# “ENERGIEWENDE” – GERMAN ENERGY TRANSITION
# - INTEGRATION OF RENEWABLE ELECTRICITY -

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## INTRODUCTION

The German Government has decided to make an almost revolutionary transition in power and energy production, which is now known as the German “Energiewende”. It consists of the following main actions: fast introduction of renewable energy sources (RES) for power production, reduction of fossil fuels and complete abandonment of nuclear power. The main milestones are:

- 2022 – closing of the last nuclear power plant,
- 2025 – 40-45% power from RES,
- 2035 – 55-60% power from RES and
- 2050 – 80% power from RES [1].

In the meantime it is clear that the energy efficiency has to be increased and that energy consumption for heating and transportation has to increase the amount of RES usage, too. The targets for energy efficiency are 10% and 25% reduction of electricity consumption until 2020 and 2050, respectively, both compared to the year 2008. At last, one of the main targets is the reduction of $CO_2$ emissions, or more general, the reduction of the green-house gases (GHG). Till 2020 it has to be reduced by 40% and till 2050 by 80%!

This paper shows a neutral and critical view on the present achievements of the “Energiewende”, its successes and failures, as well as problems imposed on it and possible solutions. There are new records achieved in 2014, like maximum solar power of 24.6 GW on Friday $6^{th}$ of June, maximum wind power of 35 GW on Friday $12^{th}$ of December, or maximum wind and solar power of 38.2 GW on Monday $14^{th}$ of April. There are other figures which shows the complexity of the RES introduction, like just 10% of electricity production feom RES on Wednesday $12^{th}$ November. Lastly, there are fake “records” like the one from Sunday $11^{th}$ of May, which will be discussed in details.

## INSTALLED CAPACITIES AND ELECTRICITY GENERATION FROM RES

The official statistic has announced that in the year 2014 for the first time the electricity generation from renewable sources has overcome the generation based on lignite. With a share of 27.8% [3] the renewables are the most important source of power generation. That is a great success having in mind that in year 2000 the same share was just 6.6%. Germany is in a good position to reach the above mentioned targets, which seem to be very realistic – at least till the year 2025.

It is important to analyse the data on Figure 1. It shows the installed capacity of the various power generation plants. Solar energy takes the first place, with an installed capacity three times higher than that of nuclear power plants. Wind parks take second place, with an almost equal capacity. Regarding fossil fuels, the highest capacity is installed by the natural gas plants, followed by the hard coal plants and the lignite generation plants.

The bottom part shows the net electricity generation from the named sources. Here the order changes dramatically: the first three are lignite, hard coal and nuclear energy. The total energy generation from solar and wind energy is 84.2 TWh, which is still less than the generation from nuclear energy (that is important to consider in view of closing all nuclear power plants till 2022). Once biomass and hydro are added, we get an electricity generation greater than that from lignite. There are, however, other significant conclusions, e.g. that biomass is an important and reliable power source. Despite a four times smaller installed capacity, biomass produces more electricity than all wind turbines combined. The mean load factor of wind turbines is just 16.4% and that of biomass facilities 75.5%.

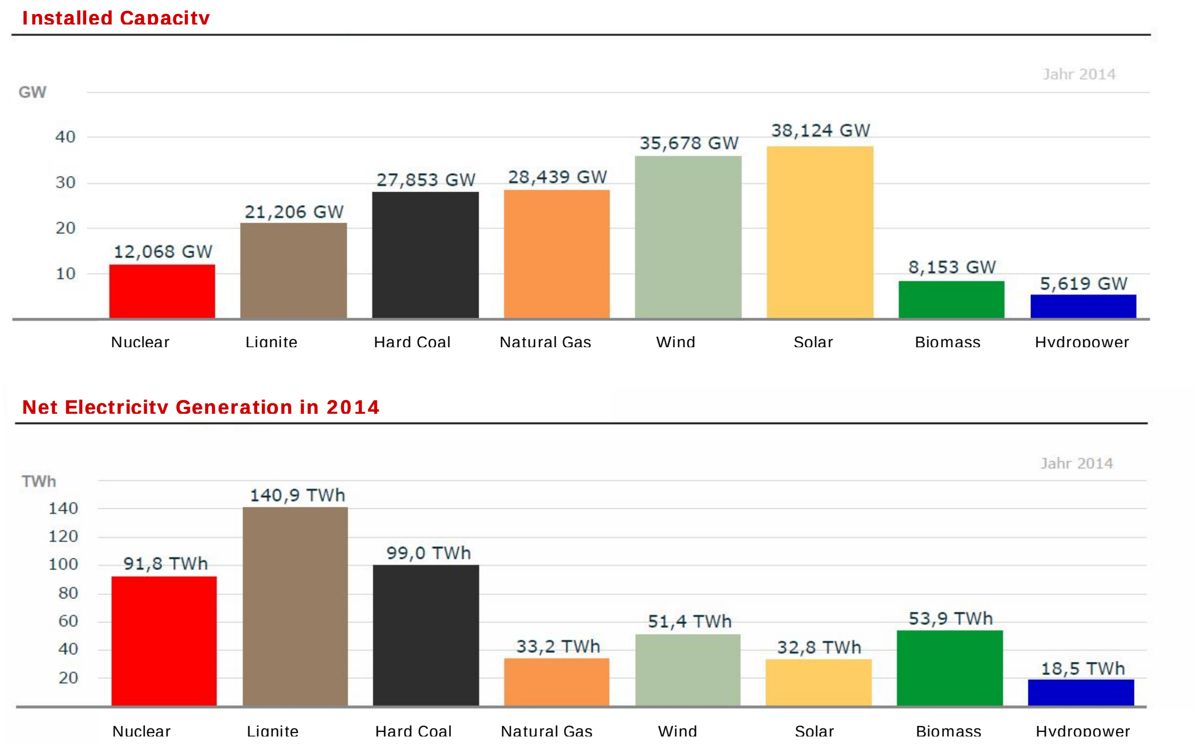


Figure 1: Installed capacities and electricity generation in Germany in 2014, Bauer [2]

## ELECTRICITY STOCK EXCHANGE PRICES

According to the German Renewable Energy Act the electricity produced from RES has the priority access to the grid and is remunerated with a guaranteed price for the next 20 years, the so-called feed-in tariff. The feed-in tariff distinguishes between the different renewable energy sources for remuneration and from time to time is adjusted, according to the technological development. The consumers of electricity have to pay a surcharge to each kWh, through which the difference between the feed-in tariff and market price is covered. That surcharge is a levy (the so called “EEG-Umlage”) which is adjusted for each year according to the produced renewable electricity. That surcharge was 6.24 Eurocent/kWh for year 2014 and is slightly reduced to 6.17 Eurocent/kWh in 2015. In general, the amount of surcharge depends on the difference between the feed-in costs and the market price of electricity and on the amount of produced renewable electricity. As the share of electricity from RES rises, the surcharge will rise, too. However, due to the technological development, the feed-in tariffs are reduced almost every second year, which will damp that increase. Once the production cost meets the market price of electricity, that increase will be stopped and afterwards will go slightly down. However, that is not to expect before 10-20 years.

Since the year 2002 the market price of electricity in Germany is defined by the European Energy/Electricity Exchange market (EEX, i.e. EPEX) in Leipzig. In summer 2008 the exchange market price reached a maximum in the range of 120-80 €/MWh (peak/base load), but then dropped suddenly due to the world financial crisis and continued to drop steadily since then. At the end of 2014 it was 45-35 €/MWh. There are three main reasons for that low electricity price: low coal price on the world market, low carbon emission prices in EU and high share of RES. The first two reasons have induced a very low price of electricity based on coal (especially lignite).

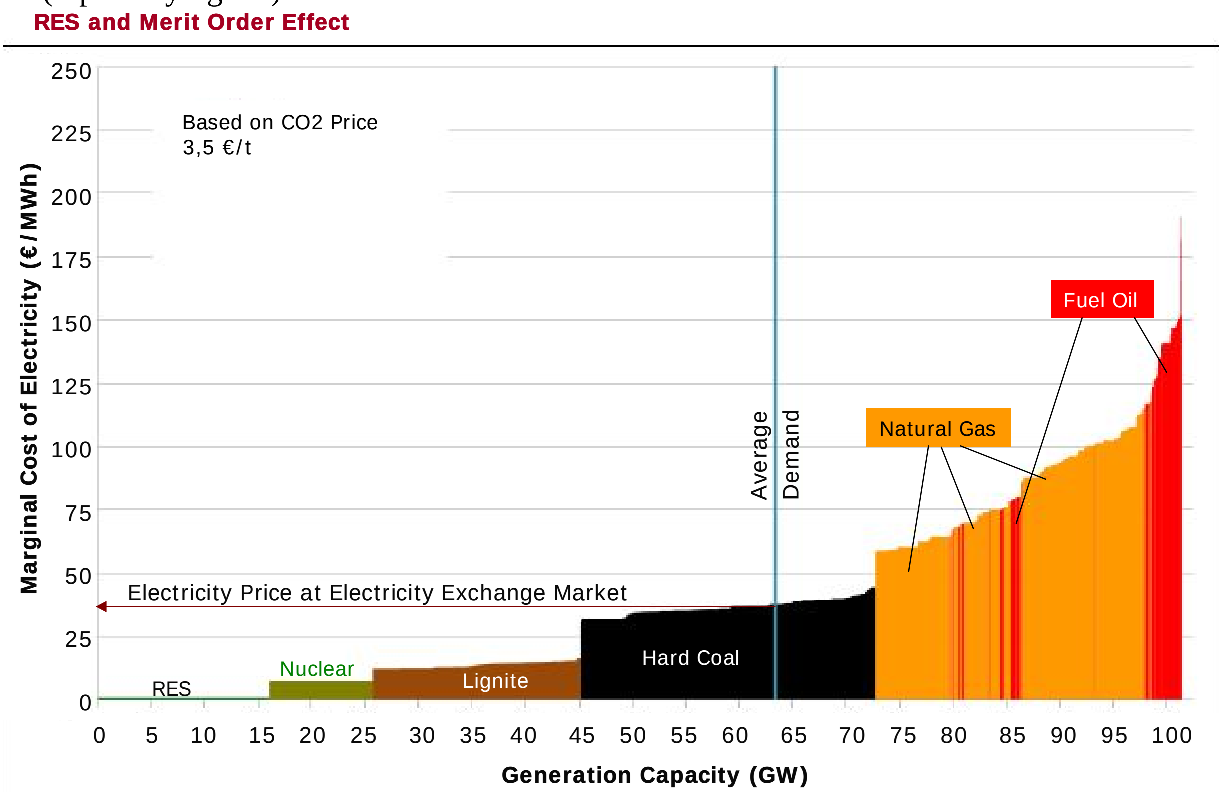


Figure 2: Merit order effect and influence of RES power generation on the stock exchange price of electricity, Haller et al. [4]

The effect of RES may be explained using Figure 2. Each generation plant offers on the exchange market its capacity with its marginal cost. According to merit order, the plants with the lowest cost will be selected, till the required capacity demand is fulfilled. In the case of Germany, those are all nuclear power plants, then the lignite power plants and some of the hard coal plants. Previously, with the low RES share in power generation, a lot of the natural gas plants were selected as well. Nowadays, the electricity from RES has the priority and it enters the exchange market with the price zero, as its costs are covered by the above mentioned surcharge. Due to the high share of RES, natural gas power plants are usually not selected. Just in cases when the power demand is much higher than the average and/or the production from RES (especially wind and sun) is limited, the electricity from natural gas is a viable option. Therefore the load factor of natural gas plants was just 13.3% in 2014 (see Figure 1). In the same time the load factors of nuclear, lignite and hard coal power plants were 86.8% , 75.8% and 40.6%, respectively. This is quite in opposition to their efficiencies: 35% for lignite, 38% for hard coal and 57% for natural gas power plants.

The following conclusions are obvious:

- The production price of electricity is not just the market price, but the sum of market price and surcharge for RES electricity; that surcharge is presently almost twice as high as the market price;
- An over-capacity exists in the German electricity market, making the most of natural gas and some of hard coal plants non-profitable.
- There is a big anomaly in the usage of fossil fuels for electricity generation – the most pollutant and the least efficient plants are used much more than clean and efficient natural gas plants; the $CO_2$ emissions are therefore considerably higher.

Knowing those facts and effects, it is clear why, in spite of very low market prices, the electricity in Germany is the second most expensive in Europe (after Denmark). Household prices are presently about 29 Eurocent/kWh.

With further closure of nuclear power plants in Germany, two scenarios are possible. One is that all fossil fuel plants will move to the left of the diagram in Figure 2, so that some of natural gas plants would be more in use and the marginal cost will rise. The other possibility is that the whole capacity would be replaced by additional RES capacities, increasing the required amount for the surcharge on renewables. As the nuclear power plants are the most reliable in the system and used for base-load, and the new RES capacities will be mostly based on solar and wind, a combination of those two scenarios is the most probable. Therefore the authorities do not allow the closure of some natural gas plants, which are presently not profitable. The total production cost has to rise in any case.

## POWER EXPORT

It is usually said that, in spite of the high ammount of electricity generated from RES, Germany is the European champion in electricity export. In the year 2014 it has reached 34.1 TWh. Is this good news? Is it profitable for Germany to export so much electricity?

In order to answer those questions, some further data has to be analysed. Figure 3 shows the yearly increase of the net electricity export (export – import): from 2003 onwards it rises almost steadily, with just two short interruptions. The same effect is seen in Figure 4, showing how the gap between generation and production of electricity continues to increase. However, a really good news is that the consumption has fallen in the year 2014 (hopefully not just due to the mild winter) and that the gross national product rose further, completely uncoupled from energy consumption!

In 2014 the net export was almost the same as the production from solar energy. Immediately, one gets the impression that this is connected with the introduction of the feed-in system with the German Renewable Energy Act (introduced in the year 2000), the corresponding increase of RES usage and the foundation of the electricity exchange market (2002). If this electricity surplus is generated from arbitrary energy sources (wind and solar), the export share is 40.4%. Throughout 2013, this share was at 39.1%. Those assumptions have to be further analysed.

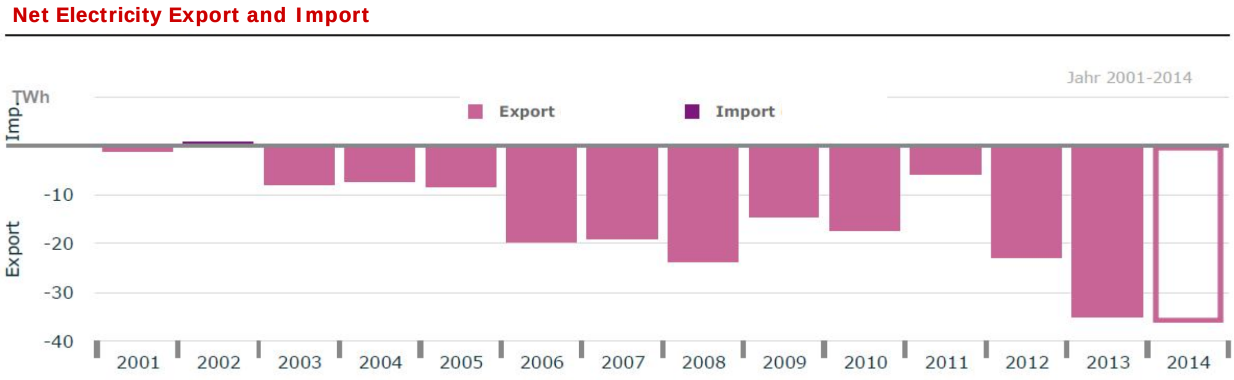


Figure 3: Net electricity export and import from 2001 till 2014, Bauer [2]

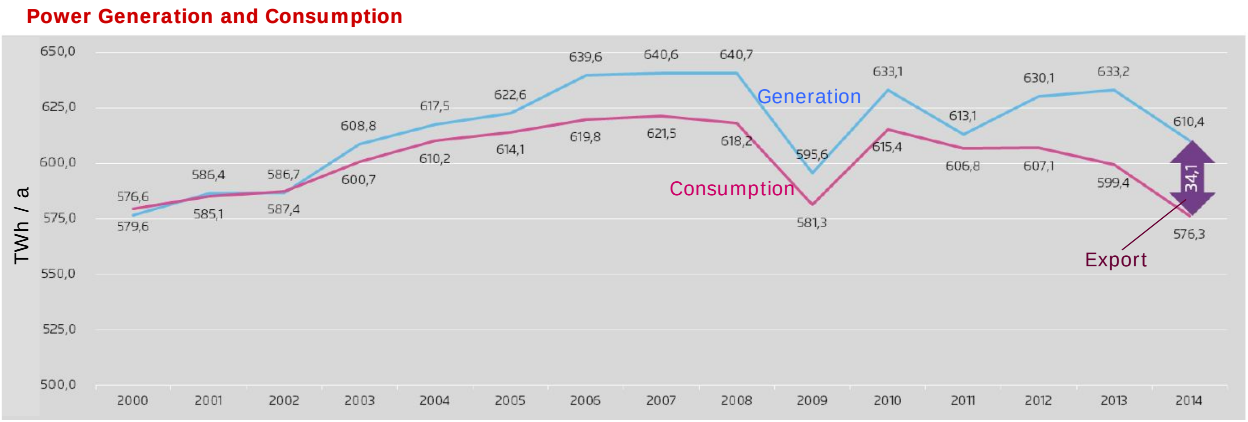


Figure 4: Gross electricity generation and consumption in Germany from 2000 till 2014, Kleiner [5]

The monthly electricity generation from solar and wind is mostly between 7 and 8 TWh, being only in autumn somewhat lower, as shown in the upper part of Figure 5. In the winter months there is more energy produced from wind and in the summer months more from solar, but in total this value is pretty consistent. This means that fluctuations in solar and wind generation are more in the range of hours, days and weeks, but not in months.

The bottom part of Figure 5 shows the monthly export and import figures. For the first three months the export was almost identical with the electricity generation from wind and solar. Such a large amount of arbitrary electricity generation cannot be used up and therefore has to be exported. On the other hand, electricity import is still high, because the fast fluctuating daily requirements cannot be compensated by arbitrary electricity generation, nor by sudden increase of conventional plants. In order to balance supply and demand, electricity has to be imported.


Figure 5: Monthly electricity production from solar and wind versus monthly export and import in Germany in 2014, Bauer [2]

Figure 6 confirms this observation. It shows, for example, the actual power output or electricity generation from wind, solar and conventional sources for one week (Calendar week 24, 9th to 15th June). Both the import and the export rates are entered. In the morning and in

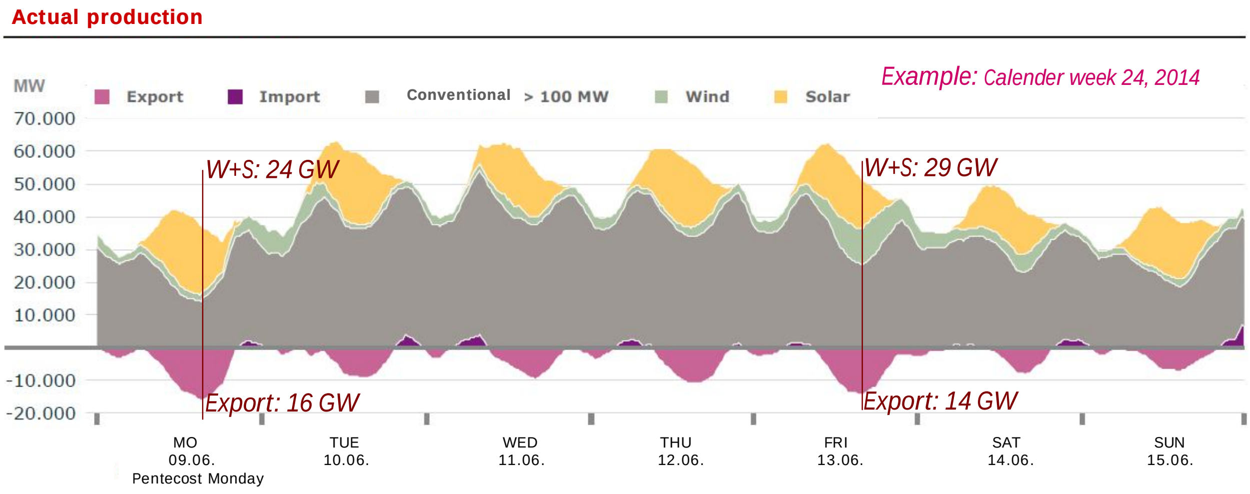


Figure 6: Actual generation with export and import at calendar week 24, 2014, Bauer [2]

the evening the load changes are so significant that conventional electricity generators are not able to balance this fluctuation. It is clearly discernible that the maximum electricity generation from wind and solar is in the same position as the maximum electricity export. On 9 June 2014 (Pentecost Monday) the maximum capacity from solar and wind was about 24 GW. At the same time the maximum export capacity was about 16 GW (67%). On Friday, 13 June 2014, the maximum capacity from solar and wind was 29 GW, export 14 GW (48%).

On the other hand, the maximum import rate is connected to the solar generation. Evenings, when the solar generation disappears rapidly, the conventional plants cannot increase their production so fast and some electricity has to be imported. The same may be observed some days in the morning (e.g. on Wednesday, 11th of June), when the solar generation is still not as high as predicted and the electricity consumption has already increased. This effect is especially to be observed in summer, when solar generation is high and some conventional power plants are in the yearly maintenance.

**Export and Import**

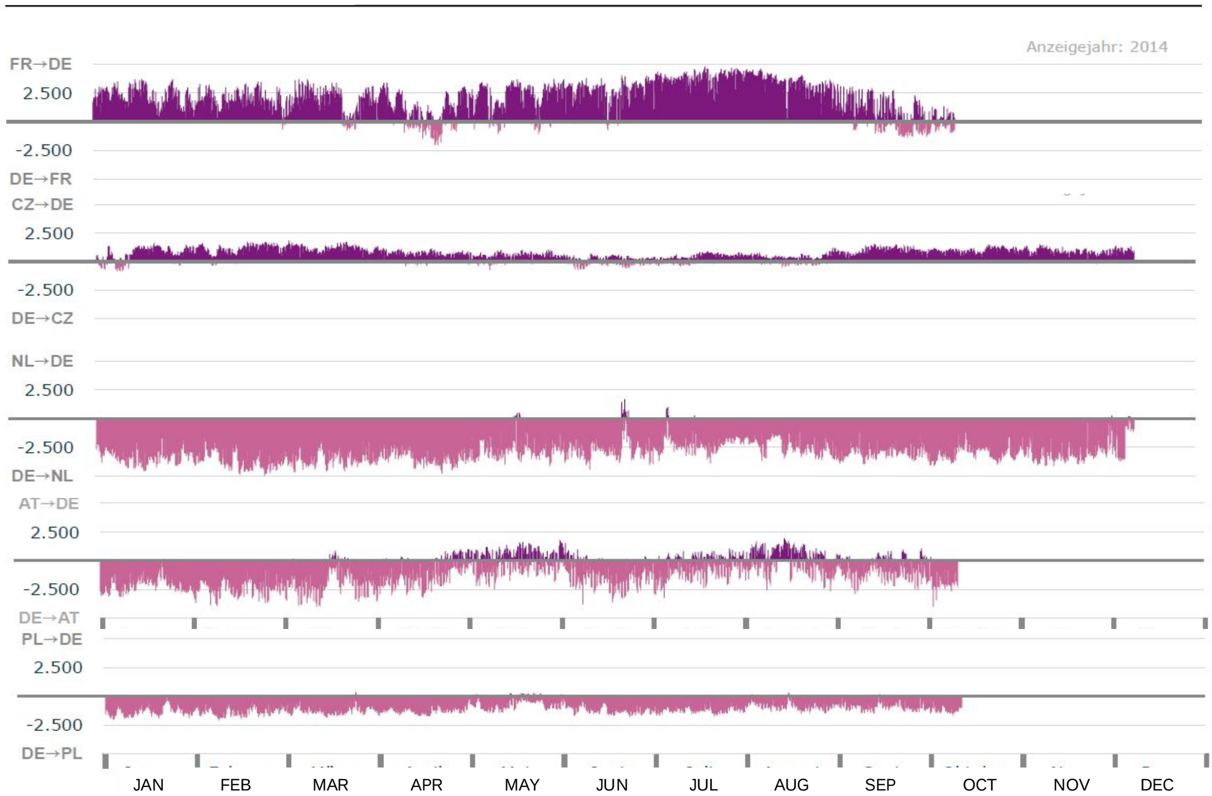


Figure 7: Main export and import countries for German electricity in 2014, Bauer [2]

Where is German electricity exported to and imported from? Figure 7 shows the most important export and import countries. The most important export countries are the Netherlands, Austria and Poland, whereas the most important import countries are France and the Czech Republic. The Netherlands and Poland buy electricity from Germany but do not sell almost any to Germany. It should be noted that electricity for households in Germany costs 0.29 €/kWh, in the Netherlands 0.19 €/kWh.

Is it economically viable to export so much electricity? Some years ago it was presented as a big success of the German "Energiewende", however, in the meantime there are more and more critical voices, Wetzel [6], Marth [7], [8]. The problem is that the export price is the price of the energy market (EEX) and the real price of electricity, as mentioned above, is the sum of market price and the surcharge "EEG-Umlage". If we take into account that the export is induced through the high share of the renewable electricity, than the cost of export electricity should be the cost of renewable electricity, which is now about 180 €/MWh, i.e. 4 to 5 times higher than the market price! This fact is not clearly presented from the politics and just the positive sides of "Energiewende" are pointed out.

That is especially obvious in the case of situation that happened on Sunday, 11th of May 2014. Usually it is reported that a new record of 80% of power from RES has been achieved on that day. Looking on Figure 8a) one can see that in the early afternoon great majority of consumed electricity was really produced from renewables. However, from Figure 8b) it may be seen that much more electricity has been produced and exported on that day. Taking the whole amount of produced electricity, the share of RES was considerably lower. It is not correct to say that just conventional electricity has been exported (as this graphic presentation suggests), as those were necessary in order to prevent the grid stability. That is clear from Figure 8c) where the market prices are plotted as well. On that day the spot market prices were negative during the day between 6 am and 4 pm (Mayer [9]). The minimum values were between 2 pm and 3 pm reaching -65.03 €/MWh (Day-Ahead) and -48.19 €/MWh (Intraday), ibid.

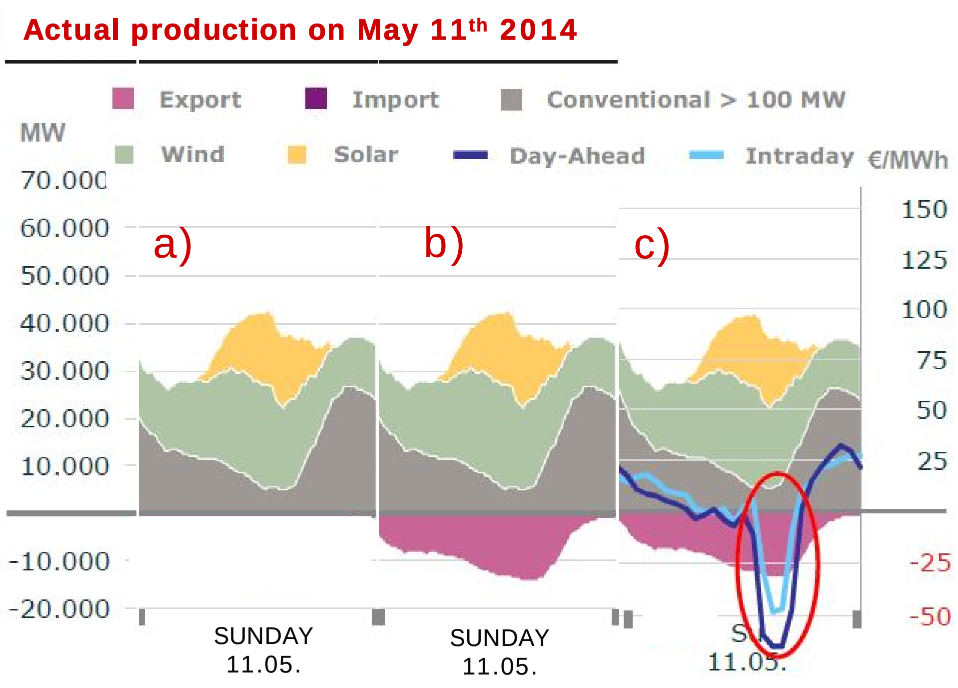


Figure 8: Actual electricity production and market price on May 11th 2014 (based on data from Bauer [2] and Mayer [9])

## PROSPECTS FOR POWER UTILITIES AND GRID OPERATORS

All power utilities in Germany are in a substantial crisis. Especially the biggest utilities have not reacted on time and prepared themselves for the business with renewable energy sources. Instead, they have continued to invest in new fossil power plants, which are now very limited in operation and therefore not economical, in spite of very high efficiencies. A positive aspect is that the monopolistic position of big utilities has been removed and the importance of small, mostly city based utilities has increased. They have to fight with a new born monopolist, the transmission grid operators, who lobby for new power lines. Despite distributed power generation, what should be the case for RES, and planned reduction of electricity consumption through the increase of energy efficiency, the new situation will occur with closure of all nuclear power plants (in South Germany), additional capacities of off-shore wind-mills (North Germany) and lignite power plants still required for the grid stability (East Germany).

However, the costs of transmission and distribution have increased in the last years, so that nowadays, with about 60 €/MWh, those are the same order of magnitude as the electricity production costs. Therefore, the municipal utilities have plans to build their own micro grids with their own generation and power storage, which would be virtually in the so-called island operation. Only in exceptional circumstances they would exchange the electrical energy with external grid operators. That way they can reduce tremendously the transmission cost and could allow something higher generation costs. Only the utilities which adapt to the new, revolutionary conditions at the electricity market would survive and prosper.

## PROBLEMS AND SOLUTIONS

The situation that, as an example, occurred in Germany on Sunday 11th of May, 2014 will happen much more frequently once the nuclear power plants are completely closed and the share of renewables (especially wind and solar energy) in power generation is even higher. Presently, a similar situation happens every Sunday or holiday with high insolation and intensive wind. The usage of export as the predominant method for grid stabilisation is an expensive and limited solution. With increased shares of RES in power generation in other European countries, they will have problems with the import of that arbitrary power from Germany. There are other methods which have to be investigated and developed, like:

- power storage as the most reasonable method
- demand response programs (load management)
- new transmission grids to redistribute the electric power throughout Germany
- curtailment of wind and/or solar generation (in combination with power storage?).

Power storage technologies need further development (especially small and medium scale facilities which could be combined with RES on the most effective way) in order to meet full viability. However, there are already some technologies that are more economical than the present day export under unfavourable conditions.

The next problems are the present and future emissions of $CO_2$, or generally of GHG. Due to the above mentioned anomaly in the usage of fossil fuels and the low efficiency of lignite power plants, the $CO_2$ emissions are higher than expected with such high share of power generated from RES. The present and future closure of nuclear power plants, which cannot be completely replaced by RES generation, increases that problem. Moreover, in the period 2009 – 2013 the $CO_2$ emissions from power generation have increased – quite opposite to the main target for the introduction of RES and of “Energiewende” in general! In the year 2014 the emission is reduced to 301 million t (-6 million t compared to 2013), however that is due to the mild winter and the lower total consumption of electricity. There is no firm confirmation for the reduction of $CO_2$ emissions through the increased share of RES. Specific values were 493,6 $kgCO_2$/MWh in 2009 and 493,1 $kgCO_2$/MWh in 2014.

It is absolutely clear that the target of 40% reduction till 2020 cannot be reached. That would require the reduction of $CO_2$ emissions to 214 million t, i.e. for 87 million t in the next 5 years. In the previous 25 years the reduction was only 56 million t! In order to improve that situation, new developments, again primarily in the energy storage, are necessary.

## CONCLUSIONS

The German energy transition program "Energiewende" has achieved some remarkable successes in a very short time period achieved. The share of RES in power generation of approx. 28% is a unique achievement in such a big economy. On the other hand, the arbitrary energy sources like wind and solar energy are still very badly integrated in the total electrical system. In order to preserve the grid stability the fossil power plants have to operate more than would be optimal. The combination of a privileged position of RES and the electricity exchange market laws leads to the anomaly that the most pollutant lignite power plants are preferred towards the much more efficient and cleaner gas power plants. The surplus of electricity is exported under unfavourable conditions. The imported electricity is used to solve the problems with the fast decrease of the solar energy production. That results in an insufficient reduction of $CO_2$ emission, or even its rise in some years. With the complete closure of the nuclear power plants in the year 2022 the situation could become even worse.

Therefore some adaptation of energy policy is required in order to fulfil all planed targets. First of all the power storage technologies have to be further developed (especially small and medium scale facilities) in order to meet full viability. Even today there are technologies that are more economical than the present export under unfavourable conditions. The right combination of other measures, like load management, new transmission grids or curtailment of wind and/or solar generation could improve the present situation. Otherwise, the "Energiewende" could be compromised, leading to a very inefficient power generation system.

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