A Methodology to Improve the Predictability of Offshore Wind Energy Generation: Evidence from Great Britain

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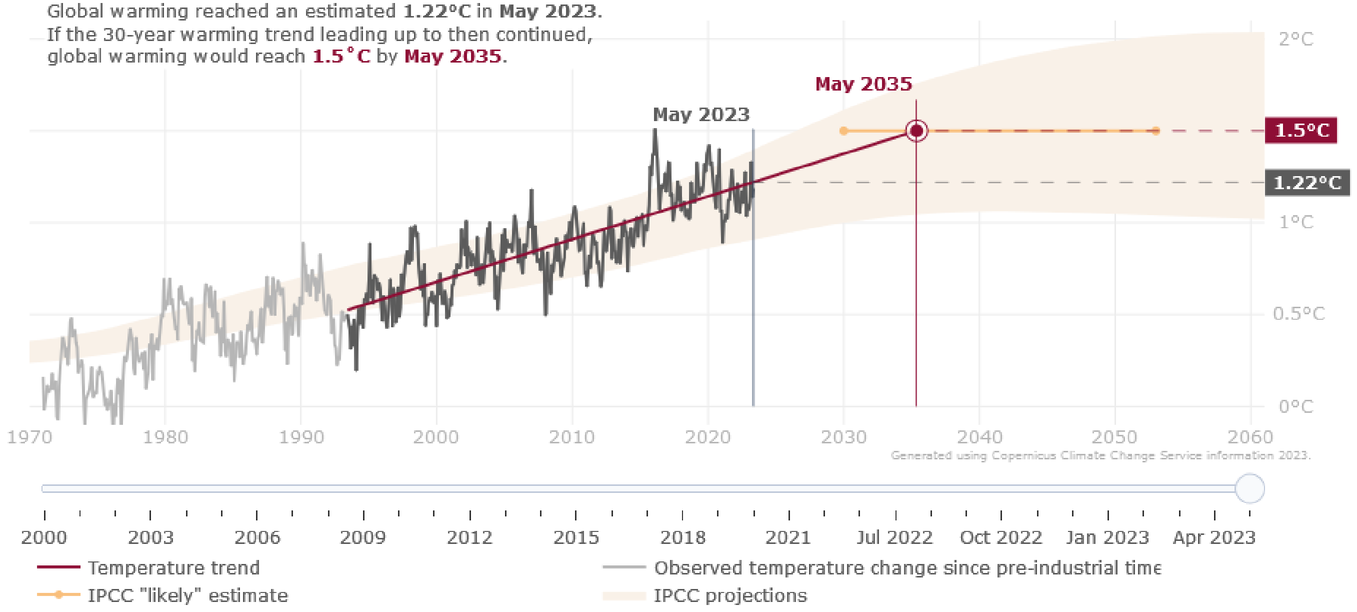
1) Background

- CO_2 concentration levels are now more than 50% higher than they were before the onset of the industrial era.

- The successful integration of offshore wind energy into the power grid is seen as an important component of policies that will hopefully reduce net carbon emissions to zero.

- Achieving the goal of net zero by 2050 is not assured. Indicative of this, ExxonMobil has recently indicated that the prospect of the world achieving net-zero CO_2 emissions by 2050 is remote. (https://www.reuters.com/business/energy/exxon-rebuts-proxy-advisor-says-net-zero-emissions-scenario-unlikely-2023-05-18/)

Global warming of 1.5˚C is closer than you might think.

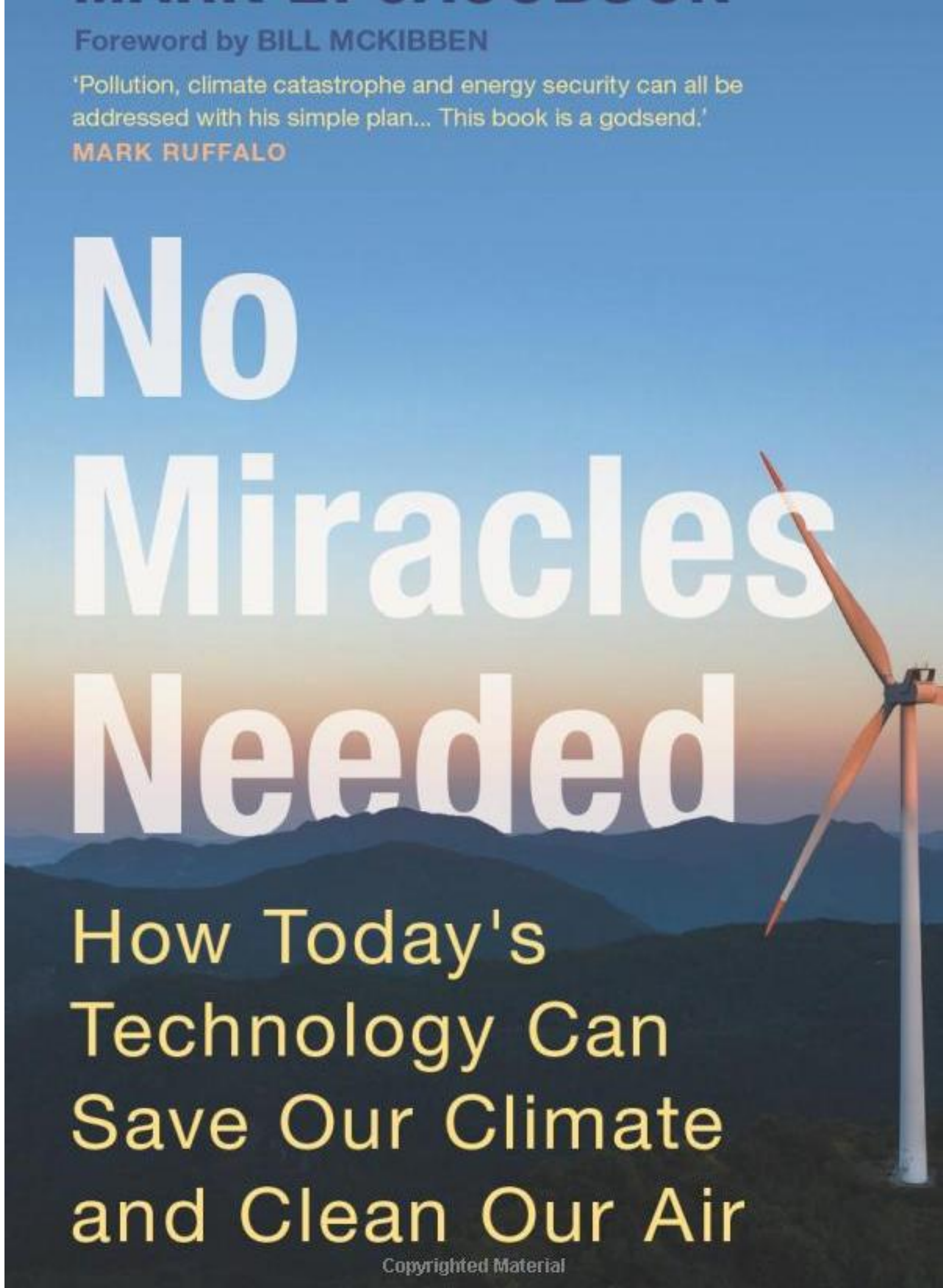


Source: Copernicus Climate Change and Atmosphere Monitoring Services:

2) More Background

Some researchers such as Professor Mark Z. Jacobson of Stanford University, believe that we know all that is needed to achieve an electricity system with 100 % renewable energy

Unfortunately, the industry's expertise is so limited that power grid operators respond to periods of excess wind energy supply by largely wasting the energy instead of storing it for future periods (the wastage level in the British onshore is over 15% even though there is ample storage capacity).



3) Some Insightful Quotes

“Facts are stubborn, but statistics are more pliable.”

Mark Twain

"The first principle is that you must not fool yourself and you are the easiest person to fool.“

Richard Feynman
Nobel Prize laureate

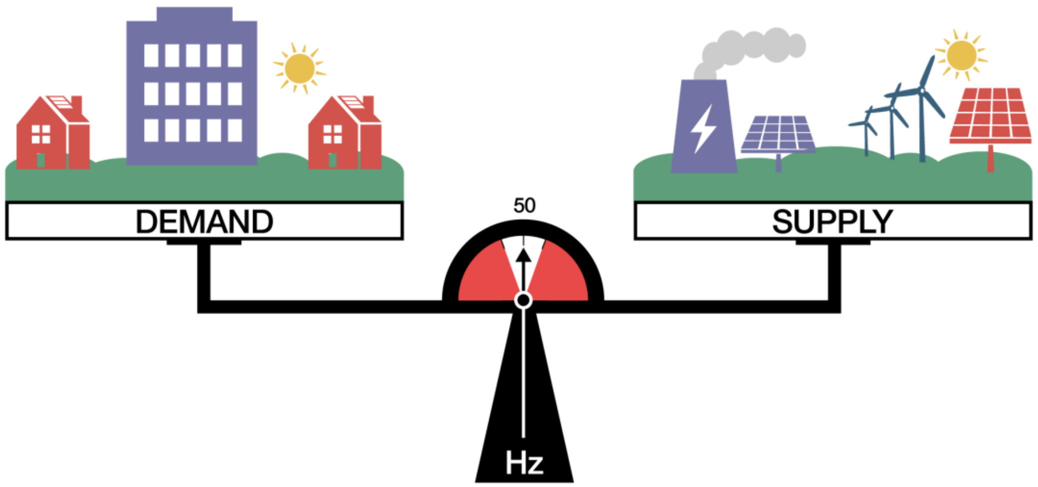
4) Background on Wind Energy Developments in Great Britain

As of late 2022, onshore wind energy capacity was about 7.5 GW while offshore capacity was about 13.6 GW.

Under its new strategy, the UK government increased its 2030 offshore wind target from 40 GW to 50 GW. No new target has been set for onshore wind.

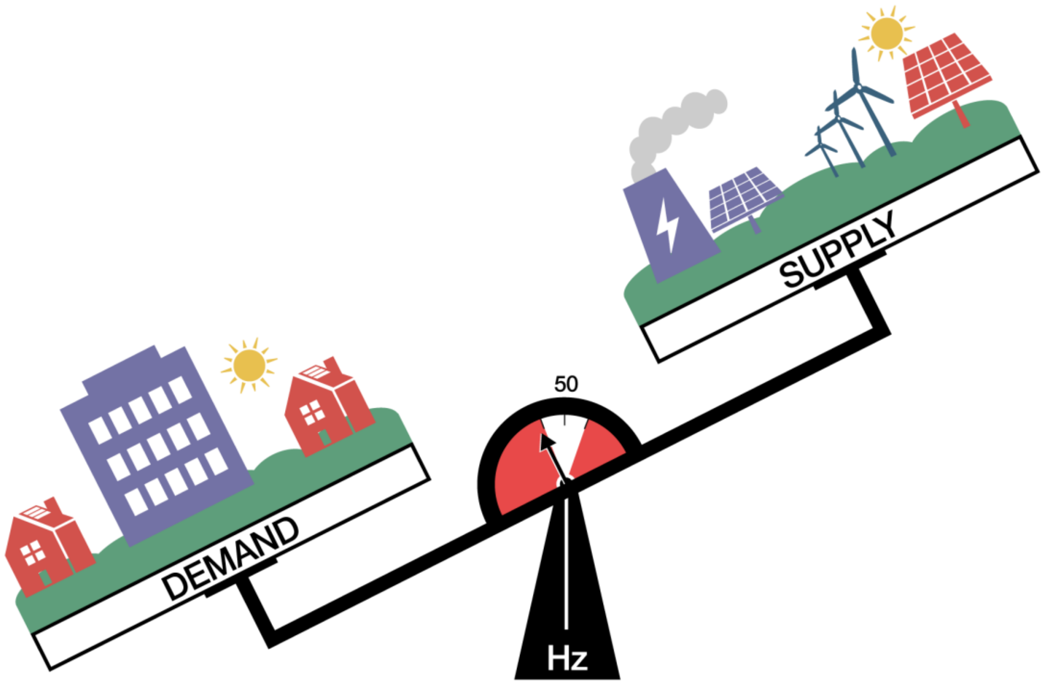
5) Wind Energy Forecasting: Why should we care?

The Resiliency of the power grid is enhanced when there is a balance between supply and demand



- The Power Grid is an Alternating Current System
- In Europe, the target level of system frequency is 50 Hz.
- System frequency will equal its target level when demand = supply

Renewable Energy Forecasting: Why should We Care?



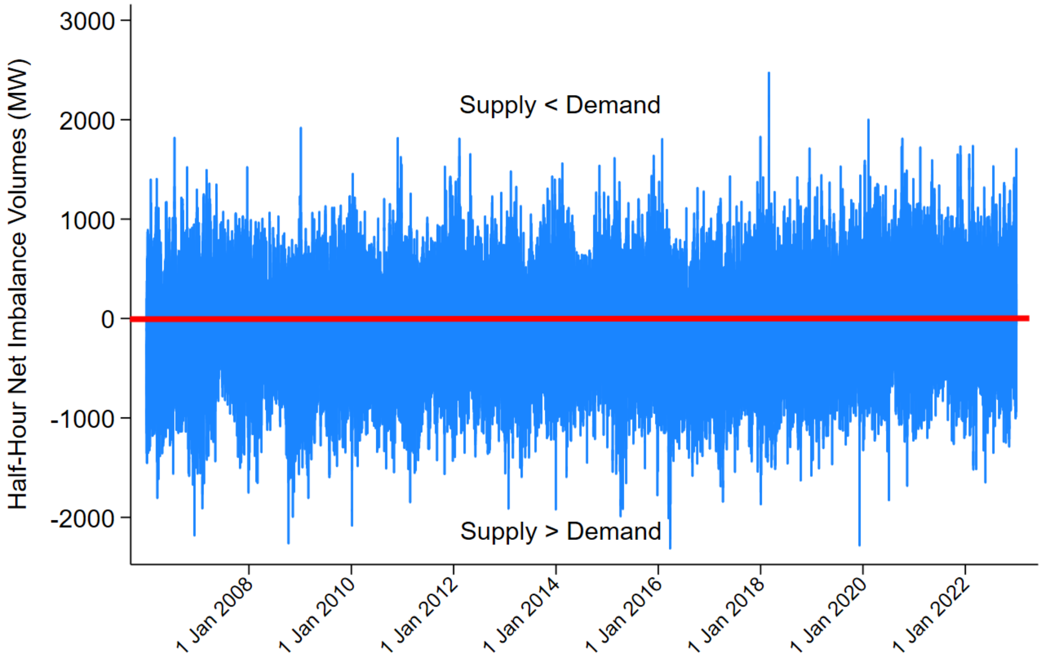
- System Frequency falls when demand > supply
- System Frequency outcomes outside the “normal range” can be destabilizing.
- In this light, accurate forecasts enhance resiliency by providing the system operator with advanced knowledge of possible challenges.

6) In Great Britain, the Net Imbalance Volume (NIV) is a key metric of the Power Grid's Operational Performance

- The NIV equals the sum of all the balancing actions directed by the system operator.

- It is driven by forecast errors and any generation/transmission scheduling errors
- Large positive NIV outcomes can pose operational challenges
- Large positive NIV outcomes are largely fueled by fossil fuels even though there is substantial storage capacity.

The Net Imbalance Volume, 1 Jan 2006-31 Dec 2022



Source: Elexon

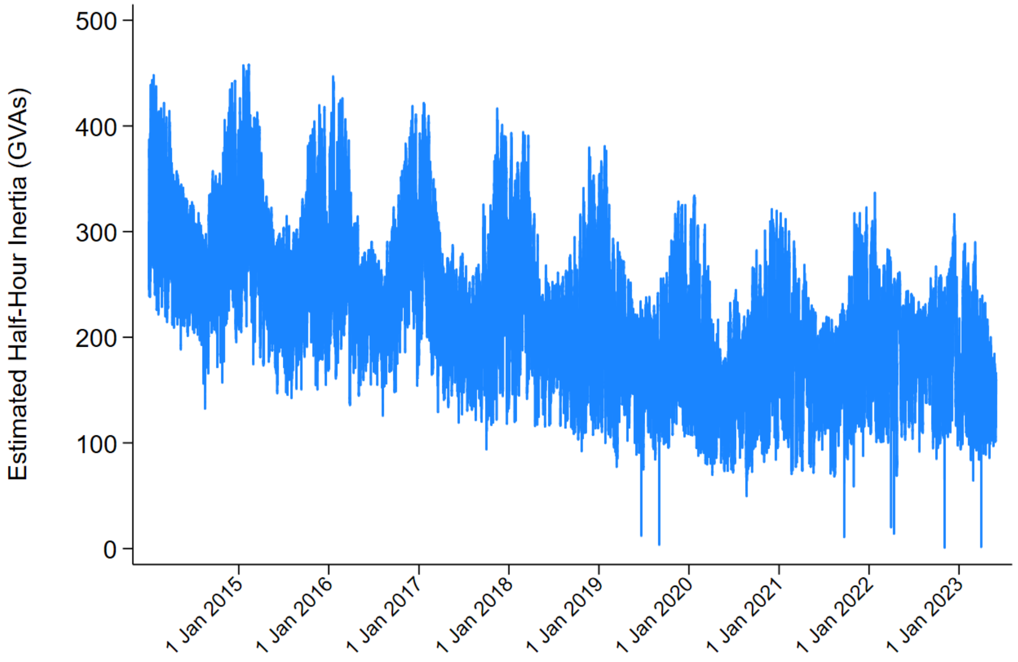
7) The Trend in System Inertia is Troubling

- System Inertia helps keep system frequency within its operational limits and thus is a key source of grid reliability

- Theory suggests that increases in solar and wind energy generation can reduce system inertia

- Despite countermeasures, the decline in Great Britain has been significant.

Estimated System Inertia in Great Britain, 1 Jan 2014 – 31 May 2023

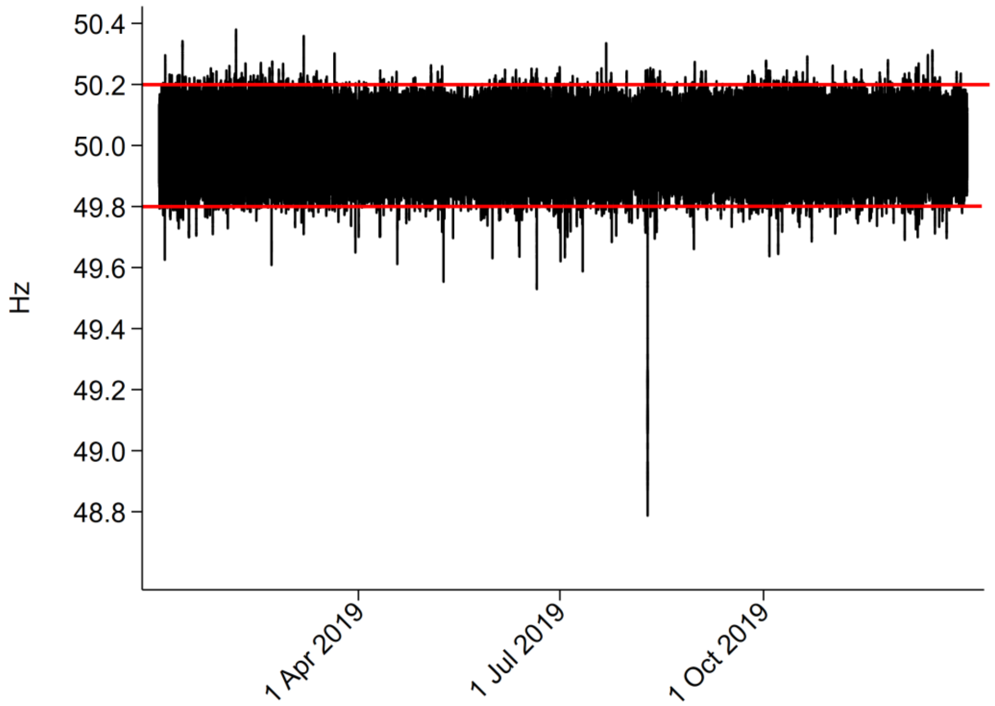


Source: EnAppSys

8)System Frequency in Great Britain

- System frequency's normal range is 49.8 to 50.2
- According to [1] the number of "violations" of these limits has significantly increased in recent years.
- On August 9, 2019, a series of unfortunate events led frequency to plunge to 48.8 Hz. To stabilize the system, the system operator disconnected about one million customers.

System Frequency in Great Britain, 1 Jan 2019 – 31 Dec 2019



Source: National Grid ESO

9) The Conventional Approach to the Measurement of Forecast Accuracy as a percent

The Mean Absolute Percent Error (MAPE)

When the forecast error is represented as a percent, most forecasters outside the renewable energy sector calculate the error as

$$MAPE = \frac{1}{T}\sum_{t=1}^{T}\left|\frac{Actual_t - Forecast_t}{Actual_t}\right| *100\%$$

One shortcoming of this metric is that it can exaggerate the effect of small errors that are large in percentage terms

The Weighted Mean Absolute Percentage Error (WMAPE)

Another legitimate method is to calculate a weighted MAPE as

$$WMAPE = \frac{\frac{1}{T}\sum_{t=1}^{T}|Actual_t - Forecast_t|}{\frac{1}{T}\sum_{t=1}^{T} Actual_t} *100\%$$

WMAPE avoids some of the shortcomings of MAPE

10) How to Mislead Yourself and Others

- When applied to solar or wind energy generation, the "Mark Twain" inspired measure of the forecast error is almost guaranteed to make an inaccurate forecast appear accurate. It is calculated as follows:

A "Mark Twain" Inspired Forecast Error Metric $= \dfrac{\sum_{i=1}^{T} e_t^2}{\sum_{t=1}^{T} Capacity_t^2}$

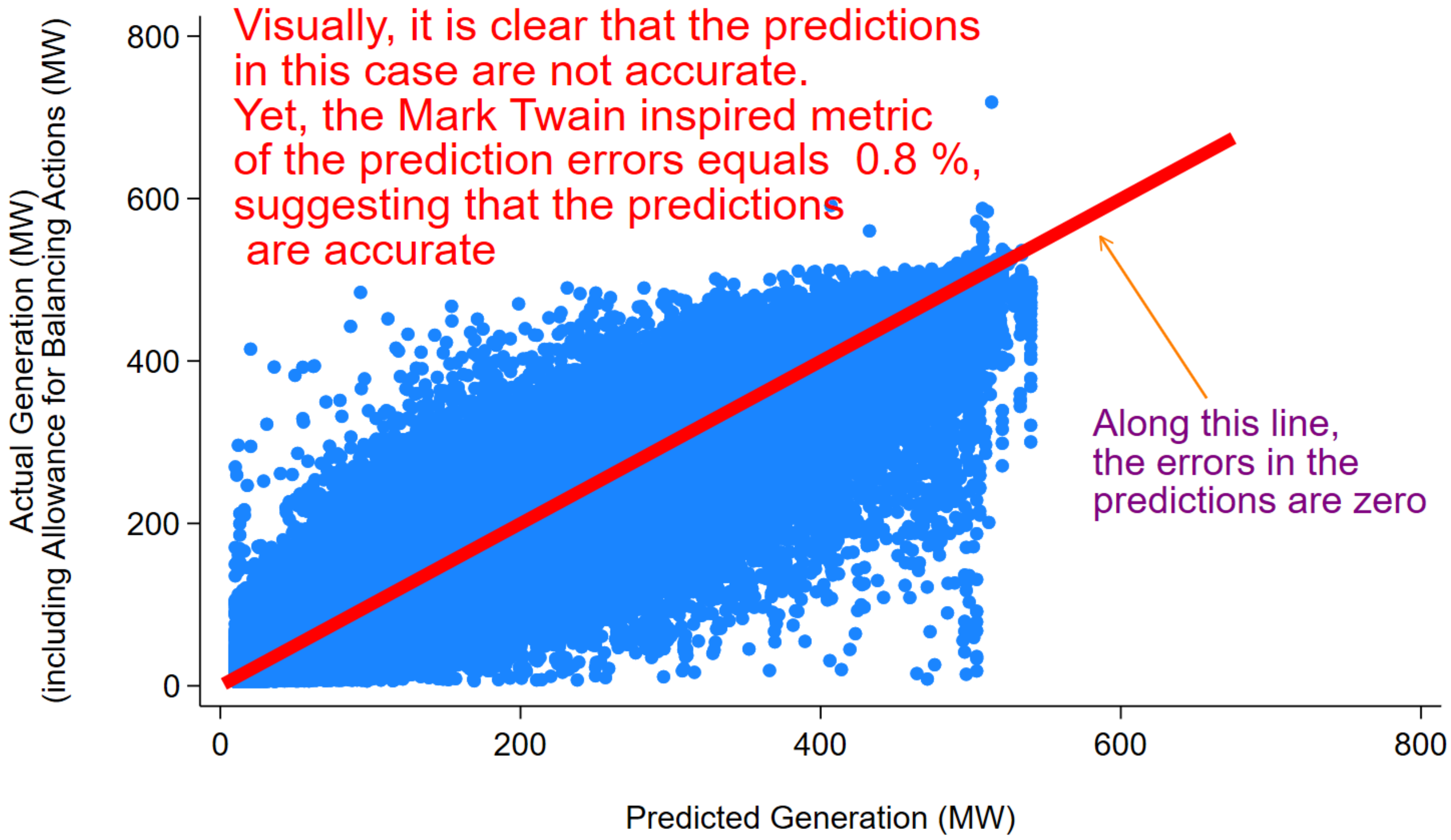
It looks Scientific !

where

e_t is the prediction error in time period t

$Capacity_t$ is the capacity level in time period t

11) The Application of the "Mark Twain" Inspired Metric of Forecast Accuracy to one of Britain's Largest Wind Farms



12) National Grid ESO's Self-Assessment of its Forecasts

- Under the reporting approach adopted by National Grid ESO, the error in the wind energy forecasts is about 4.2% [2, p. 8]. Based on this statistic, National Grid ESO indicates that the accuracy of its wind forecasts "exceeds expectations."

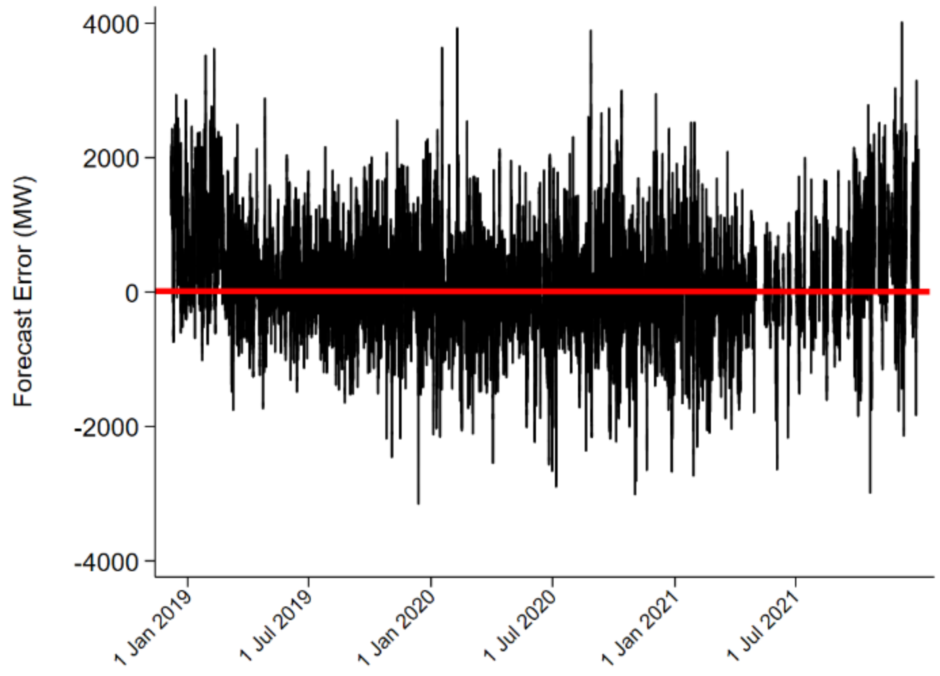
- National Grid's assessment is based on a capacity weighted metric[3, p. 38], i.e., it is a less extreme variant of the highly misleading "Mark Twain" Inspired measure of forecast error reported earlier. Previous research has presented evidence that this metric is misleading [1].

- According to [4], National Grid is not alone in employing this misleading approach in assessing the accuracy of its wind energy forecasts.

13) The Forecast Errors in the British Offshore

The error in the offshore wind energy forecasts in Great Britain, December 7, 2018 – December 31, 2021

- The Sample Period is 7 Dec 2018- 31 Dec 2018 (on 7 Dec 2018, National Grid ESO improved its reporting of the wind forecasts)
- The WMAPE in the offshore wind forecasts equals 12.8%
- Using the methodology employed by National Grid ESO, the offshore wind forecasts equals 4.92%



14) The Errors in the Generation Schedules : How Does Wind Energy Compare?

- All generating stations directly connected to the transmission system inform the system operator of their intended level of generation 1 h before real-time. This value is known as **the final physical notification (FPN)**.
- Generators also submit bids (proposals to reduce generation) and offers (proposals to increase generation) to provide balancing services. During real-time, the system operator accepts bids and offers based on its assessment of system conditions.
- Using this data, one can calculate the generation scheduling errors by fuel type

The WMAPEs (weighted mean absolute percentage error) in the Generation Schedules, 7 Dec 2018 – 31 Dec 2021

- Offshore Wind – 7.71%
- Onshore Wind – 15.54%
- Combined Cycle Gas Turbines (CCGT) - 1.64%
- Pumped Storage – 2.96 %
- Nuclear – 4.18%
- These scheduling errors have real world implications for balancing the system

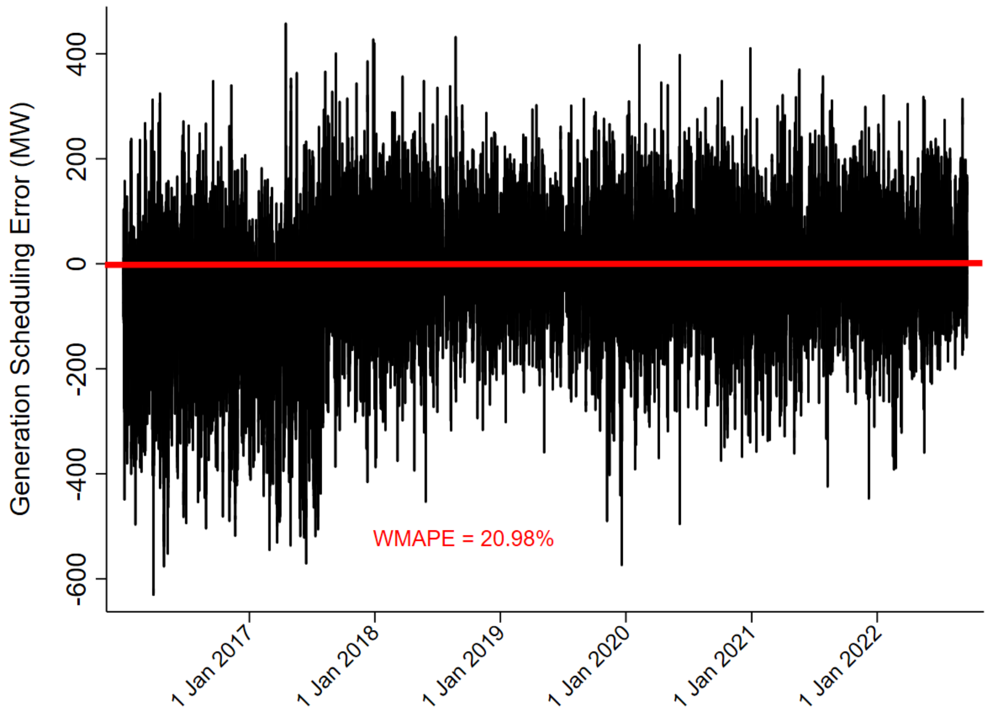
Based of data reported by EnAppSys

15) The Operating Challenge at the Wind Farm Level

London Array

- London Array is a 175-turbine 630 MW wind farm located 20 kilometres off the Kent coast in the outer Thames Estuary
- Observe that some of the scheduling errors are nontrivial. The overall data series is highly volatile.
- Based on the error calculation method employed by National Grid, the average scheduling error is 7.94 %. The reported error equals 1.53 % if the extreme version of “Mark Twain” inspired method is employed.
- While the WMAPE equals 20.98%, it is very easy to downplay the magnitude of the errors by weighting the mean absolute errors by a number that is large.

Generation Scheduling Errors Corresponding to the London Array Wind Farm, 1 Jan 2016- 15 Sep 2022

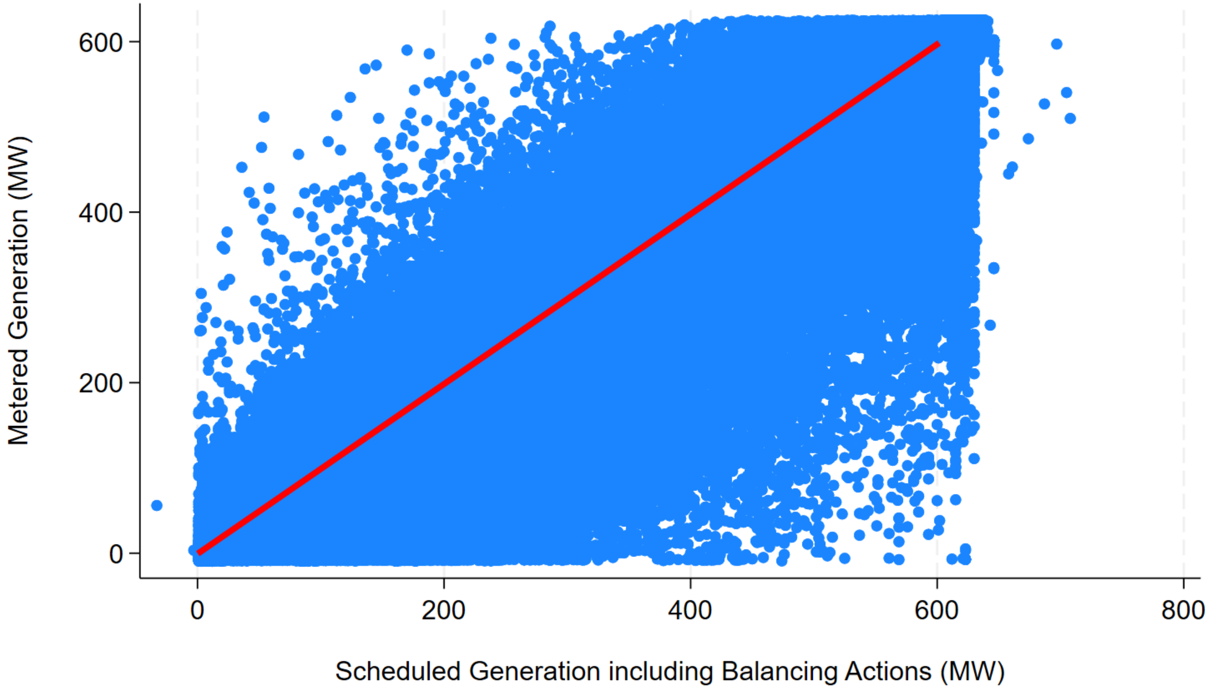


Data Source: EnAppSys

A Closer Look at the Data for the London Array Offshore Wind Farm

Those who want to believe that either of the two Mark Twain inspired metrics are appropriate are invited to reflect on the scatter diagram on the right.

Scheduled Generation vs Metered Generation at the London Array Offshore Field, Jan 1 2016 – Sept 15 2022.



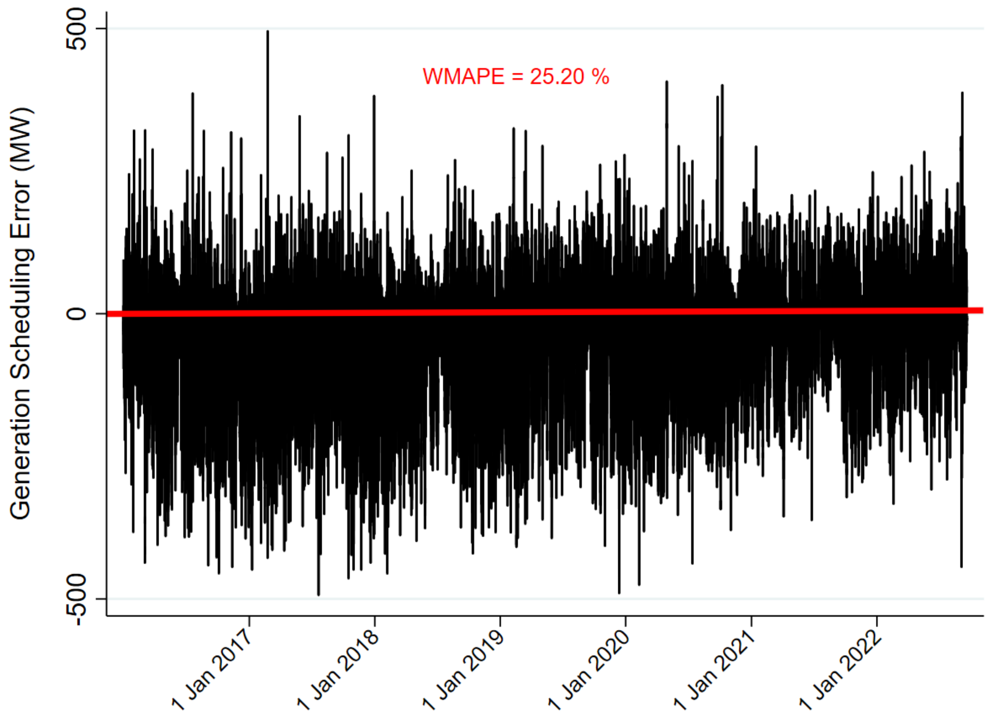
A Look at the Operating Challenge at the Wind Farm Level (Continued)

Gwynt y Môr is a wind farm in the Irish sea off the coast of Wales with a capacity of about 576 MY

Observe that some of the scheduling errors are nontrivial. The overall data series is highly volatile.

Based on the calculation method employed by National Grid, the scheduling error is 8.69 %
The reported error is even smaller if the more extreme version of the "Mark Twain" inspired method is employed.

Generation Scheduling Errors Corresponding to the Gwynt y Môr Wind Farm, 1 Jan 2016- 15 Sep 2022



Data Source: EnAppSys

A Look at the Operating Challenge at the Wind Farm Level

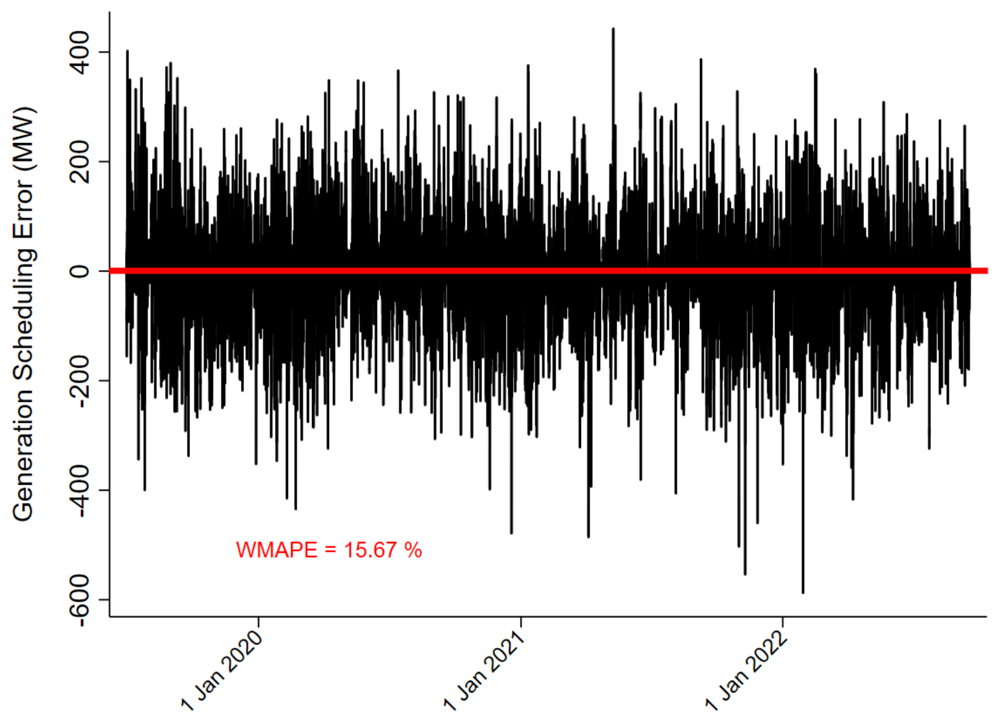
Beatrice

This 588 MW capacity wind farm is located in the North Sea about 13 km from the northeastern tip of the Scottish coast

Observe that some of the scheduling errors are nontrivial. The overall data series is highly volatile.

Based on the calculation method employed by National Grid, the scheduling error is a seemingly modest 4.41 % The reported error is even smaller if the more extreme version of the "Mark Twain" inspired calculation method is employed.

Generation Scheduling Errors Corresponding to the Beatrice Wind Farm, 1 Jul 2019- 15 Sep 2022



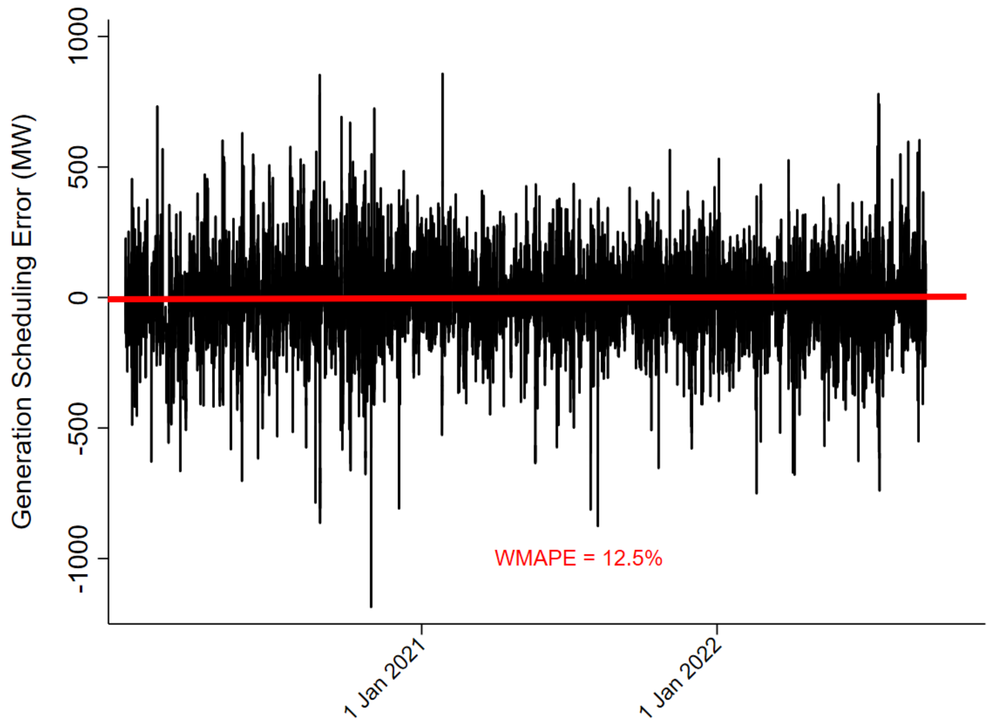
Data Source: EnAppSys

A Look at the Operating Challenge at the Wind Farm Level(Continued)

Hornsea One

- The current capacity of this wind farm is about 1,200 MW. It is located in the North Sea about 120 km off the east coast of England.
- Observe that the scheduling errors are highly volatile and can be large in magnitude.
- Based on the calculation method employed by National Grid, the scheduling error is a seemingly modest 5.8 % The reported error is even smaller if the more extreme version of "Mark Twain" inspired calculation method is employed.

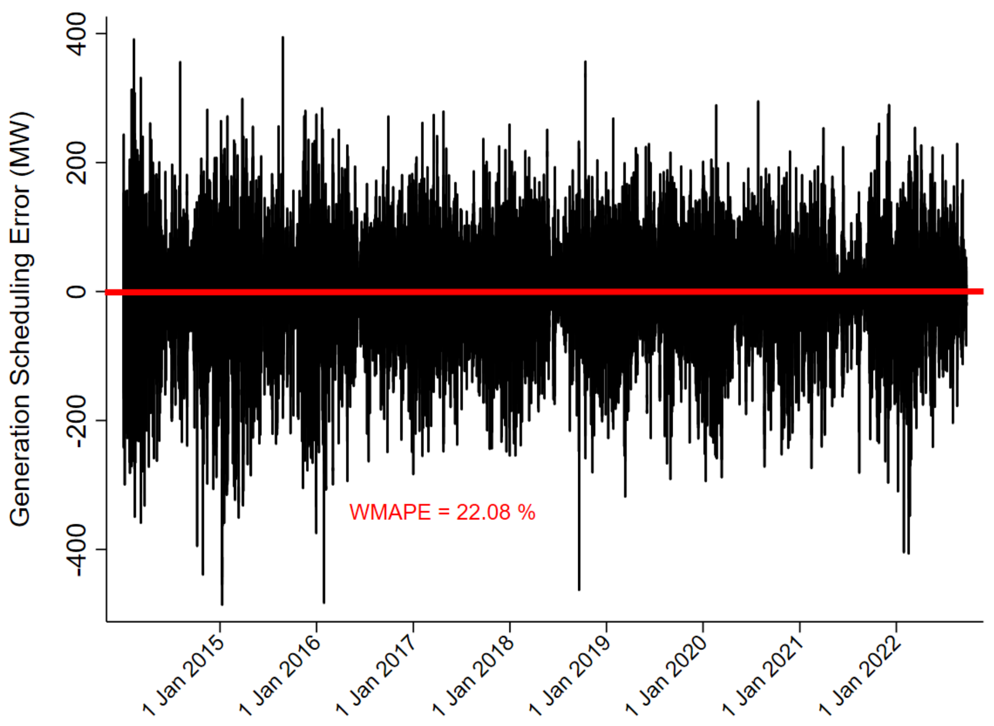
Generation Scheduling Errors Corresponding to the Hornsea Wind Farm, 1 Jan 2020- 15 Sep 2022



Data Source: EnAppSys

A Look at the Operating Challenge at the Wind Farm Level

Generation Scheduling Errors Corresponding to the Whitelee Wind Farm, and its extension 1 Jan 2014 - 15 Sep 2022



Data Source: EnAppSys

Whitelee

- In terms of installed capacity, Whitelee is the largest wind farm in onshore Great Britain. The main farm and its extension have a total capacity of about 500 MW.

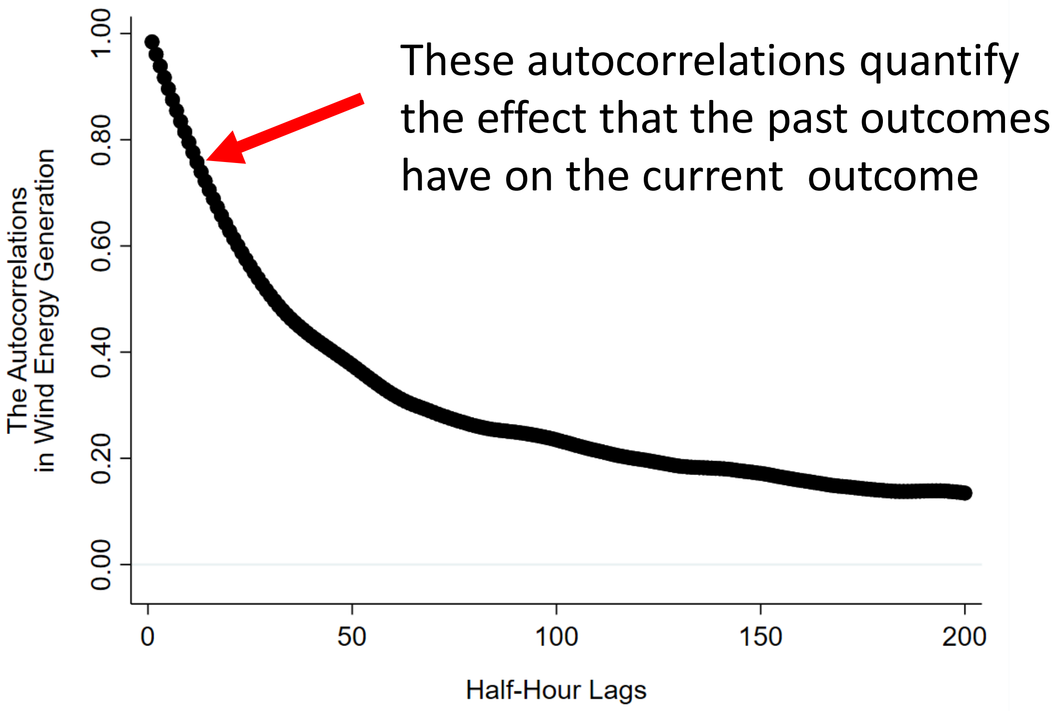
- Based on the calculation method employed by National Grid, the scheduling error is a seemingly modest 5.50 % The reported error is less than 1% if the more extreme version of the “Mark Twain” inspired calculation method is employed.

The previous slides indicate that the generation scheduling errors are nontrivial on average. The errors are also highly volatile. It is also important to recognize that the generation data are significantly autoregressive.

- Observe that the level of wind energy in period t is statistically related with the generation levels in previous periods.

- Given that the "past is known" this characteristic is very useful in making short run predictions.

The Autocorrelative Nature of Wind Energy Generation at the London Array Wind Farm



16) An ARCH/ARMAX Model of Wind Energy Generation

An ARCH/ARMAX (Autoregressive Conditional Heteroskedasticity/Autoregressive - moving average with exogenous inputs) modeling framework is a useful modeling approach when the data are **autocorrelated** and the **dependent variable exhibits turbulence at times**. Wind energy data exhibits both of these characteristics.

An ARCH/ARMAX model can be represented using two equations. A simple mathematical representation when Y_t is the dependent variable is

$$Y_t = \sum_j X_{j,t}\,\beta_j + \sum_i \theta_i\, g(\sigma^2_{t-i}) + \sum AR(p) + \sum MA(q) + \varepsilon_t \qquad (1)$$

$$Var(\varepsilon_t) = \sigma^2_t = \sum_k Z_{k,t}\,\phi_k + \gamma_1\, \varepsilon^2_{t-1} \qquad (2),$$

Where

the X's are the exogenous explanatory inputs in equation (1)

The Z's model the structural nature of the volatility

the AR and MA terms model the autoregressive process

$g(\sigma^2_{t-i})$ reflects the possible linkage between the two equations.

The dependent variables are the onshore and offshore levels of wind energy generation

The Exogenous Inputs

- The Onshore and Offshore Forecasted Level of Wind Energy Generation.
- The Onshore and Offshore Final Physical Notifications
- Simulated Meteorological Data

The locations of the wind farms whose simulated meteorological data are employed in this study

The sample period is 7 December 2018 - 31 December 2021

The estimation makes use of half-hour data

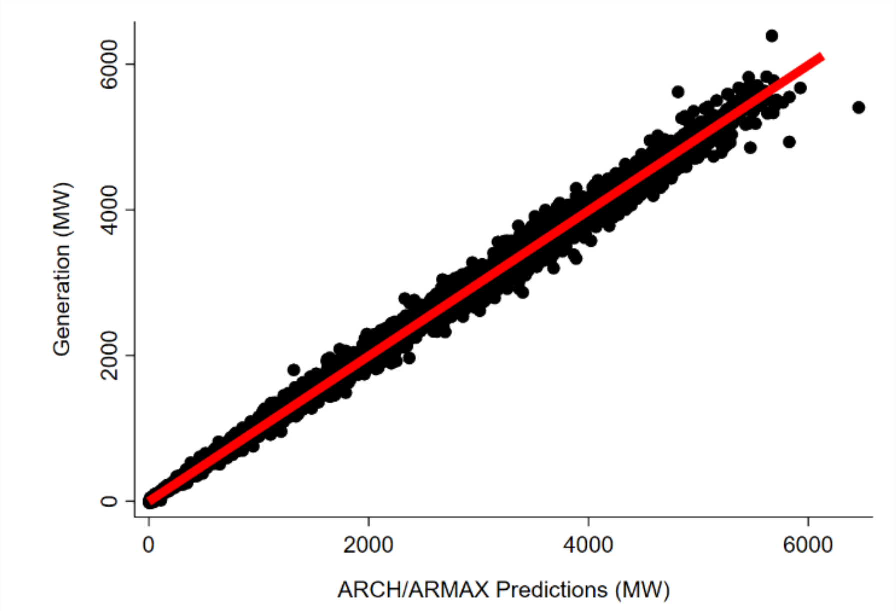
17. Discussion of the Results

- Several of the simulated meteorological variables are highly statistically significant(e.g., Simulated Offshore Windspeeds at 80m and Simulated Offshore Air Density).Given that the forecasted wind energy is also included as a covariate, it follows that the forecasted wind energy variable does not fully reflect the meteorological conditions that were expected to occur.

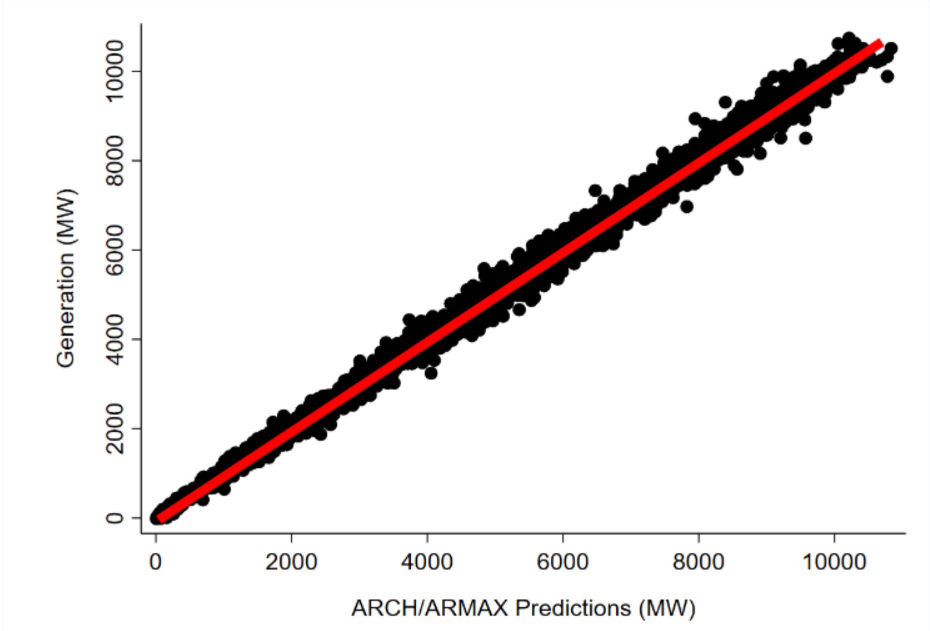
- Concerning the offshore time-series variables, 19 of the 23 ARMA terms are statistically significant. Seven of the seven ARCH terms are statistically significant. It is also worth noting that two of the five ARCH-in-means terms in the offshore model are statistically significant

18. Out of Sample Evaluation over the period 1 Jan 2022 – 15 September 2022.

Onshore



Offshore



Observe that there is high degree of visual correspondence between predicted and actuals for both the onshore and offshore. In both cases, the WMAPEs of ARCH/ARMAX predictions are substantially less than the WMAPEs associated with the scheduled levels of generation. Specifically, the ARCH/ARMAX WMAPEs are 2.69 and 3.26 % for the offshore and onshore, respectfully, while the scheduled based measures are 8.5 and 12.11%, respectively.

19. Conclusion

- This research has presented evidence that the ARCH/ARMAX method can significantly improve the predictive accuracy of wind energy generation in both the British onshore and offshore.

- The appeal of the ARCH/ARMAX predictive method to National Grid ESO is problematic given that it has reported that the accuracy of its existing wind energy forecasts "exceeds expectations"

- It would be tragic if a forecasting metric that falsely purports predictability has the effect of discouraging the introduction of methods that actually deliver true predictability.

- To avoid this outcome, National Grid is encouraged to examine the statistical relationship between the forecast errors measured in MWs and expected meteorological conditions. The absence of a statistical relationship would constitute *prima facie* evidence that the forecasts are accurate. However, based on [1, p. 11], the analysis is likely to find that this is not the case, an indication that improved modeling has the potential to improve accuracy.

References

[1] Forbes, K.F. and E.M. Zampelli. (2020).Accuracy of Wind Energy Forecasts in Great Britain and Prospects for Improvement, *Utilities Policy* https://doi.org/10.1016/j.jup.2020.101111

[2] National Grid ESO. (2022) 2021-23 Mid-Scheme Report: Executive Summary. https://www.nationalgrideso.com/document/249951/download (Accessed May 31, 2023)

[3] National Grid ESO. (2022) 2021-23 Mid-Scheme Report: Evidence Chapters https://www.nationalgrideso.com/document/250091/download (Accessed May, 5 2023)

[4] Forbes, K.F., Stampini, M., and E.M. Zampelli (2012) Are Policies to Encourage Wind Energy Predicated on a Misleading Statistic?, The *Electricity Journal*, April 2012, Volume 25, Issue 3, pp. 42-54 https://doi.org/10.1016/j.tej.2012.03.002

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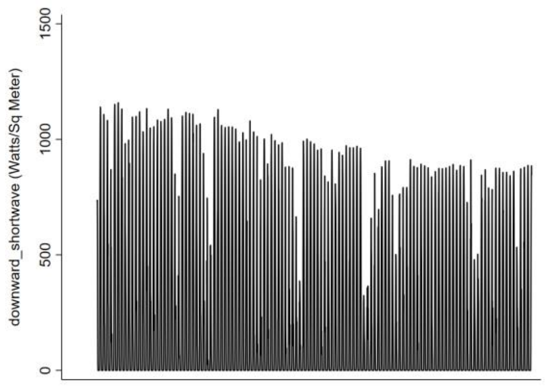
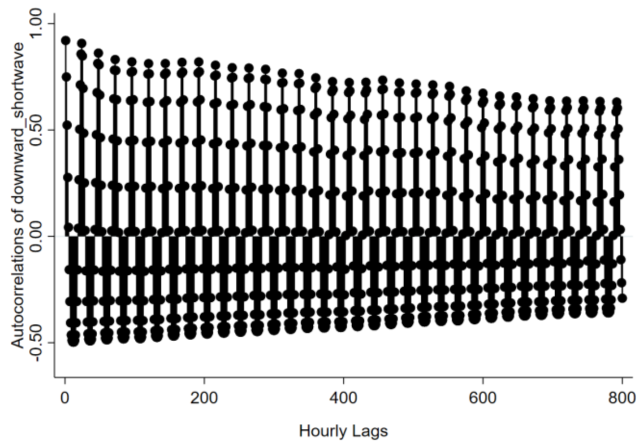


From Data Chaos to Pattern Recognition



Information about EEDS:

https://www.EEDS.solutions

Any Questions?

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