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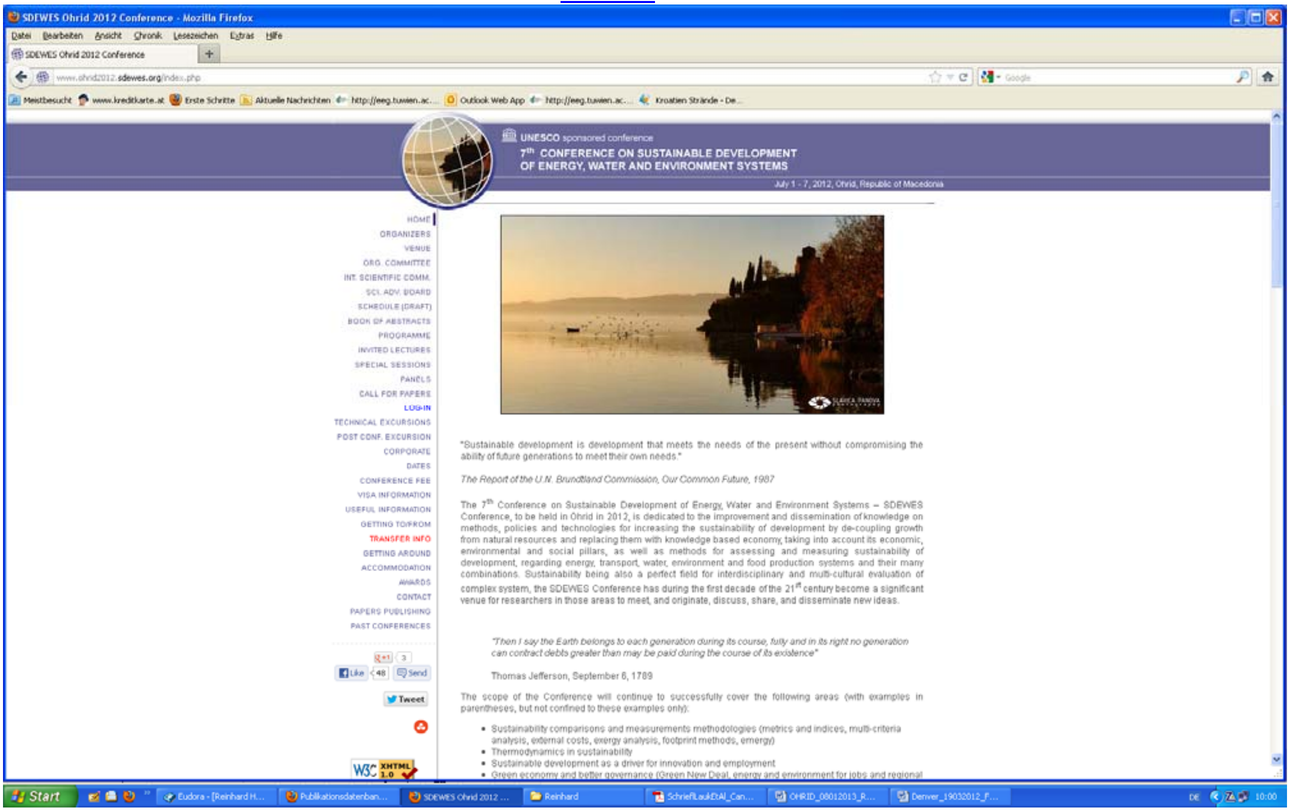

THE LOOMING REVOLUTION: HOW PHOTOVOLTAICS WILL CHANGE ELECTRICITY MARKETS IN EUROPE FUNDAMENTALLY

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ABSTRACT

The increase in PV capacities mainly in Germany had in 2011 on some days significant impacts on spot market prices at the German electricity exchange. The core objective of this paper is to investigate the possible effects of a further uptake of PV on the prices in the EU-4 (German-French-Austrian-Swiss) electricity market. We analyse two major effects: (i) the direct impact of PV at specific times of the year when PV shifts the supply curve of conventional electricity virtually out of the market, leading to temporarily very low market prices close to Zero; (ii) the indirect impact of PV (and wind) on the costs at which fossil capacities are offered. The major effects of these developments on the electricity markets will be: (i) a much higher price volatility from hour-to-hour and day-to-day; (ii) higher costs and prices for fossil capacities mainly based on gas turbines; (iii) increasing importance of flexible balancing power plants.

KEY WORDS: Photovoltaics, electricity markets, wholesale electricity prices, grid parity

INTRODUCTION

For a long time Photovoltaic systems have been seen as a mature (1) and environmentally benign technology with a huge potential (2) for electricity generation yet very high costs (3, 4, 5, 6). In recent years due to the drop of costs of PV systems in sever a l countries – with Germany leading – a remarkable increase in capacities took place, see Fig. 1. These increased PV capacities had in 2011 on some days significant impacts on the spot market prices at the German electricity exchange EEX, see Fig. 9.

In this geographical area in the next years at least a continuous further growth of PV capacities can be expected. In Germany only it is expected that total installed PV capacity will increase from about 20 GW (installed by the end of 2011) to at least 50 GW by 2020. This is half of total fossil and nuclear capacity in Germany in 2011. Moreover, the looming grid-parity will further emphasize this trend because PV will become economically more attractive.

The core objective of this paper is to investigate the possible effects of such a further uptake of PV on the prices in an electricity market. Because Western Europe is currently already influenced by this effect we explain the likely consequences for the example of the EUR-4 electricity market (Austria, Germany, France, Switzerland)[1]. We analyse two major effects: (i) the direct impact of PV at specific times of the year when PV shifts the supply curve of conventional electricity virtually out of the market leading to temporarily very low market prices close to Zero; (ii) the indirect impact of PV (and wind) on the costs at which fossil and natural gas capacities are offered;

Moreover, of specific interest is the likely competitiveness of PV due to “grid parity” – leading to lower costs of PV than the household electricity price is.

[1] Despite this analysis is conducted for a rather small area the perceptions and conclusions of this analysis can be used in many countries world-wide.

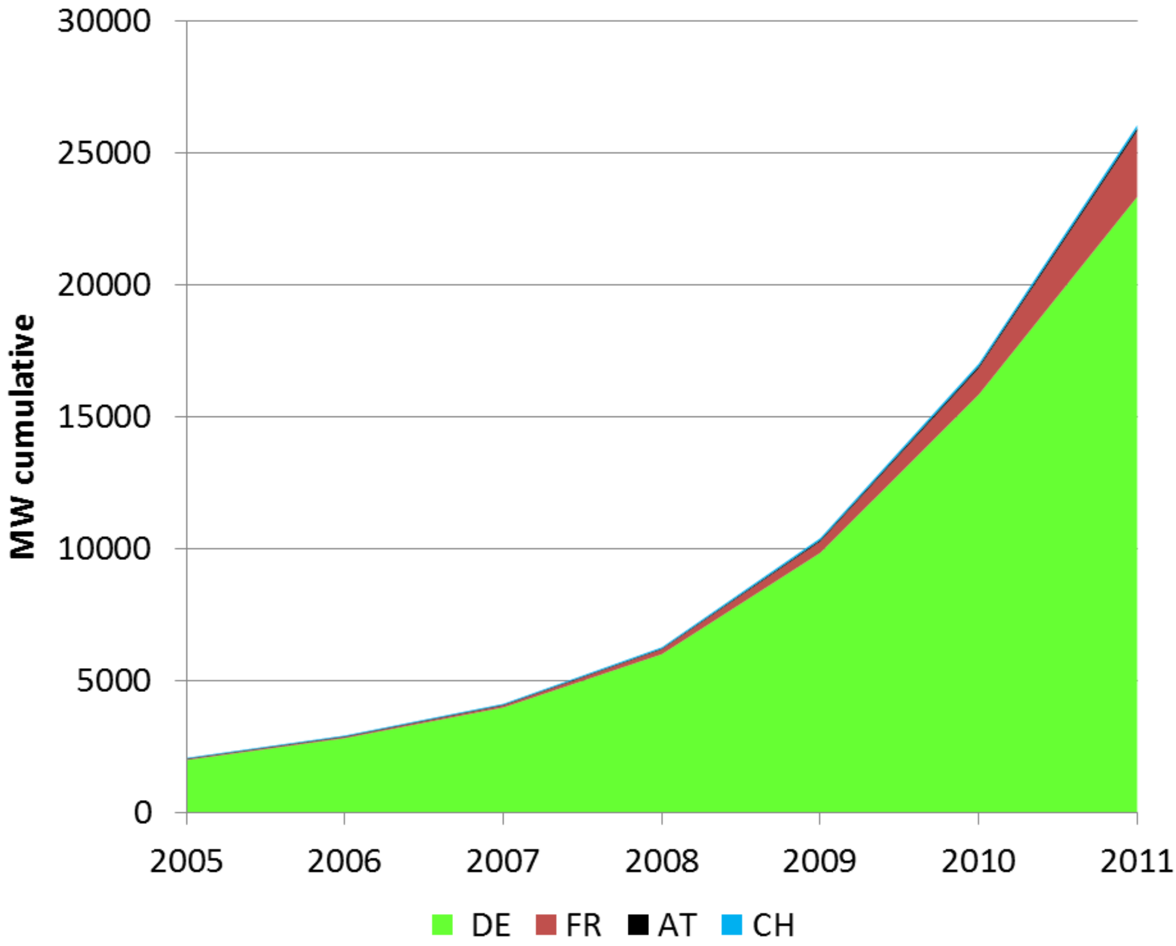

Figure 1. Development of cumulated PV capacities in EUR-4 in recent years

METHOD OF APPROACH

The method of approach applied in this work is based on a fundamental approach where the intersection of supply and demand at every point-of-time gives the corresponding market price. Specific emphasis is put on the difference between short-term and long-term marginal costs.

HOW PRICES IN ELECTRICITY MARKETS COME ABOUT

The price developments in different European electricity sub-markets from 2000-2012 (preliminary) is shown in Fig. 2. We can see a high volatility and considerable differences between different sub-markets. How does this price pattern come about?
Figure 3 shows a typical merit order supply curve for a specific point-of-time with conventional capacities (incl. large hydro).
In the typical historical pattern of electricity generation in the EU-4 electricity market consisting of conventional fossil, nuclear and large hydro capacities since the 1990s at every point-of-time nuclear contributed the largest share, followed by fossil and by hydro.
Finally Figure 4 shows how prices come about in markets with conventional capacities (incl. large hydro): intersection of supply curve with demand gives electricity price at the short term system marginal costs The change in this pattern due to considering wind in addition is described in Fig. 5.

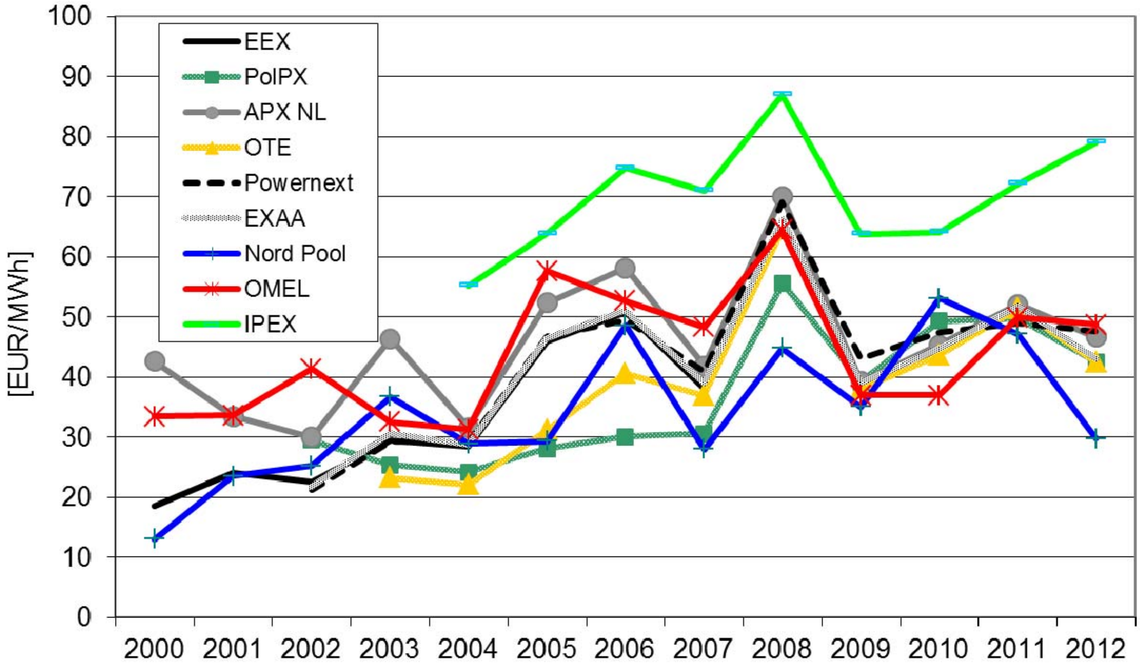

Figure 2. Price developments in different European electricity markets 2000-2012

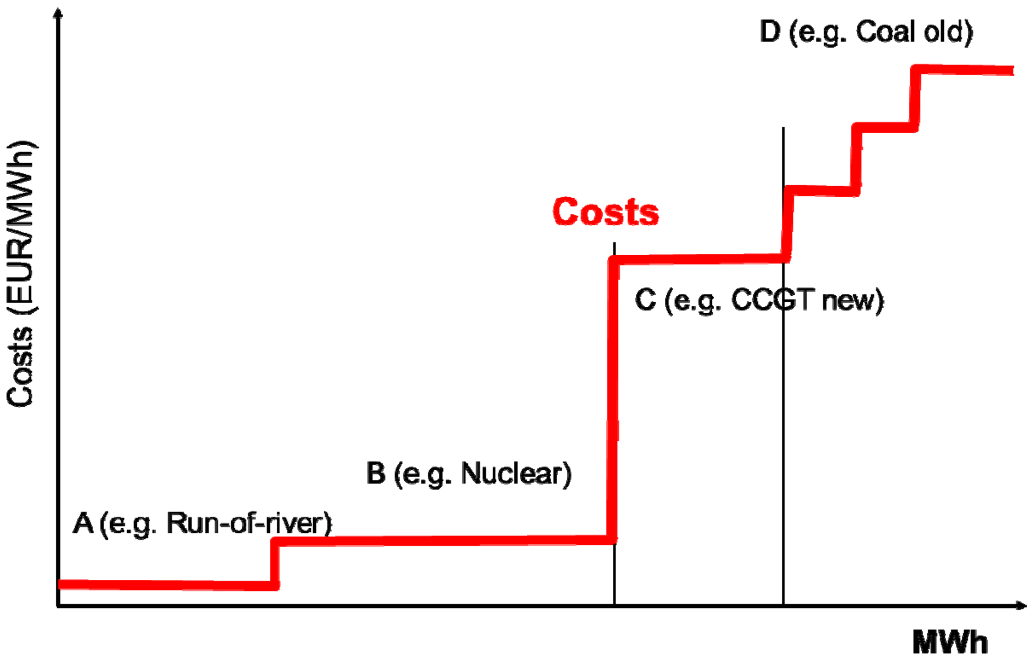

Figure 3. Typical short-term merit order supply curve for a specific point-of-time with conventional capacities (incl. large run-of-river hydro)

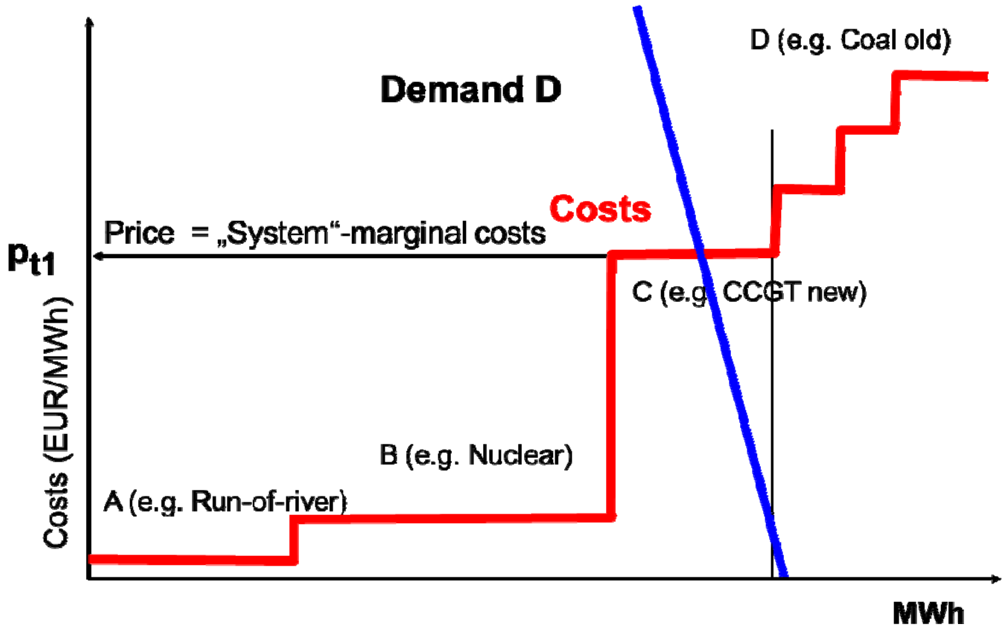

Figure 4. How prices come about in markets with conventional capacities (incl. large hydro): intersection of supply curve with demand gives electricity price at the short term system marginal costs

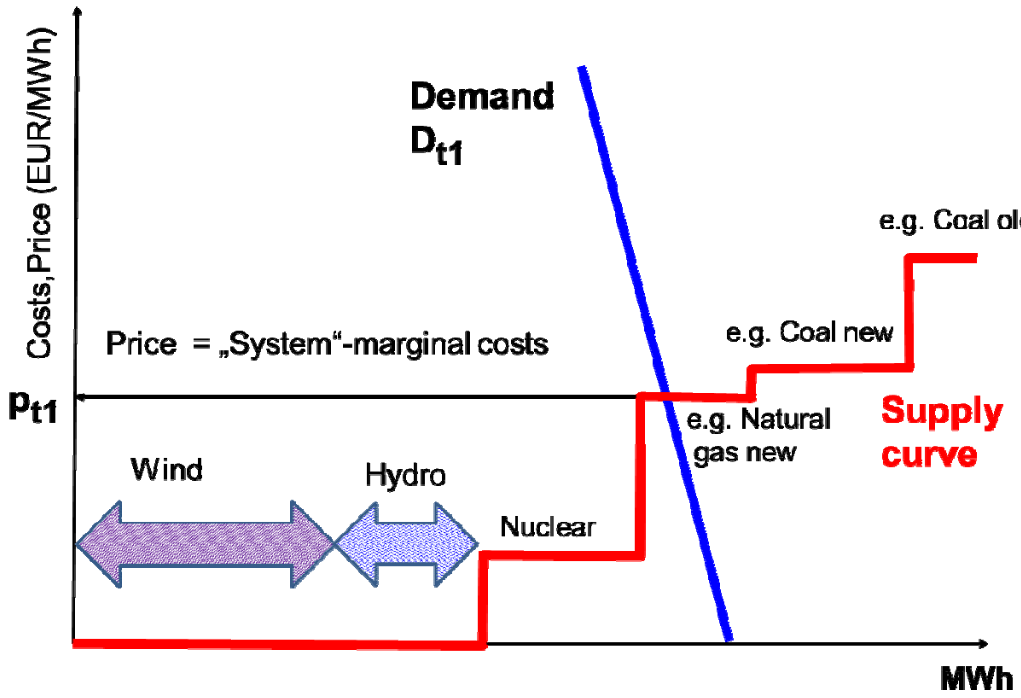

Figure 5. Merit order supply curve with additional wind capacities (incl. large hydro) at off-peak time

EFFECT OF TEMPORARILY HIGHER SHARES OF RENEWABLES ON THE PRICING OF FOSSIL CAPACITIES IN ELECTRICITY MARKETS

In a market with larger shares of RES the role of gas capacities will change see e.g. Auer (16), Pantos (18), Hasoni/Hosseini (19), Carraretto (20). In Fig 4 and 5 the supply curve is still based on the short-term marginal costs of the fossil capacities. Usually for natural gas this corresponds to about 6000 full-load hours per year. But what will happen, if the full-load hours per year drop to 1000-2000 hours/year?

Figure 6 depicts the total and variable (short term) electricity generation costs of a new CCGT depending on yearly full-load hours. As can be seen the share of fix costs is considerably higher when full-load hours are low (e.g. 1000 h/yr)[2] than when full-load hours are high (e.g. 6000 h/yr). In the market that prevailed in recent years and where old coal power plants determined often the STMC there was more "room" for covering the fixed costs of new CCGT than in a future system where this might not apply.

This leads to the perception that pricing with long term marginal costs (incl. the capacity costs, the so-called levelized costs of electricity (LCOE)) or even short-term strategic costs becomes much more important than today.

The characteristics depicted in Fig. 6 will also lead to an end of the myth of the dogma : price = STMC.

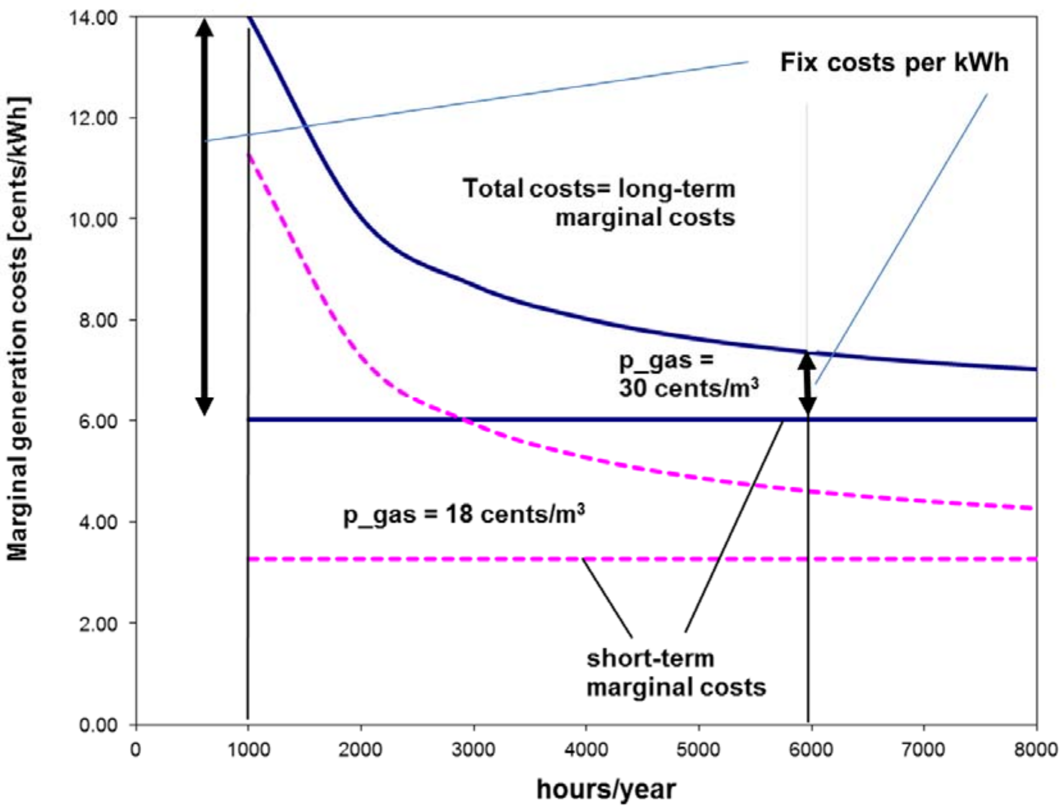

Figure 6. Total and variable (short term) electricity generation costs of a CCGT depending on yearly fullload hours

Figure 7 depicts the merit order supply curve with additional wind capacities (incl. large hydro) at off-peak time with total costs for conventional capacities.

We can see that intersection of supply and demand leads to a higher price if long term marginal

[2] Of course, these FLH will also vary year-by-year. They will be lower a year with higher hydro power than on average and vice versa.

costs are applied than for short term marginal costs, see also Walls (17). Moreover, for short periods of time there will even strategic prices take place, higher than the STMC. And important: These prices will then also be applied to hydro storage electricity.

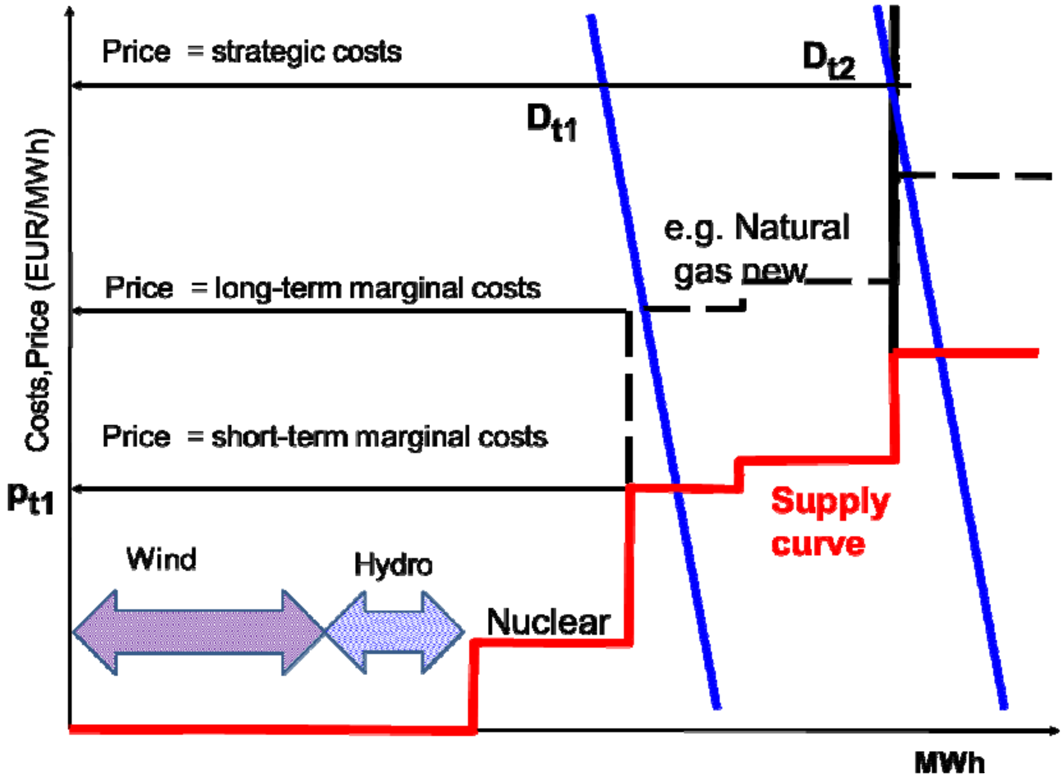

Figure 7. Merit order supply curve with additional wind capacities (incl. large hydro) at off-peak time with total costs or strategic bidding for conventional capacities

THE SPECIFIC IMPACT OF PV ON THE ELECTRICITY MARKET PRICE

That RES have an impact on electricity prices (or in former regulated markets at least at the conceived marginal costs of electricity generation) is already known since volatile hydro power was used for electricity generation. Later in the time of starting wind booms (about 2007 to 2009, in Denmark already earlier) there was experience with temporarily high wind in the systems and sometimes even negative prices (see also 9, 23, 25, 27, 28). However, these effects due to wind happened mostly at off-peak times (at some times also due to wrong or careless wind forecasts).

What makes PV now specifically different? Figure 8 depicts an example from Germany for the impact of PV capacities on the price developments in the German electricity market on 22nd October 2011. As this Figure depicts on sunny days PV- electricity generation follows the daily load profile and on these days it substitutes virtually completely the former production of hydro storages. We can see that around noon – when prices historically were typically high –prices dropped. In addition it changes the increase of prices at noon to a decrease.

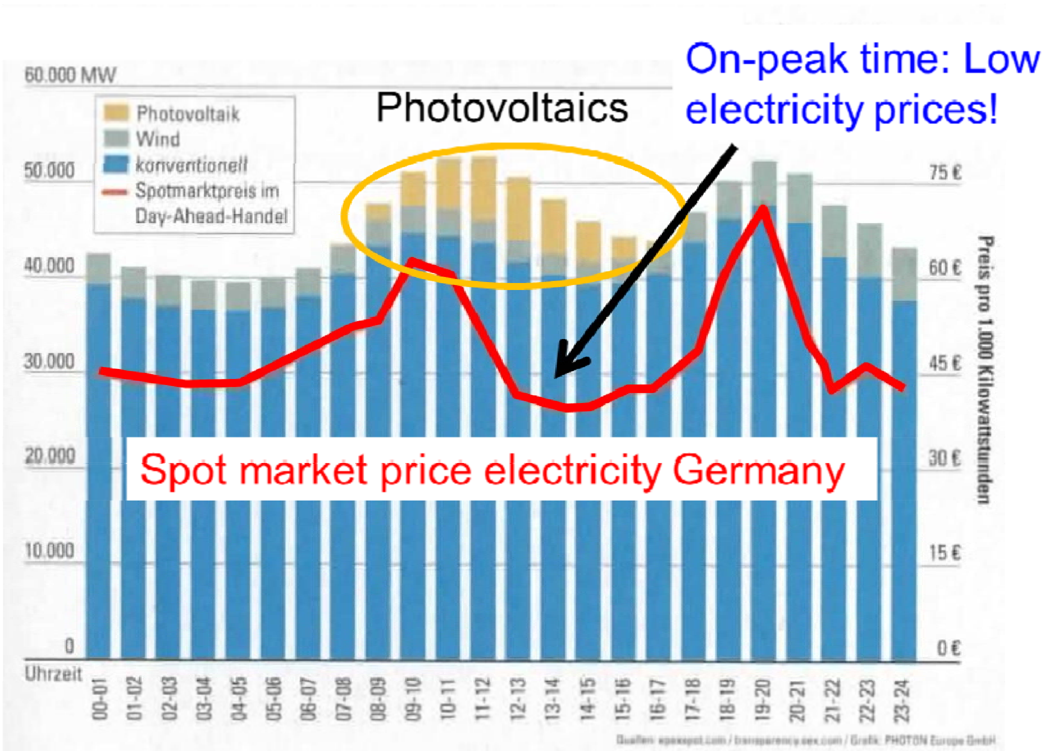

Figure 8. Example for the impact of PV capacities on the price developments in the German electricity market on 22nd October 2011

Figure 9 shows the merit order supply curve with additional wind and PV capacities (incl. large hydro) at on-peak time of a nice summer day with short term marginal costs for conventional capacities.

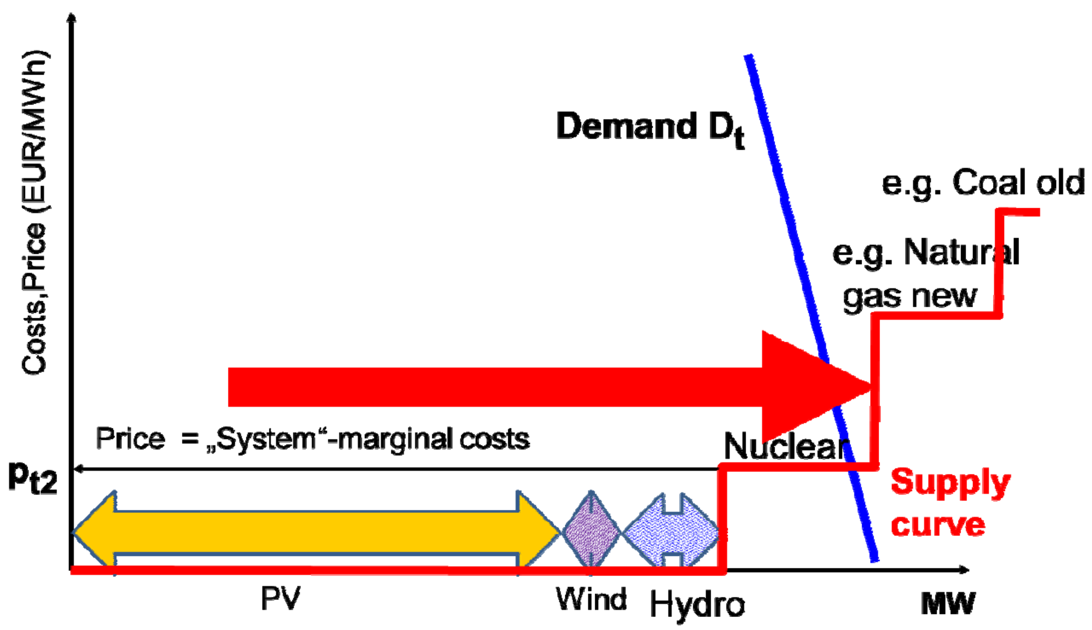

Figure 9. Merit order supply curve with additional wind and PV capacities (incl. large hydro) at on-peak time of a nice summer day with short term marginal costs for conventional capacities

Fig. 10 depicts the consequences of large amounts of PV and wind electricity for electricity prices in a dynamic picture for the example of a week in summer (based on synthetic data over an average year in Germany and Austria). We can see that tremendous volatilities in electricity prices ranging from zero to 14 cents/kWh are expected for such a week[3].
What is also a perception of Fig. 10 is that the price spread increases. But in future high prices will not necessarily appear at peak-demand times but at times with low RES availability. And the low price level will be associated with high RES-E production. Among other effects this will also change the handling of hydro storages. These will in future not work mainly in the night-to-day-shift rhythm but in the RES-availability context.

The following remark is also important. For the price effect it does not make a difference whether PV electricity is fed into the grid or directly used by the customer. As the total demand profile over a day will not change (except some possible minor shifts due to individual customer behaviour) the price effects described in Fig. 10 will be in principle the same.

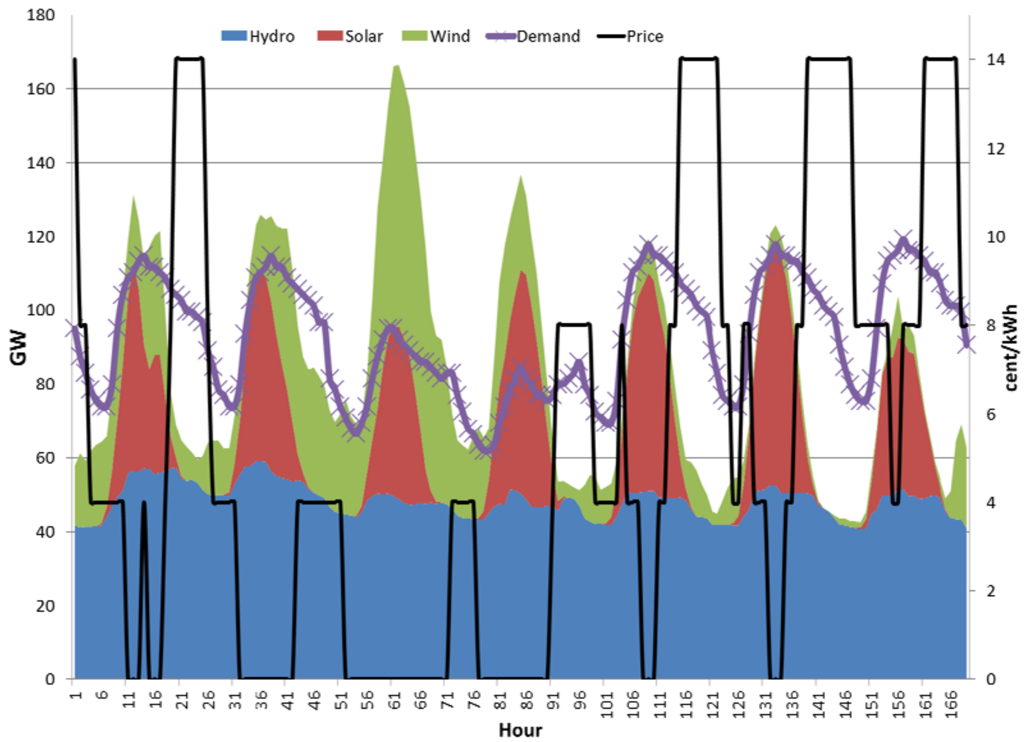

Figure 10. Development of wind and PV electricity (incl. large hydro) over a week on an hourly base in comparison to demand and the resulting electricity market prices with total costs for conventional capacities

FUTURE PROSPECTS FOR PV: LOOMING GRID PARITY ?

However, all in all these European developments led to a significant cost decrease which bring PV systems on the:verge to cost-competitiveness with household electricity prices , the so-called "grid parity" in most cases before 2020 (see Lopez and Haas (7), Breyer/Gerlach (13), Lund (22)).
Fig. 11 depicts for Germany possible developments up to 2020 for small-scale systems (<30kW) in an upper and a lower "corridor" depending on the overall capacity of systems installed. In this

[3] Note, that the number 14 cents/kWh results from Fig. 7 with FLH of about 1000 h/yr.

Figure also household electricity prices are included. For small-scale systems in the lower corridor scenario the so-called grid parity could already be brought about before 2015.The major latest development which are important in this Figure are the FIT of 28.74 cent/kWh for 2011 in Germany and of 24.43 cent/kWh for 2012 (12).

In total the situation for Germany can be considered rather promising for PV grid parity. The only reason why there might be some backlash would be if the market – which is still very sensitive – depending on imports from China and the effective financial support from government – collapses and system prices start to increase again as depicted in Haas (8) for the past. Yet, it is also important to state that grid parity does by far not mean fully economic competitiveness. This depends strongly from the feed-in price for the remaining electricity. However, if a net metering approach is introduced this criteria is fulfilled.

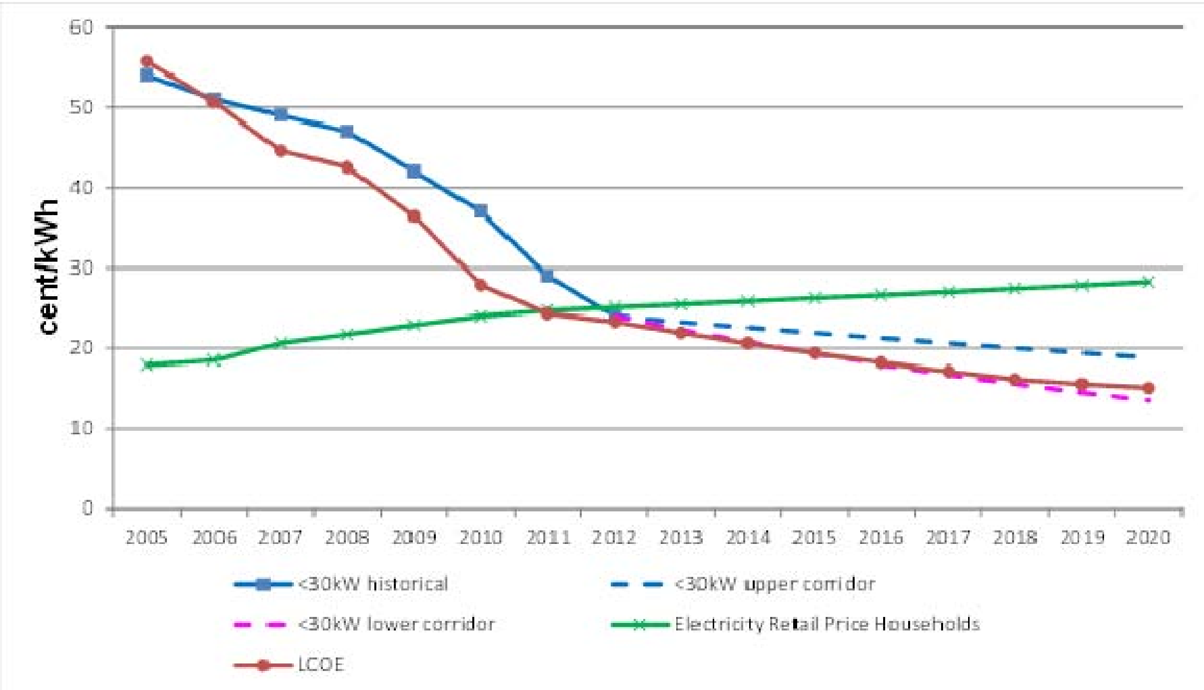

Figure 11. Historical development of PV FIT for small systems in Germany and expectations up to 2020 vs household electricity prices leading to “grid parity” between 2013 and 2015 (12, PHOTON various issues, last issue 11/2011)

FUTURE CHALLENGES

The above described developments and effects lead to further reflections and requests that may accompany the further uptake of PV. The most important are (see also Auer (9), Nielsen et al (17), Pantos (18), Wen (20), Lund (21), Lund (22)):

1. *From a rigid supply system to a breathing system:*
   The major change must be a paradigm change in our understanding of the whole electricity system – from generation over “smart” grids to electricity-based services finally provided. This major change in thinking is to switch from a unflexible rigid static one-way system to an over-all “breathing” system, which allows bi-directional flows, technical flexibility in the system, incl. DSM, load management from utilities and storages (see Krajacic (15)) which also contribute to “breathing”.
2. *Are there needs for capacity markets?*
   The discussion of the economics of remaining fossile power plants – see Fig. 7 and Fig. 8 – leads to the question whether there is a need for so-called capacity markets. The major argument of the proponents of this idea is that only if a fixed “stand-by fee” is paid for these mainly fossil plants, operators/owners of these plants will be retained from closing

down these plants respectively temporarily high strategic prices will be avoided. However, in practice it is only necessary to get rid of one simplified and anachronistic argument of the initial theoretical requests of liberalised markets: That prices must equal short-term marginal costs.

3. *New market structures:*
   With respect to time-dependent market structures different new patterns will emerge. Regarding the role of Hedging and future contracts an argument raised recently is that in markets with high shares of RES no hedging is possible and future markets will break down. We think that actually the opposite will be true: With hedging and tradable long-term contracts these instruments will take over to a large extent the role of capacity markets. E.g long-term contracts (LTC) traded years ahead on an annual basis will serve to reserve (and ensure) long-term capacity. The closer the delivery date comes the more fine-tuned will b the capacity reservation due to purchasing LTC. E.g. if good hydro power conditions are observed less capacity will be hedged than vice versa.
   On the other hand there is a growing relevance of short-term markets like intraday- and secondary energy markets. In this context it is likely from our perspective that also "longer" term markets for secondary energy will emerge.

MAJOR RESULTS AND CONCLUSIONS

The major effects of these developments on the electricity markets will be: (i) a much higher price volatility from hour-to-hour and day-to-day; (ii) increasing relevance of intra-day markets; (iii) reduced load factors of thermal power plants increasing their LCOE, being detrimental to high investment cost conventional technologies like coal and nuclear; (iv) higher costs and prices for fossil capacities (due to higher shares of investment depreciation costs if no capacity markets are implemented); (v) increasing relevance and complexity of balancing supply, storages, "smart" grids and demand response; (vi) higher incentives for PV owners in households for own use of electricity; (vii) balancing markets will gain higher market shares, which will be filled in by hydro and gas; (viii) Regarding the final electricity price for customers the share of costs for auxiliary services will increase remarkably compared to the pure energy production costs.

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