Statistical Evaluation of Variable Renewable Energy Source's Contribution to the Variability of Swiss Electricity Prices 2015-2020

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Contents

Introduction

Governments and scientists around the world largely agree on the need for a low-carbon electricity grid. A step in this direction is the construction, installation and connection of Renewable Energy Sources (RES) such as Hydropower, Wind and Solar to the electricity grid. These produce no direct emissions while supplying electricity and have life cycle carbon costs far lower than fossil fuels. A substrate of RES are so called Variable-RES (VRES), which are electricity sources who's production cannot be increased or decreased by the operator. Wind and Solar both rely on meteorological conditions, if these are not right, nothing is produced. This is contrary to most other sources who's production can be increased or decreased according to market needs. Although the time it takes to ramp production up or down can present a challange, it is far more manageable than VRES.

The lack of control over production with VRES presents a huge challange to the adoption of such sources, since there is no large scale energy storage available. Battery Storage, Pumped Hydro and Heat Pumps do store energy, but currently these forms of power would not be able to power a country for even a couple of hours.

Worst yet for all energy producer, the addition of electricity from VRES has the possibility to:

1. Drastically lower electricity prices.
2. Increase price volatility.

The reason for the first claim is that VRES has practically no marginal costs. No fuel rods, pumping, gas or other notable inputs are required to produce solar and wind energy. This means producers of VRES will bid their energy at almost any price. If they cannot profit - maximize, they will loss - minimize.

The second claim is the case because meteorological events tend to be fairly consistent across an area. When one wind / solar farm is producing, so are the ones around it. This means there is huge downward pressure on prices during periods of favorable VRES production and none at all during unfavorable conditions.

Relevance

Policymakers would be interested in these results, particularly those countries considering feed-in-tariffs (FIT).

FIT - paying a fixed price for renewable energy, if the price is volatile, government's expenditure will also be.

Consumers of energy (so most people), will also want to know how prices could fluctuate in the future.

Providers of energy storage, who require volatility in prices to make.

more will be added here

Literature Review

Although generally speaking the academic literature identifies increases V-RES sources as being correlated with volatile prices, it is unclear whether these effects are generalizable to the Swiss grid without further research. A number of studies find an increase in variability as V-RES penetration increases. Amongst them: Pereira da Silva and Horta (2019) who use EGARCH time series and regression while studying the Iberian power market; Frauendorfer, Paraschiv, and Schürle (2018) who find that the Swiss are "importing" lower German power prices during peak solar production, as Germany has much more solar energy sources than the Swiss. Finally, the authors Dong et al. (2019) find that the Swedish have more stable prices due to the relativley high proportion of non variable fossil and hydropower than the Danes, who are more reliant on V-RES in the form of wind and solar.

Other studies are more conflicted, such as Rintamäki, S. Siddiqui, and Salo (2017) who compare Germany and Danish prices and wind that the effect of increasing wind production on day ahead prices is not constant. They caution that interconnectivity with other grids is important in determining the direction of effect. As such, this is further motivation to study each nation's grid independently, as there may be a large number of variables influencing the price. Although the previously mentioned Frauendorfer, Paraschiv, and Schürle (2018) paper studies the Swiss grid, it does so in the context of transnational energy trade, and not increases in domestic capacities. This is the gap we are evaluating.

Sources

Electricity Prices

Swissgrid provides data on 15-minute electricity prices, divided into secondary and tertiary.

Link: https://www.swissgrid.ch/en/home/operation/grid-data/generation.html

Generation Share Wind and Solar

https://data.open-power-system-data.org/time_series

*more will be added here

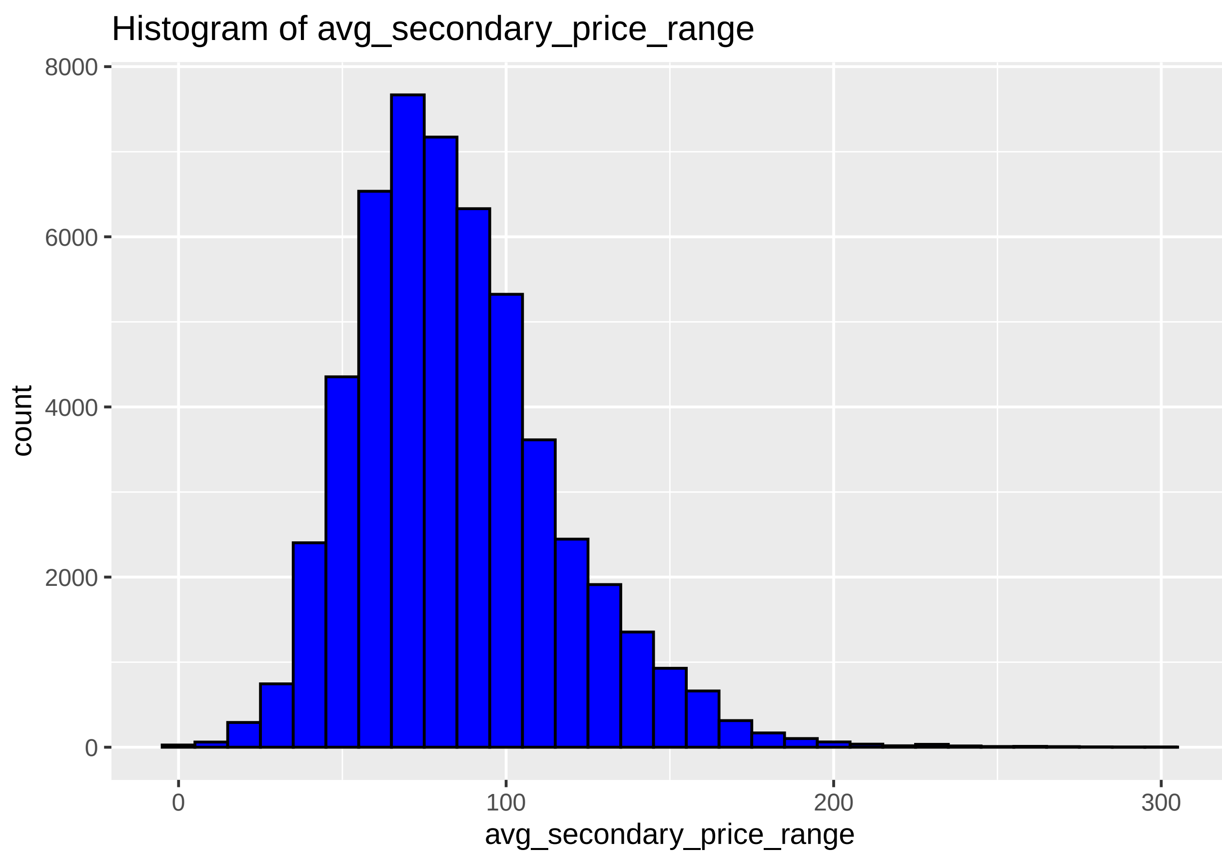
Exploratory Data Analysis (EDA)

```r
head(d)
```

```
## # A tibble: 6 x 10
##   Timestamp           avg_secondary_price_~1 avg_tertiary_price_r~2 VRES_percent
##   <dttm>                               <dbl>                  <dbl>        <dbl>
## 1 2015-01-01 01:00:00                   89.9                    0       NA
## 2 2015-01-01 02:00:00                   87.6                   16.0      0.00184
## 3 2015-01-01 03:00:00                   78.8                   64.2      0.00174
## 4 2015-01-01 04:00:00                   72.2                   64.2      0.00188
## 5 2015-01-01 05:00:00                   66.7                   64.2      0.00146
## 6 2015-01-01 06:00:00                   63.8                   64.2      0.00174
## # i abbreviated names: 1: avg_secondary_price_range,
## #   2: avg_tertiary_price_range
## # i 6 more variables: CH_load_actual_entsoe_transparency <dbl>,
## #   CH_load_forecast_entsoe_transparency <dbl>, CH_solar_capacity <int>,
## #   CH_solar_generation_actual <dbl>, CH_wind_onshore_capacity <int>,
## #   CH_wind_onshore_generation_actual <dbl>
```

```r
# Histogram for avg_secondary_price_range
ggplot(d, aes(x = avg_secondary_price_range)) +
  geom_histogram(binwidth = 10, fill = "blue", color = "black") +
  ggtitle("Histogram of avg_secondary_price_range")
```

```
## Warning: Removed 7 rows containing non-finite outside the scale range
## (`stat_bin()`).
```




```
min_tpr <- min(d$avg_tertiary_price_range, na.rm = TRUE)
max_tpr <- max(d$avg_tertiary_price_range, na.rm = TRUE)

min_tpr
```

```
## [1] 0
```

```
max_tpr
```

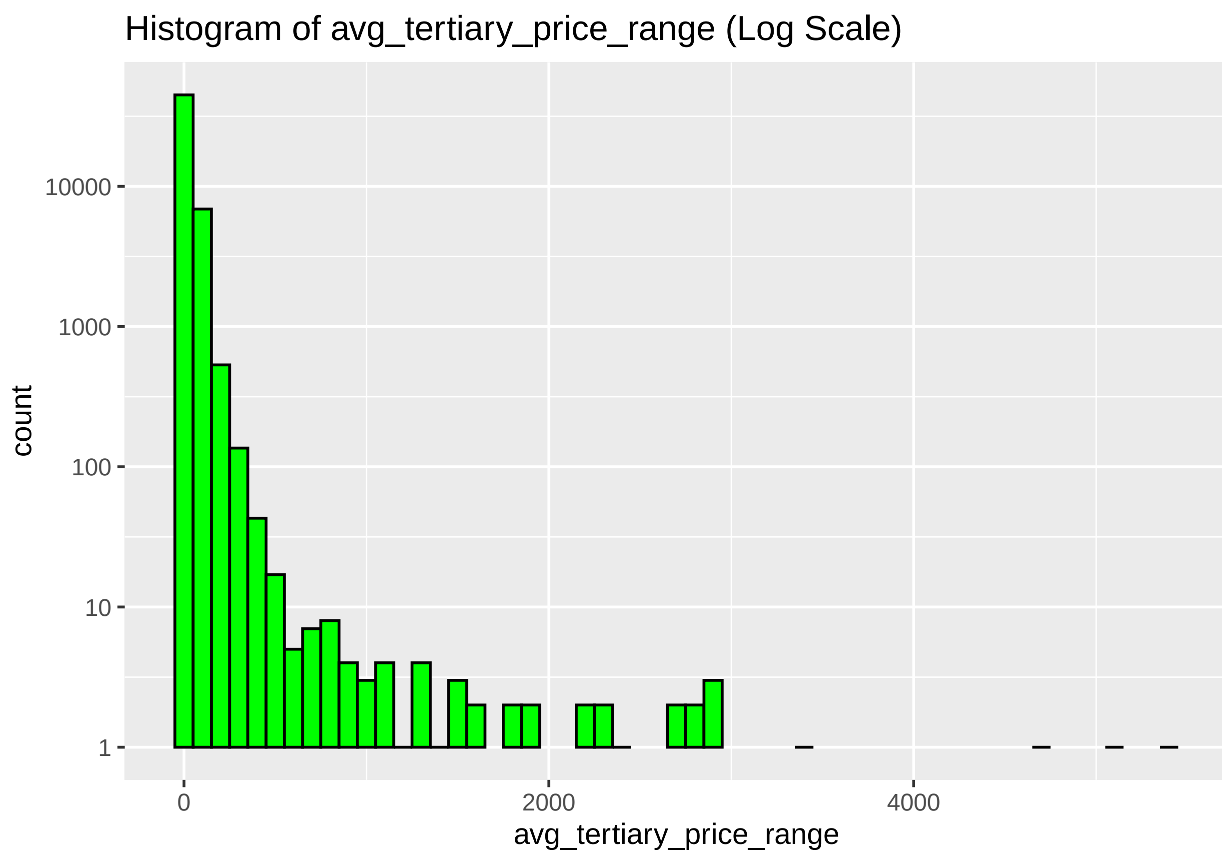
```
## [1] 5389.266
```

```
# Histogram for avg_tertiary_price_range with log scale on the x-axis
ggplot(d, aes(x = avg_tertiary_price_range)) +
  geom_histogram(binwidth = 100, fill = "green", color = "black") +
  scale_y_log10() +  # logarithmic scale for y-axis
  ggtitle("Histogram of avg_tertiary_price_range (Log Scale)")
```

```
## Warning: Removed 7 rows containing non-finite outside the scale range
## (‘stat_bin()‘).
```

```
## Warning in scale_y_log10(): log-10 transformation introduced infinite values.
```

```
## Warning: Removed 26 rows containing missing values or values outside the scale range
## (‘geom_bar()‘).
```




```
# VRES_percent Range

min_VRES <- min(d$VRES_percent, na.rm = TRUE)
max_VRES <- max(d$VRES_percent, na.rm = TRUE)

min_VRES
```

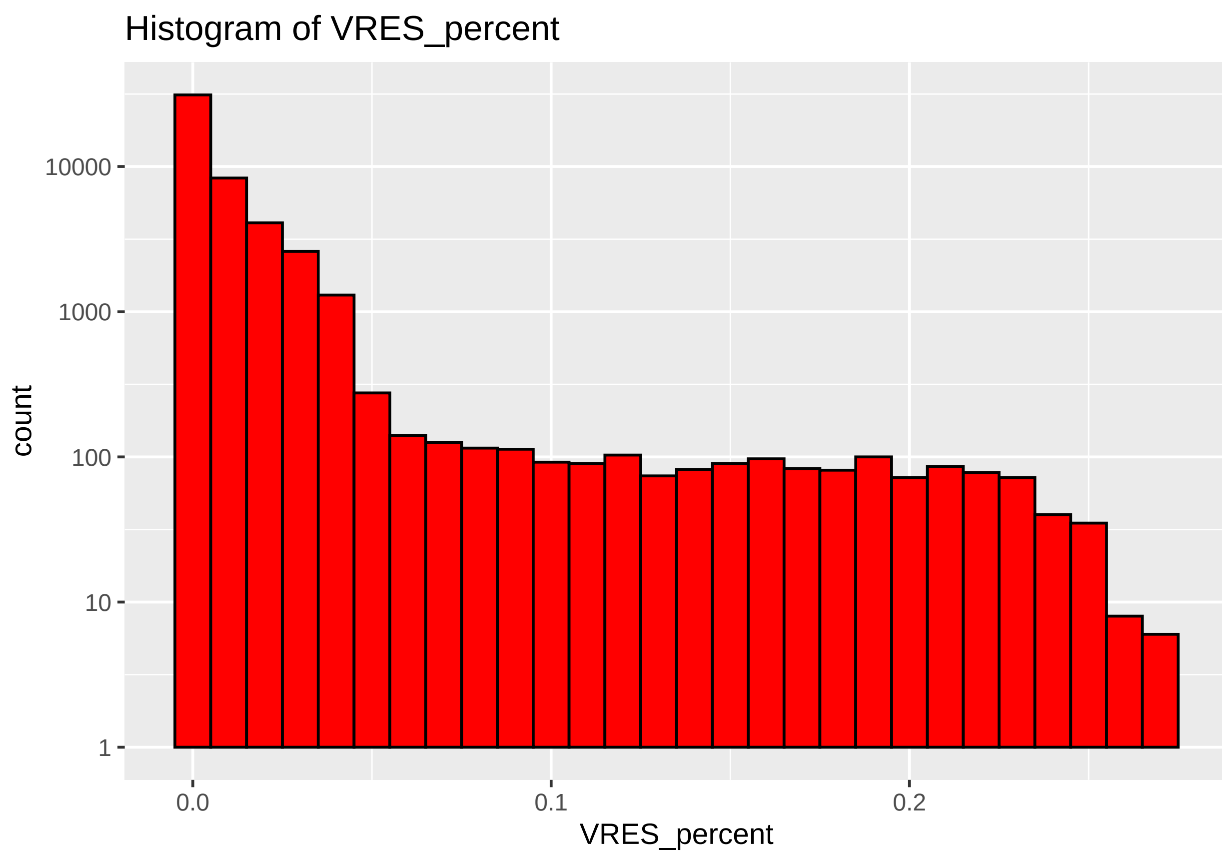
```
## [1] 0
```

```
max_VRES
```

```
## [1] 0.2742438
```

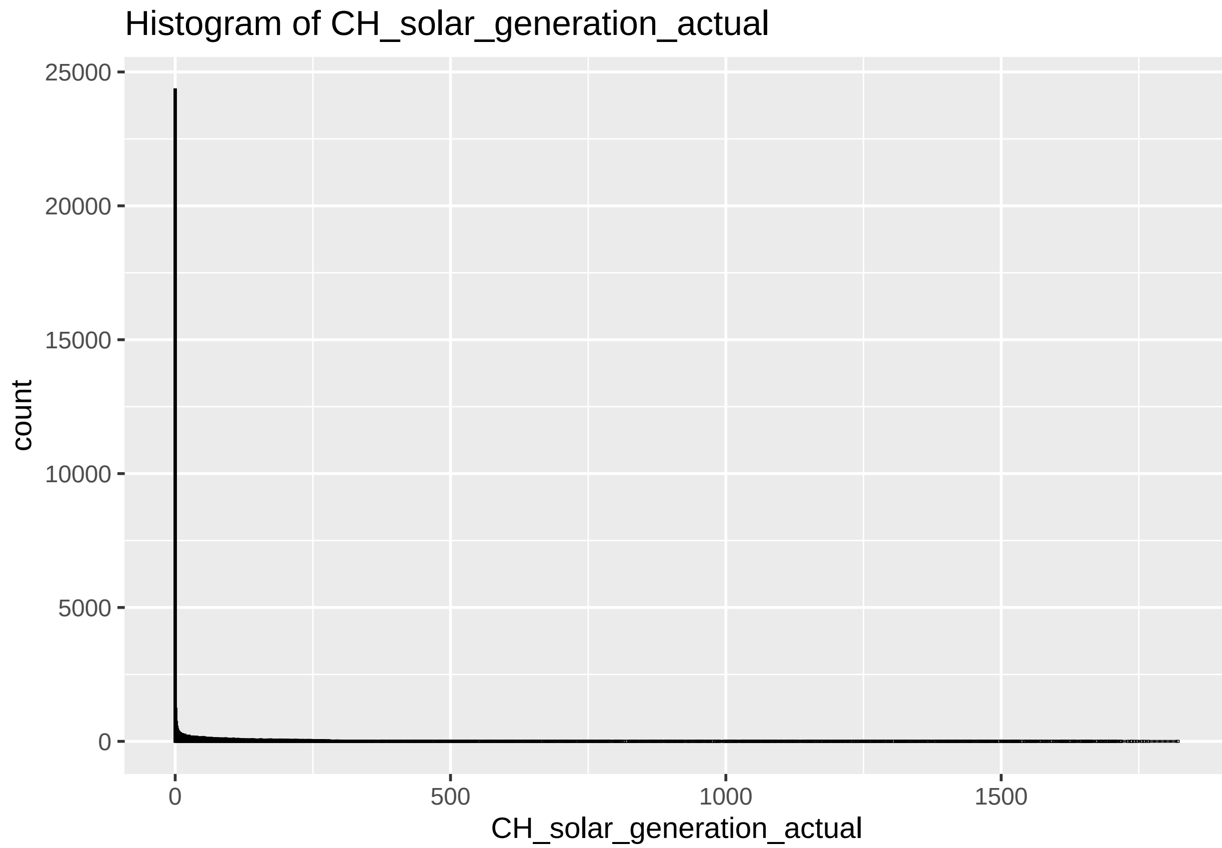
```
# Histogram for VRES_percent
ggplot(d, aes(x = VRES_percent)) +
  geom_histogram(binwidth = 0.01, fill = "red", color = "black") +
  scale_y_log10() +
  ggtitle("Histogram of VRES_percent")
```

```
## Warning: Removed 3005 rows containing non-finite outside the scale range
## (‘stat_bin()‘).
```



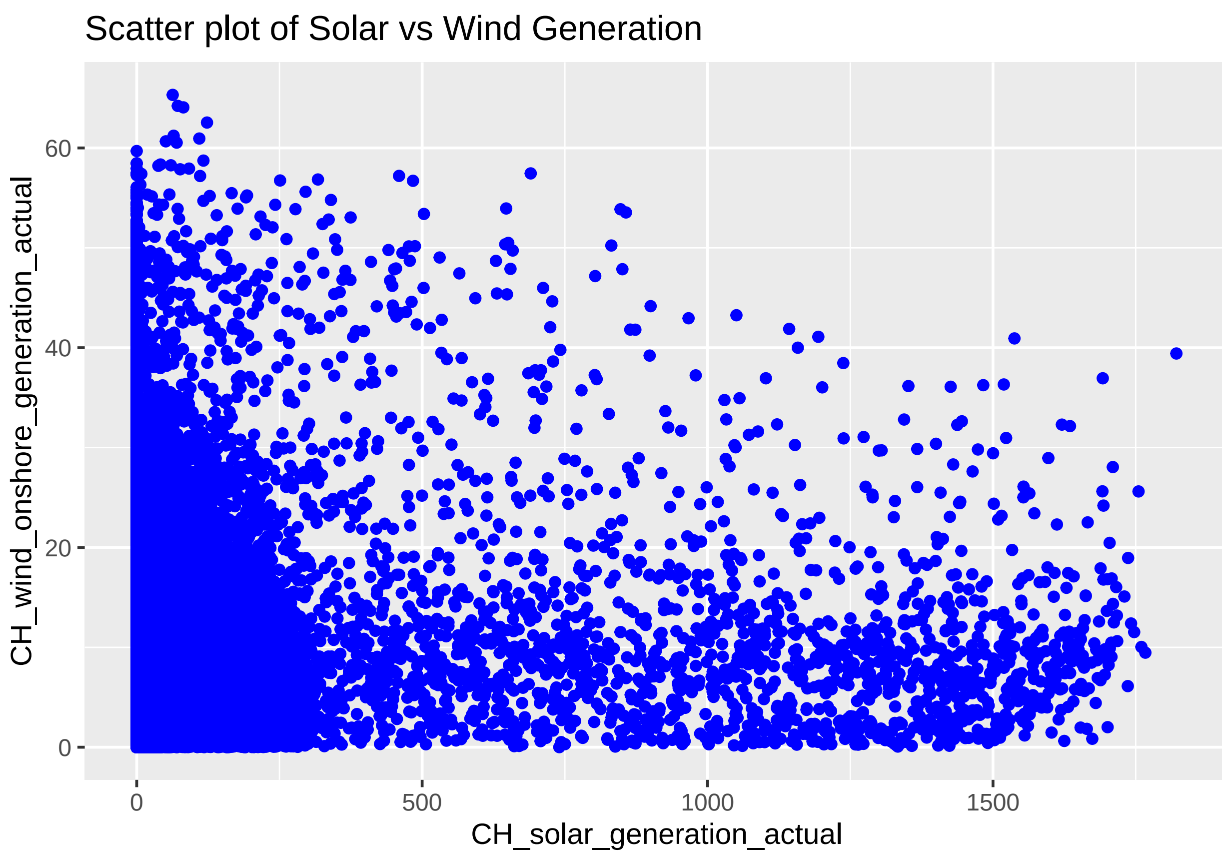

```r
# Histogram for CH_solar_generation_actual
ggplot(d, aes(x = CH_solar_generation_actual)) +
  geom_histogram(binwidth = 1, fill = "red", color = "black") +
  ggtitle("Histogram of CH_solar_generation_actual")
```

```
## Warning: Removed 2265 rows containing non-finite outside the scale range
## (‘stat_bin()‘).
```



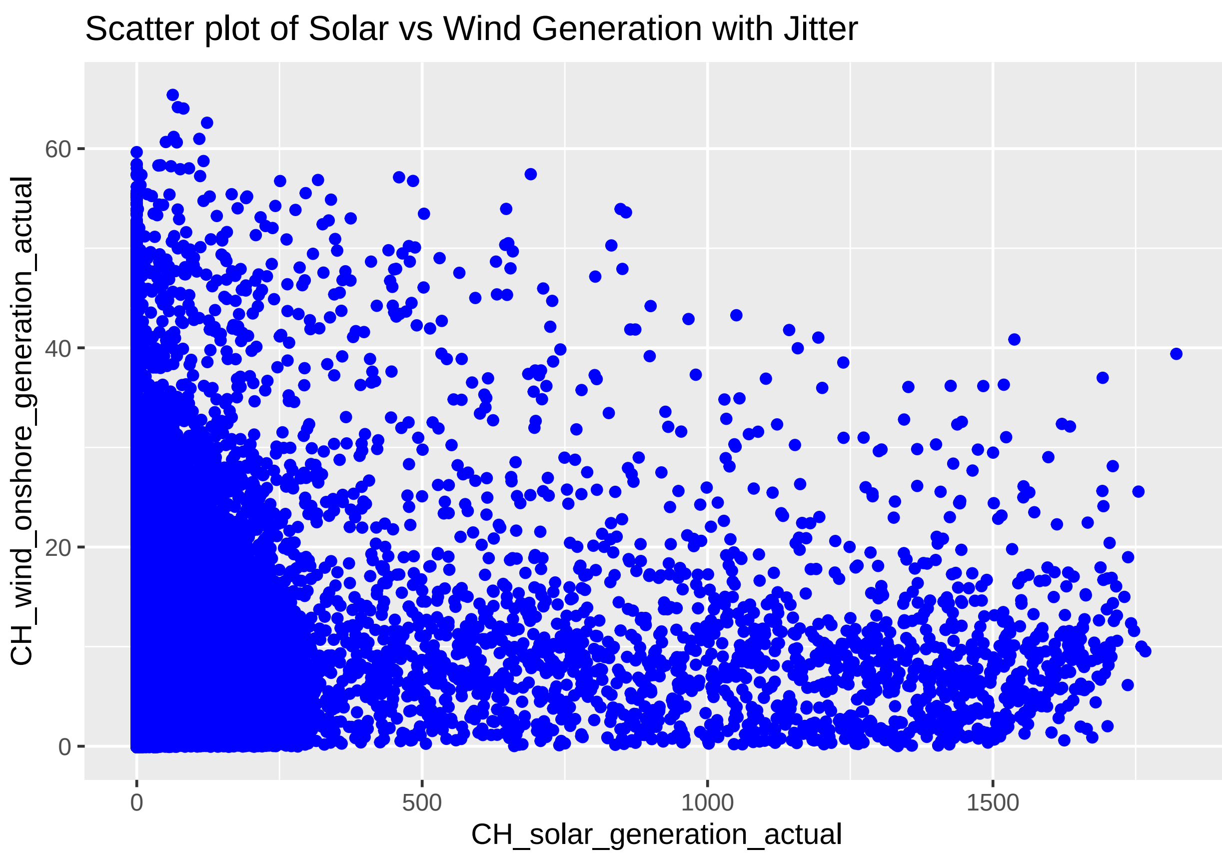

```r
# Scatter plot between CH_solar_generation_actual and CH_wind_onshore_generation_actual
ggplot(d, aes(x = CH_solar_generation_actual, y = CH_wind_onshore_generation_actual)) +
  geom_point(color = "blue") +
  ggtitle("Scatter plot of Solar vs Wind Generation")
```

```
## Warning: Removed 3005 rows containing missing values or values outside the scale range
## (‘geom_point()‘).
```




```r
# Scatter plot between CH_solar_generation_actual and CH_wind_onshore_generation_actual with jitter
ggplot(d, aes(x = CH_solar_generation_actual, y = CH_wind_onshore_generation_actual)) +
  geom_jitter(color = "blue", width = 0.1, height = 0.1) +
  ggtitle("Scatter plot of Solar vs Wind Generation with Jitter")
```

```
## Warning: Removed 3005 rows containing missing values or values outside the scale range
## (`geom_point()`).
```

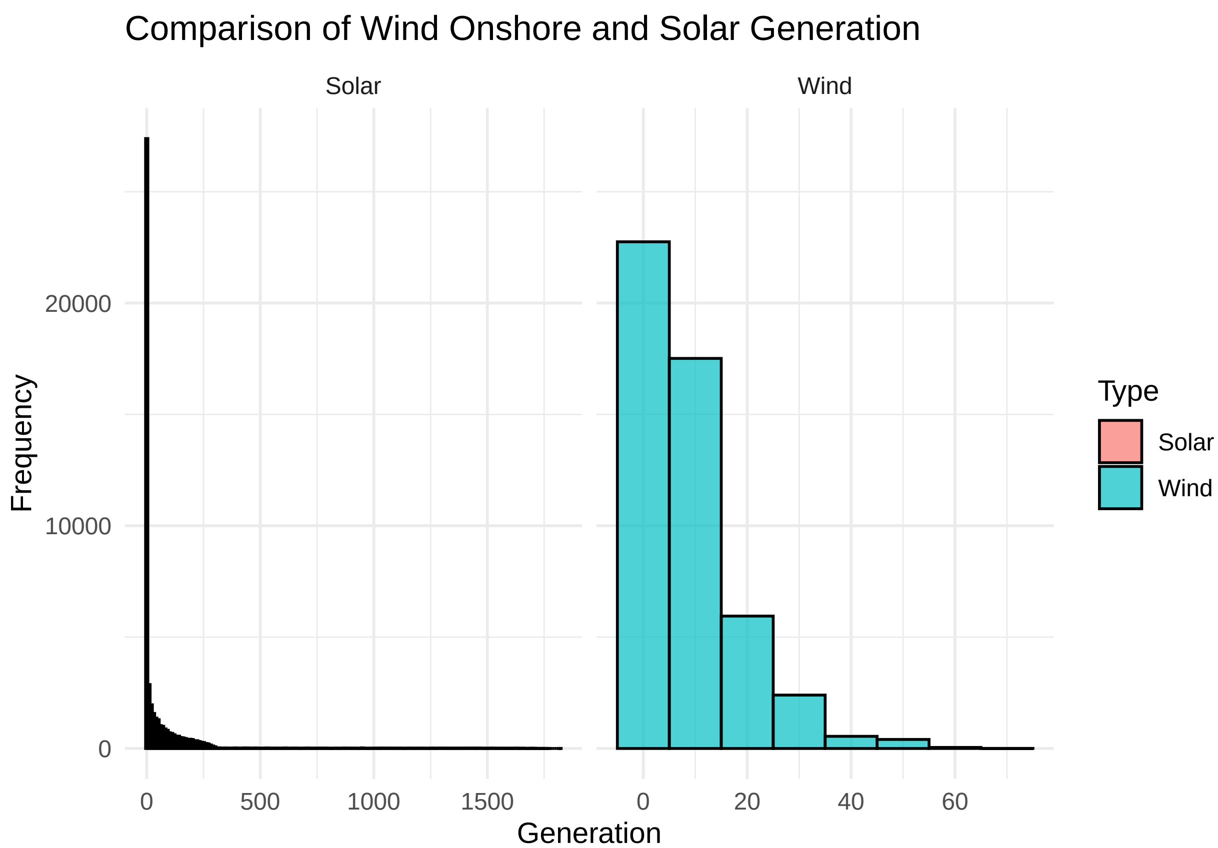



```r
# Reshape the data into a long format
library(tidyr)

data_long <- d %>%
  pivot_longer(cols = c(CH_solar_generation_actual, CH_wind_onshore_generation_actual),
               names_to = "Type", values_to = "Generation") %>%
  mutate(Type = ifelse(Type == "CH_solar_generation_actual", "Solar", "Wind"))

# Faceted Histogram
ggplot(data_long, aes(x = Generation, fill = Type)) +
  geom_histogram(binwidth = 10, color = "black", alpha = 0.7) +
  facet_wrap(~ Type, scales = "free_x") +
  ggtitle("Comparison of Wind Onshore and Solar Generation") +
  labs(x = "Generation", y = "Frequency") +
  theme_minimal()
```

```
## Warning: Removed 5270 rows containing non-finite outside the scale range
## (‘stat_bin()‘).
```



Histograms

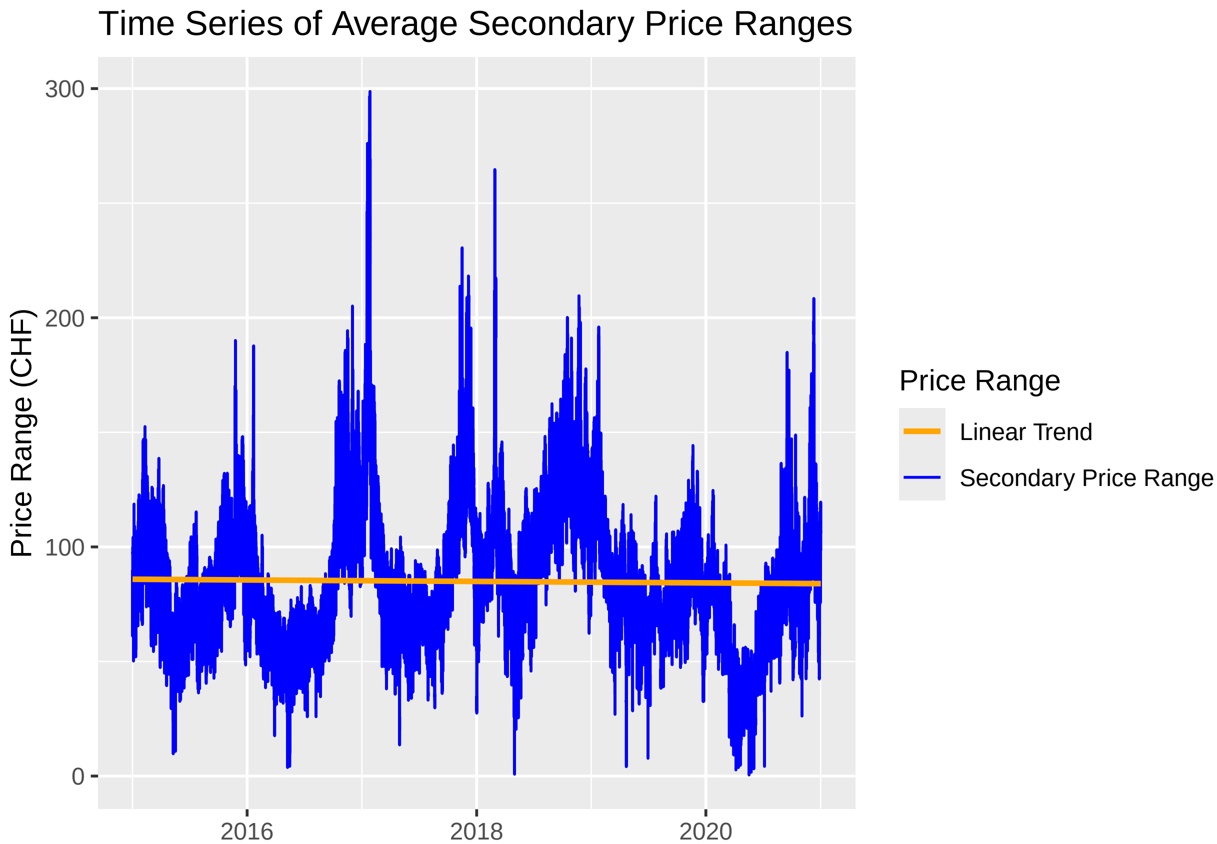
Time Series Plots

«»

Time Series of Electricity Price Ranges

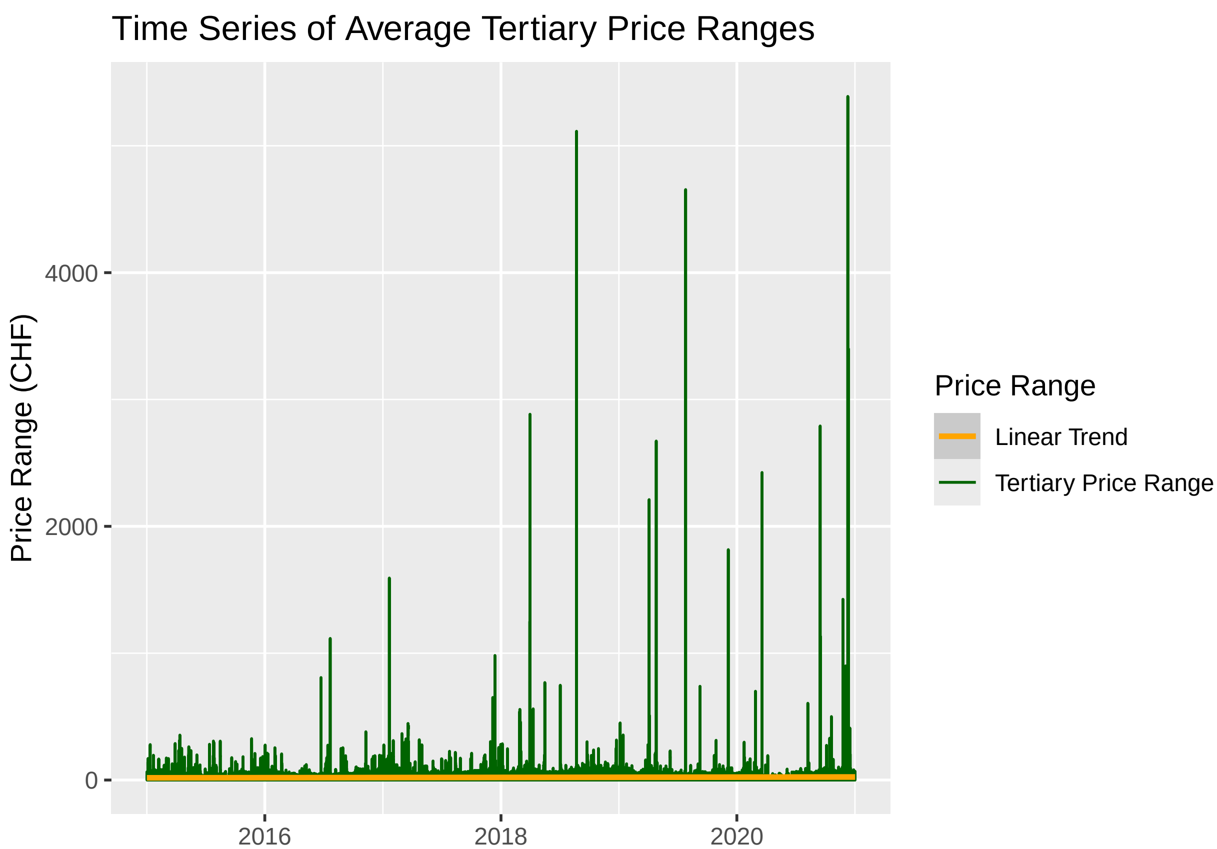
Plot: Time series plot showing the average secondary electricity price ranges over time. Purpose: To visualize how the secondary price ranges fluctuate over time.

```
## ‘geom_smooth()‘ using formula = ’y ~ x’
```



Plot: Time series plot showing the average tertiary electricity price ranges over time. Purpose: To visualize how the tertiary price ranges fluctuate over time.

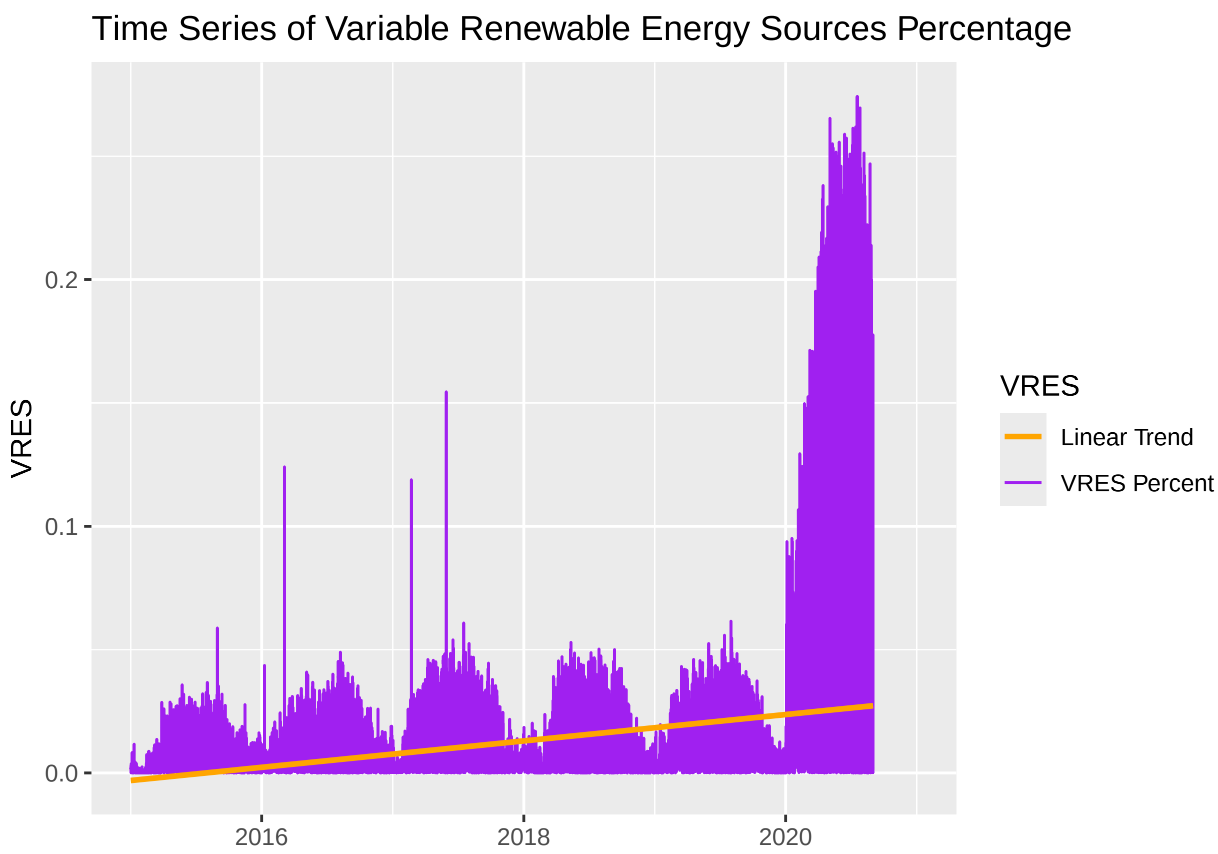
```
## ‘geom_smooth()‘ using formula = ’y ~ x’
```



Time Series of VRES Percent

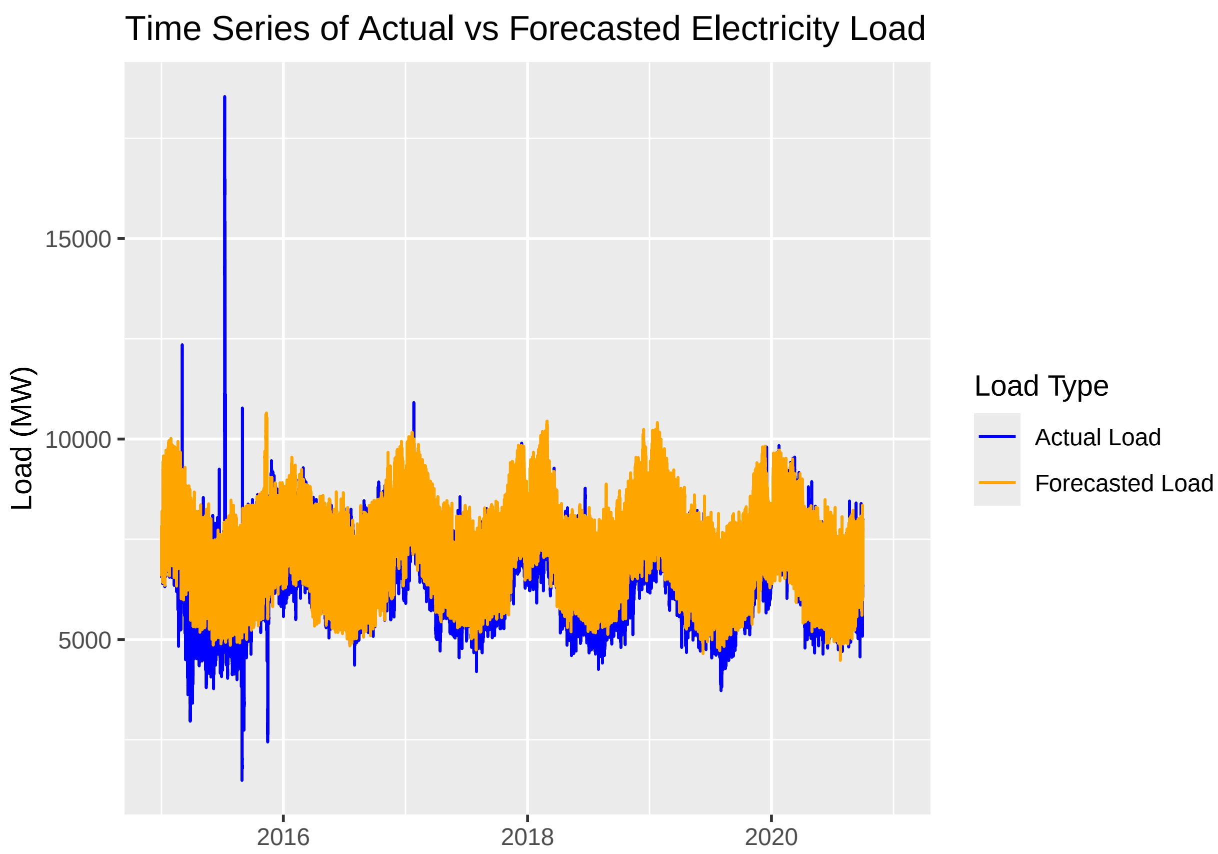
Plot: Time series plot showing the percentage of Variable Renewable Energy Sources over time. Purpose: To analyze the penetration of VRES in the energy grid over time.

```
## `geom_smooth()` using formula = 'y ~ x'
```



Time Series of Actual vs Forecasted Load

Plot: Time series plot comparing the actual and forecasted electricity load in Switzerland. Purpose: To evaluate the accuracy of load forecasting and identify discrepancies.



Models

Suggest 2-3 models, done well. This means verifying the assumptions and making neccesary transformation. I suggest doing the results in a seperate section

Results

Model 1:

for each model cover the important and interesting statistical models and how they relate the research question. Also, discuss model specific limitations in this context.

Model 2:

for each model cover the important and interesting statistical models and how they relate the research question. Also, discuss model specific limitations in this context.

Limitations

-cover general limitations

Conclusion

What did we learn, what did we not learn, how does this relate to policymakers.

Bibliograhpy

Dong, Shuaili, Hailong Li, Fredrik Wallin, Ander Avelin, Qi Zhang, and Zhixin Yu. 2019. "Volatility of Electricity Price in Denmark and Sweden." *Energy Procedia* 158 (February): 4331–37. https://doi.org/10.1016/j.egypro.2019.01.788.

Frauendorfer, Karl, Florentina Paraschiv, and Michael Schürle. 2018. "Cross-Border Effects on Swiss Electricity Prices in the Light of the Energy Transition." *Energies* 11 (9): 2188. https://doi.org/10.3390/en11092188.

Pereira da Silva, Paulo, and Paulo Horta. 2019. "The Effect of Variable Renewable Energy Sources on Electricity Price Volatility: The Case of the Iberian Market." *International Journal of Sustainable Energy* 38 (8): 794–813. https://doi.org/https://doi.org/10.1080/14786451.2019.1602126.

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