FLEXIBILITY IS THE ANSWER

EUROPEAN POWER EXCHANGE AS A COMPONENT OF SECURITY OF SUPPLY DURING THE SOLAR ECLIPSE

AYMEN SALAH ABOU EL-ENIEN, EPEX SPOT

April 30, 2015

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EUROPEAN POWER EXCHANGE AS A COMPONENT OF SECURITY OF SUPPLY DURING THE SOLAR ECLIPSE

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April 30, 2015

30-SECOND SUMMARY

PURPOSE

This paper is part of the effort by EPEX SPOT to continue to explain how its markets, mechanisms, and products – which include the Day-Ahead Auctions, Market Coupling, the 15 minutes Auction, and Continuous Intraday – help to keep the lights on.

SUMMARY

The March 2015 solar eclipse provided some insight into the increasing role of solar photovoltaic in the European fuel mix.

In Germany, which has the highest market penetration of solar power in Europe, solar generation for delivery Friday March 20, 2015 was forecast to reach 15 GW just before the solar eclipse, falling below 7 GW at around 10:30 am CET and rising again sharply above 22 GW around noontime CET.

The primary goal of this paper is to outline the role that EPEX SPOT ensures to cope with the dramatic mutations that Europe's electricity structures are undergoing, and help the whole system to face the natural and inescapable intermittency of renewable energy, both in the short and long run.

THE KEY MESSAGES OF THIS PAPER:

- **The adverse flows on uncoupled Swiss borders deserve our attention. Some market participants overestimated the solar eclipse impact on the German merit curve. Their anchored judgments led them to schedule commercial flows from Switzerland to Germany, but Switzerland settled at premium to Germany.**
- **EPEX Germany 15 minutes auction sends excellent signals to generators, consumers, transmission system operators, regulators, and policy makers.**
- **The liquid continuous intraday markets allowed market participants to adjust continuously and until nearer to real time, their Day-Ahead forecasts to the most recent news.**

There is no question about the abundance of solar energy striking our earth. According to an article[1] published in Scientific American, "The energy in sunlight striking the earth for 40 minutes is equivalent to global energy consumption for a year."

Both forms of solar[2], however, suffer from the intermittency[3] problem, which reduces their potential for replacing fossil fuels.

The March 2015 solar eclipse provided a pretty insight into one form of solar intermittency – according to Entso-e (European grid operator association), the eclipse was forecast to affect some 35 GW of solar photovoltaic production Europe-wide. According to RTE (Réseau de Transport d'Electricité), solar output across Europe was forecast to drop 400 MW per minute and rise again at 700 MW per minute, four to five times faster than normal sunrises and sunsets.

In Germany, which has the highest market penetration of solar power in Europe, solar generation for delivery Friday March 20, 2015 was forecast, as illustrated in Figure 1, to reach 15 GW just before the eclipse, falling below 7 GW at around 10:30 am CET and rising again sharply above 22 GW around noontime CET, according to the TSOs Day-Ahead forecast.

Germany has enough conventional capacity[4] to respond to such swings in solar output, but the speed of these swings was an unprecedented challenge.

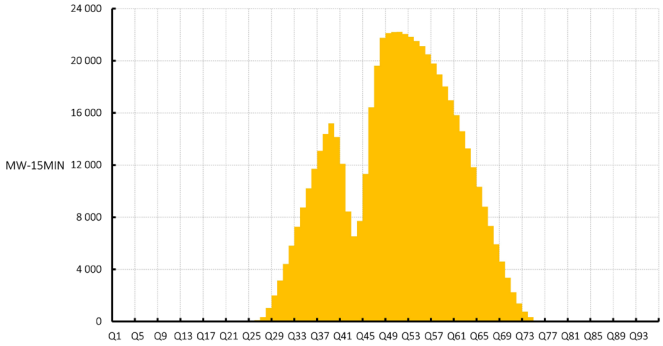

Figure 1. German solar generation day-ahead forecast for delivery Friday March 20, 2015
[Source: EEX transparency platform]

The paper at hand explains the critical role EPEX SPOT market structures, mechanisms, and products – including Day-Ahead Auctions, Market Coupling, the 15 Minutes Auction, and Continuous Intraday – played in the overall scheme of keeping the lights on for delivery Friday March 20, 2015. It is written for individuals who have some knowledge of European short term power markets.

UNUSUAL DAY-AHEAD CURVE'S SHAPE, ADVERSE FLOWS ON THE SWISS BORDERS

There are generically two distinct periods of peak hourly power prices on a normal March business day in the continent. They are mainly driven by demand – the first occurs in the morning when people wake up for work, and homes and offices need to be heated, and the second occurs in the evening when people arrive home from work. The black curve in Figure 2 illustrates the shape of EPEX Germany/Austria Day-Ahead hourly prices for a normal business day[5] in March 2015.

The orange curve depicts EPEX Germany/Austria hourly prices for delivery Friday March 20, 2015. At first glance, one notices an unusual third jump at €/MWh 49.41 on Hour 11. Unlike the two peaks invoked above, this peak was mainly driven by the fall in solar output during the peak of the partial solar eclipse.

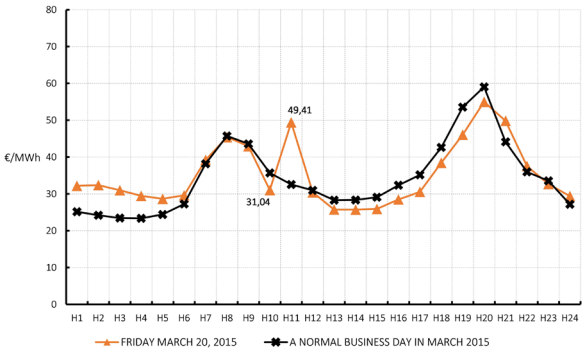

Figure 2. EPEX Germany/Austria Day-Ahead hourly prices
delivery Friday March 20, 2015 VERSUS March 2015 previous business days
[Source: EPEX SPOT]

As illustrated in Figure 3, power for delivery Hour 11 jumped in the Day-Ahead auctions across the region:

- €/MWh 49.41 both in France and Germany/Austria.
- €/MWh 74.94, the highest hourly price on the day, both in The Netherlands and Belgium.
- €/MWh 52.30 in Switzerland.

Several factors, however, including (1) reduced demand on Friday afternoon, (2) warmer temperatures, (3) additional conventional units to help offset solar output drop du-

1 Zweibel, Mason, and Fthenakis 2007

2 Solar power comes in two varieties, photovoltaic (PV) and concentrated solar power (CSP). In solar PV light falls on photo-electric panels and generates an electric current, while in CSP sunlight is concentrated by mirrors and used to generate steam and drive a turbine that produces electricity.

3 One way of thinking about intermittency is to say that there is a social cost associated with the use of an intermittent power source – the cost of constructing capacity to replace the power source when it is not operating, or alternatively the cost of leaving demand unsatisfied at such times. This is not an externality in the classical sense, but it emphasizes the fact that there is a system-wide cost linked to the use of intermittent power sources.

4 Nuclear availability was at 10.6 GW with only the 1.3 GW Grafenrheinfeld reactor offline for maintenance ahead of its final decommissioning in May, according to plant operator data. Hard-coal and lignite plant availability for Friday was pegged at 12.9 GW, with lignite adding 19.4 GW, according to EEX transparency data.

5 An average of all business days over March 01 – March 19, 2015.

ring the eclipse, and (4) capacity restrictions on the Italian borders[6], put downward pressure on Day-Ahead Baseload and Peakload prices for delivery Friday March 20, 2015:

- In Germany/Austria, the base settled at €/MWh 35.30 and the peak at €/MWh 35.82.
- In France, the base settled at €/MWh 40.35, and the peak at €/MWh 42.18.
- In The Netherlands, the base settled at €/MWh 42.99 and the peak at €/MWh 47.54.
- In Belgium, base power settled at €/MWh 43.26, tracking Dutch power prices, with a full convergence on the peak hours.
- In Switzerland, the base settled at €/MWh 39.93 and the peak at €/MWh 40.84.

It might be puzzling to realize the extent to which March 2015 solar eclipse revealed how Central West European power markets (or at least the shape of their prices curves) are driven by the German market. Not only these curves painted the same picture, but Germany (the most concerned with the solar eclipse) was set to export to the rest of the region, as shown in the Appendix 1, Table 1 – the total available transmission capacity (ATC) of 1 691 MWh to The Netherlands, and an amount of 2 162.1 MWh out of 2 950 MWh ATC to France, on Hour 11 alone!

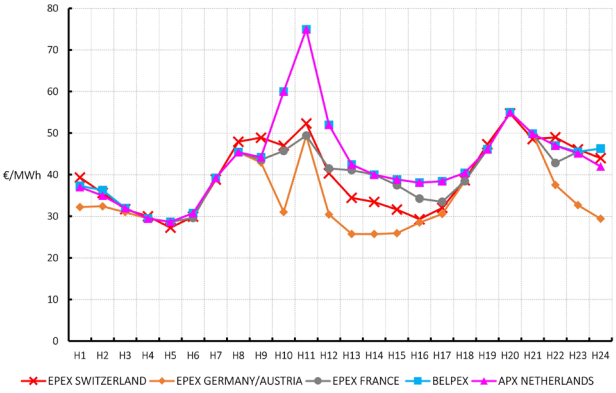

Figure 3. Day-Ahead hourly prices for delivery Friday March 20, 2015
[Source: EPEX SPOT, APX, and BELPEX]

Put another way, it would not be striking to have similar curves' shapes, with the unusual Hour 11 peak, if Germany was set to import rather than export to the rest of the region.

Equally important, is the amount of adverse flows on uncoupled Swiss borders – in particular, a total of 1 348 MWh were scheduled for commercial export from Switzerland to Germany/Austria on Hour 11, but Switzerland settled the hour at €/MWh 2.89 premium to Germany/Austria (see Figure 4). It goes without saying that market coupling plays a crucial role in such situations when anchored judgments lead some people to over or underestimate the impact of power prices drivers (in this case, the spectacular drop in German solar output during the solar eclipse). The Appendix 2, Table 2, reports the adverse flows on each of the Swiss-Austrian, Swiss-French, and Swiss-German borders, for delivery Friday March 20, 2015.

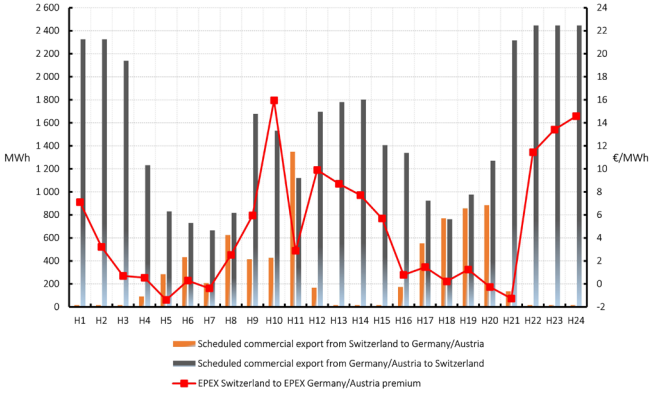

Figure 4. Adverse scheduled commercial flows between Switzerland and Germany/Austria for delivery Friday March 20, 2015
[Source: ENTSOE and EPEX SPOT]

FLEXIBLE GENERATION AND DEMAND SIDE MANAGEMENT EFFORTS COULD BE REWARDED ON THE 15 MINUTES AUCTION

In December 2014, EPEX SPOT introduced the 15 Minutes auction in Germany, in which not only "spot energy" but also "flexibility" is bought and sold within German control areas.

This "uniform price auction" is conducted every day at 03:00 pm CET and relies on offers to sell and bids to purchase for 15 minutes dispatch intervals.

EPEX SPOT accepts price-quantity offers (in €/MWh, ranging from – 3 000 to + 3 000)[7] to sell and price-quantity bids to purchase for the ninety-six 15 minutes dispatch intervals of the day[8]. The price for the 15 minutes dispatch interval is set by the intersection of supply offers and demand bids, and all successful purchase and sale offers are settled at the same price – the "uniform" price.

6 Italy curtailed the long-term allocated capacity on four of its five international links as a direct impact to the solar eclipse "due to network security reasons".

7 E.g., each generator may submit a series of offer prices or a supply curve showing how much energy it would produce at increasing price levels if selected for dispatch.

8 Or hundred, or ninety-two on daylight saving time.

Just as with the Day-Ahead auction, the settlement rule is a "no regrets" principle. No party that submits an offer or bid on the 15 minutes uniform price auction would regret the auction's results and being paid/charged at the resulting prices – if a seller submits an offer and EPEX SPOT selects that offer (because it is part of the lowest-cost set of supplies to meet demand for flexibility[9]), the seller will receive a price that is equal to or greater than its offer price. The seller will not lose money (or receive at least its offer price) as a result of accepting the resulting spot price, because the spot price will be high enough to at least cover his or her price offer, which is likely to reflect her costs for providing the requested flexibility. Similarly, no buyer would regret purchasing at the uniform price, because the price she pays will be no greater than the bid she submitted.

Because the sellers know they will receive prices set by the "no-regrets" rule above, this principle also tends to encourage them to submit offers at or near their costs. In other words, the rule encourages the sellers to submit offers at the lowest price at which they would be willing to sell their flexibility. The result is a "least-cost" dispatch.

Such pricing helps flexibility to come into play in both the short and long run. In the short run, 15 minutes prices encourage flexible generation and flexible demand-side resources to participate in the dispatch, as explained later for delivery Friday March 20, 2015. In the long run, they support maintaining system's flexibility (and thus, reliability) with the lowest cost set of resources that can meet the total system's flexibility needs, while pricing flexibility at a level consistent with long-run investment requirements.

Another way of saying this, is that the 15 minutes auction provides additional correct incentives, so that both flexible generators and flexible demand-side, do what the system needs them to do to keep the lights on.

This has been said, March 2015 solar eclipse illuminated the role the 15 minutes auction plays to help the system face the natural and inescapable renewable energy intermittency, and power prices volatility.

Figures 5 and 6, illustrate the cleared volumes and prices[10] for delivery Friday March 20, 2015 (in orange) against a normal business day in March 2015 (in black). Though normal business days show important variations within the day, the spectacular flexibility needs during March 2015 solar eclipse deserve emphasis.

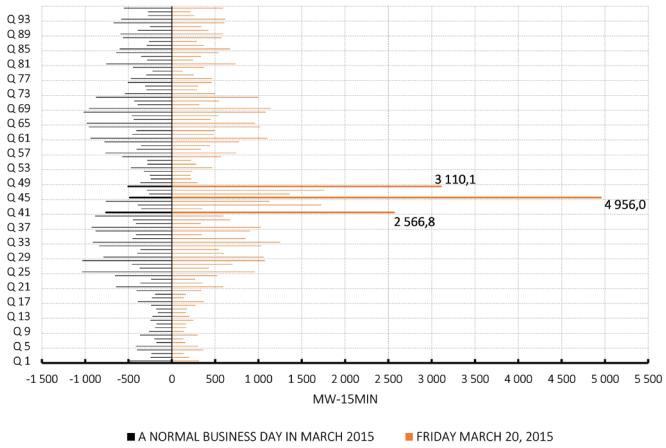

Figure 5. EPEX Germany 15 minutes auction volumes
delivery Friday March 20, 2015 VERSUS March 2015 previous business days; Qj is the nomenclature used in this paper for the ninety-six 15 minutes contracts of the day.
[Source: EPEX SPOT]

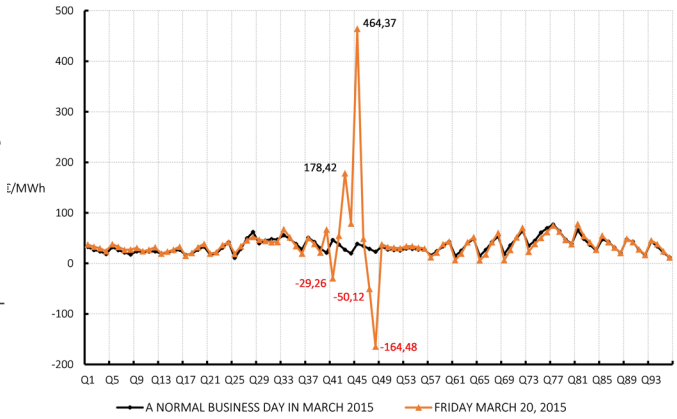

Figure 6. EPEX Germany 15 minutes auction prices
delivery Friday March 20, 2015 VERSUS March 2015 previous business days
[Source: EPEX SPOT]

Figure 7 focuses on the period from 09:00 am to 01:00 pm. It tells us, in particular, that:

- About 5 GW capacity of flexibility, able to operate over the time window 11h00 – 11h15 CET (denoted Q45 in Figure 7) was required at a price of €/MWh 464.37.
- About 3 GW capacity of flexibility, able to operate over the time window 11h45 – 12h00 CET was required at a price of €/MWh - 164.48.

There were significant price saving for consumers (or their utilities or other demand-side providers) capable of responding to prices. In particular, for large industries capable of (1) doing something less energy intensive, over 11:00-11:15 am CET, and selling back up to 5 GW of their energy[11] to the market at a price of €/MWh 464.37, and

9 Flexibility demand here doesn't necessarily mean energy demand. A solar generator who sold in the Day-Ahead auction his average solar forecast for the 15 minutes periods on a given hour and knows he will produce more than that average on one of the 15 minutes intervals, might require another flexible generator to buy the difference and ramp downwards with the same amount. In this case, flexibility demand corresponds to energy supply and not energy demand.

10 Note that EPEX SPOT has triggered a second auction for delivery Friday March 20, 2015.

11 Which they would have acquired through long term or Day-Ahead commitments, for instance.

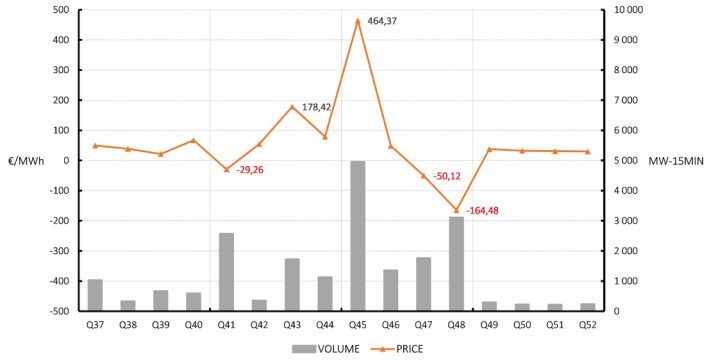

Figure 7. EPEX Germany 15 minutes auction prices and volumes during the eclipse of Friday March 20, 2015
[Source: EPEX SPOT]

(2) consuming more than normal, over 10:00-10:15 am CET and 11:30-12:00 am CET, and being paid up to €/MWh 164.48 for each MW consumed.

The same was true for generators capable of quickly ramping upwards and downwards, to quickly start up and shut down, and flexible pumped storage power plants.

In the long run, the 15 minutes auction resulting prices and transacted volumes constitute a critical set of information for investors, inflexible generation and load, transmission system operators, regulators, and policy makers:

- In which additional technology (ramps, new plants, storage facilities, demand-response, etc.) should one invest?
- Should one (re)think of renewable energy deployment and diversification of the power portfolio by giving more incentives to renewable energy resources with high capacity factors, like biomass, and less to those with lower capacity factors, like solar photovoltaic?

FLEXIBLE GENERATION AND LOAD COULD ALSO BE REWARDED ON THE CONTINUOUS INTRADAY MARKETS

The previous section explained how the 15 Minutes auction helps flexibility to come into play, both in the short and long run. In sum, it reveals a required flexible quantity – through the clearing volume of the auction –, and a required set of flexible technology – through the clearing price, the highest cost that allows matching demand for flexibility –.

Moreover, running the 15 minutes auction at 03:00 pm CET after the Day-Ahead auction is conducted allows market participants to adjust their foreseeable 15 minutes variations to their already known scheduled Day-Ahead hourly commitments. The 15 Minutes auction also eases market participants operations (instead of trading continuously and simultaneously up to ninety-six products, on the already established 15 Minutes continuous intraday[12].)

The truth is that the continuous intraday markets, both for the 15 Minutes and hourly products, still play a major role in the overall scheme of keeping the lights on. In fact, the Day-Ahead auction and the 15 Minutes auction are based on forecasts of the next day's fundamentals as the actual values are not known when they are run. The continuous intraday markets provide an interesting venue which allows market participants to balance, continuously and until nearer to real time, the actual demand and supply for "spot energy" and "flexibility" against the Day-Ahead forecasts. And thus, they also reward flexibility, and help demand-response to come into play.

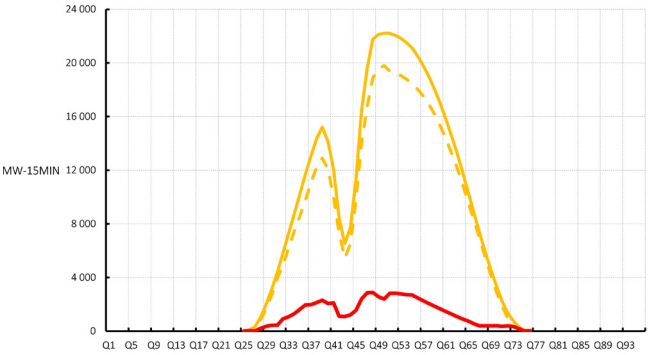

Figure 8. German solar generation for delivery Friday March 20, 2015
Day-Ahead Forecast VERSUS Actual
[Source: EEX transparency platform]

For delivery Friday March 20, 2015, as shown in Figure 8, solar output in Germany turned out to be lower than its Day-Ahead forecast. In particular, the Day-Ahead forecast overestimated the actual output by 1 400 MWh for Hour 11, and 1 700 MW for average Peakload hours.

Figure 9 compares the intraday hourly weighted average prices for delivery Friday March 20, 2015 to their related Day-Ahead auction hourly prices. It illustrates how the intraday market responded to the most recent news on solar energy forecast. For power delivered on Hour 11, the peak of the solar eclipse, the intraday price index was

12 EPEX SPOT has launched the 15 minutes continuous market on December 14, 2011. At a first stage, 15 Minutes continuous trading sessions were open two hours before the related hour delivery, within the German control areas.

As of November 05, 2012, they are open one day before delivery at 04:00 pm, and last until forty-five minutes before delivery. The minimum volume increment is 0.1 MW, the minimum price increment is €/MW 0.01, and allowed prices range from €/MW – 9 999 to €/MW + 9 999.

EPEX Swiss 15 Minutes intraday market within the Swissgrid control area, and cross border trading of the 15 Minutes contracts between Germany and Switzerland, both launched on June 26, 2013, have similar market rules, except that trading is possible until 75 minutes before delivery begins.

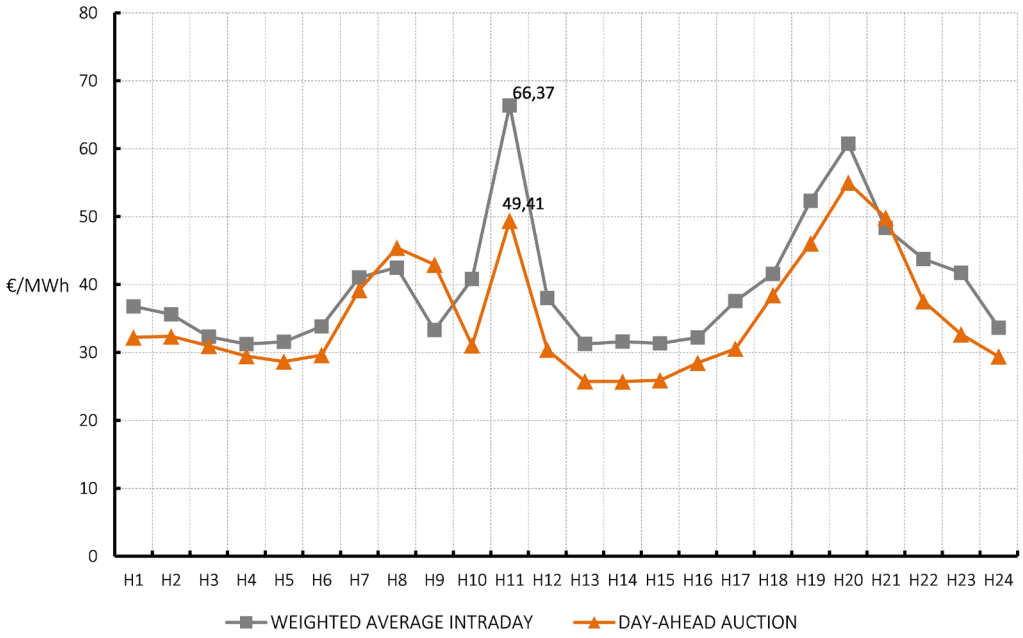

Figure 9. German hourly prices for delivery Friday March 20, 2015
Intraday VERSUS Day-Ahead
[Source: EPEX SPOT]

assessed at €/MWh 66.37, which partly reflects the cost of the technology that provided the backup supply to cover the Day-Ahead forecast error in solar output.

On the 15 minutes continuous intraday, there were important price swings on the first and fourth contracts of Hour 11. Figure 10 illustrates these swings – The 11:00-11:15 contract transactions occurred at prices ranging from 35 to €/MWh 382.1, averaging at €/MWh 146.5, with 25% of prices ranging from 146.5 to €/MWh 285, and another 25% set of prices between 285 and €/MWh 382.1. Most of the transactions of the 11:45-12:00 contract occurred at negative prices, with an average of €/MWh -2.7. Appendix 3 Figures 11 and 12 depict the prices swings for the 15 minutes contracts over 09:00-11:00 am CET.

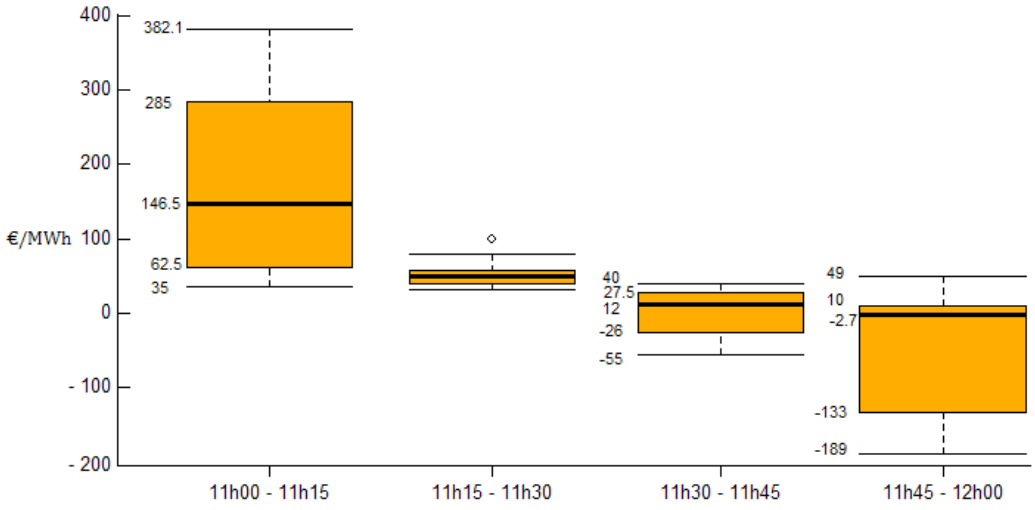

Figure 10. The boxplot of 15 Min prices on EPEX continuous market for delivery Friday March 20, 2015
Over 11h00 – 12h00 [Source: EPEX SPOT]

APPENDIX 1

Table 1. Available Transmission Capacities and their Allocation through Market Coupling

for delivery Friday March 20, 2015

[Source: CASC]

	DE To NL		FR To BE		NL To BE		BE To NL		DE To FR		FR To DE	
	ATC	ALLOC.	ATC	ALLOC.	ATC	ALLOC.	ATC	ALLOC.	ATC	ALLOC.	ATC	ALLOC.
Hour 1	1 691	1 691	1 688	1 004.1	1 448	1 448	1 552	0	2 950	2 950	1 850	0
Hour 2	1 691	1 691	1 688	916.6	1 448	1 448	1 552	0	2 950	2 950	1 850	0
Hour 3	1 691	1 691	1 688	1 086.4	1 448	1 394.7	1 552	0	2 950	2 950	1 850	0
Hour 4	1 691	1 691	1 688	1 473.4	1 448	905.5	1 552	0	2 950	1 694.5	1 850	0
Hour 5	1 691	1 687.2	1 688	1 688	1 448	854.8	1 552	0	2 950	0	1 850	123.2
Hour 6	1 691	1 691	1 688	1 688	1 448	986.8	1 552	0	2 950	1 125	1 850	0
Hour 7	1 691	1 472.3	1 688	1 560.1	1 448	890.7	1 552	0	2 950	802.9	1 850	0
Hour 8	1 691	1 691	1 688	1 502.5	1 448	886.5	1 552	0	2 950	1 881	1 850	0
Hour 9	1 691	1 691	1 688	1 688	1 448	286	1 552	0	2 950	2 950	1 850	0
Hour 10	1 691	1 691	1 688	1 688	1 448	0	1 552	272.6	2 950	2 950	1 850	0
Hour 11	1 691	1 691	1 688	1 688	1 448	0	1 552	349.9	2 950	2 162.1	1 850	0
Hour 12	1 691	1 691	1 688	1 688	1 448	0	1 552	357.8	2 950	2 950	1 850	0
Hour 13	1 691	1 691	1 688	1 688	1 448	0	1 552	163.4	2 950	2 950	1 850	0
Hour 14	1 691	1 691	1 688	1 445.9	1 448	227,8	1 552	0	2 950	2 950	1 850	0
Hour 15	1 691	1 691	1 888	1 888	948	74,5	1 052	0	2 950	2 950	1 850	0
Hour 16	1 691	1 691	1 888	1 888	948	144	1 052	0	2 950	2 950	1 850	0
Hour 17	1 691	1 691	1 888	1 888	948	293.8	1 052	0	2 950	2 950	1 850	0
Hour 18	1 691	1 691	1 888	1 888	948	454.7	1 052	0	2 950	1 763	1 850	0
Hour 19	1 691	1 130.7	1 888	1 888	948	742.3	1 052	0	2 950	0	1 850	286.3
Hour 20	1 691	1 486.4	1 888	1 542.1	948	860.7	1 052	0	2 950	804.9	1 850	0
Hour 21	1 691	1 691	1 888	1 773.2	948	914.6	1 052	0	2 950	2 285.5	1 850	0
Hour 22	1 691	1 691	1 888	1 888	948	721.6	1 052	0	2 950	2 950	1 850	0
Hour 23	1 691	1 691	1 888	1 807.9	948	948	1 052	0	2 950	2 950	1 850	0
Hour 24	1 691	1 691	1 888	1 693.5	948	948	1 052	0	2 950	2 450	1 850	0
Total	40 584	39 597	42 512	38 950	29 752	15 431	32 248	1 143.7	70 800	53 319	44 400	410

ATC: Available Transmission Capacity in MWh

ALLOC.: The allocated quantity out of the ATC in MWh

BE: Belgium

DE: Germany

FR: France

NL: The Netherlands

APPENDIX 2

Table 2. Scheduled commercial flows on the Swiss borders

[Source: ENTSOE Transparency Platform]

	Scheduled Commercial Exchanges						Net Swiss Export	
	DE TO CH	AU TO CH	CH TO DE	CH TO AU	FR TO CH	CH TO FR	TO DE/AU	TO FR
Hour 1	1 564	762	**16**	0	2 972	**128**	- 2 310	- 2 844
Hour 2	1 564	762	**16**	0	**2 925**	40	- 2 310	**- 2 885**
Hour 3	1 470	669	**16**	0	**2 590**	189	- 2 123	**- 2 401**
Hour 4	856	375	**91**	0	2 766	**29**	- 1 140	- 2 737
Hour 5	**576**	**254**	234	50	**2 506**	38	**- 546**	**- 2 468**
Hour 6	492	238	**351**	**82**	2 442	**102**	- 297	- 2 340
Hour 7	**483**	**183**	207	0	**2 437**	158	**- 459**	**- 2 279**
Hour 8	584	233	**545**	**79**	2 387	**332**	- 193	- 2 055
Hour 9	1 162	516	**396**	**19**	2 764	**1 802**	- 1 263	- 962
Hour 10	924	607	**427**	0	2 805	**1 850**	- 1 104	- 955
Hour 11	722	398	**1 146**	**202**	2 846	**1 200**	**228**	- 1 646
Hour 12	1 089	607	**142**	**25**	**2 651**	1 658	- 1 529	**- 993**
Hour 13	1 223	557	**16**	0	**2 599**	1 839	- 1 764	**- 760**
Hour 14	1 220	582	**16**	0	**2 721**	2 054	- 1 786	**- 667**
Hour 15	889	517	**16**	0	**2 591**	3 446	- 1 390	855
Hour 16	855	483	**173**	0	**2 521**	2 658	- 1 165	137
Hour 17	741	183	**518**	**35**	**2 878**	2 057	- 371	**- 821**
Hour 18	587	176	**404**	**366**	3 500	**1 580**	**7**	- 1 920
Hour 19	664	312	**717**	**139**	3 442	**1 167**	- 120	- 2 275
Hour 20	**809**	**461**	868	16	**2 779**	1 227	**- 386**	**- 1 552**
Hour 21	**1 569**	**747**	119	16	**3 426**	1 183	**- 2 181**	**- 2 243**
Hour 22	1 646	800	**16**	0	3 213	**267**	- 2 430	- 2 946
Hour 23	1 646	800	**16**	0	3 220	**768**	- 2 430	- 2 452
Hour 24	1 646	800	**16**	0	**3 556**	1 957	- 2 430	- 1 599

AU: Austria

BE: Belgium

DE: Germany

CH: Switzerland

FR: France

NET CH EXPORT: export from CH – import to CH

Adverse scheduled commercial exchanges are shown in red.

Cells in grey correspond to the net (adverse minus non adverse scheduled commercial exchanges) adverse flows, negative for net adverse flows from Switzerland to Germany/Austria, or to France, and positive for net adverse flows to Switzerland.

APPENDIX 3

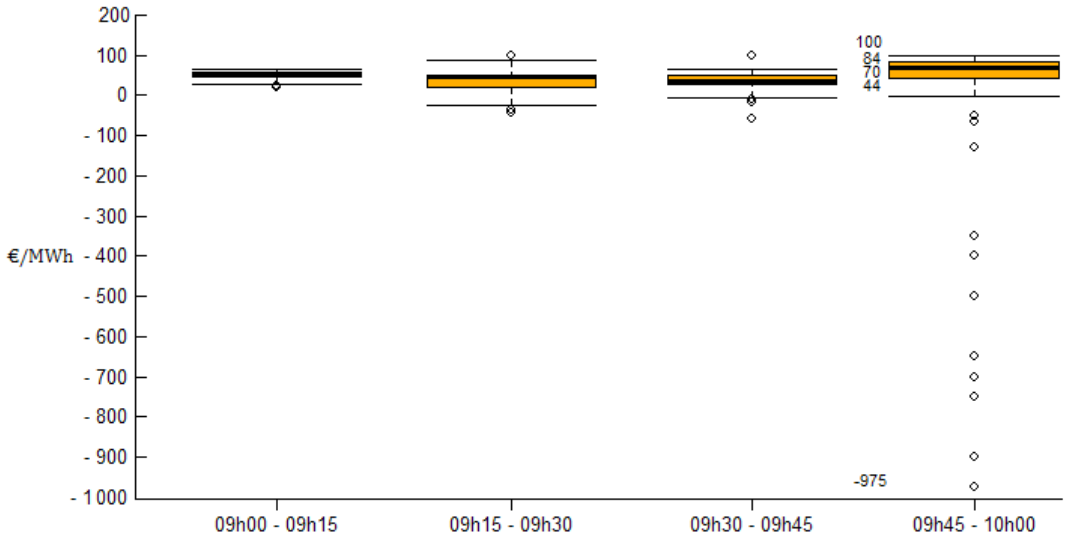

Figure 11. The boxplot of 15 Min prices on EPEX continuous market for delivery Friday March 20, 2015
Over 09h00 – 10h00
[Source: EPEX SPOT]

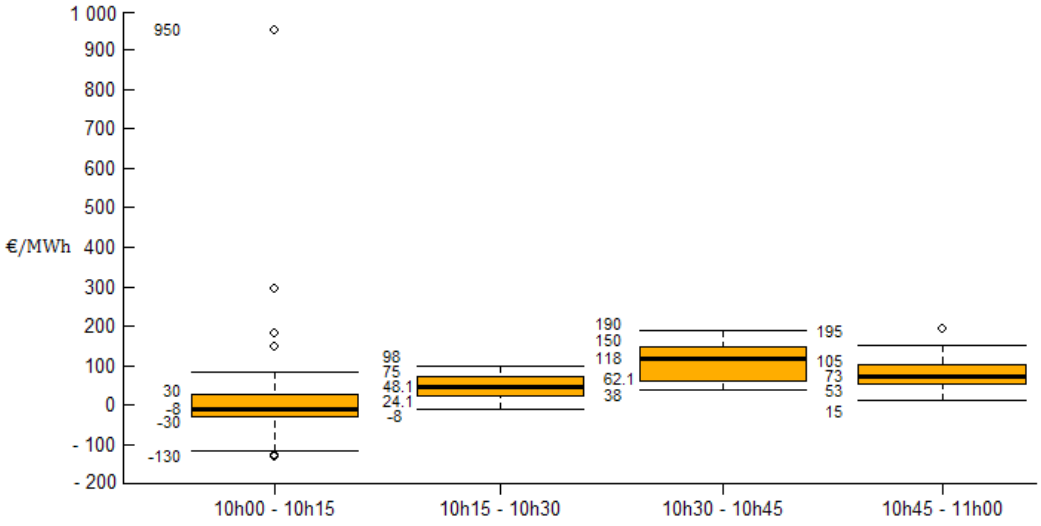

Figure 12. The boxplot of 15 Min prices on EPEX continuous market for delivery Friday March 20, 2015
Over 10h00 – 11h00
[Source: EPEX SPOT]

EPEXSPOT

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