THE IMPACT OF HEAT WAVES ON ELECTRICITY SPOT MARKETS

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(1) Overview

Increasing mean temperature and frequency of heat waves due to climate change will impede energy generation in several ways, e.g. due to water scarcity (Mideksa and Kallbekken, 2010). Thermoelectric power plants that are located inland depend on cooling water for production drawn from rivers, nearby lakes or other freshwater reservoirs. To protect the environment from thermal pressure, standards have been established that restrict the discharge and temperature of the effluent water (e.g. EU Freshwater Fish Directive). As a consequence, several power producers already had to cut their production in Europe in the past (e.g. summers of 2003 and 2006) due to legal restrictions and/or scarce cooling water (Strauch, 2011). Climate projections for Germany reveal that the challenge of water scarcity and high river temperatures for the power industry will most likely tighten in the future (Deutschlaender et al., 2012).

So far, the effect of forced capacity reductions has been quantified for single power plants (Förster and Lilliestam, 2010) and for future generation systems based on energy system scenarios (Golombek et al, 2012; Rübbelke and Vögele, 2013). The first finds annual income losses between € 5.2 million and € 81 million for a (nuclear) plant owner. The latter find only marginal price effects of capacity reductions but a substantial increase in producer profits. Apart from an econometric analysis (McDermott and Nilsen, 2011) the effect of the actual capacity reductions experienced in the past has not been investigated. A reference case based on real data is thus missing.

This paper seeks to analyze the impact of historic capacity reductions of thermal power plants on the electricity market in Germany. We focus on and use real data of the heat wave in July 2006. We investigate which effects the reductions of 20 thermal power plants had on prices, rents and CO_2 emissions. We use a model of the German electricity wholesale market, which allows us to separate the capacity reduction from other price driving effects.

(2) Methods

To analyze the effect of heat wave induced capacity reductions, a model of the German electricity market is used to simulate the electricity market price in summer 2006. The spot market prices are calculated on an hourly basis for July 2006. The model represents in detail all thermoelectric power plants (> 20 MW) of the German power system. In addition pumped storage power plants are represented in the model. Feed-in of renewable power plants, heat-led combined heat production (CHP) plants and of industrial power plants as well as power exchange are exogenous variables in the model. Since the focus is on small time scales, power demand is assumed to be inelastic. The power suppliers' bid is based on variable and start-up costs. In addition we presume that the entire electricity demand is traded on one single spot market[1].

The model is implemented in GAMS. We try to fit the model as closely as possible to historic EEX prices. By adequate choice of pump storage availability and input of historic data, we achieve an explanation of 89% of the variation in the real electricity price data.

To determine the impact of the historic capacity reductions on the electricity market, the simulation is run for two different scenarios: The first is the scenario of the heat wave that includes the real capacity reductions based on Strauch (2011). Cross-checked with monthly data from the International Atomic Energy Agency (IAEA, 2007) the listed load reductions by Strauch can be considered conservative. The second scenario is the counterfactual with normal temperatures and plant availabilities; all other parameters are held constant. The two runs cover 20 days in July that cover the 14 days during which the reductions occurred. To test for further heat-induced impacts on the energy sector that are not recorded, levels of demand, hydro power availability and net exports were varied in the sensitivity analysis. In addition the feed-in of renewable energies is increased in the sensitivity analysis to give an outlook for future vulnerability of the power sector.

(3) Results

Our simulation results show that the wholesale electricity price increased on average by 11.2 % (4.14 €/MWh) during the heat wave. The increase is even more pronounced during demand peak times (8am-8pm on weekdays), i.e. 17.3 % (8.29 €/MWh), than during off-peak times 6.5% (2.07 €/MWh).

In total, the costs were incurred by the electricity buyers. Though production costs increased in total by almost € 16 m producer surplus rose simultaneously by approx. € 53 m during the heat wave. At the same time the surplus of the demand side decreased by € 69.9 m. Hence, in sum welfare effects were negative (- € 15.9 m).

Yet, not all producers gained from the price increase. An operator of a nuclear power plant with 1,345 MW net installed capacity that had to reduce capacity by 65 % during 9 days (189 GWh in sum), lost € 5.4 m of surplus during this time even if the prices had remained unchanged. With the price increase the operator could have gained approx. € 6.5 m more if the plant would have been able to operate at full capacity.

[1] While this is true for only 20- 30°% of the traded power, the day ahead spot market price serves as point of reference for forward markets and over-the-counter trade due to opportunities of arbitrage (c.f. Ockenfels, 2008).

The replacement in particular of nuclear power plants with more carbon-intensive plants led to an increase of carbon dioxide emissions of about 5 % per MWh. If we assume social costs of 50 € per ton CO_2 (IPCC, 2007), and subtract the already priced-in costs from emission certificates (16.25 €), additional welfare costs of approx. € 5 m result from the capacity reductions.

In the sensitivity analysis we tested for additional changes during the heat wave of hydro power capacity, demand and net exports that we had abstracted from in the first case. The results show that the welfare effect is slightly more sensitive to cuts in hydro power capacity and/ or net exports (in the heat wave scenario) than to increases in demand (in the model equivalent to a lower demand in the counterfactual scenario).

With regards to the influence of renewable energy generation (excluding hydro power) on the results, the analysis shows that it is not negligible: e.g. in case of a 30 % coverage of inland production from wind, solar and biomass as projected for 2030 (Prognos et al., 2011) the welfare loss during the heat wave would have been 51 % lower.

(4) Conclusions

We show in this paper that the capacity reductions during the heat wave of July 2006 substantially affected electricity wholesale prices, especially during times of peak demand. The resulting welfare effects are negative and at the expense of the buyers. The model results hence confirm the distributional effects also found by Rübbelke and Vögele (2013). In an industry that provides one of the basic public services this distributional effect could be a critical political issue. Welfare decreases even more when additional CO_2 costs are considered.

Qualifying the model results are the implicit assumptions of an inelastic demand and the absence of longer term contracts. A more price elastic demand would decrease the price and welfare effects. Since over the counter business is not transparent, it can only be speculated how price increases at the EEX influence these contracts. Yet if heat waves are to become more frequent it can be assumed to show in longer term contracts, too.

As the sensitivity analysis shows, if assumptions of insensitive demand, hydro capacity and net exports during the heat wave is relaxed, welfare losses are even more substantial.

Assumptions for future generation systems can only be made on a tentative basis as we only vary the renewable feed-in. With a RES share of 30 % of inland production, the mean price increase would (c. p.) have been approx. 4 % instead of 11 %. Compared to other studies using this share(c.f. Golombek et al., 2012; Rübbelke and Vögele, 2013), the model price increase is slightly higher, owing to the fact heat vulnerable nuclear power plants are still included in our model. In conclusion countries with a shift to RES can be expected to be much less susceptible in this regard to heat waves than those with a high share of nuclear and coal-fired power plants. Yet if large gas-fired power plants are to be constructed to balance RES vulnerability and/or a dependence on power imports exists, the issue could still persist.

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