31761 - Renewables in electricity markets
Assignment 2

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1. Introduction

The analysis performed during the first assignment gave a brief introduction about some of the aspects present in the real-life electricity market in Denmark. At a glance, the satisfactory capital earned by wind producers could be potentially taken as a positive sign. Unfortunately, the day-ahead market revenue only shows half the picture and is not the final revenue earned by the producers. Due to the likelihood of failure to provide the scheduled amount by the producers which increase with an increase in the non-dispatchable renewable energy system in the market. To prevent such mishappenings the term "balancing market" has been coined which could be defined as the last stage for trading electric energy.
Nordpool follows a dual-price imbalance system wherein the deviations from production schedule are traded at different prices depending upon the imbalance sign. It makes sure that any producer that helps in reducing the system imbalance is not rewarded with extra revenue but rather its deviation is traded at the day-ahead market price, avoiding possible bonuses. On the other hand, producers failing to meet the scheduled amount are priced at the balancing market price (i.e., usually penalized). Hence as a wind producer, it becomes crucial to bid the right amount of electricity in the day ahead market due to the volatile nature of the system. Forecasting, therefore, becomes a key tool to allow the possibility of reducing the uncertainty and thereby improving the revenues of the wind producers in the market.
This report gives a brief introduction to some of the available techniques for forecasting wind production for a wind producer. It is investigated how to emulate an energy market participant "Horns Rev", with a wind farm of 160 MW generation capacity for a whole year (2017) and try to find a strategy to optimize the revenue. The Wind Farm is in the DK1 region and hence participates in that market. It is to be noted that all data used here is from Nordpool for DK1 Market. Furthermore, it should be noted that the wind farm in question is a price-taker, meaning the energy offered into the market and all other aspects of the wind farm participation, does not affect the energy market or the market prices. Finally, a comparison has been drawn for the different revenues obtained from these techniques with the revenue that would have been obtained with a perfect forecast to get an idea about the performance of these forecast techniques. A point to be noted is that the number present in front of the months in the axis of some graphs represent the number of the month this was done to ease the process of drawing the graphs.

2. Introduction to strategies

1. Perfect Information Case: In this first case, the perfect information scenario has been analyzed. Here, the quantity bid by the "Horns Rev" wind farm is exactly equal to the quantity it will produce. The producer's profit will, therefore, be maximized: since the bid and production are equal, it will never face cases of up or down regulation in the balancing market. This is the optimal solution for the wind farm and the objective that it would like to achieve by bidding in each hour of 2017 according to the following strategies.

2. Base Case:

   - Nominal Capacity Bidding: This strategy is purely based on the idea of bidding into the market, without forecasting the wind production. This strategy is based on the nominal capacity of the wind farm, which is 160 MW. This means the strategy will offer 160 MW throughout the year into the day-ahead market, and then accept to be penalized if the wind farm produces less than the nominal capacity.

- Average Prognosis Bidding: For this second base bidding strategy, data of wind prognosis from 2013, 2014, 2015, and 2016 from Nordpool was utilized. This data represents the total offshore wind production for the DK1 area: since in DK1 there are various wind farms, including the studied one "Horns Rev", the data required for the analysis was obtained by multiplying the total wind data by 0.1353. This coefficient represents what capacity the "Horns Rev" wind farm constitutes with respect to the total offshore wind farms capacity in DK1 [Wikipedia]. Once the "Horns Rev" production values for the four years was found, average hourly quantities were determined. These average values were then utilized as the value bid by the wind farm for the same hour in the market.

- Capacity Factor Determined Bidding: Following the data processing method stated in the previous base strategy, utilizing data from 2013, 2014, 2015, and 2016 from Nordpool, the average hourly production quantity was calculated. This time, each average hourly production value was divided by 160 MW to obtain an hourly capacity factor value (between 0 and 1). By taking the average of all capacity factors, a result of 0.65812 was obtained: this value was multiplied by 160MW to obtain a quantity of 105.3 MW. This quantity is then bid by "Horns Rev" for each hour of the year.

- Correction Bidding: This last base strategy utilizes once again the average hourly production values of 2013, 2014, 2015, and 2016 from Nordpool as processed in the Average Prognosis Bidding case. Furthermore, also an average of the hourly forecast for the four years has been calculated. By performing the difference between the average forecast and the average production, a value that represents the error committed is calculated. This error is then used as a correction which is added or subtracted to the hourly forecast in 2017 which was taken out from the internet, always taking into account the capacity of the wind farm. From figure 1 it could be seen that the correction factor varies throughout the year, reaching extreme values that have been highlighted (red) in the figure 1. These factors could at times change the data by half its value thereby creating a significant change in the final bid.

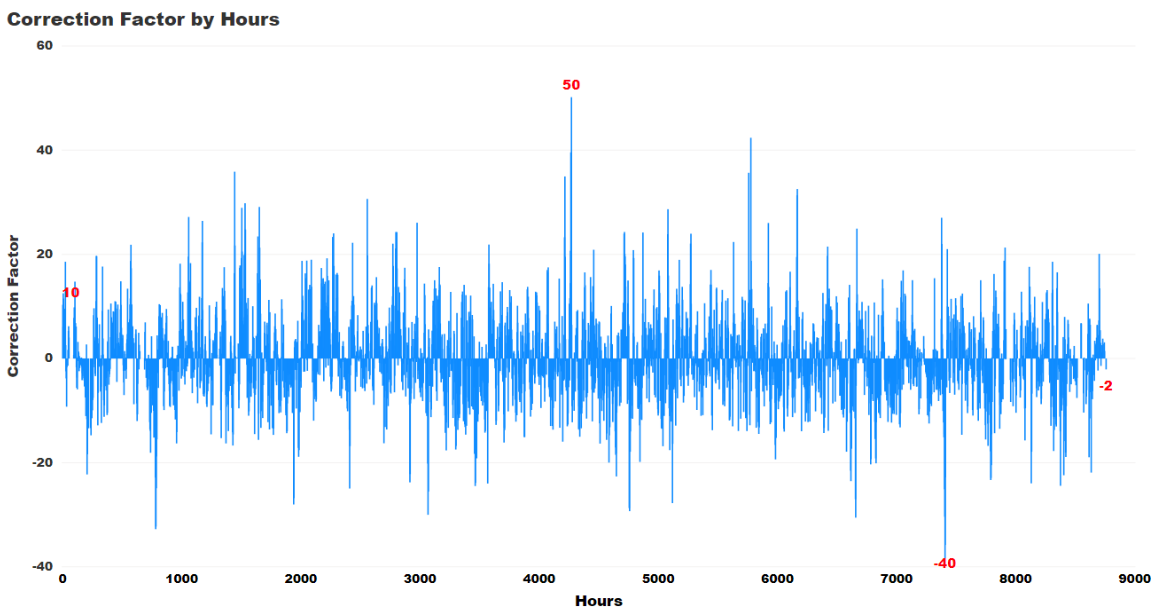

Figure 1: Correction factor

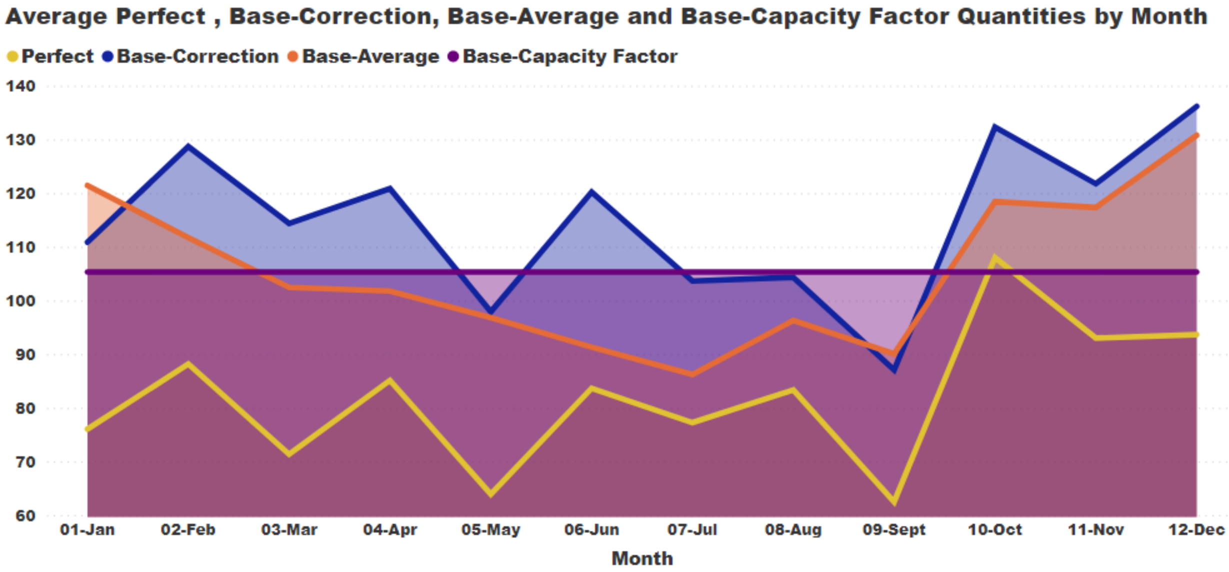

Figure 2: Different base strategy bidding quantities compared to the perfect information case

3. Deterministic Case: For this strategy, the forecast that was provided in the data files was utilized. After having calculated the day ahead revenue, the balance revenue was obtained as the product between the forecasted production and the balancing prices. The profit of the wind farm is then obtained by subtracting the latter to the day ahead results.

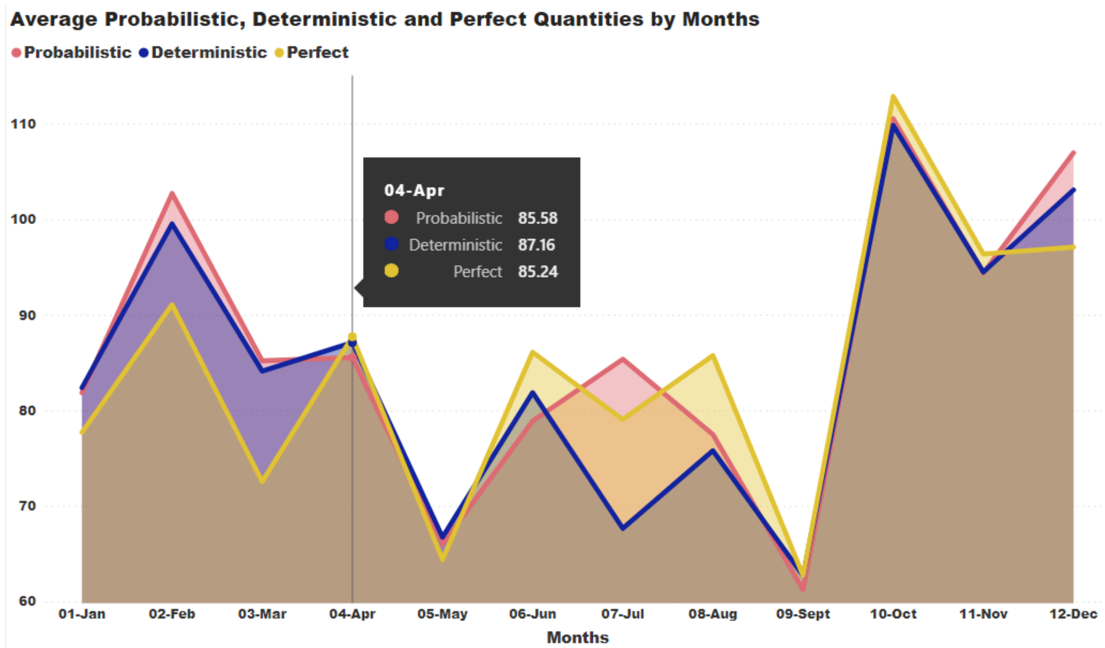

Figure 3: Deterministic and Probabilistic production

4. Probabilistic Case: In this strategy, the production quantity of the wind farm is predicted with a certain probability. An optimal quantile, a probabilistic threshold for power generation, is utilized in this case. The quantiles are calculated using formula 1.

$$\frac{\pi^{\mathrm{Dw}} \cdot \psi^{\mathrm{Dw}}}{\pi^{\mathrm{Up}} \cdot \psi^{\mathrm{Up}} + \pi^{\mathrm{Dw}} \cdot \psi^{\mathrm{Dw}}} \tag{1}$$

π^{Dw} is the probability that the system is downregulated
π^{Up} is the probability that the system is upregulated
$\psi^{\mathrm{Dw}} = \lambda_{\mathrm{Up}} - \lambda_{\mathrm{s}}$ with λ_{Up} upregulation price and λ_{s} the day ahead price

$\psi^{\mathrm{Up}} = \lambda_{\mathrm{s}} - \lambda_{\mathrm{Dw}}$ with λ_{s} the day ahead price and λ_{Dw} the downregulation price

The probabilities π^{Dw} and π^{Up} have been calculated using data from past years, precisely 2013, 2014, 2015 and 2016. By calculating the up regulation, down regulation, and market balance hours for each year and then taking the average of them, these probabilities have been determined. Similarly, λ_{Up}, λ_{s} and λ_{Dw} are average prices from the 4 sample years. Having taken the average values for the previous 4 years to 2017, 52 quantiles have been calculated, one for each week of 2017: the quantiles are shown in figure 4.

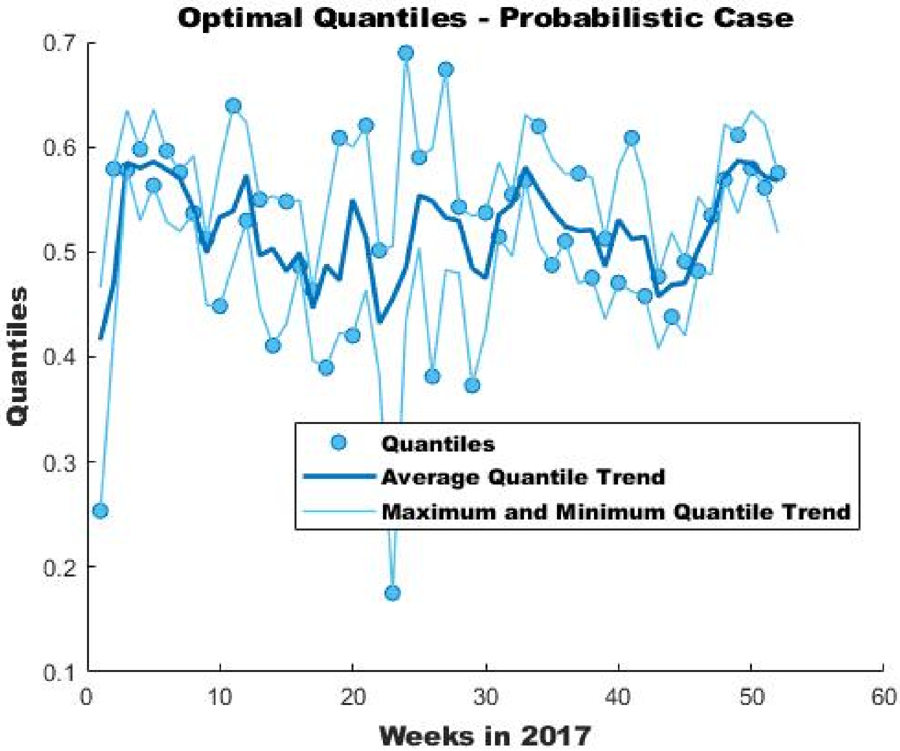

Figure 4: 52 quantiles for each week in 2017

Given the quantiles, the wind farm's production values are found from the "Horns Rev" data and are used to calculate the revenues for the balancing market. Since in the data, not all quantiles were present, for the cases in which a different quantile from the stated ones was calculated, an interpolation was undertaken: in this way new quantities for the specific quantile were found, making it possible to find a more precise forecast. This is also an important factor to consider when analyzing the performance ratio value. Subtracting this value from the day ahead revenue, we obtain the final profit of the analyzed wind farm.

3. Revenue Calculation

The calculated day ahead revenue follows a simple approach of multiplying the market price with the amount of energy that is bid. This is calculated on a hourly basis for the given time period.
As mentioned in the introduction the balancing revenue accommodates for the deviation in the system by penalizing the producers who create the imbalances. The balancing revenue is calculated by multiplying the difference between the amount that has been bid and the actual power produced with the imbalance price (down-regulation or up-regulation) for each hour of the given time period. The balancing revenue could take both a positive or negative value for a given hour depending upon the deviation between the bid and the actual production.

Finally the overall revenue is calculated for each hour using the following equation

$$\text{Overall revenue} = \text{Day ahead revenue} + \text{Balancing revenue}$$

Meaning, the revenue is the sum of the two market clearings, the first depending on the day-ahead price and the offer made into the day ahead market. The second depending on both the day-ahead price and the offer made, but also the actual production the state of the system and the relevant balancing price.

4. Analysis

In this section, revenue analysis of the various market participation strategies that could be performed by the "Horns Rev" wind farm is undertaken. The section furthermore consists of a comparison of the fluctuation of the strategies, based on the minimum and maximum revenue (Day-ahead and balancing markets) for a given time unit.
For each strategy, the goal of improvement in performance with respect to the previous strategy was tried to be obtained, striving for the best forecast to get as close to the perfect information case as possible. Also, the strategy performance is calculated by the equation given below:

$$\text{Performance (\%)} = \left(\frac{Strategy\ revenue}{Perfect\ revenue}\right) \text{ x } 100$$

Bidding Strategy	Strategy performance
Nominal Capacity Bidding	89.81%
Average Prognosis Bidding	92.60%
CF Determined Bidding	93.19%
Correction Bidding	95.35%
Deterministic	96.98%
Probabilistic	96.69%

Table 1: Efficiency of each bidding strategy utilized by "Horns Rev" wind farm

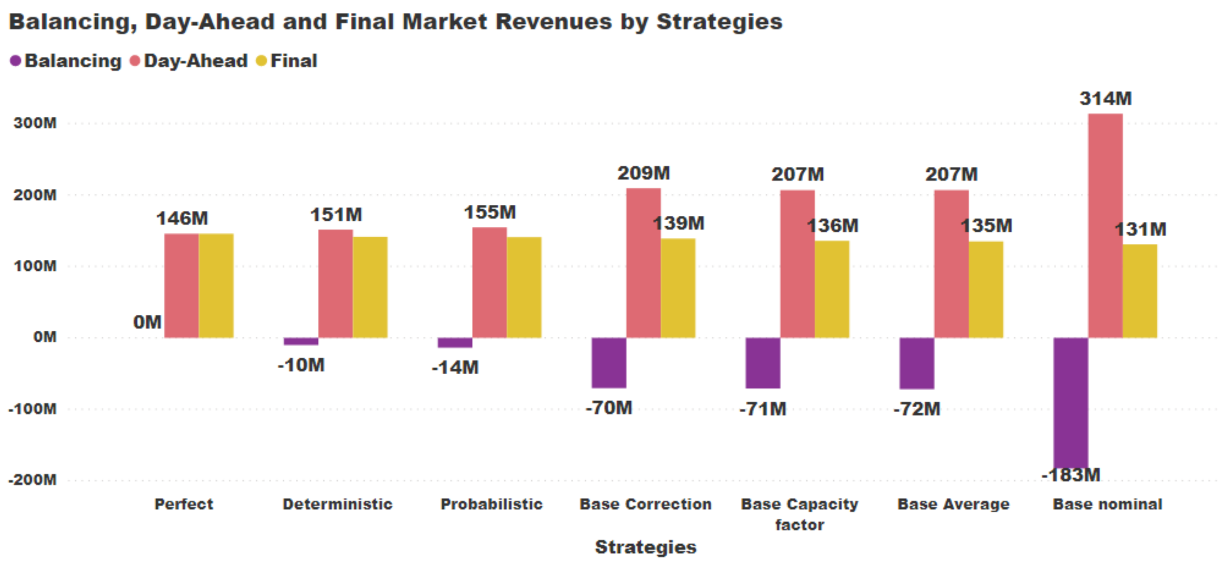

Figure 5: Day ahead, balancing & final revenues throughout 2017

1. Perfect Information Case: The production obtained in this case is exactly equal to the power produced by the wind farm. This is shown both in figures 2 and 3 where it is used to analyze the outcomes of the different base strategies. Overall, the curve follows a typical pattern for a renewable energy source: it has high volatility and production is not always constant. Furthermore, some cases of both high (October through December) and low (May and September) production occur: these are caused by times of resource availability, which is also affected by some seasonality patterns. This will affect the outcome of the different bidding strategies utilized by the wind farm as explained in the following. Finally, this case, as expected, yields the highest revenues since there are no cases of up or down regulation in which "Horns Rev" incurs in losses. Figure 5 shows this. The revenues for the wind farm throughout 2017 are shown in figures 6, 7 and 8.

2. Base Case:

   - Nominal Capacity Bidding: It is expected that this strategy would yield the worst performance (89.81%) because most of the days there will be a case of underproduction and this would lead to high penalization in the balancing market due to upward regulation. As shown in figure 5 the day ahead revenue is significantly high (314 million DKK) but it has also faced heavy penalization (-183 million DKK) and this is responsible for very low overall revenue. Also, figure 6 shows the monthly overall revenues that was earned by this strategy and as expected, the plot for this strategy is placed at the bottom since it incurs heavy penalization.

   - Average Prognosis Bidding: The performance of this strategy (92.60%) is better than the previous case because it does not participate in the market with very high quantities and would incur less revenue loss in the balancing market. Albeit, this strategy would also face frequent penalization throughout the year. As shown in figure 5 the day ahead revenue is 207 million DKK but due to numerous up regulations (figure 11) in the balancing market (-72 million DKK) would lead to a decent final revenue of 135 million DKK. Also, figure 6 shows the monthly overall revenues for this strategy and the plot for this strategy is placed above the plot of base nominal capacity bidding strategy.

   - Capacity Factor Determined Bidding: The performance of this strategy is shown in table 1. In accordance with the goal set to improve the performance in each strategy, the Capacity Factor strategy shows a performance of approximately 93.19%: this is a good improvement compared to the previously implemented base cases. From figures 2 and 6 respectively bid quantities and revenues for this strategy can be seen. As expected, the quantity bid by "Horns Rev" with this strategy is represented by a constant line at the value of 105.3 MW. When comparing it to the perfect information case, the difference between the two stands out: if one were to calculate the average value of the perfect information case though, a value of 103.9 MW would be obtained. This quantity is very close to the one bid each hour by the implemented strategy, explaining the good performance obtained. Furthermore, one can observe how in the months of May and September the biggest difference between the forecasted and the perfect information quantities is obtained: this difference is reflected in the revenues obtained by the wind farm, that drop significantly in these two months since the over estimation and reduced production incur in substantial losses. More can be seen in figure 5. The reason for this drop in production is due to low wind experienced at the site, which happens seasonally throughout the years.

- Correction Bidding: With a performance of 95.35% this strategy exceeds the performance of the previously applied base strategies. Although figure 11 from the appendix shows that for the majority of the time (84.83%) this strategy falls in the negative imbalance, figure 5 draws quite a contrast picture, with base correction having almost the same balancing revenue as compared to the other base strategies, this could be attributed to the fact that during those negative imbalances the up-regulation price could have been lower or as seen in figure 2 by virtue of a similar trend as the actual production the difference between the two quantities could have been negligible, thereby leading to better performance compared to other cases.

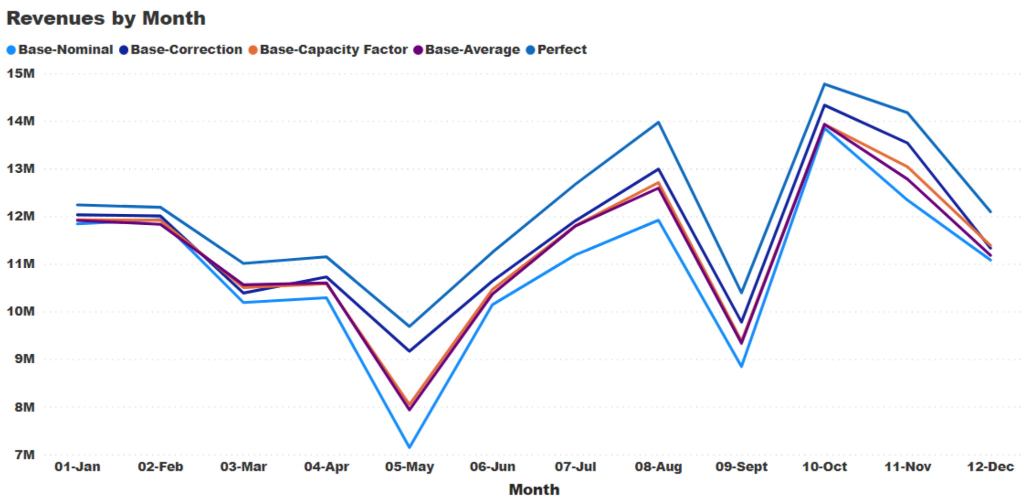

Figure 6: Revenues for the base cases

Figure 6 draws a clear picture of how the revenues perform over the provided time period, with the nominal performing quite poorly for most of the time. One interesting point to be noted is that the trend of capacity factor and base average are quite similar and in the initial few months earn a similar revenue as the correction case does.

3. Deterministic Case:

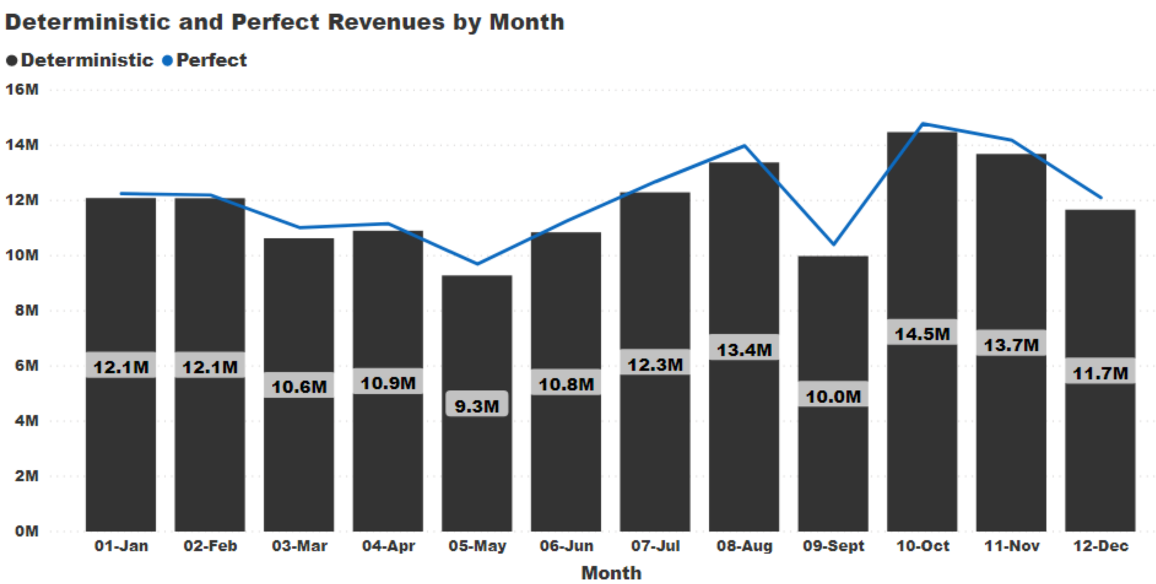

Figure 7: Revenues Deterministic case

The revenues for this strategy are shown in figure 7: it can be seen that overall, this strategy comes very close to the perfect information one in terms of profit, obtaining a performance of 96.98%. In fact, for all months the revenues just differ by a small quantity, making it the best bidding strategy among the ones presented: taking the month of April as an example, in fact, a very close estimation is obtained. Another factor to be considered in the low number of negative imbalance hours in the market which helps the case to accumulate the lowest balancing revenue of -10 million DKK thereby boosting the final revenue. This month in fact, as can be seen in figure 3 the quantities that were bid following the deterministic strategy and the actual energy produced are very close to each other, showing the effectiveness of this forecasting method.

4. Probabilistic Case: Probabilistic with a performance of 96.69% along with the deterministic comes closest to the perfect case when compared to the other strategies. This could be attributed to the bids as shown in figure 3, the trend for the probabilistic case is almost similar to the perfect and deterministic case and the average bids for some months miss the perfect case by a negligible value. This pushes the revenue of probabilistic to be at par with the perfect revenue for several months as shown in figure 8. As expected due to more hours of negative imbalance (58.63%) as shown in figure 11 compared to the deterministic case, probabilistic ends up with a bit larger balancing revenue of -13.7 million DKK. In conclusion, as shown in figure 5 a better day-ahead revenue (154 million DKK) along with a low balancing revenue helps the probabilistic case to outperform the base strategies by a good margin.

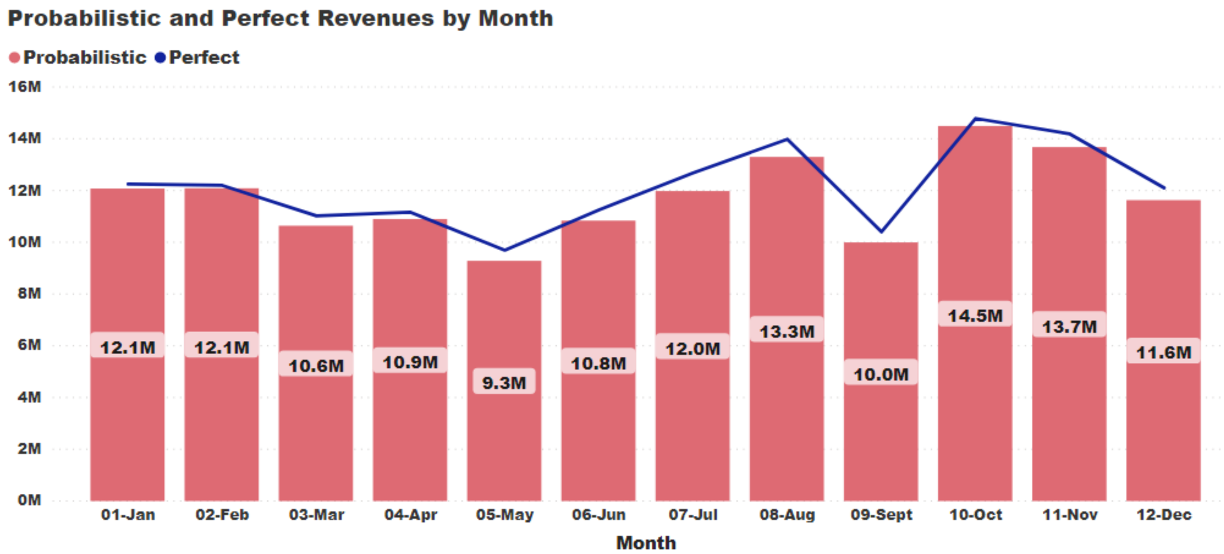

Figure 8: Revenues by Probabilistic forecast

4.1. Fluctuations

Some strategies depend on forecast values mainly, while some could also utilize historical data. The better the models are at predicting the prices, the less penalization should be observed. Furthermore, the more accurate the forecast is, the less fluctuation should be observed and the revenue loss from balancing should be minimized. This is seen for the perfect strategy (figure 12), where the revenue is the highest overall, and the daily fluctuation is limited to be in the positive plane for most of the days, rarely achieving negative revenues.

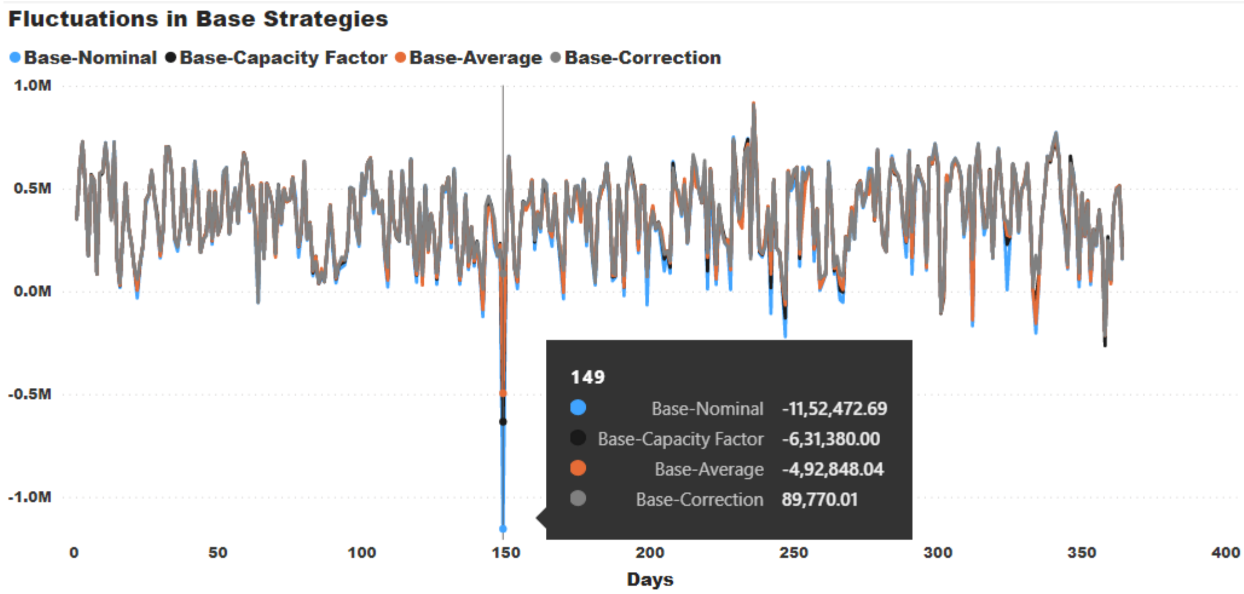

Figure 9: Fluctuation in daily Revenues for Base strategies

In figure 9 the fluctuations of daily revenues in the base strategies is clearly seen. The correction based strategy is less volatile and would act like a reference for other base strategy. As expected, the nominal capacity strategy would be highly volatile since it is not forecast based. On day 149, the correction based strategy (gray) is earning around 90,000 DKK and nominal capacity strategy (blue) is losing maximum money i.e. -11,52,472 DKK because this is case of underproduction and the system is in upward regulation having an adverse affect on the revenue. Also the average actual power produced on day 149 is 71.5 MW and in case of average prognosis strategy (orange), the average forecasted power is 97.7 MW for that day and this would lead to a revenue loss of -4,92,848 DKK. On the other hand the capacity factor strategy (black) participates in the market with 105.3 MW and obviously loses more money i.e. -6.31,380 DKK.

4.2. Cumulative revenues

The figure (10) below shows the comparison of all the participation strategies in terms of cumulative revenues. The abscissa represents the month (time) and the ordinate represents the accumulated revenues (million DKK).
A perfect forecast consists in participation with exactly what you can produce, therefore bidding "perfectly". This means no penalization for not having bid enough (overproduction) and no penalization for having bid too much (underproduction). Therefore, the sum of all the day ahead prices and balancing prices in case of a prefect forecast would be maximum compared to all strategies. Also it is essential to note that the balancing prices in a perfect forecast would be zero (no overproduction & underproduction).
This plot would also show the difference between the other strategies. Particularly, the perfect forecast would yield a higher revenue and for other strategy the revenue would decrease according to the strategy performance with deterministic being the second, probabilistic being the third and so on for the base strategies.

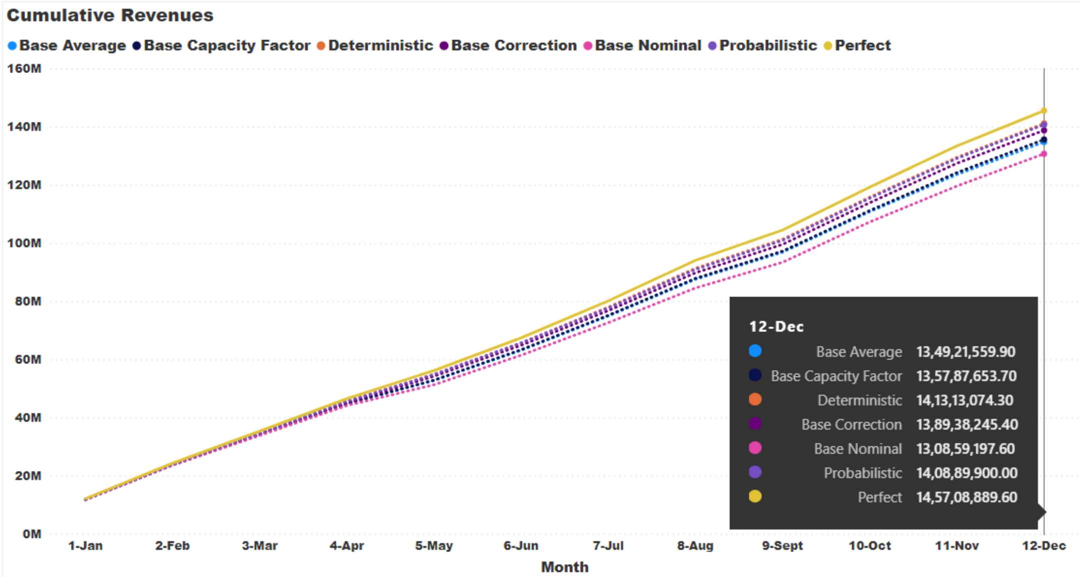

Figure 10: Cumulative revenues for all strategies

5. Recommendations

In this section, recommendations and possible improvements for the bidding strategies implemented by "Horns Rev" wind farm are discussed.

- Nominal Capacity Bidding: Since this strategy is the one that yields the worst performance, it is not recommended for the wind farm to adopt it.
- Average Prognosis Bidding: Since the data utilized to calculate was that of the whole DK1 area and not specific to the "Horns Rev" farm, this may have led to some imprecision. By utilizing data specific to the analyzed wind farm, more accurate average values may be obtained.
- Capacity Factor Determined Bidding: In this case, similarly to the one above, more detailed data would produce a better forecast. Nonetheless, this strategy performs very well and it is recommended for "Horns Rev" to implement it.
- Correction Bidding: By analyzing the error committed in predicting the forecast for past years, the most precise base strategy is obtained. If the data used to find this error was specific to the wind farm taken into analysis, an increased performance would surely be obtained. "Horns Rev" wind farm is highly recommended to use this strategy for their forecast formulation.
- Deterministic Case: Since utilizing data from the wind farm directly the resulting performance is the best out of all the strategies. The forecasting performed by the wind farm is very accurate and is overall quite close to the actual production obtained. This strategy is recommended to be used.
- Probabilistic Case: With the high resolution given by the calculation of the weekly quantiles, this forecast gives the second best performance and should be used by the wind farm. A more precise estimation could probably be obtained if daily quantiles were calculated.
  Further parameters if included could lead to better performance, during the analysis a similar trend for the regulation hours was found for the previous years as shown in the figures 13, 14 & 15. With sufficient data, the status of the market could be predicted on an hourly basis.

6. Appendix

Strategy	Day-Ahead Market	Balancing Market	Final Revenue
Perfect Information Case	145708889.6	0	145708889.6
Nominal Capacity Bidding	313689204.8	-182830007.2	130859197.6
Average Based Bidding	206803413.3	-71881853.33	134921559.9
CF Based Bidding	206740791.5	-70953137.87	135787653.7
Correction Based Bidding	209349387.5	-70411142.07	138938245.4
Deterministic	151428533.1	-10115458.76	141313074.3
Probabilistic	154631718.1	-13741818.05	140889900

Table 2: Day ahead, balancing and final revenues (DKK) for the different bidding strategies

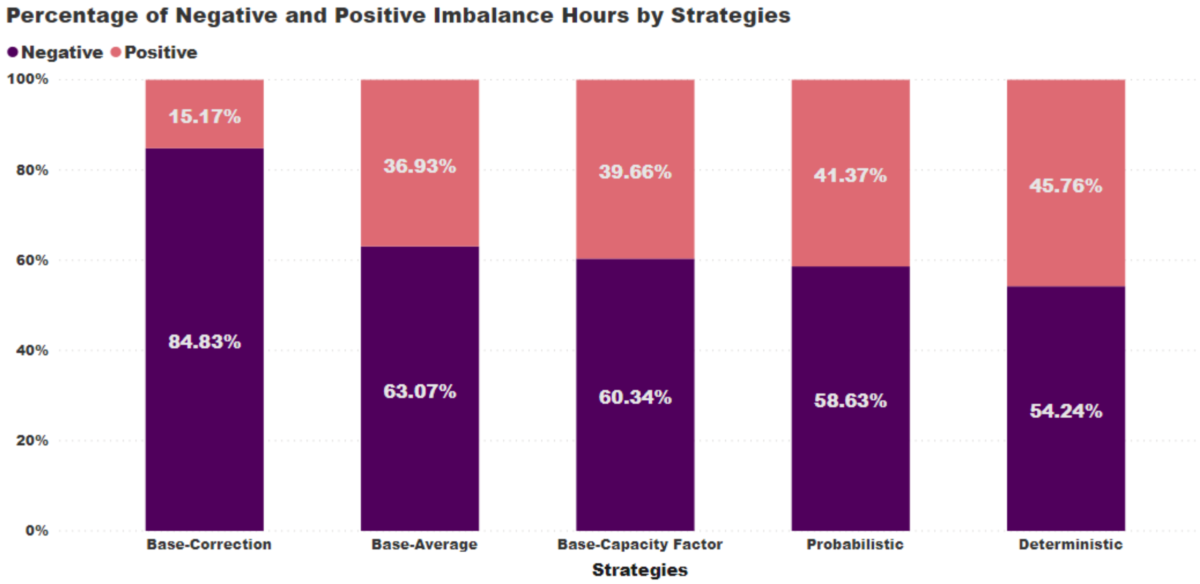

Figure 11: Imbalances faced by the strategies

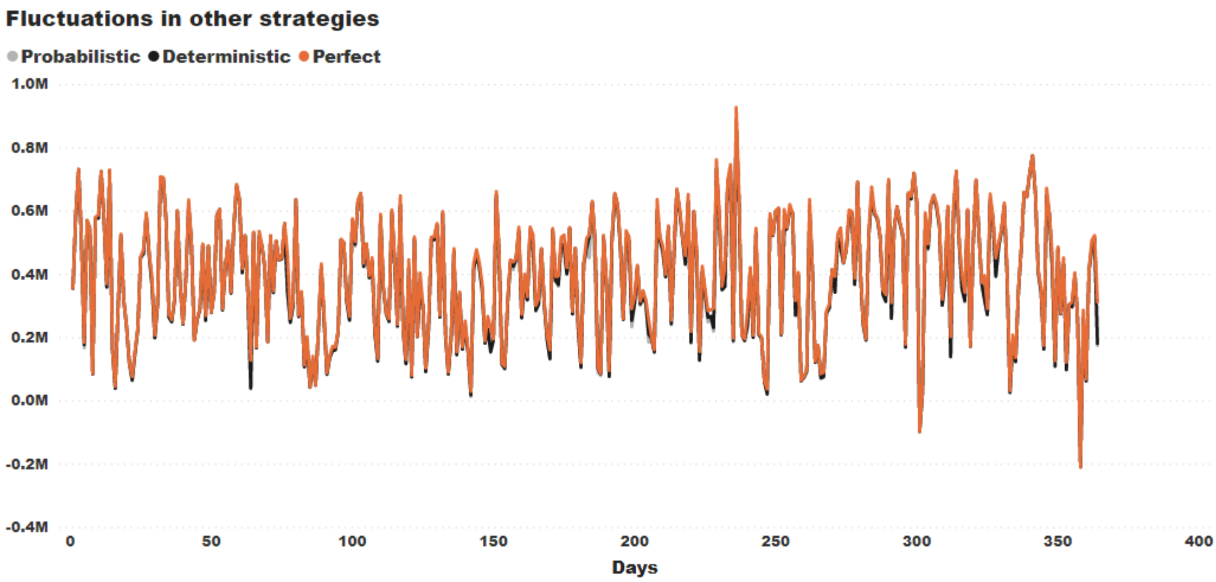

Figure 12: Daily Revenue Fluctuations for other strategies

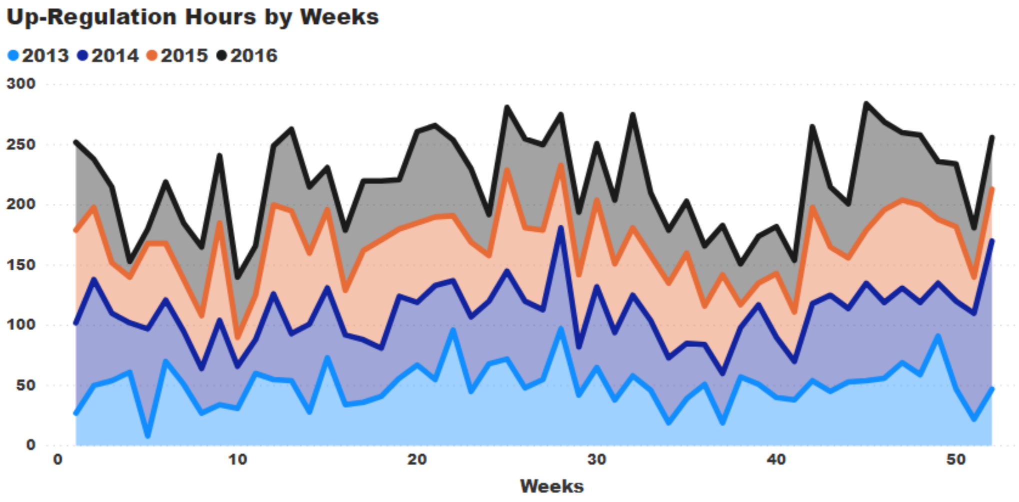

Figure 13: Stacked weekly up-regulation hours for previous years

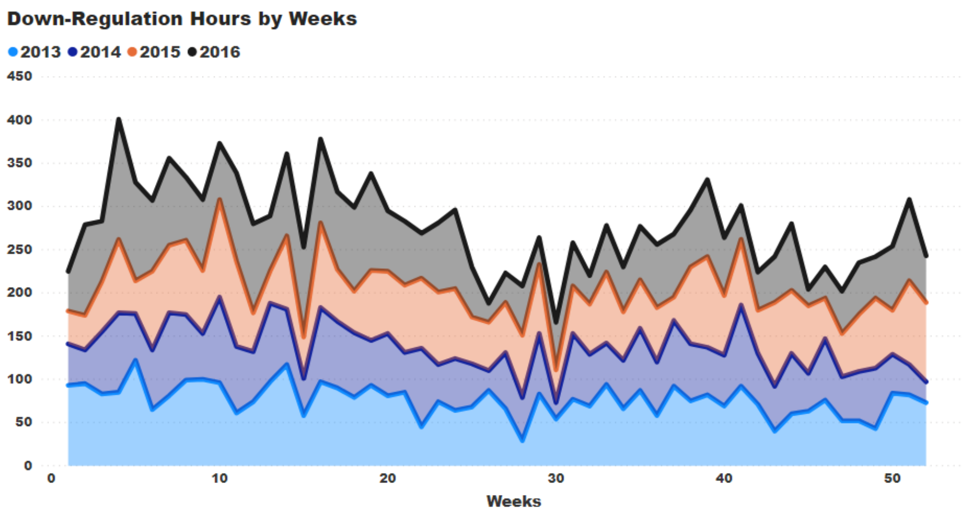

Figure 14: Stacked weekly down-regulation hours for previous years

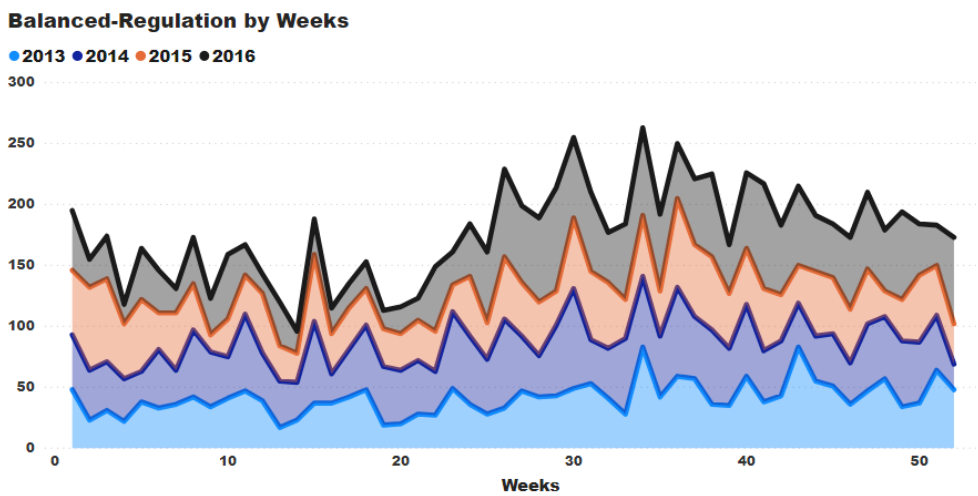

Figure 15: Stacked weekly balanced-regulation hours for previous years