Challenge Energy Transition: Managing Volatility and Integrating Renewables into the Energy System

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1. Introduction

The share of renewable energies in the world's energy mix is increasing. There are several reasons why the path towards a higher share of renewables is necessary. Besides the most often mentioned argument of climate change, increasing energy demand and declining cheap fossil fuel resources force the world to explore new energy sources and implement new solutions.

Due to these new solutions often being more expensive in their infancy, as the technology evolves, politicians worldwide are promoting support schemes for renewable energies. Europe, especially Germany, is leading the way in implementing ambitious targets in energy policy, to deploy renewable capacities in a very short time period. The target is to have at least 34 % of electricity generation from renewables by 2020 in the EU.[1] Germany's target of 50 % renewables by 2030 is even more ambitious.

In Germany, the success of renewable energy developments up to now has mainly been based upon priority access to the grid and attractive financial support. As the share of renewable energy developments was very small, neither the technical nor the price effects were noticeable in the existing system.

However, the technical and economic challenges of implementing or even complementing renewable energies into the existing energy mix and market designs are increasingly in the focus of the political debate.

As Germany is one of the countries with the highest share of renewables in Europe, this article will concentrate on the challenges witnessed in Germany. However, some of these challenges could also be seen as typical of those faced by other countries focusing on increased renewable energy generation, e.g. Spain and, in the long run, Europe in general.

Initially, the industry focus around renewable technology deployment was on cost reduction and volume. Little or no attention was paid to the future development of grid infrastructure and the rebound effects on the existing energy mix.

In the most recent years, mainly wind – up to now mostly onshore – was added to the electricity system, which is, next to hydropower, the most mature and low-cost renewable technology available. Also, the share of photovoltaic (PV) is rapidly increasing, due to attractive support schemes and, in parallel, decreasing module prices on world markets. By the end of 2011, the electricity produced from wind energy in Germany alone was 46.5 terawatt-hours (TWh).[2] Estimates for 2030 suggest electricity produced from onshore wind will equate to 77.4 TWh, approximately 30 % of the total renewable electricity generation target; offshore wind accounting for 25 % and PV, with 41.4 TWh, equating to another 16 %.[3]

Both wind and PV technologies are weather-dependent and therefore can be intermittent by their nature. This has an impact on the entire electricity system, which, up until now, has been based on continually available and dispatchable electricity production. What effects does this high share of volatile production have?

2. Intermittency of Renewable Energy Sources

The stormy weather of the last weeks of 2011 brought a record for wind energy in Germany. December 2011 was the first month after a long period of light winds in which the turbines rotated most of the time. That month, wind turbines in Germany produced nearly 8 billion kWh of electricity. That is about one-sixth of their total production of 44.3 billion kWh in 2011. To balance supply and demand across the network and allow so much wind energy into the system, conventional capacities, which had ensured electricity production during the low-wind month before, had to be constrained off. The challenges are how to deal with steep load ramps and how to bridge periods with high generation from renewables and periods with low generation from renewables. The challenges increase with the amount of renewables in the system. Having more renewable generation means that, over time, conventionally produced electricity will decrease. As conventional power plants must earn their money by selling power to the wholesale markets, the reduced production hours threaten their economics. This is valid for existing and also for new-build power plants, if wholesale electricity prices do not increase significantly.

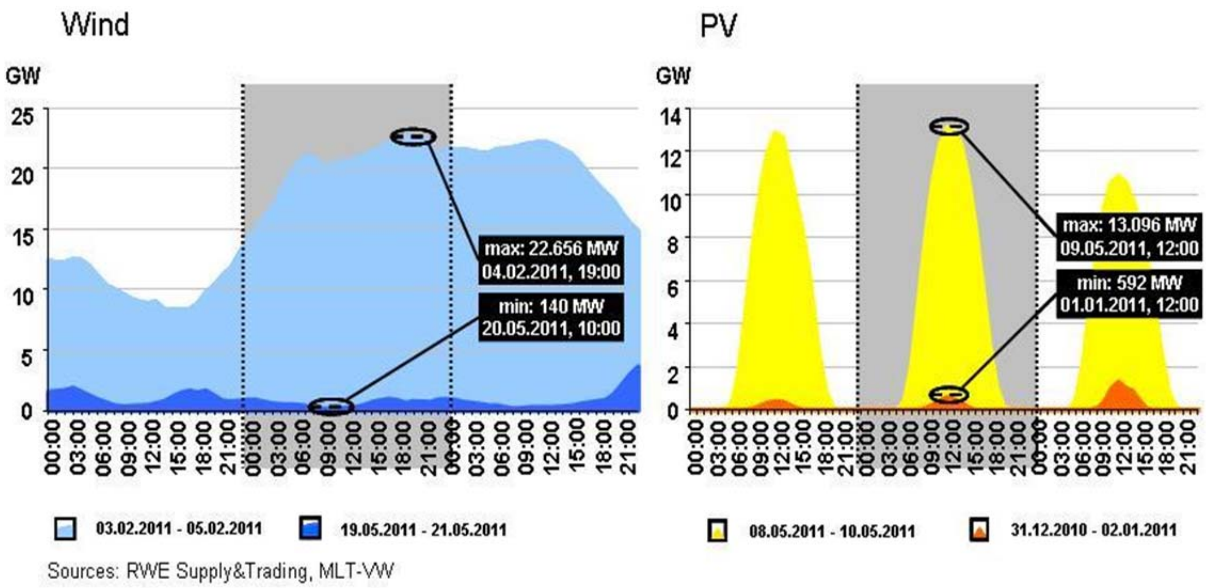

Figure 1: Volatility of Wind and PV feed-ins: impact of the intermittency of renewable energy sources

However, independently of the share of renewables, there will be times, even in the future, where generation capacity must bridge periods with less wind or sun. Looking back into the weather statistics, for example in Germany over the last few years, every year there was a period of more than 10 days where the real performance of wind was below 10 % of the available generation capacity.

There is no obvious indication that this effect will not occur in the future and therefore back-up capacity is essential. To illustrate this intermittency, *Figure 1* compares wind and PV feed-ins for two periods (February and May 2011 for wind feed-ins and December 2010/January 2011 and May 2011 for PV feed-ins). On 4 February 2011 a wind power generation of 22,656 MW was observed and on 20 May 2011 one of only 140 MW. PV feed-ins varied from 592 MW on 1 January 2011 to 13,096 MW on 9 May 2011. Thus, in the first half-year of 2011 variations in wind feed-ins of 23 gigawatts (GW), and in PV feed-ins of 13 GW, could be observed.

Another effect is that the intermittency and the priority access of renewables[4] lead to unpredictable electricity prices on the spot market of the German electricity exchange European Energy Exchange (EEX). High electricity supply, due to high production from wind power and a simultaneous low electricity demand, can lead to negative prices. In the case of negative prices electricity consumers are paid for their consumption, which signals a flaw in the functioning of the electricity market.

Figure 2 shows a constellation on the EEX for the first days of January 2012, in which negative prices occurred. Even the newly introduced market premium was not able to avoid this effect.

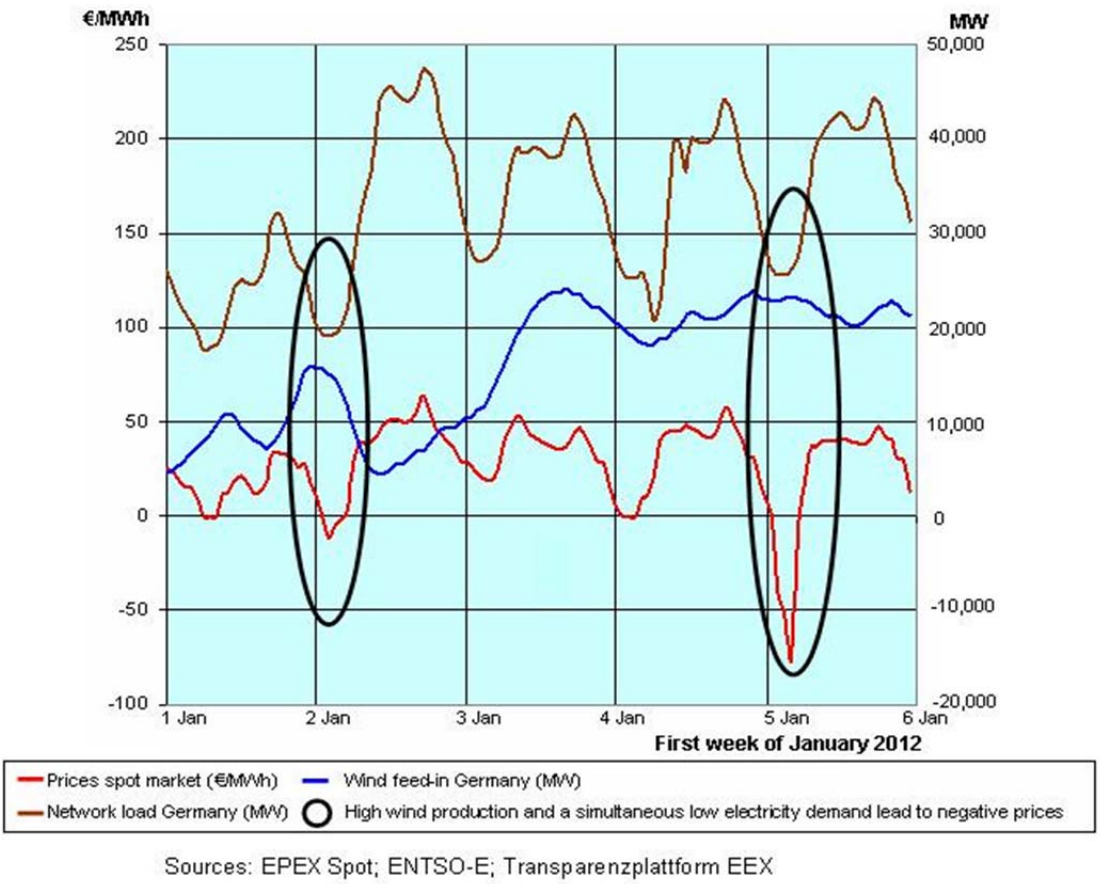

Figure 2: Increasing unpredictability of electricity prices due to volatility of renewables

A special characteristic of PV is peak production during noon. Power generation peaks twice a day for just a few minutes around 12:00 and 6:00 p.m., when households demand most of their electricity. Due to natural conditions, PV also feeds in most electricity at 12:00, the time of day with the strongest solar radiation. The bell curve-shaped generation graph only increases in its scale. Consequently the energy supply increases and, according to economic principles, the electricity price decreases. This phenomenon has a negative impact on the conventional power plant fleet. The merit order shifts to the right. Peak-load plants, such as gas or hard coal plants, run below full capacity, reduce their hours or are switched off completely. This effect due to PV brings down the wholesale price and also decreases the attractiveness of pumped-storage new builds, as they benefit from large base–peak spreads at the same time.

This is in total contradiction to the need for new builds, as both generation technologies – gas and pump storage – are always named as the two perfect complements to intermittent renewables, but the rebound effects from renewables in the existing system have to be considered carefully.

What options are available to integrate and deliver an increasing share of mainly intermittent renewable energies?

Option 1 – Grid Extension

The existing German distribution and transport grid guarantees the transport of every kWh of electricity produced to the end consumer, to cover the demand in time and to ensure security of supply. Currently, as the main generation centres move away from the existing load centres, a new grid infrastructure is needed. This is the most important measure to integrate renewable generation, if it is possible to transport and deliver the electricity in time. As the expansion and new build of transmission lines takes a long time and has started too late compared with the increase in renewable generation capacity, the grid will be a critical bottleneck in the coming years. Having a massive increase in wind energy capacities (on- and offshore) in the northern part of Germany, and PV capacities – on the distribution network level – in the southern part, running a stable grid will be a challenge. As a direct result, constraint measures by one exemplary German grid operator (TenneT) increased from two in 2003 to 156 in 2009. In a short time period of only approximately 45 days in 2011 (half of March plus April), 523 constraint measures took place.

The necessary grid extension, at least for Germany, has been investigated in the German Energy Agency's (dena) Grid Study. According to this study, Germany will need up to 4,500 km of new high-voltage transmission lines by 2020. So far, only 214 km have been realised[1].

Looking beyond the German border, it is obvious that, next to the national grid capacities, interconnector capacities between countries also need to be enhanced. The link to Norway is especially important to, for example, transport the above mentioned production from pumped-storage capacities. Germany is also dependent on energy transfer to and from the Netherlands, Switzerland, the Czech Republic and Poland.

In the long run, only an integrated European energy market will help overcome the challenges of rebuilding the electricity system. Therefore, the measures suggested by Commissioner Oettinger to support and accelerate grid extensions and interconnectors are crucial.

But to realise concepts such as an offshore grid or stable power generated in the desert of North Africa, we need a European approach to grid regulation to gain trust from investors for

[1] Of the grid expansion measures totalling 850 km determined in the dena Grid Study I.

such projects. Having support schemes in place does not fulfil the need for future regulation of grid infrastructure.

Option 2 – Flexible Conventional Plants

As already mentioned, a higher share of renewables will have a further impact on the operation of the conventional power plant fleet. To ensure electricity supply during downtimes of wind and solar plants, we will need conventional back-up generation to balance electricity supply and demand at any one time. Due to their high utilisation period, lignite and nuclear plants, as well as run-of-river plants, operate mainly as base-load plants. Gas and hard coal plants operate as peak-load plants. However, even these are highly dispatchable. Therefore the decision by the German government to phase out nuclear energy in Germany by 2022 will increase the need for new balancing and back-up power plants.

Beside technical challenges, such as shorter start-up and shut-down periods or general enhancements, the main problem relates to the financial aspect. The market has to pay for the needed flexibility. Investments in new power plants are only economically feasible if the weighted average production costs are lower than the average electricity price. The production costs are strongly dependent on the operating times of the power plants. Due to the high share of renewables, the conventional power plants will have, on average, fewer operating hours. Accordingly, the cost per amount of energy produced will increase. Against the background of currently low electricity prices and continuously high gas prices (oil indexation is currently maintained), this is not economically feasible. The clean spark spread has been negative in recent years.

Option 3 – Storage Capacities

Managing increased intermittency also calls for more storage capacities. Like flexible conventional plants, storage facilities are also able to balance energy to manage the generation from wind and solar power. They can decouple electricity consumption and supply from each other. This can minimise the above-mentioned cost-intensive availability of conventional capacities.

Currently, the amount of pumped storage connected to the German grid could not supply Germany with electricity in the long term. To overcome, for example, 10 days without wind in the winter months, we would need about 313 times today's pumped-storage production capacity of approximately 40 GWh.

Massive new builds of storage capacities, such as pumped-storage hydropower plants, would be necessary. Besides massive protest against big new builds, the entire potential for hydro pumped storage is limited in Germany, which makes the potential outside Germany very interesting. The Scandinavian hydropower potentials – Norway with approximately 84 TWh and Sweden with approximately a further 30 TWh – are many times larger than the technically available capacities in the Alpine region, with some 30 TWh. So a possible expansion of capacities can be considered as realistic in regard to technical potential, when including foreign countries, but the question of cost-efficiency has to be considered separately.

However, the realisation of this is, at the moment, highly questionable because, from a technical point of view, even the interconnector capacities from Germany to the Scandinavian region are still to be delivered. In addition, the arbitrage between the electricity price levels must be sufficient (this was not the case in 2008) because the interconnector will not be supported by German grid regulation.

Electric vehicles will soon be an everyday sight in city traffic. The batteries in modern electric vehicles can also contribute to the necessary storage capacities. Since most vehicles are parked for an average of 95 % of the time, their batteries could be used to let electricity flow from the car to the power lines and back. The potential is less significant than that of pumped-storage plants but, as one solution among many, it is worth mentioning. However, there is still a need for considerable improvement in the capacity, safety and affordability of batteries.

In addition to pumped-storage solutions, further affordable storage options, such as adiabatic compressed-air reservoirs and methanisation[2] have to be investigated. But besides their technical realisation, they must also be economically feasible compared with the other options already mentioned above.

Alternatively, the decentralised use of open-cycle gas turbines is competitive with pumped-storage hydropower plants. They are also a quickly available back-up capacity with a high load gradient. Due to their low capacity, of mostly 50–100 MW, they can be relatively easily used in an increasingly decentralised generation and distribution system. They can also be used to support the grid at critical demand points. Moreover, they have lower investment costs and, therefore, may be more acceptable to society than, for example, large pumped-storage plants.

Option 4 – Electricity Imports

Historically, Germany has been a net exporter of electricity. The existing capacities allowed stable security of supply and a net export. The increase in renewable capacities leads to even more exports. However, since Germany shut down its eight nuclear power plants in spring 2011, it has been importing electricity from France and the Czech Republic. The imports have amounted up to 3,000 and 2,000 MW, respectively (see *Figure 3*).

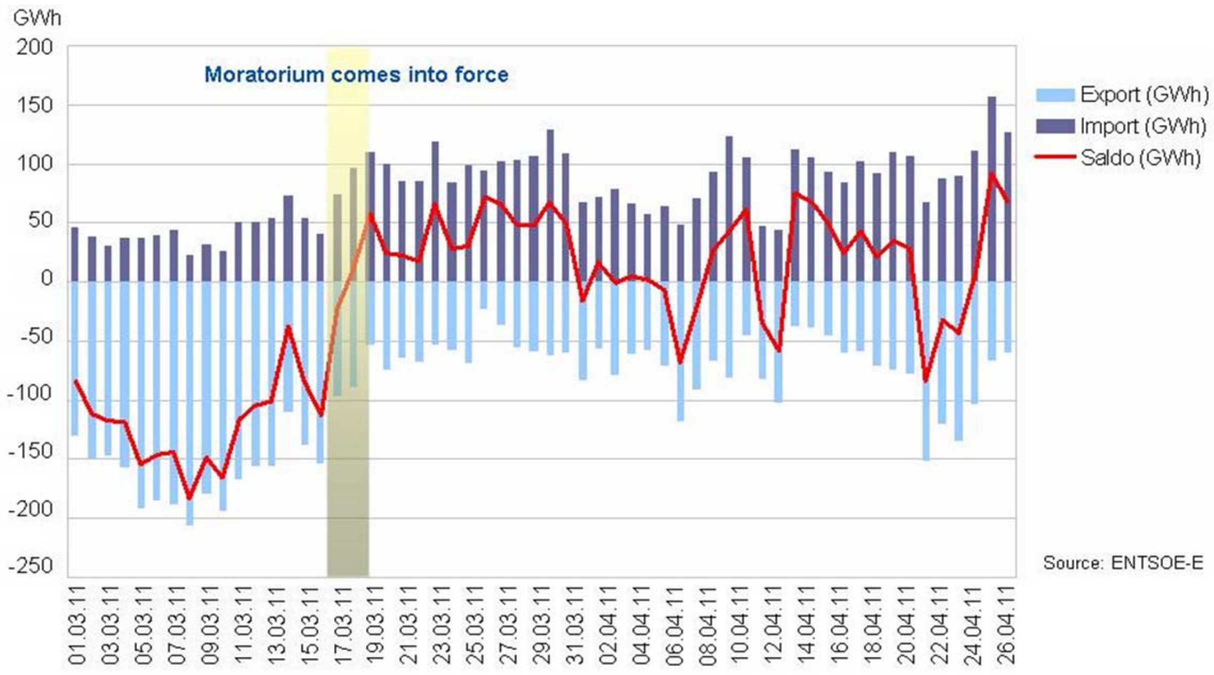

Figure 3: Development of German electricity imports due to the Moratorium on nuclear energy

[2] Methanisation allows the storage of synthetic gas within the existing gas grid and re-electrification via open-cycle gas turbines when necessary.

Germany will, at least in the short term, be dependent on electricity imports. Even in the long run, the energy concept of the German government stipulates a share of almost 10 % electricity imports until 2030 and almost 30 % until 2050. This has also to be seen in a European context, as the other European countries also plan on significant electricity imports.

Option 5 – Demand-side Management

The last option considers the demand side. The principle of so-called demand-side management (DSM) is to encourage the consumer to use less electricity during peak hours. The consumer should shift the times of electricity use to off-peak times such as night-time, weekends and times when plenty of renewable energy is produced. The energy system would benefit from the corresponding smoothing of the load curve because a reduced peak demand avoids the operation of expensive peak-load power plants. Also, the consumer would benefit from the cost advantages.

One of the words currently most used in the discussion surrounding DSM is perhaps 'smart'. A smart grid is an electricity network that can intelligently integrate the actions of all users connected to it in order to efficiently deliver electricity supplies.

With a smart grid, not only the consumer but also the grid operator has access to the consumer units and can regulate their consumption depending on the load level of the energy system (peak or off-peak). It will unavoidably lead to temporary shutdowns of individual consumers, such as industrial enterprises, for example.

To realise the vision of a smart grid, customer involvement in grid control has to be increased. To make this possible, information and communication technology is needed to connect to the devices inside the house. Thus, a wholly new market of home appliances arises. The European Commission recently launched an ambitious Energy Infrastructure Package[5] that promises to deliver the hardware aspects of a smart grid.

3. Conclusions

Energy transition means more than just extending renewable capacities. It means the rebuild of the energy system in total. Regardless of what the energy transition will look like, it is a fact that it will involve a combination of, at least, the infrastructure measures outlined above. There is no all-in-one solution. All stakeholders must be aware that the upcoming transition period will be a very tough time for society as a whole and will require a lot of effort until all grid and integration measures are implemented.

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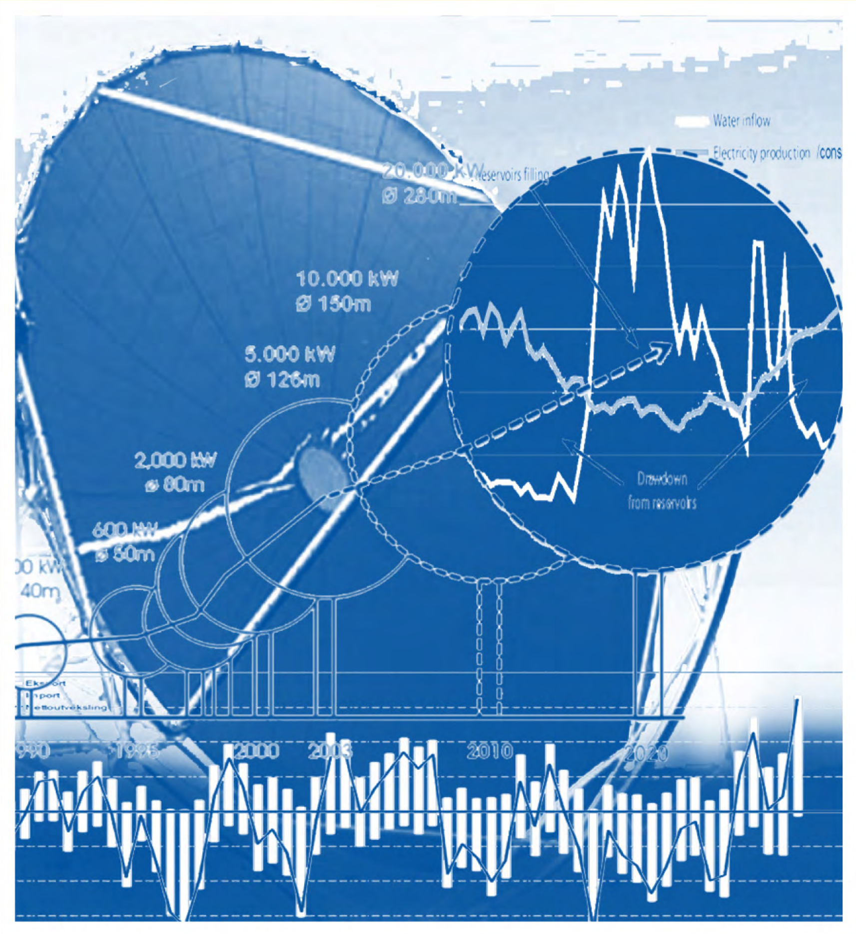

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Aspekte, Optionen, Herausforderungen

Vorträge auf der DPG-Frühjahrstagung in Berlin 2012

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(von dort gelangt man zum Archiv des AKE) eingesehen werden. Allen Autoren, die zu diesem Sammelband beigetragen haben, sei an dieser Stelle sehr herzlich gedankt.

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