Modeling and forecasting of electricity prices and demand

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1 Introduction

¡¡struktura energetyki w Danii¿¿

The electricity market in Denmark is divided into 2 groups (DK1 and DK2). First group (DK1) consists of regions: Nordjylland, Midtjylland and Syddanmark; second group (DK2) consists of regions Sjælland and Hovedstaden with the capital Copenhagen.

Figure 1: An image of a galaxy

2 Forecasting methods

3 Data analysis

All data I used to perform forecasts I downloaded from the official webpage of Nordpool power exchange[1]. Datasets are divided into the year files and periods (hours, weeks etc.). I managed to download following datasets (valid for the day 14.05.2020):

- Consumption - hourly
- Consumption prognosis - hourly
- Wind power - hourly
- Wind power prognosis - hourly
- Elspot prices (as Price) - hourly

All of the datasets were available for years 2013-2020, except for Consumption prognosis (2015-2020). So I decided to focus on analysis only on the period 2015-2020, because 4 years time frame is still sufficient for calculations.

Units of downloaded data are following:

- Consumption and Wind Power- MWh
- Price - DKK/MWh

The files were downloaded, merged, splitted for regions DK1 and DK2, pivoted in order to have separated hours as parameters for each day and merged for all years. Example for consumption DK1 is presented below.

	date	holiday	0	1	2	...	22	23
0	2016-01-01	1	1818.0	1741.0	1660.0	...	1858.0	1713.0
1	2016-01-02	0	1615.0	1510.0	1461.0	...	2027.0	1822.0
2	2016-01-03	1	1724.0	1665.0	1671.0	...	2127.0	1998.0
3	2016-01-04	0	1844.0	1803.0	1789.0	...	2293.0	2079.0
4	2016-01-05	0	1940.0	1891.0	1952.0	...	2372.0	2193.0

Table 1: First 5 rows of merged file Consumption DK1.

Missing values

Data was very consistent and almost only single values were missing. Single missing values were replaced by average of neighbor cells and in case of missing value in neighbor cell, value was fixed manually (with file fill_empty_cells.py). Half of day 2018-09-18 from Wind prognosis files was filled taking closest neighbors and counting average for whole vector (with file fill_empty_cells_wind_prognosis_DK.py). Missing values were reduced to zero.

Dataset	DK1	DK2
Consumption	5	5
Consumption prognosis	5	5
Price	21	12
Wind power	12	6
Wind power prognosis	18	19

Table 2: Missing values in files.

3.1 Load data

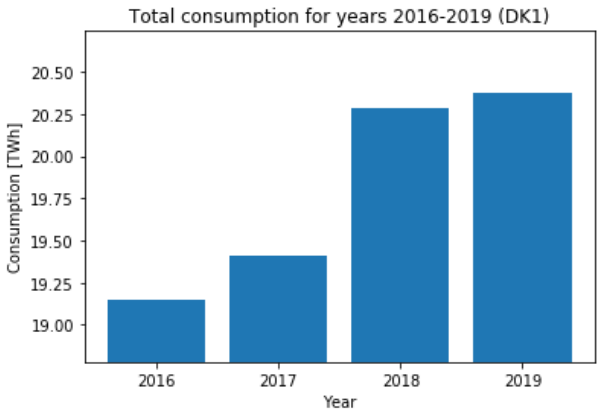


Figure 2:

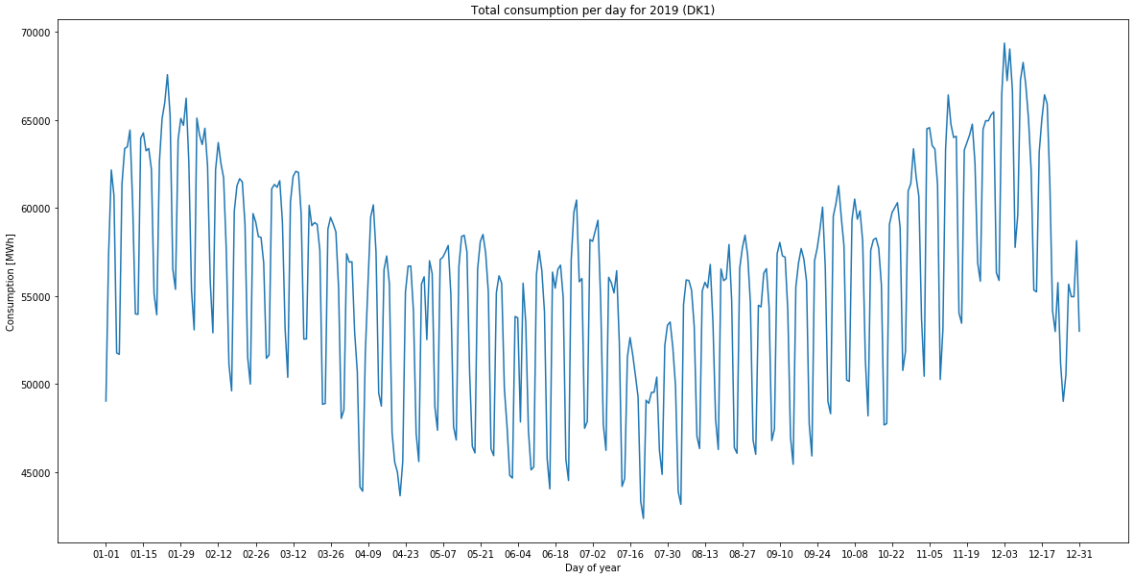
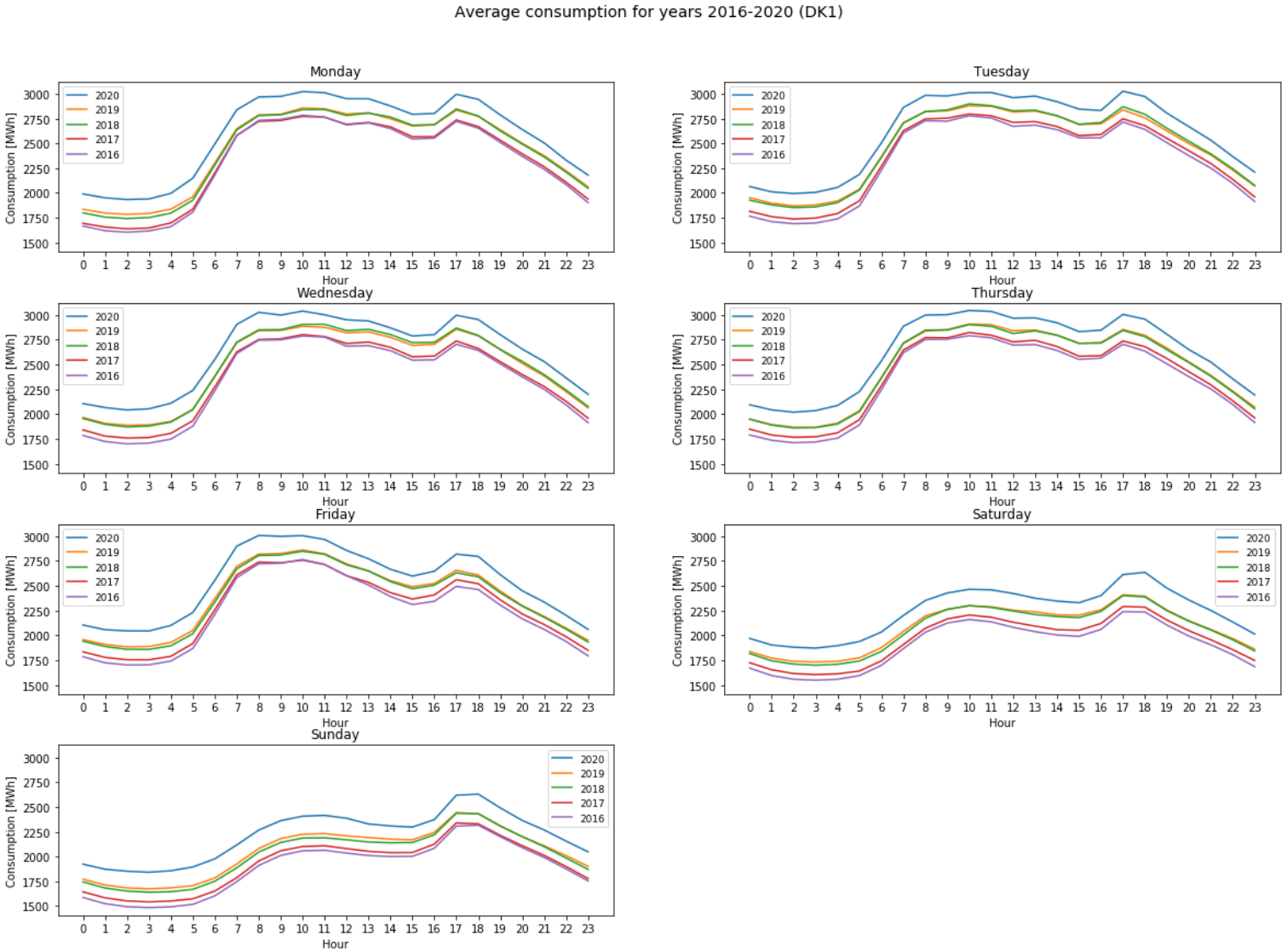


Figure 3:



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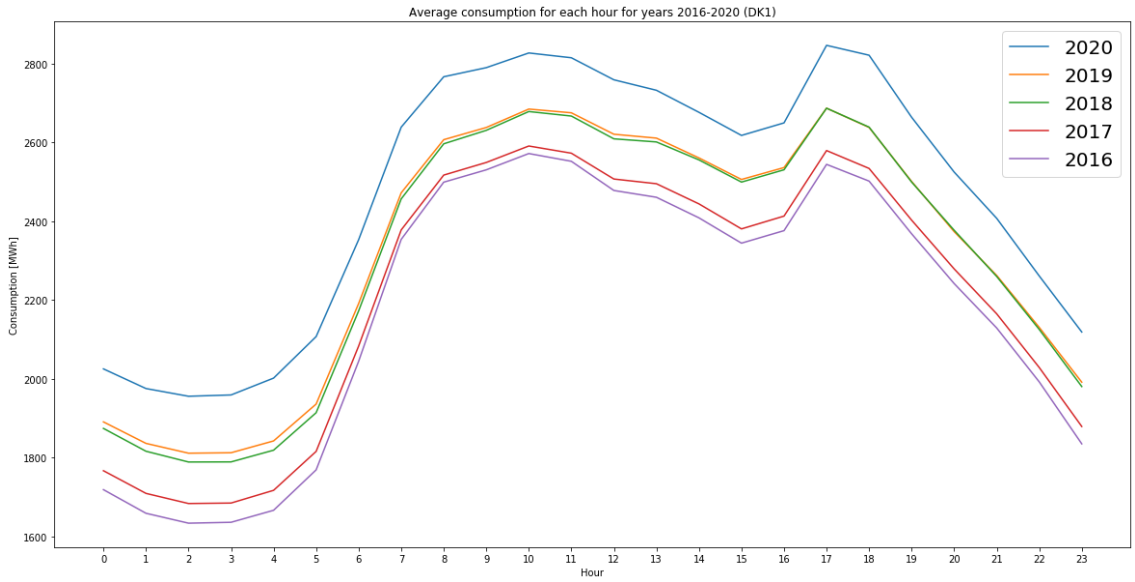

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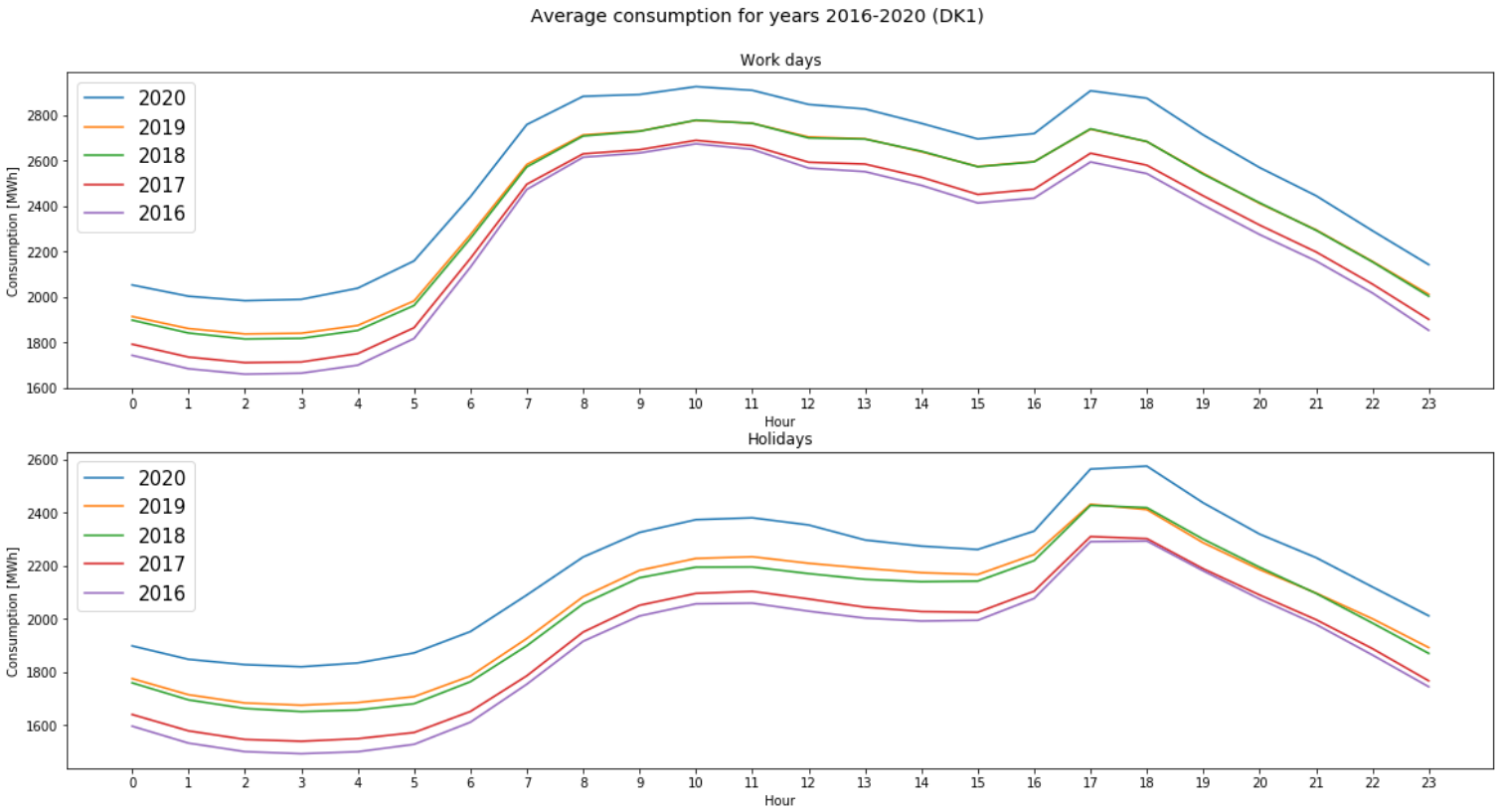


Figure 6:

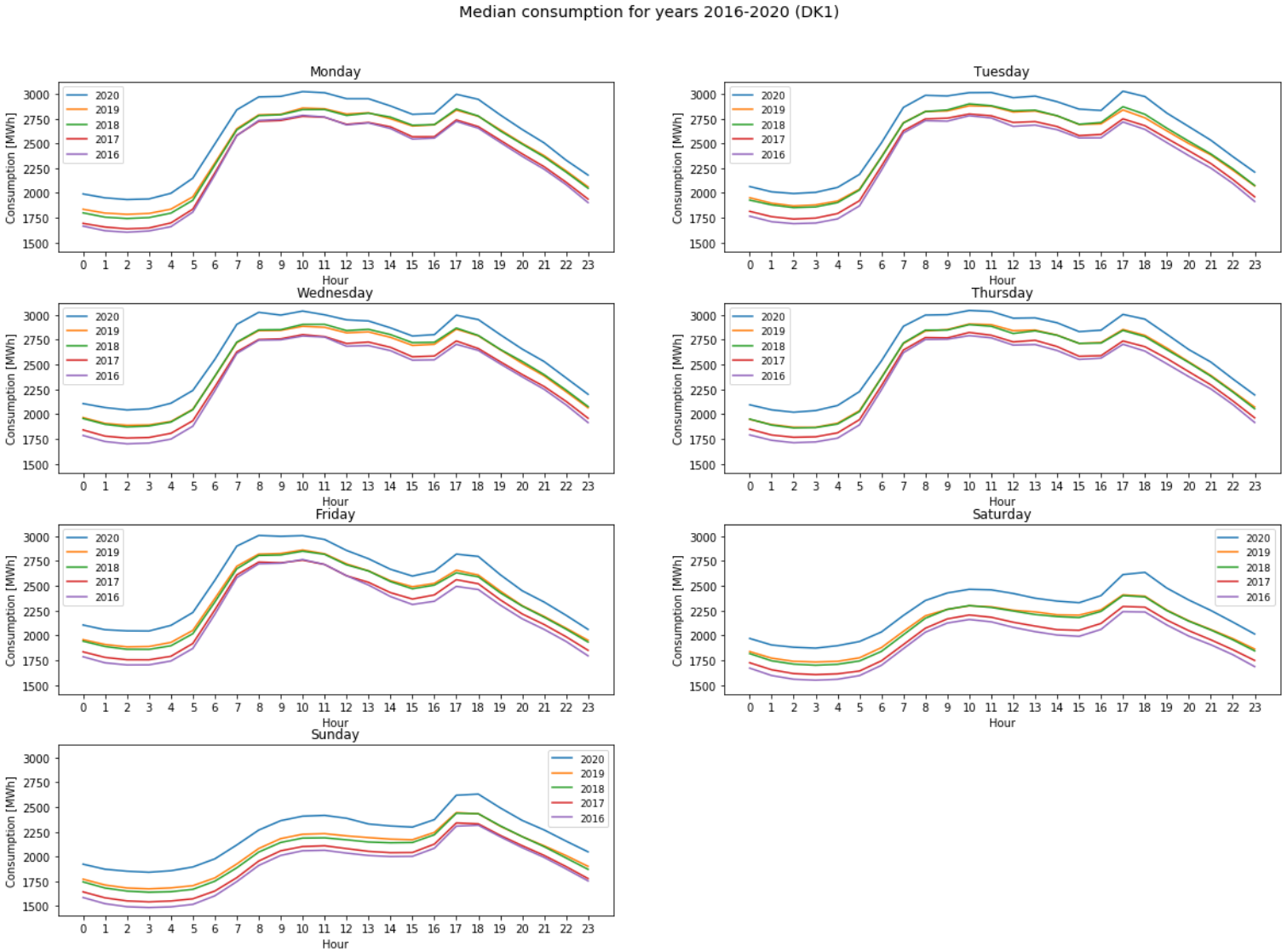
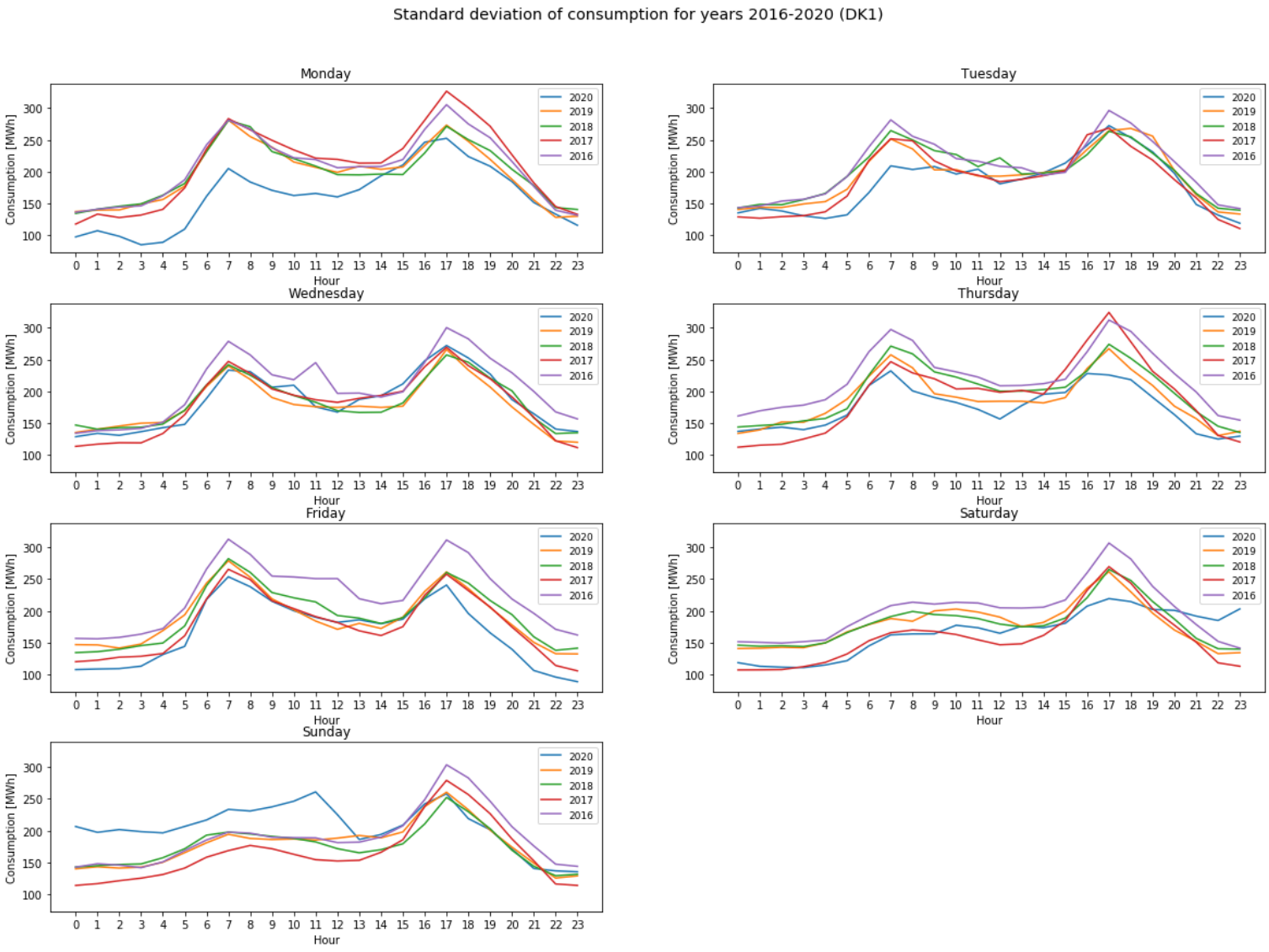

Median consumption for years 2016-2020 (DK1)
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Consumption [MWh]
Hour
2020
2019
2018
2017
2016

Figure 7:



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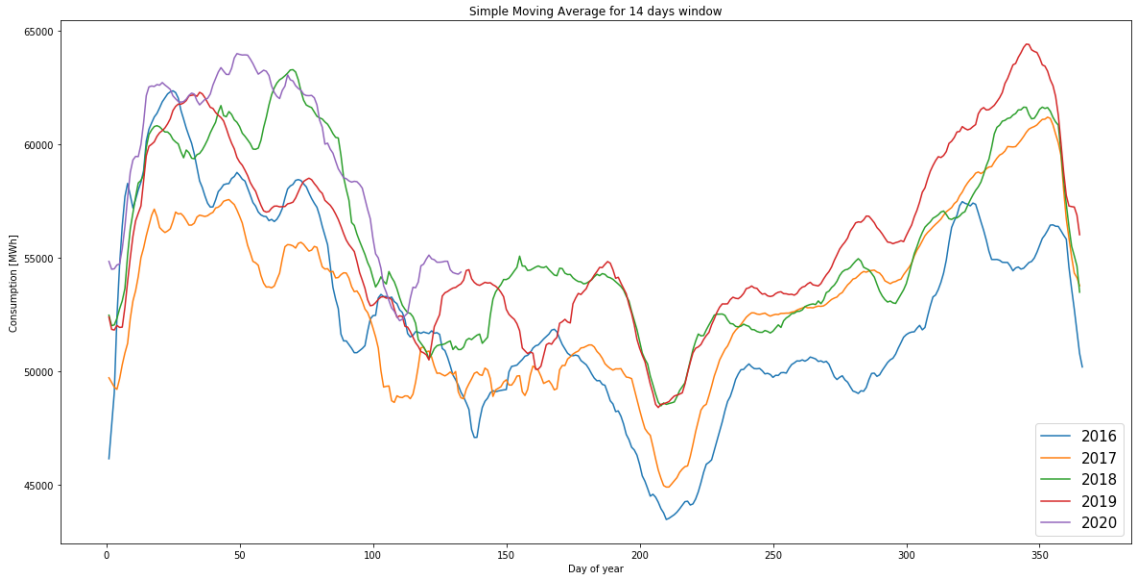

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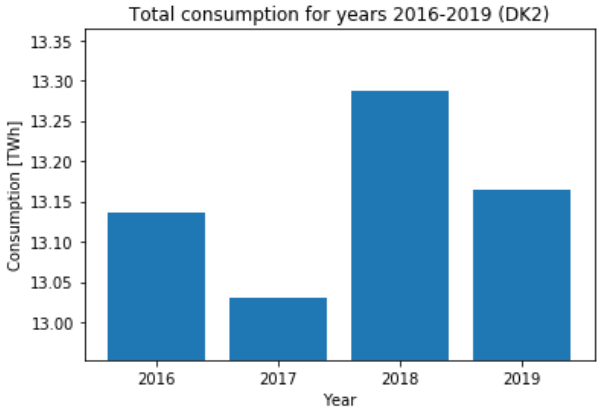
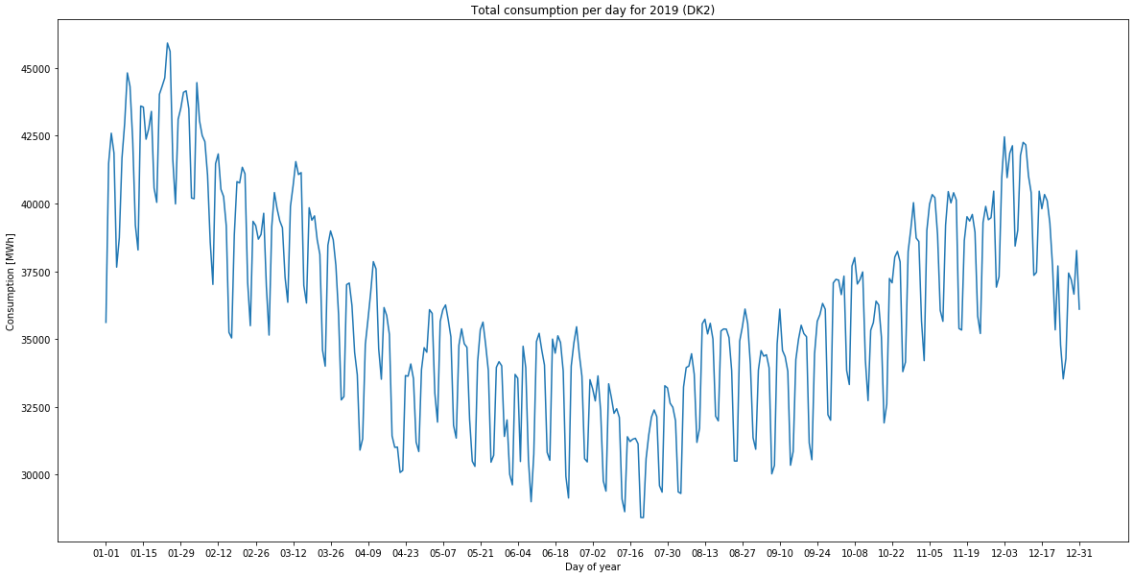


Figure 10:



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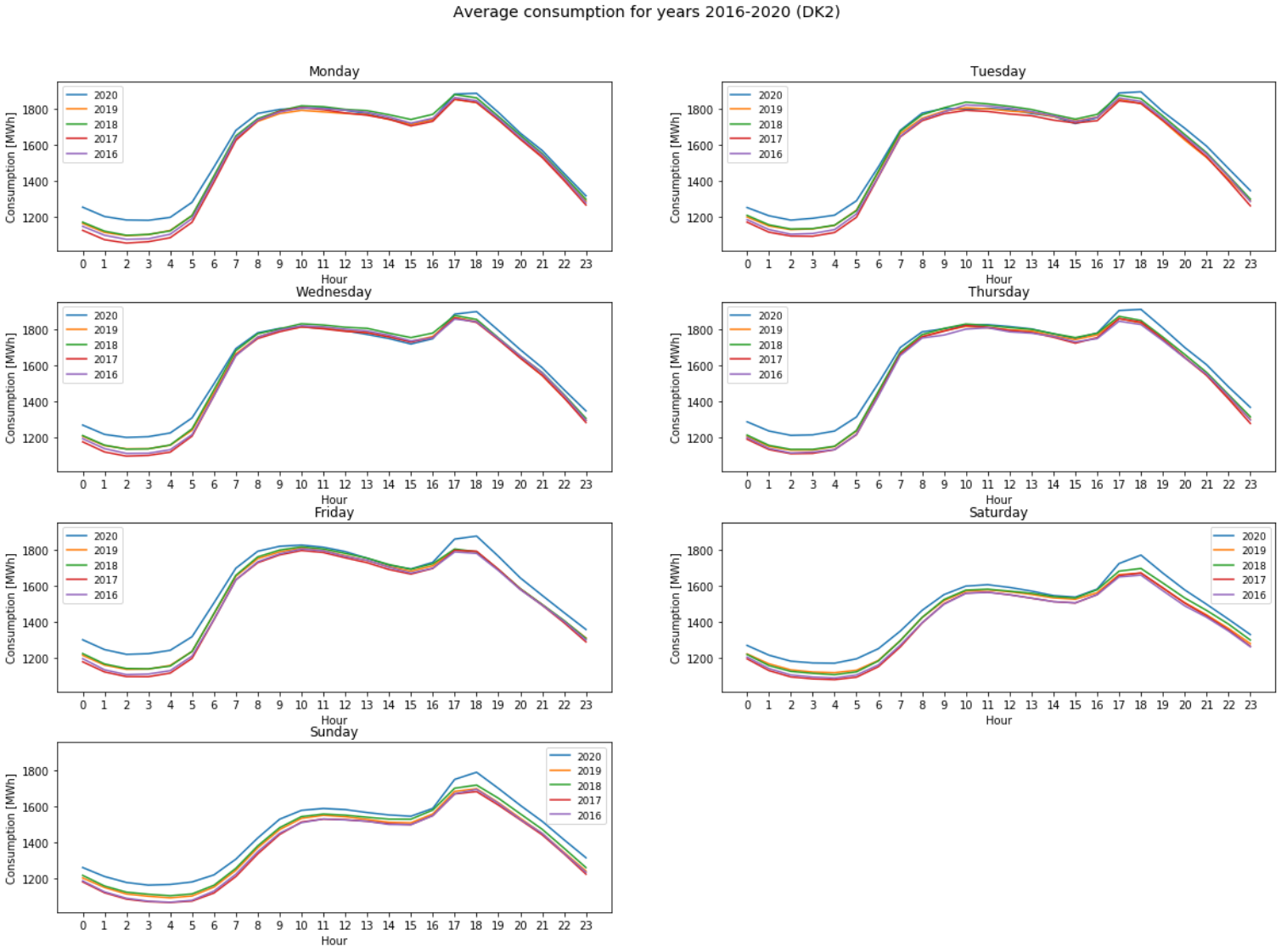

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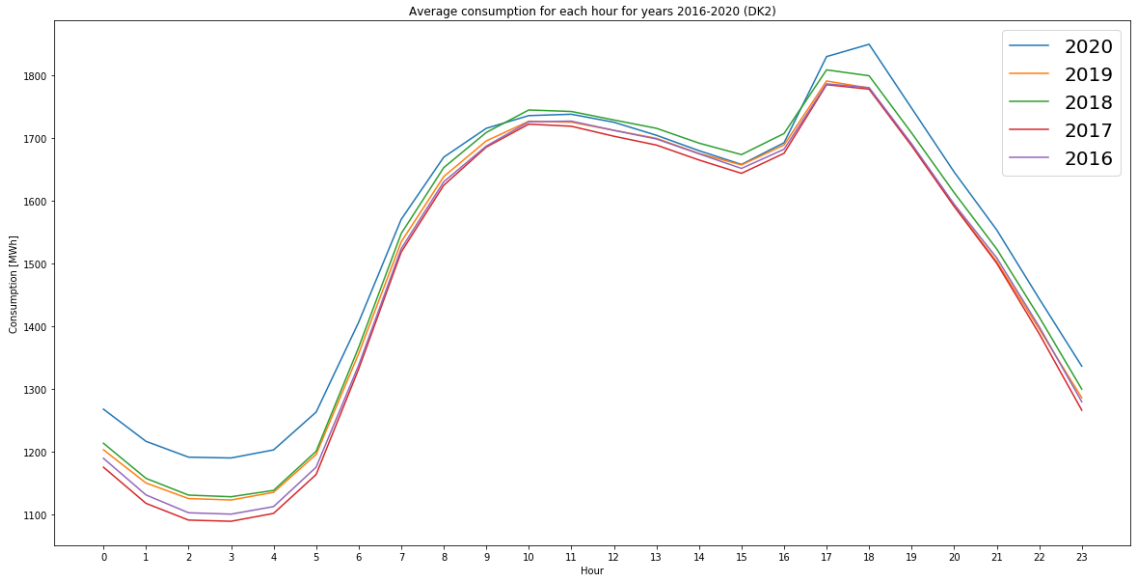

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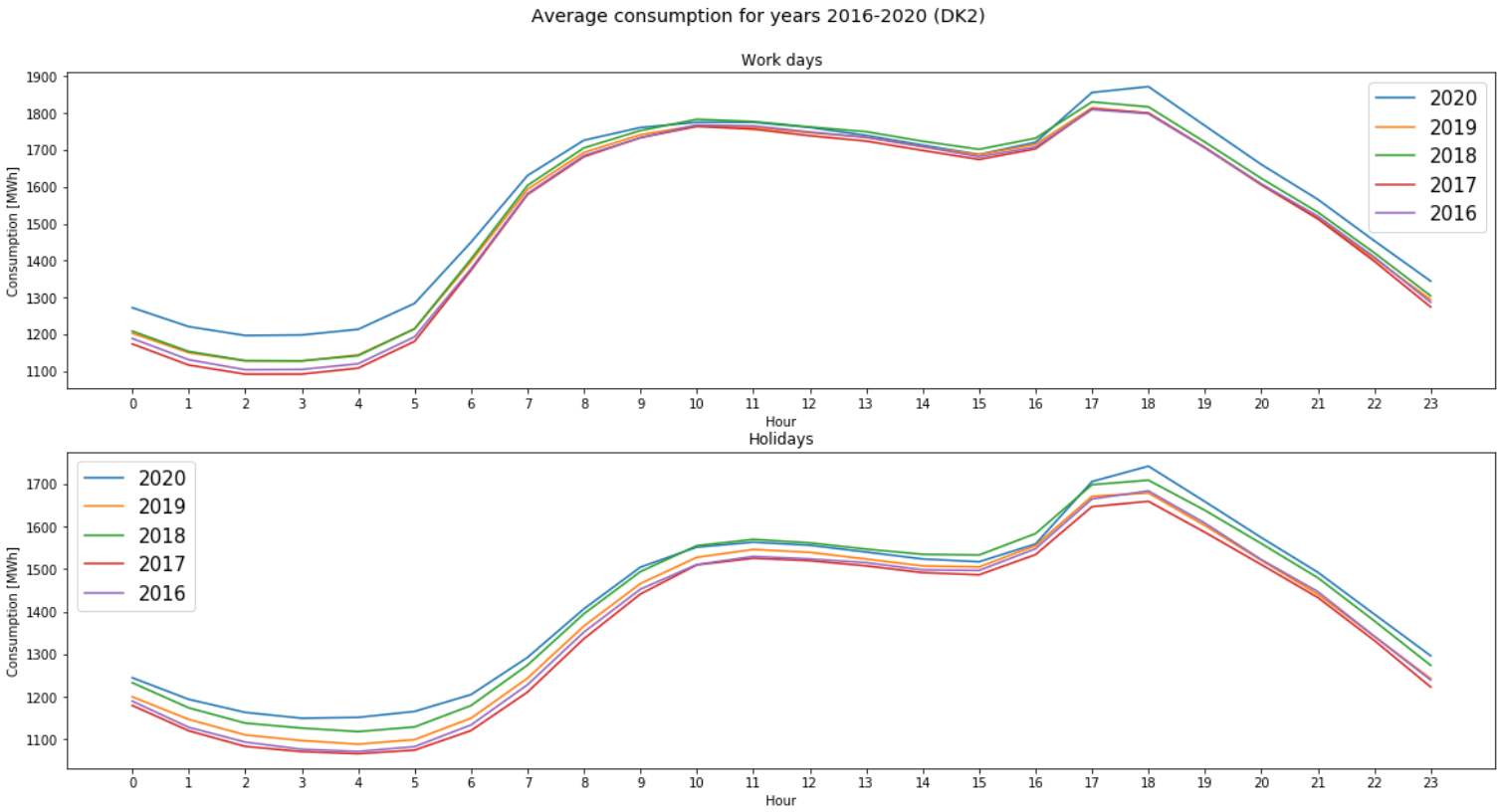
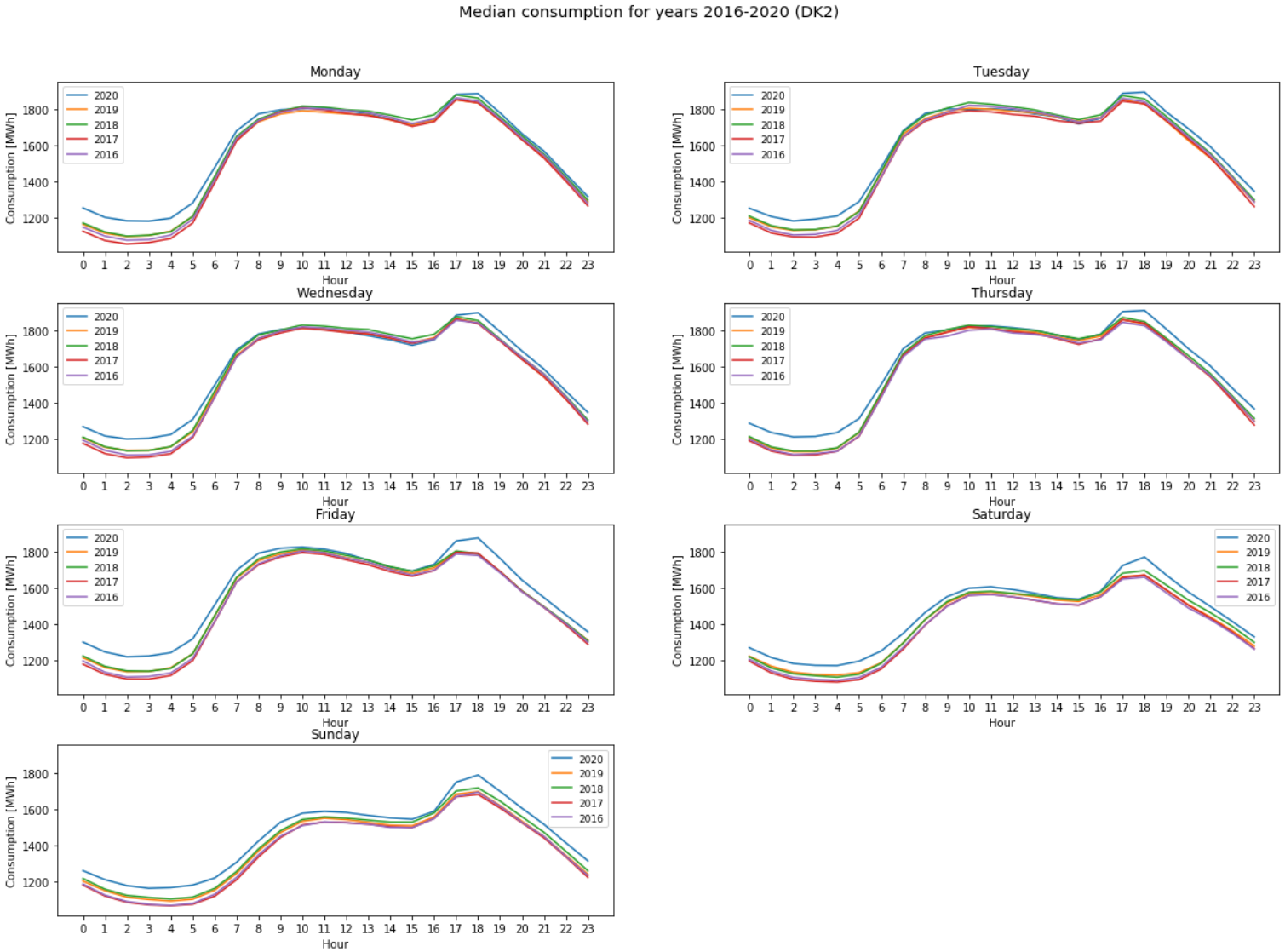

Average consumption for years 2016-2020 (DK2)
Work days
Consumption [MWh]
Hour
2020
2019
2018
2017
2016
Holidays
Consumption [MWh]
Hour
2020
2019
2018
2017
2016

Figure 14: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Consumption [MWh]
Hour
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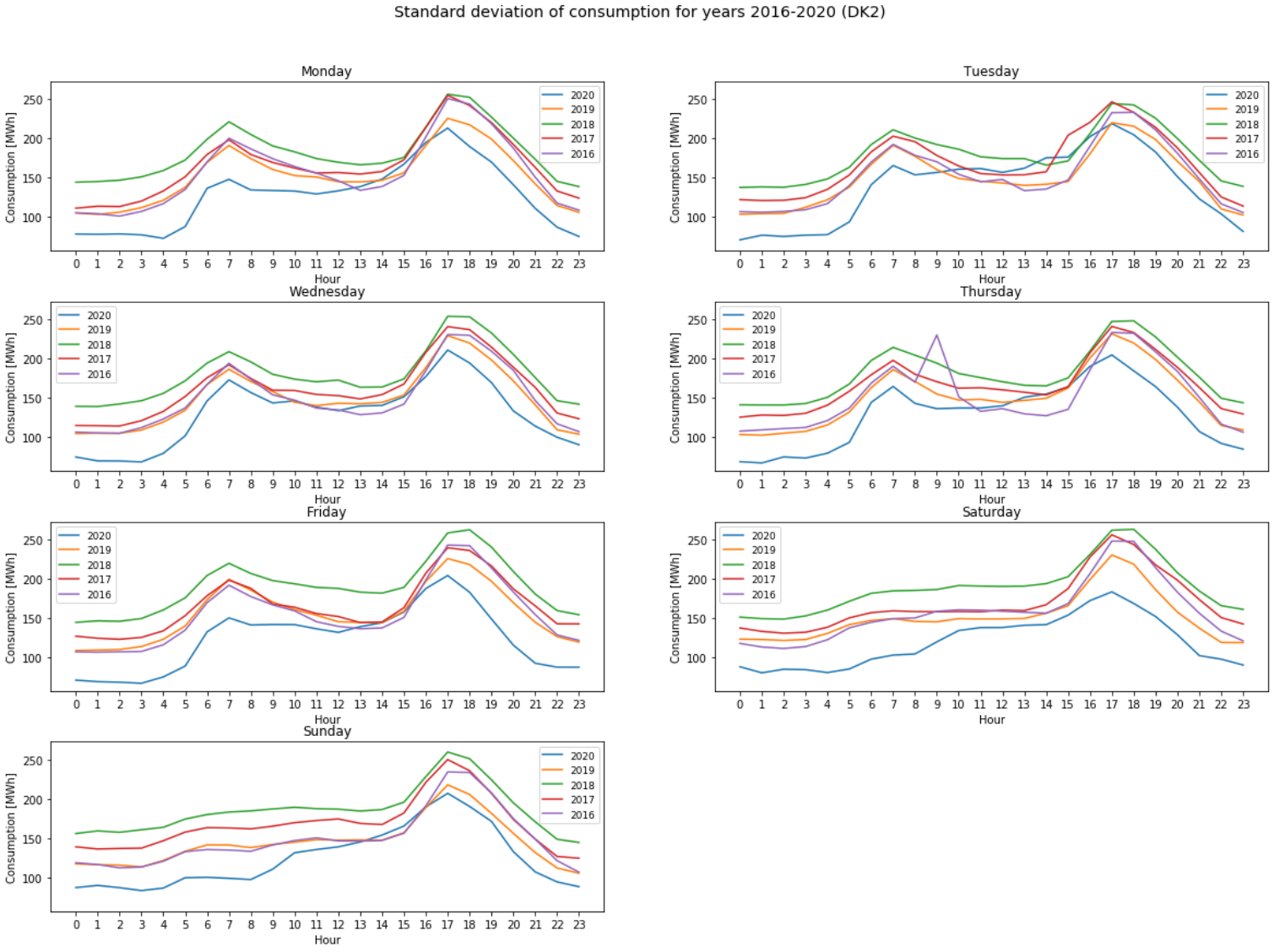
Figure 15:



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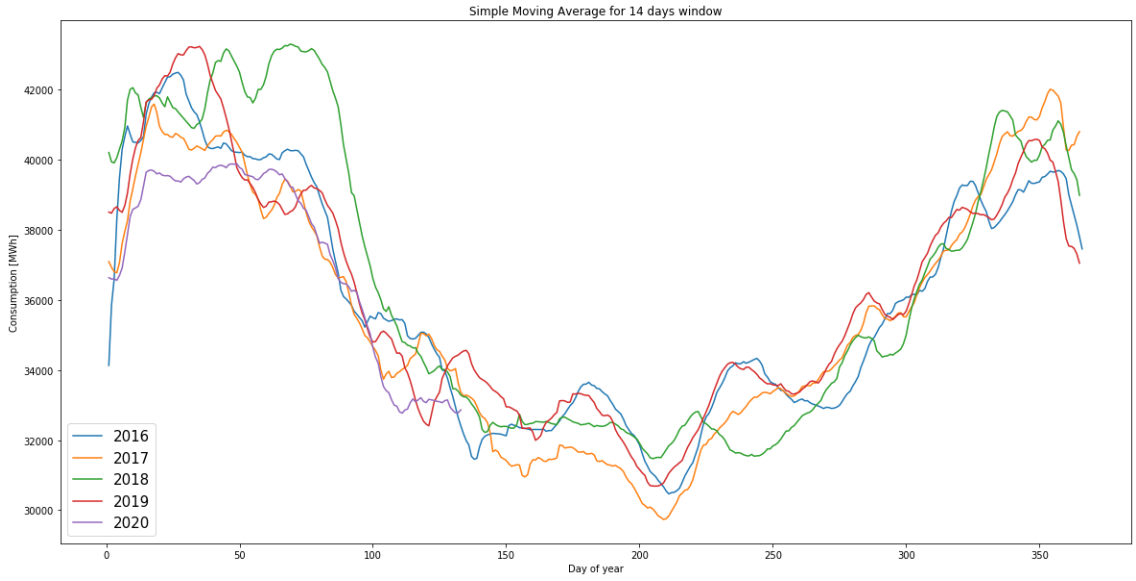
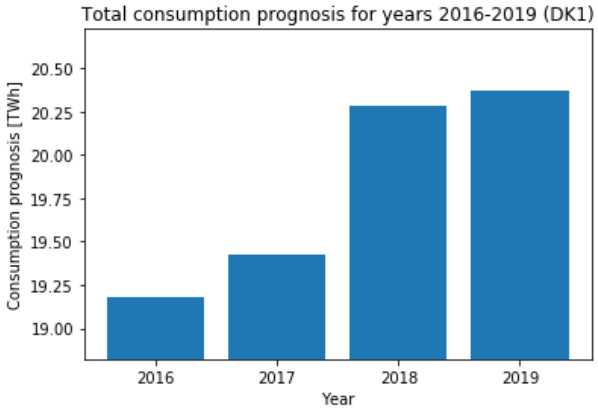


Figure 17:

3.1.1 Load data prognosis



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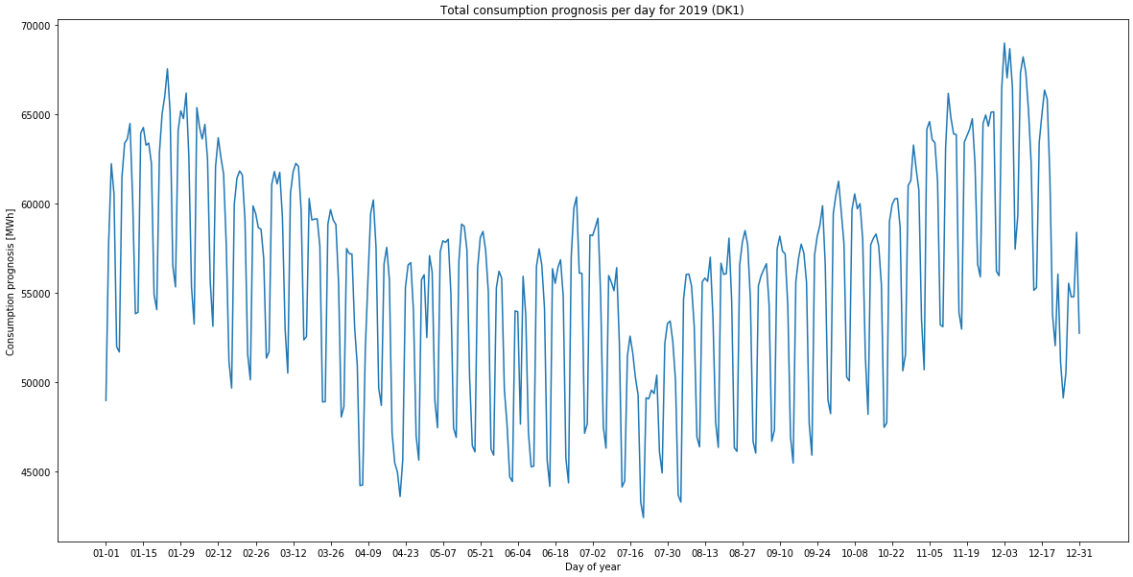

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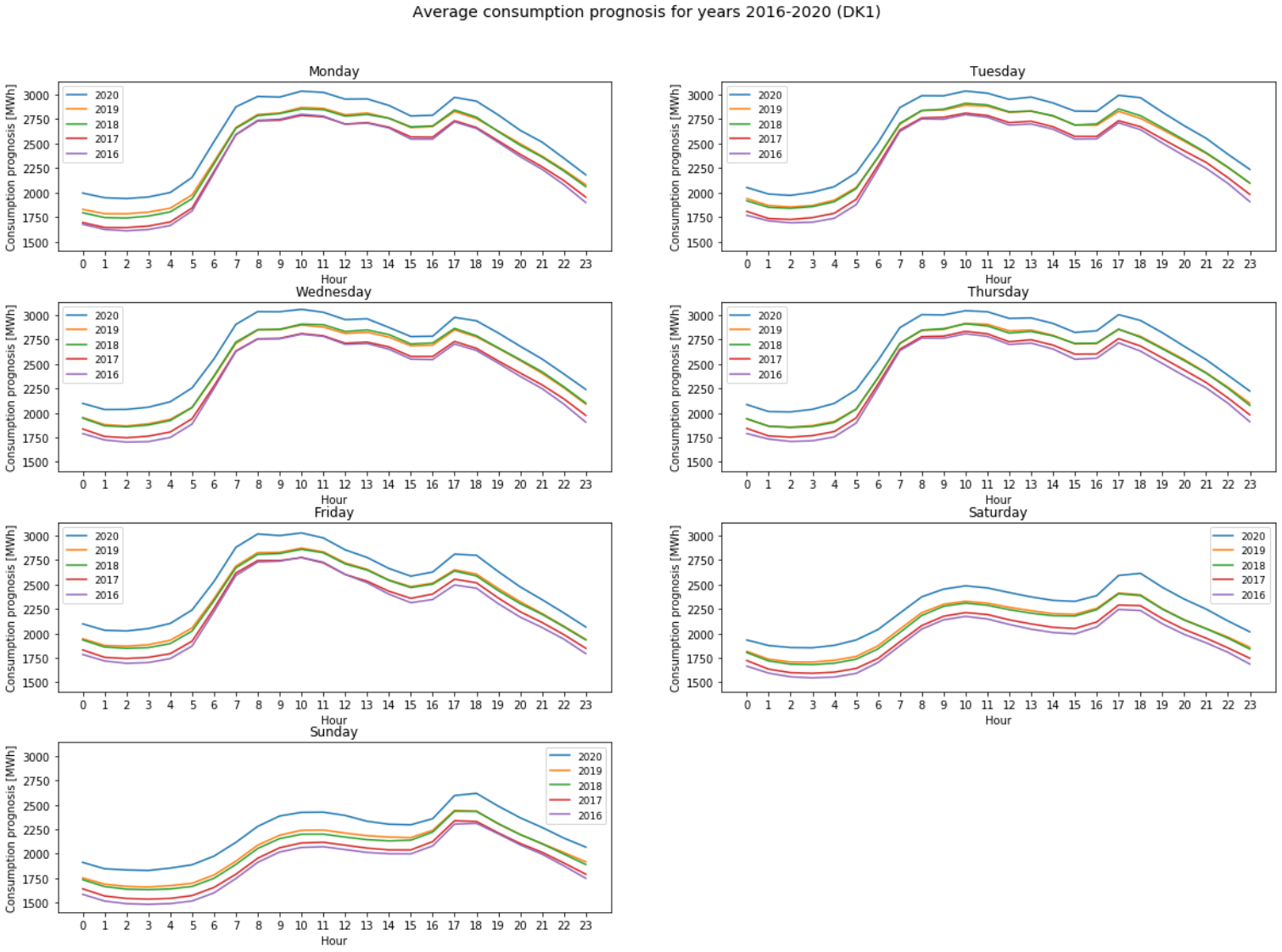

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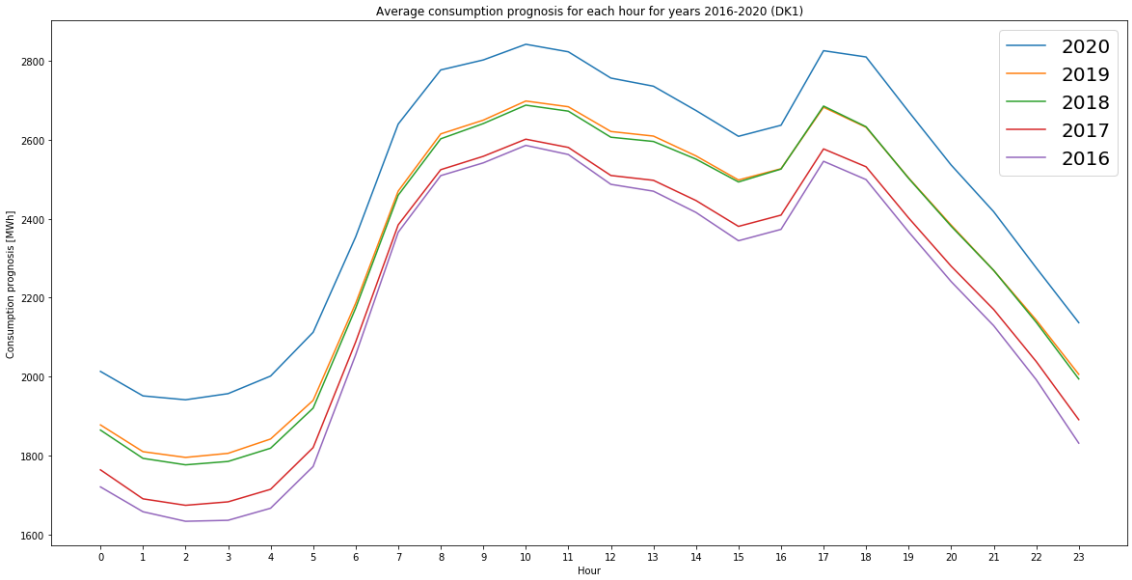

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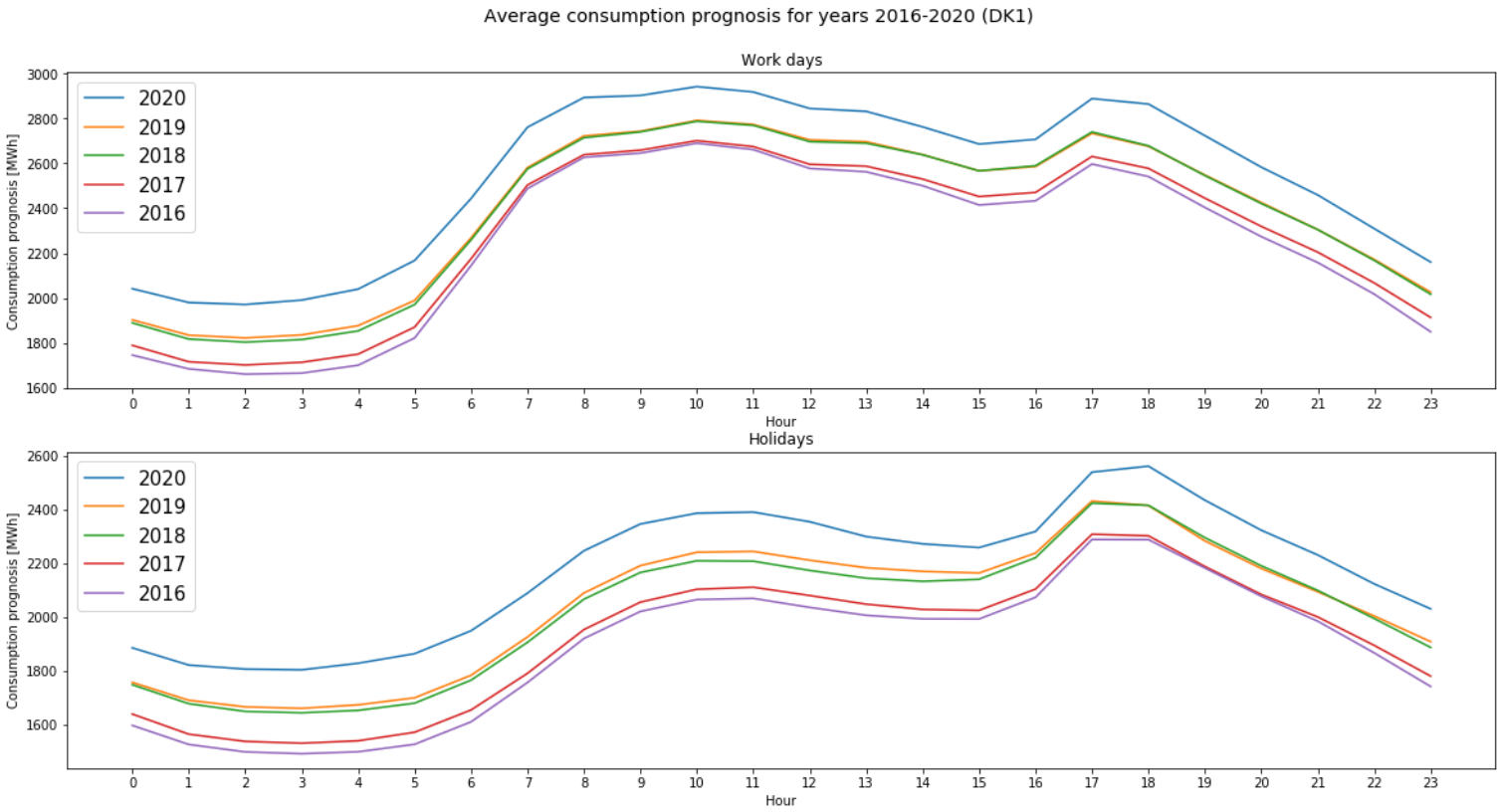
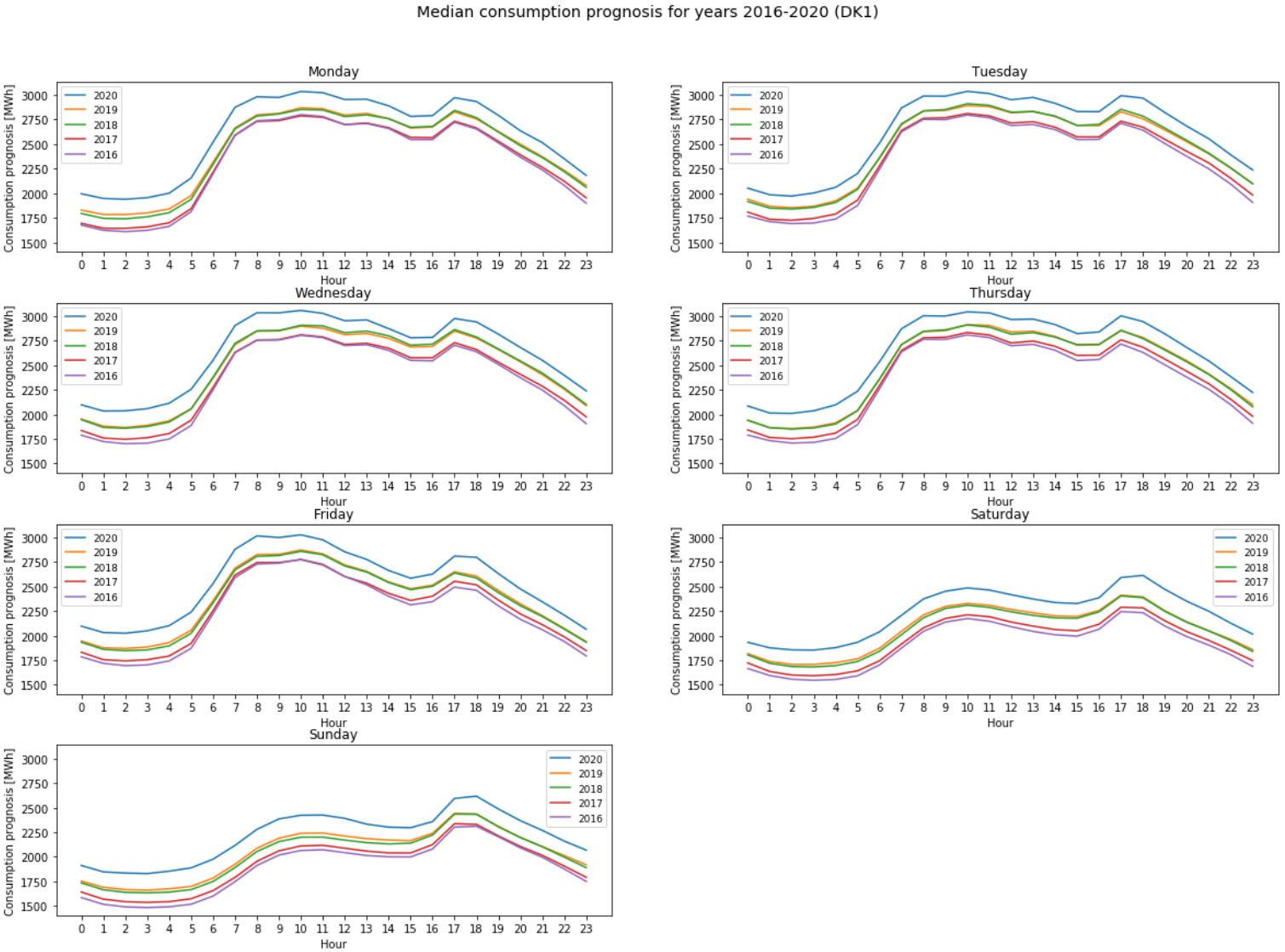

Average consumption prognosis for years 2016-2020 (DK1)
Work days
Consumption prognosis [MWh]
Hour
Holidays
Consumption prognosis [MWh]
Hour
2020
2019
2018
2017
2016

Figure 22:


Median consumption prognosis for years 2016-2020 (DK1)
Monday
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Consumption prognosis [MWh]
Hour
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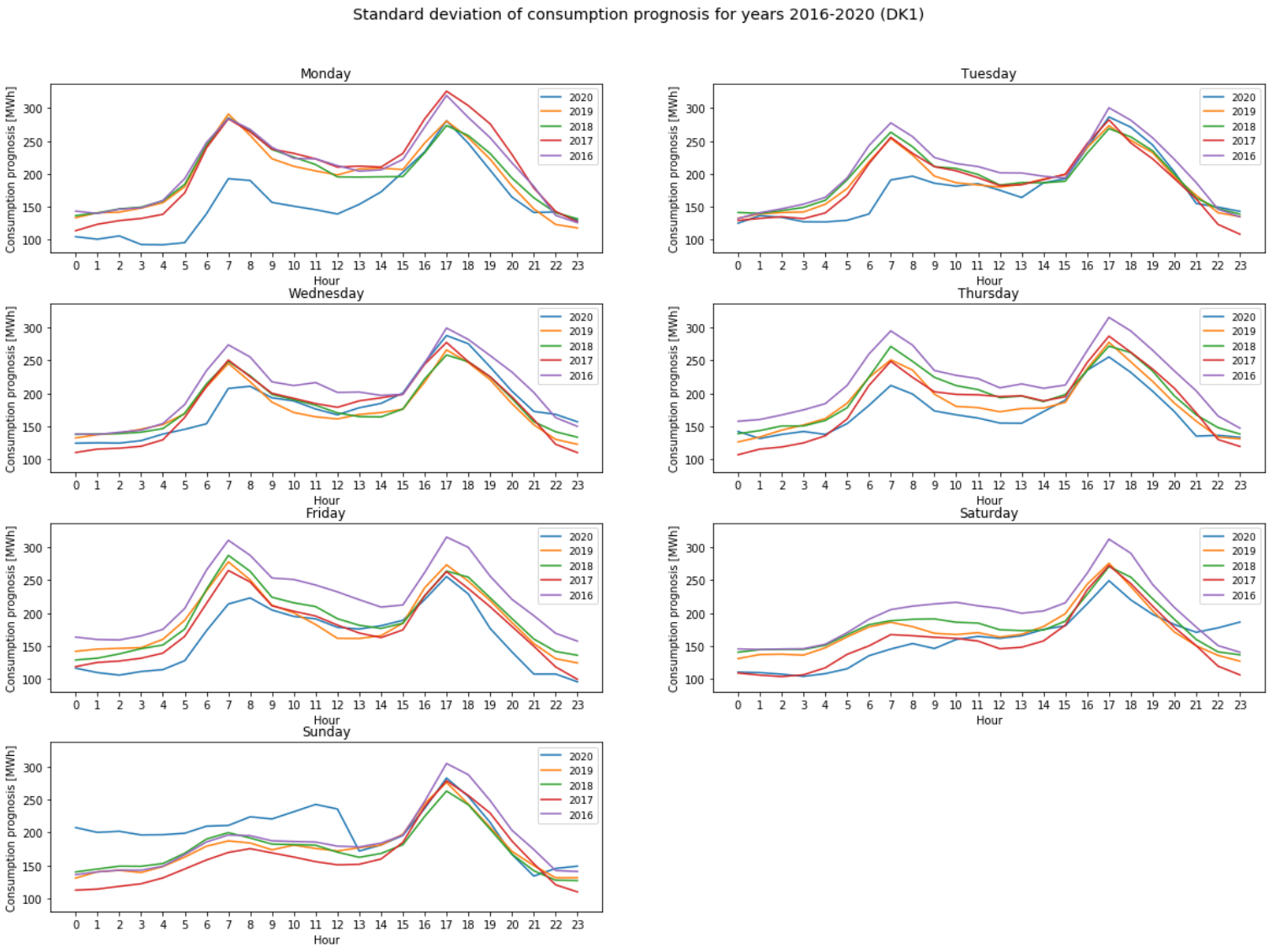
Figure 23:



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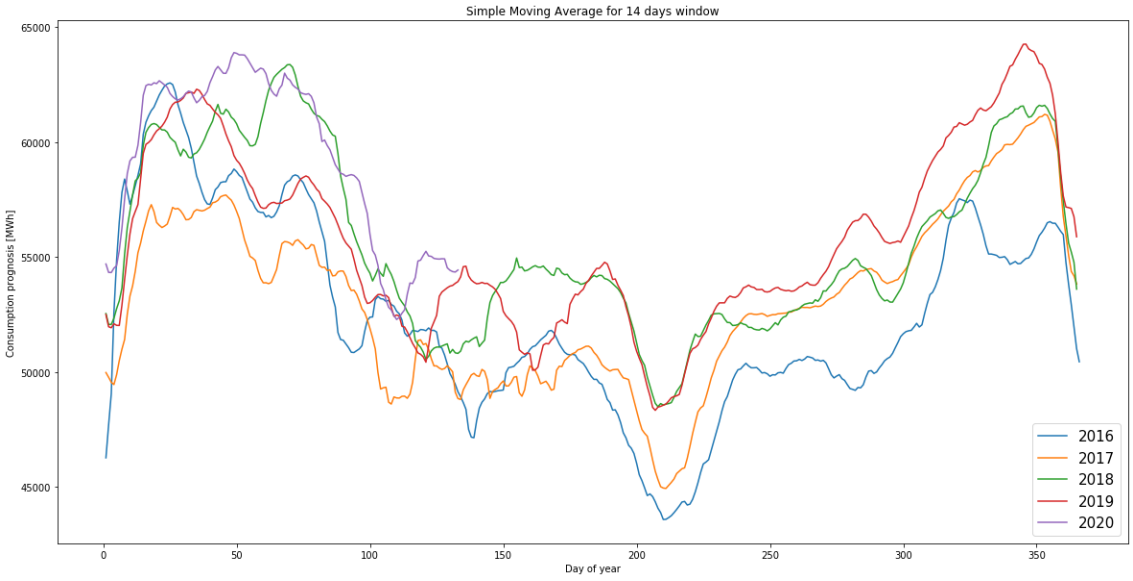

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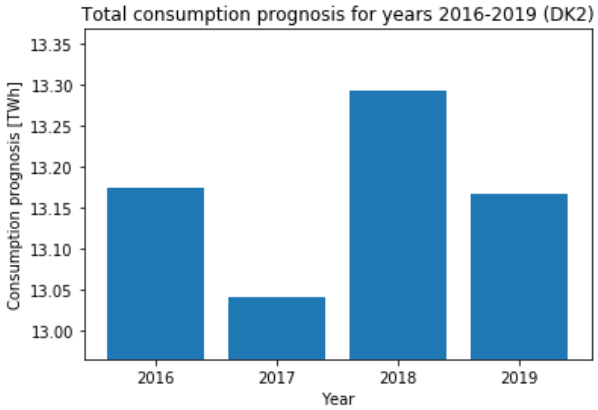

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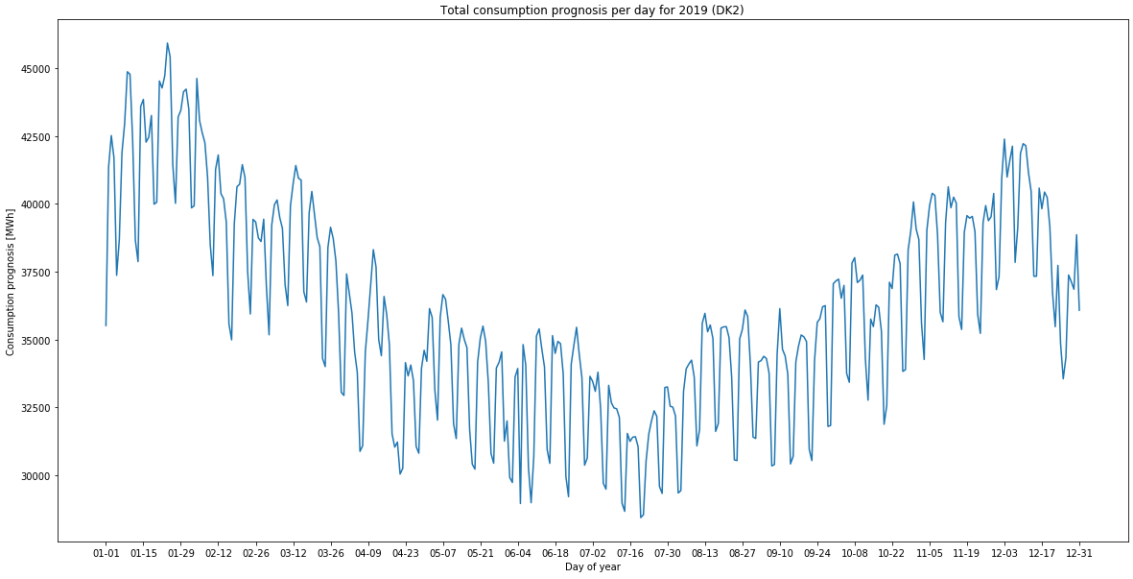

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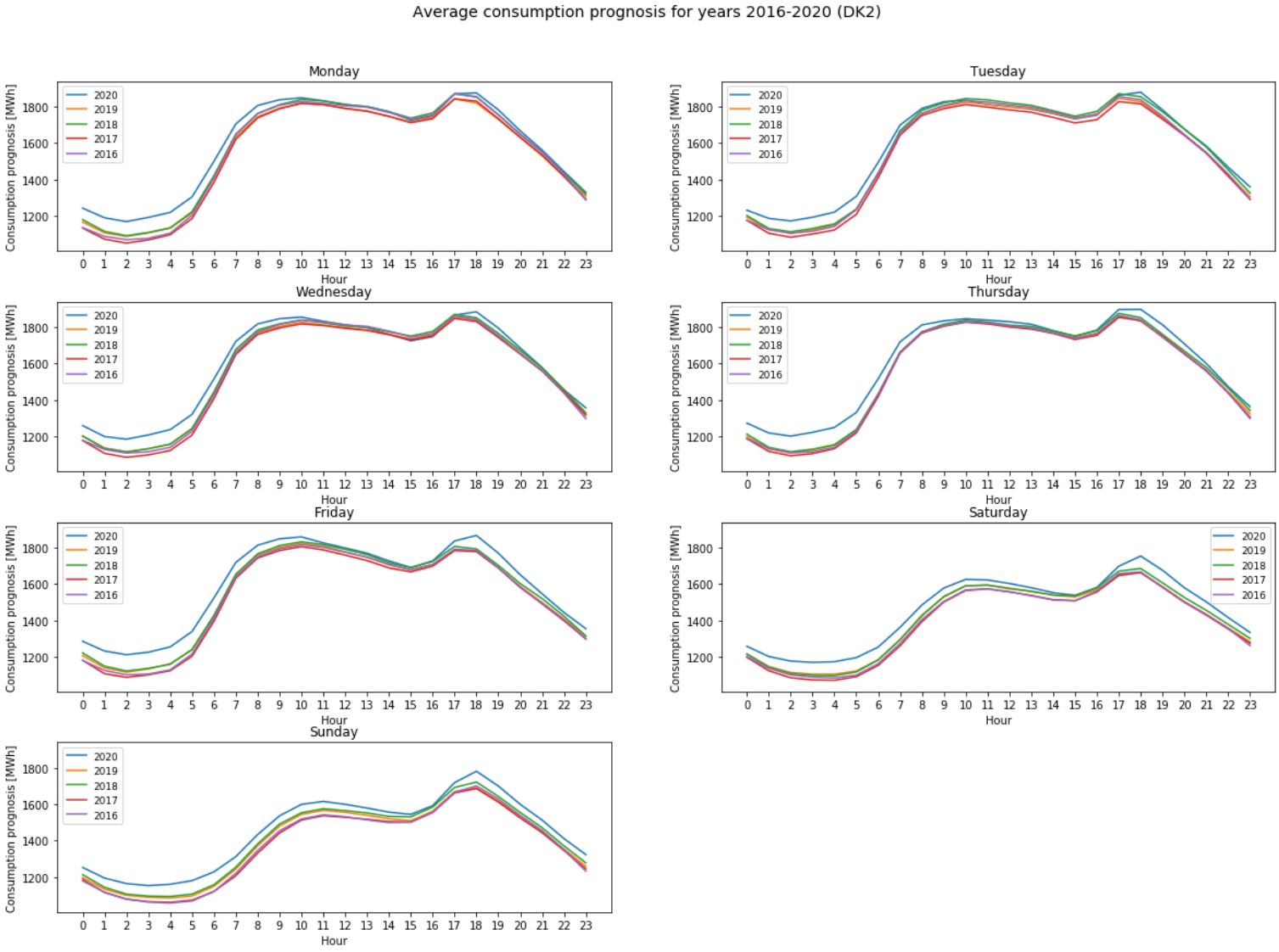

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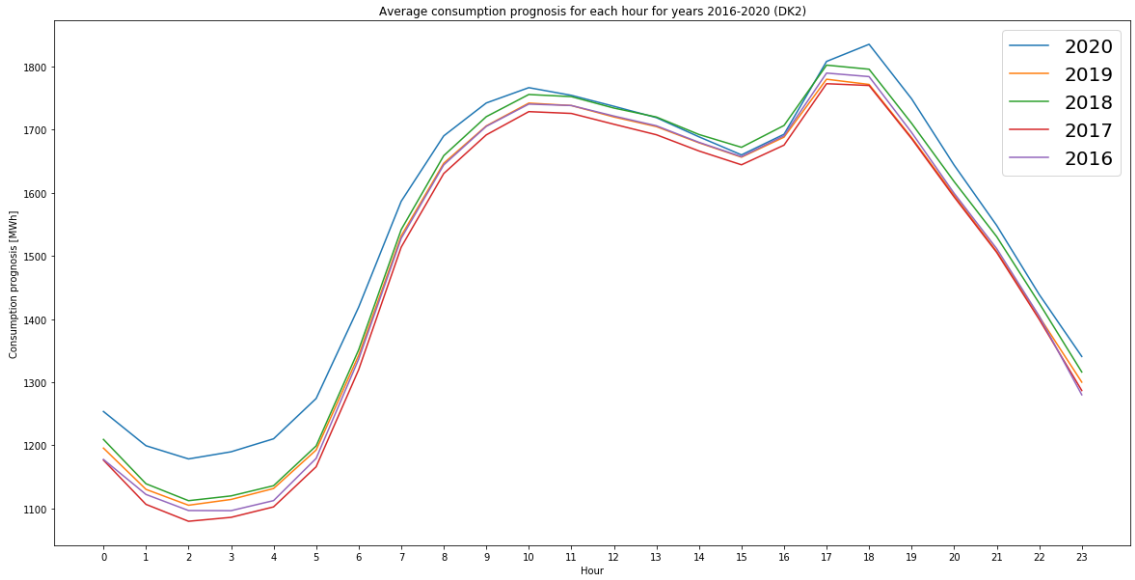


Figure 29:

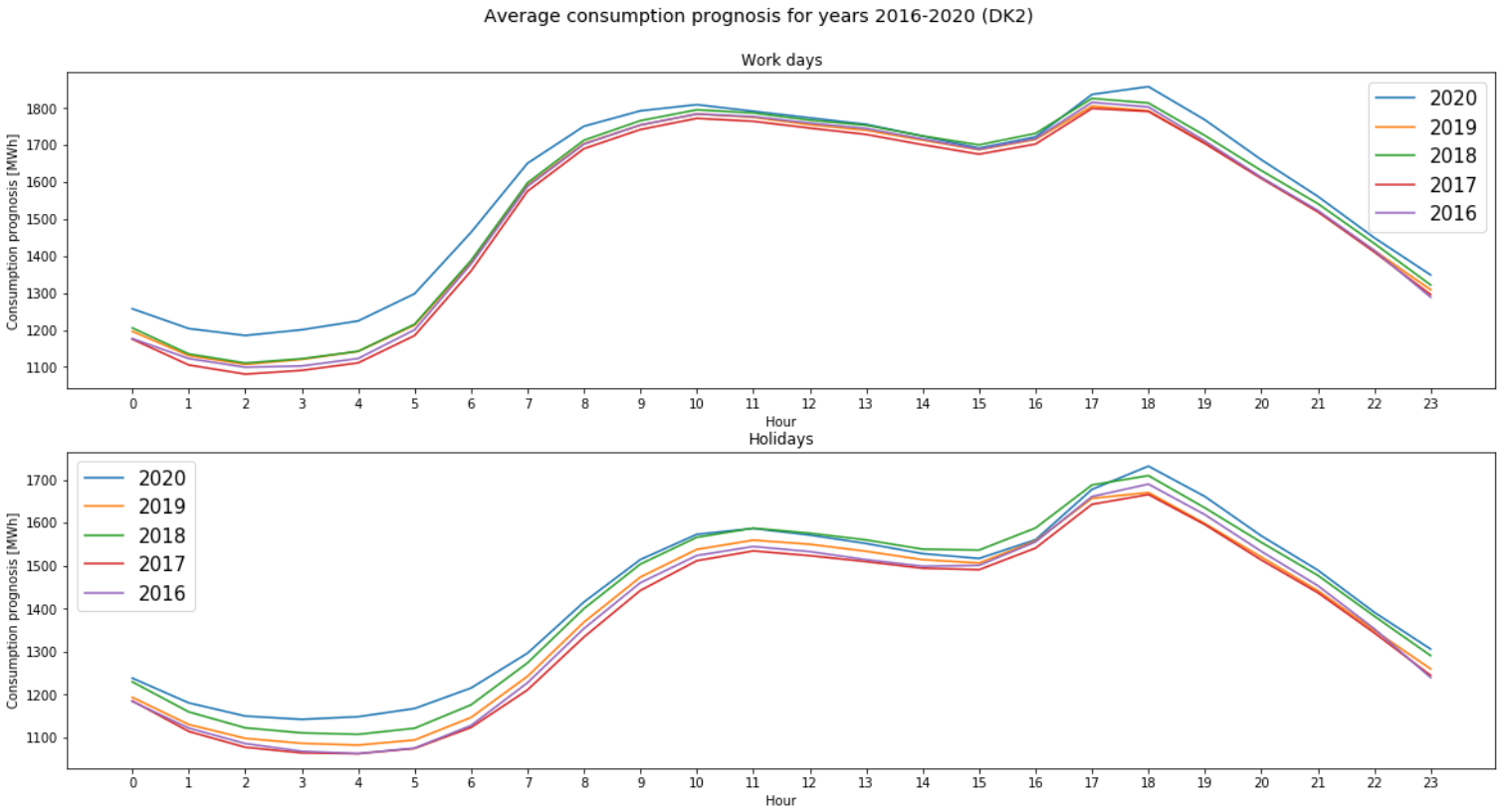
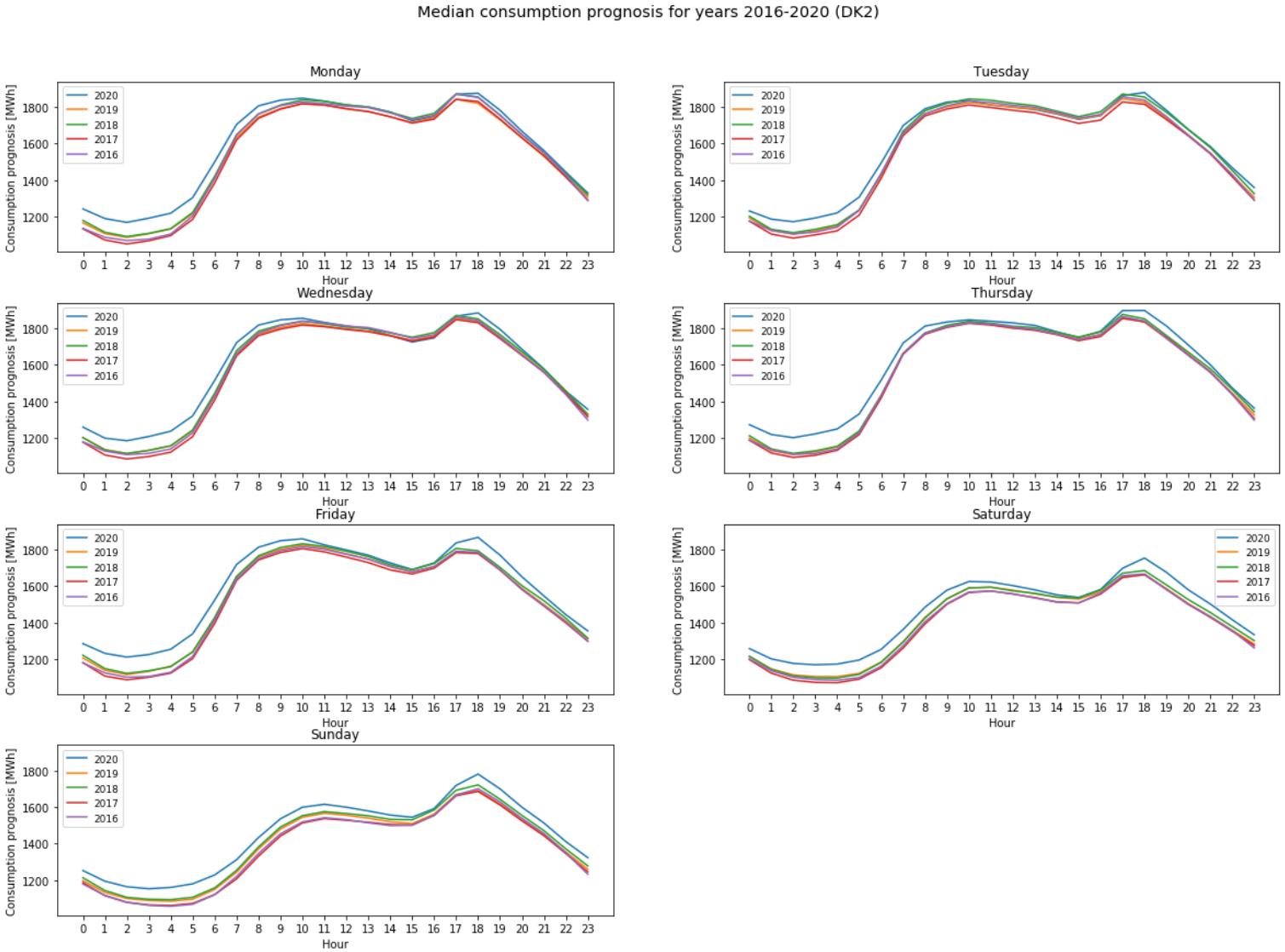

Average consumption prognosis for years 2016-2020 (DK2)
Work days
Consumption prognosis [MWh]
Hour
2020
2019
2018
2017
2016
Holidays
Consumption prognosis [MWh]
Hour
2020
2019
2018
2017
2016

Figure 30:


Median consumption prognosis for years 2016-2020 (DK2)
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Consumption prognosis [MWh]
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Figure 31:

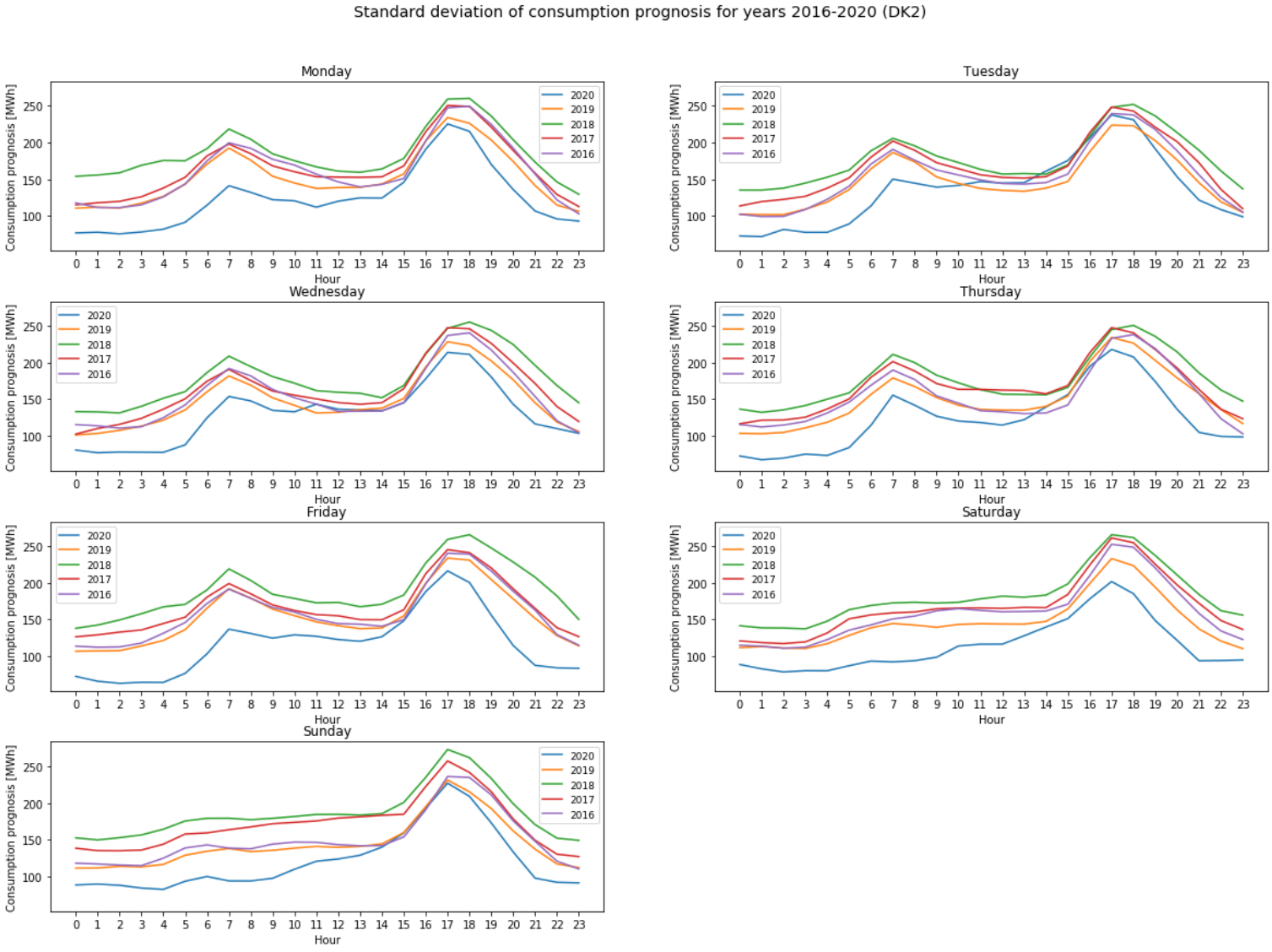


Figure 32:

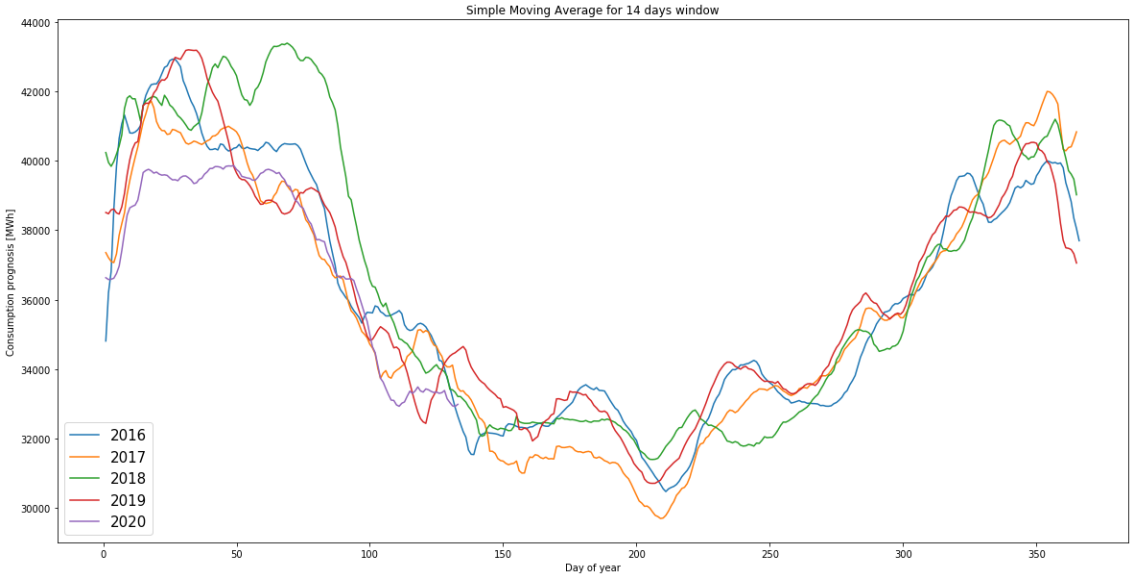


Figure 33:

3.1.2 Load data prognosis metrics

$$RMSE_t = \sqrt{\frac{1}{24}\sum_h (y_{t,h} - \hat{y}_{t,h})^2} \tag{1}$$

$$RMSE_h = \sqrt{\frac{1}{T}\sum_t (y_{t,h} - \hat{y}_{t,h})^2} \tag{2}$$

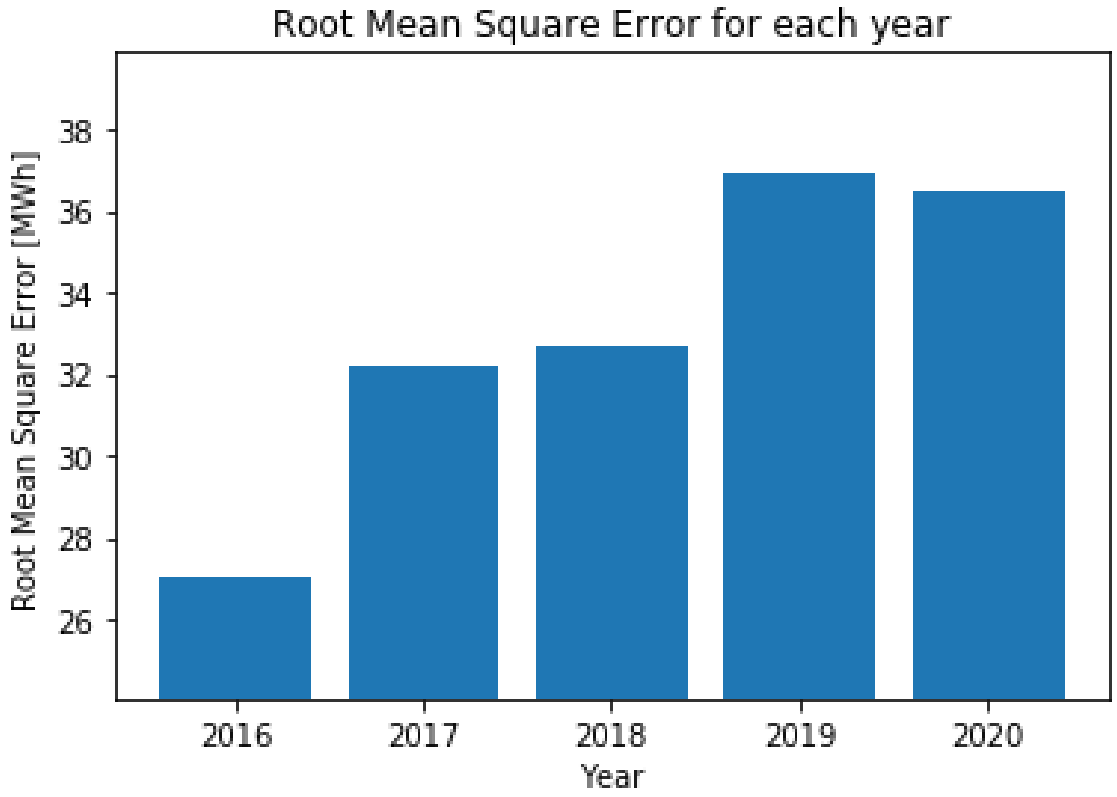


Figure 34:

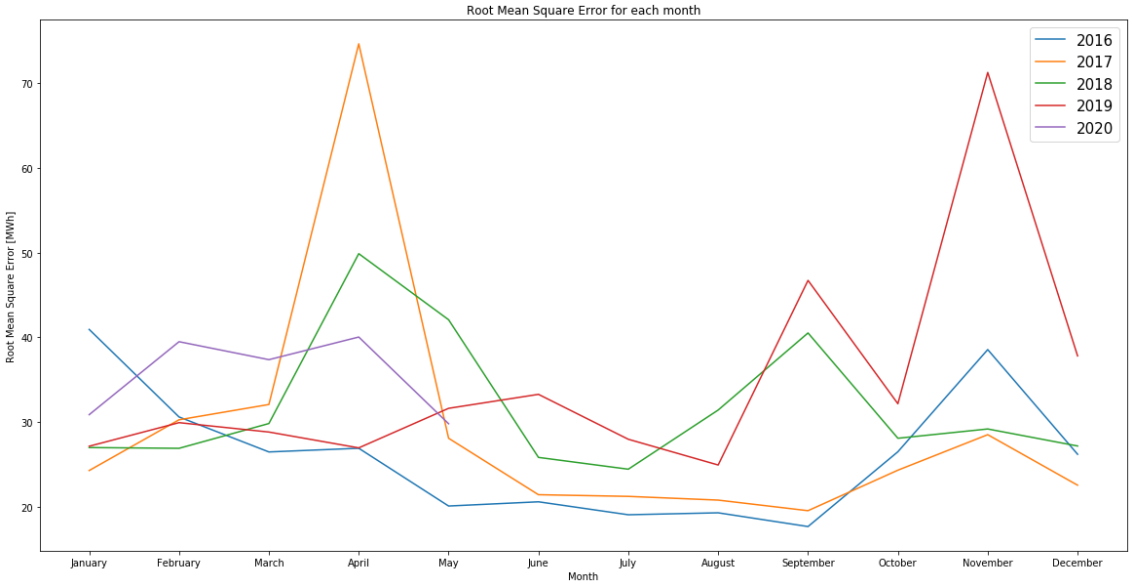
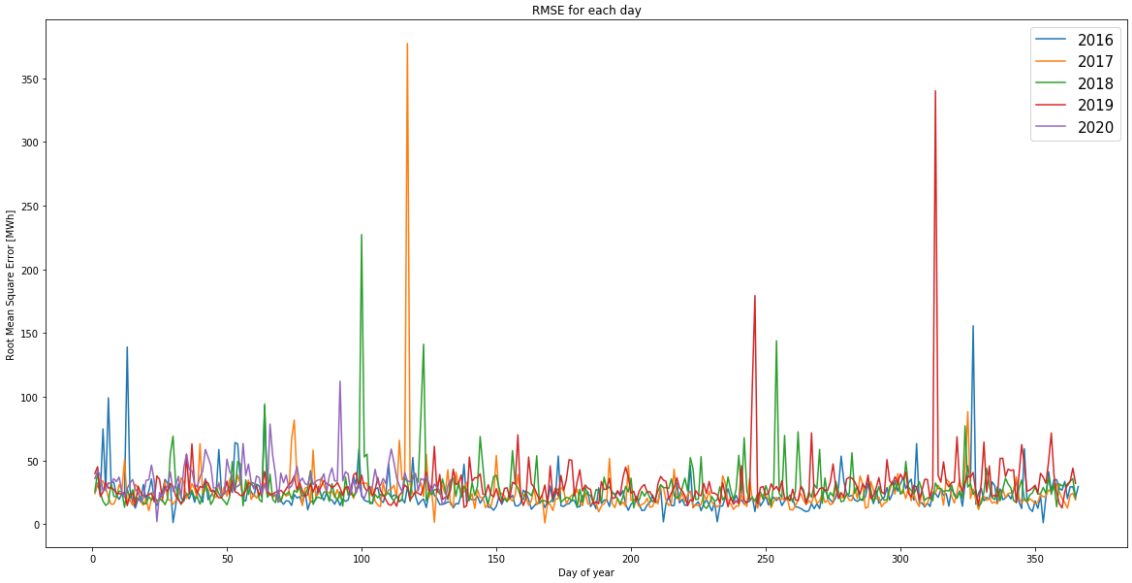


Figure 35:



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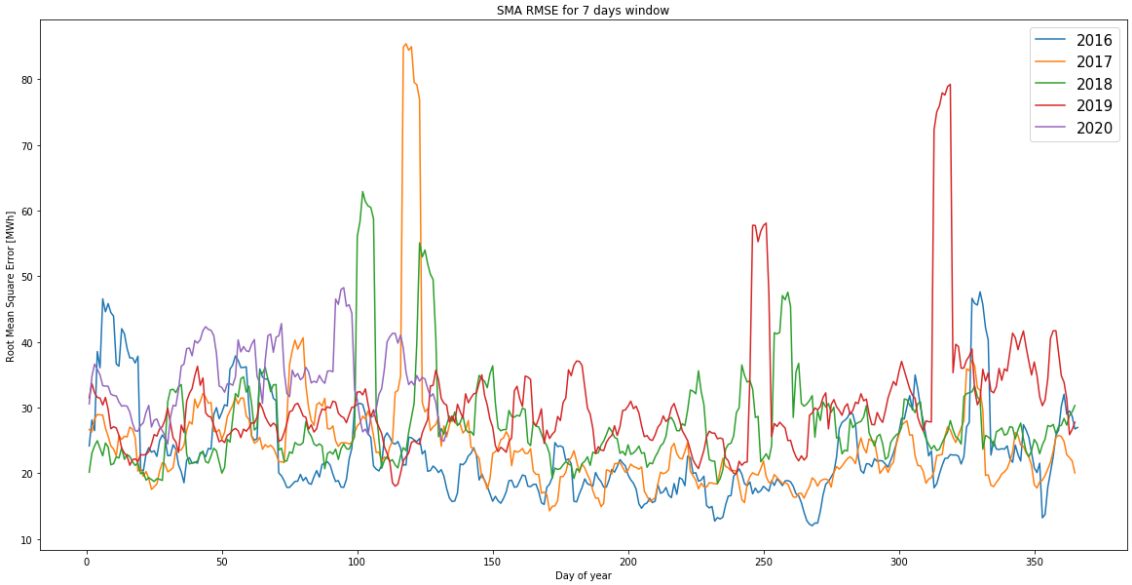

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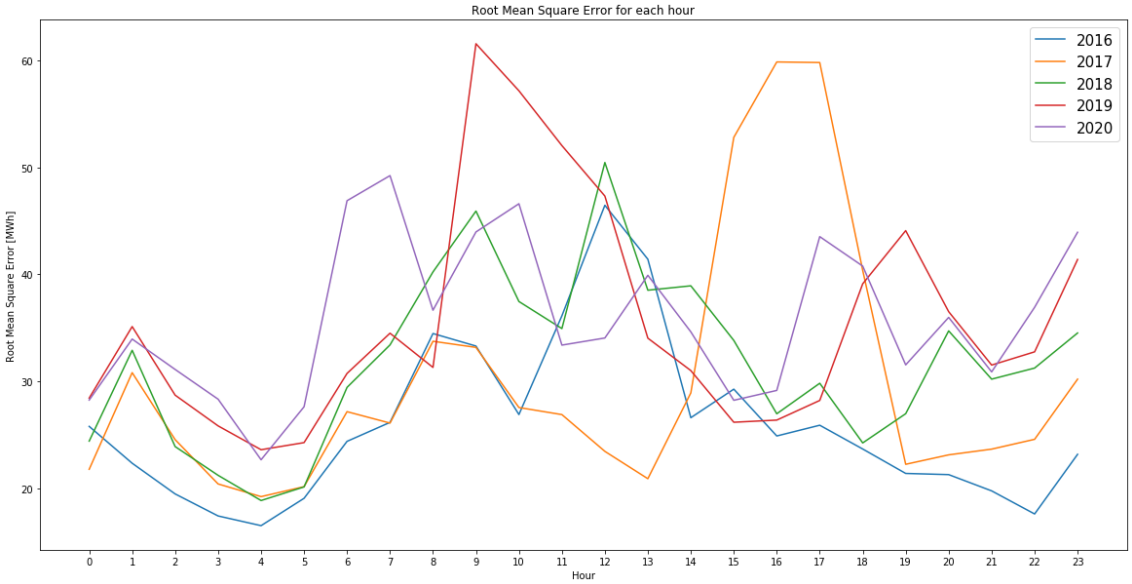


Figure 38:

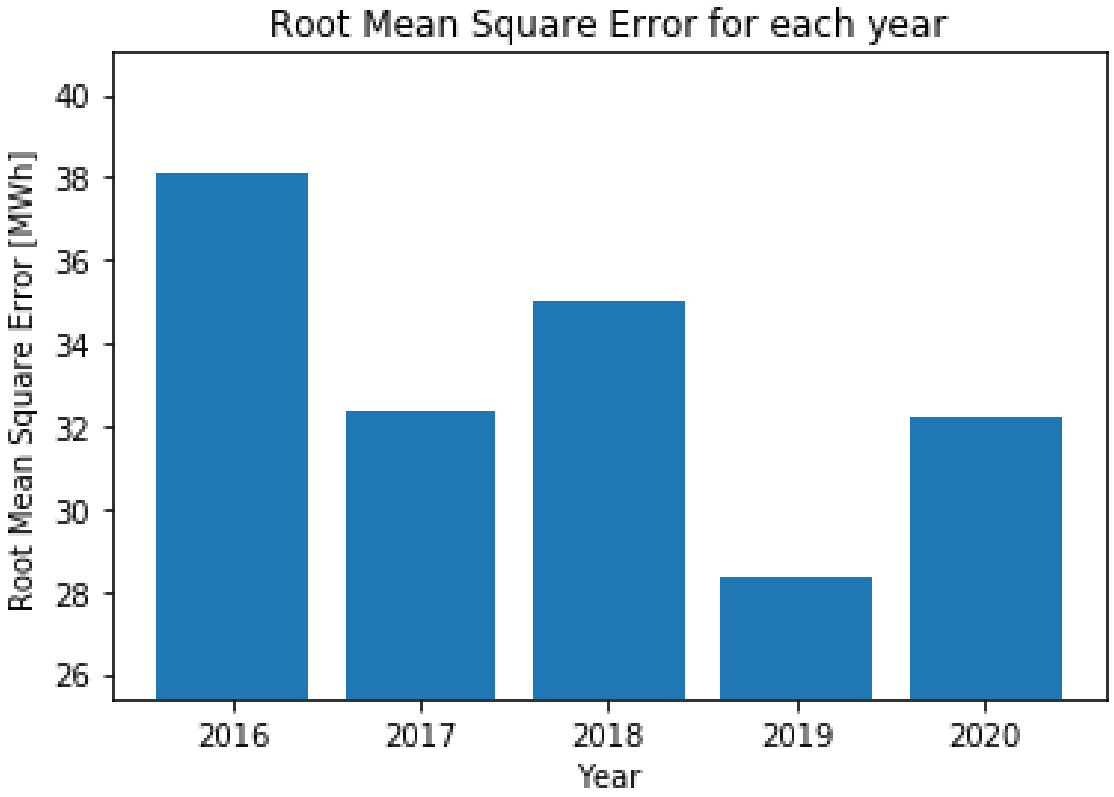


Figure 39:

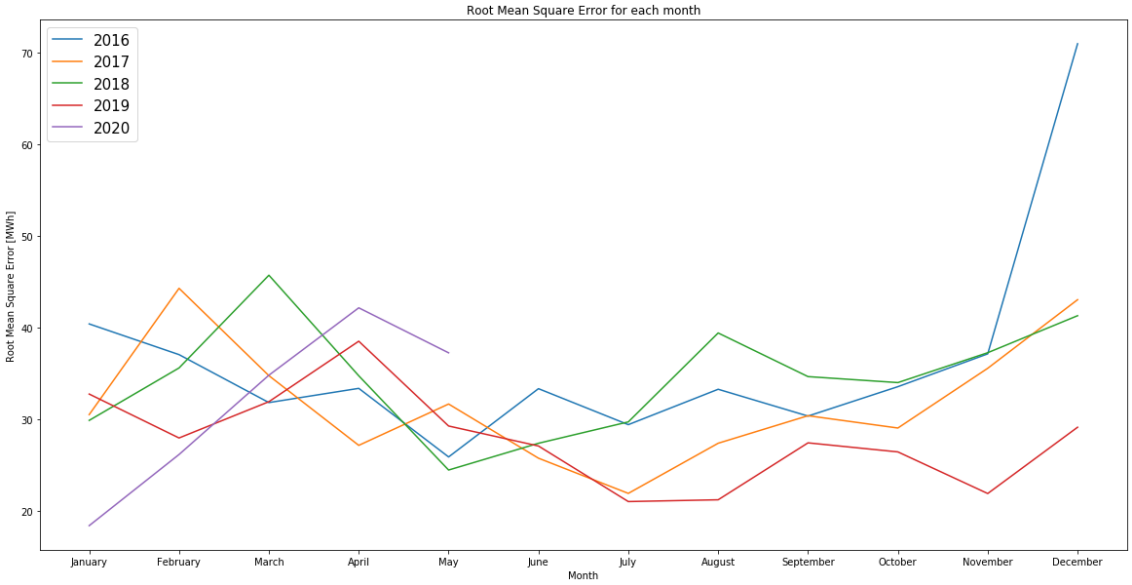


Figure 40:

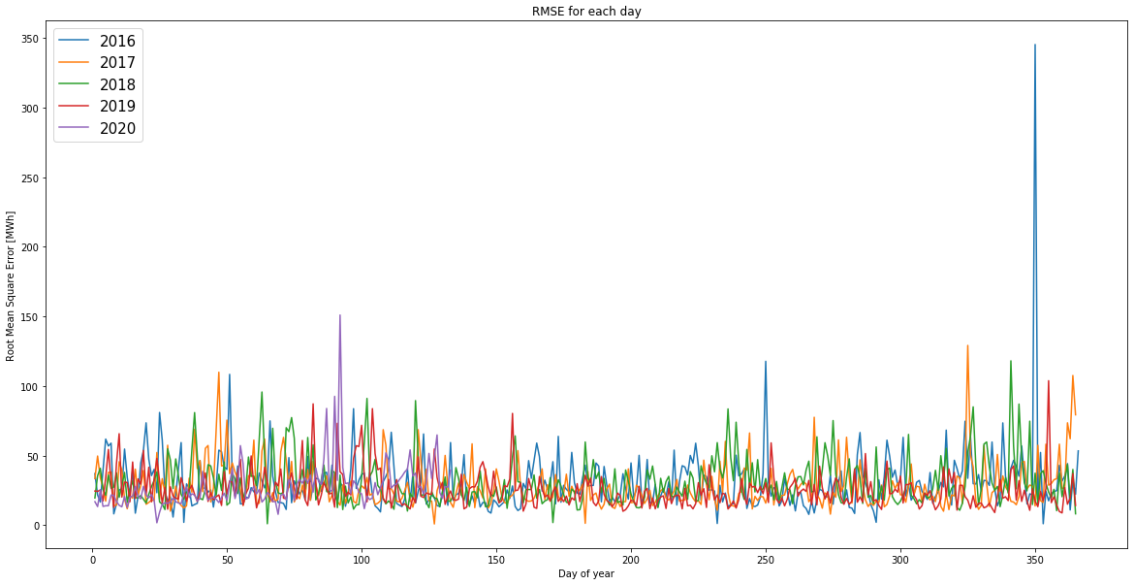


Figure 41:

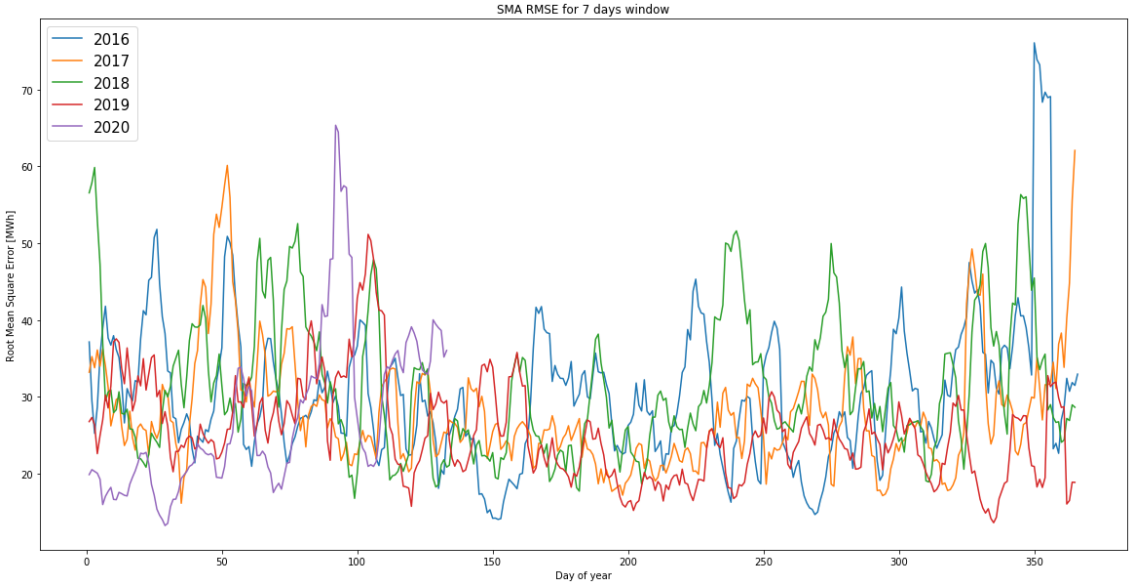


Figure 42:

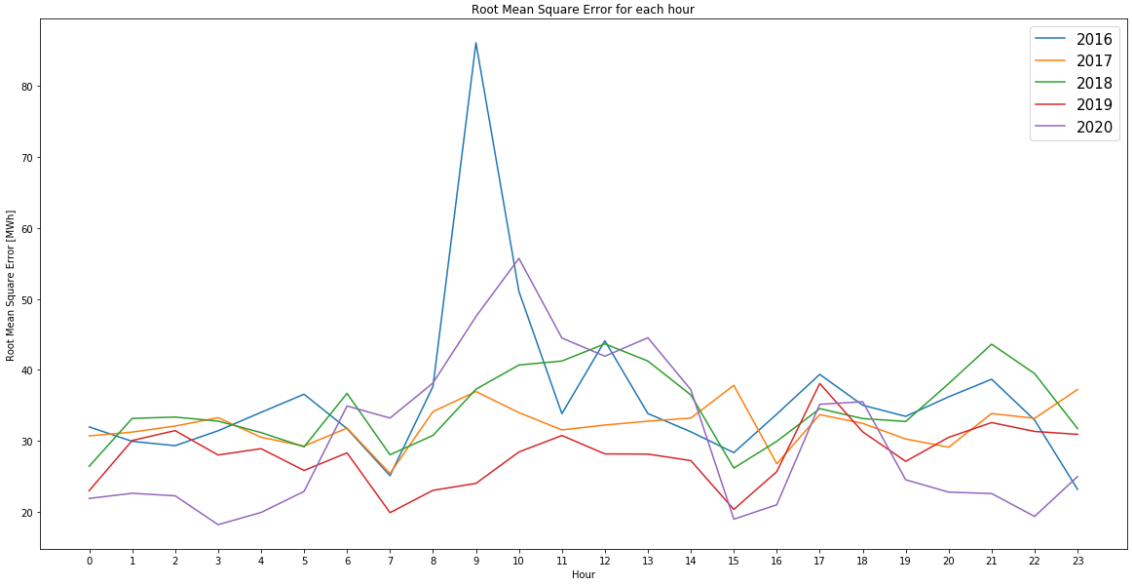


Figure 43:

3.2 Wind power data

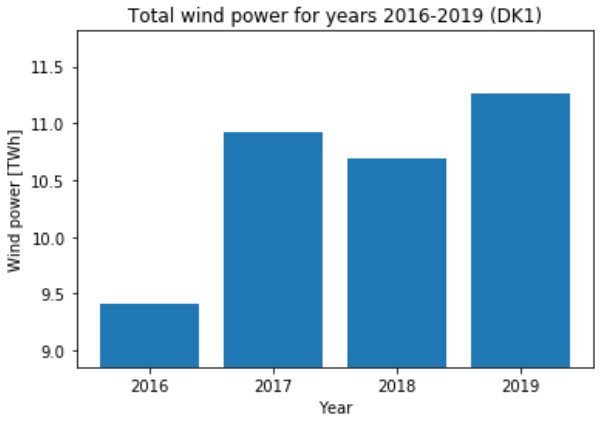


Figure 44:

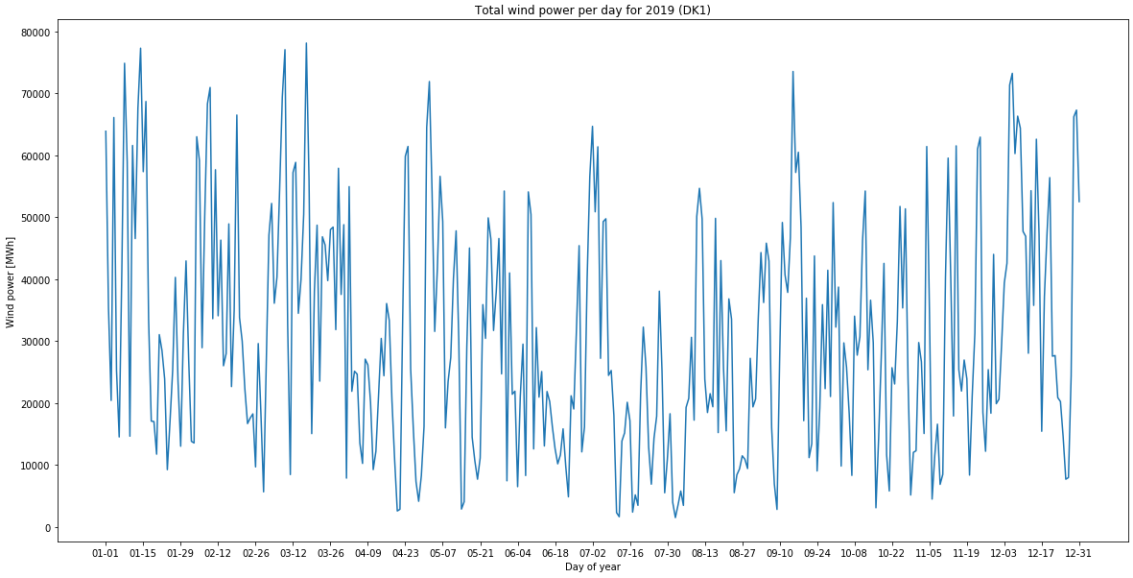


Figure 45:

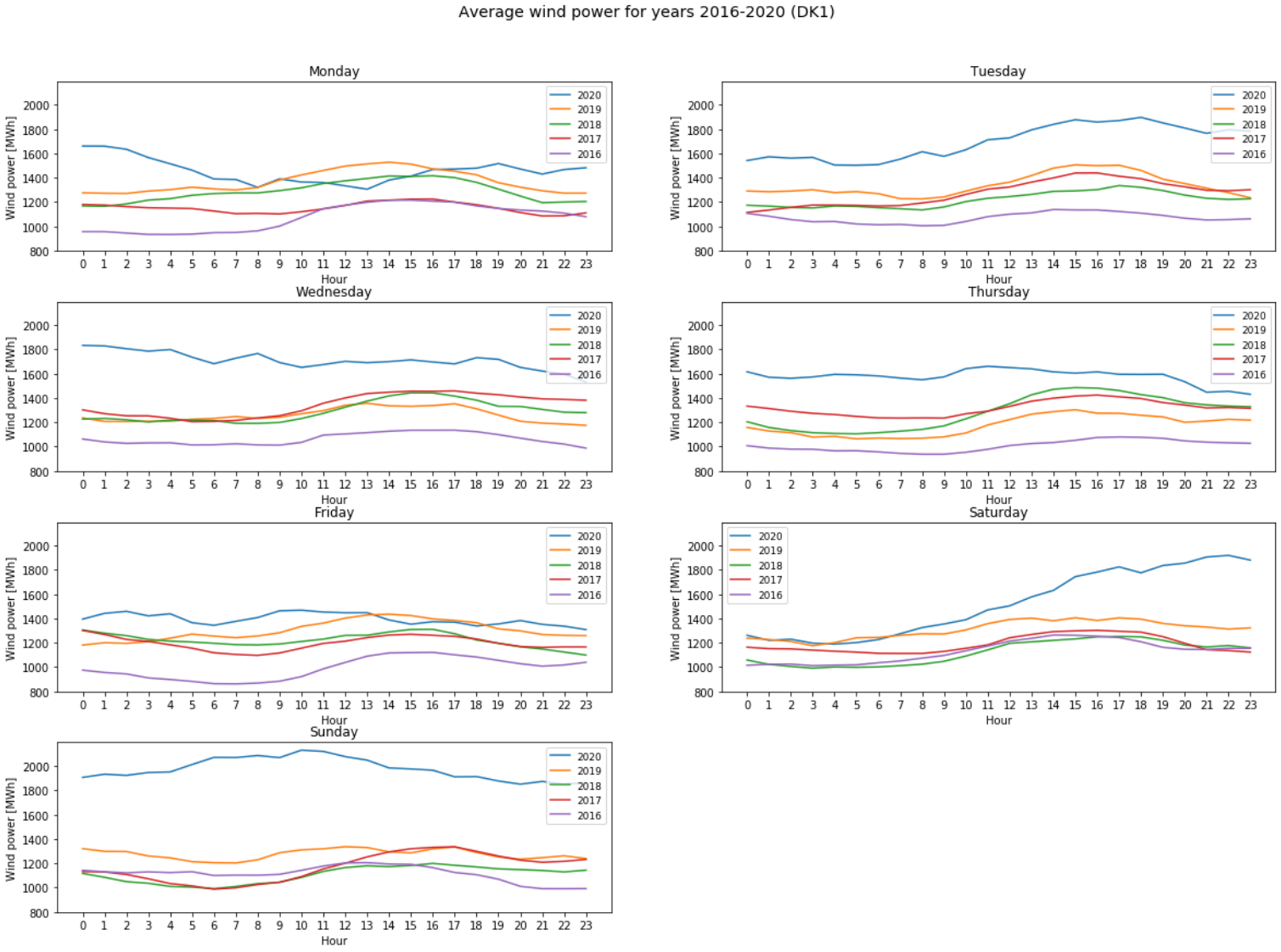


Figure 46:

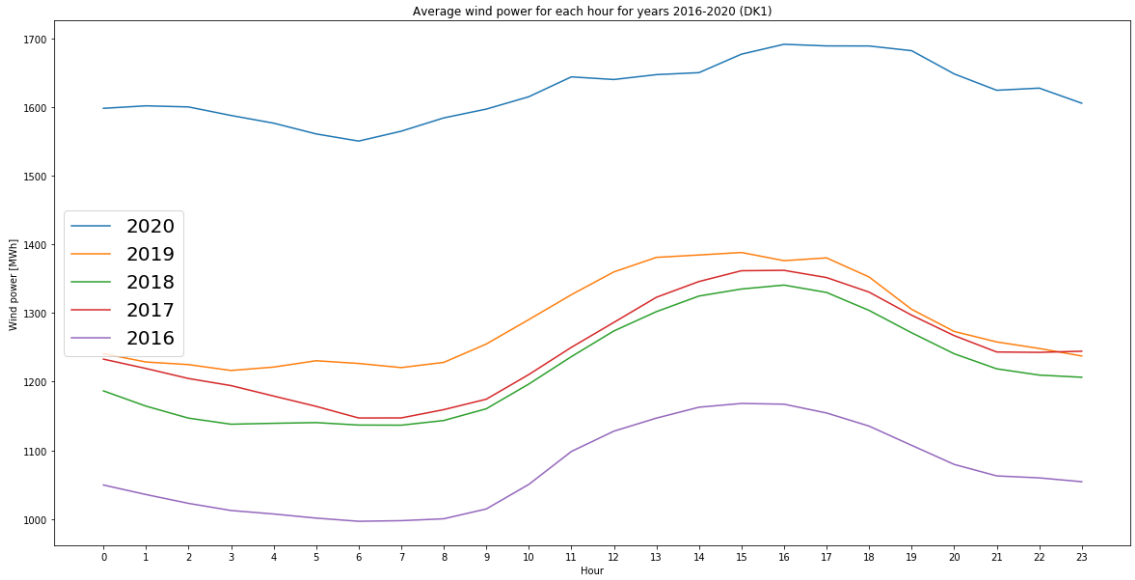
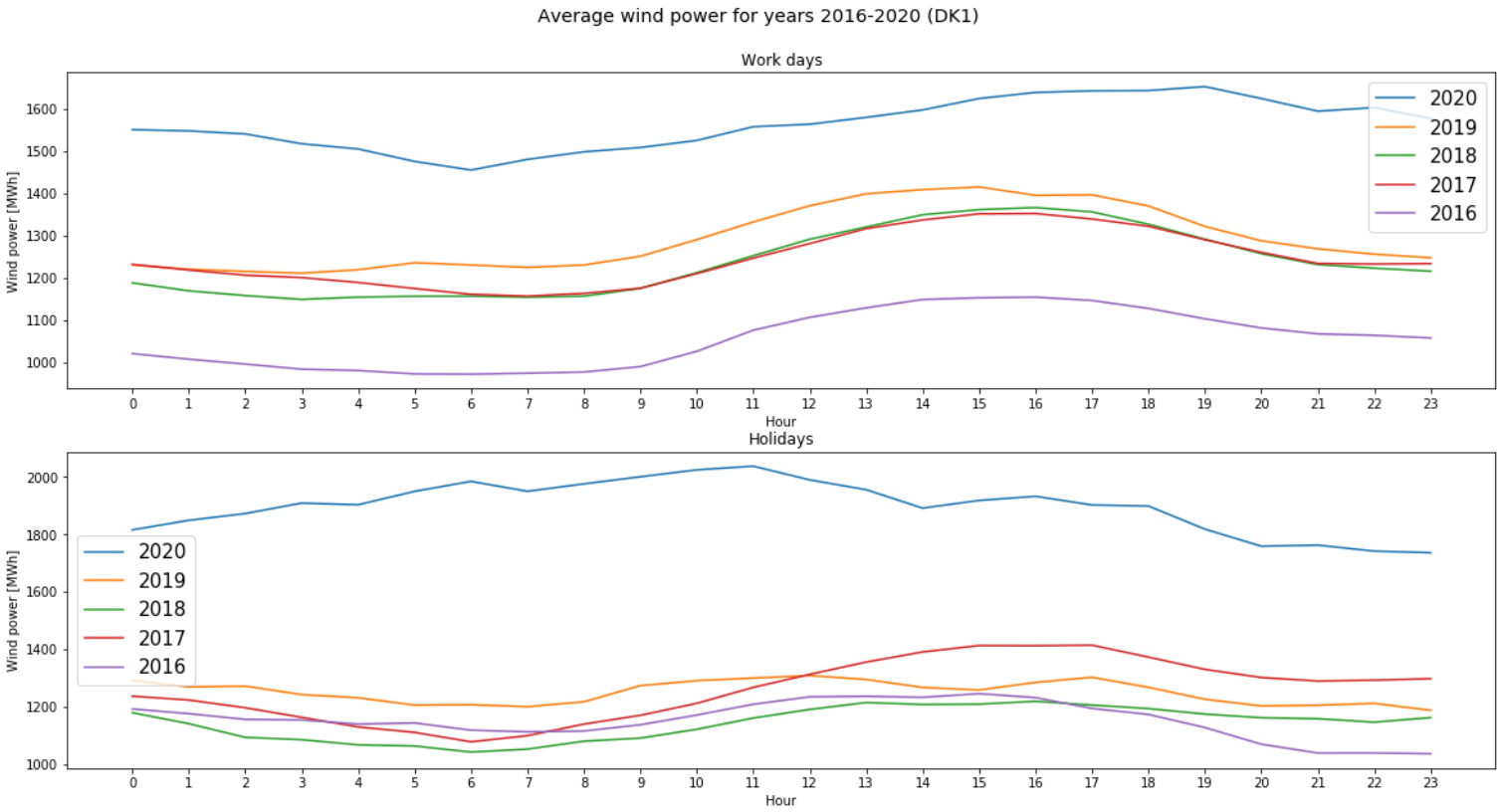


Figure 47:


Average wind power for years 2016-2020 (DK1)
Work days
Wind power [MWh]
Hour
2020
2019
2018
2017
2016
Holidays
Wind power [MWh]
Hour
2020
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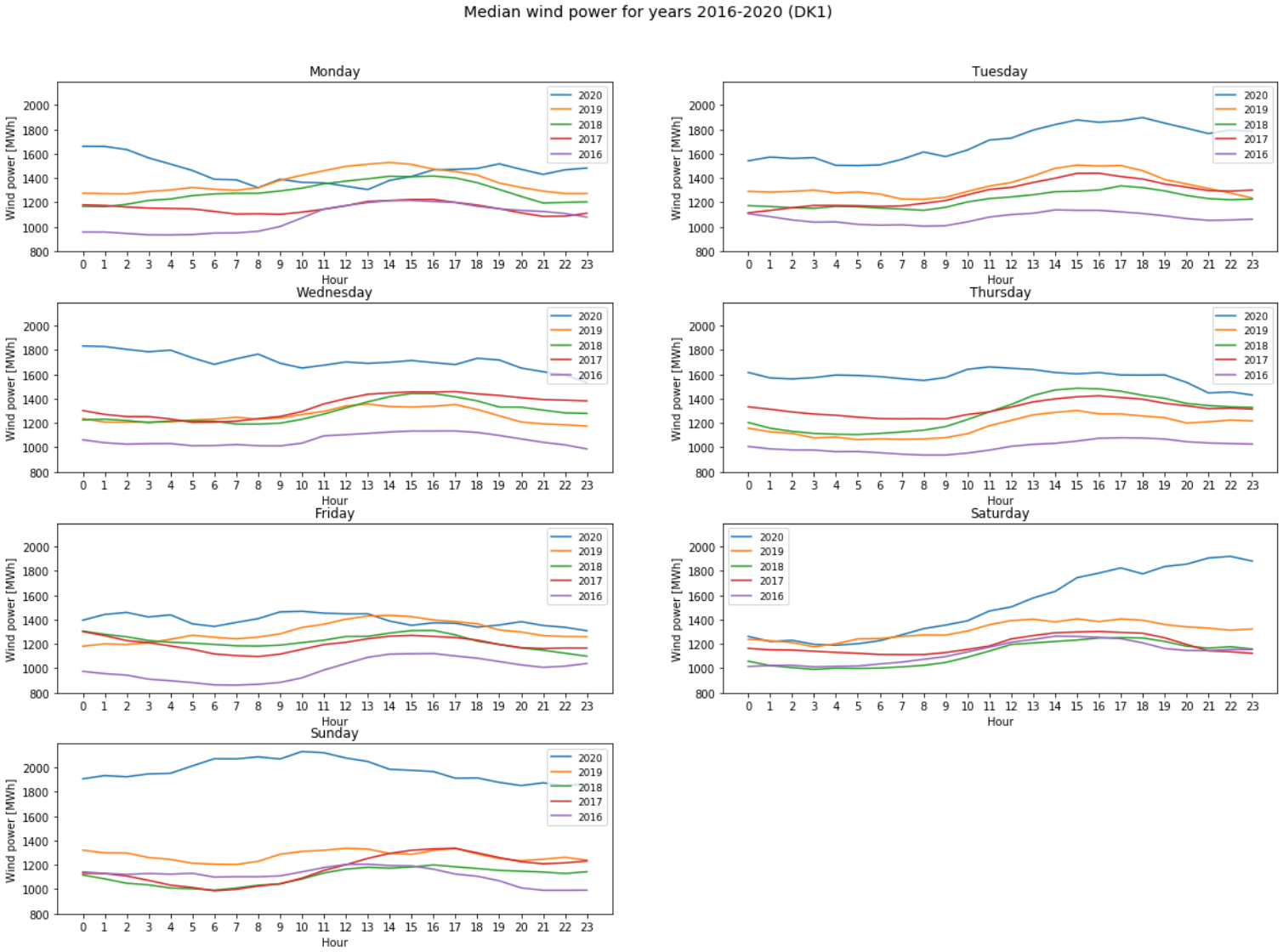
2017
2016

Figure 48: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Monday
Tuesday
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Wind power [MWh]
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Figure 49:

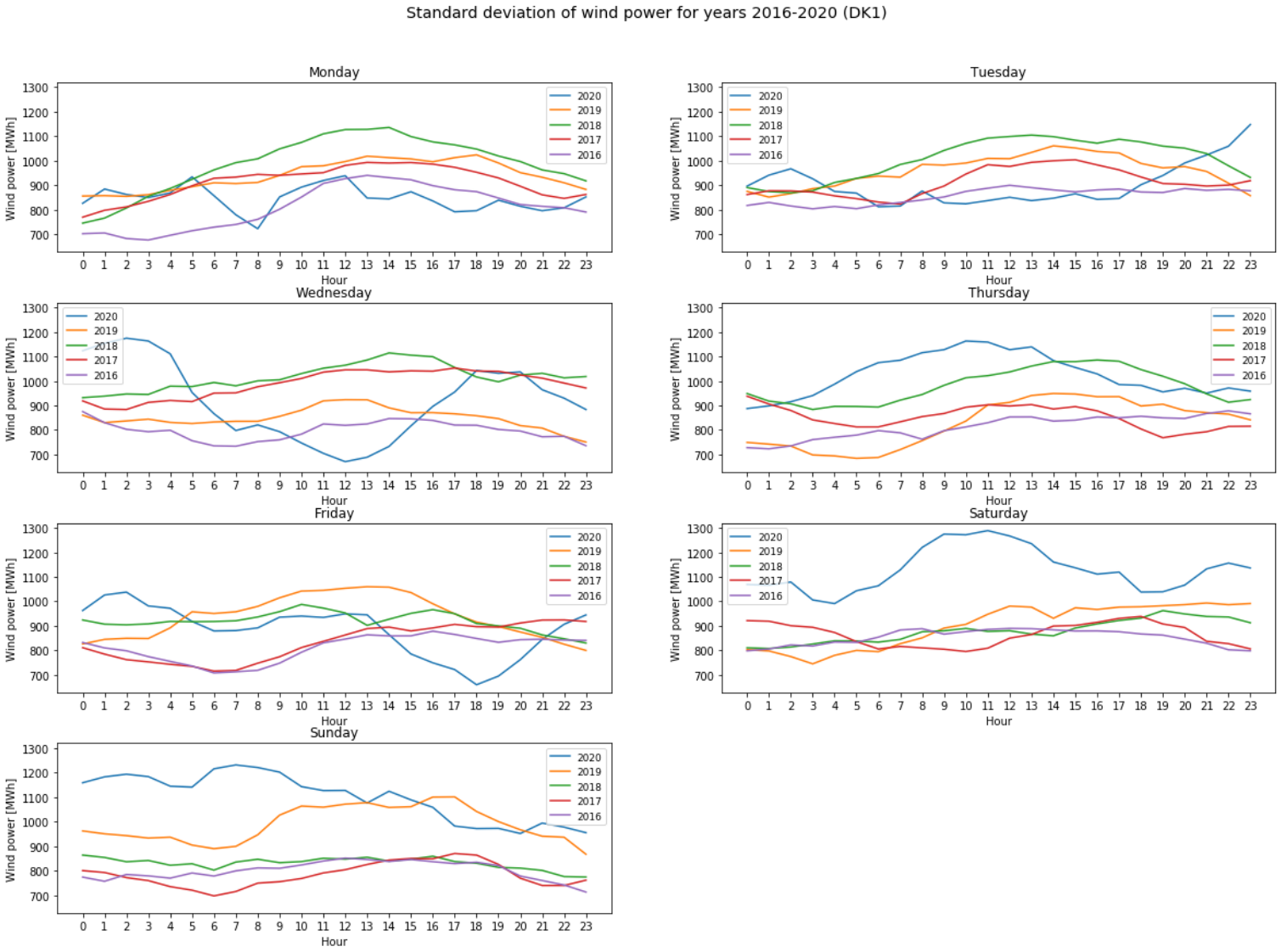


Figure 50:

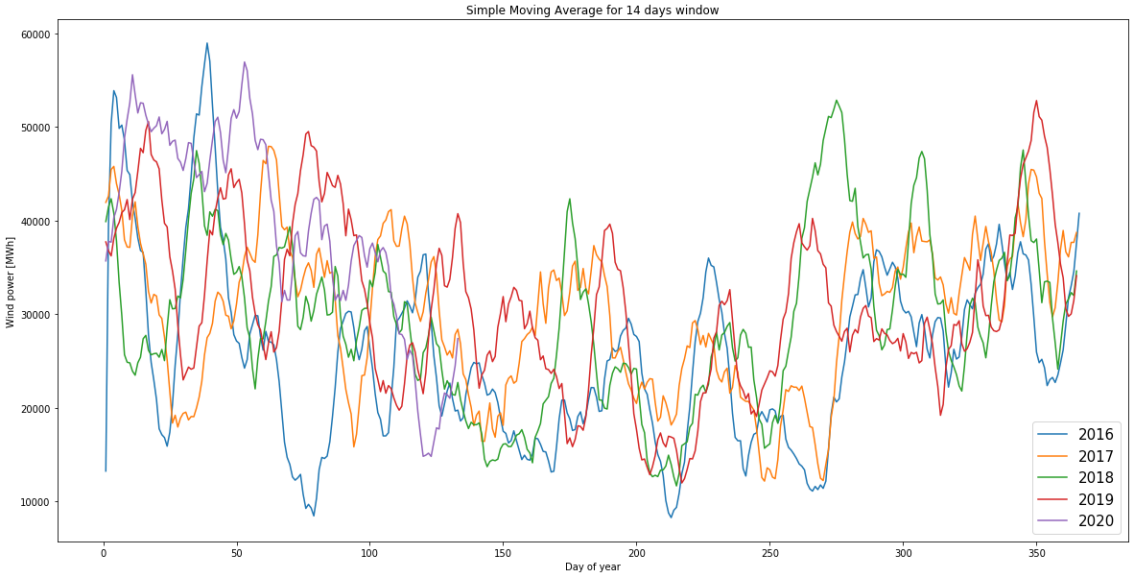
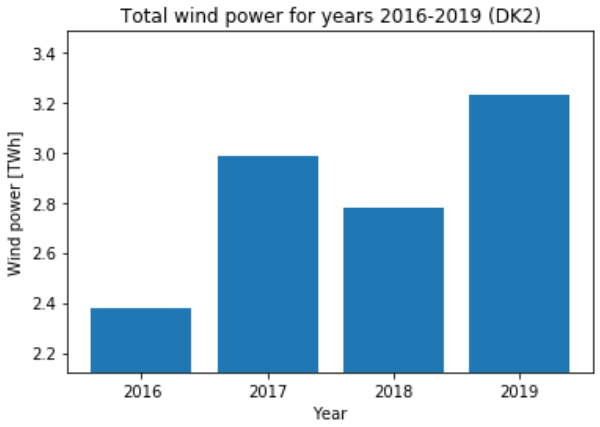


Figure 51:



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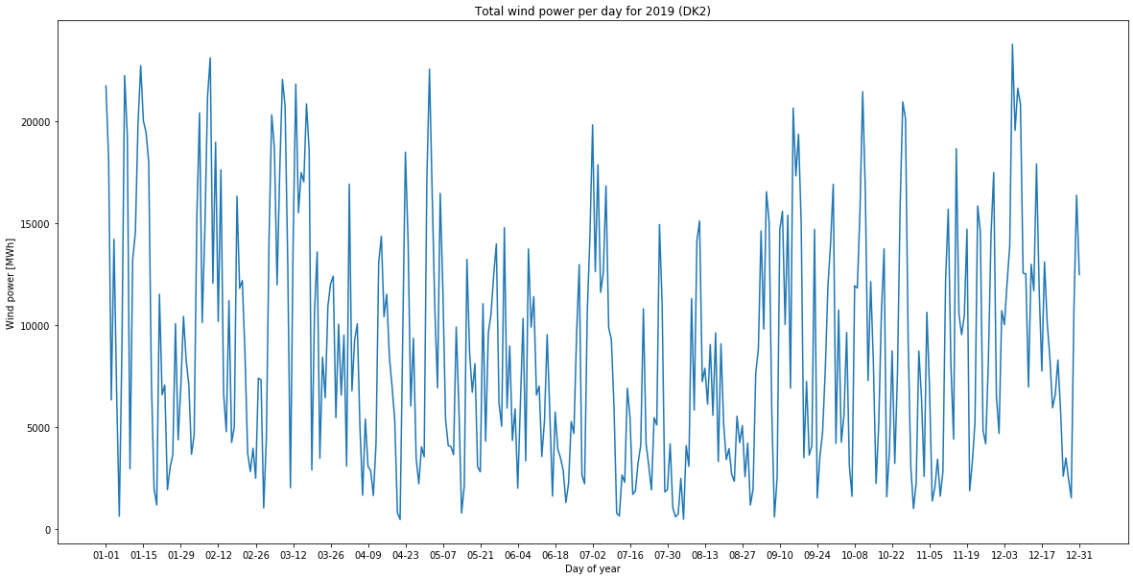

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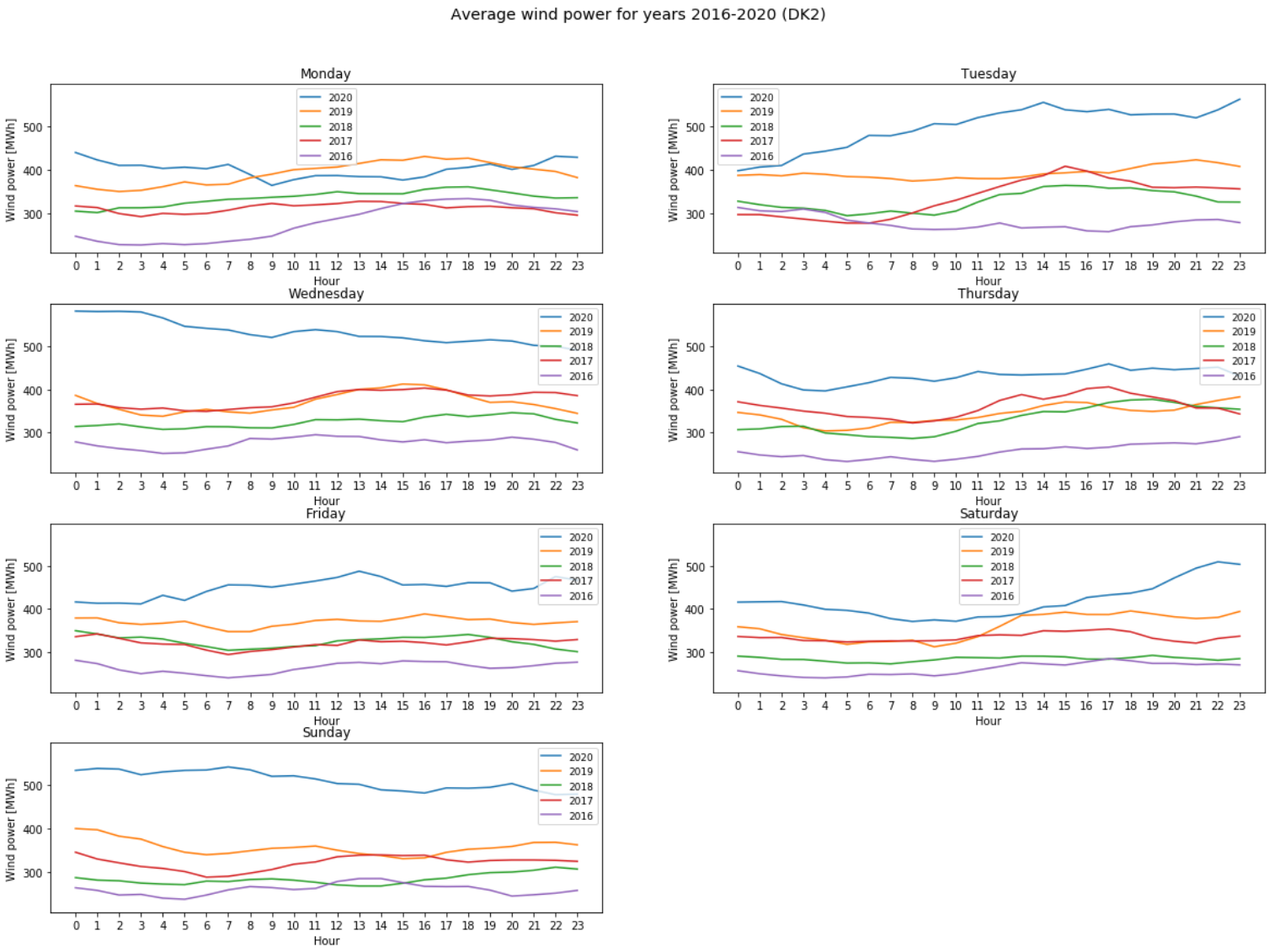

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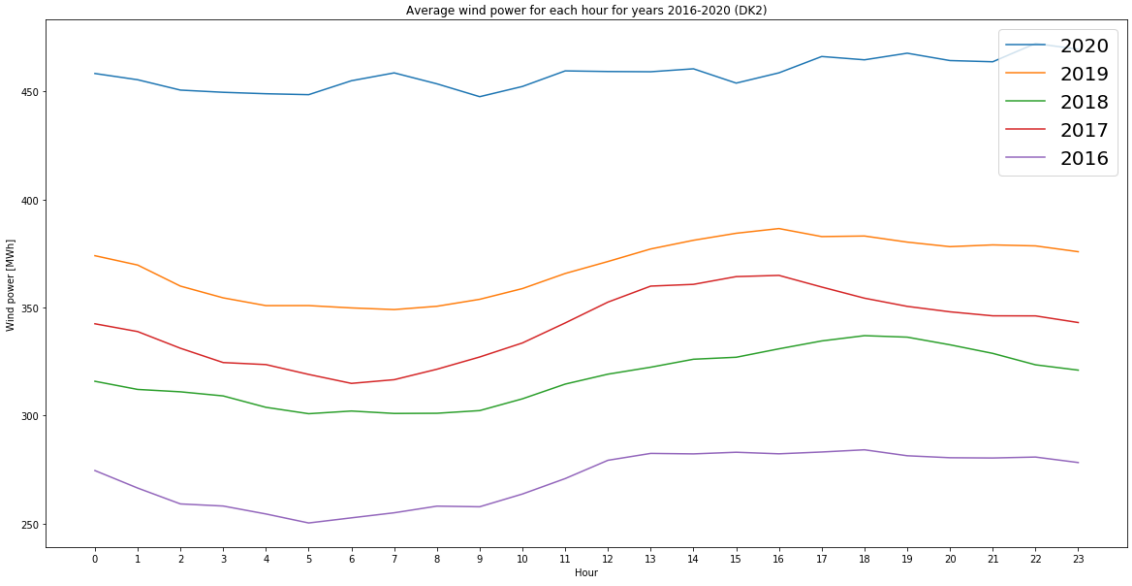

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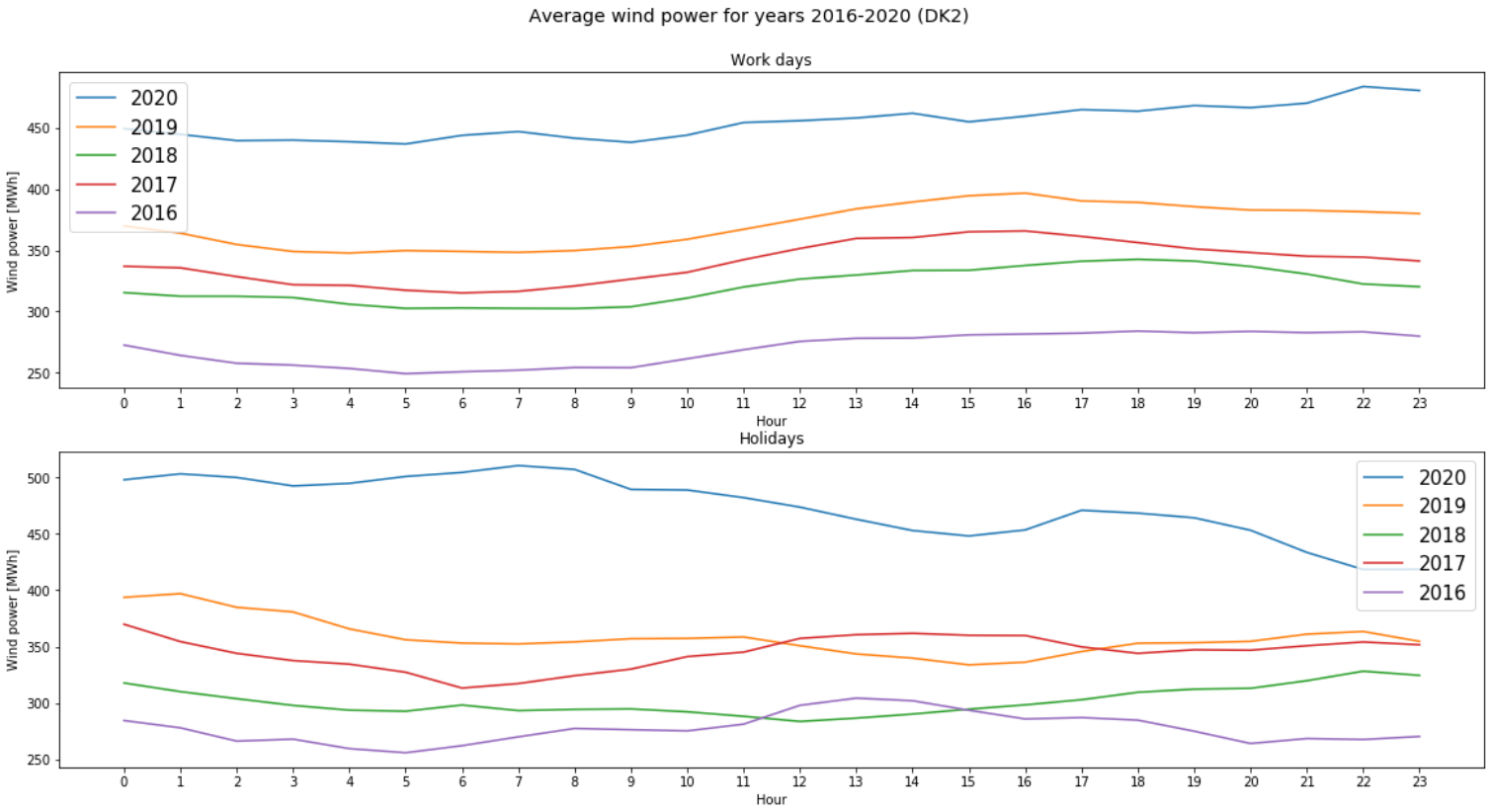

Average wind power for years 2016-2020 (DK2)
Work days
Wind power [MWh]
Hour
2020
2019
2018
2017
2016
Holidays
Wind power [MWh]
Hour
2020
2019
2018
2017
2016

Figure 56:

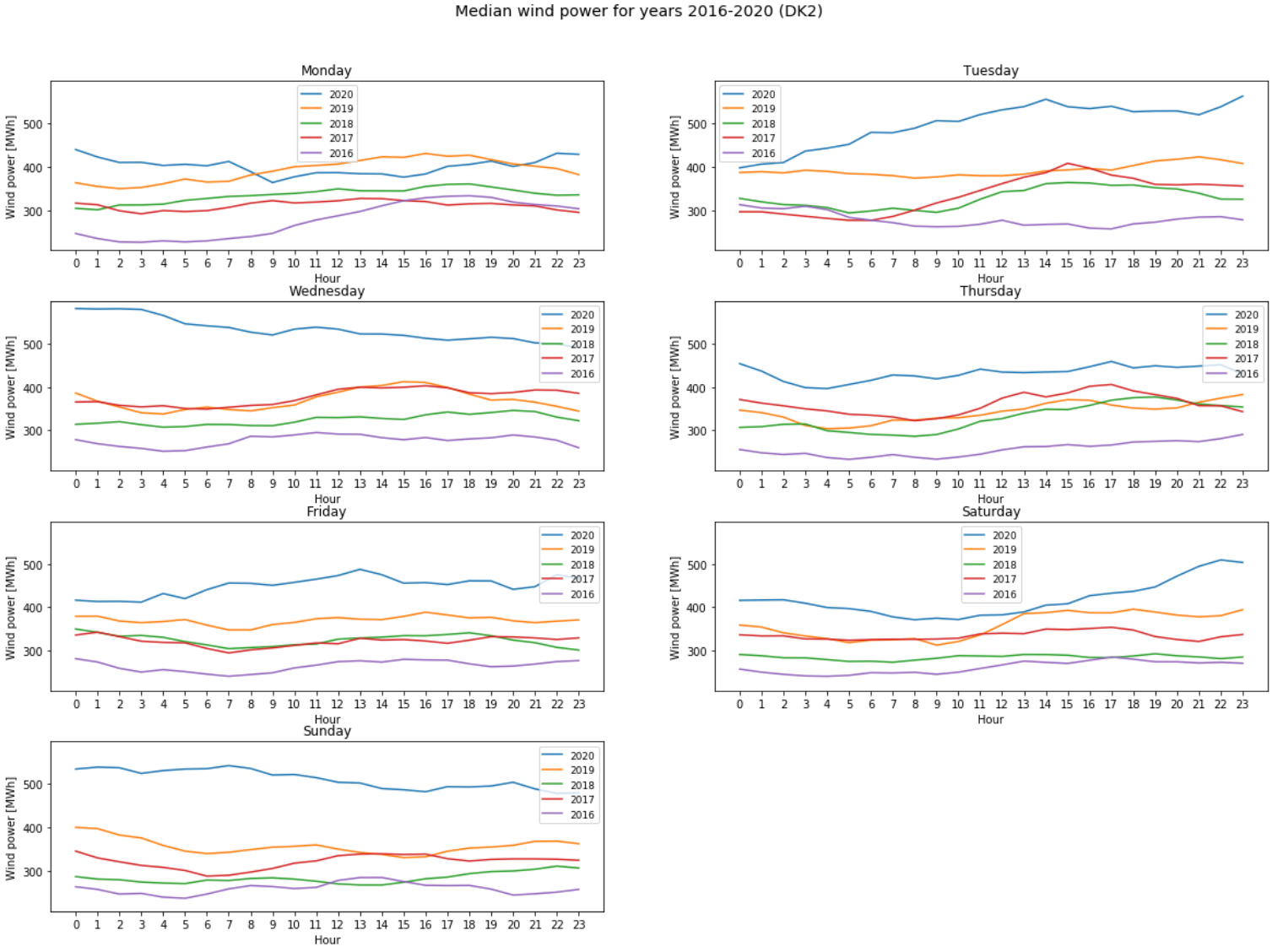
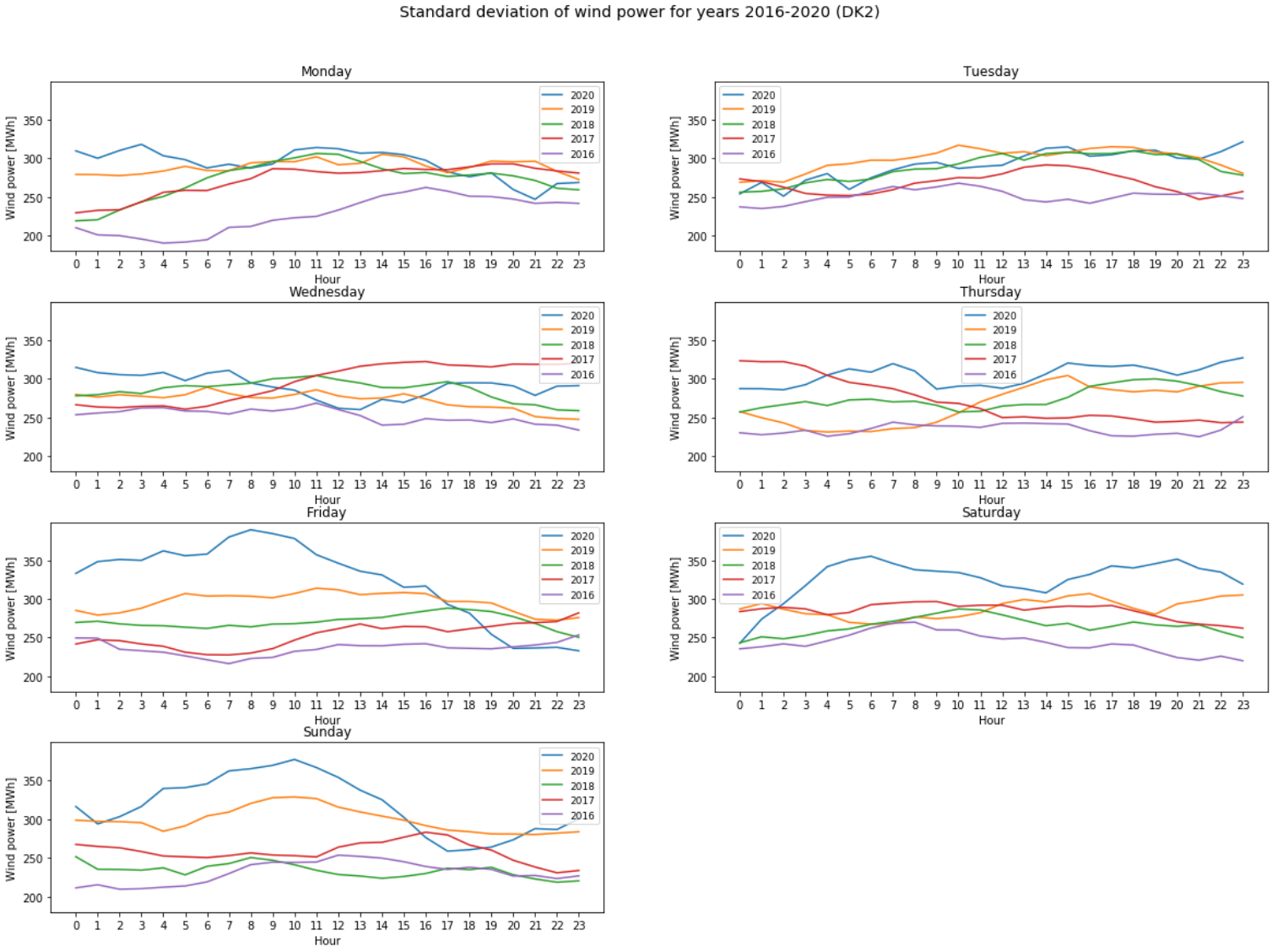

Median wind power for years 2016-2020 (DK2)
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Wind power [MWh]
Hour
2020
2019
2018
2017
2016

Figure 57:



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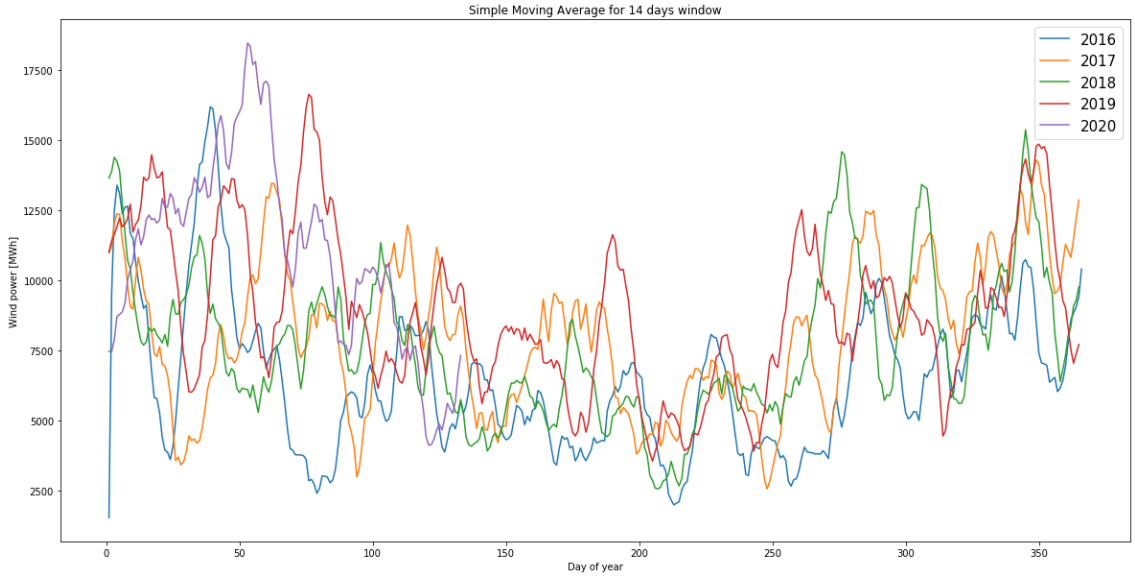
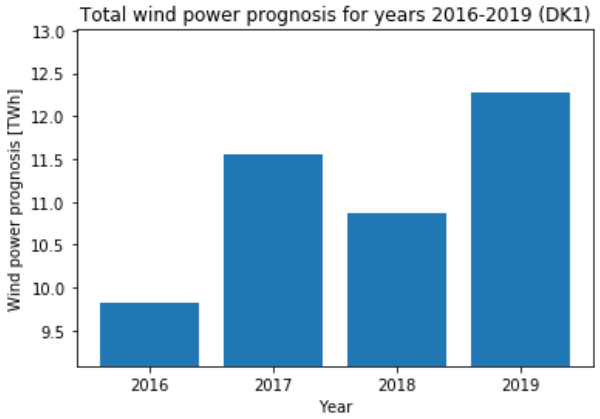


Figure 59:

3.2.1 Wind power data prognosis



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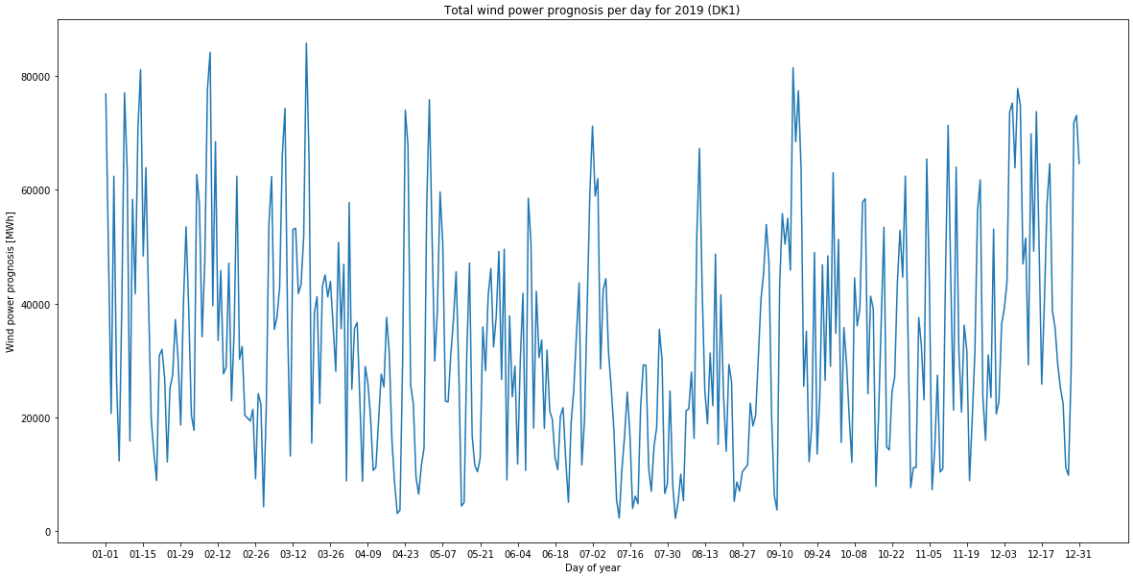


Figure 61:

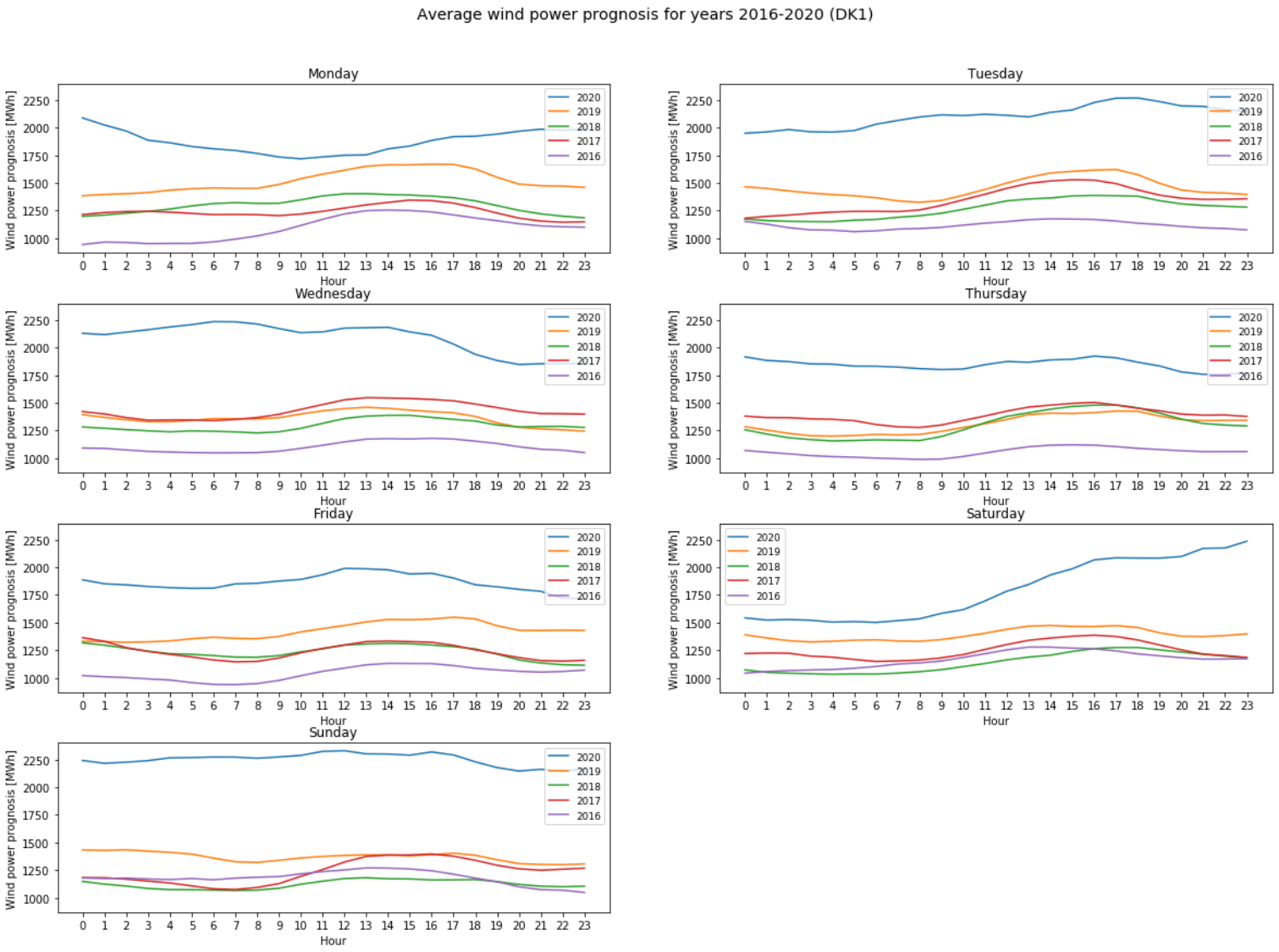


Figure 62:

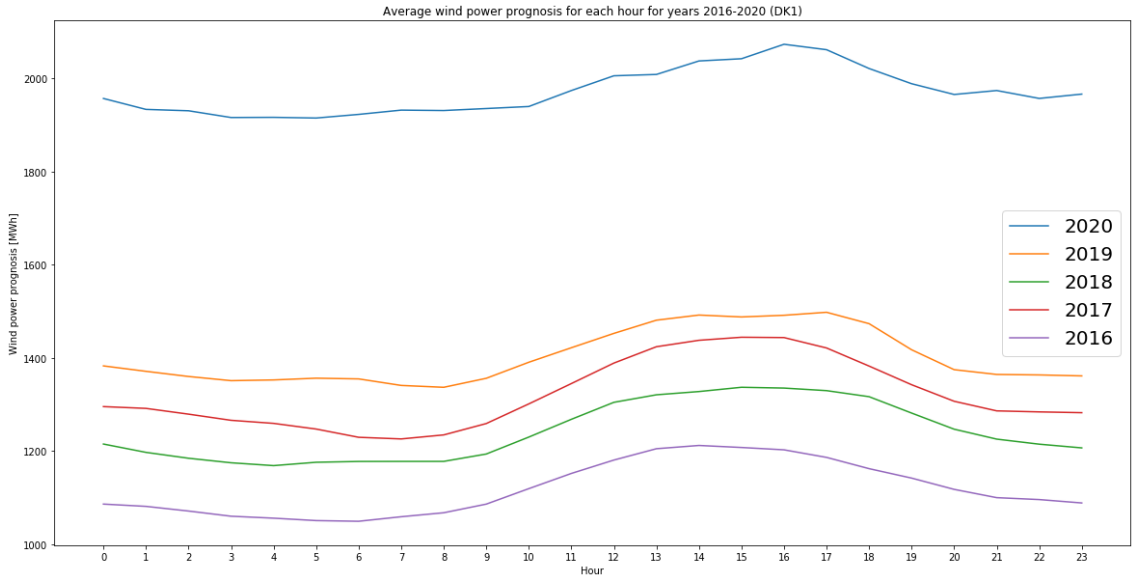


Figure 63:

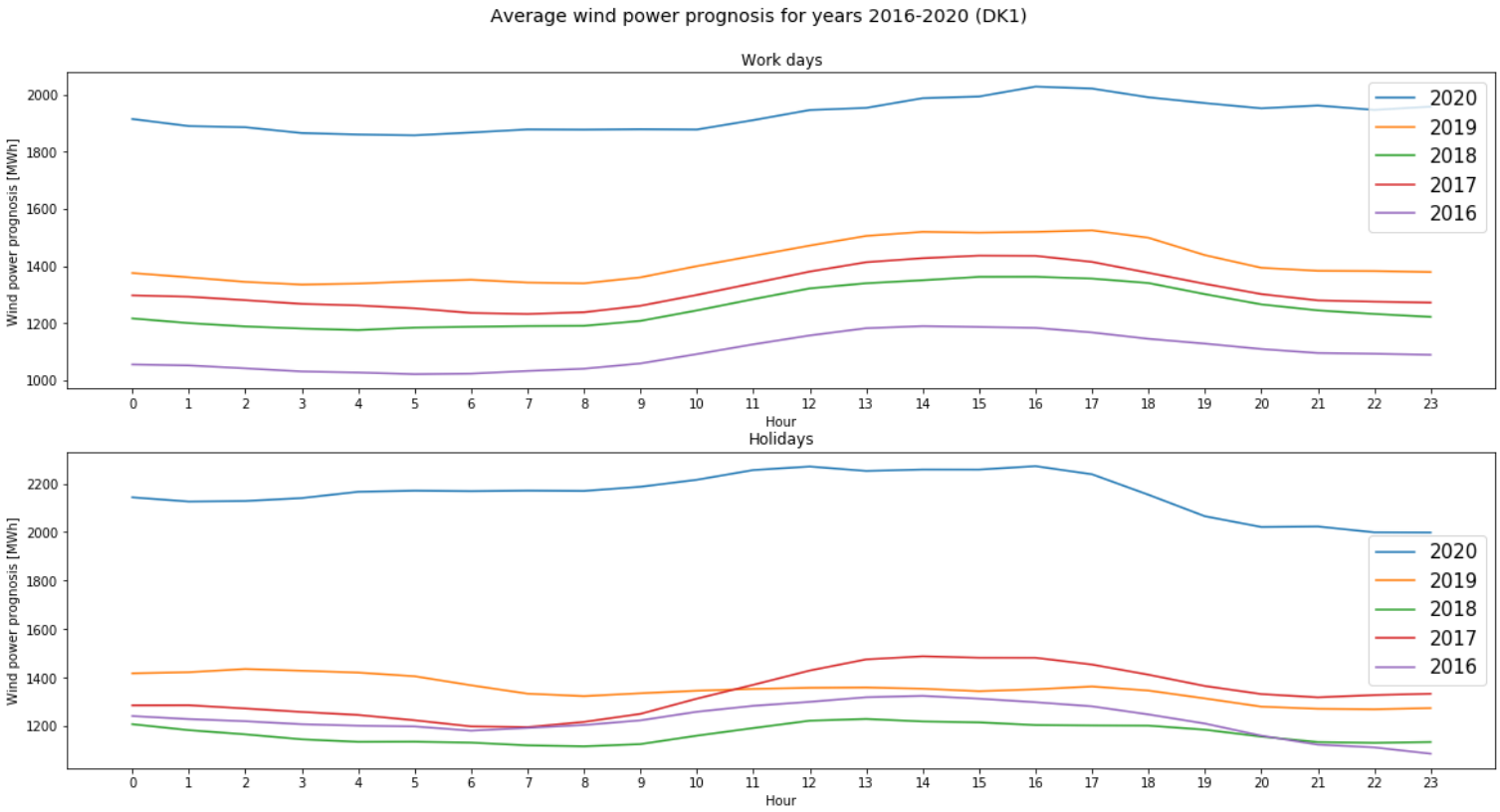

Average wind power prognosis for years 2016-2020 (DK1)
Work days
Wind power prognosis [MWh]
Hour
Holidays
Wind power prognosis [MWh]
Hour
2020
2019
2018
2017
2016

Figure 64:

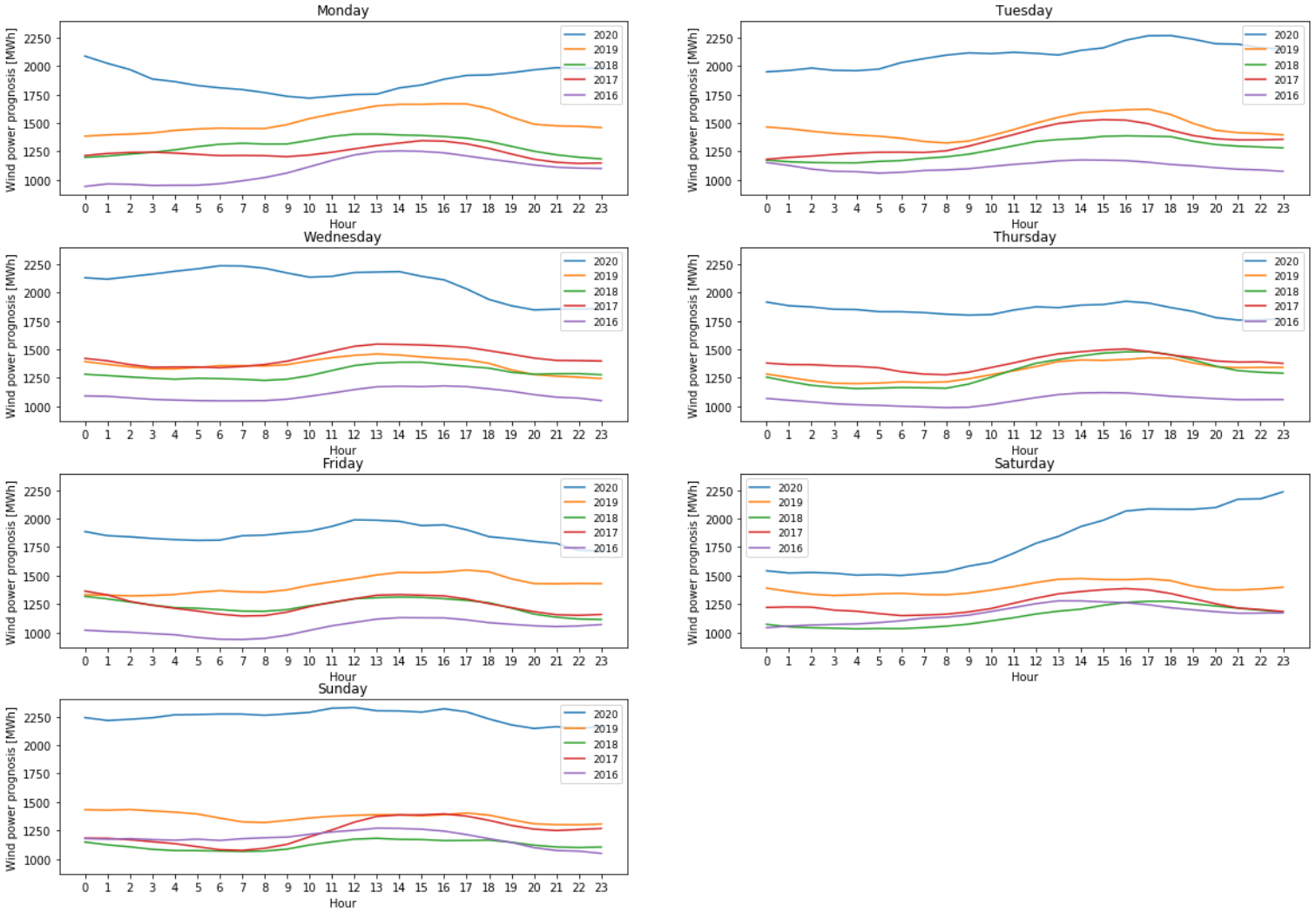

Median wind power prognosis for years 2016-2020 (DK1)
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Wind power prognosis [MWh]
Hour
2020
2019
2018
2017
2016

Figure 65:

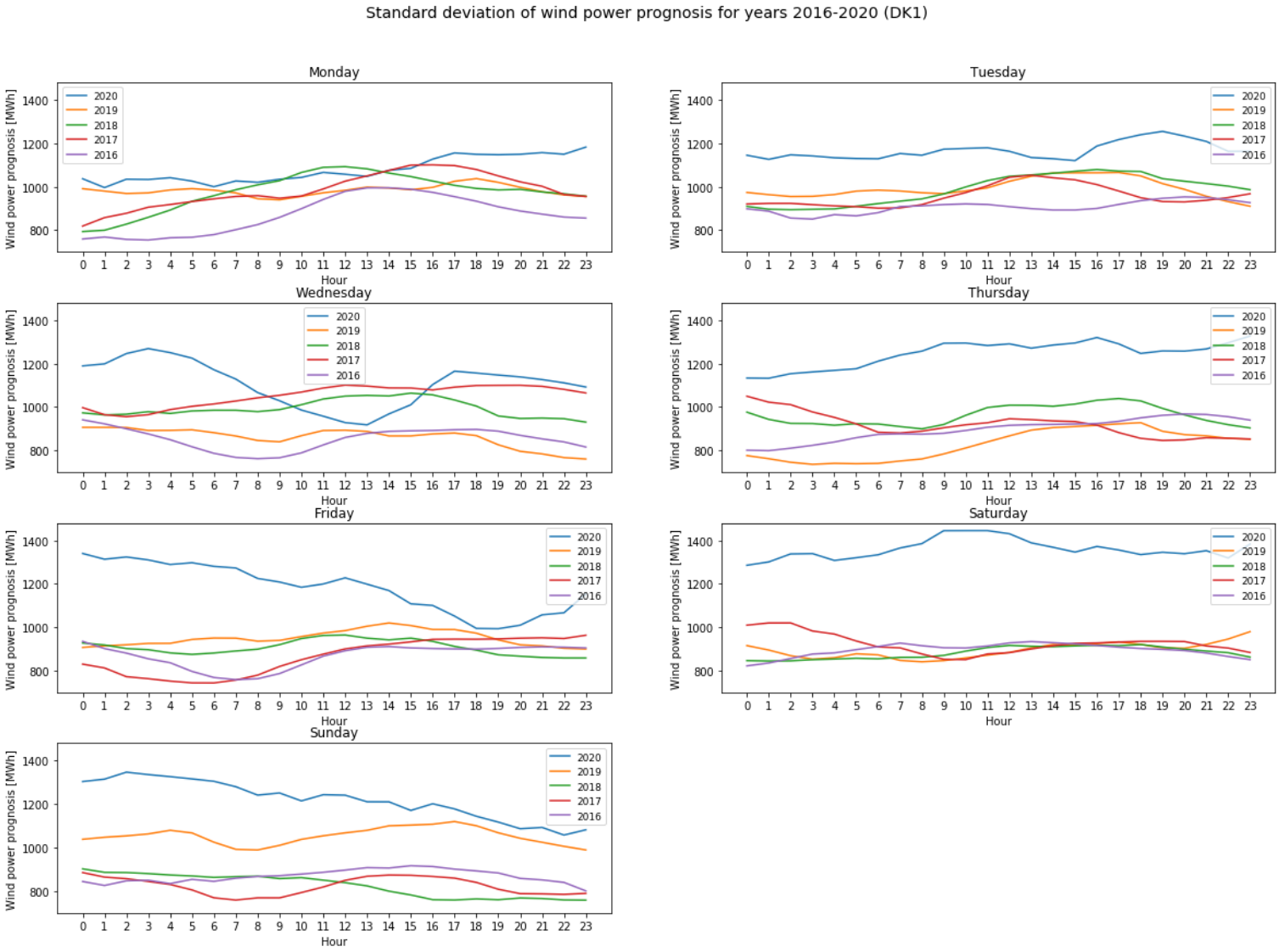


Figure 66:

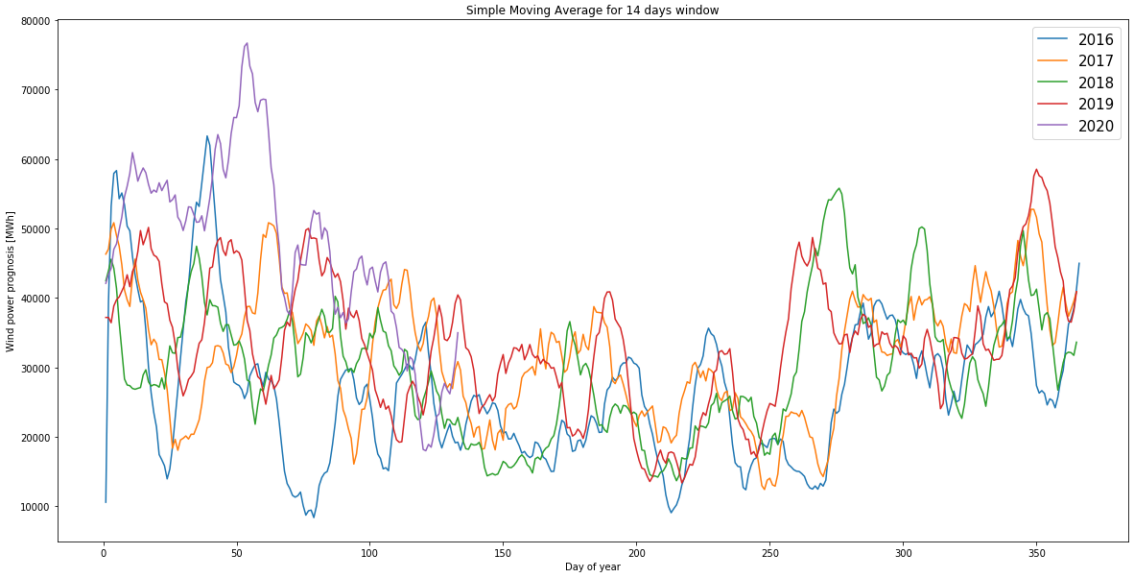


Figure 67:

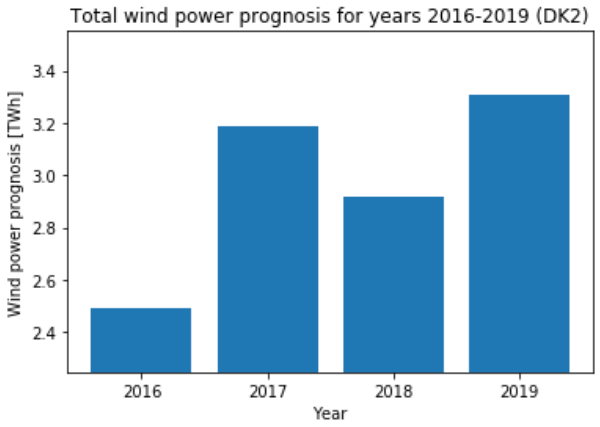


Figure 68:

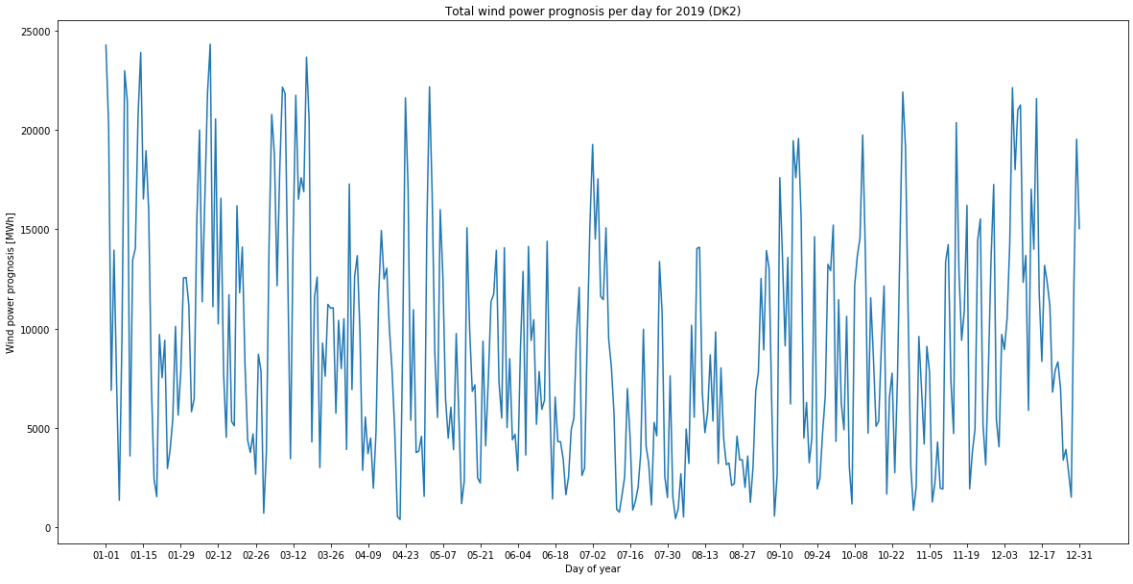


Figure 69:

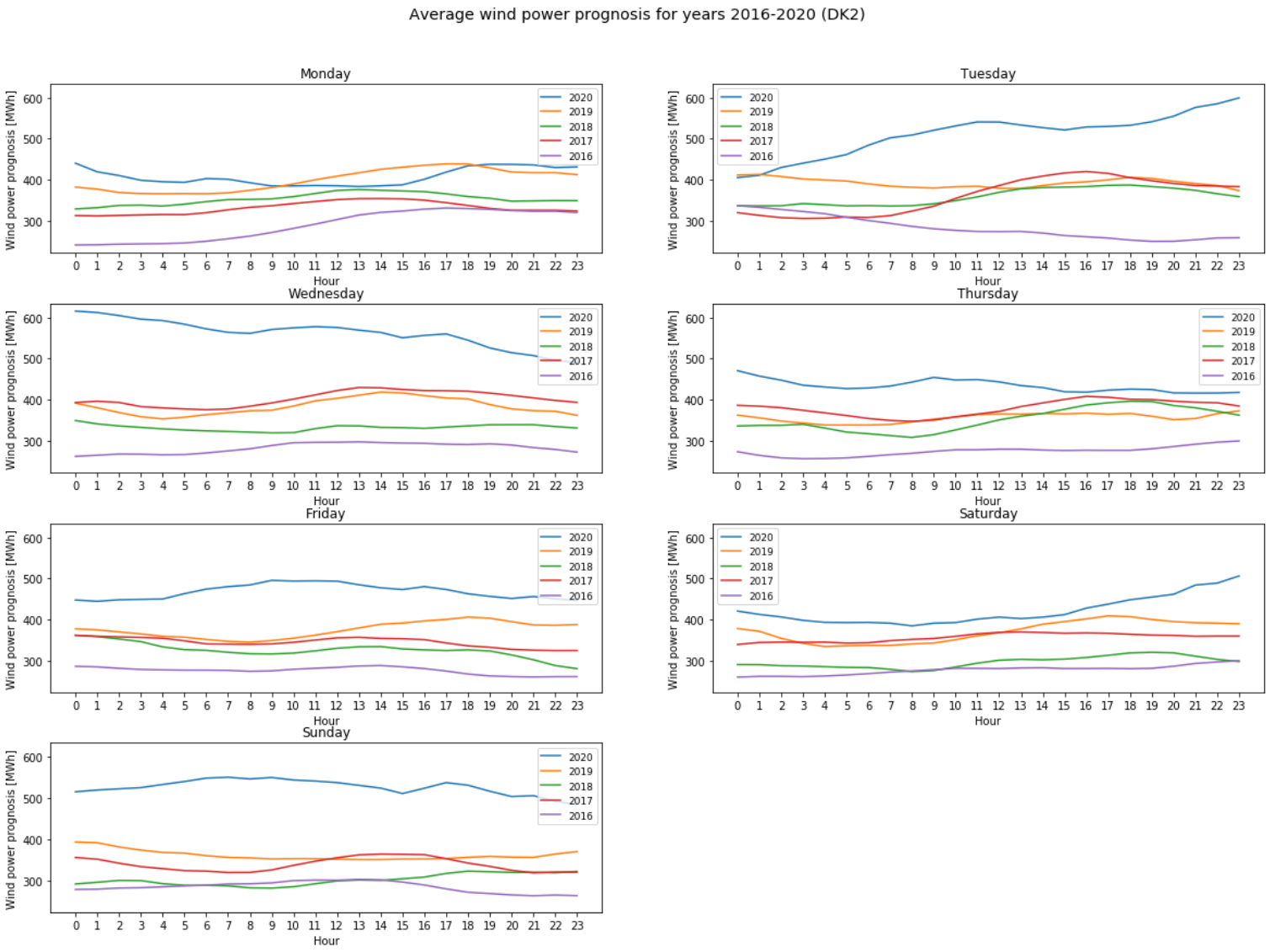


Figure 70:

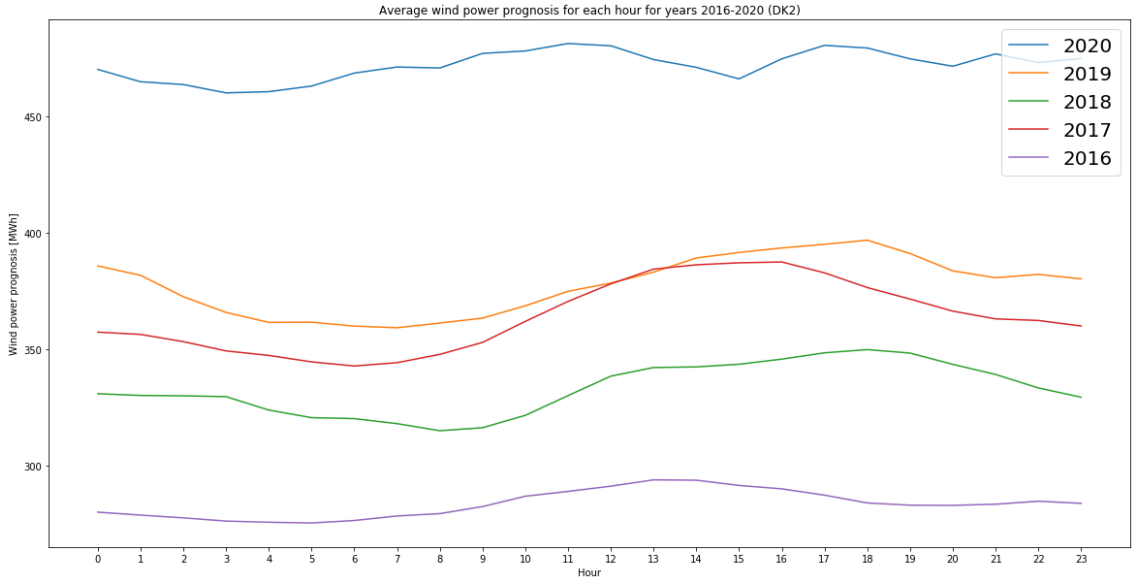


Figure 71:

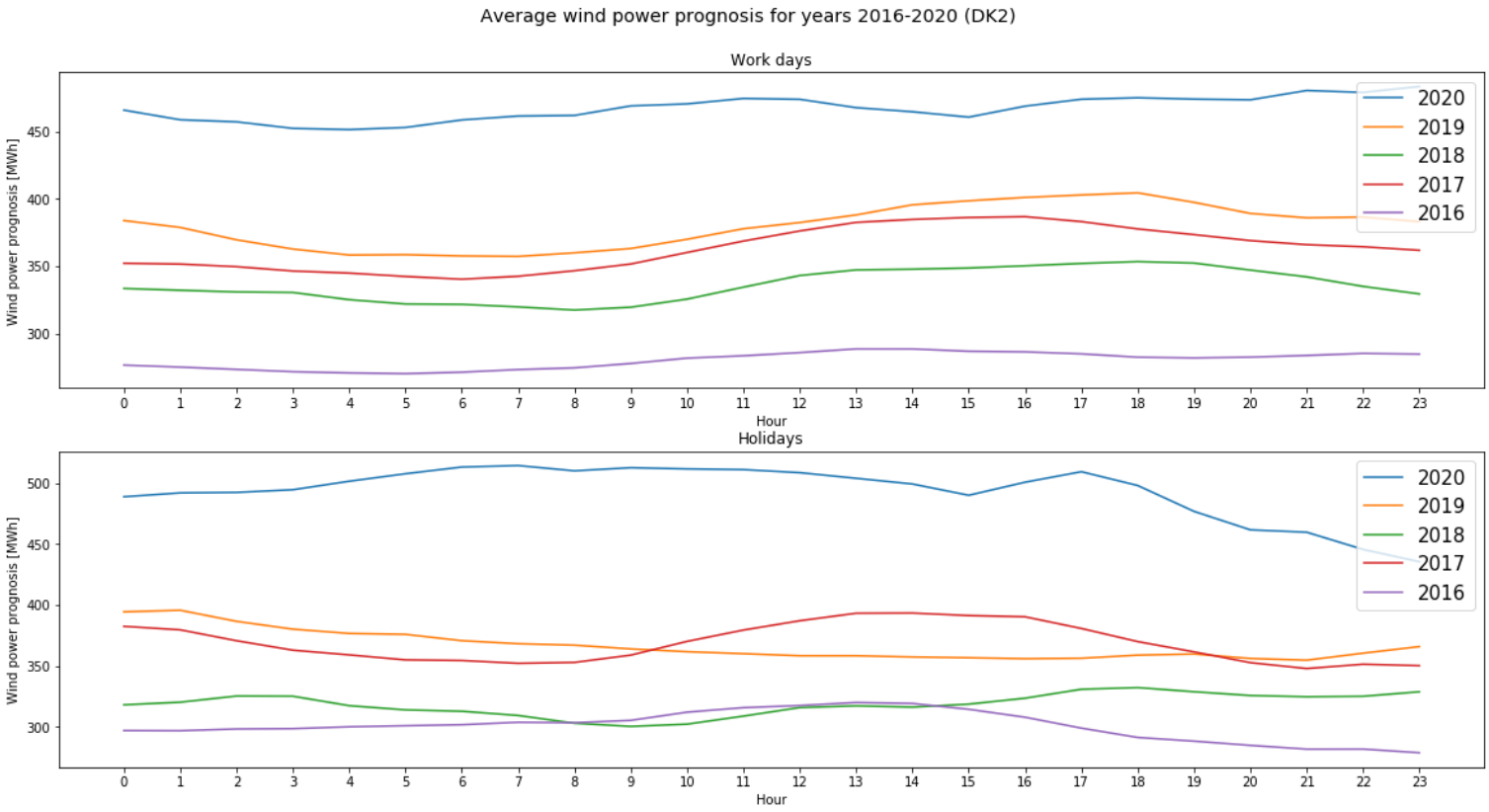

Average wind power prognosis for years 2016-2020 (DK2)
Work days
Wind power prognosis [MWh]
Hour
2020
2019
2018
2017
2016
Holidays
Wind power prognosis [MWh]
Hour
2020
2019
2018
2017
2016

Figure 72:

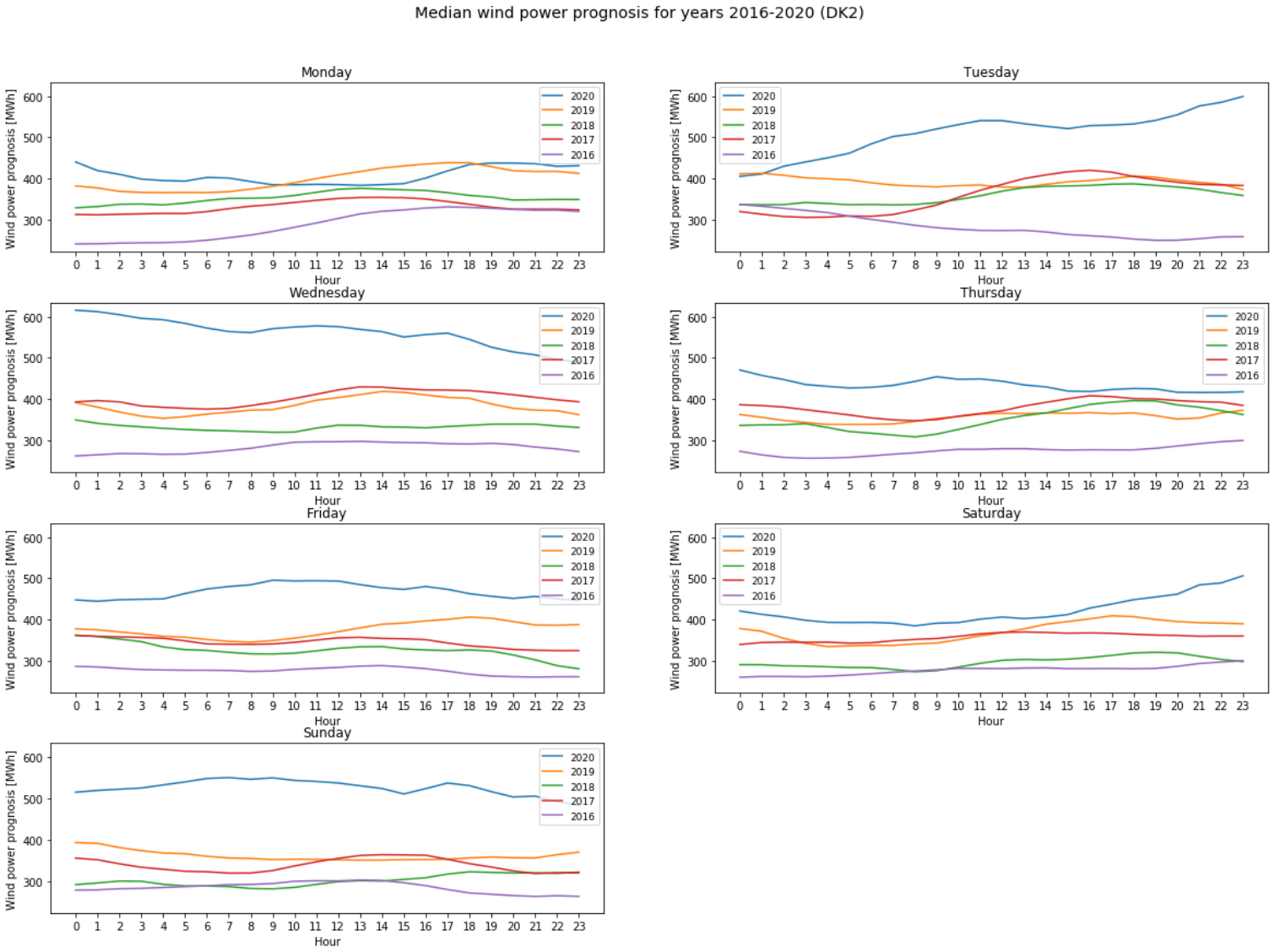

Median wind power prognosis for years 2016-2020 (DK2)
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Wind power prognosis [MWh]
Hour
2020
2019
2018
2017
2016

Figure 73:

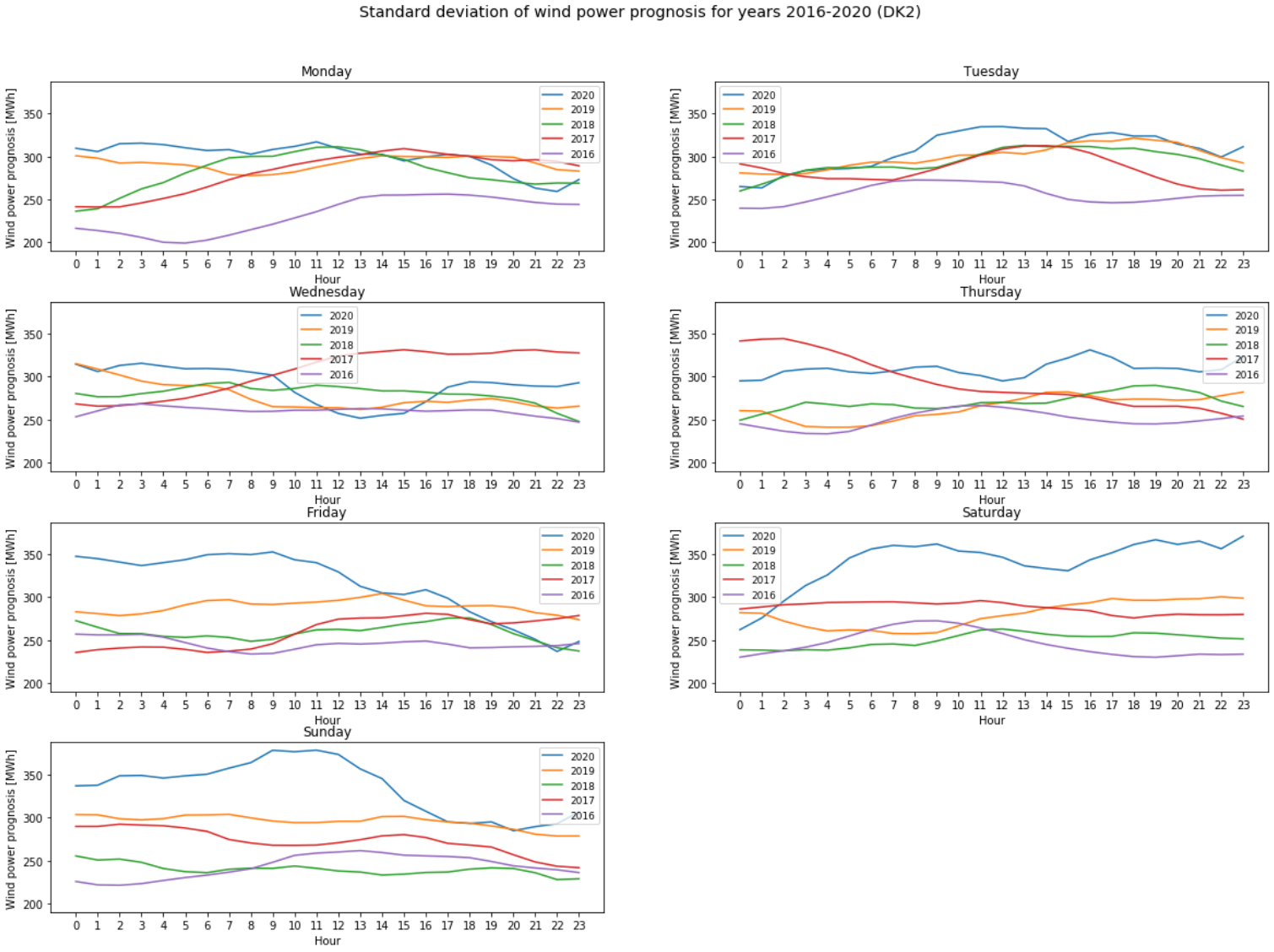


Figure 74:

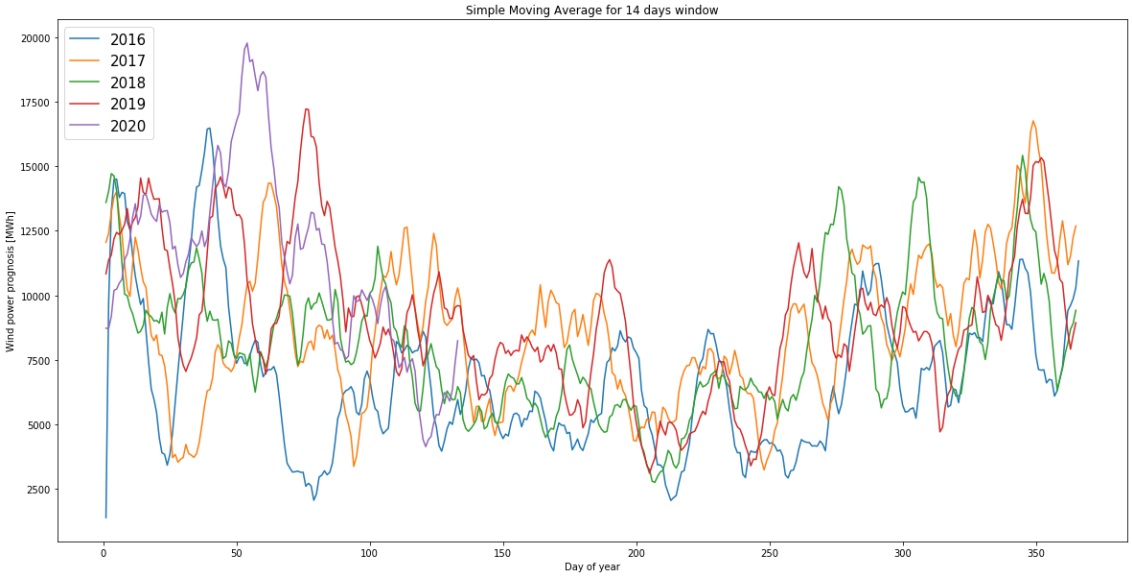


Figure 75:

3.2.2 Wind power data prognosis metrics

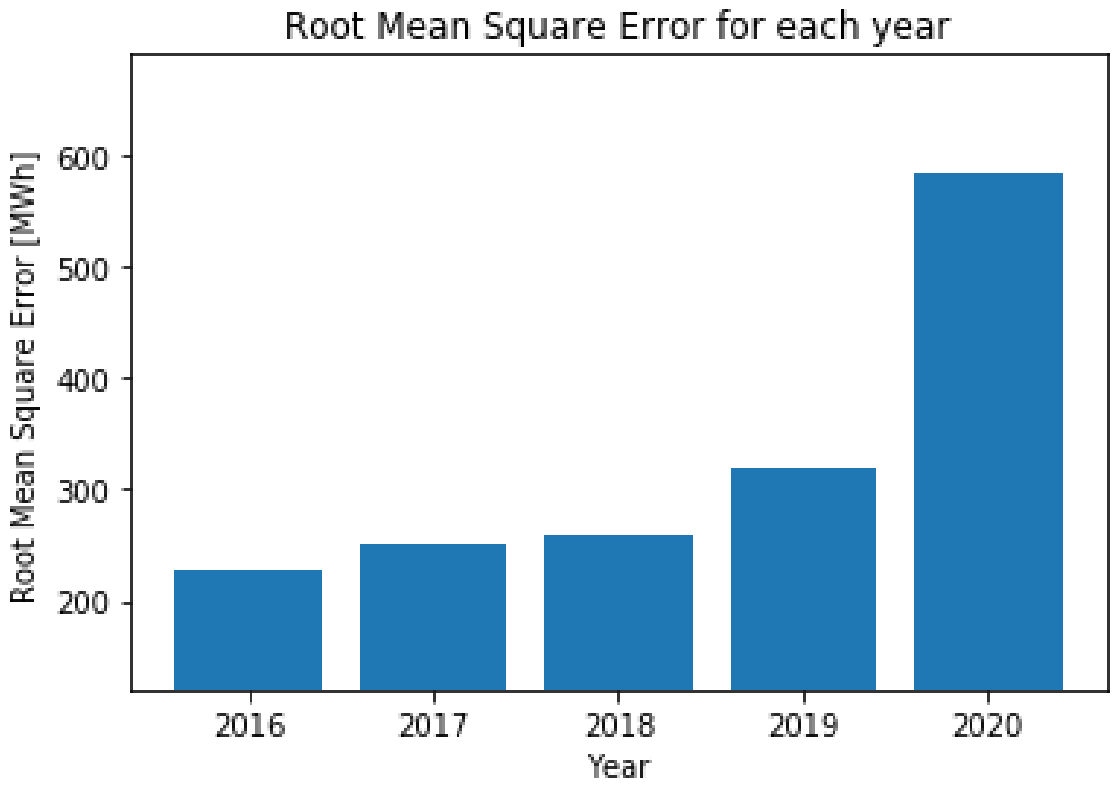


Figure 76:

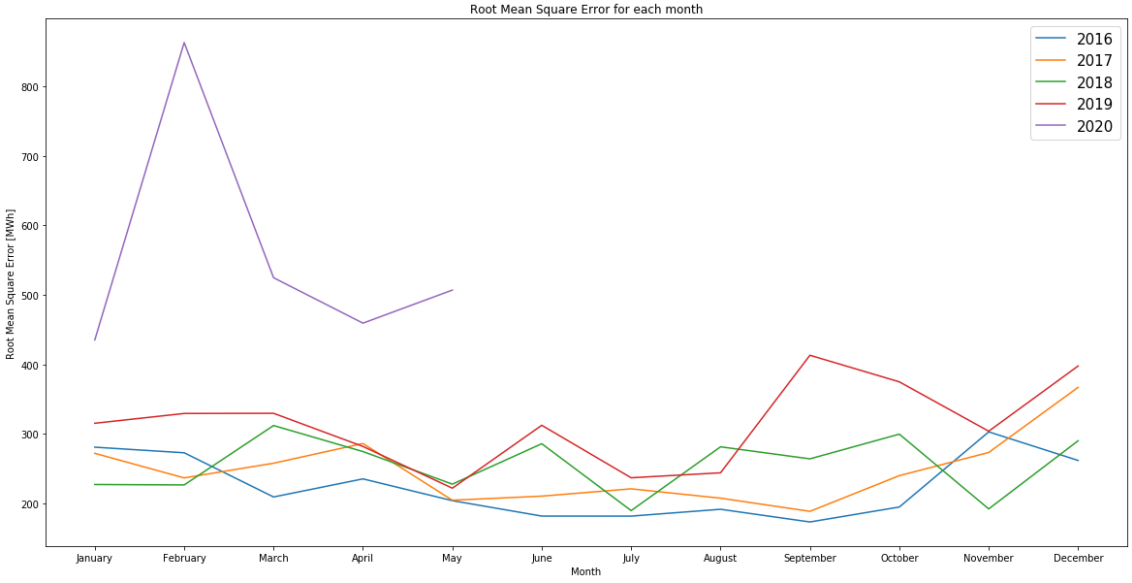


Figure 77:

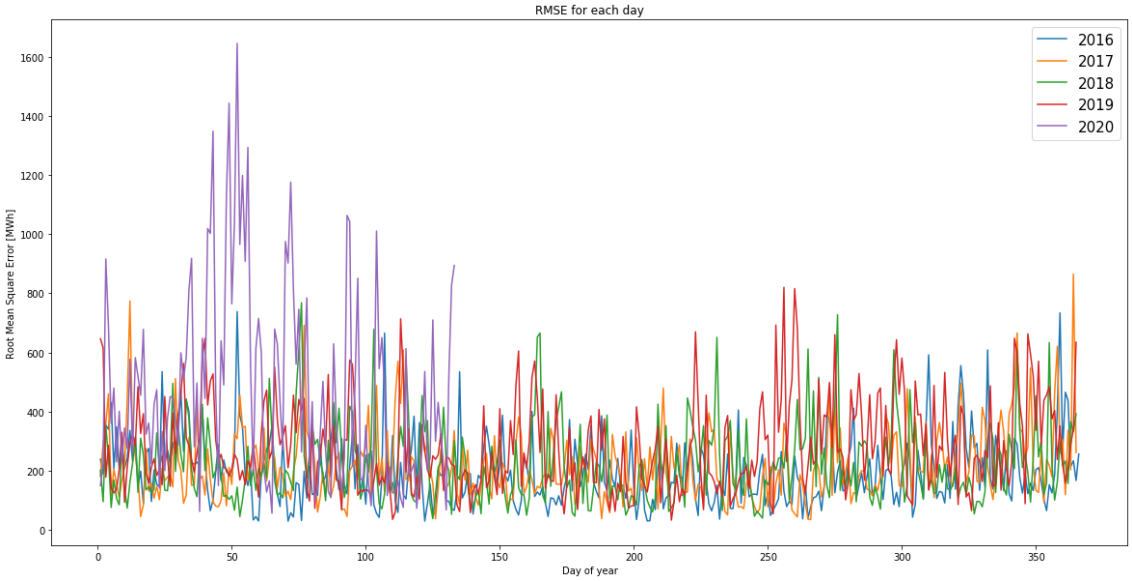


Figure 78:

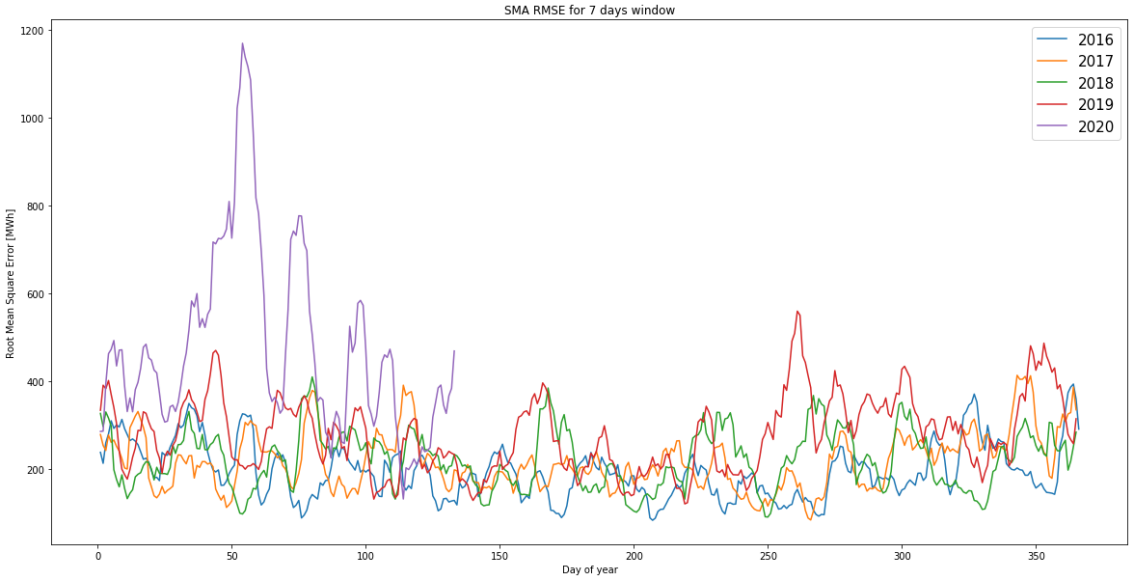


Figure 79:

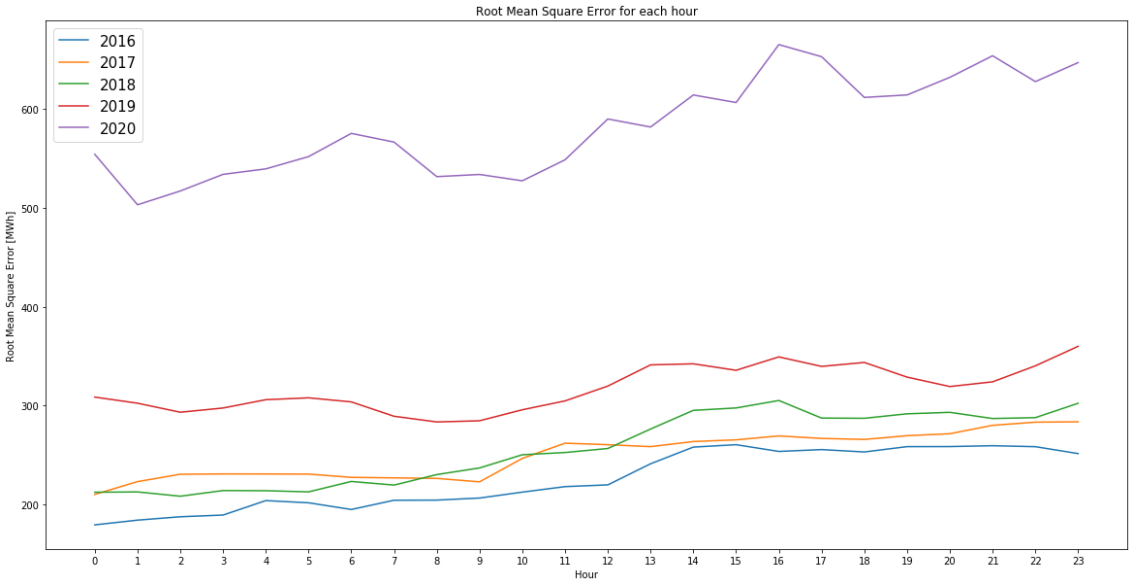
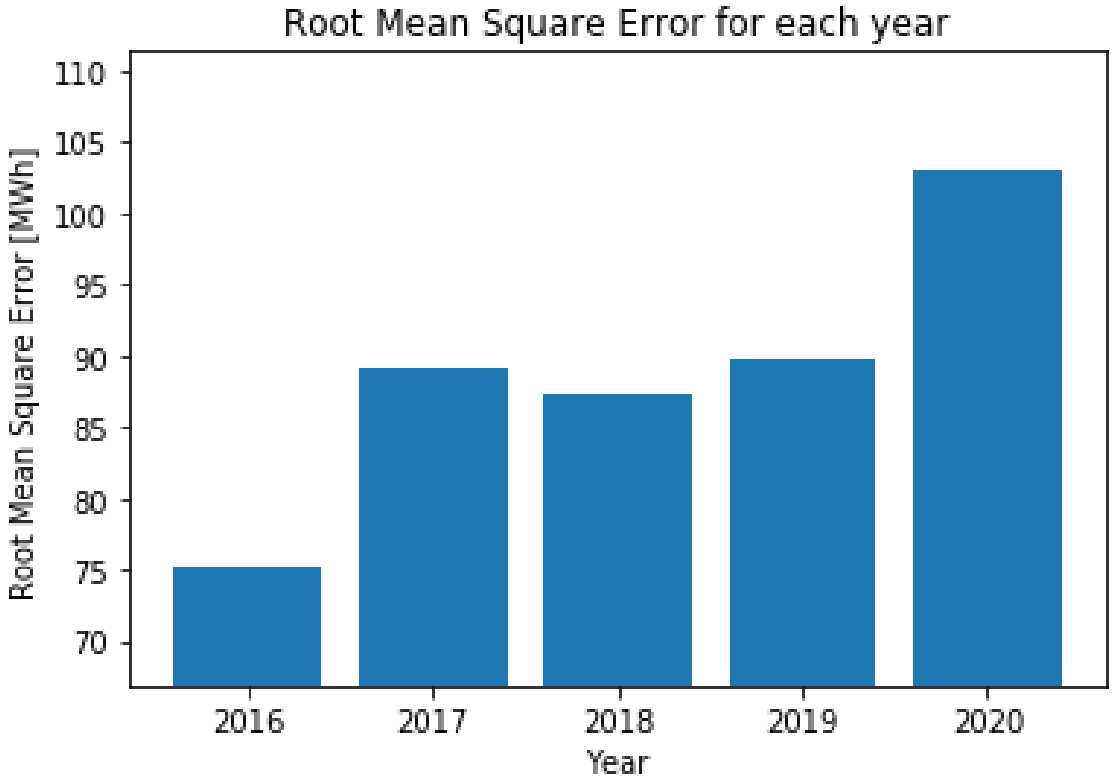


Figure 80:



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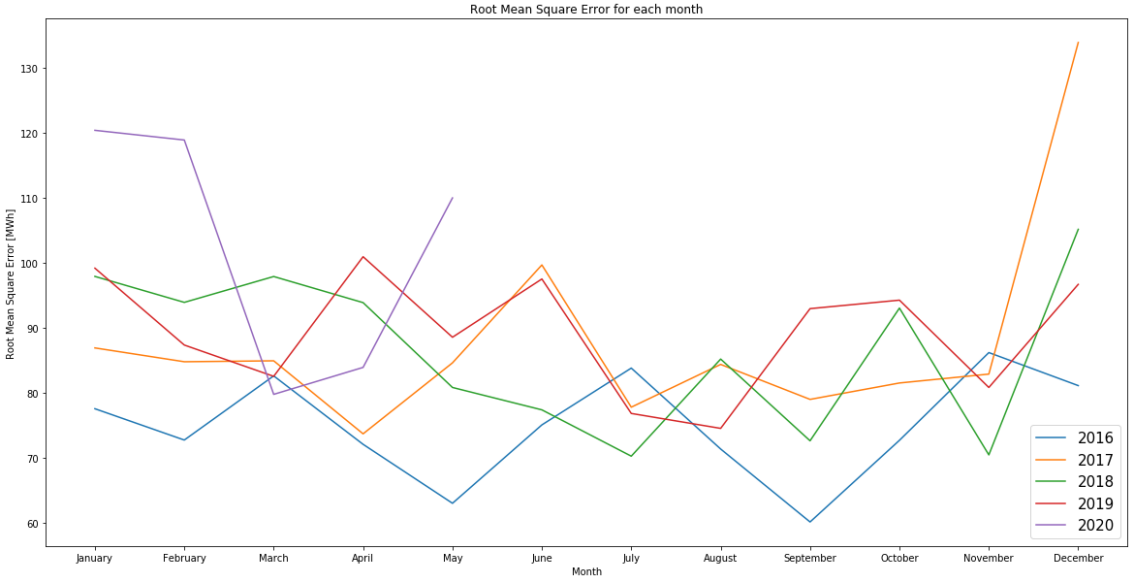

Figure 82:

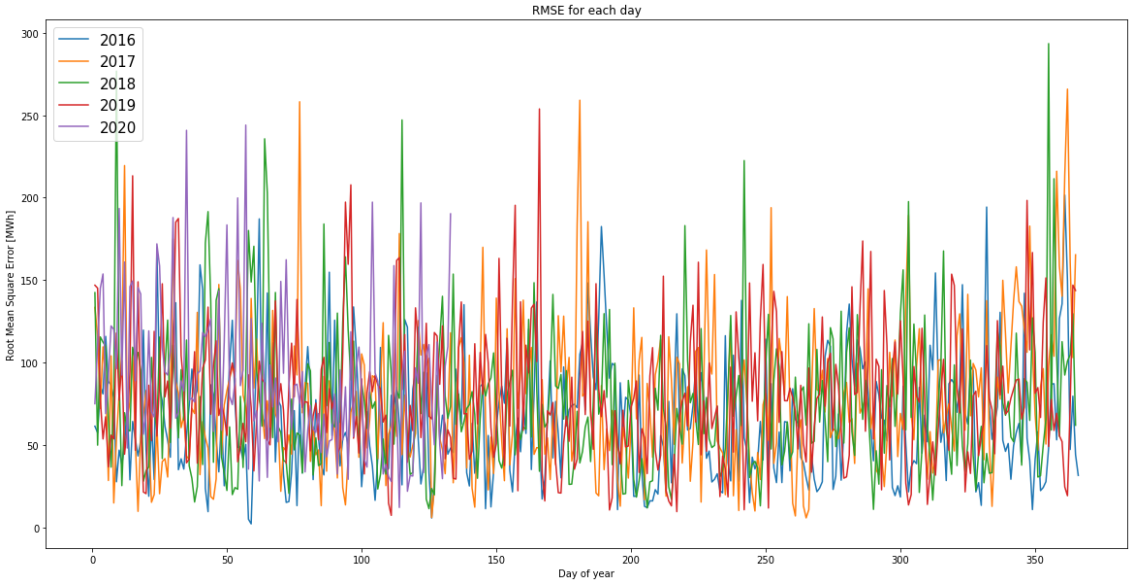

Figure 83:

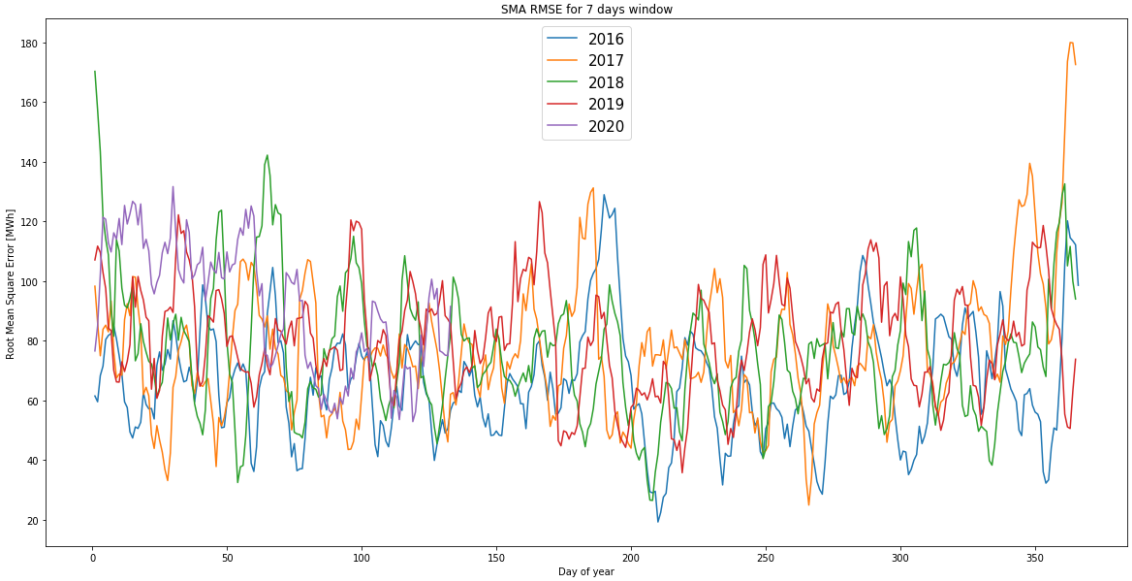

Figure 84:

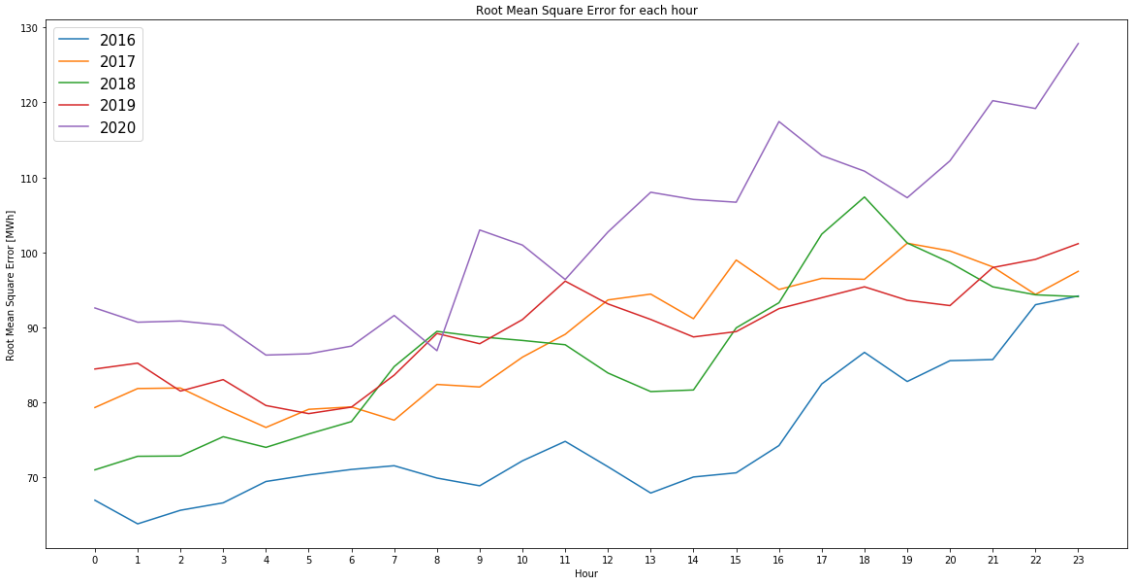

Figure 85:

3.3 Price data

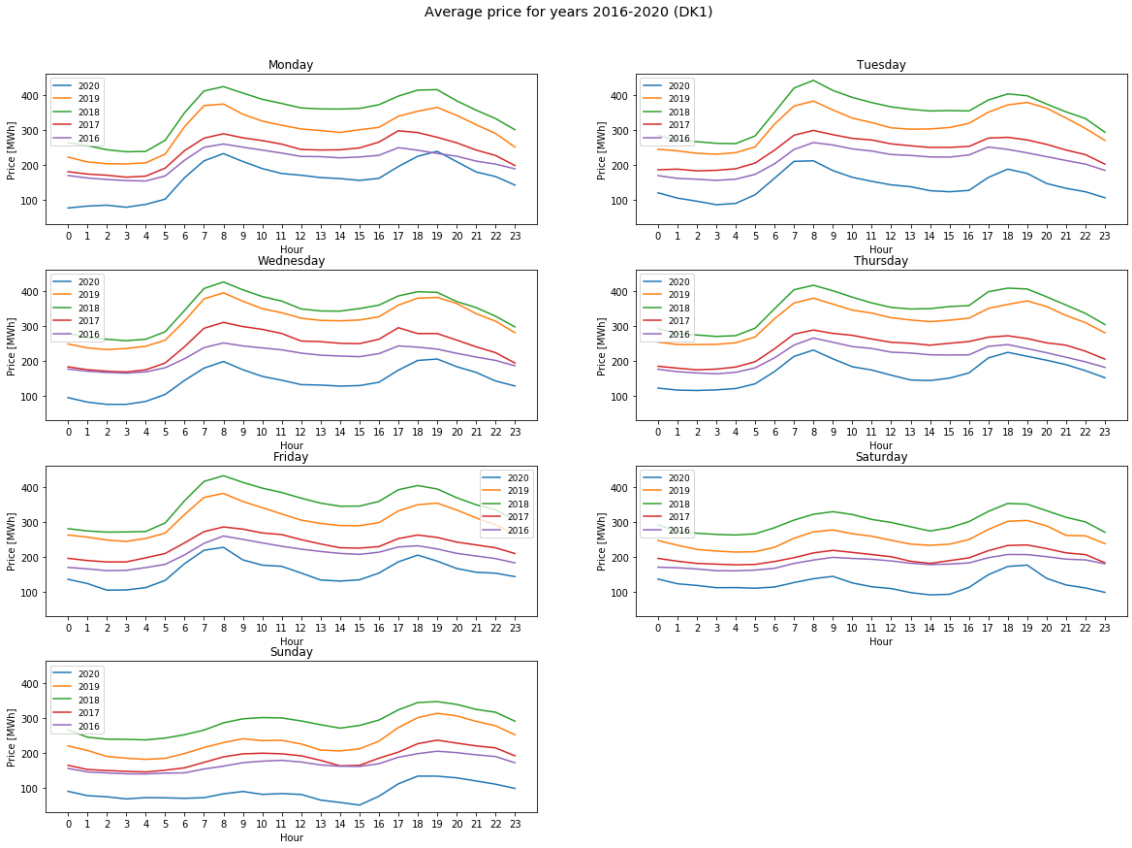

Figure 86:

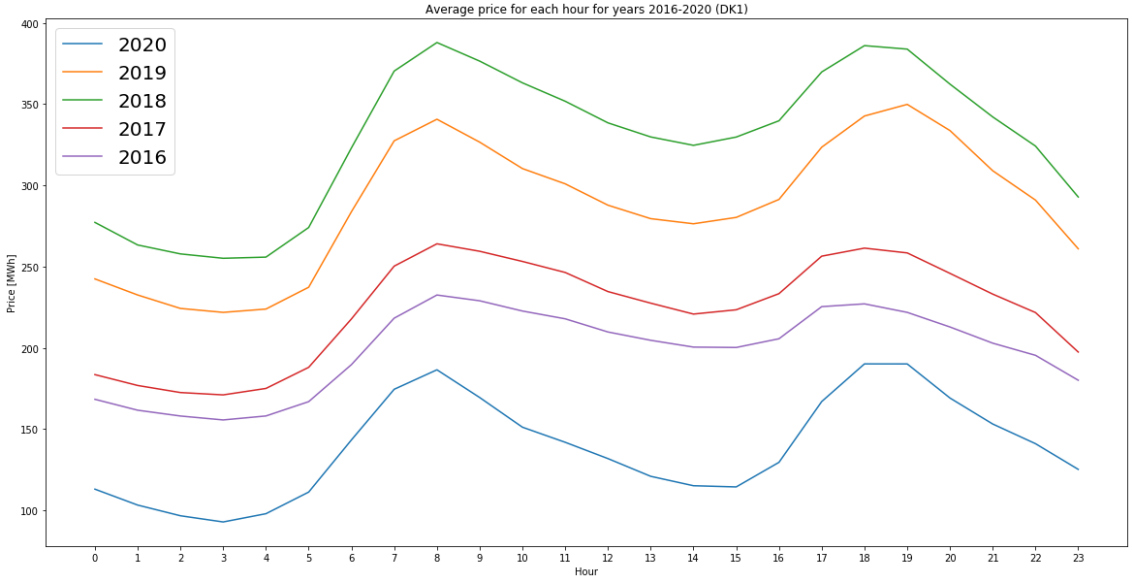

Figure 87:

$$RMSE_t = \sqrt{\frac{1}{24}\sum_{h}(y_{t,h} - \hat{y}_{t,h})^2} \tag{3}$$

$$RMSE_h = \sqrt{\frac{1}{T}\sum_{t}(y_{t,h} - \hat{y}_{t,h})^2} \tag{4}$$

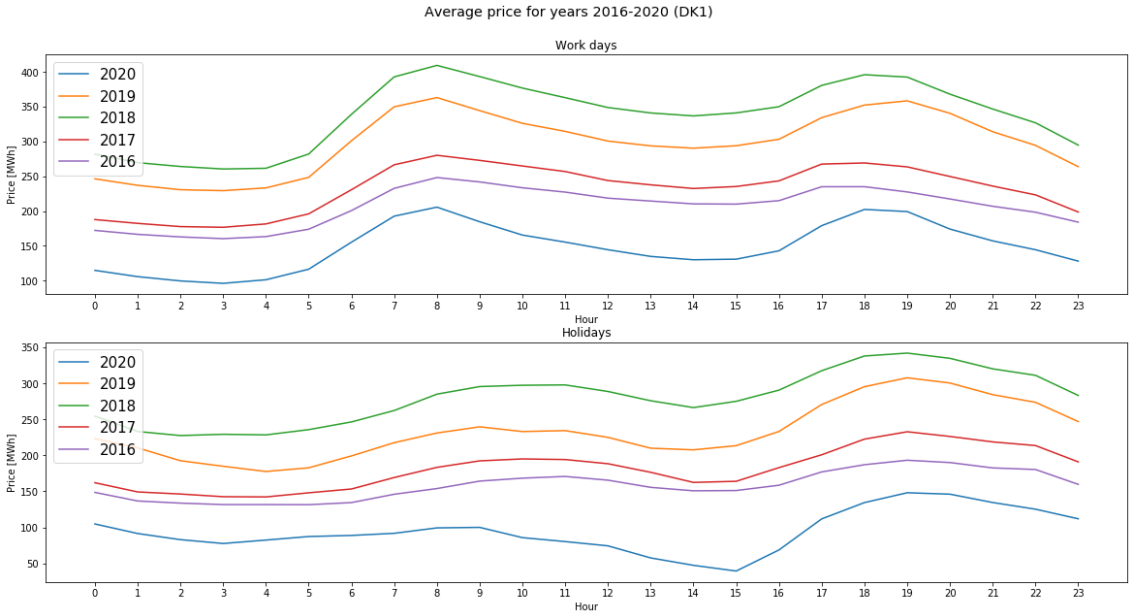

Figure 88:

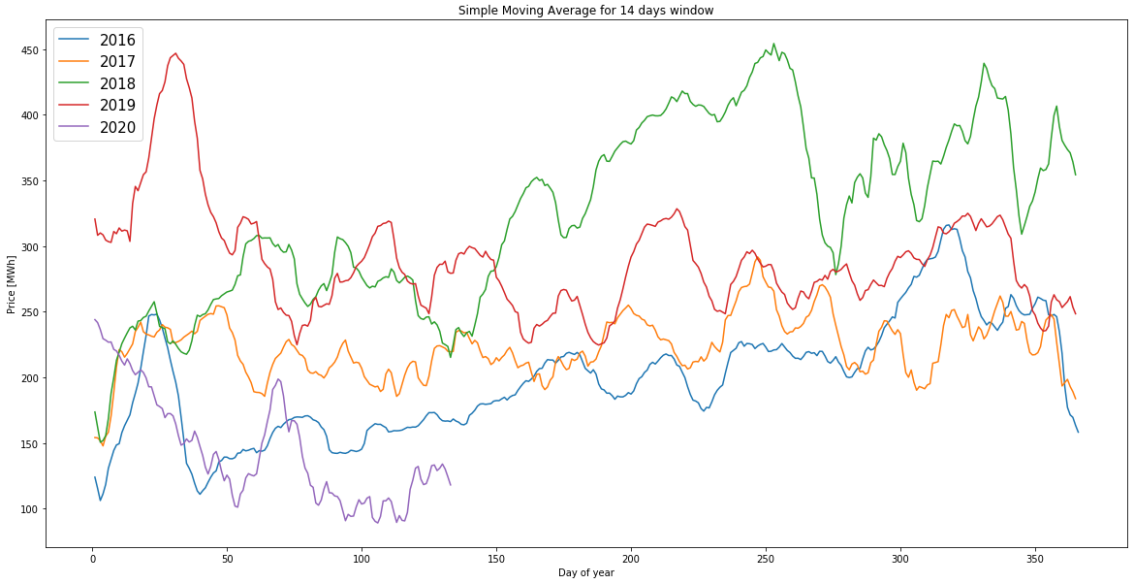

Figure 89:

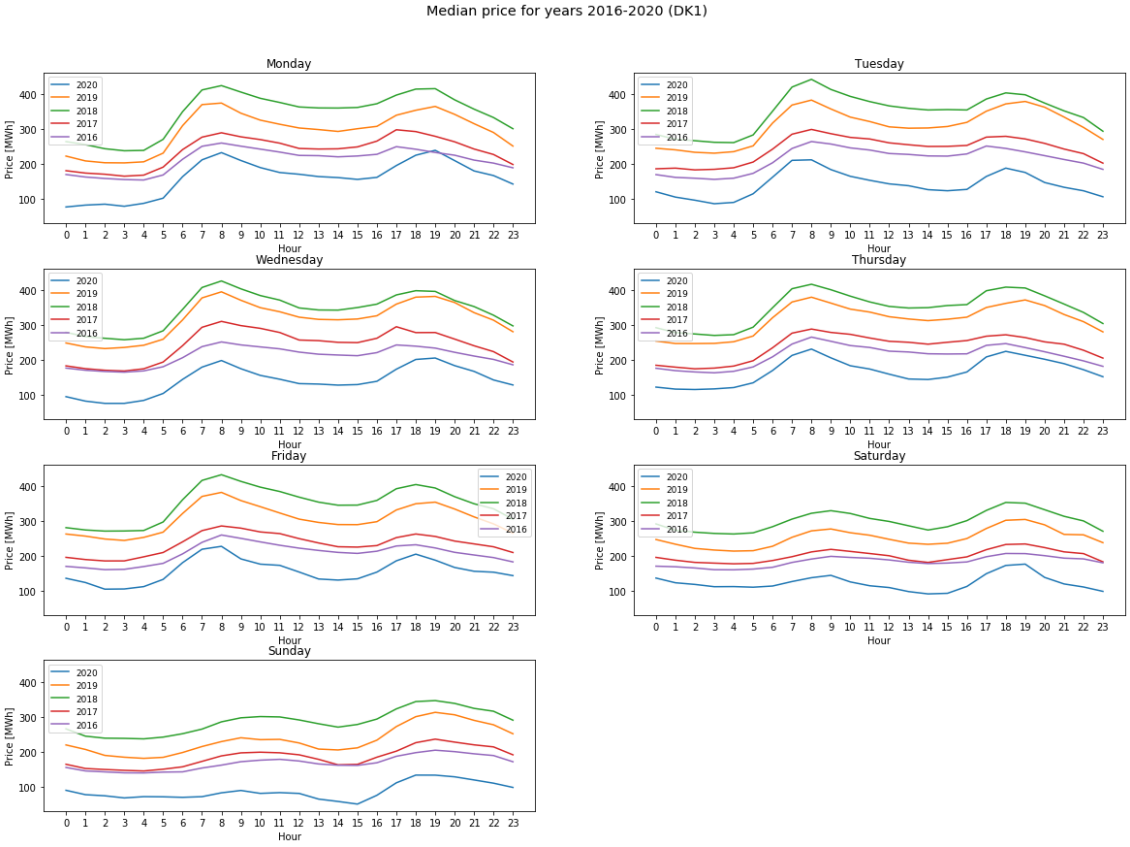

Figure 90:

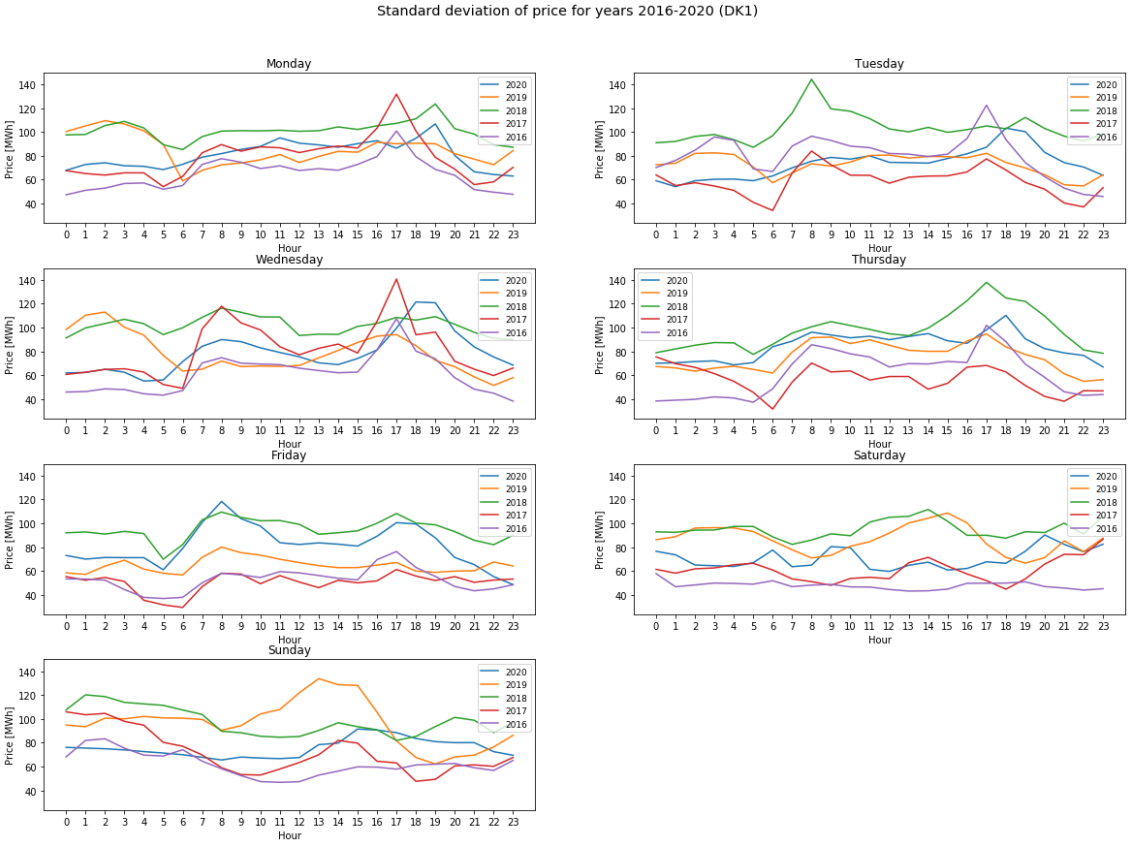

Figure 91:

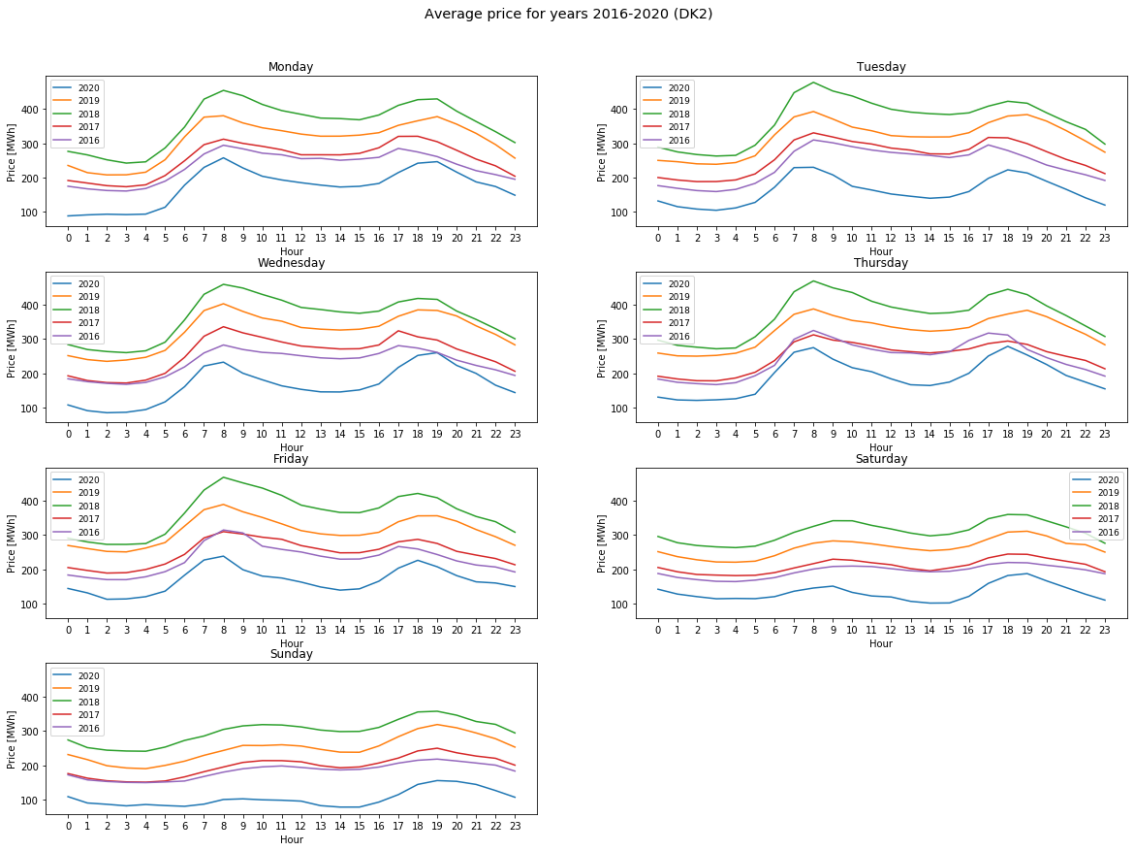

Figure 92:

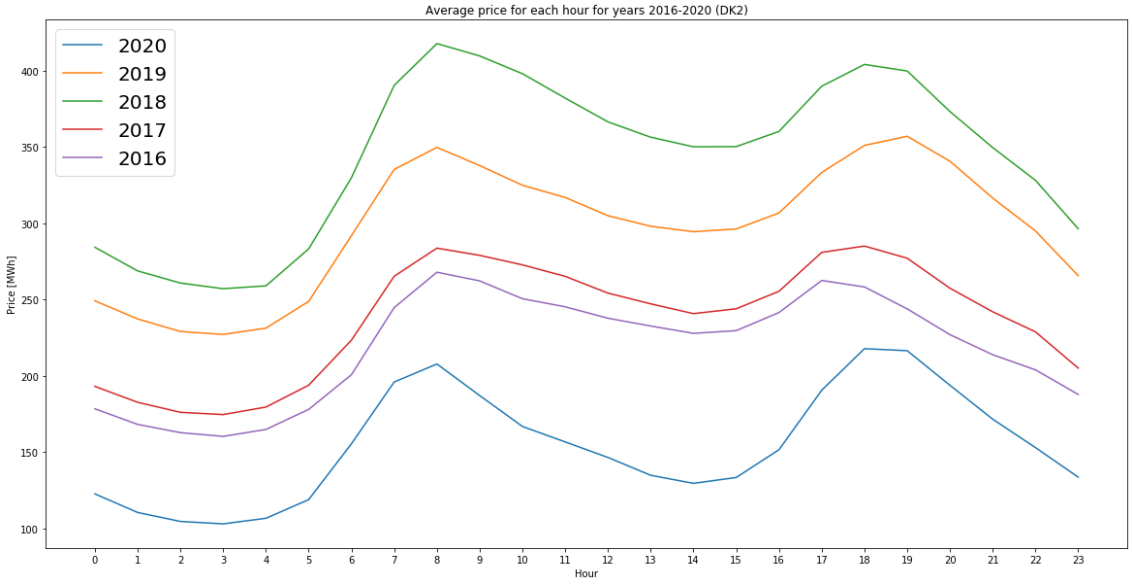

Figure 93:

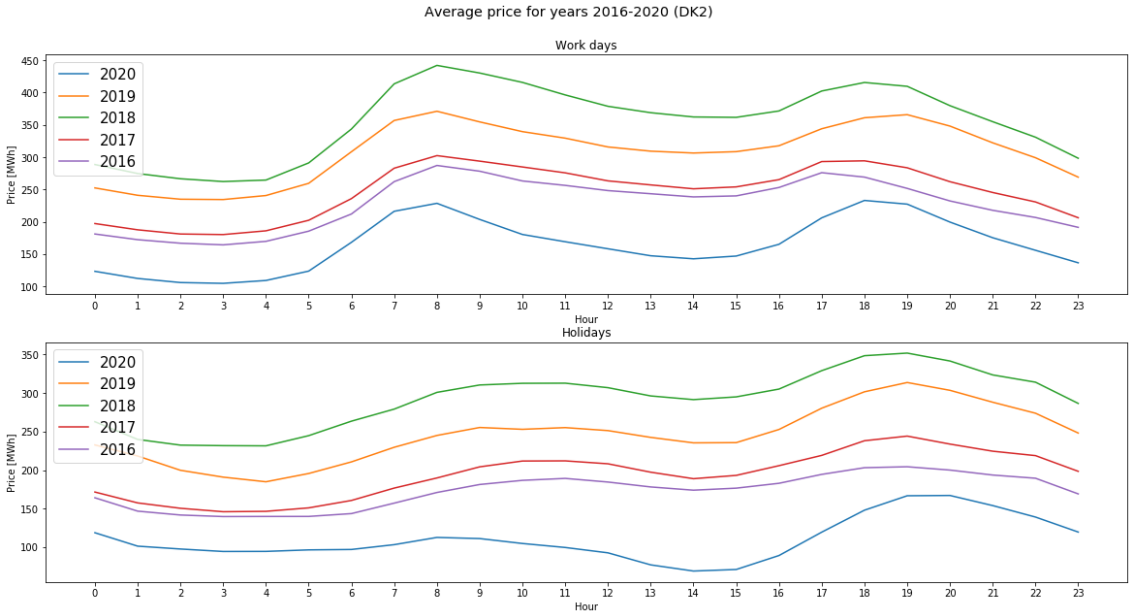

Figure 94:

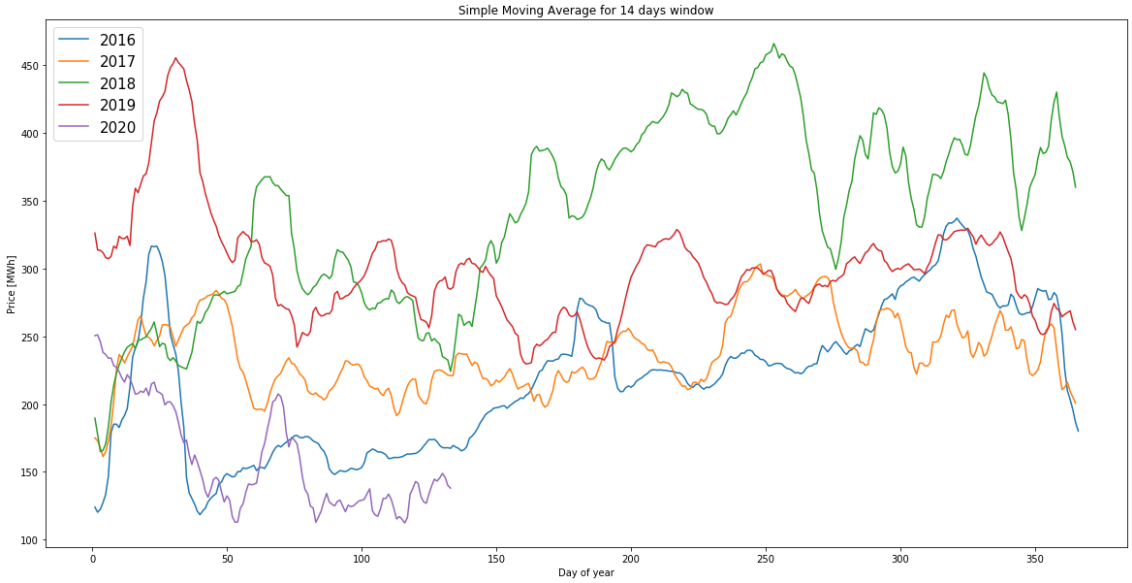

Figure 95:

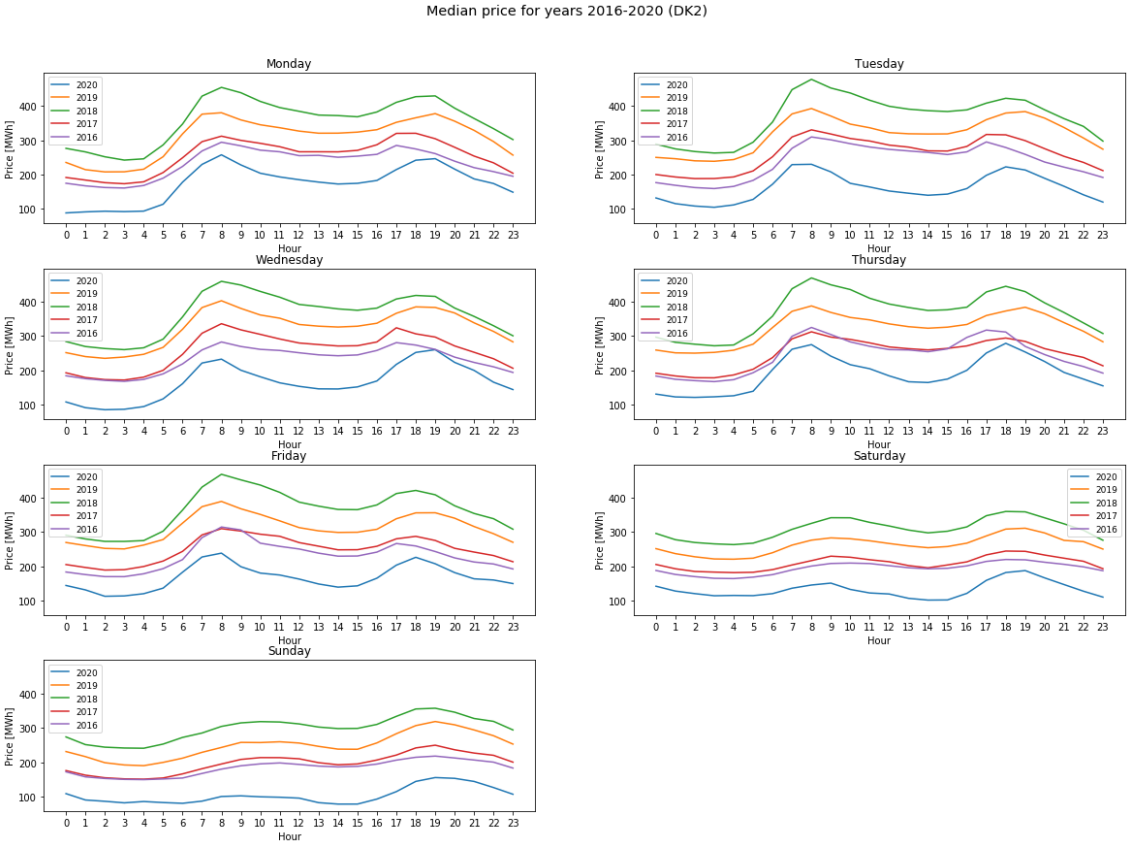

Figure 96:

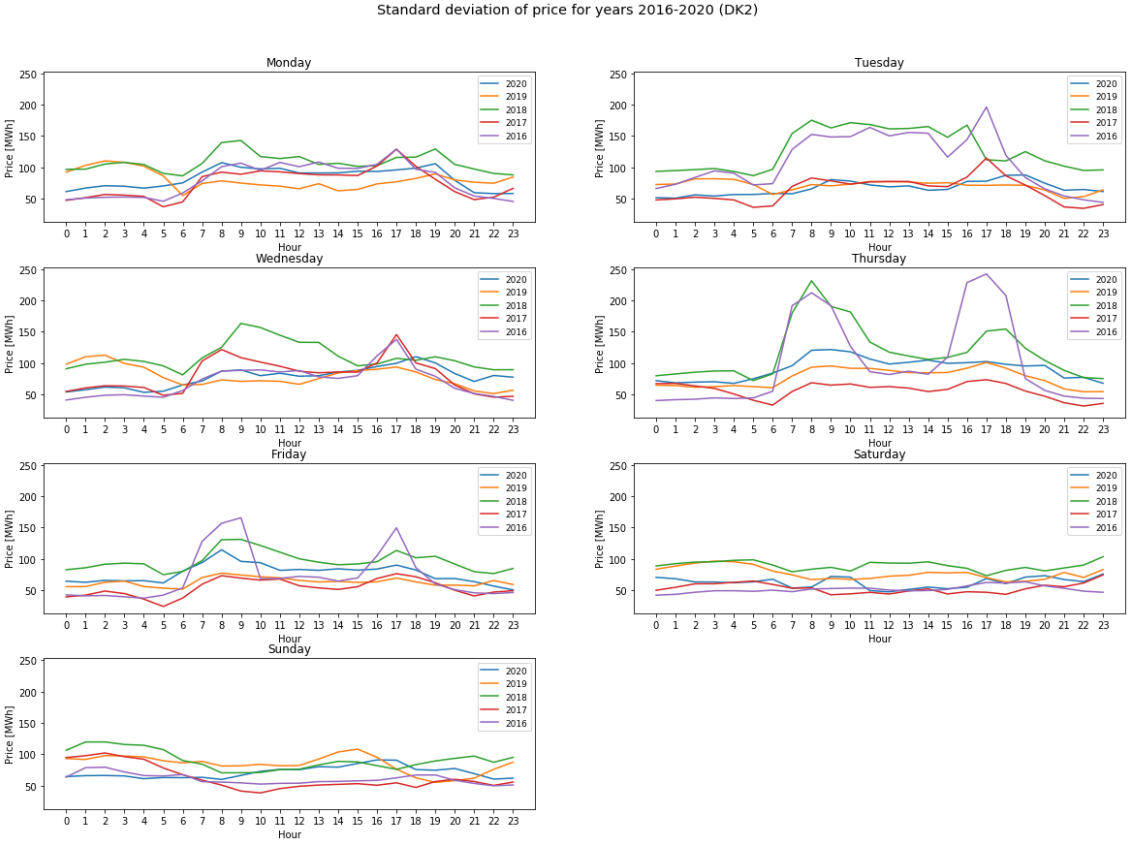

Figure 97:

3.4 Holidays

Usage of the electricity decreases during weekends and public holidays and this has significant effect on prediction especially during Christmas or Easter. Due to that fact, each day was aligned with variable holiday with following value based of occurrence of day of week or public holiday:

- 1 - National Holidays (e.g. Easter Monday)[2]
- 1 - Sundays
- 0 - Not a public holidays (e.g. New Year's Eve)
- 0 - Other days

4 Demand forecasting

$$L_{t,h} = \sum_{i=1}^{7} L_i Dit + \phi_1 FL_{t,h} + \varepsilon_t \tag{5}$$

$$L_{t,h} = \sum_{i=1}^{7} L_i Dit + \phi_1 FL_{t,h} + \beta_1 L_{t-1,h} + \beta_2 L_{t-2,h} + \beta_3 L_{t-7,h} + \varepsilon_t \tag{6}$$

$$L_{t,h} = \sum_{i=1}^{7} L_i Dit + \phi_1 FL_{t,h} + \beta_1 L_{t-1,h} + \beta_2 L_{t-2,h} + \beta_3 L_{t-7,h} + \phi_1 FW_{t,h} + \varepsilon_t \tag{7}$$

$$L_{t,h} = FL_{t,h} \tag{8}$$

5 Analysis of demand forecast

6 Wind power forecasting

$$W_{t,h} = L_0 + \phi FW_{t,h} + \varepsilon_t \tag{9}$$

$$W_{t,h} = L_0 + \phi FW_{t,h} + \beta_1 W_{t-1,h} + \beta_2 W_{t-2,h} + \varepsilon_t \tag{10}$$

$$W_{t,h} = L_0 + \phi_1 FW_{t,h} + \beta_1 W_{t-1,h} + \beta_2 W_{t-2,h} + \phi_2 FL_{t,h} + \varepsilon_t \tag{11}$$

$$W_{t,h} = FW_{t,h} \tag{12}$$

7 Analysis of wind power forecast

8 Price forecasting

$$y_{t,h} = \sum_{i=1}^{7} L_i D_{it} + \varepsilon_t \tag{13}$$

$$y_{t,h} = \sum_{i=1}^{7} L_i D_{it} + \beta_1 y_{t-1,h} + \beta_2 y_{t-2,h} + \beta_3 y_{t-7,h} + \varepsilon_t \tag{14}$$

$$y_{t,h} = \sum_{i=1}^{7} L_i D_{it} + \beta_1 y_{t-1,h} + \beta_2 y_{t-2,h} + \beta_3 y_{t-7,h} + \beta_4 y_{t-7,min} + \beta_5 y_{t-1,h} + \beta_6 y_{t-1,24} + \varepsilon_t \tag{15}$$

$$y_{t,h} = \sum_{i=1}^{7} L_i D_{it} + \beta_1 y_{t-1,h} + \beta_2 y_{t-2,h} + \beta_3 y_{t-7,h} + \beta_4 y_{t-7,min} + \beta_5 y_{t-1,h} + \beta_6 y_{t-1,24} + \beta_7 FW_{t,h} + \beta_8 FL_{t,h} + \varepsilon_t \tag{16}$$

9 Analysis of price forecast

10 Conclusions

11 Data analysis

References

[1] *Historical Market Data — Nordpool*. URL: https://www.nordpoolgroup.com/historical-market-data/. (accessed: 2020-05-10).

[2] *National Holidays in Denmark*. URL: https://www.officeholidays.com/countries/denmark. (accessed: 2020-05-10).