

The interaction of Conventional Power Production and Renewable Power under the aspect of balancing Forecast Errors

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Abstract

With the Integrated Energy and Climate Programme (IEKP) /IEKP-01 07/ of the German Government 175 TWh (68 GW) power from renewable energy sources are expected until 2020 /DLR-01 08/. Wind energy plays a key role achieving this goal. From 1998 to 2008 the annual wind power production in Germany has increased from 4.5 TWh (2.9 GW) to 39.5 TWh (22.2 GW) and with the IEKP additional 48 TWh (16 GW) wind power are assumed until 2020.

To assess the interaction of renewable power and conventional power, it is essential to model their load profiles. Hence, methods are presented for modelling the consumer load and load curves for renewable power and combined-heat-and-power plants for the year 2020. The conventional power plants have to fulfil the need of the residual load, which is defined as the consumer load minus the production of the must-run plants. Interesting days in the year 2020 with a negative residual load or high gradients are examined.

In contrast to conventional power production (defined as thermal power plants and controllable hydropower plants), which can be scheduled, wind power can only be forecasted. In case of an incorrect wind power forecast the power gap or surplus has to be balanced by conventional power plants. Hence, the accuracy of wind power forecast in 2008 is analysed in regard to interesting days (offset errors, time-shift errors, high forecast errors), frequency distribution and the root mean square deviation (RMSD) of the forecast errors, the medial forecast error as a function of the forecasted power and the RMSD of the forecast errors as a function of the forecast period.

A tool named ProFeT has been developed to synthesize the chronological sequence of wind power forecast errors in 2020. The frequency distributions of the forecast errors in 2008 and 2020 are compared. To assess the interaction of conventional power production and renewable power, the forecast errors in relation to the residual load is regarded.

After the proposition of the Bundesnetzagentur the power for balancing forecast errors should be covered in the intraday market. Hence, the intraday market at the European Energy Exchange has been examined in regard to traded volume, the frequency distribution of the price differences between intraday and day-ahead market, the price difference as a function of the forecast error and as function of the traded volume.

The IEKP and the expected Growth of Renewable Power Production

On the 23rd of August 2007 the Federal Cabinet of Germany decided to implement the European guidelines concerning climate protection, renewable energy sources and

efficiency in the so called Integrated Energy and Climate Programme (IEKP). The result was two packages of measures and a bunch of acts and regulations. Considering the power production the two goals with the most significant impact are:

- raising the fraction of renewable energy sources up to 30 % until 2020 and
- doubling the electricity output from combined-heat-and-power (CHP) up to a fraction of 25 % of the electricity consumption.

It is not said how the future mixture of the renewable energy sources should be precisely, except that 10 GW offshore wind power should be installed. By order of the Federal Environment Ministry the Deutsches Zentrum für Luft- und Raumfahrt (DLR) has described a scenario, which fulfils the federal goals. **Table 1** shows the situation in the year 2007 and the power production in 2020.

Table 1: *Power Production 2007 and 2020 in the DLR scenario /DLR-01 08/*

	Installed Power in GW		Generation in TWh	
	2007	2020	2007	2020
Net Power Consumption	-	-	514	498
Gross Power Consumption			614	584
CHP	20.9 ¹⁾	30.1	71.6 ¹⁾	118.5
Wind	22.2	38.1	39.7	87.2
Photovoltaics	3.8	17.9	3.1	15.5
Hydropower	4.7	5.1	20.7	24.3
Biomass/gas	3.2	7.1	21.8	46.2
Geothermal Energy	0.0	0.3	0.0	1.8
Sum Must-Run	51.6 ²⁾	91.5 ²⁾	135.1 ²⁾	247.3 ²⁾

1) 2005 2) without biomass/gas, which is already balanced in CHP

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Power plants on the basis of CHP or renewable energy sources are called "must-run" power plants. Must-run means that under

- technical aspects, e.g. the thermal demand of a dwelling, which is supplied by a CHP device, must be fulfilled,
- or economical aspects, e.g. the marginal costs of a PV device is approximately 0, so it is always economical reasonable to produce power in case of sunshine,

the production schedule of the power plants is not flexible. The output of the must-run plants increases from 135 TWh to 247 TWh, which is half of the net power consumption in 2020. Interesting is that even in the DLR scenario, which is developed by order of the Federal Environment Ministry, the goal of doubling the CHP outcome is missed by a growth of only 65 %. This matches well with studies about CHP /FFE-13 07/, which shows that even in optimistic scenarios there won't be a doubling of the CHP output until 2020. One way to verify the chances of a success of each scenario of the renewable energy sources is to look at the achievements of the last years (as you can see in **Figure 1**).

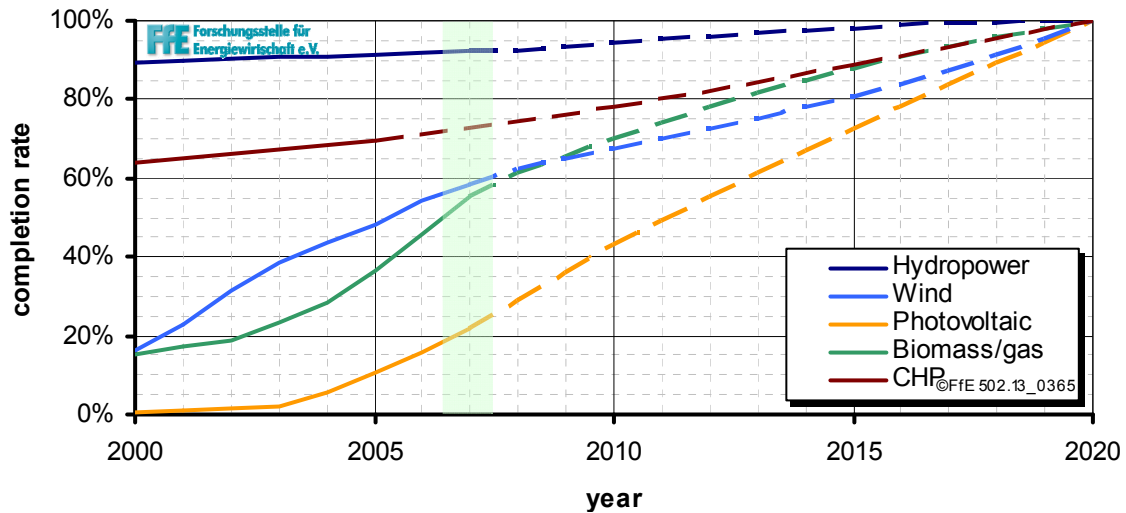


Figure 1: *Development of the installed capacity from 2000 to 2007 (drawn through lines) and the future growth according to the DLR scenario (normalised with installed capacity in the year 2020 = 100 %)*

Figure 1 shows that the assumed increase of renewable energy sources is feasibly taking into account the growth since 2004. Even the target capacity of Photovoltaic, meaning a growth up to five times of the current value, seems to be manageable by a continuation of the additional capacity of the last years. The growth of wind power slows down and is primarily carried out by the new installed offshore capacity. Summarised, the assumed capacities of renewable energy sources of the DLR scenario are reliable and are the basis for further calculations.

Load Profiles

To assess the interaction of renewable energy sources and conventional power, it is essential to model their load profile. Therefore, methods for modelling the load profile in 2020 of the consumer load, wind power, Photovoltaic power, hydropower and CHP have been developed.

Consumer Load

At the FfE a method has been developed to synthesize consumer load profiles on the basis of public data. The most important input in the model is the vertical system load, which is published by the four TSO in Germany for every quarter of an hour. The vertical system load is defined as the total amount of the power that flows out of the transmission network into distribution and large consumer networks. Hence, the power production on lower levels, e.g. from municipal utilities or renewable energy sources is missing in the vertical system load. The difference between the sum of vertical system load /TSO-01 06/ and the overall power consumption /BMWI-01 07/ accounted 180 TWh in 2006. On every third Wednesday of each month (the so called Wednesday balances) the total hourly electricity output is registered at the Federal Statistical Office and is published afterwards /STBA-01 08/. The missing power for each hour was added by a function that was gauged by the 12 x 24 values of the Wednesday balances. The method is described in /BVR-01 08/.

Wind Power Load

At the FfE a wind power model for Germany has been developed /FFE-04 08/. The physical approach is based on datasets of the atmospheric conditions contributed by the Deutschen Wetterdienst (DWD). The chosen 49 stations of the MIRIAM-station-net of the DWD are geographically corresponding with the installed wind power capacity. A year with good, medium and poor wind conditions with a temporal resolution of 10 minutes can be chosen. In Germany a multitude of different wind power plants are installed, therefore 20 different types are embedded in the model.

Photovoltaic Load

In a PV potential study at the FfE the overall roof surface in Germany has been determined, considering the inclination, what is appropriate for PV. For the load curve each rural district is related to a TRY region /DWD-01 04/ and to the global radiation /DWD-01 06/. This is the required data basis for building up 117 reference regions and for simulating the hourly PV load with the method DIN 5034. The model approach is described in /FFE-02 09/.

CHP Load

At the FfE a CHP load model for Germany has been developed. Data basis had been the load curves of the district heating from five big German municipal utilities, the ambient temperature of three gauging stations in the geographical centre of Germany, the annual power and heat output of the CHP plants of the German Heat & Power Association (AGFW) /AGFW-02 07/ and the monthly power and heat output of CHP registered at the Federal Statistical Office /STBA-01 08/. The result is the hourly load of CHP heat and power. On the assumption that the future characteristic of the CHP load is similar to the present load it is possible to synthesize with the FfE model the hourly CHP load in 2020 only by the input data of annual CHP output and the ambient temperature. The method is described in /BVR-01 08/.

The Load of further Renewable Energy Sources

The load of hydropower (only run-off-river plants) is approximately constant over the day but shows high seasonal differences. This was proven by the Wednesday balances of the Federal Statistical Office /STBA-01 08/. The seasonal profile has been derived from the seasonal profile of the years 2005 to 2007.

For the analysis of the residual load in 2020 there is no need to model the load of biomass/gas on its own, because biomass and -gas is combusted regularly in a CHP process.

The power out of geothermal with 1.3 TWh/a will be negligible in 2020. Hence, the load is not modelled and it could be expected that the load will follow a base load characteristic.

Analysis of the Residual Load

The load curves of 2007 and 2020 are compared and interesting time segments are identified. In 2020 there are periods, where the power production of the must-run plants exceeds slightly the consumer load (see **Figure 2** top left). The figure shows the load curves of a winter day. In the morning hours the consumer load is still very low and the CHP output already starts to increase to fulfil the thermal demand. It's a windy day with high wind power in the morning. The consequence is a negative residual load in the morning hours as you can see in the Figure 2 (down left). Additionally it must be regarded, that in reasons of system stability there always should be a minimum of controllable power plants running.

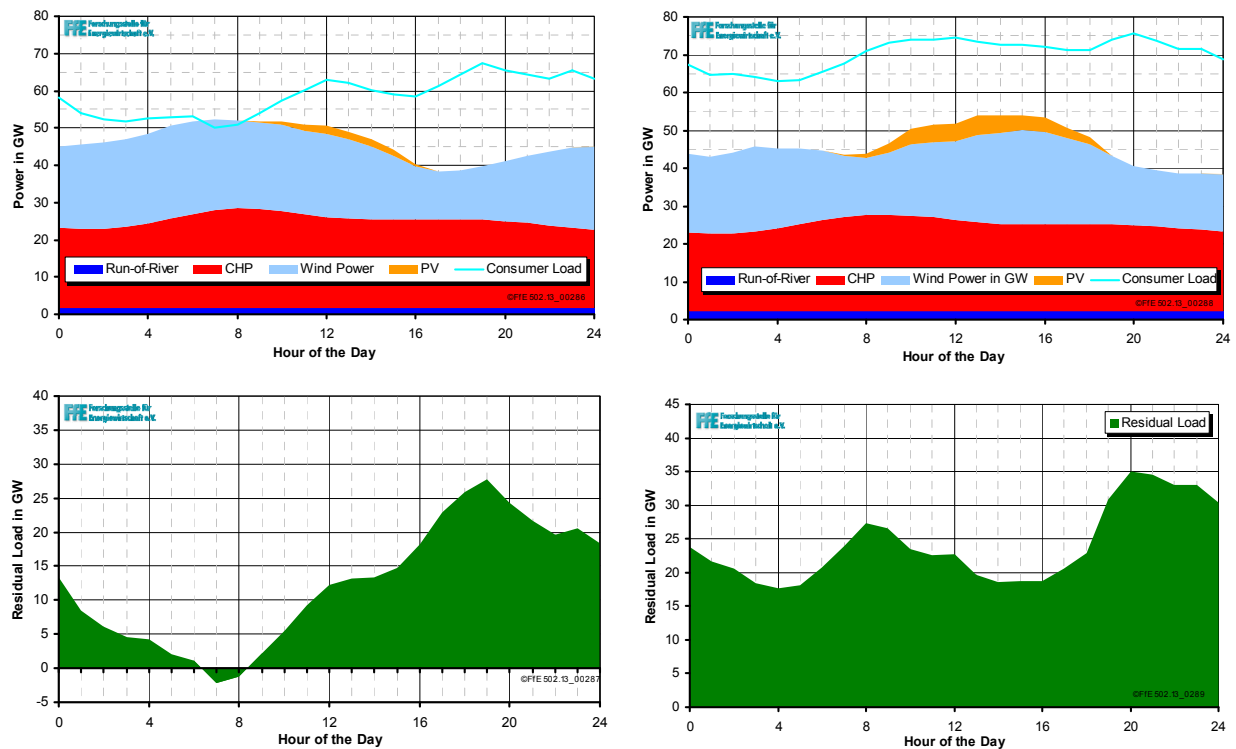


Figure 2: Consumer load and load of the must-run plants on two selected days in 2020 (top left & right) and the resulting residual load (down left & right)

Another important point is the analysis of the gradients of the residual load. Figure 2 (top right) shows the load curves on a day in March 2020. In the evening hours the consumer load increases, while at the same time PV power decreases due to sun set and wind power reductions because of a downturn of the wind. The result is a gradient of 8 GW/h of the residual load as it can be seen in Figure 2 (down right). This verifies that the integration of the renewable power is quite a technical challenge taking into account that the average residual load is about 37 GW.

The analysis of the load instead of the yearly output delivers more interesting aspects. For instance, in Germany for Photovoltaic power with less than 3 % of the overall power demand in 2020, no significant role is seen. However, the analysis of the load curve shows that there will be periods, when up to a quarter of the consumer load can be covered by Photovoltaic.

The Accuracy of the Wind Power Forecast

The transmission system operators (TSO) publish the forecast and the actual value of the hourly wind power in their control area. The forecast error is the difference between these two values and is defined as:

$$\text{Power}_{\text{Forecast Error}} = \text{Power}_{\text{Forecast}} - \text{Power}_{\text{Actual Value}}.$$

Hence, a positive forecast error means that the output of wind power has been over-estimated and positive reserve power has to be activated. A negative forecast error means accordingly, that the output of wind power has been underestimated and negative reserve power (activation of electrical consumer or decrease of conventional power) has to be activated. **Figure 3** shows the forecast and the actual value of four selected days in 2008.

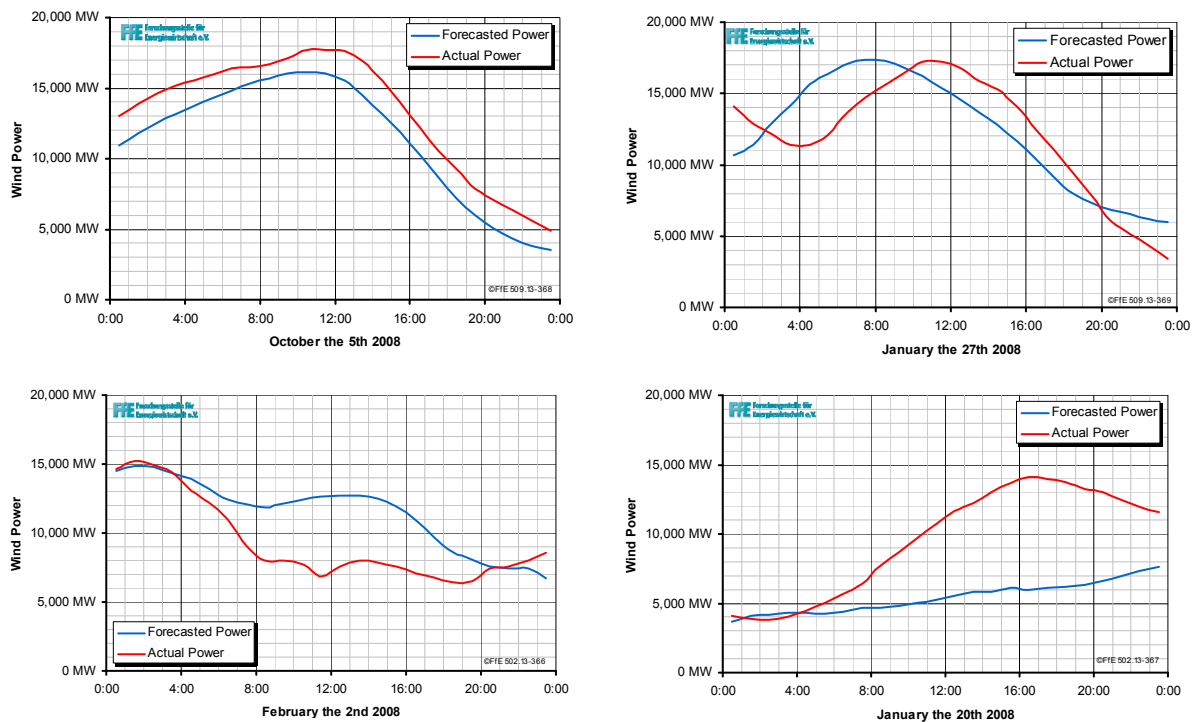


Figure 3: Selection of interesting forecast errors 2008: Off-set error (top left), temporal error (top right); maximum positive error (down left), maximum negative error (down right)

Besides randomized forecast errors two very typical kinds of forecast errors occur. The first one is an off-set error (e.g. Figure 3 top left) and the second one is a time shift (e.g. Figure 3 top right). The maximum positive forecast error has occurred on February the 2nd, with 5.7 GW (Figure 3 down left). The maximum negative forecast error has occurred on January the 20th with 8.1 GW (Figure 3 down right). All hourly forecast errors for the year 2020 were calculated. **Figure 4** shows the frequency distribution of the forecast errors.

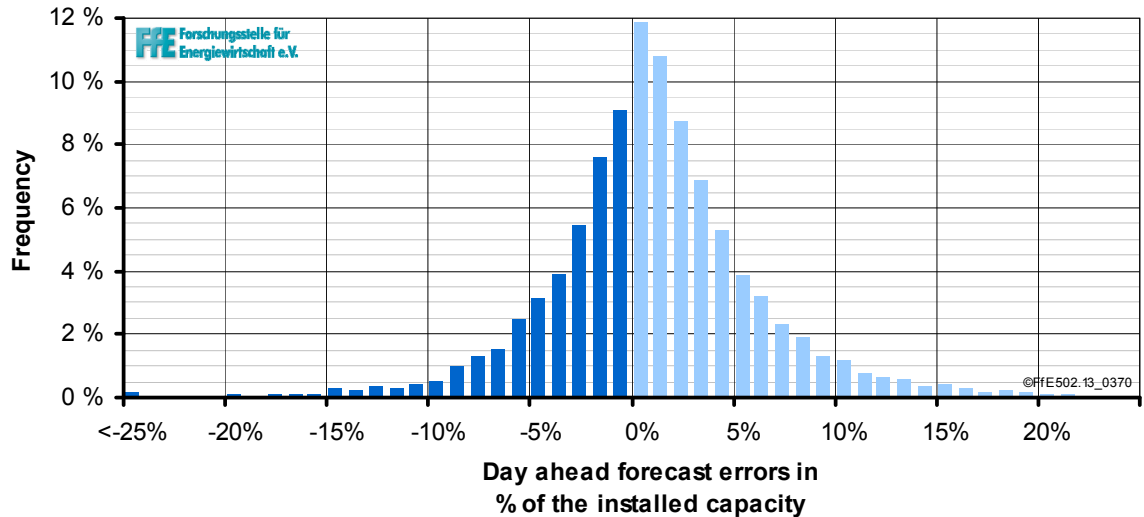


Figure 4: Frequency distribution of forecast errors in 2008

There is a little right shift in the frequency distribution that means that more frequently the day ahead forecast overestimates the wind power, than underestimates it. The majority (73 %) of the forecast errors are smaller than 5 % of the installed capacity.

For the interaction of the conventional power plants and the wind power plants concerning forecast errors, it would be meaningful if there is a function between the forecasted power and the medial forecast error. This function shows **Figure 5**.

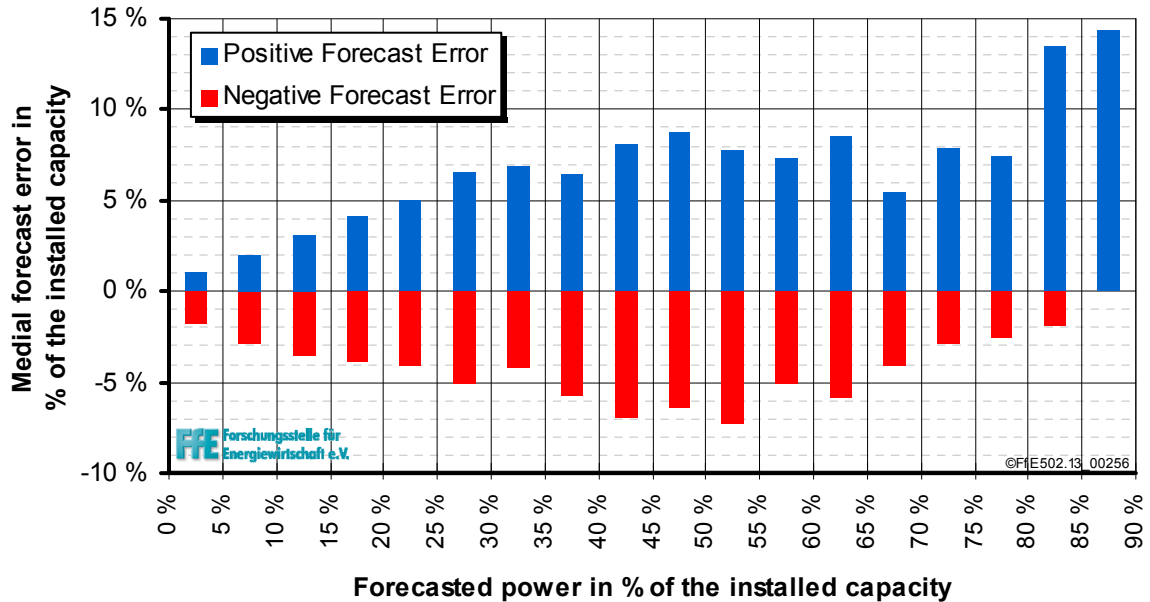


Figure 5: Medial forecast error as a function of the forecasted power

With increasing values of the forecasted wind power up to about 30 % of the installed capacity the forecast error is increasing as well. Then, with higher values of forecasted wind power, the positive forecast errors stay on the same level, except the extreme forecast values of more than 80 % of the installed capacity. The negative forecast errors even decreases with higher forecasted power.

To measure the accuracy of the wind power forecasts the root mean square deviation (RMSD) of the hourly forecast error was calculated. The RMSD of the hourly forecast errors for the sum of the wind power in Germany's four control zones has been 5.6 % in 2008. This is an improvement in comparison to the year 2007 with a RMSD of 6.1 %. The accuracy of the day ahead forecast is much better for the first hours of the following day as for the last hours, because of the shorter forecast period (see **Figure 6**).

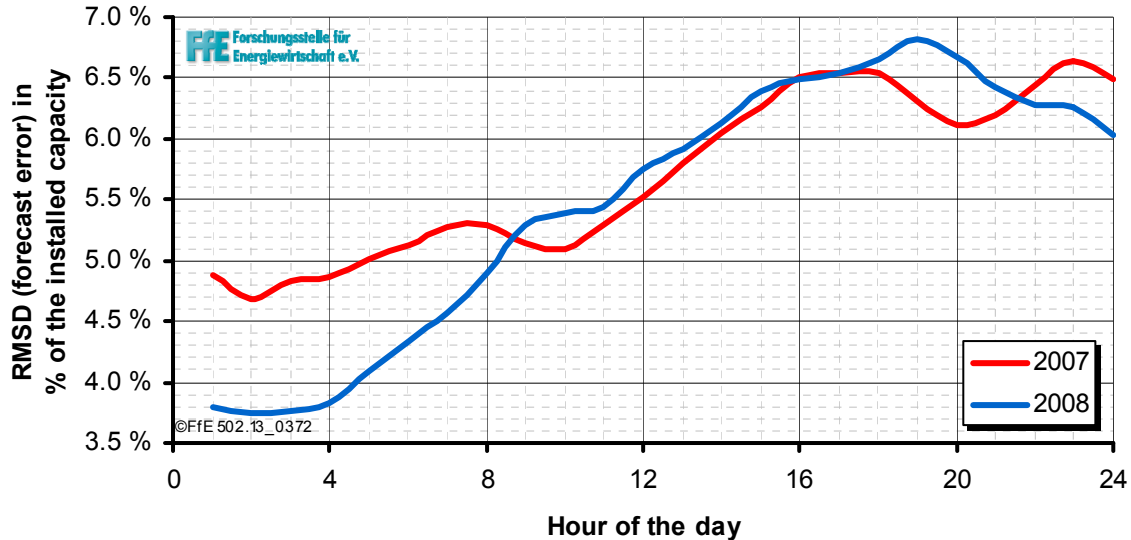


Figure 6: *The RMSD of the forecast error as a function of the hour of the forecasted day*

The RMSD of the forecast errors for every time of the day was calculated. For the first four hours of the following day the RMSD is less than 4 %. For the last four hours of the following day the RMSD is between 6 % and 7 % in the year 2008. This analysis shows also that the improvements of the wind power forecast from 2007 to 2008 are mainly due to a better short term forecast.

Balancing Wind Forecast Errors in 2020

For assessing the interaction of conventional power production and renewable power under the aspect of balancing forecast errors, the characteristics of the forecasts errors in 2020 have to be determined. This means that besides the future distribution and the RMSD of the forecast errors the chronological sequence of the forecast errors must be modelled correct. Therefore, within the project a method (ProFeT: Prognosefehlertool) for generating the future distribution of the forecast errors has been developed. The goal was to meet the expected RMSD, e.g. a day-ahead RMSD of 3.7 % in 2020 /ISET-02 08/, as well as the characteristic of the forecast errors, as they have typically occurred in 2008. Besides the public data, the forecasts of different tools and sources applied by one TSO were taken into account determining time dependency of the wind power forecasts.

For the year 2020 the demand of conventional power capacity to fulfil the forecast errors is quantified by the tool ProFeT. The distribution of the forecast errors in the year 2020 in comparison to the year 2008 is shown in **Figure 7**.

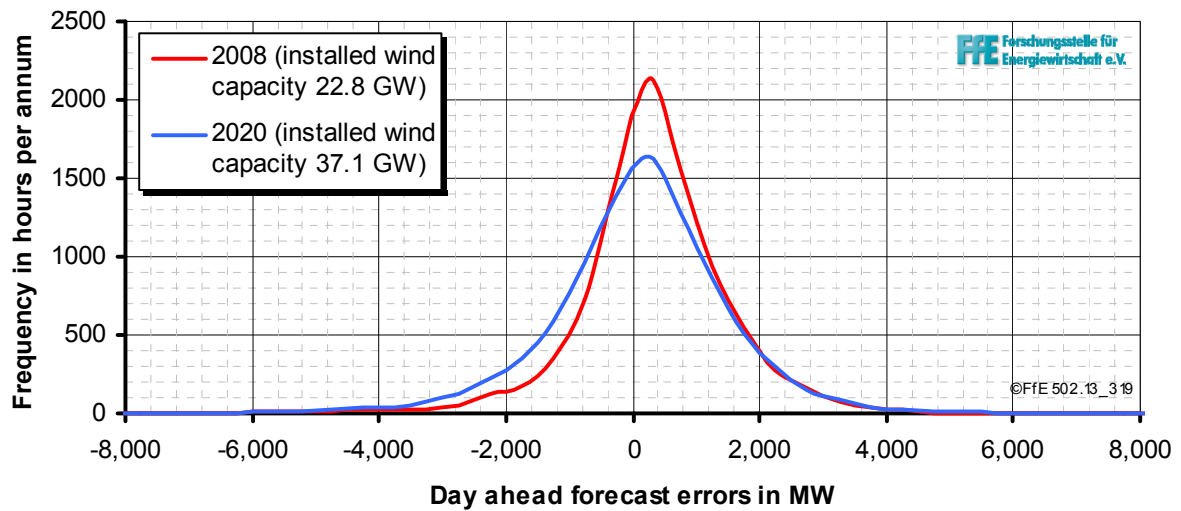


Figure 7: Comparison of the frequency distribution of the day ahead forecast errors in 2008 and 2020

On the one hand the average power to balance the forecast errors will only raise from 833 MW to 1025 MW (+23 %) due to improvements of the forecast tools and the additional offshore share, in spite of a 72 % increase of the installed wind capacity. On the other hand the requirements for the system stability are challenged by increasing extreme forecast errors, as it is considered in **Figure 8**.

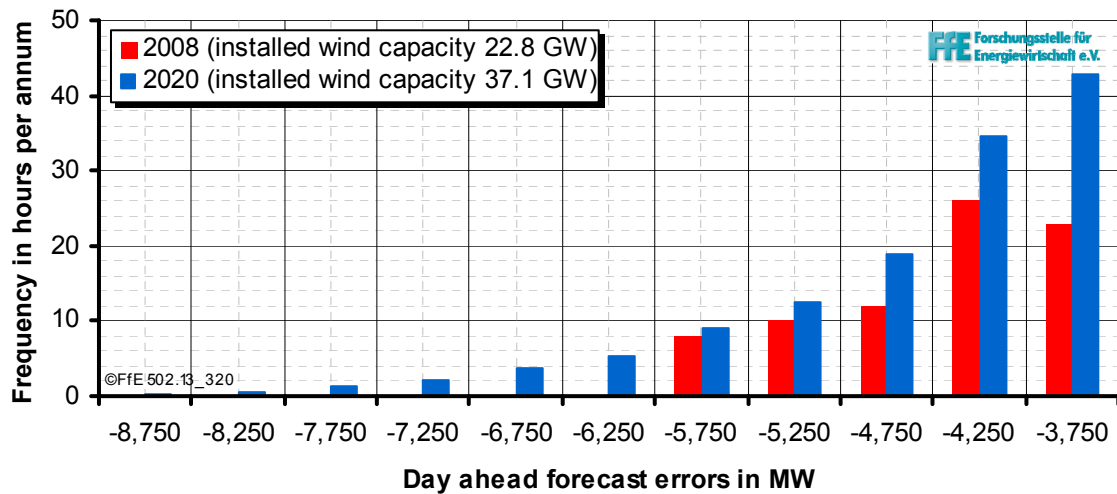


Figure 8: Distribution of extreme negative forecast errors 2008 and 2020

Extreme negative errors with values smaller than -3,750 MW occur significantly more often in 2020 than in 2008. Beyond that, there are even negative forecast errors with values smaller than -6,000 MW.

For assessing the interaction of conventional power production and renewable power under the aspect of balancing forecast errors, it is of great importance how much conventional power is online when the forecast errors have to be balanced. **Figure 9** shows the distribution of the forecast errors in relation to residual load (is consistent with the conventional power) for the years 2008 and 2020.

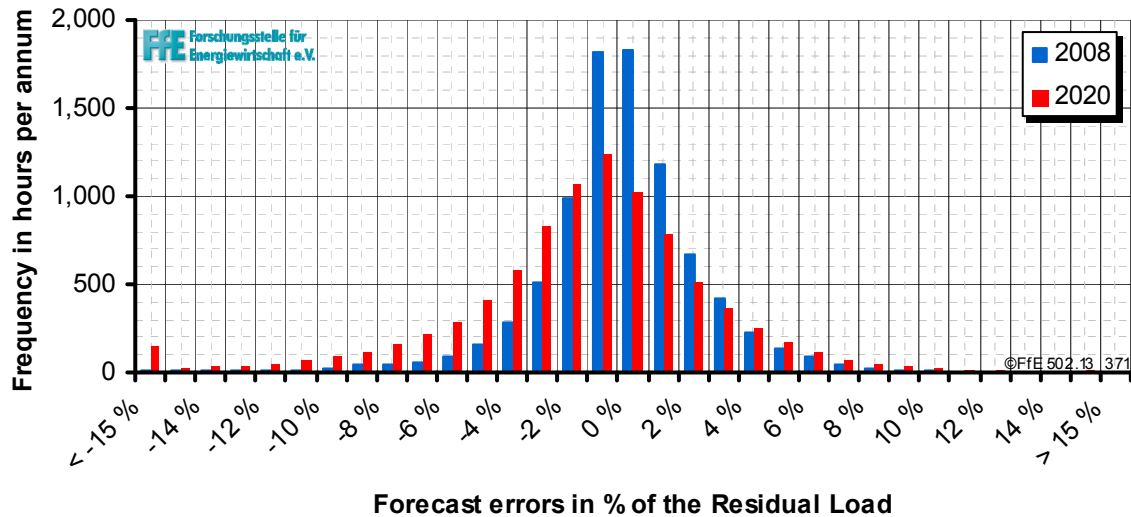


Figure 9: Comparison of the frequency distribution of the forecast errors in % of the residual load

Figure 9 shows that in 2020 much more frequently than in 2008 the forecast error is a significant fraction of the residual load. That means that the system stability is not only challenged by increasing extreme forecast errors but also by less conventional power plants being online for balancing.

Up to now two of the four German TSO balance the forecast errors with the so called "Wind Reserve". That means, that these TSO pay a price to power plant operators that in case of a need of balancing forecast errors they got enough capacity available.

The German Bundesnetzagentur demands a change of the market rules for providing the reserve power balancing forecast errors /BNA-01 08/. The new rules state, that in case of a short term forecast deviates from the "day ahead" forecast from the day before, the difference in power must be cleared in the intraday market. Therefore a statistical analysis of the day ahead and intraday prices at the European Energy Exchange (EEX) was done and the results are shown in **Figure 10**.

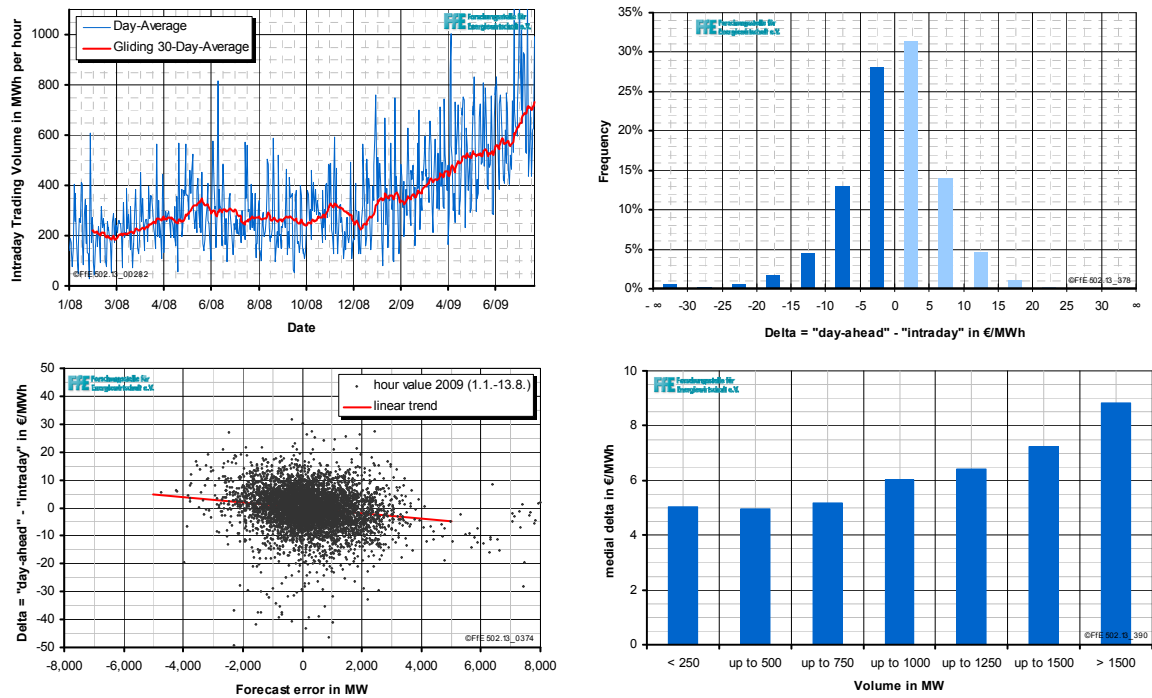


Figure 10: Analysis of the intraday-market: Trading volume in the intraday market at the EEX (top left), frequency distribution of the price differences between the day-ahead and the intraday price (top right), price difference between the day-ahead and the intraday price as a function of the forecast error (down left), price difference between the day-ahead and the intraday-price as a function of the trading volume (down right)

The medial dealt volume in the intraday-market (2008: 6 GWh per day) is negligible in comparison to the day-ahead market (2008: 400 GWh per day). However, it must be accounted that the intraday trading is still dominated by over-the-counter (OTC) deals and that there is a significant increase of the trading activity in 2009 (Figure 10 top left). There are differences between the day-ahead and the intraday prices from -20 and +20 €/MWh, but the medial price difference with -0.3 €/MWh in the time period from 01.01.2009 until 13.08.2009 is not significant (see Figure 10 top right).

It has been examined, if the difference between the day-ahead and the intraday prices is a function of the forecast error (see Figure 10 down left). The statistical spread is very high, hence the correlation between forecast error and price difference is weak. However in times of high positive forecast errors the price differences tends to be negative and in times of high negative forecast errors the price differences tends to be positive. This is consistent with the expectations, because a high positive error means that additional power for balancing is demanded in the market during the day. And correspondingly a high negative error means that a surplus power is offered during the day. The slope of the regression line is -1 €/MWh per 1,000 MW forecast error. This means that the average price in the intraday market is per 1,000 MW positive forecast error 1 €/MWh higher than in the day-ahead market for the same hour. And correspondingly the average price in the intraday market is per 1,000 MW negative forecast error 1 €/MWh lower than in the day-ahead market for the same hour. This observation matches well with the function that with increasing volume the price difference is increasing as well.

Conclusions

To assess the interaction of renewable energies and the conventional power plants it is essential to consider not only the installed capacity and the yearly power output but also the load curves. The analysis of the scenario "doubling the renewable power production until 2020" shows high requirements for the operation of the conventional power plants due to sporadic negative residual load and high gradients of the residual load.

While the installed wind capacity increases significantly up to 2020, the average power for balancing forecast errors will raise moderately. However the effects on the conventional power plants are extensive because the extreme forecast errors will be more frequent and less conventional capacity will be online for balancing the forecast error.

A future approach of balancing forecast errors in the intraday-market has to face the challenge that the traded volume is negligible in comparison to the day-ahead market and the needed balancing power. A slight interdependence between the forecast errors and the price difference between the day-ahead and the intraday market has been shown. This indicates, that today already a fraction of the balancing power is covered in the intraday market.

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