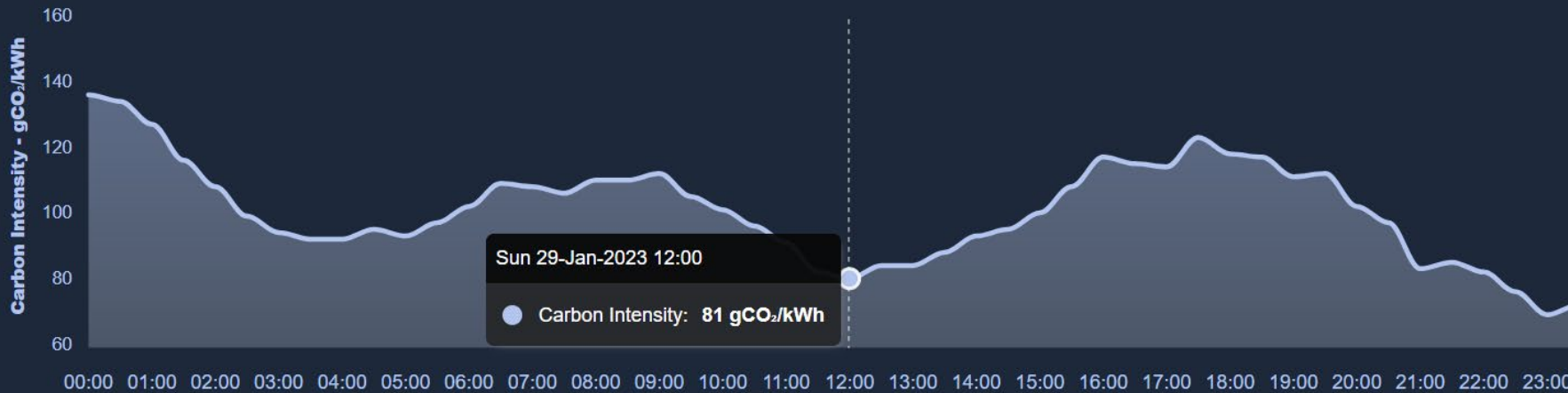
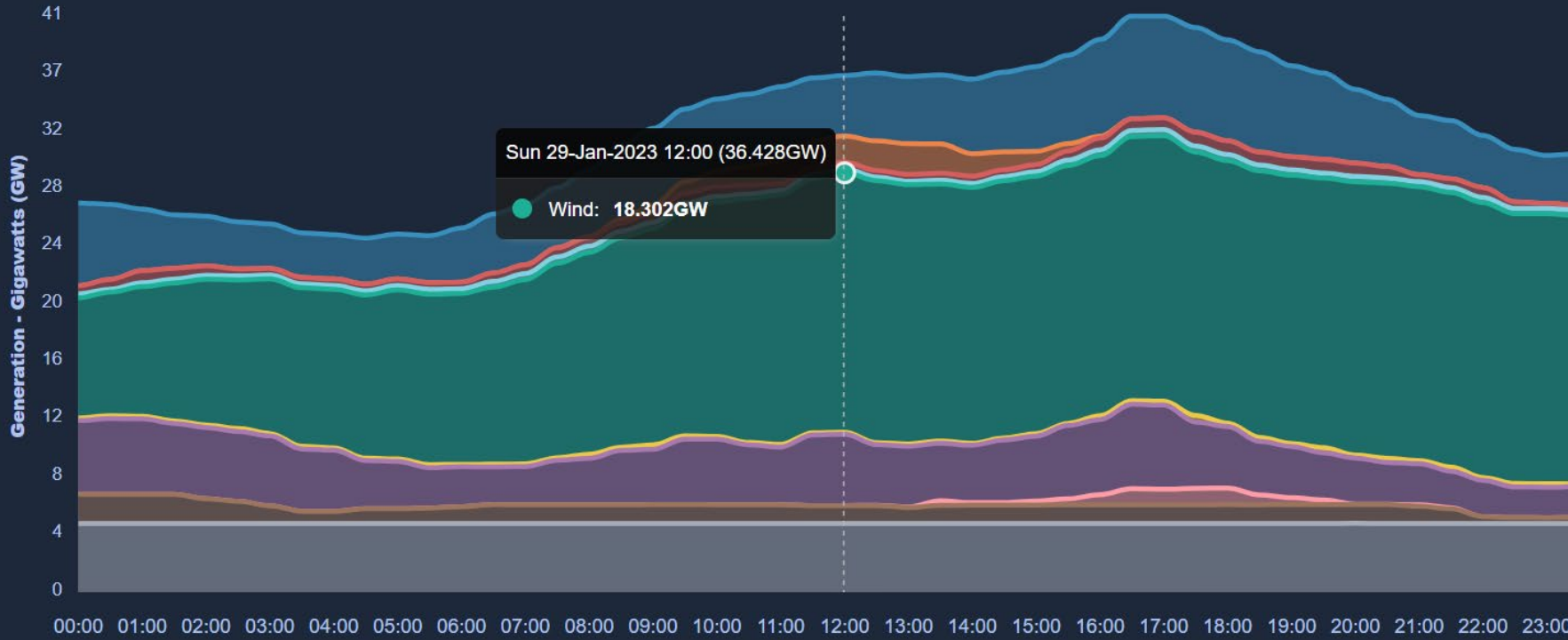
Poland – 817g



Source	GW	%	GWh
Gas	3.5	11.1	-
Solar	6.0	18.9	-
Coal	0.2	0.7	-
Hydro	0.0	0.1	-
Wind	15.2	47.8	-
Misc	0.2	0.5	-
Imports	0.5	1.7	-
PSH	0.0	0.0	-
Biomass	0.8	2.6	-
Nuclear	5.3	16.6	-
All	31.8	100	-

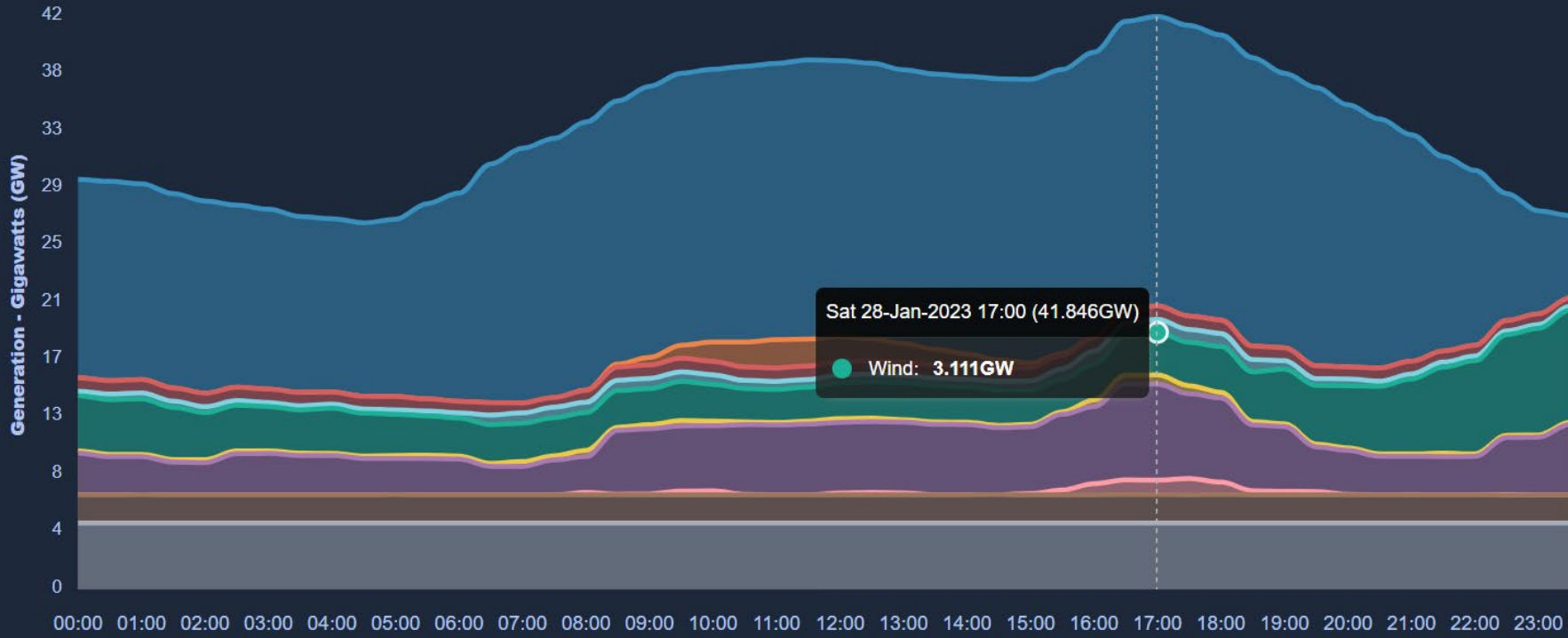


Source	gCO ₂ /kWh	%	CO ₂ (t)
Biomass	120	5.6	98
Coal	937	12.4	217
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Imports	-12	-0.4	-7
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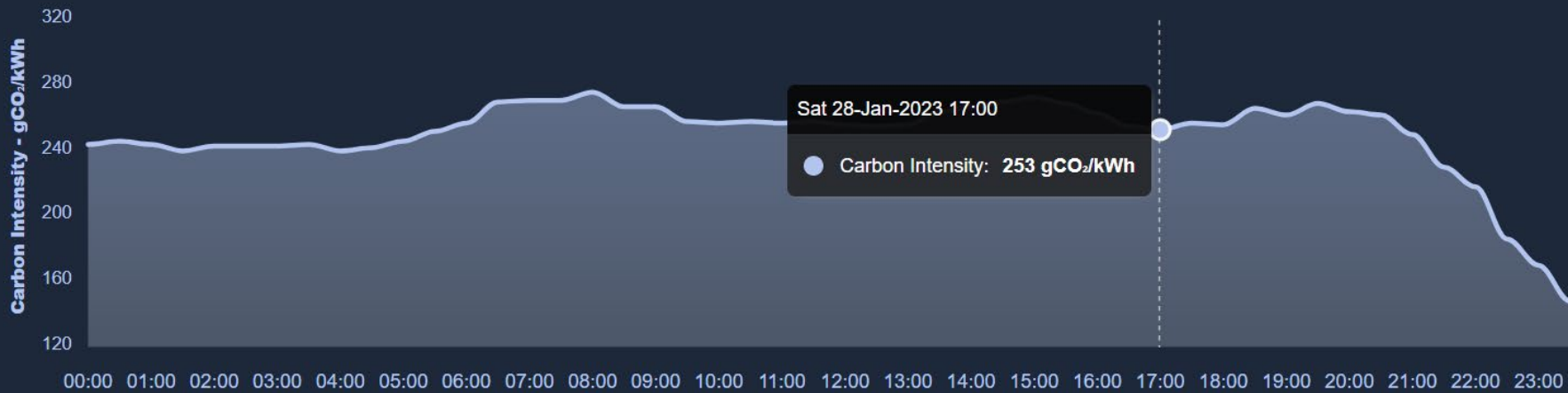


Sun 29/01/23 12:00 - 12:30

Source	gCO ₂ /kWh	%	CO ₂ (t)
Biomass	120	5.2	153
Coal	937	14.6	431
Gas	394	57.0	1,682
Misc	300	1.4	43
Imports	128	21.8	642
All	81	100	2,951



Source	GW	%	GWh
Gas	21.2	50.6	-
Solar	0.0	0.0	-
Coal	1.0	2.3	-
Hydro	0.9	2.3	-
Wind	3.1	7.4	-
Misc	0.7	1.6	-
Imports	7.0	16.8	-
PSH	1.1	2.5	-
Biomass	2.1	4.9	-
Nuclear	4.8	11.5	-
All	41.8	100	-



Source	gCO ₂ /kWh	%	CO ₂ (t)
Biomass	120	2.3	248
Coal	937	8.7	916
Gas	394	78.8	8,341
Misc	300	1.9	201
Imports	125	8.3	881
All	253	100	10,587

Electrical Interconnectors

Interconnectors of the UK

Projects	Go-live date	Capacity
IFA	1986	2GW
BritNed	2011	1GW
Nemo	2019	1GW
IFA2	2020	1GW
Moyle	2001	0.5GW
EWIC*	2012	0.5GW
North Sea Link	2021	1.4GW
Viking Link	2023	1.4GW
ElecLink	2022	1GW
EuroLink	2030	1.4GW
Nautilus	2028	1.4GW

- Existing projects
- Testing
- - -●- - - Under construction
- - -●- - - Under development



Electrical Interconnectors



octopus energy

Powering about **7 million**
heat pumps in the UK



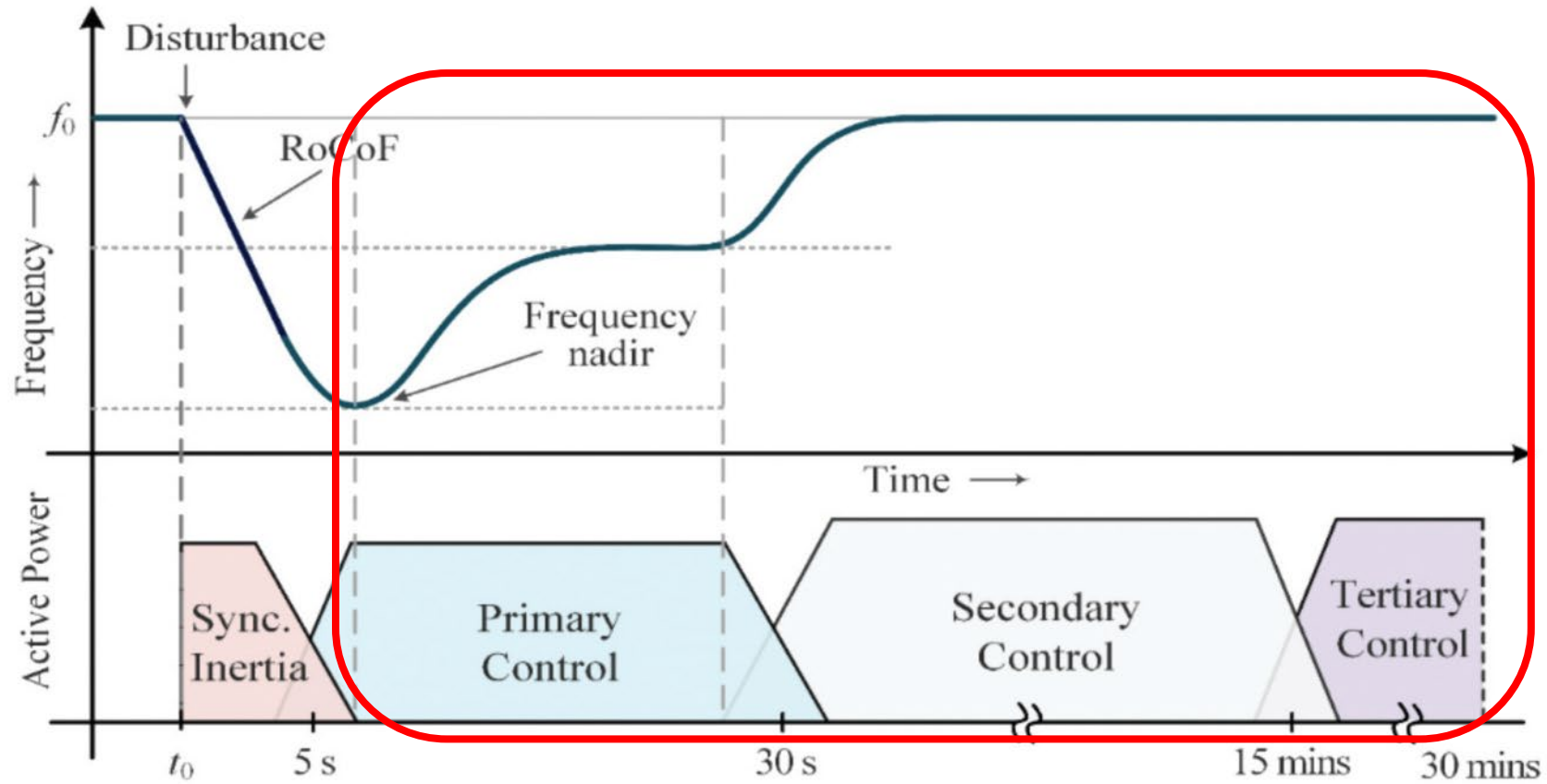
Delivering
3.6GW
for an average of
20 hours a day



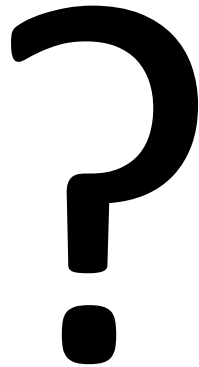
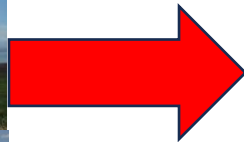
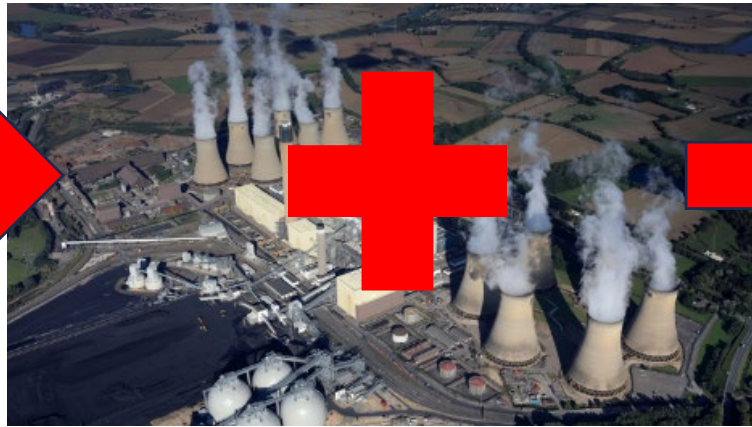
Planned for 2029-2031

Frequency Response

Fig. 1: Frequency control continuum

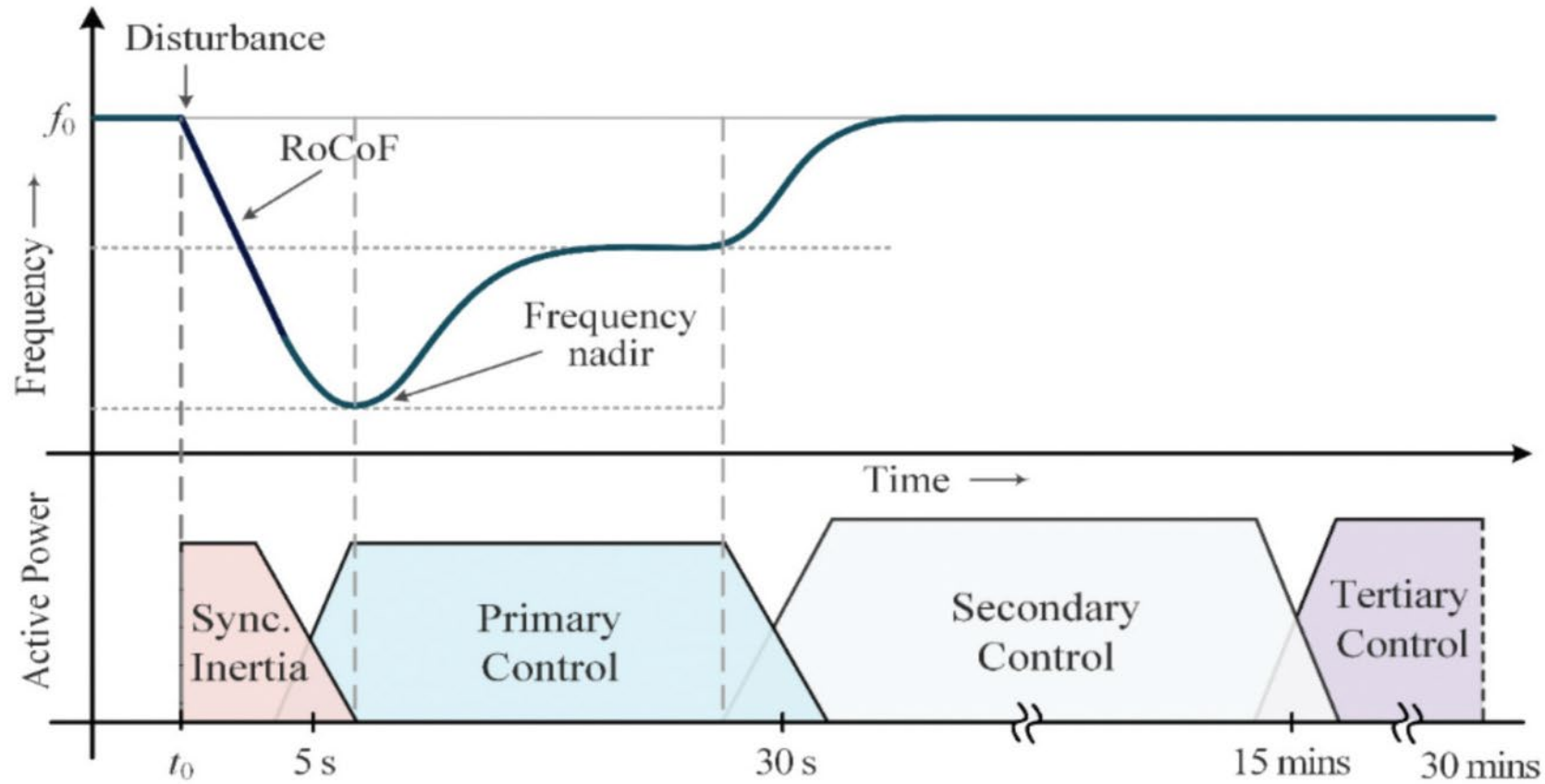


Frequency Response



Inertia

Fig. 1: Frequency control continuum



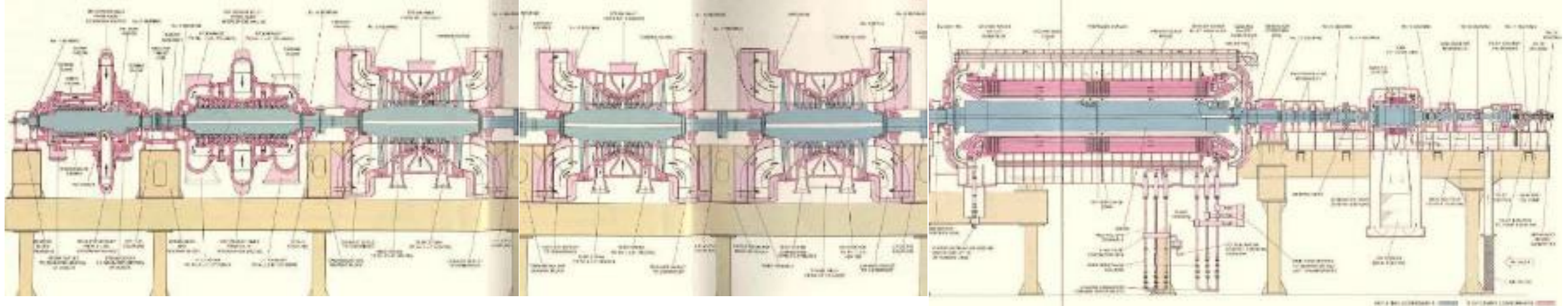
Inertia



Inertia



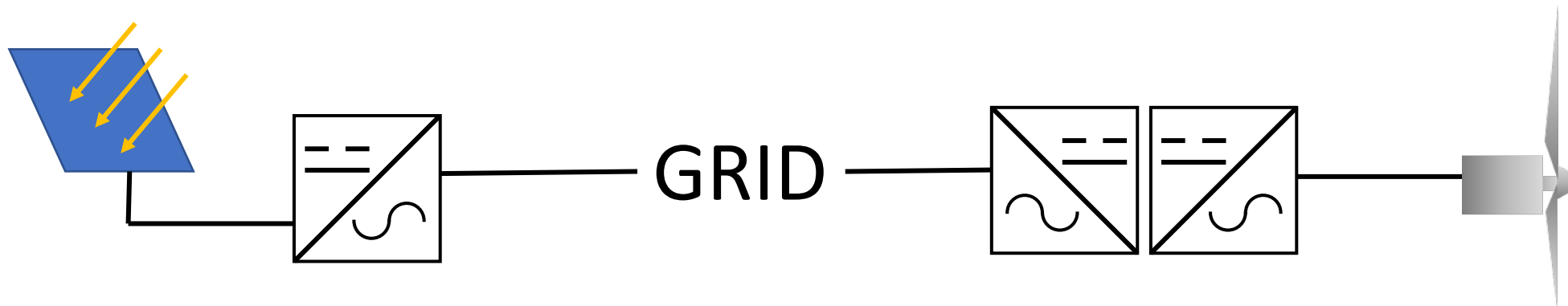
660MW Turbine
/ Generator
300-400T of
steel at
3000RPM



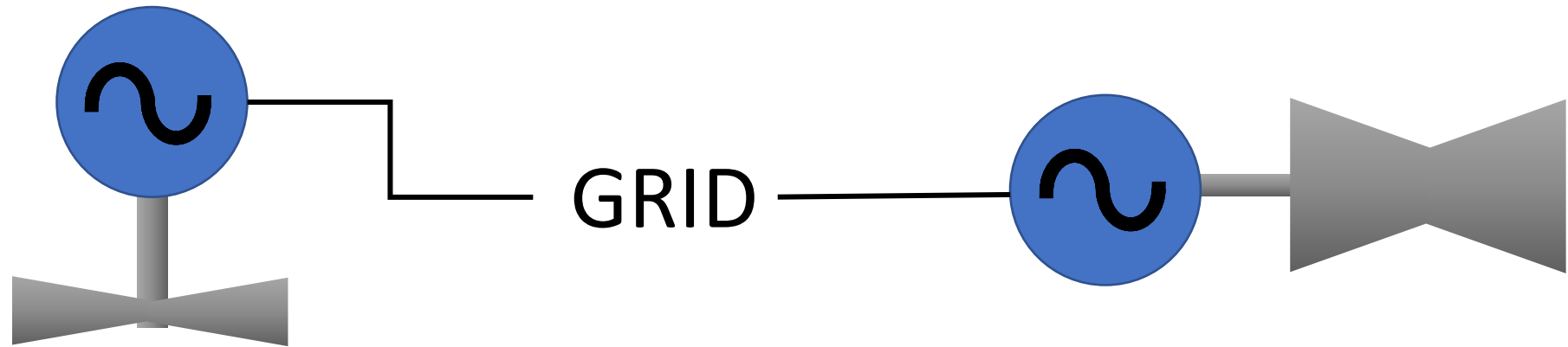
Inertia



Inertia in wind and solar PV



Inertia in Hydro and Solar Thermal



Renewable Comparison

	Predicable	Capacity	Inertia	Frequency Support	Voltage Support
Wind	Medium	Medium	Poor	Some	Good (depends)
Solar	Medium	Low	None	None	Good (depends)
Geothermal	Great	Great	Good	Good	Good
Hydro	Good	Good	Good	Good	Excellent
Wave	Medium	Medium	?	Poor	?
Tidal	Excellent	Medium	?	Good	?



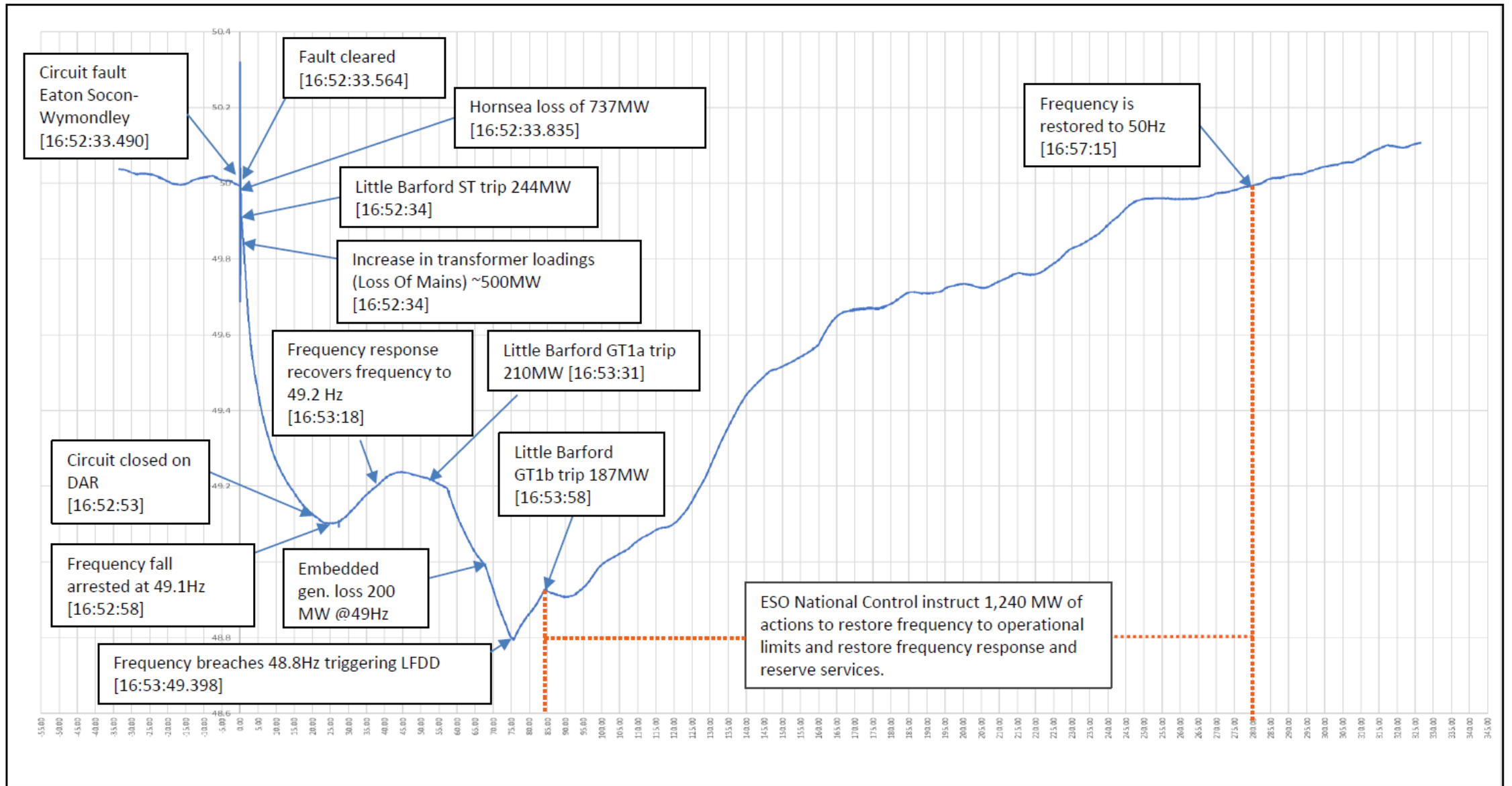
Case Study

Grid Event - 9 August 2019

- 1.1 million electricity customers without power for between 15 and 45 minutes.
- Major disruption to the rail network
- Impacts to Ipswich hospital and Newcastle airport



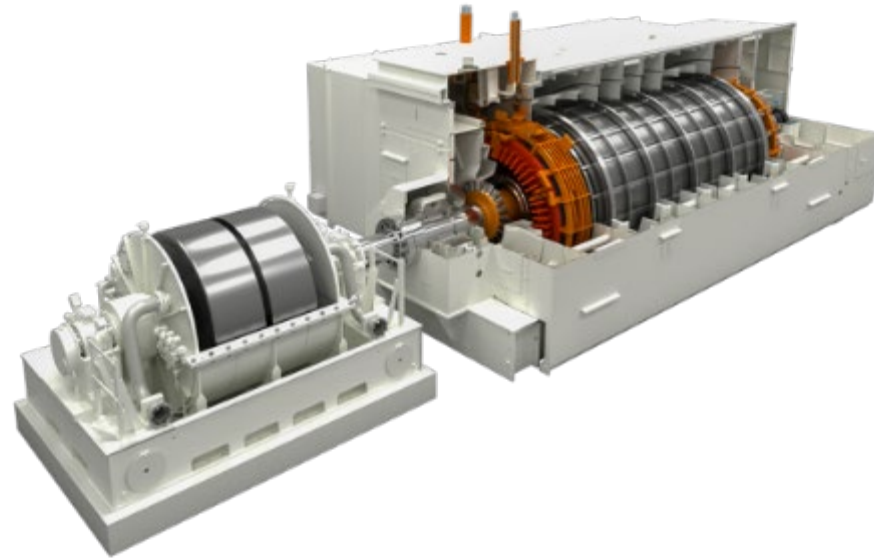
Grid Event - 9 August 2019



A faint, light blue world map is visible in the background of the slide, centered behind the main text.

Solutions to the problems

Synchronous compensators / stabilisers

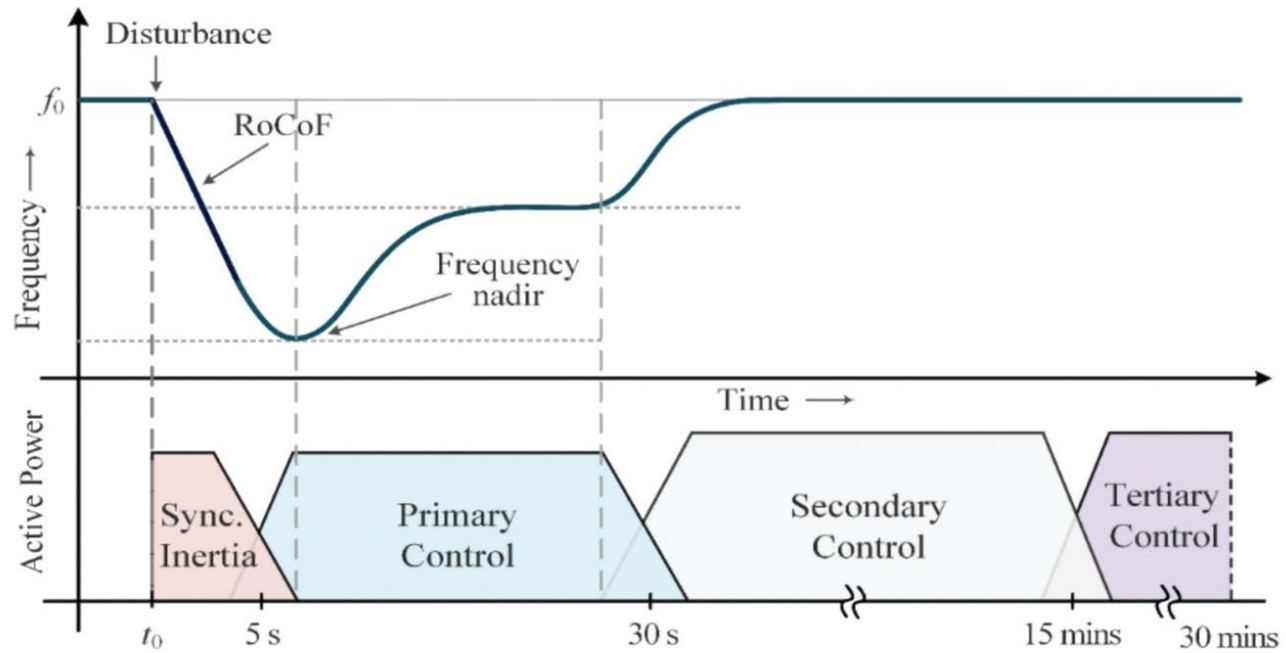


Synchronous compensators / stabilisers



Tender round	Tender timetable	Target quantity	Delivery period	Location	Price
Stability Pathfinder 1	January 2020	25GVA.s target, of which 12.5GVA.s was contracted	2021-2026	All GB	Average £280/GVA.s/sp corresponding to £3.8m/GVA.s pa revenue, with a range 142 - 552 £/GVA s/sp
Stability Pathfinder 2	Q4 2021	8.4GVA short-circuit provision, plus up to 6.0GVA.s inertia provision	2022 - 2034	Scotland with 8 specific locations designated	Tender submission window November 2021 to January 2022, results March 2022
Stability Pathfinder 3	Expressions of Interest process is underway	15GVA.s inertia plus 7.5GVA short-circuit provision	2025 - 2035	Wales and England with designated locations for SCL requirement	Tender submission window November 2021 to March 2022, results August 2022
Post-Phase 3	Short-term stability market is expected				

Fig. 1: Frequency control continuum

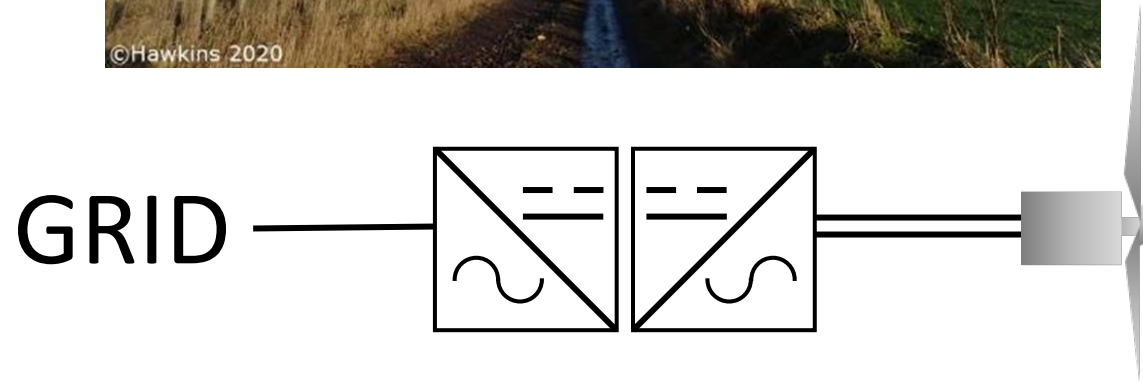


Grid scale batteries

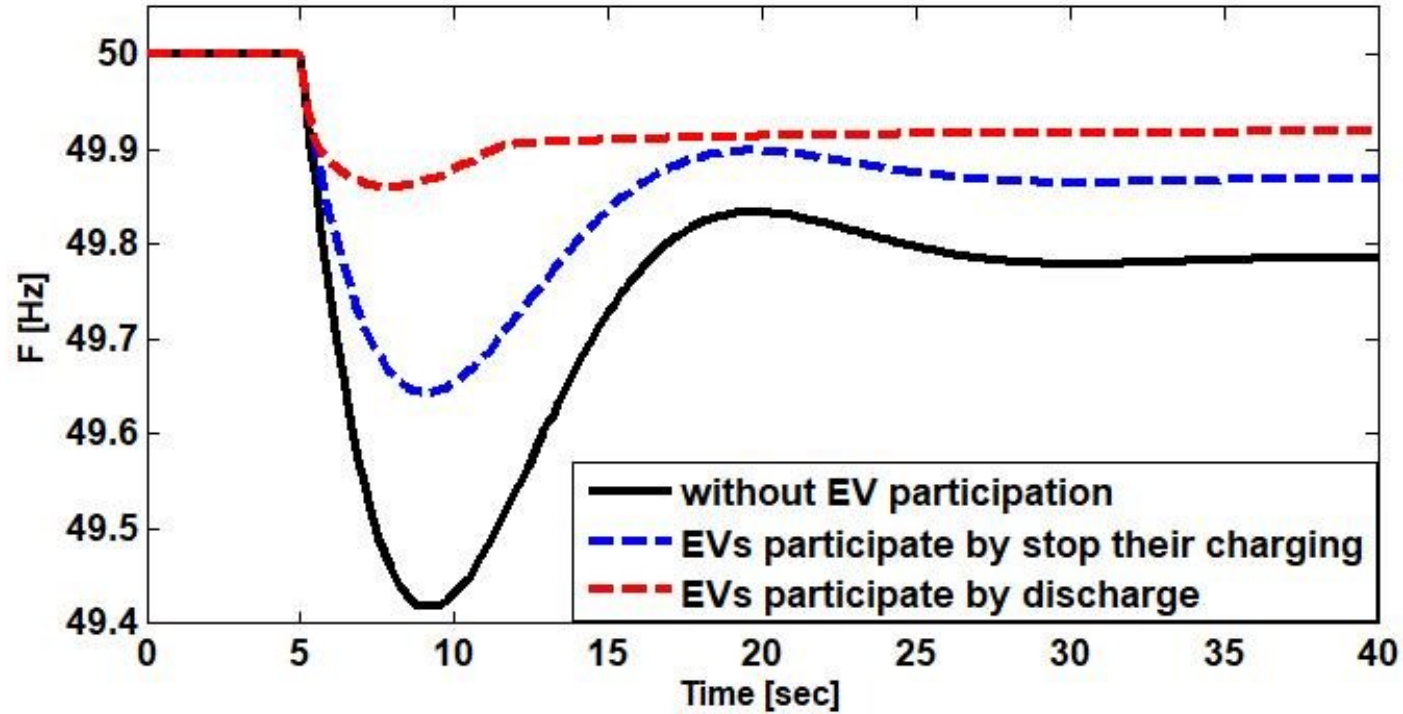
Capenhurst battery
100 MW
107 MWh



Frequency response & Synthetic Inertia



Demand side frequency response - EVs



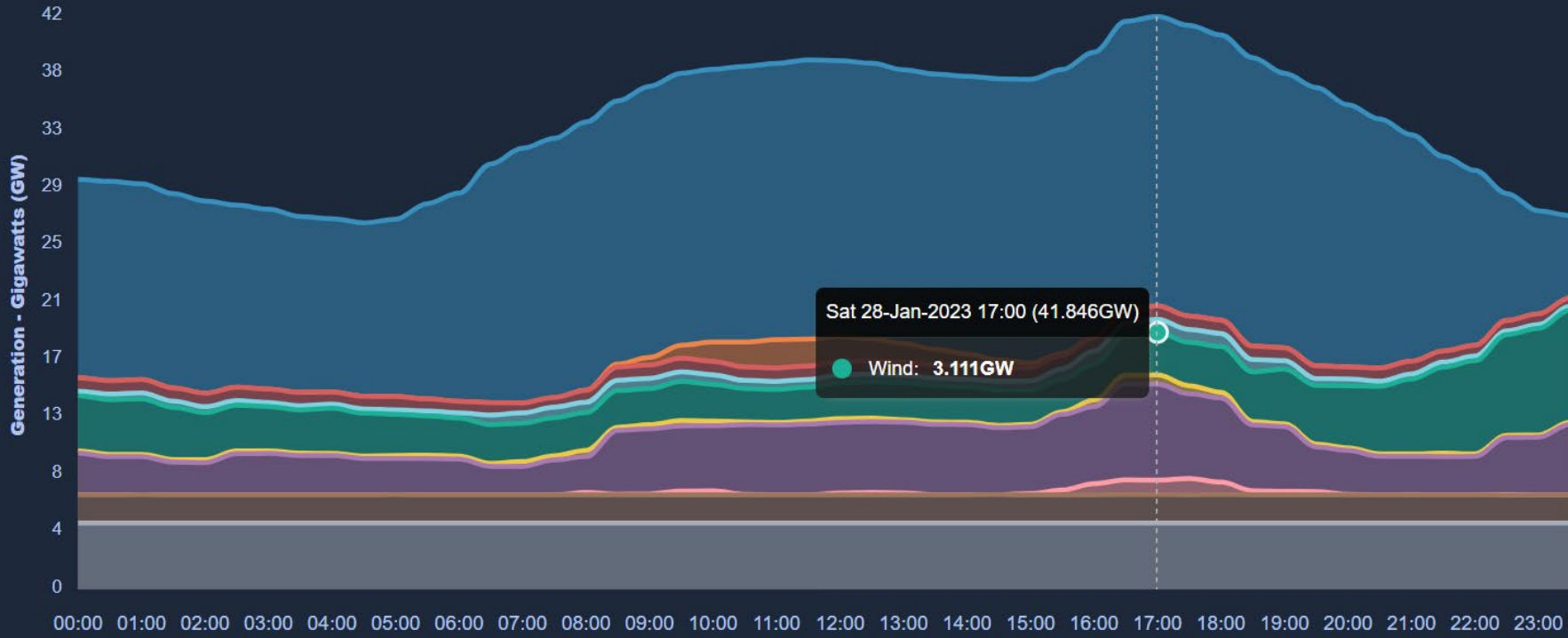
Demand side frequency response

If the findings of the trials are rolled out across Tesco's stores, its refrigeration units could provide the grid with 25 – 50MW of flexibility.

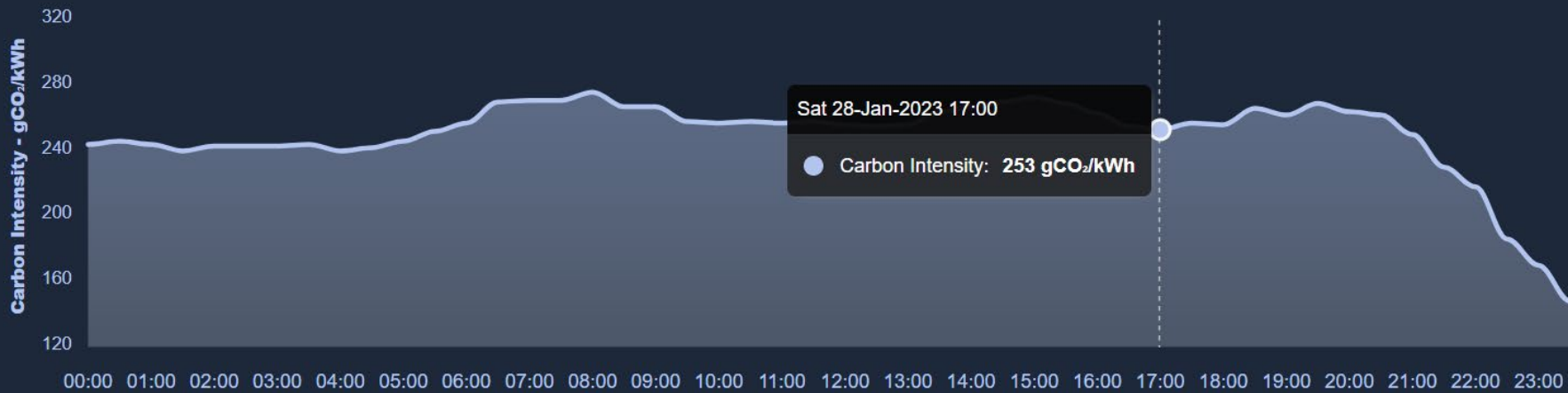


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**Brilliant, so that's all sorted
then?**



Source	GW	%	GWh
Gas	21.2	50.6	-
Solar	0.0	0.0	-
Coal	1.0	2.3	-
Hydro	0.9	2.3	-
Wind	3.1	7.4	-
Misc	0.7	1.6	-
Imports	7.0	16.8	-
PSH	1.1	2.5	-
Biomass	2.1	4.9	-
Nuclear	4.8	11.5	-
All	41.8	100	-

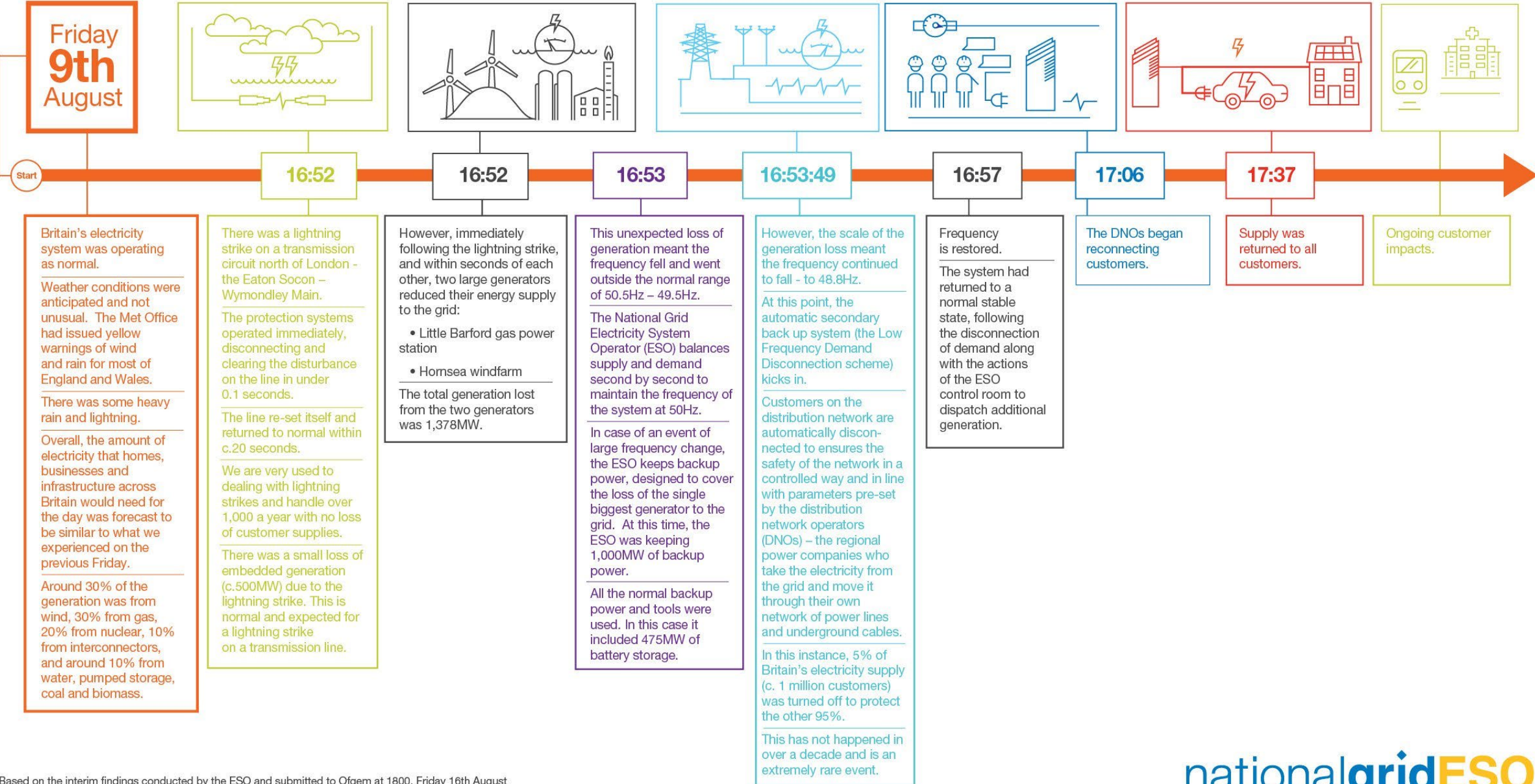


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Biomass	120	2.3	248
Coal	937	8.7	916
Gas	394	78.8	8,341
Misc	300	1.9	201
Imports	125	8.3	881
All	253	100	10,587



Backup slides

The sequence of events of Friday 9th August 2019



Britain's electricity system was operating as normal.

Weather conditions were anticipated and not unusual. The Met Office had issued yellow warnings of wind and rain for most of England and Wales.

There was some heavy rain and lightning.

Overall, the amount of electricity that homes, businesses and infrastructure across Britain would need for the day was forecast to be similar to what we experienced on the previous Friday.

Around 30% of the generation was from wind, 30% from gas, 20% from nuclear, 10% from interconnectors, and around 10% from water, pumped storage, coal and biomass.

There was a lightning strike on a transmission circuit north of London - the Eaton Socon - Wymondley Main.

The protection systems operated immediately, disconnecting and clearing the disturbance on the line in under 0.1 seconds.

The line re-set itself and returned to normal within c.20 seconds.

We are very used to dealing with lightning strikes and handle over 1,000 a year with no loss of customer supplies.

There was a small loss of embedded generation (c.500MW) due to the lightning strike. This is normal and expected for a lightning strike on a transmission line.

However, immediately following the lightning strike, and within seconds of each other, two large generators reduced their energy supply to the grid:

- Little Barford gas power station
- Hornsea windfarm

The total generation lost from the two generators was 1,378MW.

This unexpected loss of generation meant the frequency fell and went outside the normal range of 50.5Hz - 49.5Hz.

The National Grid Electricity System Operator (ESO) balances supply and demand second by second to maintain the frequency of the system at 50Hz.

In case of an event of large frequency change, the ESO keeps backup power, designed to cover the loss of the single biggest generator to the grid. At this time, the ESO was keeping 1,000MW of backup power.

All the normal backup power and tools were used. In this case it included 475MW of battery storage.

However, the scale of the generation loss meant the frequency continued to fall - to 48.8Hz.

At this point, the automatic secondary back up system (the Low Frequency Demand Disconnection scheme) kicks in.

Customers on the distribution network are automatically disconnected to ensure the safety of the network in a controlled way and in line with parameters pre-set by the distribution network operators (DNOs) - the regional power companies who take the electricity from the grid and move it through their own network of power lines and underground cables.

In this instance, 5% of Britain's electricity supply (c. 1 million customers) was turned off to protect the other 95%.

This has not happened in over a decade and is an extremely rare event.

Frequency is restored.

The system had returned to a normal stable state, following the disconnection of demand along with the actions of the ESO control room to dispatch additional generation.

The DNOs began reconnecting customers.

Supply was returned to all customers.

Ongoing customer impacts.

Based on the interim findings conducted by the ESO and submitted to Ofgem at 1800, Friday 16th August