Wind Power Generation in Germany

A Mock-up Dashboard Overview of Wind Power Production in Germany

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Introduction

As the global shift towards sustainable energy sources accelerates, wind power stands out as a prominent player in the renewable energy landscape, generating electricity with low environmental impact. In this report, we attempt to analyze, model, and predict wind power production based on wind speed data.

Wind Power in Germany

Wind Power has become a pillar of power generation in Germany, responsible for the production of 27% of the consumed electricity in 2021 (WindEurope 2021). E.g. 2022 has seen the installation of 551 onshore wind farms worth 2403MW of power (Bundesverband WindEnergie 2023).

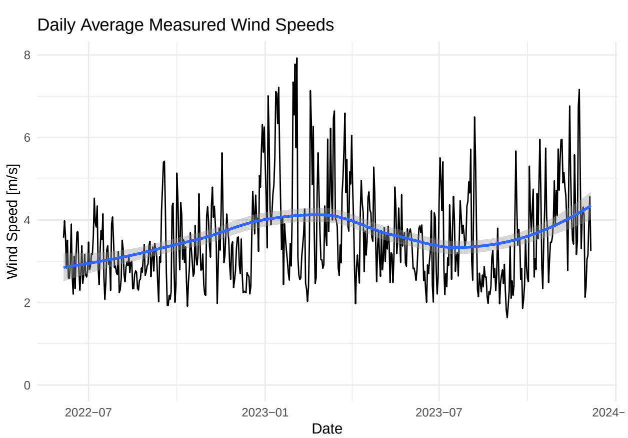
In this report, we will analyze wind power production data from the big four German transmission system operators (50 Hertz, Amprion, TenneT TSO and TransnetBW) for the timeframe of June 2022 to October 2023 (Bundesnetzagentur | SMARD.de (2021)). The Measurements record the energy generated in intervals of 15 minutes and are therefore in units of MWh per 15min (Table 1)

Table 1: Summary of 15 minte interval wind power production data for each investigated company.

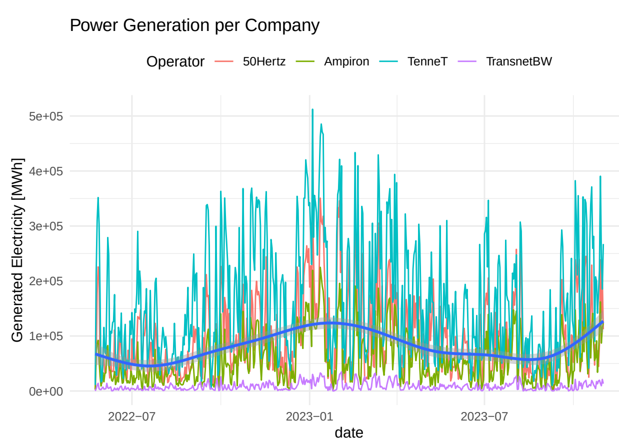
	50Hertz	Ampiron	TenneT	TransnetBW
Min.	0.8	0.0	18.2	0.0
1st Qu.	317.8	173.7	636.2	18.5
Median	727.2	420.8	1412.5	56.8
Mean	988.6	587.1	1713.8	88.1
3rd Qu.	1463.3	872.2	2647.8	134.0
Max.	4386.8	2539.2	5772.0	401.2

There is a universal dip of power production over all companies during the day as well as in the summer months (see Figure 1). This is to be expected and may reflect total power demand more than it does the capability of wind power production.

For all following anaylsis and models, Wind PP values are multiplied by 4 to convert into MW as average Power over 15 minutes instead of MWh/15min.



(a) Average daily windspeed



(b) Daily wind energy production for each operator.

Figure 1: Wind speed and wind energy production throughout the period being analyzed.

Wind Speed Data

To fit a power production prediction Model, we will use Data of wind speeds in Germany over that same time window. This data was compiled from weather stations of DWD (Deutscher Wetterdienst 2021) and only weather stations active throughout the entire time were used. `NA` measure values were removed.

Measure station location was binned into a 4 x 4 grid (see Figure 2). Stations outside of the desired grid were pushed into the closest cell which mainly affects stations too far east.

```
## Warning: `fortify(<SpatialPolygonsDataFrame>)` was deprecated in ggplot2 3.4.4.
## i Please migrate to sf.
## i The deprecated feature was likely used in the ggplot2 package.
##   Please report the issue at <https://github.com/tidyverse/ggplot2/issues>.
## This warning is displayed once every 8 hours.
## Call `lifecycle::last_lifecycle_warnings()` to see where this warning was
## generated.
```

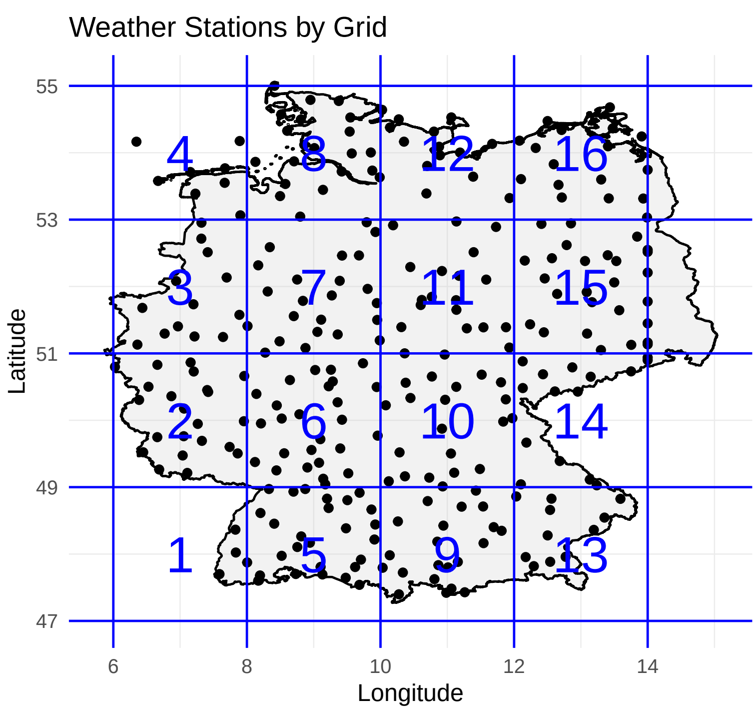


Figure 2: Aggregation to grid of active weather Stations in Germanys

Wind speeds vary over the year (see Figure 1), as well as over the time of day. In Figure 3 we can see that averaged over the whole year, wind power production reduces during the day, but wind speed increases.

```
## Warning: The `trans` argument of `sec_axis()` is deprecated as of ggplot2 3.5.0.
## i Please use the `transform` argument instead.
## This warning is displayed once every 8 hours.
## Call `lifecycle::last_lifecycle_warnings()` to see where this warning was
## generated.
```

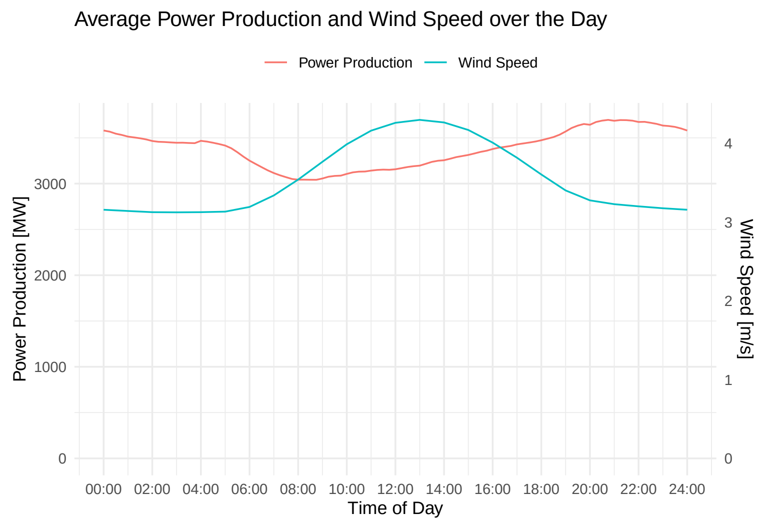


Figure 3: Average power production and wind speed (averaged over all grid cells) for each time of day (UTC).

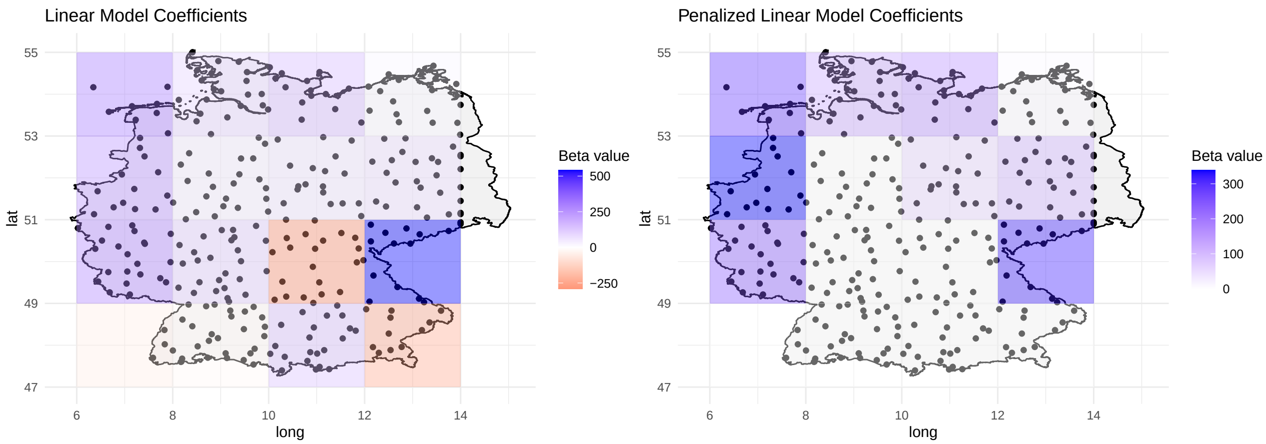
Model

We will attempt to model wind power production by the Wind Speed in each grid field. Since average wind power production throughout the day seems to follow a different pattern than average wind speed, we use a different intercept for each hour of the day. This way, we effectively model how the wind speeds in each cell effect the deviation of wind power from the average at a particular hour.

$$\text{Power}_i = \beta_{0,\text{TimeOfDay}(i)} + \beta_1 \text{Wind@Grid.01}_i + ... + \beta_{16} \text{Wind@Grid.16}_i$$

We can visualize the effect that the average wind on each grid cell has on power production as in Figure 4 (a) The fact that some grid cells have a negative coefficient is a strong hint that there are some important relationships that our model fails to capture correctly. Remember that this project is supposed to teach you how to set up a project directory, not how to model wind energy production well!

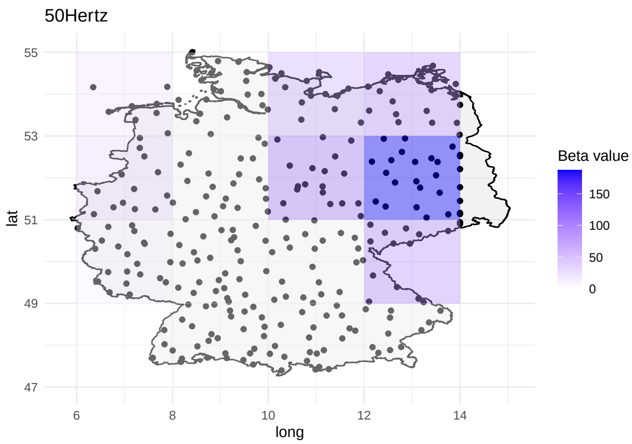
Using the `penalized` package, we can restrict the value of grid cell coefficients to positive values, and furthermore use L1 regularization to prefer coefficients with value 0 when they do not have a large effect. Figure 4 (b) shows the coefficients of the penalized model.



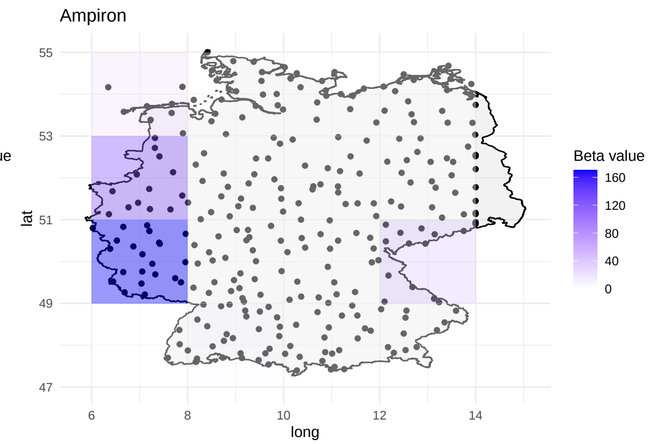
(a) (b)

Figure 4: Grid squares colored by Beta value of models.

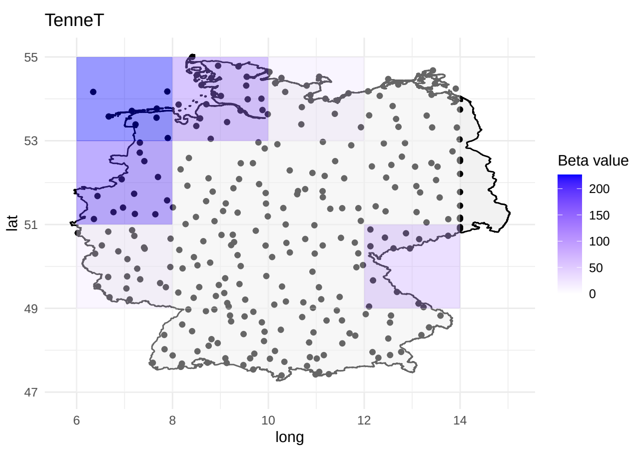
We can fit the penalized model on the subset of the data for each transmission system operator (Figure 5 (a)–(d)) and compare that with the actual areas of responsibility of each operator (Figure 5 (e)).



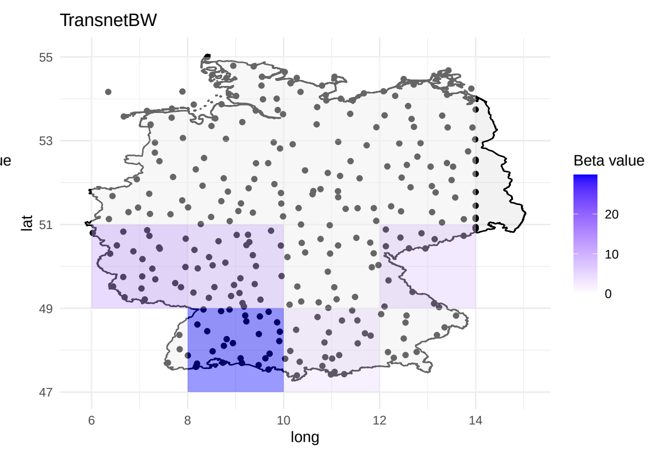
(a)



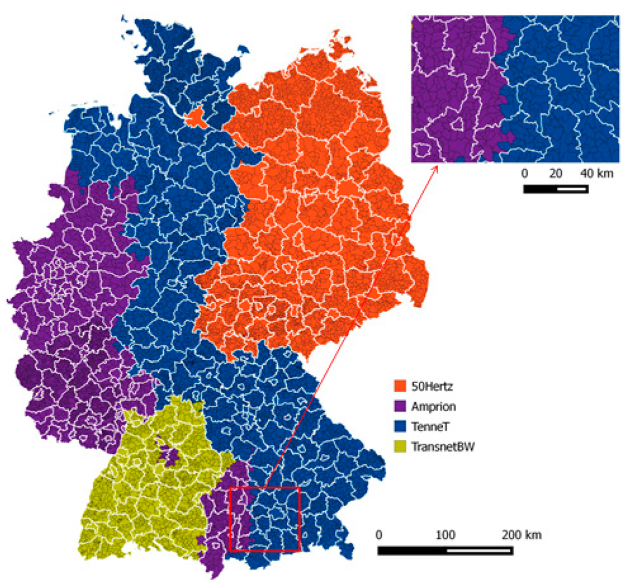
(b)



(c)



(d)



(e) Source: Robinius 2017

Figure 5: (a) – (d): Grid squares colored by penalized beta coefficients for each transmission system operator. (e): Map of control areas of german transmission system operators.

Prediction of Wind Power Production

Using these models, we predict the wind power production in Germany using wind speed data (Figure 6). We also try out a random forest model from the `ranger` package. This could then later be used to predict future power production based on predicted weather Data.

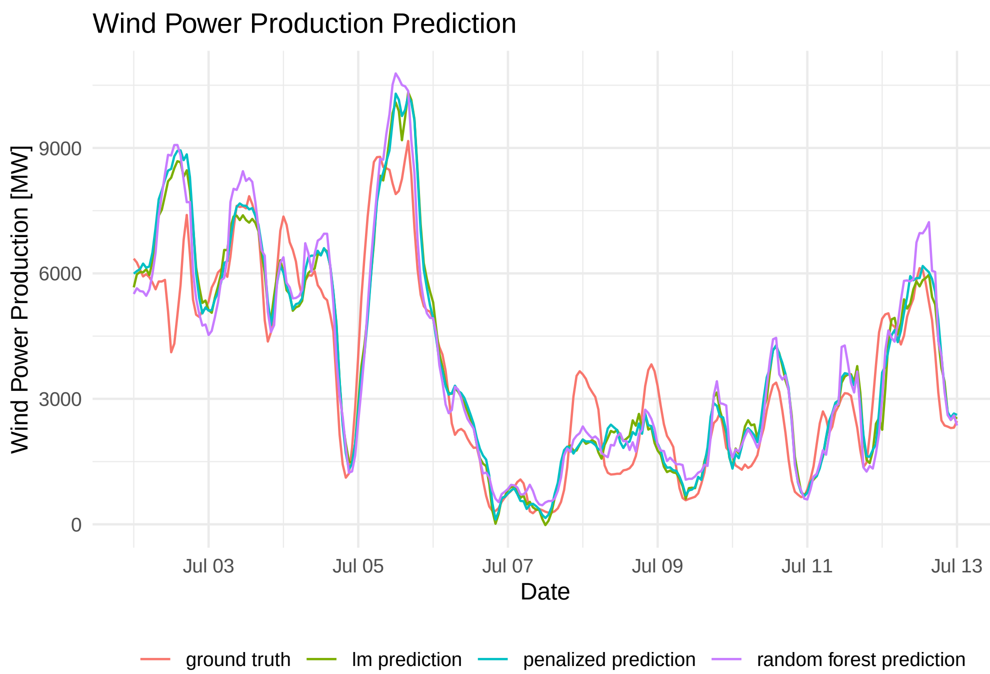


Figure 6: Prediction of wind power production based on wind speed data.

Summary

This report is only meant to teach how to set up a project directory. Therefore, the analysis or prediction modelling done here should not be seen as a good example of how to ideally tackle the task at hand.

Acknowledgements

We would like to thank Dick Brown for his report 'Analysis of German Wind Power Output' on Kaggle for the idea to analyze wind power production data of Germany.

The power production data is courtesy of 'Bundesnetzagentur | SMARD.de'.

The wind data was compiled from 'https://opendata.dwd.de' of the 'Deutscher Wetterdienst'.

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