The UK Solar Farm Assemblage: a challenge for the National Grid?

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Purpose of Research

Determine impact of PV on the Grid:

- How to measure it
- Where
- When

Outline

- Where are the solar farms?
- Grid stresses:
  - Highest number of solar farms
  - Highest solar farm capacity
  - Distance to nearest grid connection point
  - Imbalance of supply and demand
- Calculation of Solar Farm Output
- How output varies in time
- Consumption versus demand
- Achievement of Capacity

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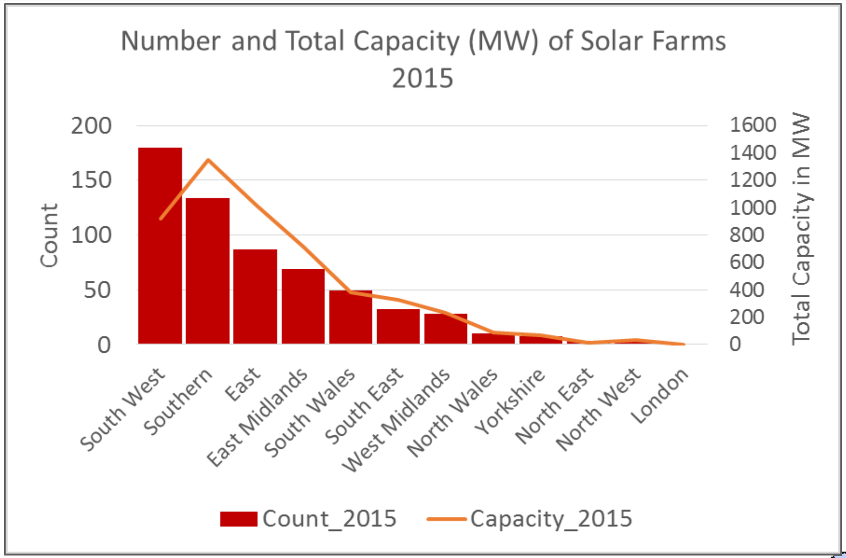
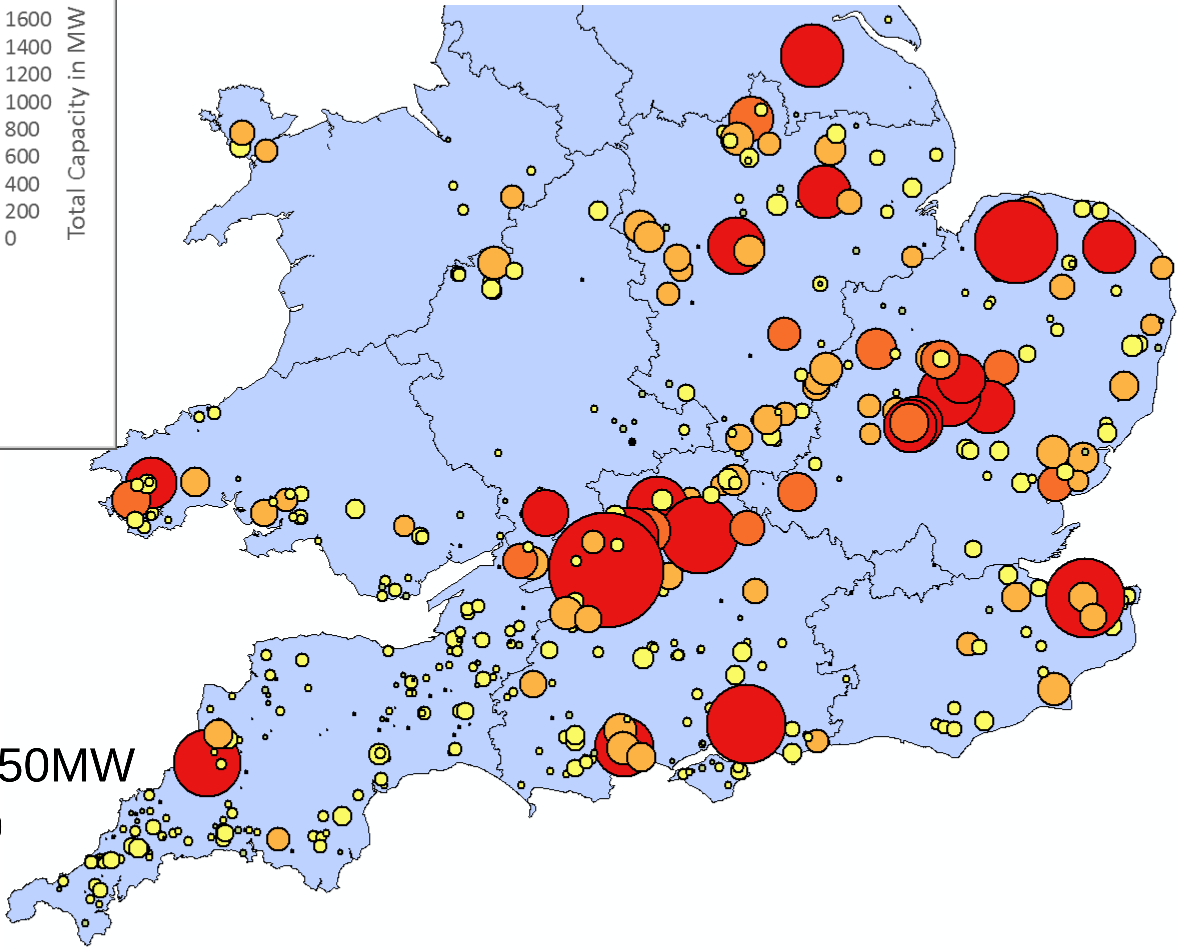
Where are the Solar Farms in the UK?

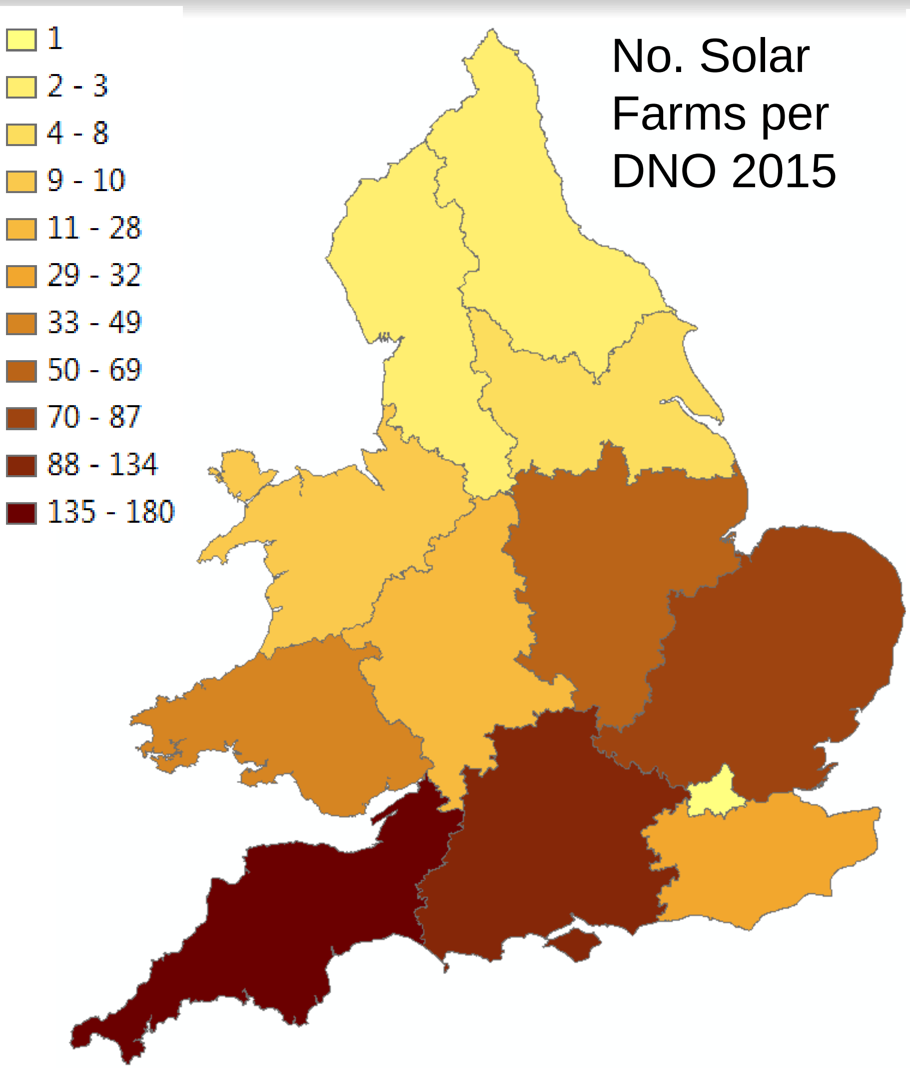


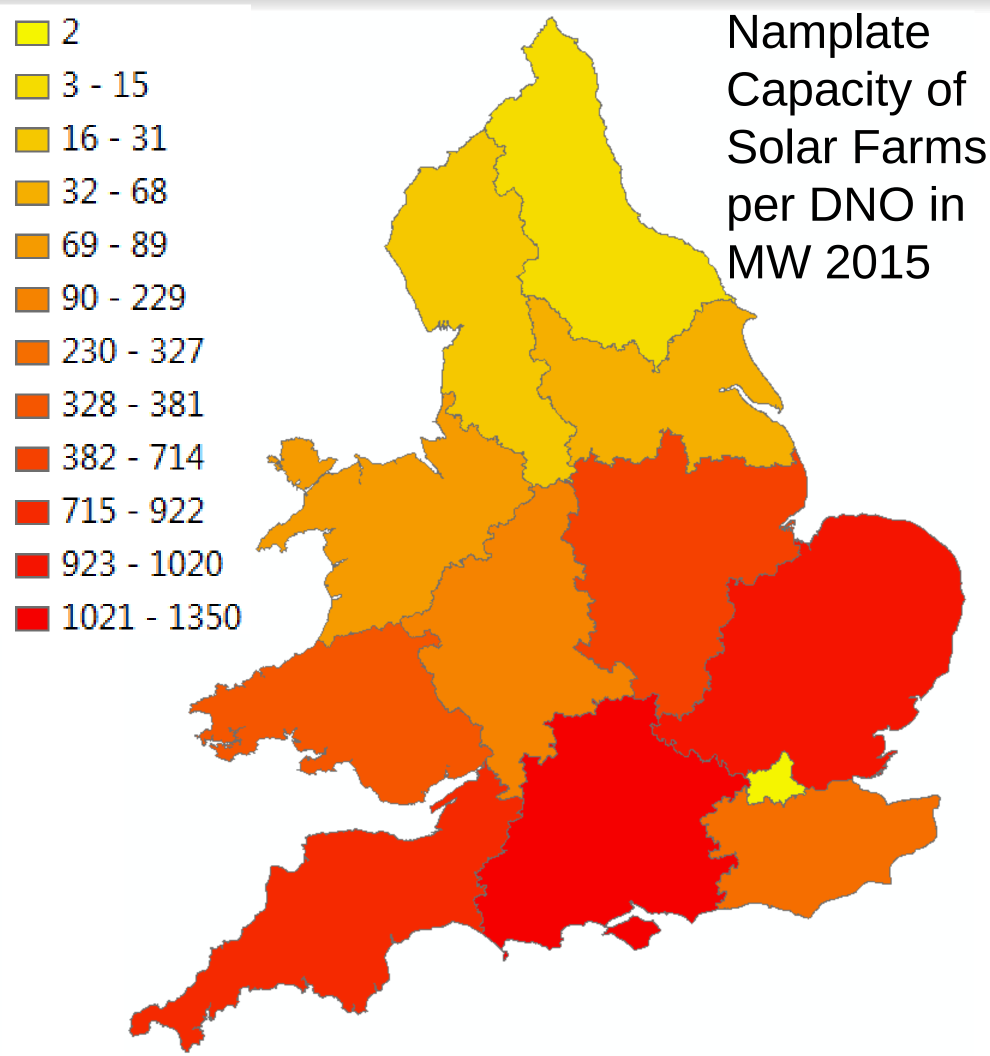
The larger and hotter the circle, the greater the capacity of the solar farm



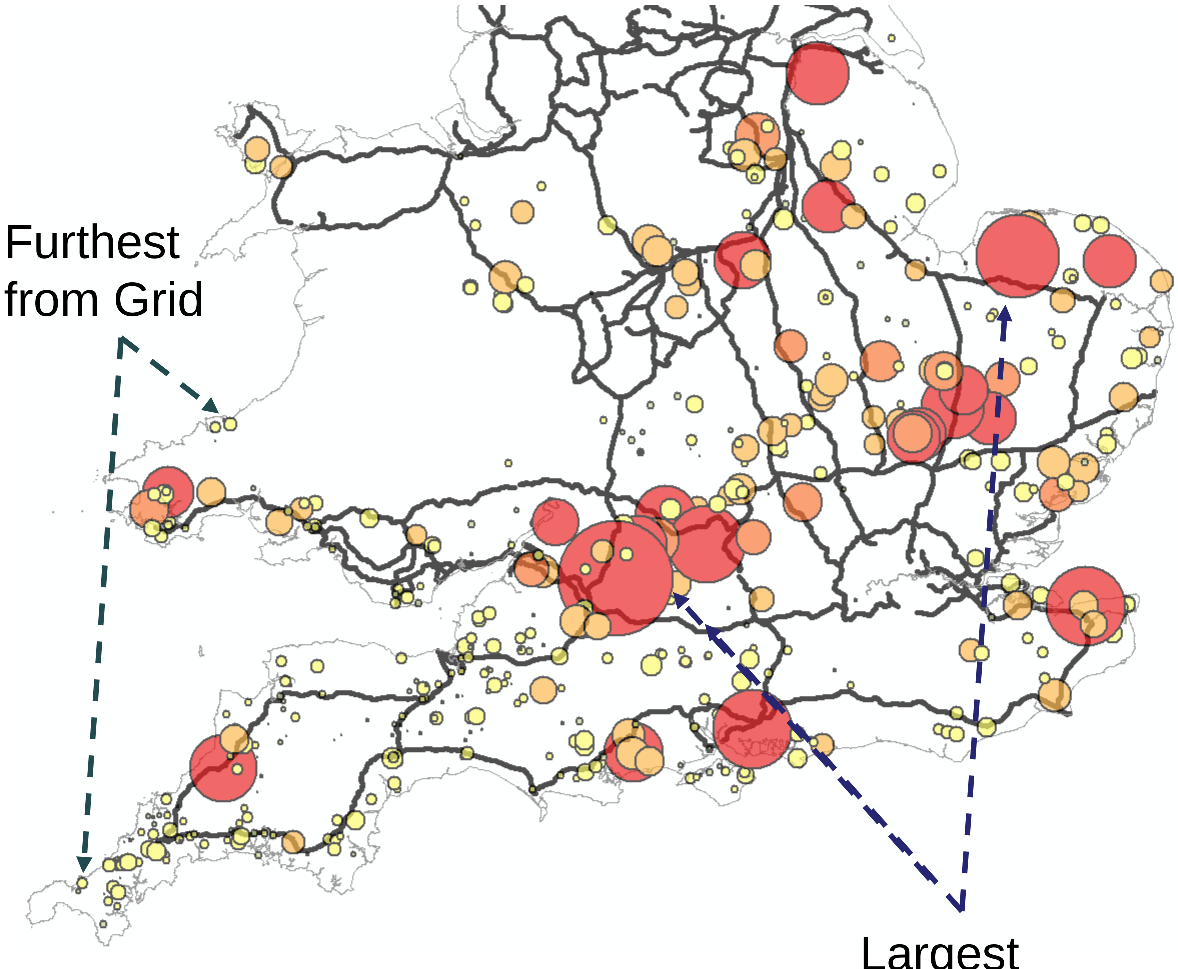
Department of Climate Change Renewable Energy Planning database, REPD 2015 (575 x 1-50MW installations at September 2015)

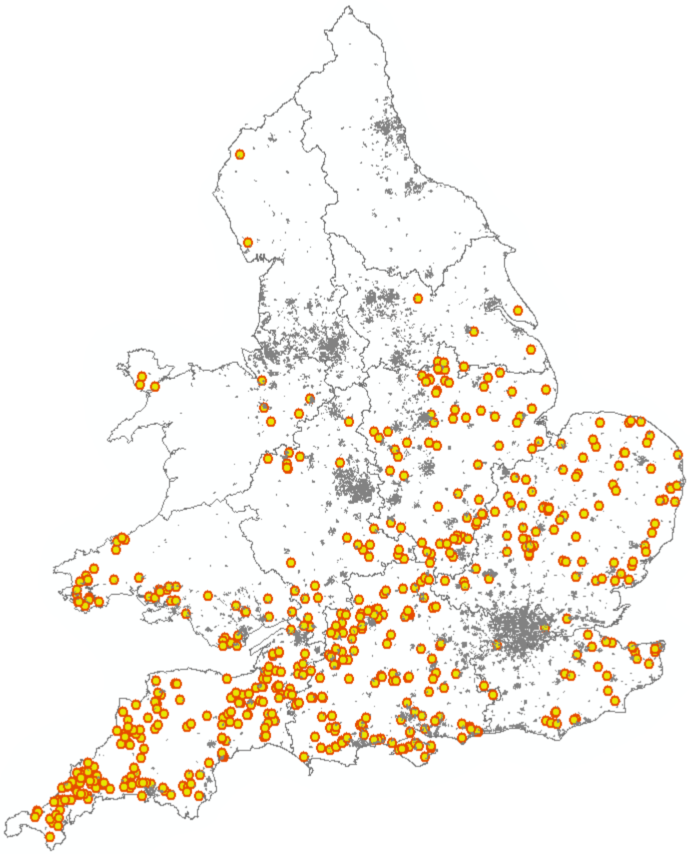
Analysis at the DNO Level





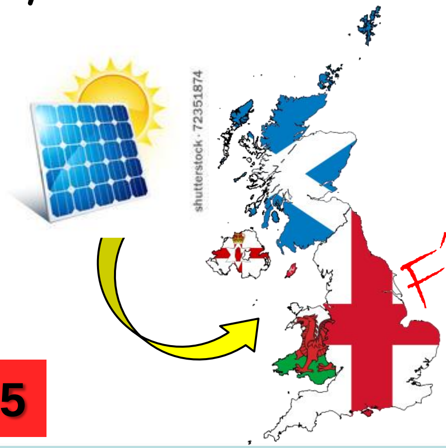
Pathway – Solar Farm to Consumer





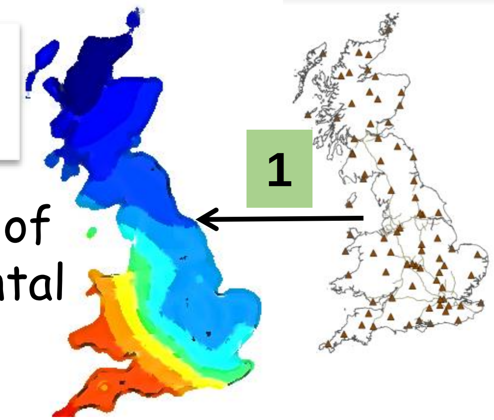
Calculation of Solar Farm Output Data

Output for any solar farm anywhere in the UK



Start

Kriging of Met. Office Data: 80 weather stations



1

UK-Wide Map of Global Horizontal Irradiation

Finish

Global Horizontal Irradiance + time/date + lat/long + Tilt + Azimuth = Tilt Irradiation

Available Data: Capacity and Location

Assumptions: Inclination angle 22o, Orientation: South, Module type: c-Si

5

King model for the maximum power point P(G,T) with adjusted coefficients

4

Ross thermal model

Plane-of-array irradiance for each solar farm

Separation: BRL model

2

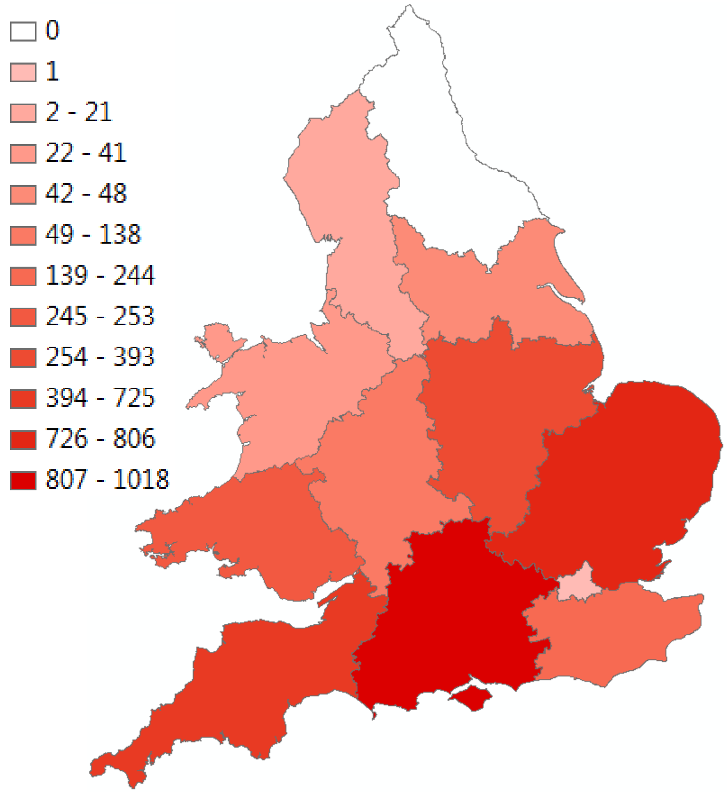
Translation: Hay &McKay with Reindl's correction

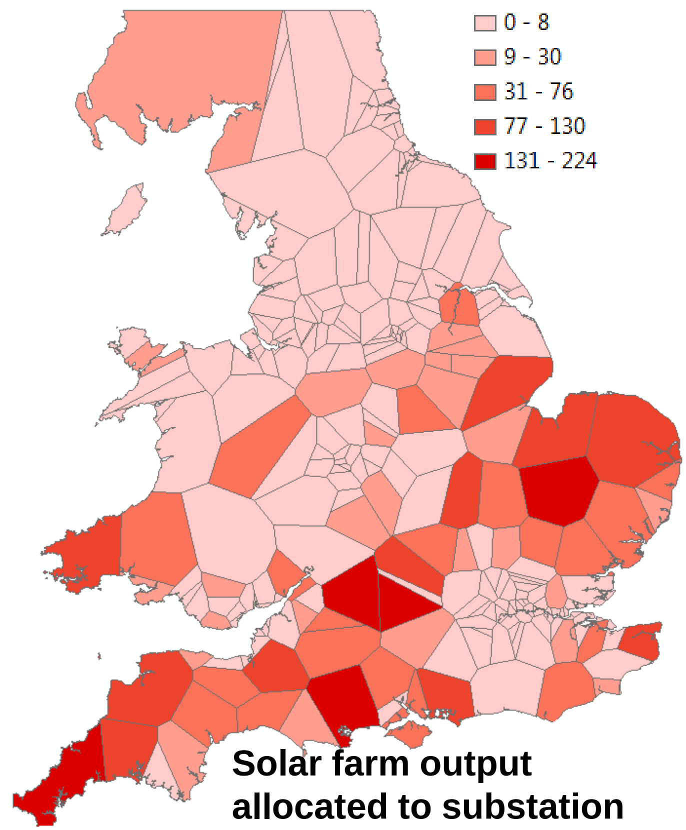
3

Models that take as input irradiance and temperature (the only available information)

Calculated Solar Farm Generation

Performance Per DNO
Modelled Output 2014 MWh





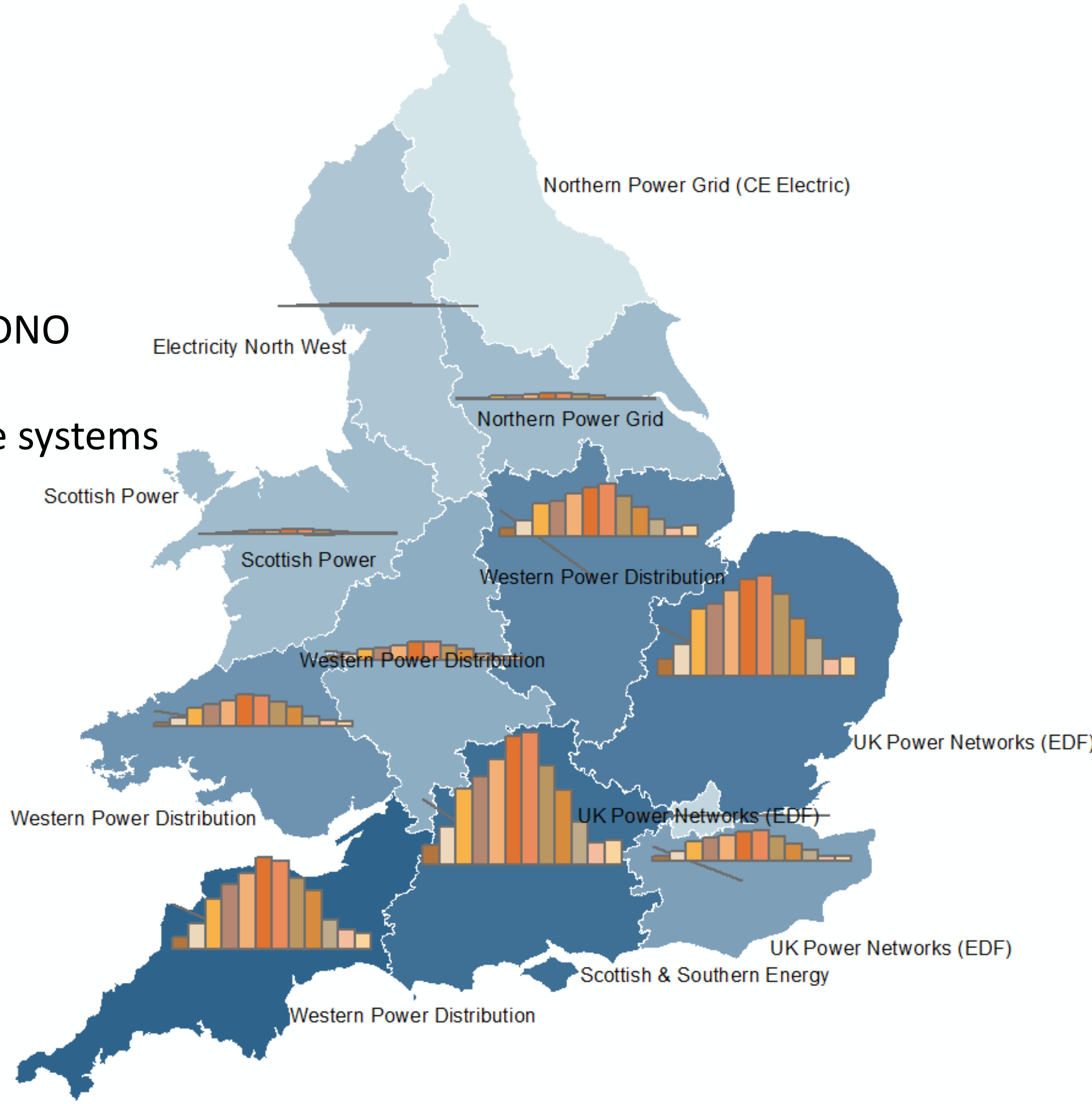
Solar farm output allocated to substation
2014 MW

CRREST

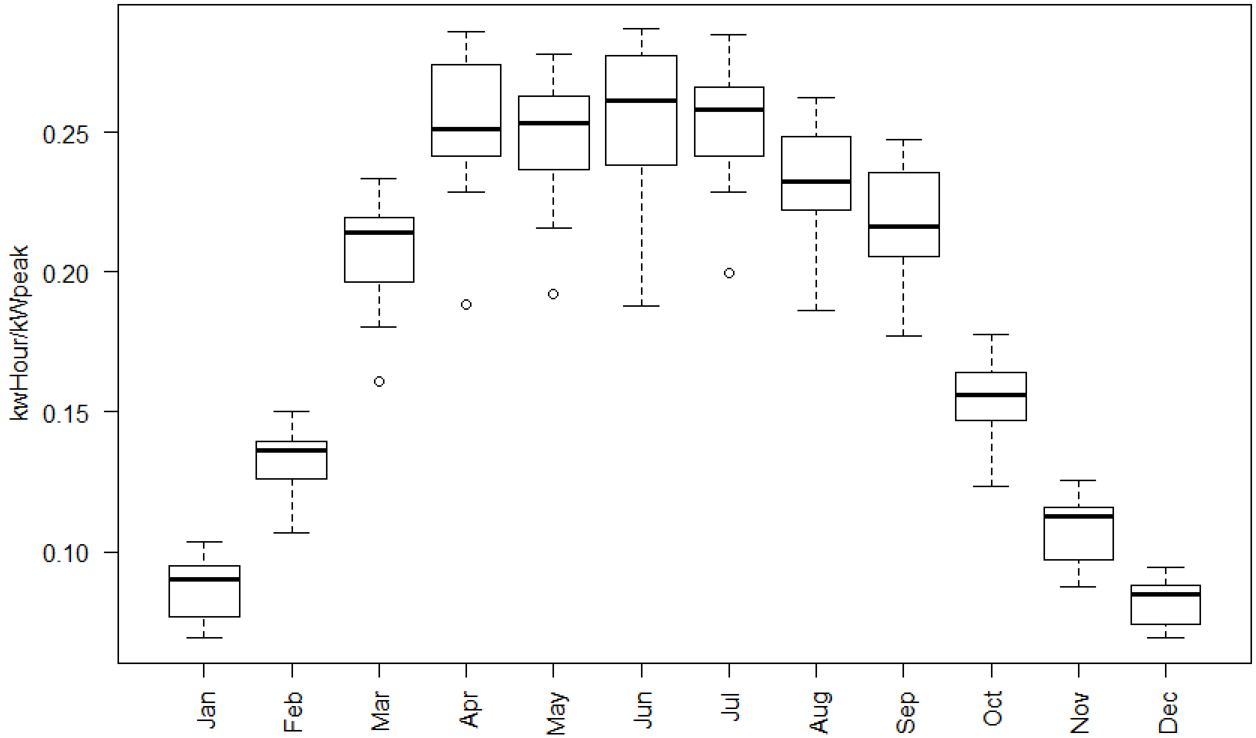
Monthly Variation in Output

Monthly Output 2014

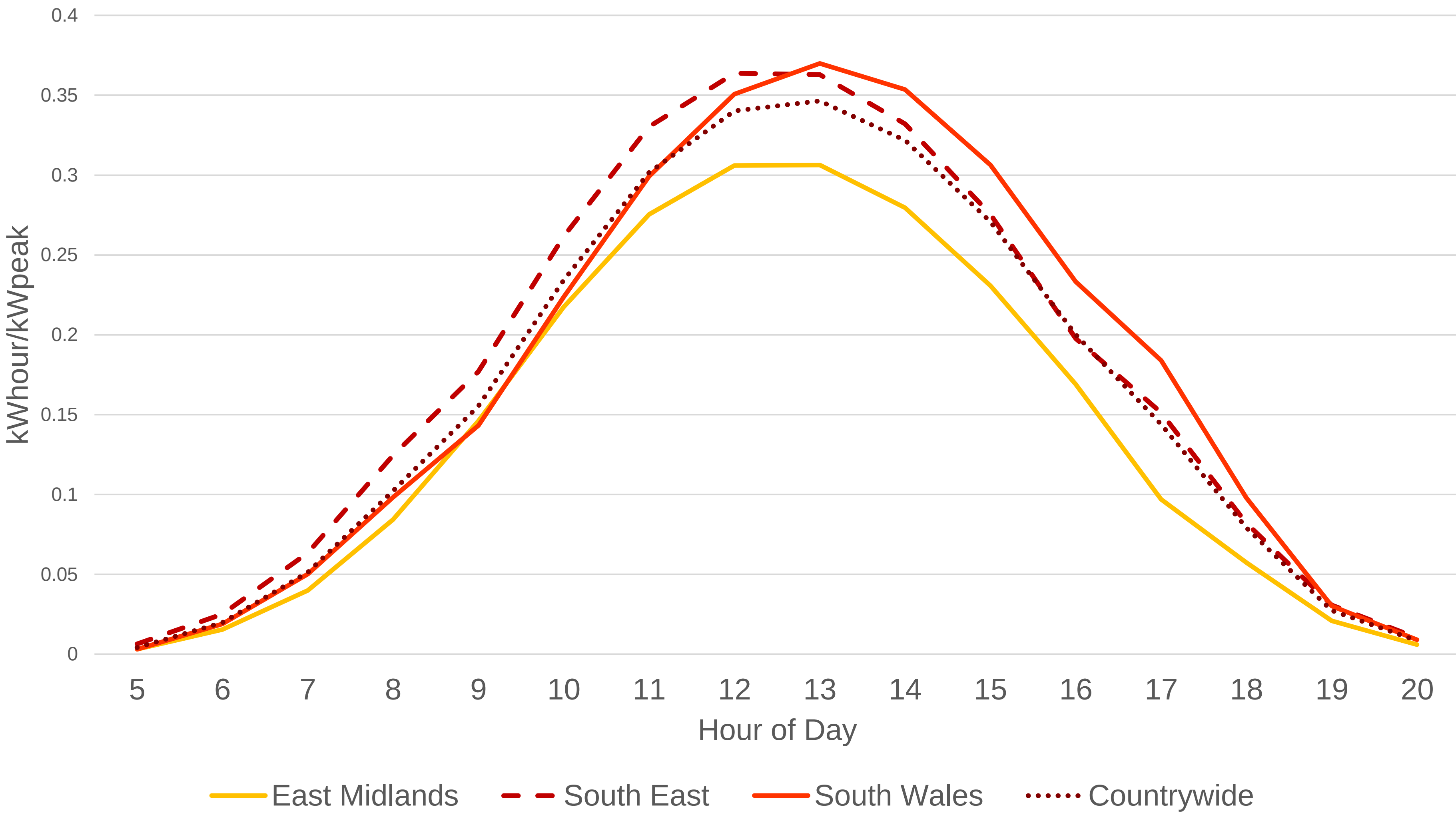
- Monthly DC Output MWh per DNO
- 452 systems 1-50 MW
- Background – darker blue more systems
- Graph max. 160K MWh



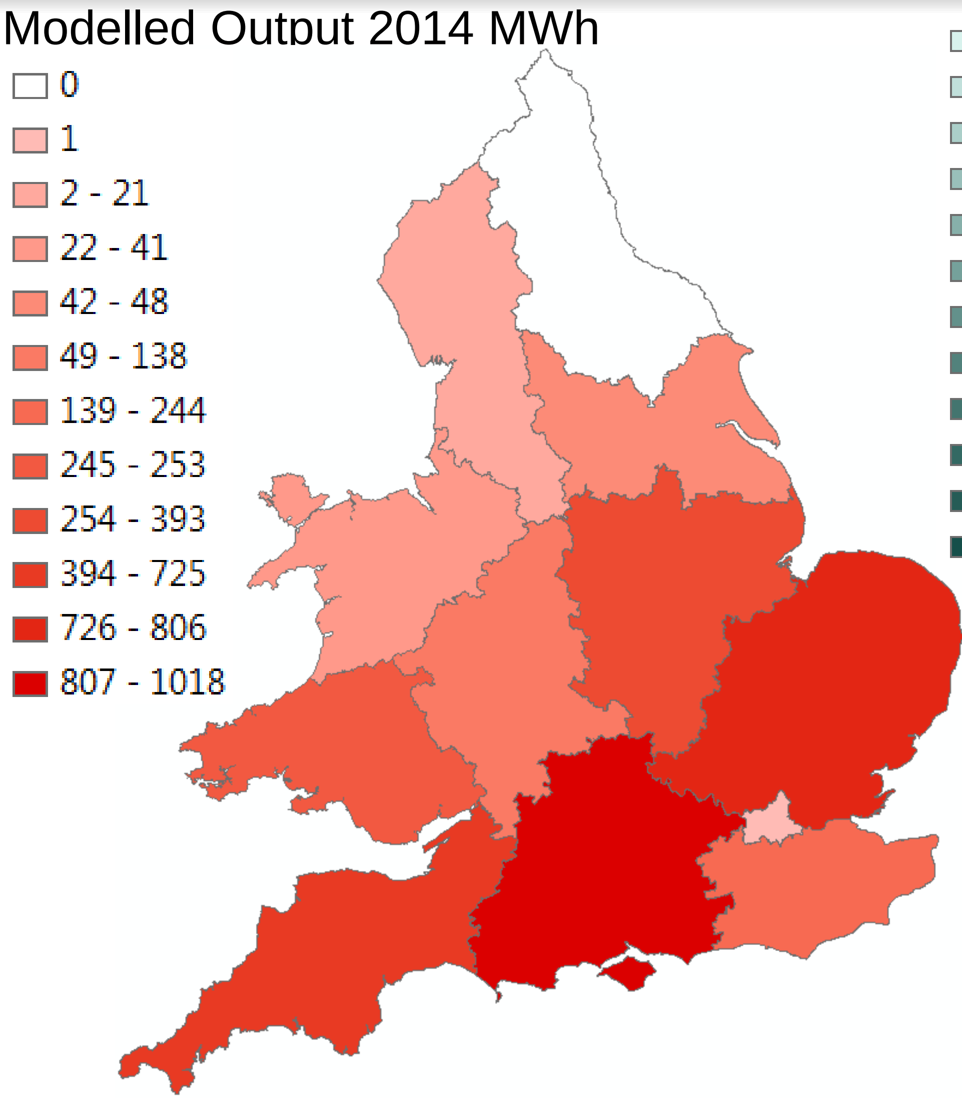
Normalised UK Average Monthly kWhour/kWpeak 2005-2014

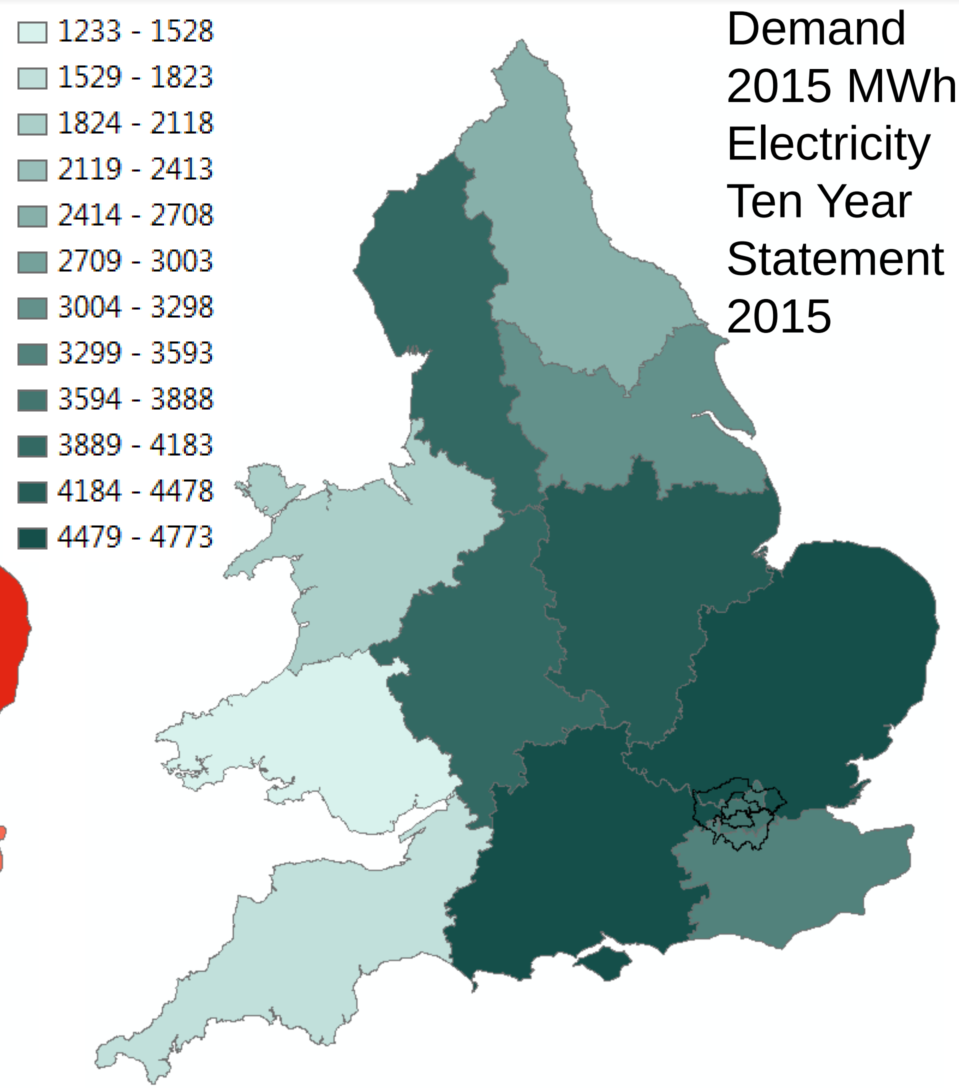


UK Average Hourly kWhour/kWpeak 2005-2014



Solar Farms Production and Demand per DNO





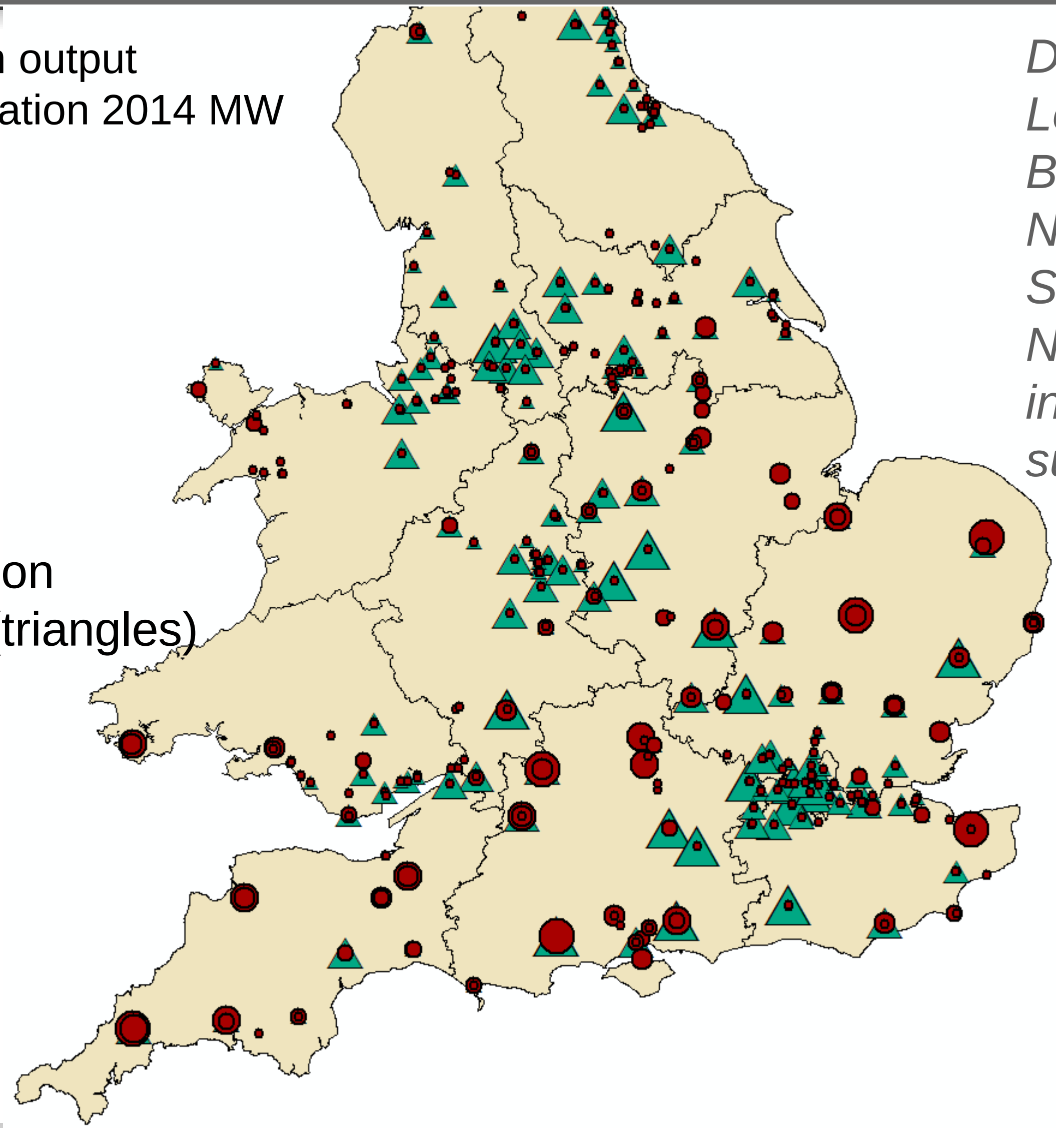
Consumption profile in 2015 (from DECC)

Annual Solar farm output allocated to substation 2014 MW (circles)

- 0 - 8217
- 8218 - 27187
- 27188 - 58658
- 58659 - 109999
- 110000 - 167089

Annual Substation demand 2015 (triangles) MW

- 52 - 151
- 152 - 278
- 279 - 443
- 444 - 867



Demand highest in: London, Coventry, Birmingham, Leicester, Nottingham, Leeds, Sheffield, Manchester, Newcastle. Completely incompatible with supply.

Case Studies of Constraints

UK National Grid Voltage Layers

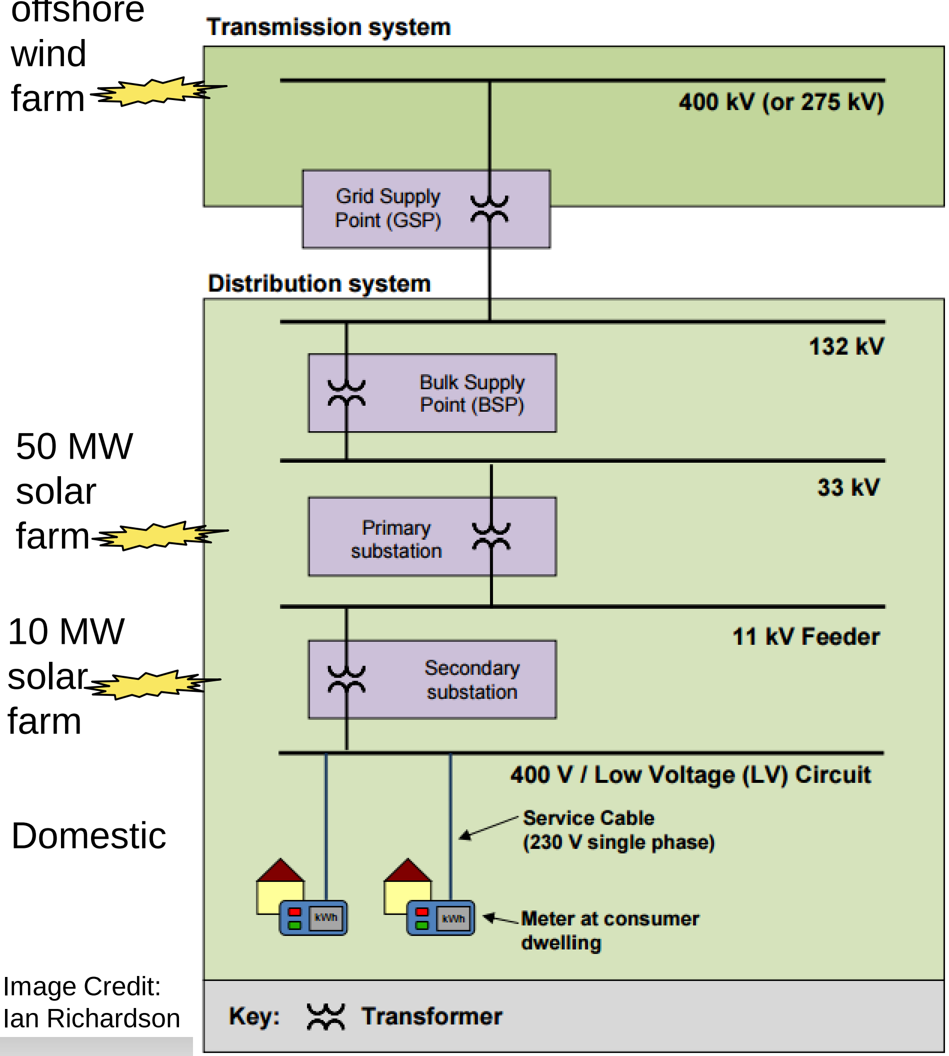


Image Credit: Ian Richardson

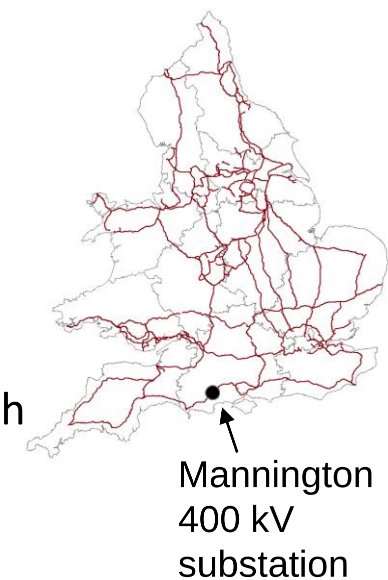
Case Study One

Case Study Two

Case Study One

22 solar farms, totalling 215 MW feeding into 1200 MW (5 x 240 MW) Station.

Even if it all goes through one Grid Supply Point (240 MW) it won't overload.



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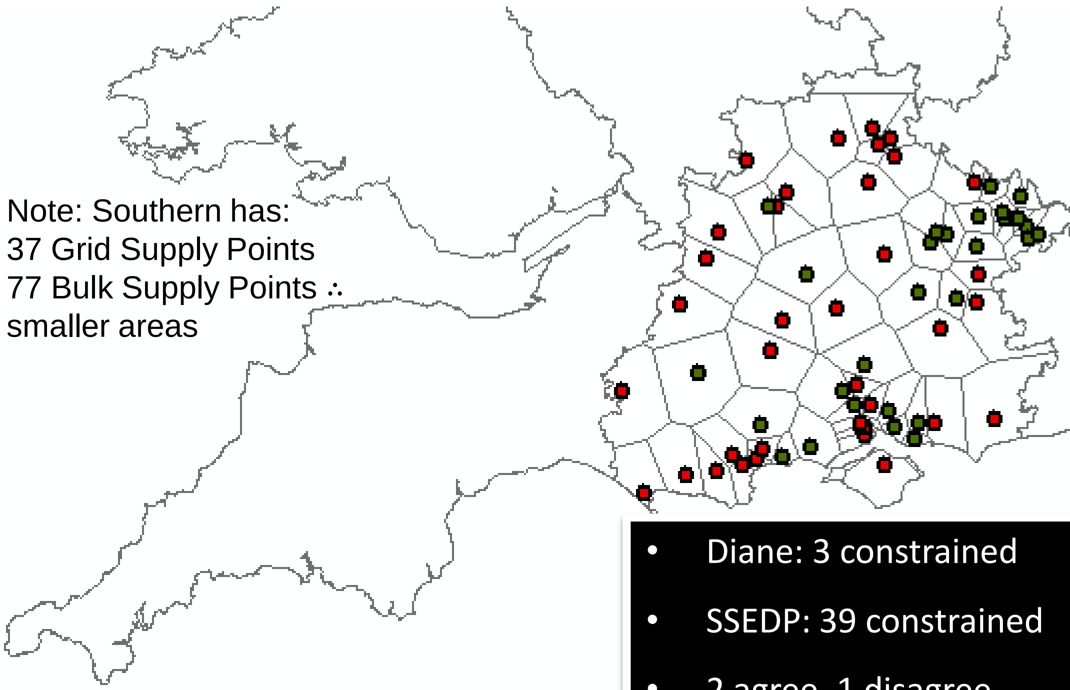
Constraints: Case Study Two

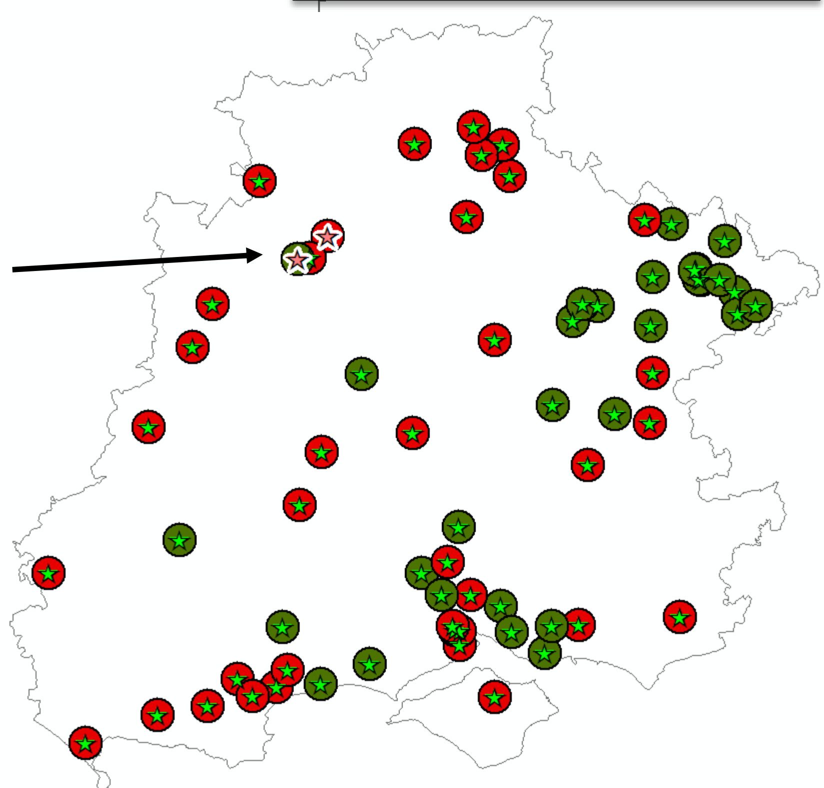
Bulk Supply Points 132 kV in Southern DNO



Note: Southern has:
37 Grid Supply Points
77 Bulk Supply Points ∴
smaller areas

- Diane: 3 constrained
- SSEDP: 39 constrained
- 2 agree, 1 disagree

Constraints:
Red - constrained
Green - Unconstrained
Circles – SSEPD
Stars - Diane



1. Calculate capacity of solar farms feeding in.
2. Subtract minimum demand from this to give net capacity.
3. If greater than transformer rating, then overloaded.

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When Do Solar Farms Achieve Full Capacity? Theoretically

Compute the solar position and intensity from time and place

Model 1:
Standard Test Conditions i.e. 1000 watts of sunlight per square meter of horizontal surface

	April	May	June	July	Aug
10:00 AM					
11:00 AM					
12:00 PM					
1:00 PM					
2:00 PM					

515 hours

5.88% of all hours

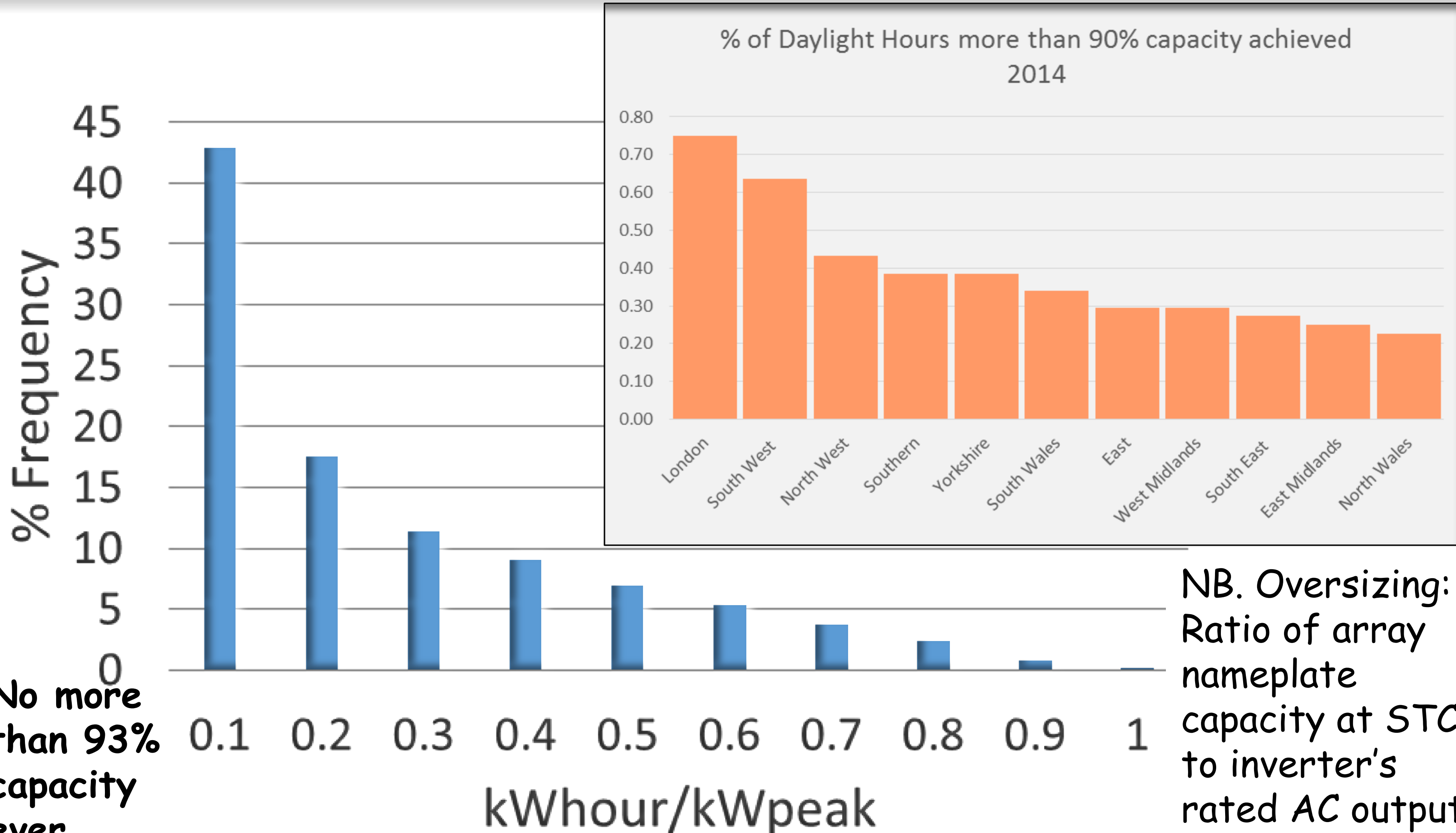
Model 2:
Tilt 22 degrees, South-facing > 1130 kWh/sqm

	March	April	May	June	July	Aug	Sept
10:00 AM							
11:00 AM							
12:00 PM							
1:00 PM							
2:00 PM							

806 hours

10% of all hours

Achievement of Nameplate Capacity: Actually

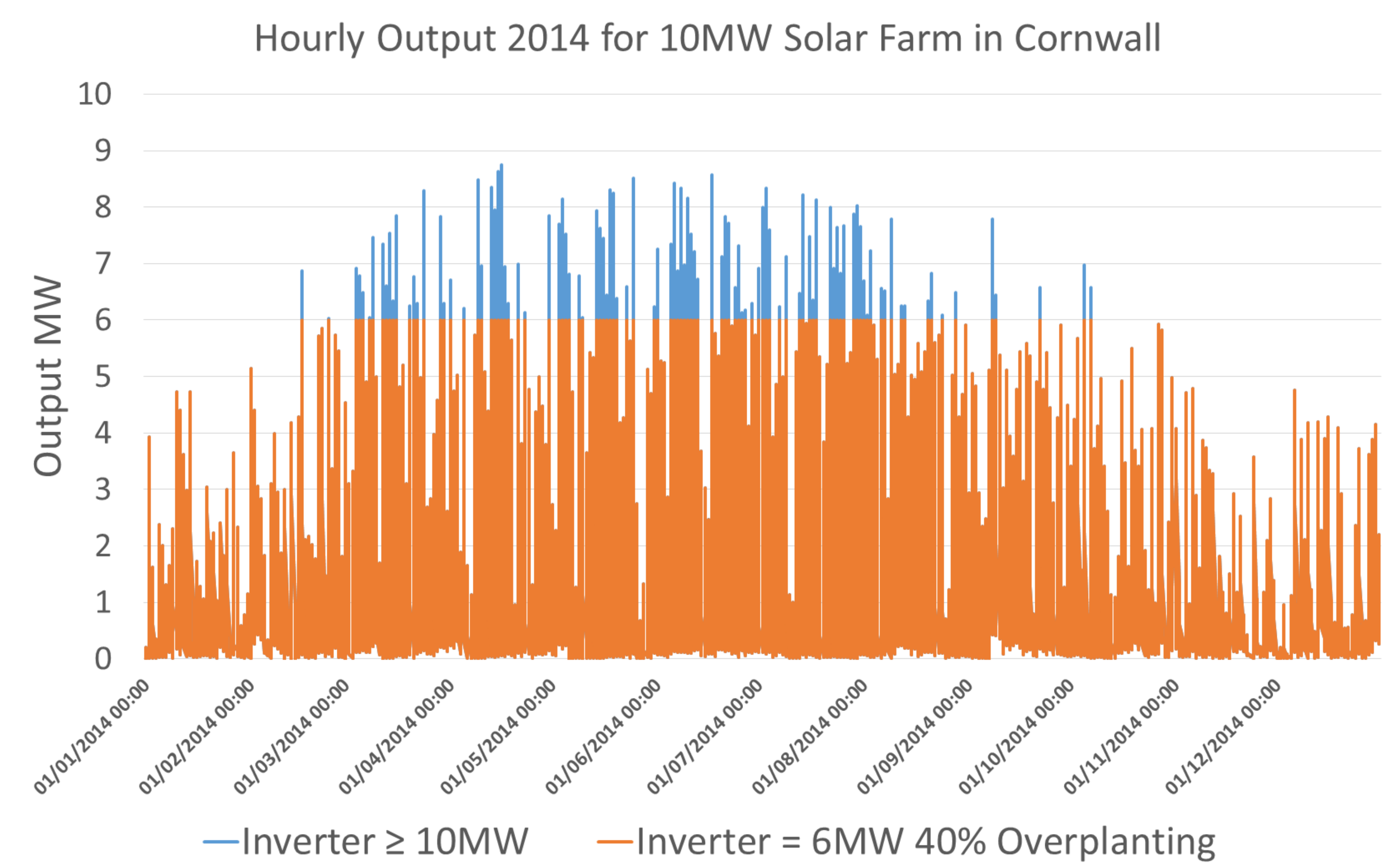


No more than 93% capacity ever achieved

NB. Oversizing: Ratio of array nameplate capacity at STC to inverter's rated AC output e.g. 1:25

6 MW Inverter capacity achieved for 333 midday hours
16 Feb to 7 Oct (8% of annual sun hours)
Cf. 10MW Nameplate capacity never achieved

Effect of Overplanting / Power Limiting e.g. 6MW Inverter for 10MW Nameplate Capacity Solar Farm



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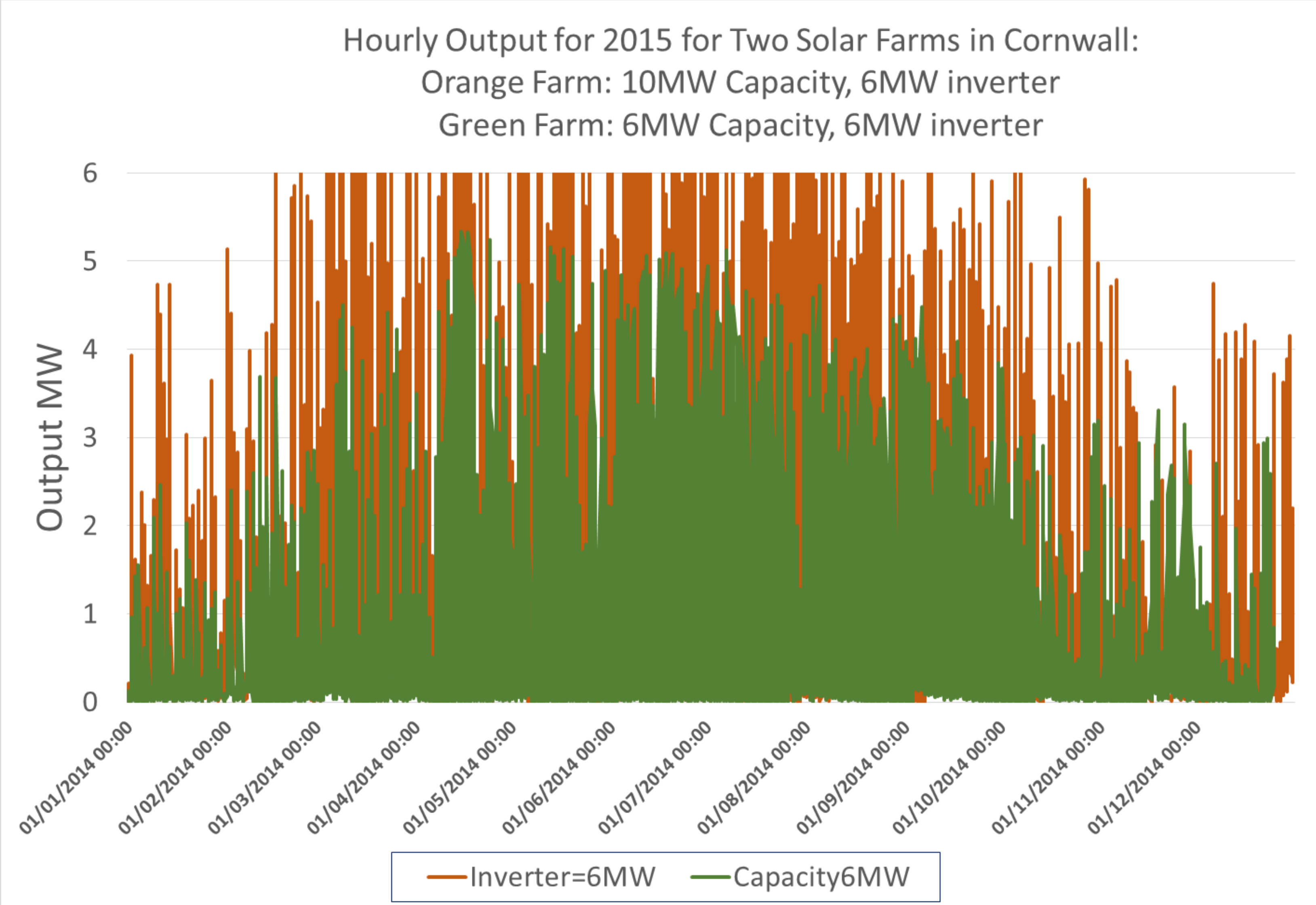
Two Scenarios . . .



Oversizing capacity to inverter ratio

- Matching inverter to capacity maximises energy harvest of each module in the system. Inverter spends little time power limiting (“clipping”).
- BUT
- Oversized inverter gives greater annual yield.

- Solar farms are required to state the maximum impact on the grid – no requirement to give details of oversizing.

- Some don’t oversize at all.

- Some oversize by 40%.

- The stated capacity in the Renewable Energy Planning database can be either – *we don’t know*.

Summary and conclusions

- Demand and Production not well balanced for solar farms.
- Plenty of Capacity on Grid (for PV).
- Achievement of full capacity:
  - Theoretically 10% of hours could have full capacity.
  - Modelling of nameplate capacity gave 0% for 2014.
  - Due to overplanting will be somewhere in between e.g. 5% of hours when down-regulation potentially required – very little impact.
  - We don’t know how much overplanting there is would be interested to find out.
- Maximum capacity / yield occurs at predictable times (middle of the day, March-Sept).
- No perceived threat to grid stability at the present time.


*Not to scale
Image provided by Sujith Rave