# Coal and Lignite Balanced German Grids in 2016

My recent note, “Getting Rid of Wind Energy in Europe”, was presented and discussed in “Energy Matters”[1]. The discussion includes questions on correlations and seasonal variations. This note is an additional study based on the comments and questions.

I am trying to understand the implications of wind and solar power on the power systems by comparing Germany and Denmark. The different penetrations of renewable power can characterize different stages of a development (table 1).

| 2016 | DE | DK |
|---|---|---|
| Wind/Load | 16,00% | 37,59% |
| PV/Load | 7,19% | 2,19% |
| Sources: Entso-e and Energinet | | |

*Table 1 – Shares of wind and solar energy in Germany and Denmark*

## Assessment of Results

- Wind and solar power are non-dispatchable. They require controllable backup and regulating capacity from other sources.
- The controllable power plants in Germany had, theoretically, sufficient capacity for balancing the German power system with the wind and PV[2] production in 2016.
- The electricity export from Germany in 2016 was driven by bottlenecks in internal German grids and by electricity demand in other countries.
- Solar power is better correlated with electricity demand than wind power. This means that additional PV requires less backup capacity than additional wind power.
- The variability range of electricity demand in Germany was 44 GW in 2016, but due to wind and PV, the controllable resources had to cover a range of 67 GW (+52%).
- The load factor of electricity demand in Germany was 73% in 2016, but only 58% for the residual load[3]. A declining load factor is an economic problem for the traditional power stations.
- Traditional German power plants were performing most of the necessary regulating work for the German power system in 2016, both by load following and by counter regulating the wind power variations.
- There are seasonal differences in operational conditions. The requirements for regulating capacity are lower during the summer season due to the influence of PV.
- The share of wind and solar energy in 2016 was 23% of the load in Germany and 40% in Denmark.
    - The share of solar power is still insignificant in Denmark. From a technical point of view, Germany seems to have a more reasonable distribution between wind and solar power.
    - Danish controllable power plants are doing load following, but most of the wind power variations are absorbed by the interconnections.
    - The regulating range to be covered by controllable sources in Denmark has increased by 72% (52% in Germany), due to wind power and PV.
    - The load factor for the residual load is only 42% (58% in Germany) and several traditional power stations have already been decommissioned or mothballed.
    - Denmark has no longer controllable capacity for balancing its own power system. The critical limit seems to be somewhere between a 23% and a 40% share of wind and PV (depending on national capacity arrangements).

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[1] http://euanmearns.com/getting-rid-of-wind-energy-in-europe/#more-18917
[2] PV: photovoltaic power (=solar power)
[3] The residual load is found by subtracting wind and solar power from the traditional load.

## How are Wind Power and Export Related?

The discussion in "Energy Matters" also includes the question if wind and solar energy have been exported. This is a philosophical matter. The usual arguments from both sides are represented.

| 2016 | | DE | DK |
|---|---|---|---|
| Export | Wind | 0,43 | 0,84 |
| Export | Wind+PV | 0,50 | 0,82 |
| Export | PV | 0,21 | -0,26 |
| Export | Load | 0,02 | -0,04 |
| PV | Load | 0,34 | 0,21 |
| Wind | Load | 0,05 | 0,16 |
| Sources: Entso-e and Energinet | | | |

*Table 2 - Correlation coefficients*

Some interesting information can be extracted from correlation coefficients of the time series (table 2). Correlation coefficients can be between -1 and +1. The correlation coefficient is zero for independent variables.

Controllable resources[4] must outbalance both the variations of *load* (load following) and the variations in *wind and PV*. In Germany, the variations of wind and load are practically independent, while there is some correlation between solar power and load. Low and negative correlations between load and non-dispatchable sources (PV and wind) indicate the need for additional controllable capacity.

The correlation between export and wind is high for Denmark and moderate for Germany. Import and export have absorbed essential parts of Danish wind energy variations.

The correlation between net export and solar power is positive in Germany and negative in Denmark. The reason is that exchanges are higher during the day, and that Germany has a net export, while Denmark has a net import. German export peaks and Danish import peaks are to some degree simultaneous with solar power peaks.

## The Residual Load Reveals Increasing Challenges

Apart from curtailments, wind and solar power are uncontrollable. This would be a minor problem if the correlation with load is high, but the low correlations in both Germany and Denmark (table 2) indicate that load following must be performed by other sources, such as dispatchable power stations, interconnections and flexible demand.

| | 2016 | Germany | | Denmark | |
|---|---|---|---|---|---|
| | | Load | Residual | Load | Residual |
| Max | GW | 75,4 | 72,4 | 6,1 | 5,6 |
| Min | GW | 31,5 | 5,8 | 2,2 | -1,1 |
| Range | GW | 43,9 | 66,6 | 3,9 | 6,7 |
| Load factor | | 73% | 58% | 63% | 42% |

*Table 3 - Residual demand is load minus wind and PV*

The residual load is the market, which is left for the controllable resources.

Table 3 reveals two challenges:

- A technical challenge, because decreasing controllable resources must cover an increasing variability range.
- An economic challenge due to a declining load factor[5] for the remaining traditional power plants.

With a 23% share of wind and PV, Germany still has a theoretical possibility to balance its power system by its own resources. This is no longer possible for Denmark with a 40% share. Without any measurable effect of demand flexibility, the critical limit could be somewhere between 23% and 40%.

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[4] Power plants and flexible demand. The effects of demand flexibility are so far modest.

[5] The load factor is the actual energy content divided by the potential energy content, found as the maximum power value times the number of hours.

## Seasonal Variations

There are some differences in German exchange patterns from month to month.

One difference is that exchanges are higher in winter than in summer (fig. 1).

In order to understand other differences we must examine two months in more detail. I have selected July and December 2016 for that purpose.

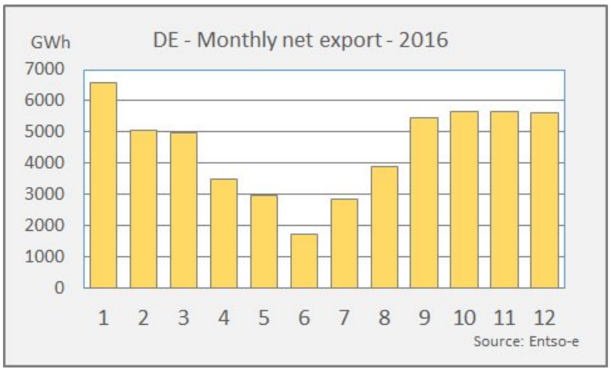


*Fig. 1 - High German export during the winter months*

## December 2016: Fossil Fired Units did Most of the Balancing Work

December 2016 was interesting (fig. 2). The variation range of German wind and solar power was about 35 GW, which is much more than the 15 GW variation range of exchanges.

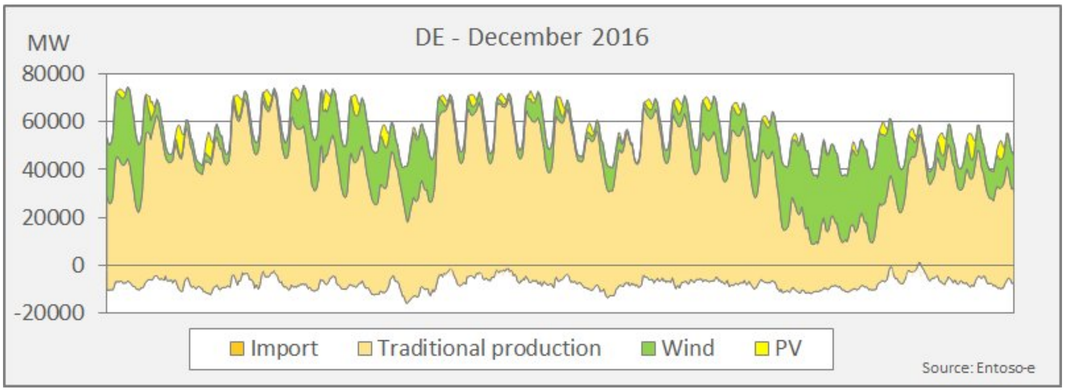


*Fig. 2 – Germany, December 2016. Export below axis.*

Solar power is modest in December, but there were PV peaks up to about 10 GW. The green areas show that there were both windy and calm periods in December 2016. The Christmas storm coincided with a series of days with low electricity demand. The orange areas are covered by controllable production. The orange area above the axis is the residual load and area below the axis is export.

The load variation was 38.6 GW in December but due to wind and PV, controllable sources had to cover a range of 63.6 GW. Interconnections did some of the balancing work, but a range of 54.8 GW was left to German power plants. The traditional German power plants were by far the most important source of regulating power in December 2016.

Fig. 3 shows how power plants, fired with gas, lignite and coal have contributed to the regulation in December. The variations reflect both daily load variations and the longer waves of wind power variation.

For the days 8 to 11 December spot prices in the range 25 to 50 €/MWh were able to reduce the fossil production to about 20 GW. For the days 24 to 27 December, volatile prices down to -67 €/MWh forced the fossil production down to a level about 10 GW.

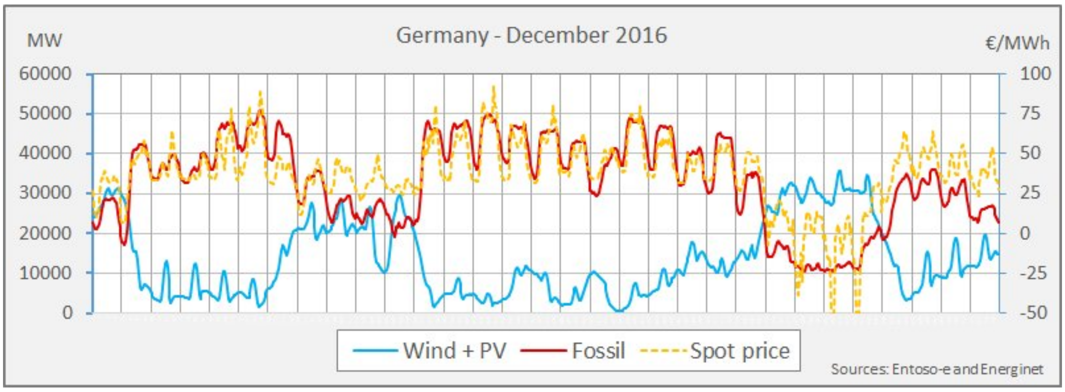


*Fig. 3 - Fossil fueled power varied between 20 and 50 GW in December*

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The total regulation range of dispatchable units was nearly 40 GW in December 2016:

- Gas-fired units: regulated from 7 to 15 GW
- Lignite-fired units: regulated from 6 to 20 GW
- Coal-fired units: regulated from 3 to 20 GW

The results show that the conventional power plants in Germany perform a larger regulating work than the interconnections. Coal- and lignite-fired units made the largest contributions. This is confirmed by the correlation coefficients for December 2016:

Wind and PV/net export: 0.29 Wind and PV/fossil production: -0.81

The question is if the windy Christmas days in 2016 forced power regulation to its capacity limits or if there will be resources left for additional wind power.

## July 2016: Peak Shaving by Solar Power

Wind and solar power had a much more regular variation in July than in December (fig. 4). The chart shows that PV saved peak power every day in July 2016.The maximum PV output was about 25 GW.

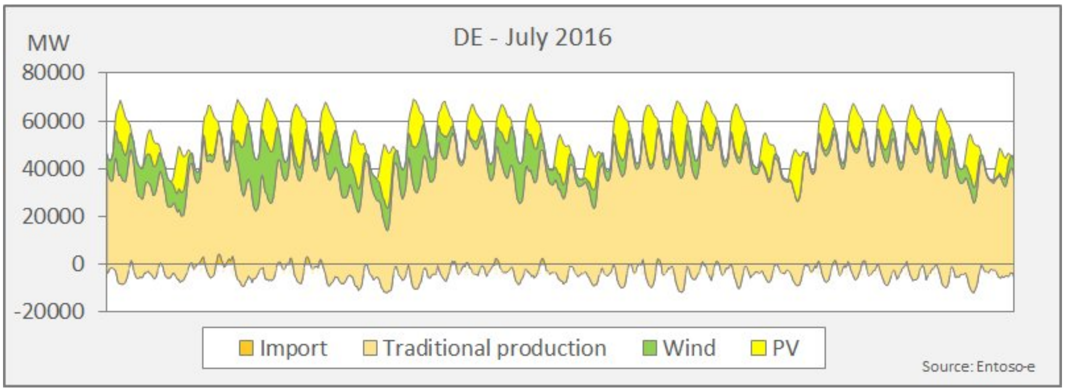


*Fig. 4 – Traditional power plants outbalanced wind power variations in July 2016*

The load variation was 35.0 GW in July. The total variation range for controllable sources was only 41.7 GW due to the helpful influence of solar power. Exchanges reduced the range to 30.1 GW. The combination of wind, PV and exchanges *reduced* the variability range to be covered by German power plants from 35.0 GW to 30.1 GW. Solar power has contributed significantly to this result.

The importance of solar power is reflected in the correlation coefficients for July 2016:

Load/PV: 0.66 Load/wind: 0.15 Wind and PV/net export: -0.69

The high correlation between load and PV in July means that PV is not the problem, but a part of the solution. The low correlation between load and wind means that there is still an additional regulation work to do.

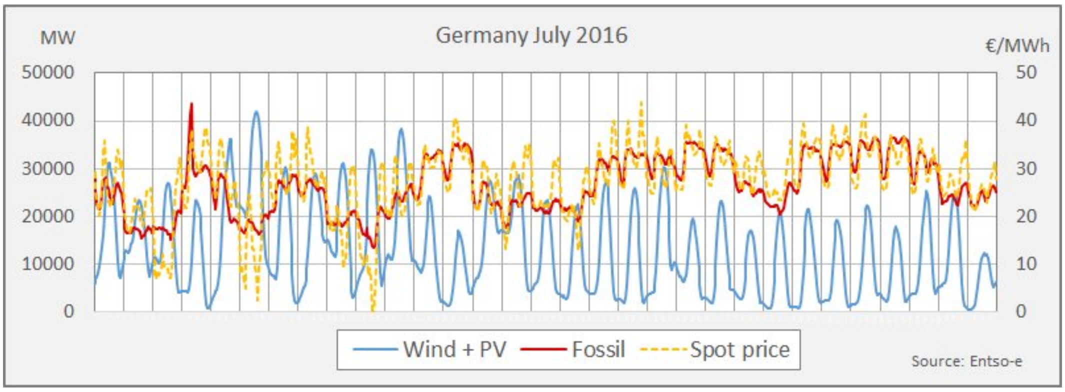


*Fig. 5 - Fossil-fueled power varied between 20 and 40 GW in July*

The spot price was also quite volatile in July with a range mainly between 0 and 40 €/MWh. The fossil-fired output seems to follow the spot price variations (correlation coefficient: 0.82).

The summer is the usual maintenance season for conventional power plants. In 2016, The German grids needed about 50 GW controllable power in December and about 40 GW in July.

## A Different Balancing Policy in Denmark

This section will discuss the different conditions in the two countries.

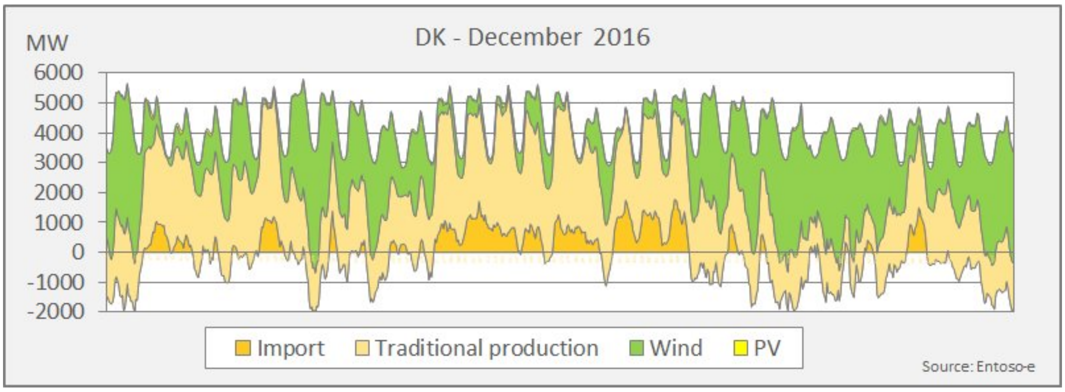


*Fig. 6 – December 2016: The unavoidable export (export below axis)*

The two countries have nearly the same pattern of calm and windy periods. Fig. 6 has the same three windy periods as fig. 2, but wind can sometimes cover all electricity demand in

Denmark. The Danish power system has been prepared for operation without large thermal units, but the district heating systems depend on heat supply from CHP[6].

The Danish dilemma is that both wind energy and CHP save fossil energy, but the electricity demand is insufficient for both. New flexible electricity demand was supposed to solve the problem, but it has so far only been implemented in small scales. Therefore, CHP is declining in Denmark.

Controllable resources had to cover a 6 GW variation in December.

The heat demand in December requires some electricity production from the remaining CHP units. The CHP systems have a considerable flexibility, due to large hot water tanks. The variation range in December was from 0.8 GW to 4.7 GW. The variation range of exchanges was 3.8 GW. The available flexibility from both CHP systems and interconnections was required for balancing the Danish power system in December 2016.

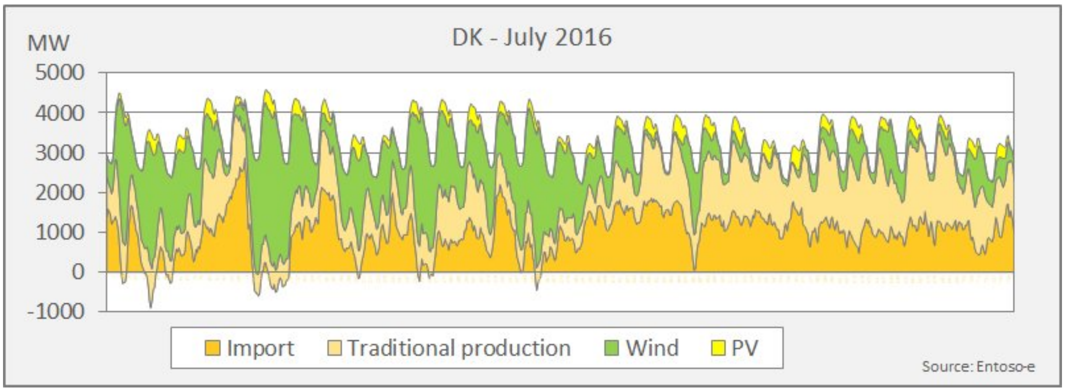


*Fig. 7 - July 2016: Import is a main source of flexibility*

In July 2016, it is just possible to see a modest PV contribution in the top of the daily load curve. From a technical point of view, Germany seems to have a more reasonable distribution between wind and solar power.

The total necessary variation of controllable resources was 4.0 GW in July. Power plants had a variation from 0.4 to 2.3 GW (1.9 GW). The variation range for exchanges was 3.8 GW. The average spot price (DK West) was 27 €/MWh with variations between 10 and 40 €/MWh. The system seems to have been less stressed than in December.

It is obvious that exchanges with other countries provide an essential part of the regulating work for the Danish power system. The Danish TSO[7] is preparing new interconnections to the Netherlands and to Great Britain in order to be able to handle an increasing amount of wind power.

Exchanges are controlled by market forces. The essential differences between Germany and Denmark are probably not related to different operational or market policies, but to the size of the countries, to the geographic location and to the development policy for interconnections.

[6] CHP: combined heat and power
[7] TSO: Transmission System Operator