Impact of PV forecasting errors

The University Of Sheffield.

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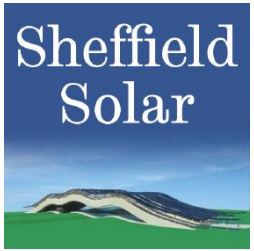

Introduction

- 4% of UK’s power from PV
- System integration costs are a significant issue for renewable energy generation
- Examine the integration costs of PV systems
  - What is the financial (system) cost of forecast errors?
  - Impact of location & PV penetration
  - Optimal distribution of solar PV fleet

System Integration Costs

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Shape Losses

- The change in value of the generation electricity generated based on the shape of the generation profile relative to baseload (constant) generation
- I.e. Generation-weighted price / average price

$$\textit{Value Factor} = 1 - \textit{Shape losses} = \frac{\overline{s_a p_f}}{\overline{s_a}\ \overline{p_f}}$$

Forecast Losses

- Generators must **forecast** generation
- Lowest risk strategy is to sell forecast power day-ahead
- **Errors** in forecast must be purchased in the real-time market

$$\begin{aligned} I &= s_f.p_f + (s_a - s_f).p_{rt} \\ &= s_a p_f + s_f p_f - s_a p_f + (s_a - s_f)p_{rt} \\ &= s_a p_f + (s_f - s_a)(p_f - p_{rt}) \\ &= \boxed{s_a p_f} + \boxed{\Delta s \Delta p} \end{aligned}$$

Income with a perfect forecast — Impact of forecast errors

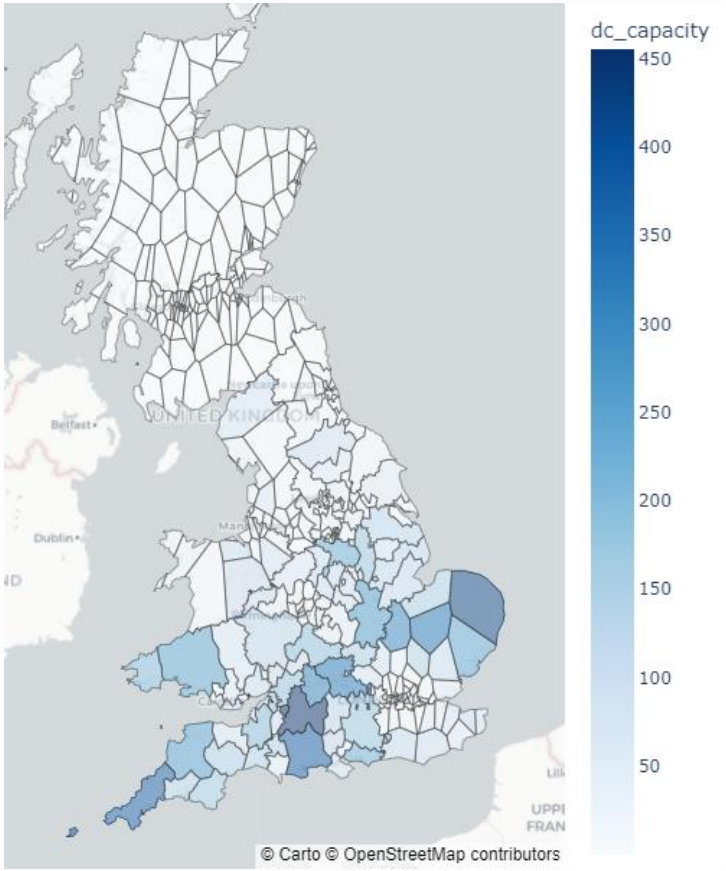
s_f is the forecast solar electricity generated in the period,
s_a is the actual solar electricity generated in the period,
p_f is the forward electricity price - the price at which the electricity can be bought or sold at the time when the forecast is known,
p_{rt} is the price at which the electricity is purchased in near real-time.

$\Delta s = (s_f - s_a)$ is the error in the forecast of solar energy generation,
$\Delta p = (p_f - p_{rt})$ is how far the real-time settlement price differed from the market expectation a day ahead.

Method

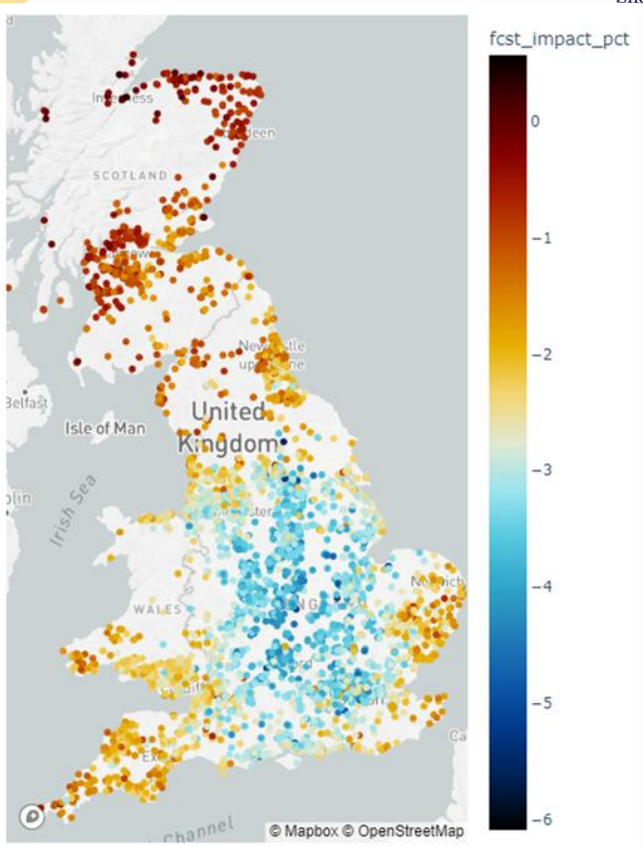
- Used generation data from:
  - Over 20,000 PV systems
  - Distributed over GB
  - 2015-2022
- Created day ahead forecasts using NWPs & ML model (xg_boost) of hourly generation for each system
- Combined with prices from Nordpool & balancing market

PV Capacity



Forecast Loss Observations

- Observe much greater forecast losses in centre of country
  - Up to 5% of revenues
- Current loss is £24.7m p.a.
  - By 2035 - with PV targets, this will be ~£125M p.a.
- Can we understand this better?



Forecast loss as % of revenues

Components of Forecast Impacts

Forecast impact can be rearranged:

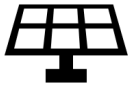
$$\begin{aligned}\mathrm{E}[ForecastImpact] &= \mathrm{E}[\Delta s \Delta p] \\ &\approx \mathrm{Cov}(\Delta s, \Delta p) \\ &= \rho \sigma_{\Delta p} \sigma_{\Delta s}\end{aligned}$$

Holds as the mean of Δp and Δs are very small:

$$\frac{\overline{\Delta s}}{\sigma_{\Delta s}} = -0.006 \;\&\; \frac{\overline{\Delta p}}{\sigma_{\Delta p}} = 0.02$$

Unbiased forecast

Unbiased markets



$\sigma_{\Delta s}$

Standard deviation of PV site forecast error (RMSE)

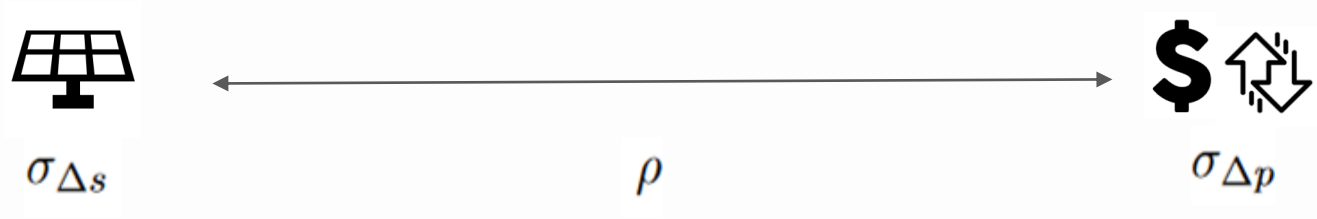
ρ

Correlation between the site's forecast error and the price difference

$\sigma_{\Delta p}$

Standard deviation of price difference between day ahead and real-time

Direct observable correlation



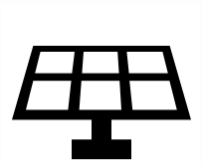
$\sigma_{\Delta s}$ ρ $\sigma_{\Delta p}$

Standard deviation of PV site forecast error (RMSE)

Correlation between the site's forecast error and the price difference

Standard deviation of price difference between day ahead and real-time

Create National Forecast Error



Site level forecast error, Δs

Aggregate

National forecast error, ΔS

Price deviation, Δp

$\sigma_{\Delta s}$ $c_{\Delta s \Delta S}$ $\sigma_{\Delta S}$ $c_{\Delta S \Delta p}$ $\sigma_{\Delta p}$

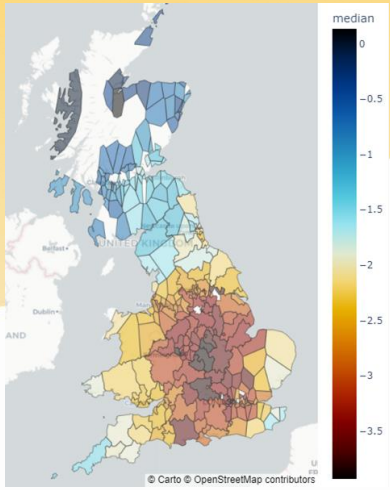
Site-level property: error (RMSE)

Properties of system & sites together

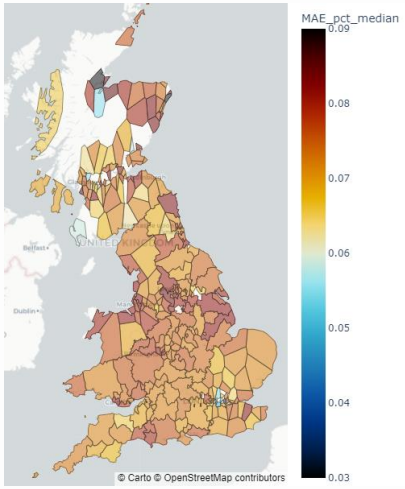
Properties of the market

Components

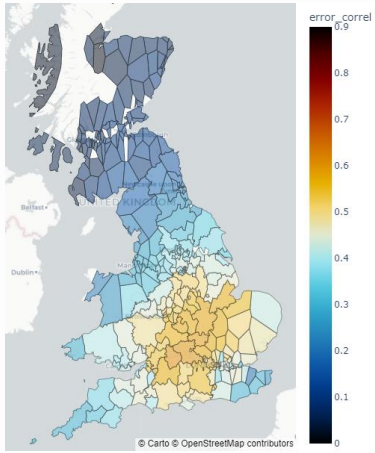
Forecast Impact (%)



Standard deviation of site-level Errors



Correlation of site-level errors with national error



Correlation of National error with Price difference:

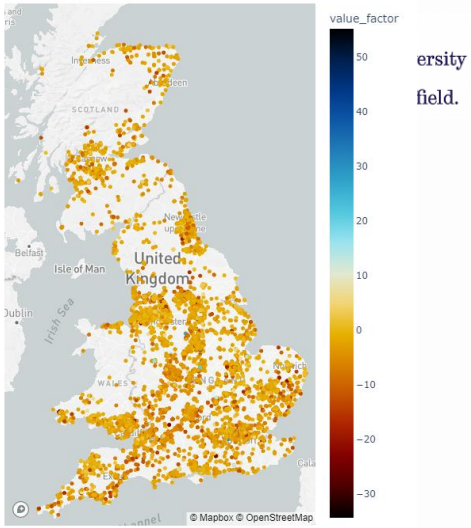
$c_{\Delta S \Delta p}$ = -13.5%

How do shape losses compare?

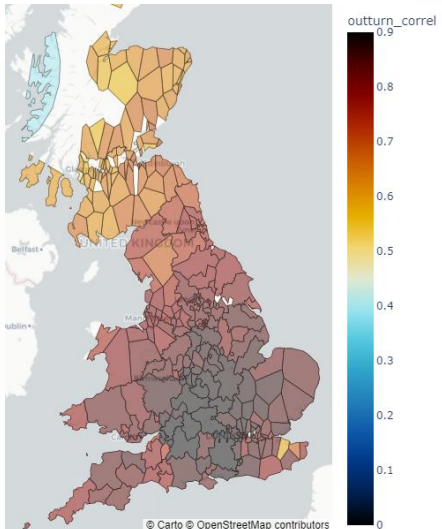
$$\textit{Value Factor} = 1 - \textit{Shape losses} = \frac{\overline{s_a p_f}}{\overline{s_a}\ \overline{p_f}}$$

- Driven by the correlation of **outturns**
- Site-level correlations of actual generation are geographically flat
- Correlation is nationally high & even

Shape losses



Correlation of site-level outturns and national outturn

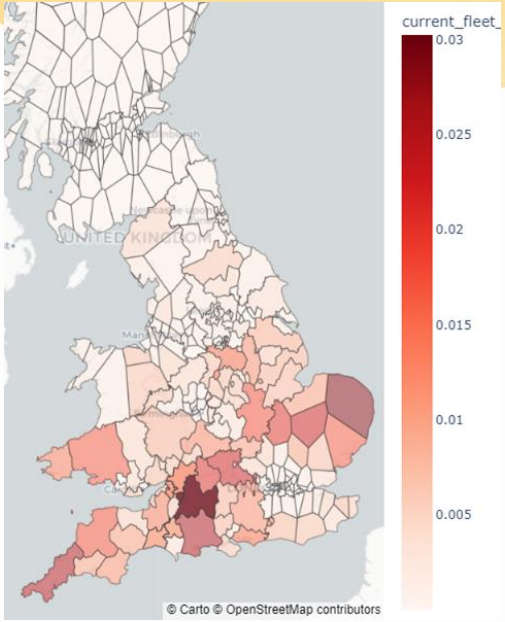


Optimising PV Fleet

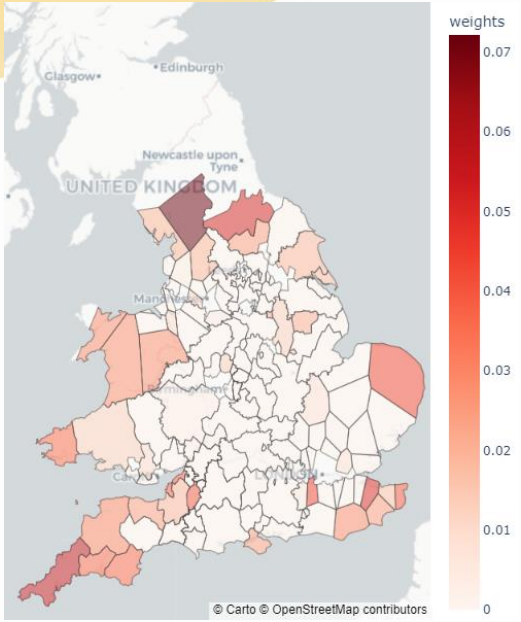
- We can take advantage of the lack of correlation of forecast errors across regions
- National forecast error (sigma) can be mimimised
- Minimise weights across covariance of forecast errors

$$\sigma^2_{\Delta S} = \mathbf{C}\mathrm{Cov}(\mathbf{S})\mathbf{C}^T$$

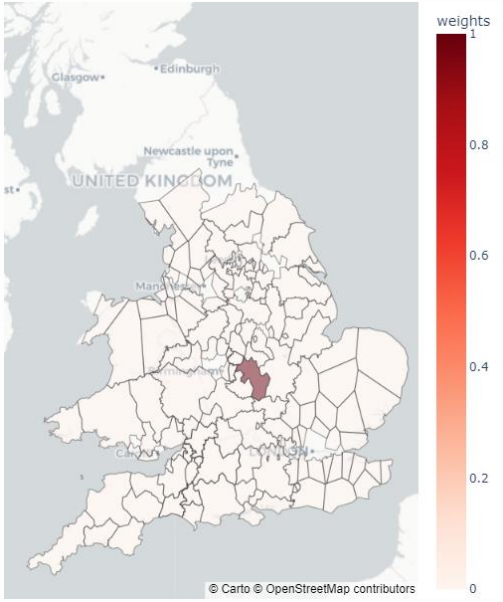
Optimal Fleet - Reduces Costs by 25%



Current fleet
Sigma = 3.6%



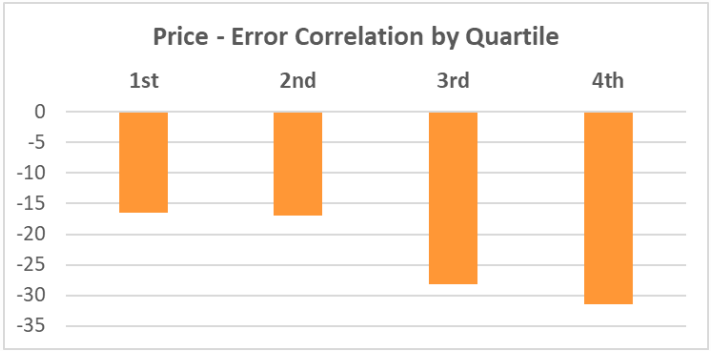
Optimal fleet
Sigma = 2.8%

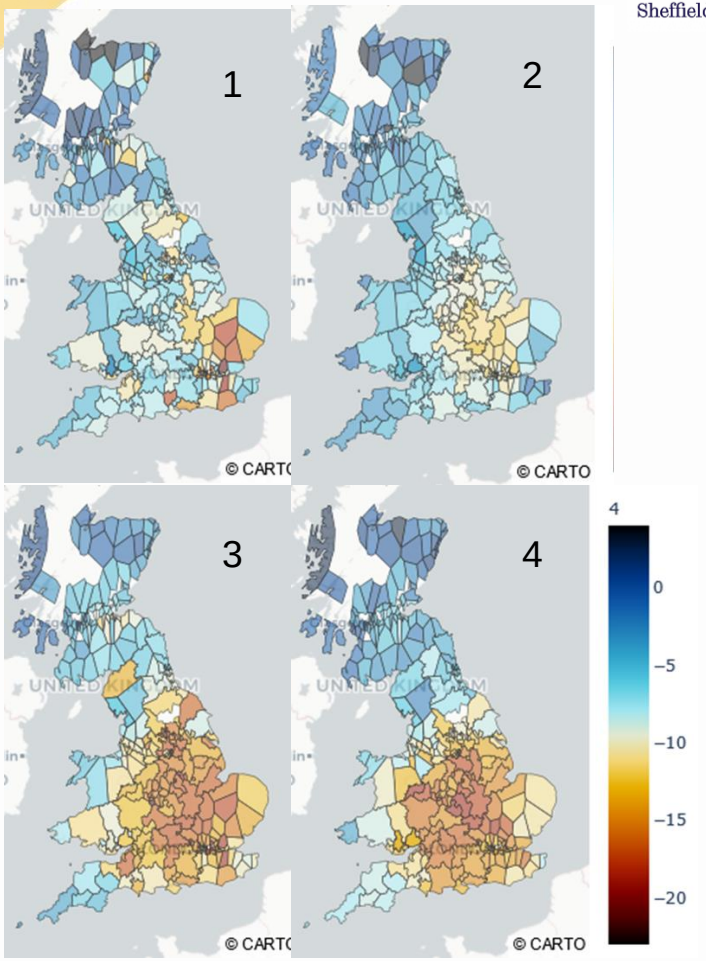


Worst fleet
(E.g. small island)
Sigma = 7.6%

Losses as PV penetration increases

- Examine correlation for hours where PV makes up a greater share of the energy mix
- Quartiles: PV as % of generation





Further Work

- Consider forecast errors in other markets
- Wind and interconnection impacts
- Further understand impact of PV penetration

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Thank You!

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