Leveraging AI / Machine Learning in Power Systems

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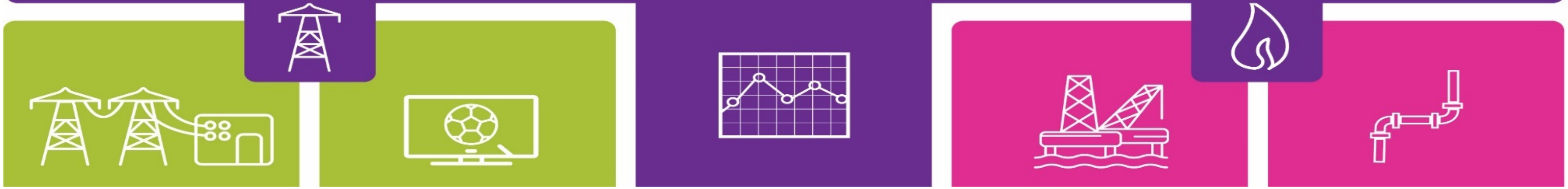
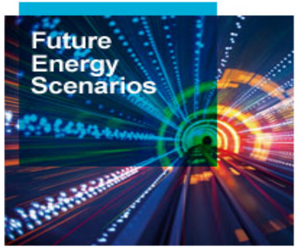
Our role as System Operator

We make sure GB's gas and electricity is transported safely and efficiently from where it's produced to where it's consumed. We ensure that supply and demand are balanced in real-time and we facilitate connection of assets to the transmission system.





We work with customers and stakeholders to shape the future energy market, providing analysis and insight into the changing nature of supply, demand and networks. We facilitate changes to market frameworks to accommodate new technologies and ways of working.

Our Mission

Energy is the lifeblood of our society and economy
As Great Britain's Electricity System Operator, we keep the lights on around the clock for all energy customers.

Climate change is the challenge of a generation
We play a leading role in the decarbonisation of the energy system by enabling the transition to a more sustainable energy future.

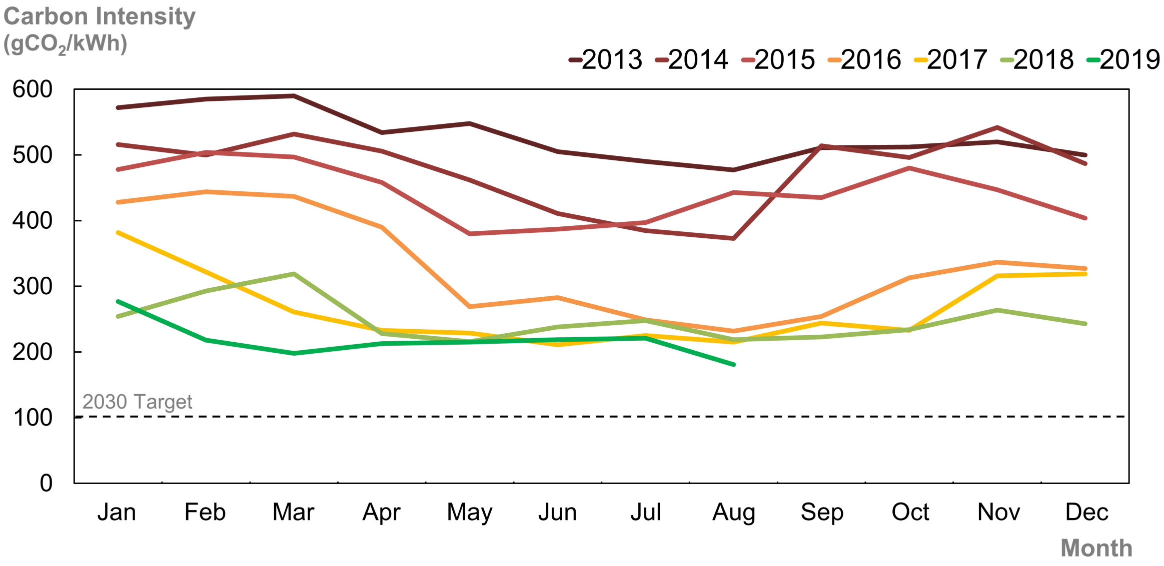
Ambition
We want to be able to operate a carbon free electricity system by 2025, and we'll invest accordingly.

What's Changing?

carbonintensity.org.uk

The Decarbonisation of British Electricity

2018 was the 'greenest' year on record in Great Britain



53.1% decrease from 2013 to 2018

2013 **529** gCO_2/kWh

2014 **477** gCO_2/kWh

2015 **443** gCO_2/kWh

2016 **330** gCO_2/kWh

2017 **266** gCO_2/kWh

2018 **248** gCO_2/kWh

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Source: National Grid ESO

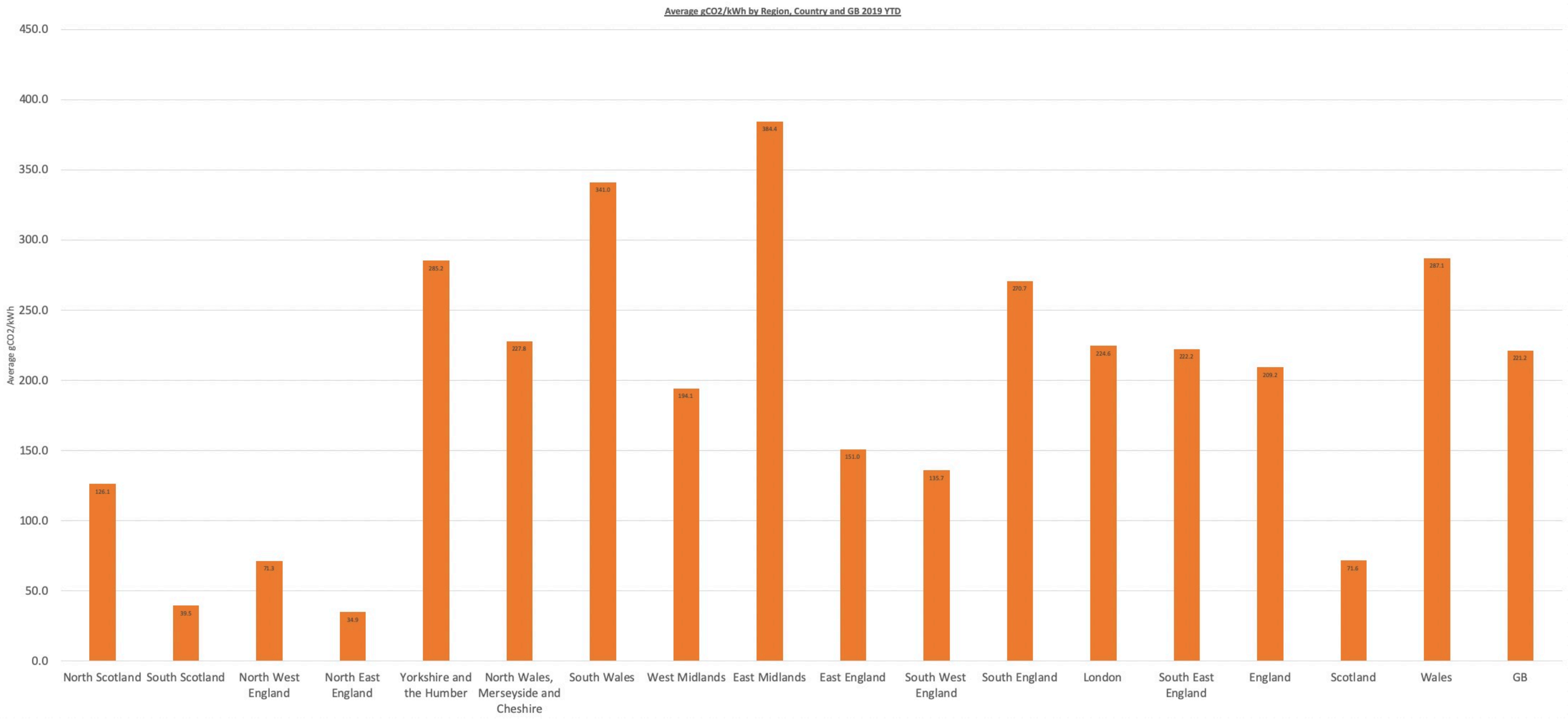
What's Changing in GB?

★Records broken since the last Smart Grid Tech Conference in Amsterdam (March)

Max Wind	15530 MW	Min Gas	1556 MW
Max Solar ★	9550 MW	Min Carbon Intensity ★	57 gCO_2/kWh
Max No Coal ★	436 Hrs	Low Carbon ★	87.9%

North Scotland (Aug 14th/15th) – 30 hours straight with 0 gCO_2/kWh

What's Changing in GB? Average Carbon Intensity by Region



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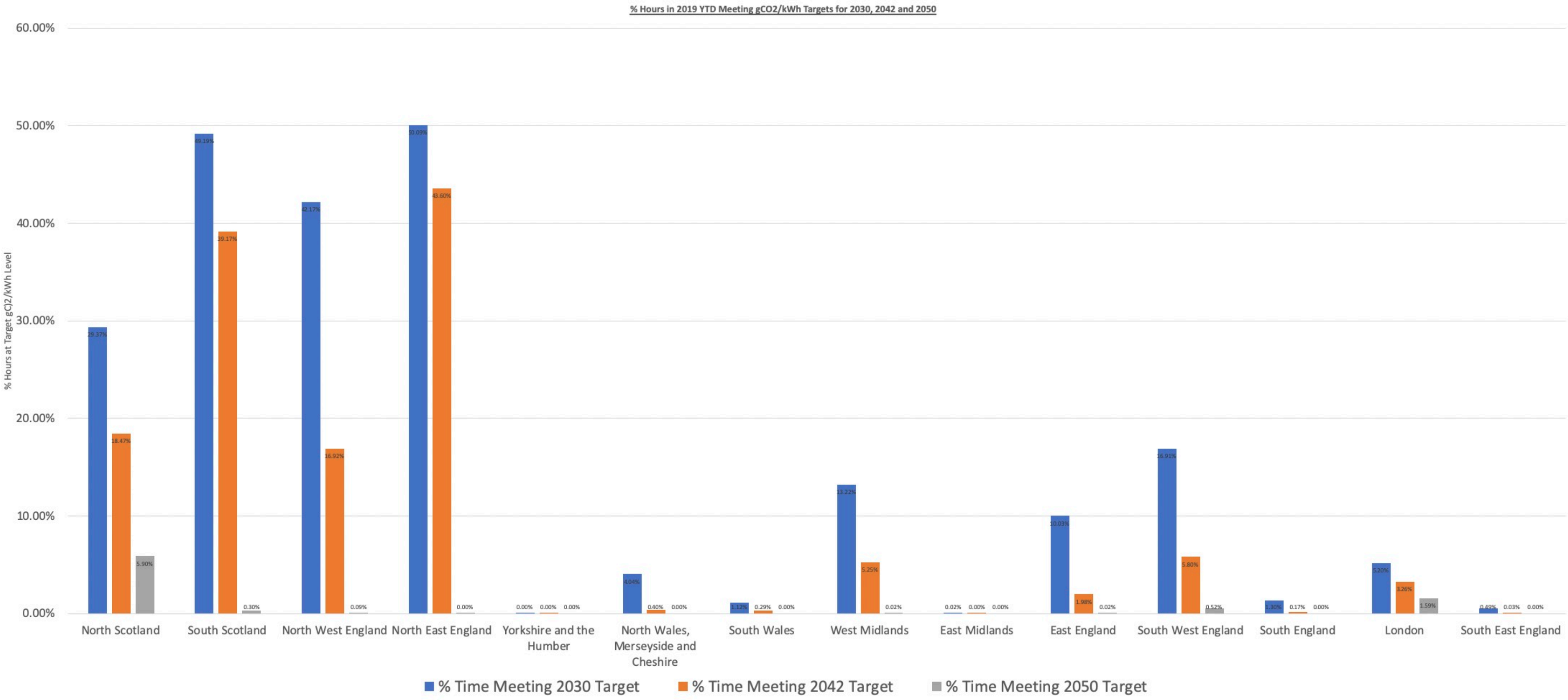
What’s Changing in GB? Time YTD at Future Target Levels



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What's Changing?

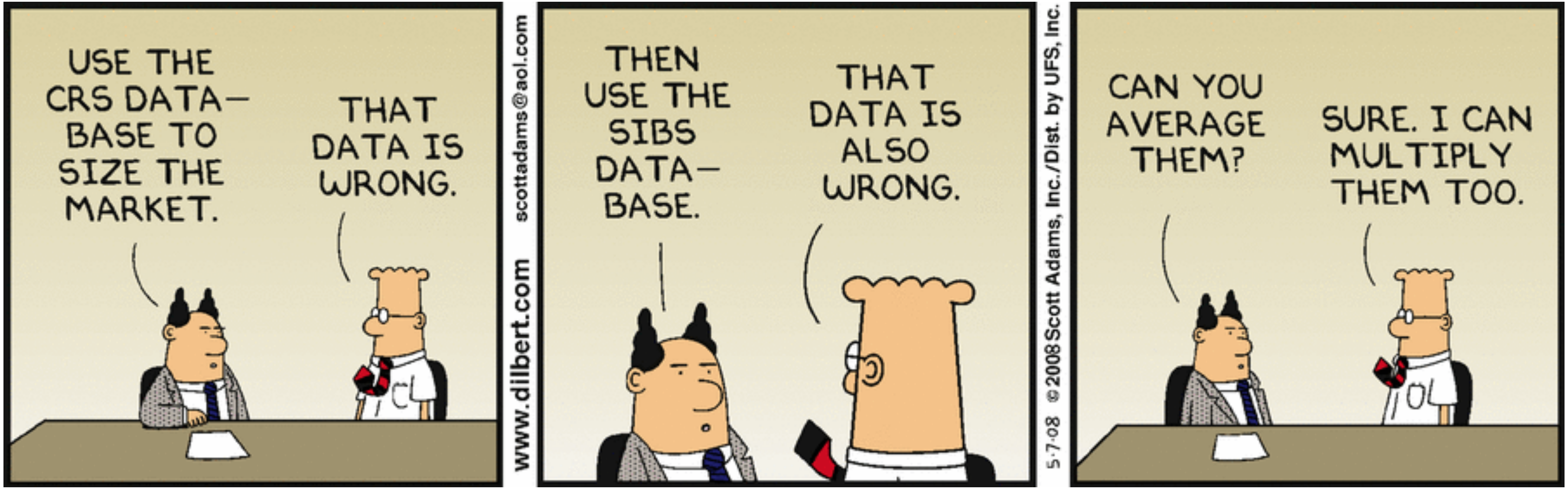
The 3Ds of the future!

Decarbonisation	Decentralisation	Digitisation
Paris Agreement – world wide reductions in CO_2 Power Sector are leaders with PV, Wind and other renewables Economics of Renewables really works	Increasing number of small power plants this is changing Germany: 1000 (yr 2000) > 1.5 Million (2017) GB > 1 Million PV installs	How do we connect? BlockChain? Smart Meters? Virtual Power Plants?

What’s Changing? Data

“The world is moving too fast for polishing!!! Data that is useful today will be redundant by the time perfect has been reached and often the people with the data are not best placed to clean it up”

Why we use AI and ML?



What is Machine Learning? Is it really AI?

Machine Learning and Artificial Intelligence are terms that are often interchanged.

We are looking at Machine Learning, not Artificial Intelligence.

Machine Learning

consists of statistical techniques to give computers the ability to "learn“.

The models progressively improve performance on a specific task with data, without being explicitly programmed.

Artificial Intelligence

is the quest to enable a machine to mimic human behavior. Machine Learning is a core underlying part of this.

What is Machine Learning?

Training and Forecasting

Training the Ensemble

This is how the model adapts to longer term changes and trends. For PV, the optimum retrain cycle is daily.

Forecasting / Prediction

This is how the trained model takes an input and uses it's training to predict an output.

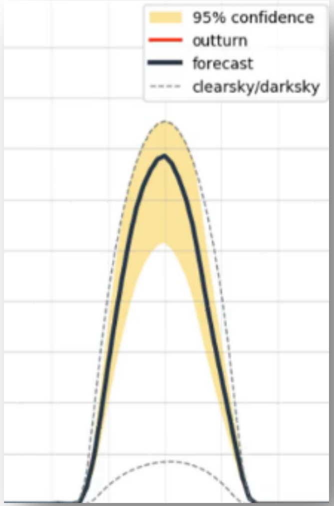
Solar Forecasting Case Study

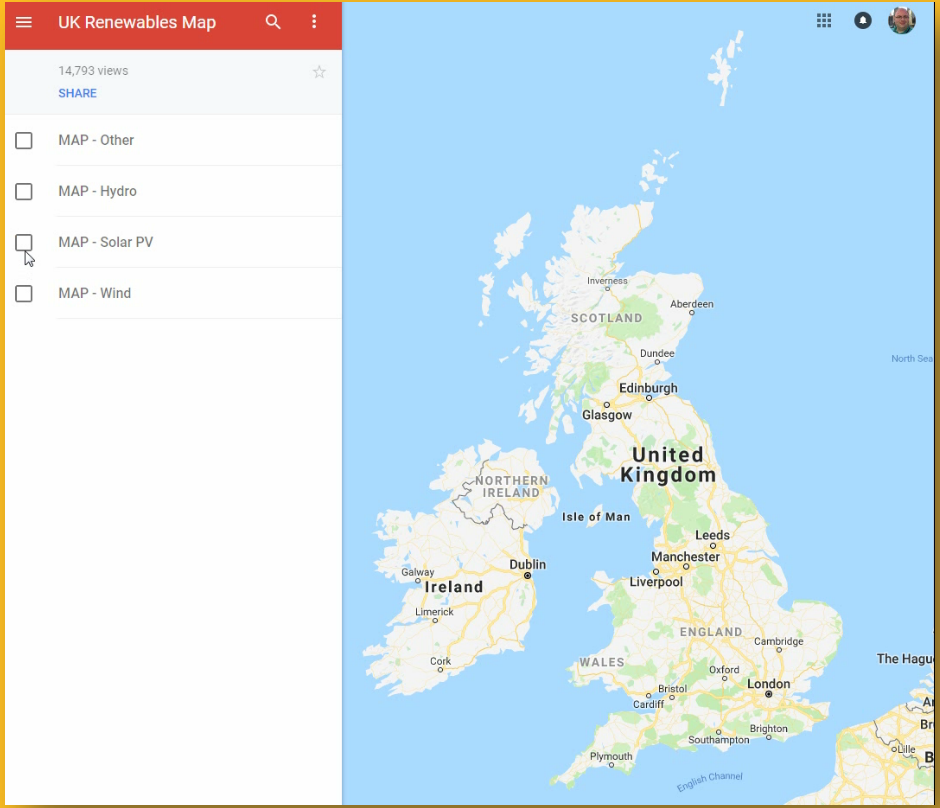
How to forecast solar net demand reduction with ML?

State of PV in GB

13.05 GW PV
(Capacity Nov 2018)

Max Yield 9.38 GW or 72%
(26/05/17)





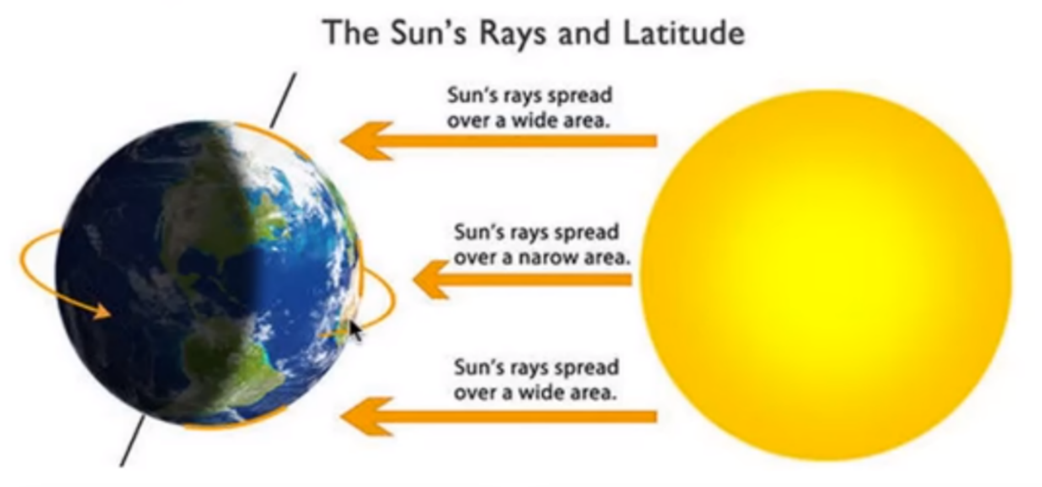
Source: DBEIS Renewable energy planning database monthly extract – Solar Sites > 1 MW

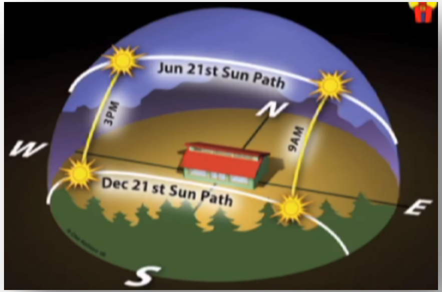
Excludes c. 1 Million Domestic PV Installations (Source MyGridGB)

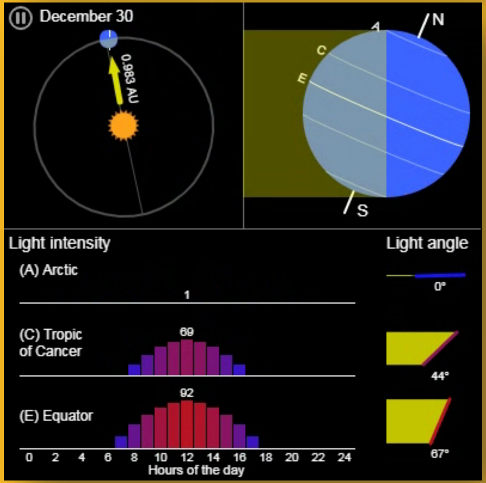
State of PV in GB

Latitude & Seasonal Impacts

Seasons not related to the proximity of the sun



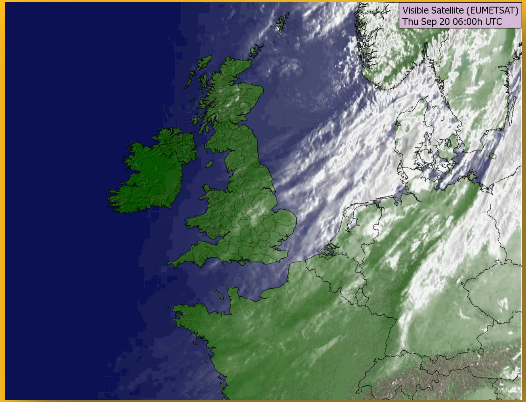


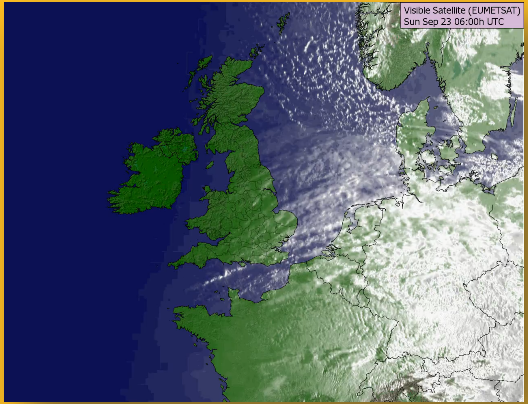


State of PV in GB

Weather

Extremes observed and impact of climate change

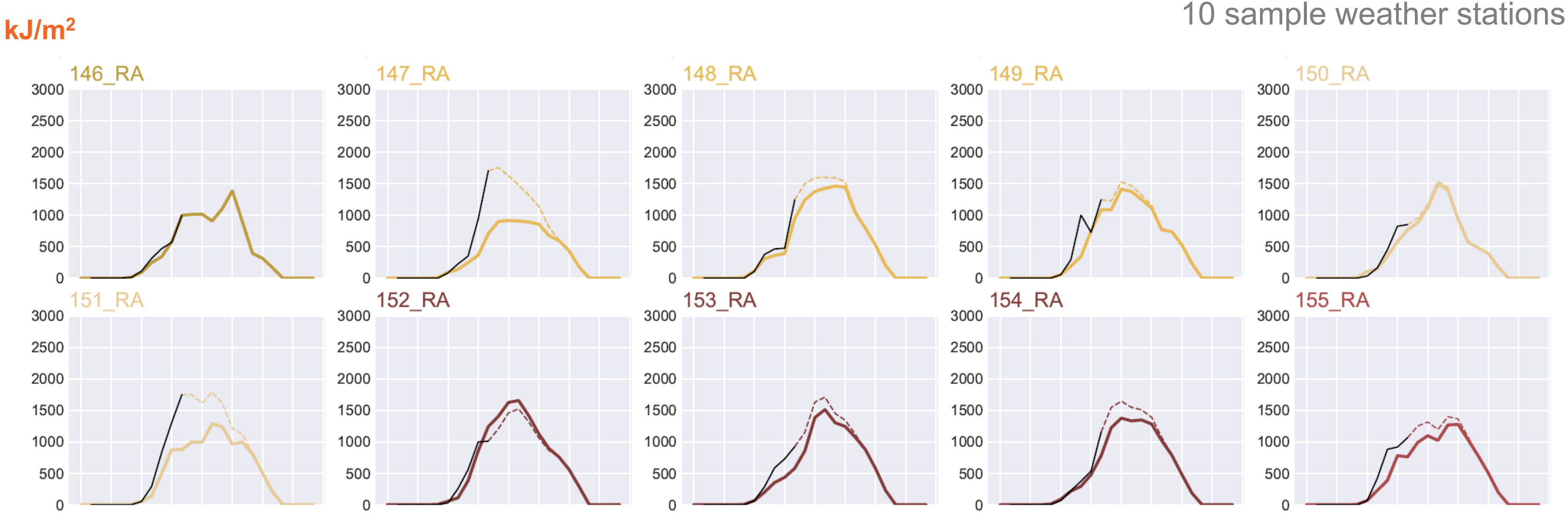




Weather has the single biggest impact on PV Generation

Nowcasting - Solar Irradiance

10 sample weather stations



Solid coloured line = forecast (6h), Solid black line = observation (1h), Dashed coloured line = Nowcast (1h)

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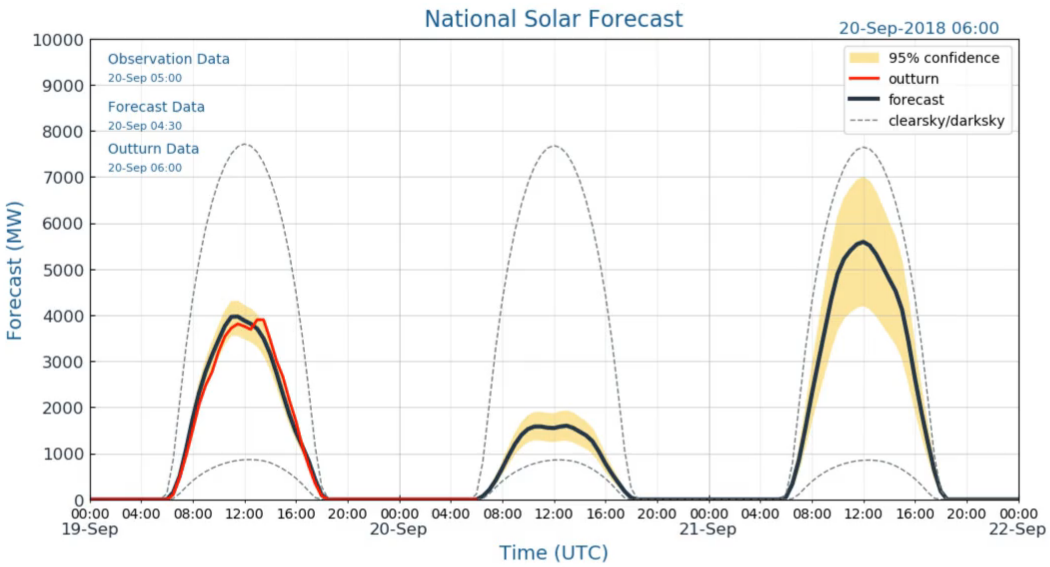
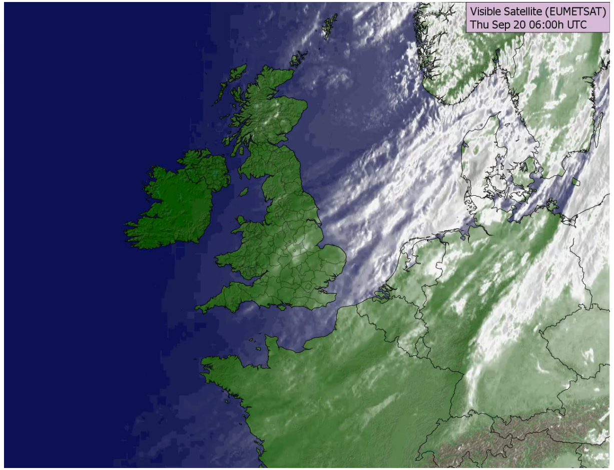
Aftermath of Storm Ali

Heavy cloud cover across GB results in very low solar PV output

Forecast dynamically adjusts to changing conditions



MetDesk:

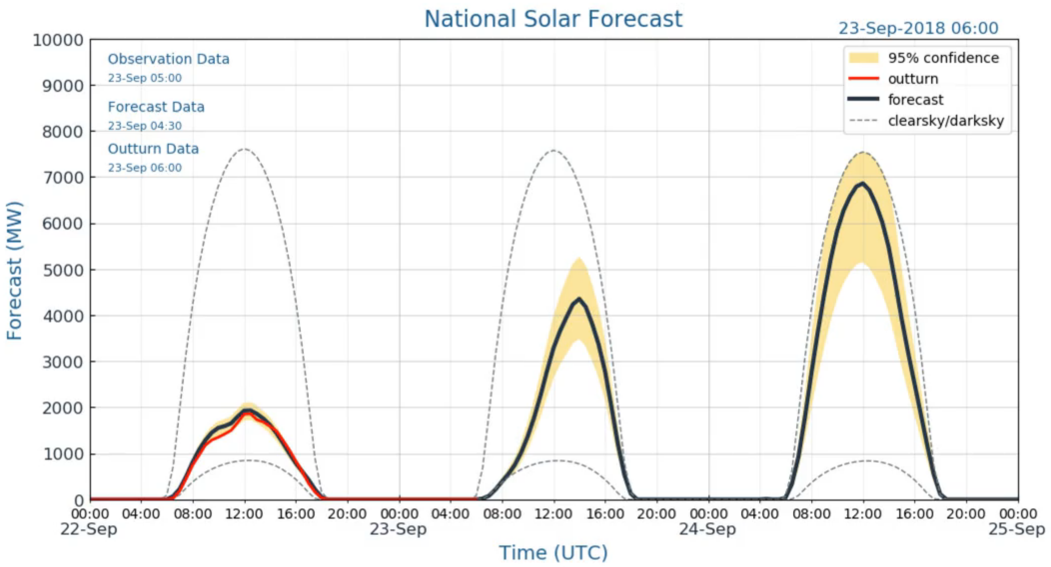


Interactive

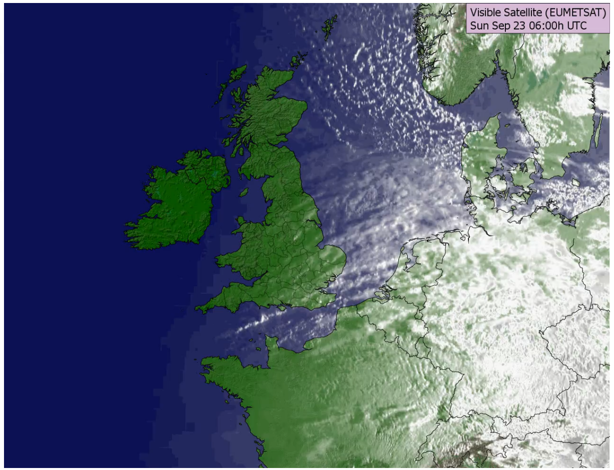
Nowcasting

Complex cloud formations are hard to predict

Forecast updates using observation data from Met Office, correcting for poor irradiance forecasts



MetDesk:



Interactive

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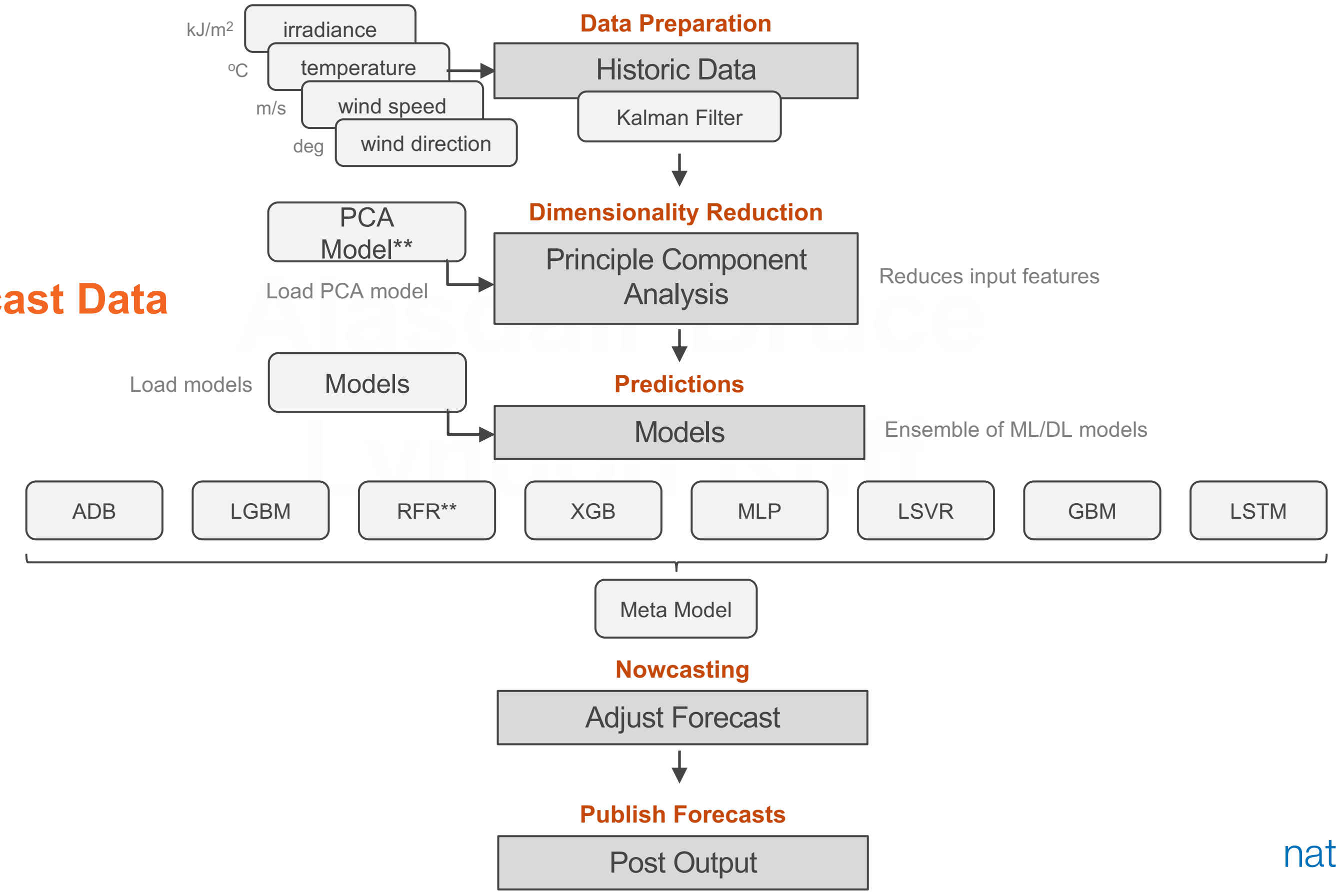
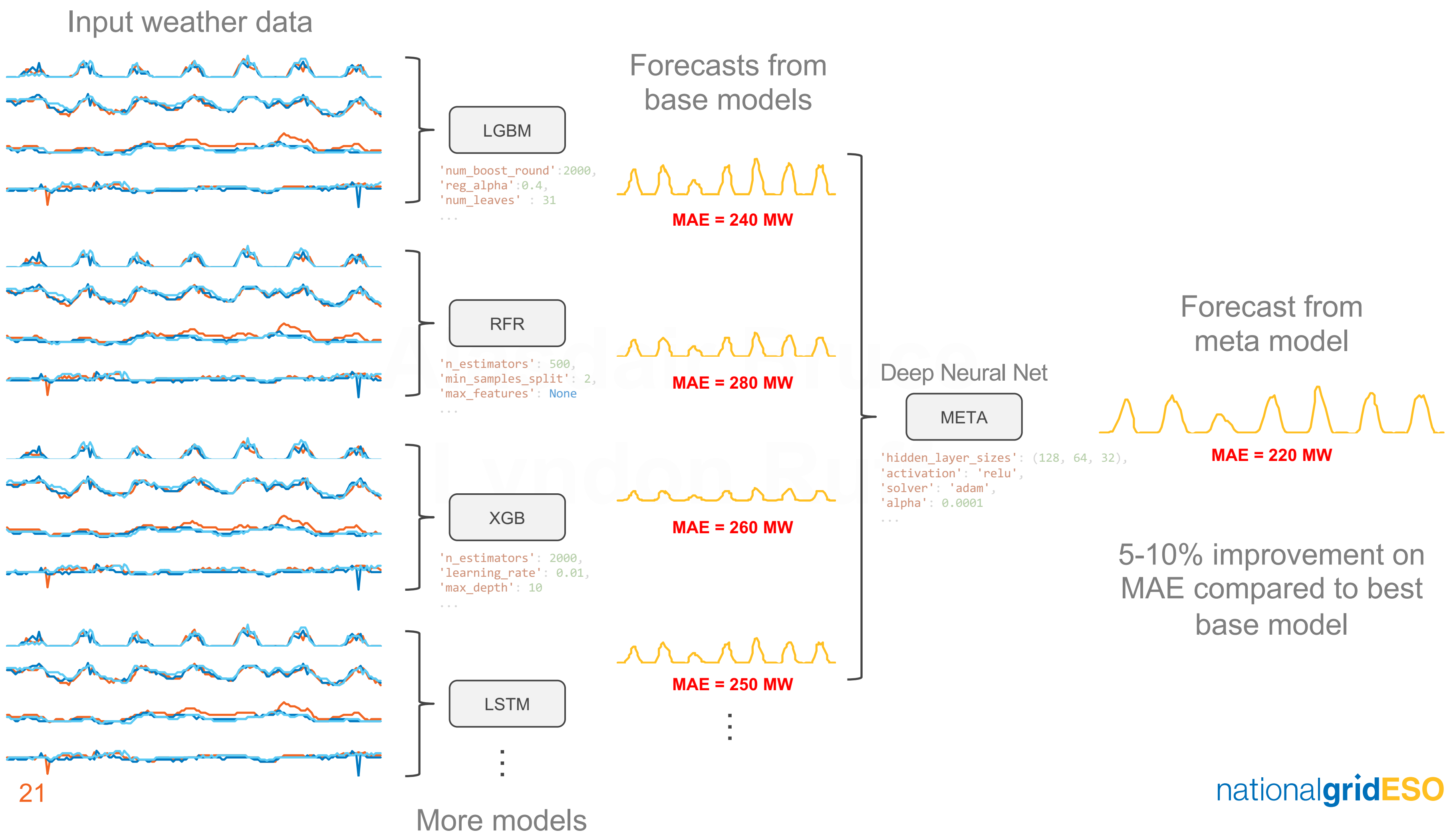
National Solar Models

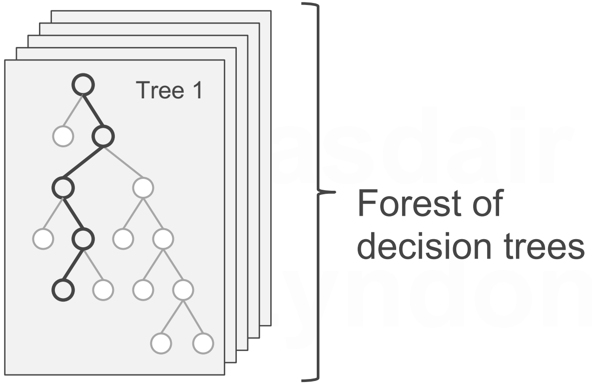
Forecast Data

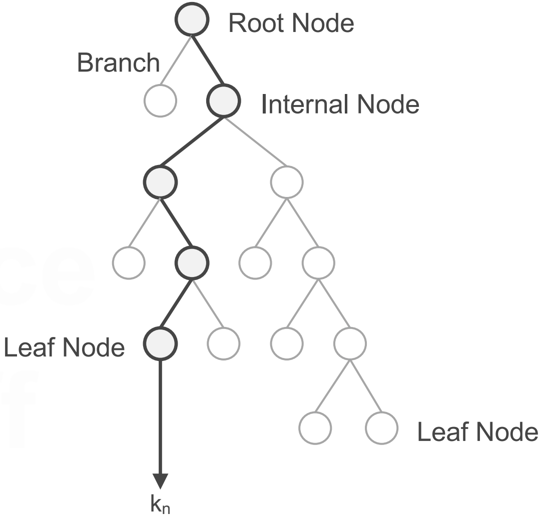



Input weather data
Forecasts from base models
LGBM
'num_boost_round':2000,
'reg_alpha':0.4,
'num_leaves' : 31
...
MAE = 240 MW
RFR
'n_estimators': 500,
'min_samples_split': 2,
'max_features': None
...
MAE = 280 MW
XGB
'n_estimators': 2000,
'learning_rate': 0.01,
'max_depth': 10
...
MAE = 260 MW
LSTM
MAE = 250 MW
More models
Deep Neural Net
META
'hidden_layer_sizes': (128, 64, 32),
'activation': 'relu',
'solver': 'adam',
'alpha': 0.0001
...
Forecast from meta model
MAE = 220 MW
5-10% improvement on MAE compared to best base model

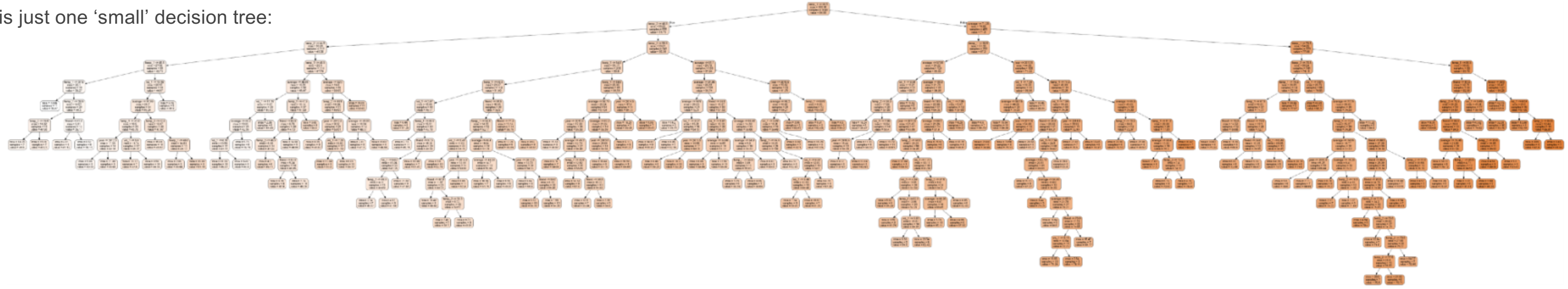
RFR - Random Forest Regression

Random Forest Regression models will typically use up to 1000 decision trees in each ensemble





This is just one ‘small’ decision tree:

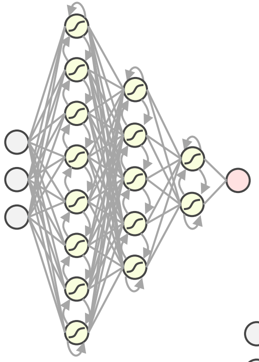


Meta - Neural Net Architecture Search

- Find optimal NN architecture by searching through large number of permutations (~20,000)
- Assess different NN architectures, activation functions, optimizers, epochs, batch size, regularization, etc.

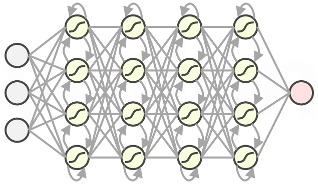
MAE = 240 MW

(128, 64, 32)



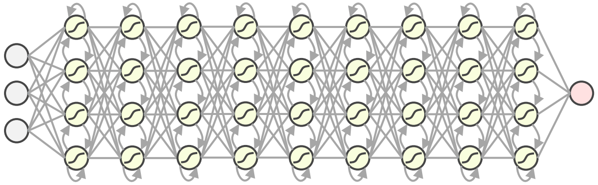
MAE = 280 MW

(64, 64, 64, 64)



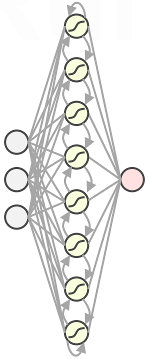
MAE = 320 MW

(64, 64, 64, 64, 64, 64, 64, 64, 64)



MAE = 400 MW

(128)



```
param_grid = {'hidden_layers': [1, 2, 3],
              'neurons_i': [64, 96, 128],
              'L1_i': [0, 0.0001],
              'L2_i': [0, 0.0001],
              'batch_normalization_i': [0, 1],
              'activation_i': [Activation('tanh'), LeakyReLU()],
              'dropout_i': [0, 0.05, 0.1, 0.15, 0.2],
              'neurons_1': [64, 96, 128],
              'L1_1': [0, 0.0001],
              'L2_1': [0, 0.0001],
              'batch_normalization_1': [0, 1],
              'activation_1': [Activation('tanh'), LeakyReLU()],
              'dropout_1': [0, 0.05, 0.1, 0.15, 0.2],
              'neurons_2': [64, 96, 128],
              'L1_2': [0, 0.0001],
              'L2_2': [0, 0.0001],
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              'activation_2': [Activation('tanh'), LeakyReLU()],
              'dropout_2': [0, 0.05, 0.1, 0.15, 0.2],
              'neurons_o': [64, 96, 128],
              'L1_o': [0, 0.0001],
              'L2_o': [0, 0.0001],
              'batch_normalization_o': [0, 1],
              'activation_o': [Activation('tanh'), LeakyReLU()],
              'dropout_o': [0 0, 0.05, 0.1, 0.15, 0.2
              'optimizer': ['adam'],
              'epochs': [1000],
              'batch_size': [train_X.shape[0]]
              }
```

TensorFlow

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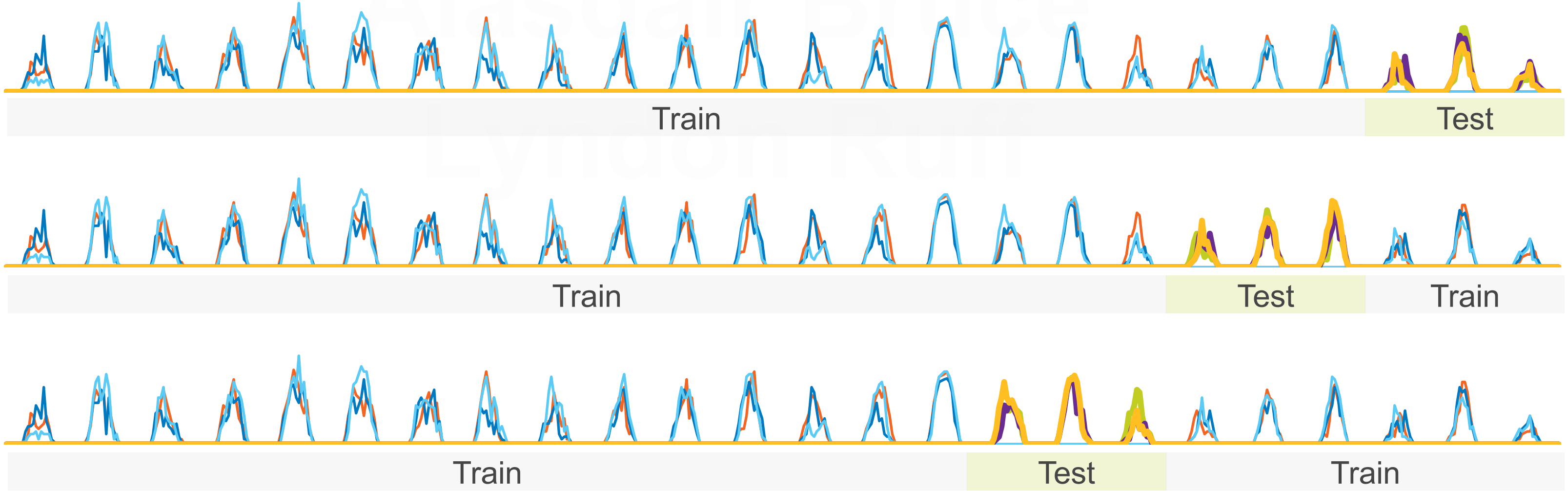
Evaluate Model Performance

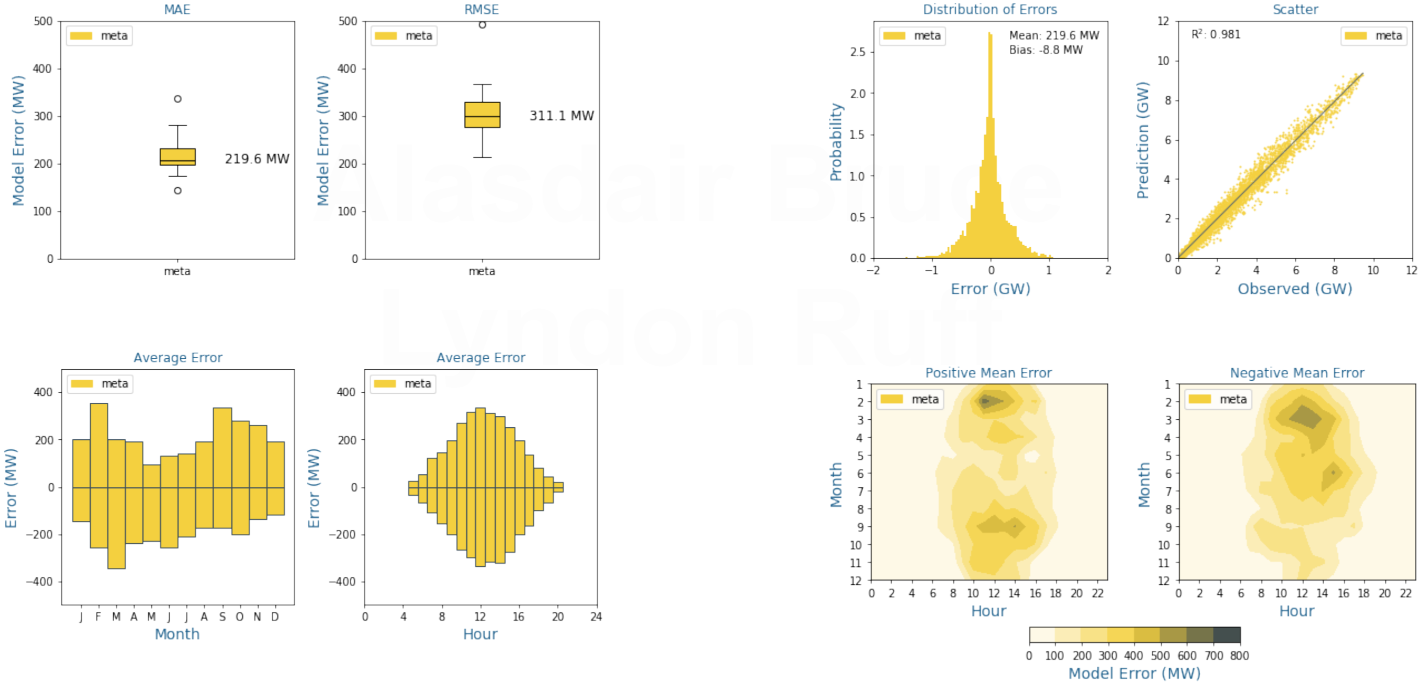
- Split/fold data into k folds using **k-Fold Cross Validation**
- Train models on train set (k-1), evaluate performance on test set (k), repeat k times on different folds
- k-fold cross validation allows models to be tested on **unseen historical data**
- Prevents Neural Nets and other complex ML models from overfitting, ensuring the model will perform well with future unseen data



Repeat for all folds…

Evaluate Model Performance

Evaluate the performance of models using k-Fold Cross Validation



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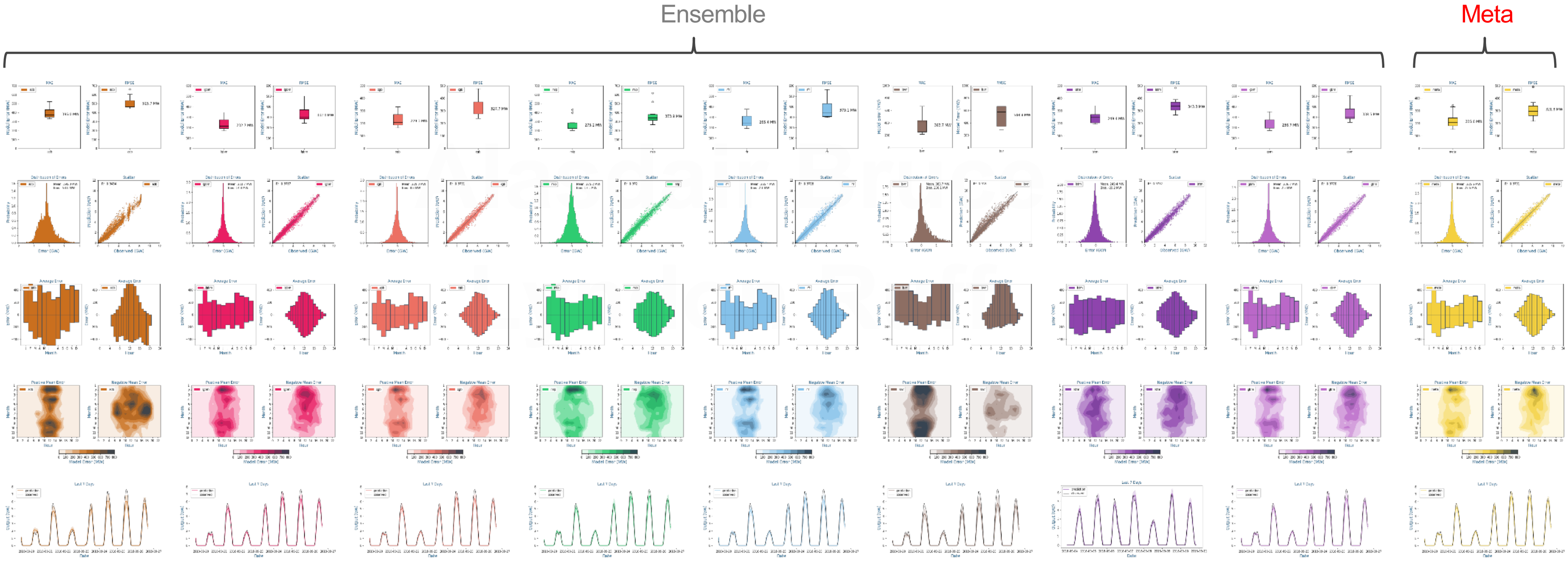
Ensemble

- Charts are generated showing the evaluation metrics during training



Super Computer

Hardware

- x8 NVIDIA® Tesla® V100 Tensor Core GPUs
- x2 Intel® Xeon® Platinum 8167M 2.00 GHz (52 cores, 104 threads)
- Fast Storage

Core Software

- Python 3.6 64-bit python™
- Anaconda 5.2 64-bit ANACONDA.
- RStudio R Studio
- CUDA Toolkit v9.0 NVIDIA CUDA
- NVIDIA cuDNN 7.0 cuDNN

TESLA V100 PRODUCT SPECIFICATIONS

	NVIDIA Tesla V100 for PCIe-Based Servers	NVIDIA Tesla V100 for NVLink-Optimized Servers
Double-Precision Performance	up to 7 TFLOPS	up to 7.8 TFLOPS
Single-Precision Performance	up to 14 TFLOPS	up to 15.7 TFLOPS
Deep Learning	up to 112 TFLOPS	up to 125 TFLOPS
NVIDIA NVLink™ Interconnect Bandwidth	-	300 GB/s
PCIe x 16 Interconnect Bandwidth	32 GB/s	32 GB/s
CoWoS HBM2 Stacked Memory Capacity	32 GB / 16 GB	32 GB / 16 GB
CoWoS HBM2 Stacked Memory Bandwidth	900 GB/s	900 GB/s

Solar Case Study

40% MAE
Improvement with ML

Our most accurate forecasting months have been the last two months

National Grid ESO

Ambition

We want to be able to operate a carbon free electricity system by 2025, and we'll invest accordingly.

UK has committed in law to be net zero before 2050.

Machine Learning is a critical part of achieving this.

National Grid ESO

Where we are now

The rate of change in our industry will never again be as slow, the volumes of data so small, or the combinations of assets so simple as they are today.

Questions?

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