Negative Electricity Prices in Germany?

This is a translation of "*Des prix d'électricité négatifs en Allemagne*" by François Poizat with a few revisions.
The translation is due to Elisabeth Huffer.

Forward:

No need to be an expert in exchange markets nor in the Kirchhoff laws to become acquainted with the "*Unidentified Financial Objects*" that we discuss here, a new type of UFO!

Electricity Day-Ahead and Intraday wholesale prices are negotiated on the Paris EPEX-SPOT stock market. On the Day-Ahead market, electricity is auctioned in "one hour" blocks while, on the Intraday market, trading is continuous with fifteen minute, thirty minute and 1 hour bids. They are executed under the provision that the buyer's and the seller's offers match.

Our study focuses on the Intraday Spot prices because the "Fraunhofer ISE" site, our main source of information for this paper, does not provide the data for "Day-Ahead Auctions".

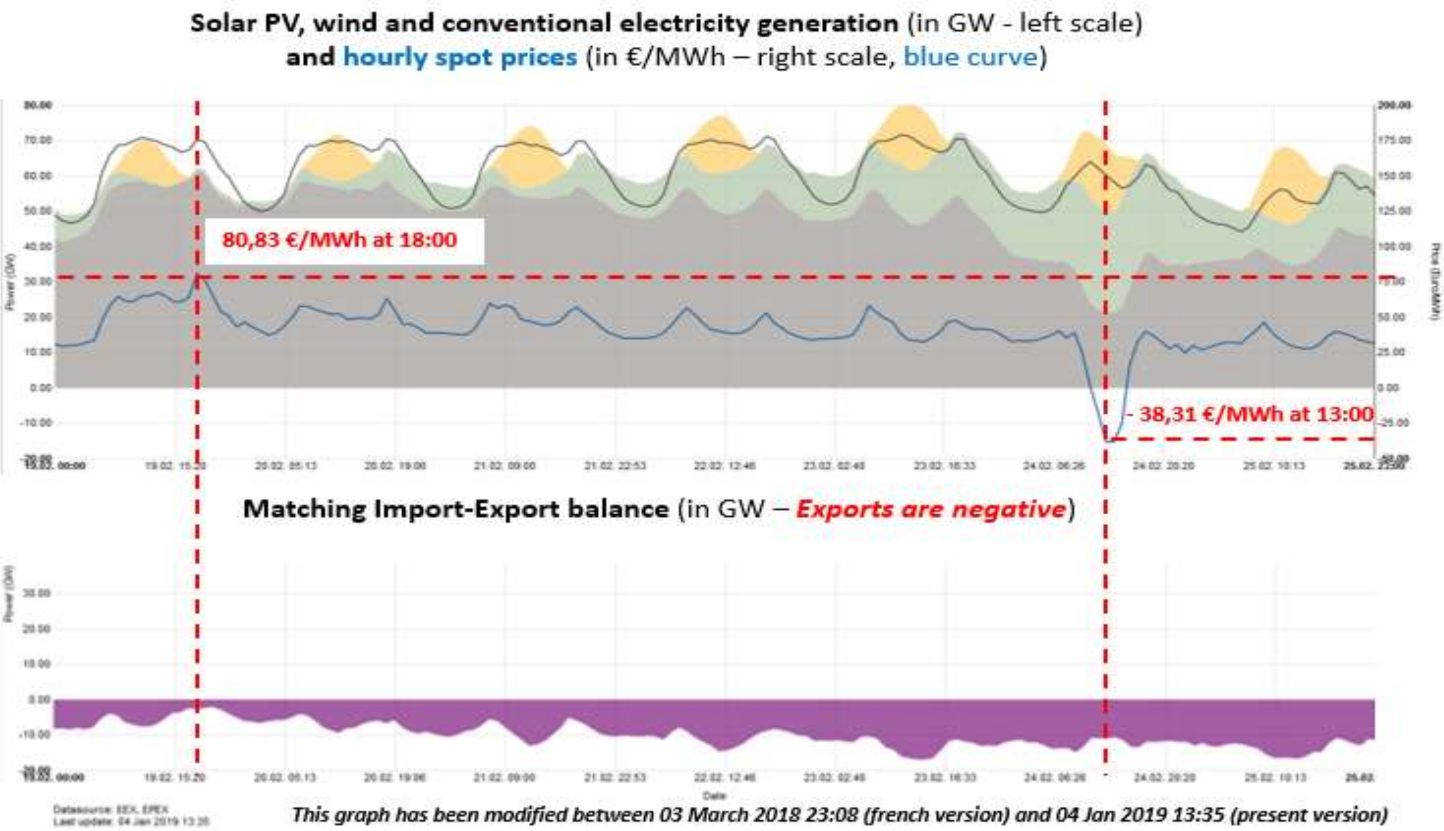

Figure 1: Germany – Week 8 of year 2018 (February 19 to 25, 2018)

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1. Negative Prices?

The graph below is taken from the https://www.energy-charts.de internet site which is handled by *Fraunhofer ISE* an *"Institut für Solare Energiesysteme"*[1]. The graph shows the **wholesale price of German electricity averaged over each fifteen minute block**[2] during the week of November 20 to 26, 2017. This index is provided by the EPEX "Spot market" (*European Power Exchange [...] resulting from the fusion of Powernext SA (France) and EEX AG (Germany), two spot electricity trading auction offices*). **The "*Intraday Continuous 15 minutes Average Price*" shown here varied between -38 €/MWh and +155 €/MWh within less than 14 hours** on November 20, 2017. During the week of November 20 to November 26, 2017, **EPEX registered 4 days with negative price episodes.**

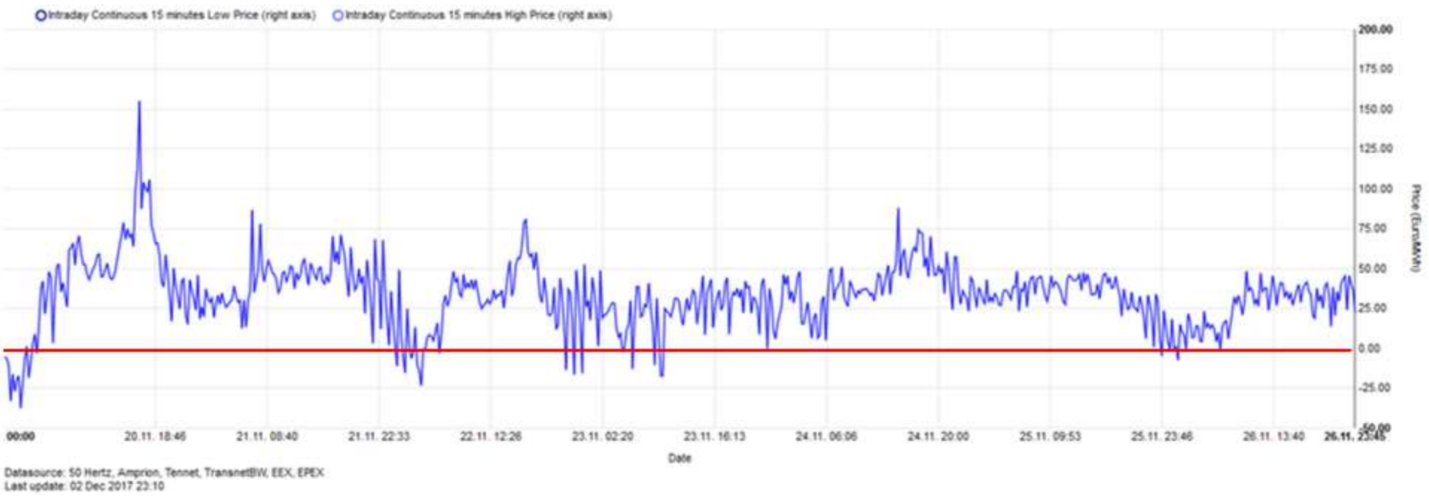


Figure 2: Intraday Continuous Fifteen Minutes Average Price - Nov 20 to 26, 2017

The other parameters available on this site (production per source and auctions) have been masked off for better legibility (we will come back to this). We have materialized the zero axis in red because, beyond the expected and obvious price variability, we feel it is important to clarify the reasons why the price can become negative.

2. Is This Something New?

This is not a new phenomenon as the (incomplete) list of events given below shows.

- As early as **Christmas Day 2009**, according to a slide from the SLC workshop on PHES plants, dated 25 March 2013.
- In September 2012, the *"Comité d'Analyse Stratégique" (Strategic Analysis Board),* a board that provides information to the French Prime Minister, reports several prior such events, with "***17 days in 2010**, **15 days in 2011 and 6 days in the first quarter of 2012**. The phenomenon has recently spread to France with 5 days in 2011 and 2 days in the beginning of 2012."*
- On **Sunday June 16, 2013** as reported by two French Newspapers, *Les Echos* and *Libération* dated 18 and 19 June 2013.
- On **Sunday March 16, 2014** according to *Enerpresse* dated 18 March 2014.
- On **April 22, 2015** reported by *Enerpresse* dated 12 May, 2015.
- On **Sunday May 8, 2016** as reported by Hartmut Lauer (talk given on 18 October 2017).
- On **Christmas Sunday 2016**, applying to Day-Ahead prices, reported by *Enerpresse* dated 28 December 2016.

As can be seen from this list (See the references quoted above in Appendix B presented in chronological order) the phenomenon is recurrent and occurs preferably on Sundays.

[1] An institute based in Freiburg, Germany, dedicated to solar energy. it seeks, "*through the data available on its site (in German and English) to stimulate transparent and objective discussions on the factors related to the German energy transition* (Energiewende)". Indeed, the data are plentiful, in spite of some imperfections (see Appendixes I and J and footnote 17) not excluding issues on the reliability of the *Eco2mix* site of French RTE (see Appendix D). To facilitate readers' access to this site (in English and German) we provide a tutorial in Appendix L.

[2] This Intraday market with fifteen minute bids was devised, according to EPEX SPOT to "*facilitate negotiations of intermittent sources and allow the handling of infra-hour production and demand variations*" (see Appendix A)

3. Back to a Recent Instructive Week

Let us return to week 8 of 2018 (19 to 25 February) which highlights the main tendencies that emerge from our detailed analysis of the year 2017[3].

On the two panels below we show for Germany the instantaneous power generated from each production source, the wholesale price (here with hourly resolution) on the Spot auction and the Import-Export balance (with 15 minutes resolution).

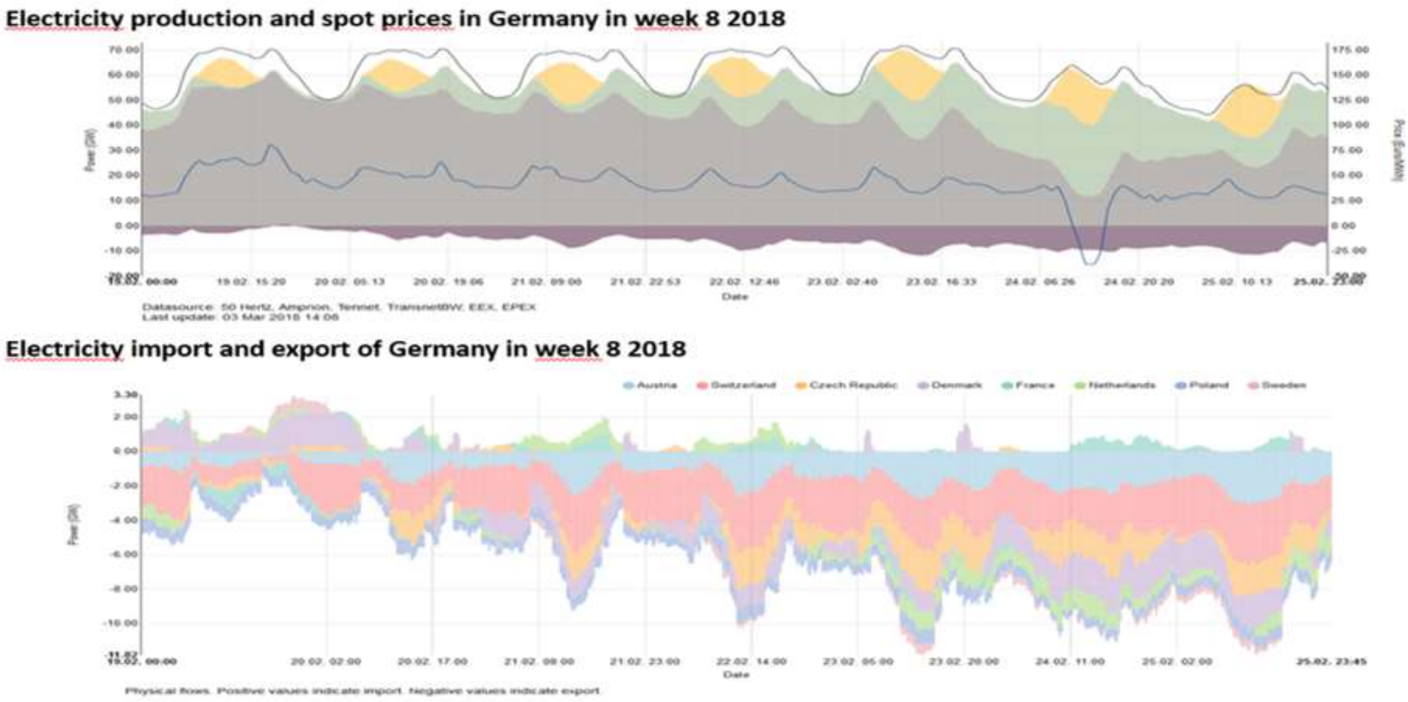


Figure 3: *Week 8, 2018 (February 19 to 25, 2018)*

These graphs (available from December 2014, the first "*updated*" month, as of 18 October 2015) provide the following data: Top graph, from top to bottom

	"***Load***": Demand on the grid (GW) (we don't know how this information is elaborated[4]) left scale
	"***Solar***": PV instantaneous power (GW) left scale
	"***Wind***": Wind turbine instantaneous power (GW) left scale
	"***Conventional > 100 MW***"; total instantaneous power (GW) from so-called conventional plants (nuclear, fossil...) whose unit capacity is larger than 100 MW. left scale
	"Intraday Continuous Average Price" here on an hourly basis, (€/MWh) right scale
	"Import Balance" (Imports are negative, Exports are positive [5]). Bottom graph - detail of international exchanges for Austria, Switzerland, Czech Republic, Denmark, France, Netherlands, Poland, and Sweden[6].

[3] Indeed, the examination of the year entailed the analysis of a large amount of data, not without difficulty (one has to move the mouse over the set of graphs and catch values for each 15 minute block). This has produced a large amount of results whose main features are not easily stated.

[4] The site manager, Bruno Burger, answered our question of March 4, 2018 as follows: "*The source for the load data is ENTSO-E*". The latter probably derives its data from the 4 grid managers for Germany, namely *50 Hertz, Amprion, Tennet, TransnetBW*. Regarding Wind and PV, the site states "*the production data of wind turbines [or] of solar plants are extrapolated from the transmission system operators on the basis of measured reference plants on the sum of all assets.* ***This extrapolation is not error-free****. Exact values for the annual production of the previous year are available in September of the following year, when the EEG billing is published. For the last year for which the annual production is available, energy corrected values are calculated and displayed.*"

[5] The instantaneous power generation by conventional plants shown here is corrected for the export balance (production minus export balance). An optical illusion that is corrected in the introductory graph (figure 1), and explained in appendix K.

[6] Unfortunately, the abscissas of the two graphs do not match, making correlations difficult.

3.1. The Week's Five Working Days (19 to 23 February 2018)

In the graph below, the pattern seems regular: 5 daily bumps followed by very mild peaks (no electric heating effect as is observed in France). But we note that:

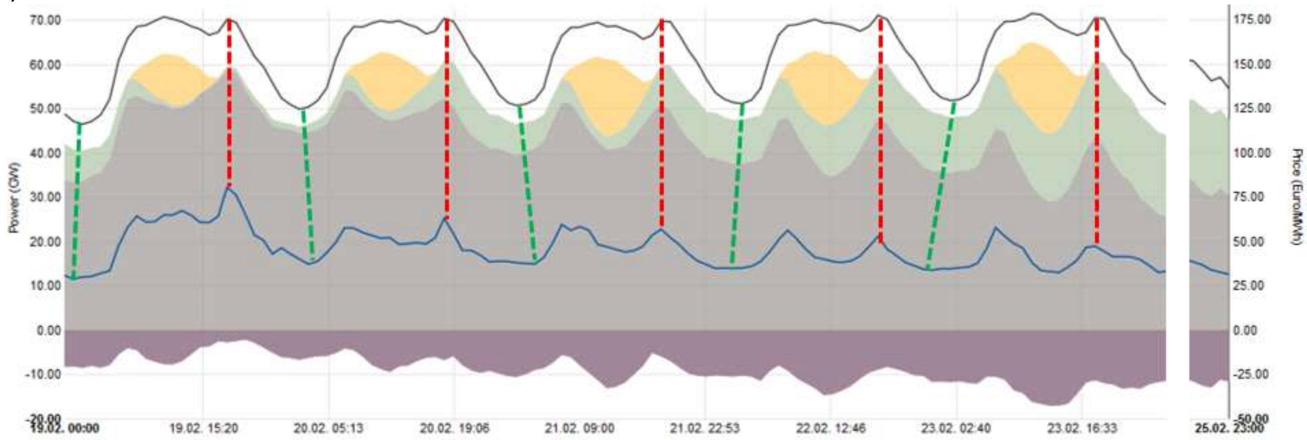


Figure 4: The five working days in week 8, 2018

- The ***load*** (which can be considered to represent national consumption) peaks regularly to about 70 GW, systematically in association with small price peaks, at around 50 €/MWh.

- Monday the 19th stands out with a price peak that reaches 80.83 €/MWh at 6 pm (76.23 €/MWh at 7 pm). This is anything but a coincidence:

- **Wind production was as low as 0.64 GW and 0.89 GW** respectively, a miserly production (relative to the 55.55 GW installed capacity), corresponding to a capacity factor less than 3%.
- German exports at 6 pm were down to:
  - 0.30 GW to Austria
  - 0.32 GW to Switzerland
  - 0.36 GW to the Czech Republic
  - 0.39 GW to France
  - 0.60 GW to Poland

  i.e. total **exports amounting to 1.97 GW**

  At the same time, Germany was importing:

  + 0.06 GW from Sweden (a country that generally has small physical flows with Germany)

  + 0.40 GW from the Netherlands

  + 1.42 GW from Denmark

  i.e. total **imports amounting to 1.88 GW**, yielding an overall export balance of -0.09 GW.
- The combined fossil and fissile instantaneous power was **up to 61.56 GW,** about 10 GW more than during the rest of the work week (Tuesday to Friday).

  All these factors point to insufficient supply, leading to an upward pressure on the wholesale price on the EPEX exchange.

- On Friday February 23rd, **the import-export balance reached 11.32 GW exports, driven by a more substantial intermittent production amounting to 34.28 GW and a conventional production amounting to 46.12 GW.**

- The night-time **demand dips** almost automatically induce price depressions, **down to less than 35 €/MWh.**

		Power (in GW)				Percentage	€/MWh	
Day	hour	Solar PV	Wind	Convention	Export balance	*iREL/Conv*	IC15IP *	ICIP **
19/02/2018	13:00	11,14	0,61	**57,34**	-2,70	*20,5%*	**73,97**	67,57
20/02/2018	13:00	12,18	2,37	55,88	-5,21	*26,0%*	**48,53**	48,50
21/02/2018	13:00	16,84	3,05	53,85	-8,38	*36,9%*	**40,95**	45,69
22/02/2018	13:00	15,67	11,79	49,17	-9,55	*55,8%*	**37,74**	38,87
23/02/2018	13:00	19,32	14,96	46,12	-11,32	*74,3%*	**35,56**	33,24
24/02/2018	13:00	18,91	**28,53**	21,34	-9,52	***222,3%***	-59,15	-38,31
25/02/2018	13:00	**21,06**	11,38	34,94	**-11,57**	*92,8%*	**28,59**	28,67
averages		*16,45*	*10,38*	*45,52*	*-8,32*		*29,46*	*32,03*
19/02/2018	18:00	0,00	0,64	61,56	-0,09	*1,0%*	**82,92**	80,83
19/02/2018	19:00	0,00	0,89	60,58	-0,56	*1,5%*	**93,56**	76,23

* *Intraday Continuous 15 minutes Index Price :* changed from the convention that applied in 2017 with no explanation except for a statement by B. Burger: "*added the ID3 and ID1 indices on the request of users of the*

** *Intraday Continuous Index Price (hourly)*

Table 1: Generation data of the five working days in week 8, 2018

3.2. What About the Weekend (February 24 and 25)?

Radical change: the wind picks up, in particular on Saturday (28.53 GW) and the sun shines, in particular on Sunday (21.06 GW). This, combined with the weekend demand slump (down by 25% on Sunday), explains the striking increase of exports (11.57 GW) in spite of reduced conventional generation (21.34 GW and 34.94 GW respectively).

Day	hour	Hourly Load (GW)
19/02/2018	13:00	69,69
20/02/2018	13:00	69,90
21/02/2018	13:00	68,73
22/02/2018	13:00	69,43
23/02/2018	13:00	69,88
24/02/2018	13:00	60,28
25/02/2018	13:00	**53,31**
average		*65,89*
19/02/2018	18:00	**70,26**
19/02/2018	19:00	69,48

Tab. 2: Load during week 8, 2018

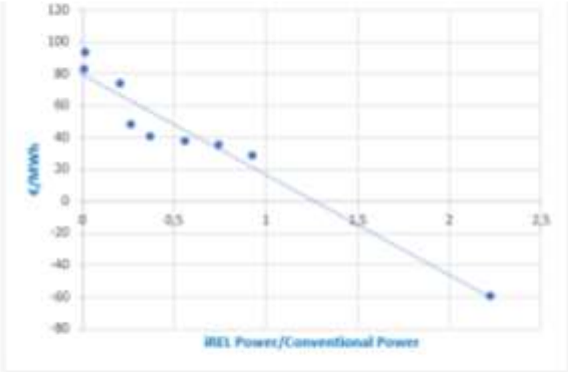


Figure 5: Wholesale price vs iREL/Conv ratio

The above graph showing the wholesale price versus the proportion of intermittent electricity (iREL) production (Wind + PV) relative to the conventional production (iREL/Conv) seems to establish that a large iREL/Conv ratio is a determining factor in the emergence of negative prices. This occurs in particular during holidays and weekends when the demand is low and, consequently, the conventional production is reduced.

4. But How Are Negative Prices Possible?

A negative price, for the average person as well as for the professional economist is much like an "***Unidentified Financial Object***". A picture being worth 1 000 words, a glance on the sort of diagram available from the same German solar institute provides the beginning of an explanation - the chart below corresponds to January 2017.

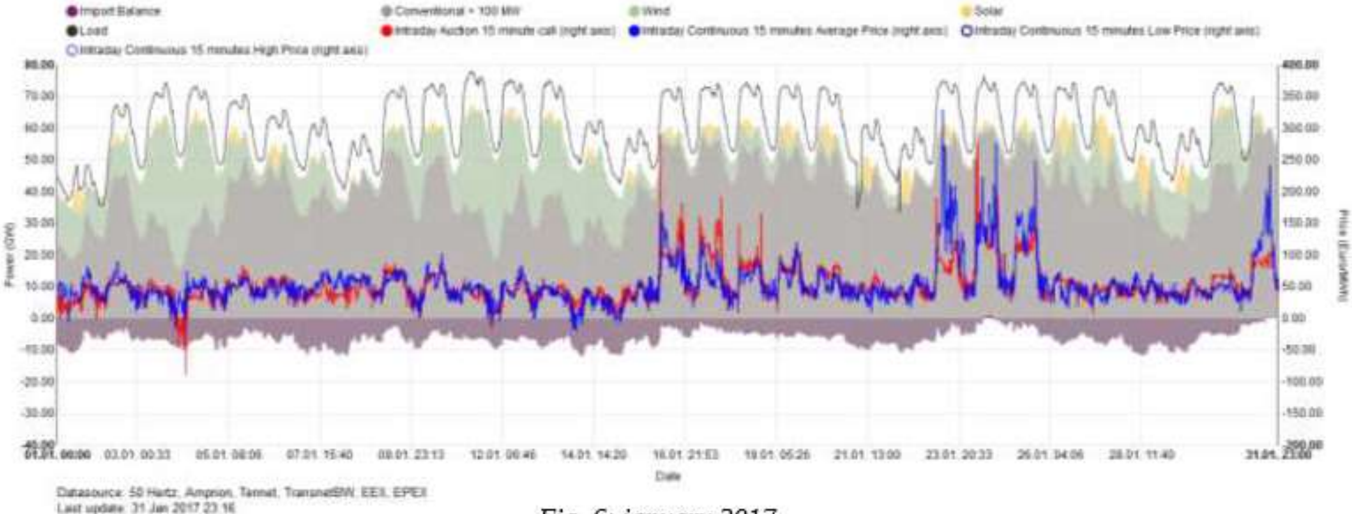


Fig. 6: january 2017

The four full weeks are easily identified, each with its 5 working days, framed by two weekends. The black continuous curve clearly delineates the 5 demand bumps of the week days (with a small spike at evening meal time[7]), followed by the Saturday and Sunday demand slump.

Below this curve, we note:

- yellow blobs that show the contribution of PV to the production (obviously zero at night)
- a grayish green edging representing the contribution of wind
- a kind of mountain range grouping the conventional power plants whose unit capacity is larger than 100 MW (a mix of coal, lignite, nuclear, cogeneration and hydro) and ...

… along the zero axis, the import-export balance, mostly negative in this particular case: Germany exports continuously except for a few hours on January 24 (we will come back to these in Appendix G).

[7] This peak occurs around 6 pm, a little earlier than the French peak (7 pm): Germany is further East.

The blue and red curves show the *Intraday Continuous 15 Minutes Average Price* and the day-ahead auction price[8], respectively (right scale). During that month, the prices varied considerably but remained globally positive.

At another time of the year, however, on **November 20, 2017 the *Intraday Continuous 15 Minutes Average Price* shifted from -38 €/MWh to +155 €/MWh within 15 hours as illustrated below**[9]:

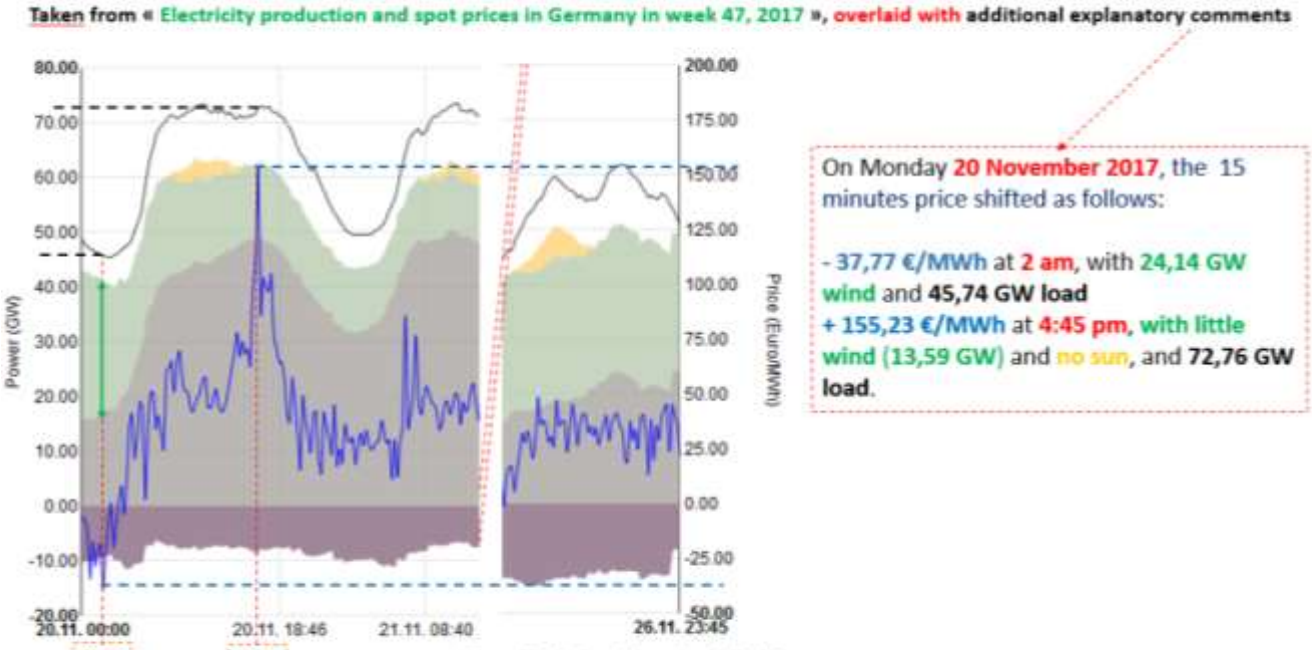


Figure 7: Monday, November 20, 2017

We again encounter our initial observation: the excessive weight of wind production (24.14 GW) relative to low demand (end of a weekend) leads to a situation with excess production (in spite of 9.39 GW exports).

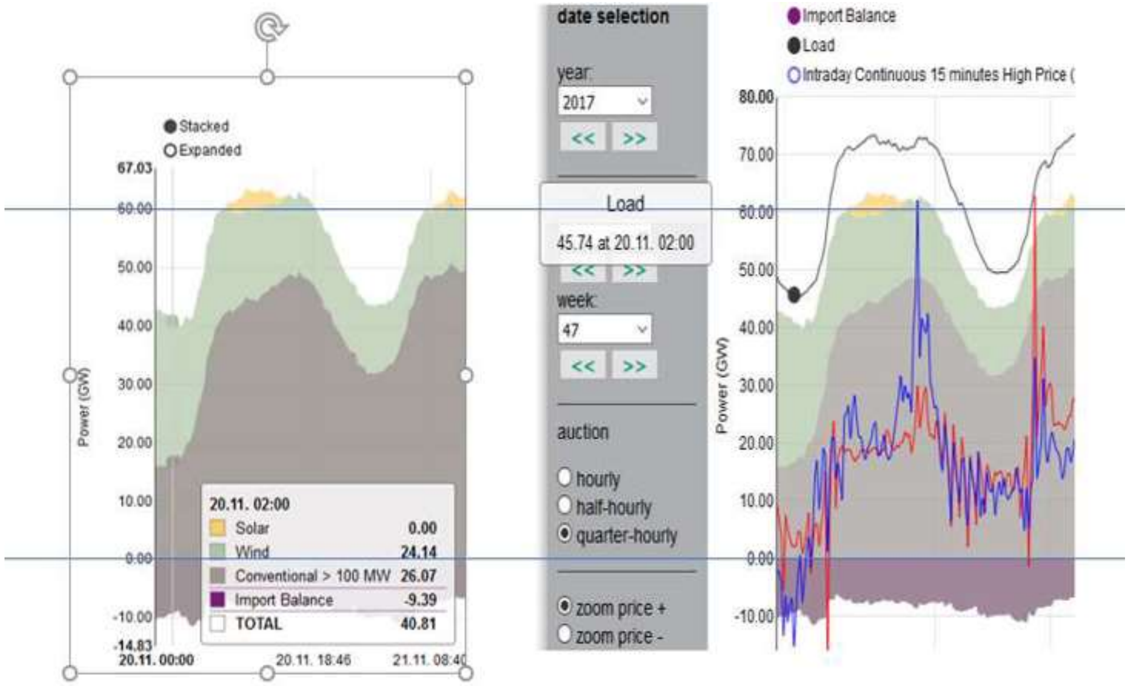


Figure 8: November 20, 2017 - further detail

This excess production pulls prices downward as our "Conseil d'Analyse Stratégique" (*Strategic Analysis Center*) stated as early as 2012: "*iREL production has priority access to the grid and [...] it is more profitable for a producer to pay a consumer for*

[8] Not being familiar with the EPEX auction system, we do not know what this "auction price" represents in concrete terms (as a matter of fact, Fraunhofer ISE does not provide this auction price but only the *Intraday Continuous 15 Minutes Average Prices*). We feel the latter are the more important as they deliver so-called *average* values.

[9] Most of our figures taken from Fraunhofer ISE are constructions combining several panels, for illustrative purposes.

accepting to consume the excess power than to shoulder the cost of stopping/starting his thermal power plants, along with the additional wear and tear this would entail".

But why do renewable energies - not just the intermittent ones - have priority access to the grid? They do:

- not only because of their zero marginal cost since they have no fuel or operational costs (their maintenance costs are very small)
- but also because they do not compete on the same wholesale market: their production is purchased upstream from the EPEX market at very rewarding feed-in tariffs by compelled buyers, namely the *transmission system operators* (the counterparts of RTE in France[10]).

Renewables, then, have *de jure* and *de facto* priority access to the grid, over conventional producers who have no choice but to back out or, if they prefer, to pay consumers so that they will .... heat pools or warehouses!

And why do these conventional producers make this apparently anti-economic calculation? Because they can thus avoid having to restart their plants a few hours later when the demand is back again (with the prospect of the associated added value). It is a way of keeping them on standby or, in the case of nuclear reactors, of avoiding fission product poisoning (the so-called Xenon or Samarium effects).

Thus we are faced with a **quasi oxymoronic situation** that involves two competing concepts:

- on a classical "***free market with undistorted competition***" which is ruled according to the well known "***merit order***" applicable to all ...
- agents, of whom some have already paid for a production that they have a **soviet-style obligation** to purchase and are in charge of the grid stability have no choice but to dispose of the said production, at any cost!

It is not surprising, then, that negative price episodes become more frequent as these fatal energies develop in a disorderly though organized manner. This is well illustrated for the year 2017 in the table below where **all the days on which the wholesale price was negative and less than -20 €/MWh during at least 15 minutes are listed**[11].

Winter(s *) 2017		€/MWh	
01-janv	Sunday		
03-janv			
12-janv			
14-janv	Saturday		
15-janv	Sunday		
19-févr	Sunday		
20-févr			
22-févr		-29,6	
23-févr			
24-févr	Friday	-21,6	
25-févr	Saturday		
26-févr	Sunday	-62,0	
27-févr			
04-mars	Saturday		
05-mars	Sunday	-33,7	
12-mars	Sunday	-22,6	
15-mars			
17-mars	Friday		
18-mars	Saturday	-20,5	
19-mars	Sunday		
20-mars			
21-déc			
22-déc			
23-déc	Saturday	-46,0	
24-déc	Sunday	-85,7	
25-déc	Christmas	-45,8	
26-déc		-24,0	
27-déc		-38,6	
28-déc		-35,1	
29-déc		-36,4	32
30-déc	Saturday	-29,1	9
31-déc	Sunday	-38,4	15

Spring 2017		€/MWh	
25-mars	Saturday	-27,0	
26-mars	Sunday	-42,1	
27-mars		-46,2	
02-avr	Sunday		
09-avr	Sunday	-20,4	
14-avr	Holy Friday		
15-avr	Saturday	-56,0	
16-avr	Sunday	-21,8	
17-avr	Lundi de Pâ.		
21-avr			
23-avr	Sunday	-59,2	
24-avr		-50,9	
30-avr	Sunday	-193,0	
01-mai	1st of May		
14-mai	Sunday		
20-mai	Saturday		
25-mai	Ascension Day		
27-mai	Saturday		
28-mai	Sunday		
04-juin	Sunday	-36,5	
05-juin	Pentecost Mo		
06-juin			
07-juin		-24,2	
08-juin			
11-juin	Sunday		
12-juin			
16-juin	Friday		29
17-juin	Saturday		11
18-juin	Sunday		11

Summer 2017		€/MWh	
23-juin	Friday		
24-juin	Saturday	-64,5	
25-juin	Sunday		
23-juil	Sunday		
29-juil	Saturday	-34,8	
30-juil	Sunday	-137,8	
04-août	Friday		
06-août	Sunday		
07-août			
12-août	Saturday		
13-août	Sunday		
19-août	Saturday		
20-août	Sunday	-23,4	
27-août	Sunday		
31-août			
06-sept			
09-sept	Saturday		
10-sept	Sunday	-30,9	
11-sept		-21,5	
12-sept			22
13-sept		-36,0	9
17-sept	Sunday		7

Fall 2017		€/MWh	
02-oct			
03-oct			
04-oct		-49,9	
05-oct		-32,2	
06-oct	Friday		
07-oct	Saturday		
08-oct	Sunday		
12-oct			
22-oct	Sunday	-20,6	
27-oct	Friday		
28-oct	Saturday	-100,9	
29-oct	Sunday	-117,8	
30-oct			
09-nov			
10-nov	Friday		
12-nov	Sunday		
13-nov			
18-nov	Saturday		
19-nov	Sunday	-25,0	
20-nov		-37,8	
22-nov		-23,5	
23-nov			
26-nov	Sunday		
27-nov		-29,5	
03-déc	Sunday		
04-déc			
05-déc			
06-déc			
07-déc			
08-déc	Friday	-23,1	
09-déc	Saturday	-27,6	
10-déc	Sunday	-45,4	
12-déc			
13-déc			36
14-déc		-29,1	9
17-déc	Sunday		13

* including last 11 days of December

119	working days	/ 365
38	Sundays	/ 53
46	days < -20 €/MWh	/ 365

Table 3 : "Negative days" in 2017

[10] In France, it is EDF (except, marginally, the local distribution companies) that is submitted to the "purchasing obligation" under provisions of the legislation « *Loi n° 2000-108 du 10 février 2000 relative à la modernisation et au développement du service public de l'électricité* ». In Germany the law that applies is « *Erneuerbare-Energien-Gesetz* » since April 2000, replacing the « *Stromeinspeisegesetz* » of 1991.

[11] For each of the days with a negative price episode, we have retained only the 15 minutes with the most negative price. In view of the large number of episodes, we gave up on providing details on the said prices, retaining only the dips below -20 €/MWh and printing in red those below -50 €/MWh . Finally, we have underscored with a thick vertical line the episodes with more than *3 consecutive days with a negative price.*

5. How Many Negative 15 Minutes Blocks During 2017?

What is most striking, at the end of such a study, is the observation of two matching phenomena, that point to the responsibility of the two modes of so-called fatal energy production, as opposed to the controllable modes (also termed dispatchable modes by RTE, because they can respond to start/stop, increase/decrease, even load following requests from the national or regional dispatchers, the technicians in charge of adapting the production to the final electricity demand - mainly nightly and weekend reductions and winter heating increase).
Here, we just list the results we obtained from a detailed analysis of the fifteen minute block statistics for 2017 made available by Fraunhofer ISE.

1. **119** days with an excursion into negative prices, or **one in every 3 days**. Among these, **46** days show a deep excursion into negatives (below -20 €/MWh) or **one in every 8 days**.

2. More significantly still, we note that of the 53 Sundays, **38** undergo these "incidents", or **nearly 3 negative Sundays in every 4**[12]! And 20 of these, more than half, are preceded by "negative Saturdays". There is thus a **clear correlation of negative price occurrences with weekends**, a statistics that **climbs to 43/58 (74%)** with the inclusion of other non working days or public holidays such as Easter Monday, Pentecost Monday, May first, Ascension Day and Christmas Day.

3. On the other hand, during 2017 at any rate, no **seasonal sensitivity is noticeable**. In particular, there is a surprising regularity in the "negative Sundays". At most, the colder seasons (winter and fall) are somewhat more exposed than the warmer ones: 68 versus 51.

	Winter*	**Spring**	**Summer**	**Fall**	**Year**
"Negative" days	32	29	22	36	**119**
"Negative" Sundays	9	11	9	9	**38**
Price below -20 €/MWh	15	11	7	13	**46**

* For this winter, we have aggregated January, February and March to the last 11 days of December 2017

4. However, the negative occurrences of December are striking: only 8 days escaped, namely December 1, 2, 11, 15, 16, 18, 19, and 20, but not one as of December 21 (the beginning of winter). The negative episode continued into the first few days of 2018.

5. Finally, a more detailed analysis shows that these negative prices occur both at night and in the daytime.

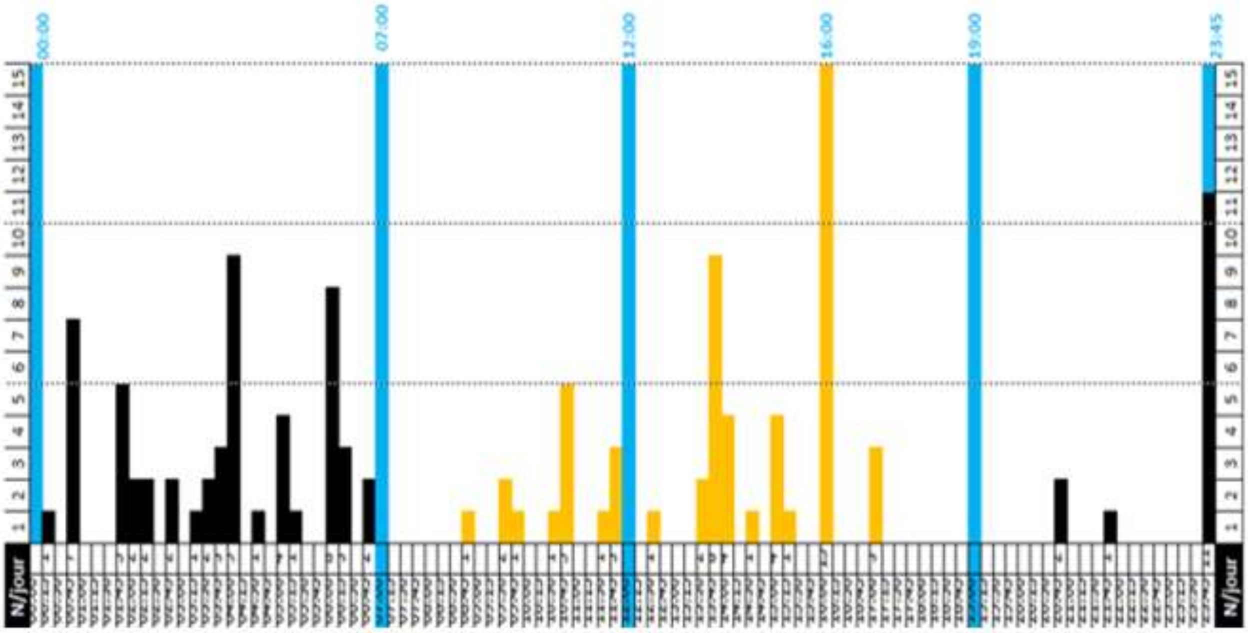


Figure 9: Annual occurrence of negative wholesale prices, in 15 minute blocks

Two daily cycle regularities seem significant:

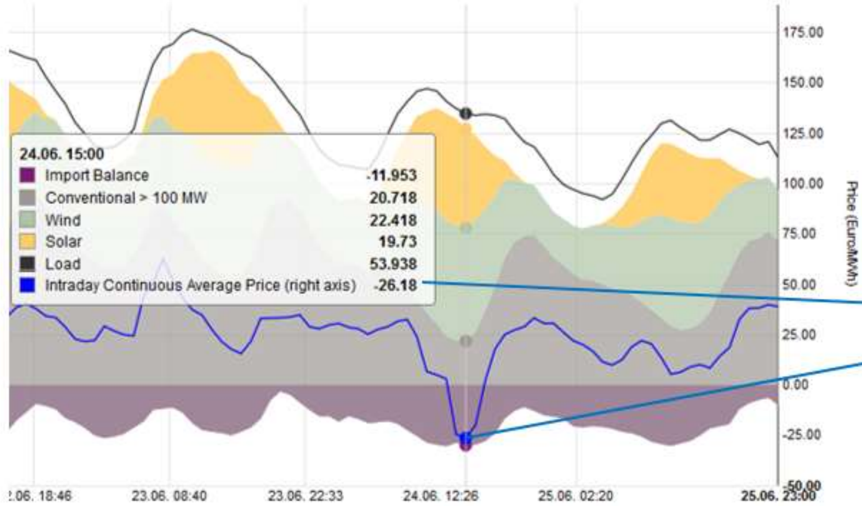
[12] Of the 119 negative days, 38 are Sundays (31.9%); there are 18 Sundays among the 46 "very negative" days, i.e. 39.1%.

- the 4 pm recurrence (15 times) demonstrates the importance of PV (we will come back to this) with its fatal character.
- as for that of 11:45 pm (with an 11/119 frequency) it is a probable sign that traders are adjusting their bids for the next day.

Already, however, we can state that **negative prices can be ascribed both to PV** in the summer when the demand is lower, **and to wind in the winter (always the more windy season)**.

6. How Long Do These Negative Prices Last?

The answer to the question can be obtained by analyzing **prices with hourly sampling** as shown in the table below where the negative hourly price series[13] are listed with the beginning (**BH**) and ending (**EH**) hours, and the **duration**.



Day(s) of 2017	BH	EH	€/MWh	Duration (h.)	Average €/MWh	
22/2	3	5	-1,42	3	-2,37	
24/2	2	2	-3,12	1	-3,12	10
26/2	13	15	-12,86	3	-9,75	
18/3	6	8	-0,63	3	-0,35	
15/4	11	14	-7,00	4	-6,20	
24/4	12	13	-4,80	2	-2,81	
30/04 et 01/05	8	9	-2,16	26	-34,22	
4/6	14	17	-10,14	4	-7,91	40
7/6	3	4	-4,19	2	-5,26	
7/6	15	15	-1,11	1	-1,11	
12/6	14	14	-0,07	1	-0,07	
24/6	14	16	-24,35	3	-23,46	
	15		-26,18			
	16		-19,85			
30/7	11	17	-12,55	7	-56,64	
20/8	4	15	-1,10	10	-1,03	34
10/9	16	16	-0,39	1	-0,39	
10 et 11/09	23	5	-0,79	7	-3,94	
13/9	1	4	-1,60	4	-4,63	
13/9	14	15	-5,82	2	-6,06	
04/10 et 5/10	23	1	-1,65	3	-2,21	
5/10	12	15	-8,51	4	-12,11	
7/10	10	15	-0,06	6	-4,07	
22/10	6	7	-1,75	2	-2,27	
28 et 29/10	12	15	-5,65	29	-44,36	53
29/10	21	21	-0,95	1	-0,95	
20/11	0	3	-3,89	4	-7,28	
10/12	0	2	-1,37	3	-2,69	
14/12	3	3	-9,18	1	-9,18	
23 et 24/12	23	14	-2,19	16	-29,26	
24 et 25/12	20	6	-18,61	11	-13,49	
26/12	12	13	-3,76	2	-4,42	45
28 et 29/12	22	4	-1,61	7	-4,36	
30/12	21	23	-0,38	3	-0,16	
31/12	11	16	-1,99	6	-4,24	

N.B. : the 3 negative hourly price hours of June 24, from 2 to 4 pm, are shown in detail

Figure 10: A summing up of the negative price episodes in year 2017 (with a focus on June 24)

Our previous findings are confirmed:

- a total of 182 hours over the year, of which 126 hours on Sundays and 23 hours on Saturdays.
- the episodes last somewhat longer in winter (108 h) than in summer (74 h).
- the average hourly price during these 182 episodes is roughly -20 €/MWh, exactly -19.79 €/MWh.

7. A Tentative Explanation of the Mechanism Involved in the Formation of Negative Wholesale Prices

Let us return to the Fraunhofer fifteen minutes spot wholesale price data and confront them with the production and demand data simultaneously observed on the grids. We detail the context of the 46 worst-case[14] episodes: date and 15 minutes block, price, power produced at that time according to source (PV, wind, conventional, export[15]), domestic consumption (~ PV + Wind + Conventional - Export), percentage of iREL (PV + Wind) relative to conventional production and percentage of iREL relative to consumption.

[13] On August 20, there were 3 episodes, with very small positive prices in between, namely 1.72 €/MWh and 0.41 €/MWh (see Appendix D). On October 29, Daylight Saving Time ended at 3 am, giving rise to violent jolts on the Fraunhofer data, shedding doubt on the price dips registered on that day (-117.8 €/MWh) and even on the previous day (-100.9 €/MWh) (See Appendix K).

[14] For completeness, we should have analyzed all 119 days concerned. The reader will understand the author's reluctance at handling all these "big data" for no additional information.

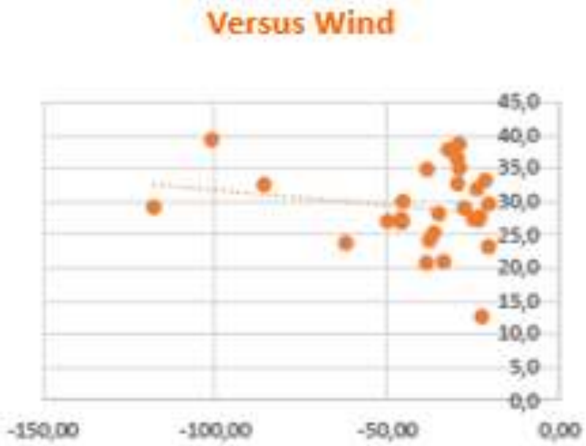
[15] Exports, here, are counted positively while Fraunhofer systematically counts them as negative (in reference to domestic consumption).

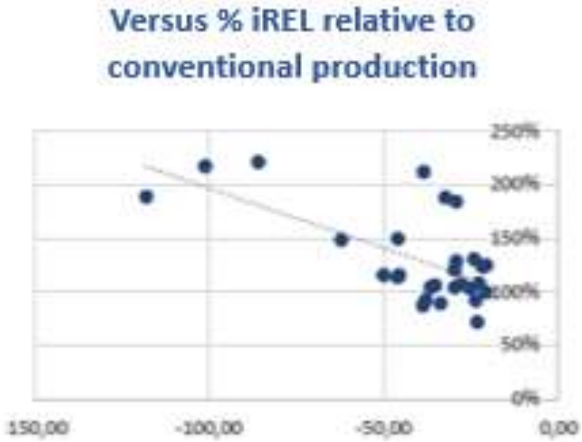
Season	Day of 2017		15 min. block	Price	PV	Wind	Conv^el	Export	Total Dem.	iREL vs conv^nal	iREL vs Demand
winter	22-févr		6:00	-29,61		36,5	30,3	10,7	56,1	121%	65%
	24-févr		5:00	-21,55		33,2	26,9	8,5	51,5	123%	64%
	26-févr	Sun	13:30	-61,99	10,9	23,7	23,3	12,7	45,2	149%	77%
	05-mars	Sun	3:30	-33,65		20,9	23,4	7,2	37,1	90%	56%
	12-mars	Sun	15:00	-22,55	15,8	12,6	26,3	8,7	46,0	108%	62%
	18-mars	Sat	16:00	-20,48	3,2	29,6	26,3	8,4	50,7	125%	65%
spring	25-mars	Sat	15:00	-26,99	19,3	10,6	27,7	5,9	51,8	108%	58%
	26-mars	Sun	16:00	-42,05	16,2	2,2	29,1	4,3	43,2	63%	43%
	27-mars		16:00	-46,19	20,8	1,6	38,6	2,9	58,1	58%	39%
	09-avr	Sun	16:00	-20,43	21,2	1,9	27,7	7,5	43,4	83%	53%
	15-avr	Sat	11:30	-55,95	10,9	26,6	23,4	10,6	50,3	160%	75%
	16-avr	Sun	6:15	-21,76		17,6	22,5	8,1	32,1	78%	55%
	23-avr	Sun	14:45	-59,22	16,7	21,2	21,5	9,9	49,5	177%	77%
	24-avr		12:30	-50,92	26,5	20,6	29,1	9,8	66,3	162%	71%
	30-avr	Sun	16:00	-193,02	23,8	18,1	15,8	13,4	44,3	266%	95%
	04-juin	Sun	16:15	-36,49	14,7	16,5	21,7	9,0	43,9	144%	71%
	07-juin		14:30	-24,24	19,6	33,5	23,4	10,8	65,7	227%	81%
summer	24-juin	Sat	15:15	-64,49	20,1	22,5	21,2	12,0	51,7	201%	82%
	29-juil	Sat	14:30	-34,77	21,2	17,1	22,7	10,2	50,8	169%	75%
	30-juil	Sun	14:00	-137,78	24,1	18,0	15,8	11,2	46,7	267%	90%
	20-août	Sun	10:45	-23,39	19,7	12,9	21,2	9,4	44,5	154%	73%
	10-sept	Sun	16:00	-30,85	12,4	16,0	21,3	6,0	43,7	134%	65%
	11-sept		4:00	-21,54		26,5	21,2	6,7	41,0	125%	65%
	13-sept.		13:45	-36,0	13,6	37,1	23,4	4,9	69,2	217%	73%
fall	4-oct.		23:45	-49,9		27,0	23,3	9,6	40,8	116%	66%
	5-oct.		14:00	-32,2	11,1	37,8	26,0	9,4	65,5	188%	75%
	22-oct.	Sun	6:15	-20,6		23,2	23,2	10,2	36,3	100%	64%
	28-oct.	Sat	20:45	-100,9		39,3	18,1	7,4	50,1	217%	79%
	29-oct.	Sun	1:45	-117,8		29,2	15,4	6,2	38,4	189%	76%
	19-nov.	Sun	23:45	-25,0		27,4	26,5	7,8	46,2	103%	59%
	20-nov.		2:00	-37,8		24,1	26,1	9,4	40,8	93%	59%
	22-nov.		3:45	-23,5		27,2	29,6	9,5	47,3	92%	58%
	27-nov.		23:45	-29,5		32,7	31,3	13,0	51,1	104%	64%
	8-déc.		6:00	-23,1		27,7	38,6	9,6	56,7	72%	49%
	9-déc.	Sat	2:45	-27,6		29,0	27,0	8,9	47,1	107%	62%
	10-déc.	Sun	0:45	-45,4		30,0	25,9	10,9	44,9	116%	67%
	14-déc.		3:15	-29,1		35,1	27,3	12,0	50,3	129%	70%
winter	23-déc.	Sat	6:15	-46,0		27,4	24,1	2,6	48,9	114%	56%
	24-déc.	Sun	3:30	-85,7		32,5	14,7	1,8	45,5	221%	72%
	25-déc.	Xmas	6:00	-45,8		26,8	17,9	9,1	35,7	150%	75%
	26-déc.		17:00	-24,0		31,9	24,4	8,2	48,0	131%	66%
	27-déc.		1:45	-38,6		20,7	23,8	7,6	36,9	87%	56%
	28-déc.		21:45	-35,1		28,1	26,5	7,1	47,6	106%	59%
	29-déc.		5:00	-36,4		25,3	24,2	7,3	42,2	105%	60%
	30-déc.	Sat	20:45	-29,1		38,7	21,0	11,0	48,6	184%	80%
	31-déc.	Sun	11:45	-38,4	4,5	34,8	18,6	9,6	48,4	212%	81%
	Power average on these 46 days				7,53	24,63	24,28	8,62	47,82		

Table 5 : Energy context of the 46 worst-case 2017 "negative days"

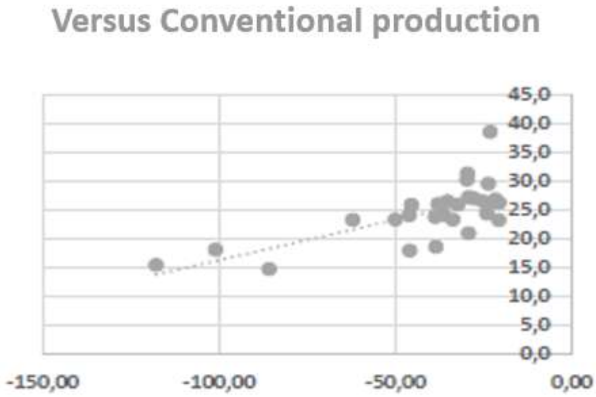
The confrontation of the two sets of data, namely the market price (in €/MWh) on one hand and the PV and Wind contributions (in GW) on the other hand gives the crux of the matter, is the key to the explanation of the "UFO mystery" as illustrated in the scatter plots below. These show the price trend (horizontal axis) versus other data. The time of year must, however, be distinguished:

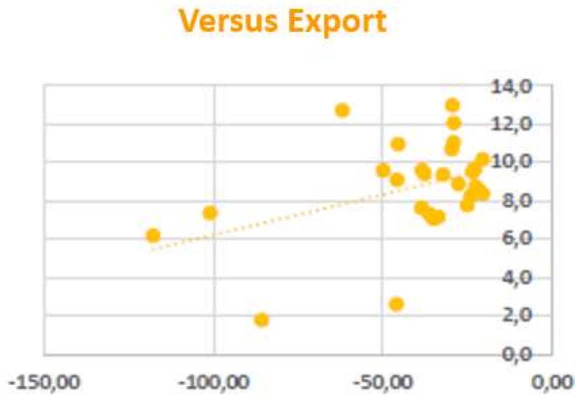
The cold seasons (from January 1 to March 20, 2017 and from September 21 to December 31, 2017):





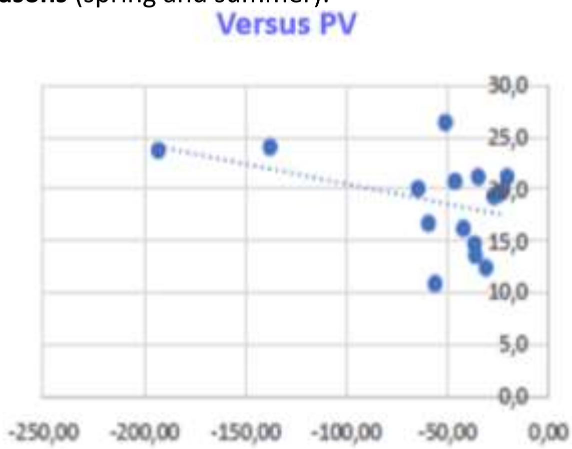
The larger the wind production, the higher the relative weight of priority energy[16], the more the wholesale price collapses.

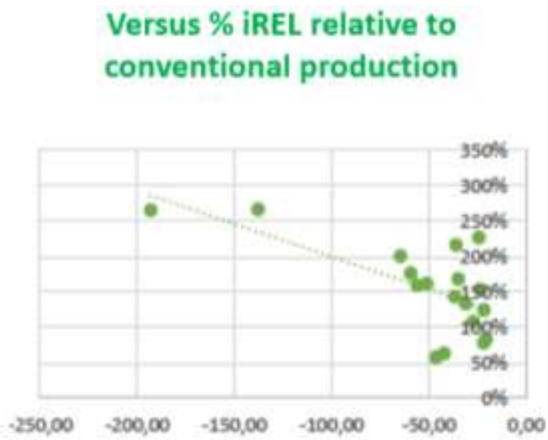




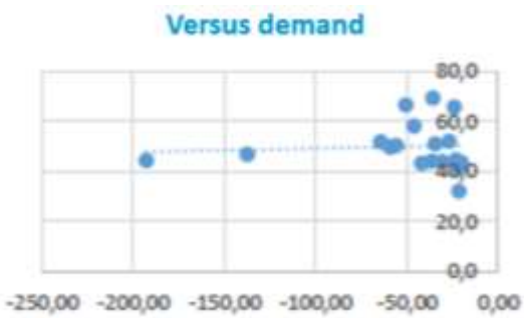
Lesser conventional production correlates to lower prices. Larger exports correlate to higher prices.

The warm seasons (spring and summer):





The larger the PV production, thereby increasing the impact of iREL, the deeper the wholesale price sinks.



But regardless of the season: (here, winter) the level of the demand does not seem to be a deciding factor. Apparently, exports serve as an adjustment variable, or rather as an a**daptation to the meteorological fatality, and the domestic consumption**.

The excessive intermittent productions (PV in spring & summer, wind in autumn & winter) relative to conventional productions do seem to be the principal cause of the wholesale price collapse.

[16] PV production is not dealt with here, it is too marginal in winter (only 5 episodes).

8. Does Excess Production Impact Exports?

As we know, the European synchronous electricity grid, despite its incompleteness, ensures substantial commercial exchanges that, as a matter of fact, France has amply taken advantage of during the auspicious years of its nuclear power. This grid must have a role to play now that Germany has developed a dual production fleet, with both conventional and renewable means whose total capacity is twice the yearly peak instantaneous power demand (see Appendix F). Let us see.

Fraunhofer has been monitoring this issue since 2011. Not only from the point of view of physical (rather than commercial) transit in real time (as we have seen early on in this paper with the graph "*Electricity import and export of Germany in week 8 2018*"), but also via annual balances displayed as a rose. However artistic these representations, they are not very handy; as a consequence, we have transcribed them as "naval battle" charts, matching exporters (left column) and importers (first line). We obtained the data by moving the mouse over each zone and reading the value displayed in the frame. Below, the France-Germany pair is highlighted, showing that in 2017, 6.2 TWh transited from West to East, while 2.2 TWh transited in the opposite direction (see Appendix C where the data are more legible than in the contrivance below).

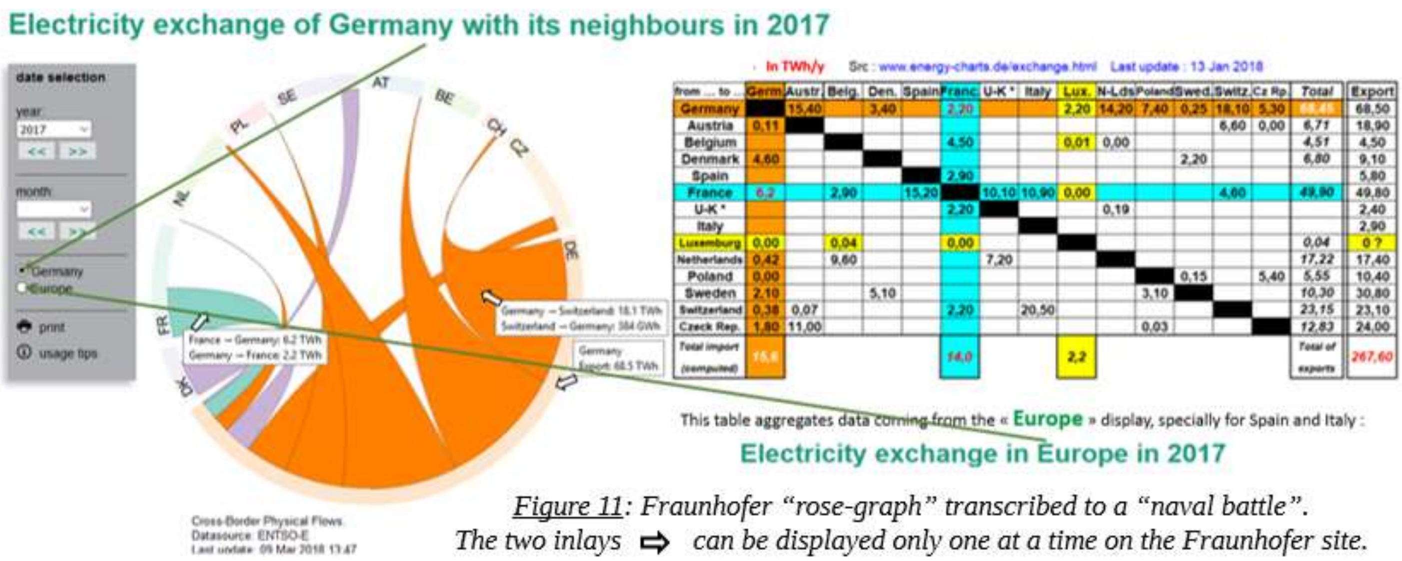


Figure 11: Fraunhofer "rose-graph" transcribed to a "naval battle". The two inlays ⇨ can be displayed only one at a time on the Fraunhofer site.

In Appendix C we further provide:

- a table showing all the 2017 exchanges in Europe (Appendix C1)
- all the exchanges from 2011 to 2016 of Germany with its neighbors and of France with its neighbors (Appendix C2).

A comparison of the performance of the two countries is enlightening.

- in 2011 France exports 20 TWh to Germany when German installed nuclear power is at its fullest, while French imports. from Germany are tiny.
- in 2017, the France to Germany export balance is divided by 5.

TWh / year	France --> Germany	Germany --> France	Franco - German balance
2011	20,3	0,1	20,2
2012	12,2	0,7	11,5
2013	11,8	1,2	10,6
2014	14,8	0,8	14,0
2015	12,1	1,4	10,7
2016	7,5	2,0	5,5
2017	6,2	2,2	4,0

Table 6: Evolution of franco-german exchanges

Concerning the global performances, the erosion of the **French positions[17] is obvious: a 28 % decline (-19.3 TWh) while Germany has gained 46.6 TWh**.

TWh / y	France			Germany			Continuous erosion
	Export	*Import*	E - I	Export	*Import*	E - I	
2011	69,2	*14,1*	55,1	56,0	*49,7*	6,3	48,8
2012	59,1	*15,5*	43,6	66,2	*44,1*	22,1	21,5
2013	63,5	*16,6*	46,9	78,0	*37,4*	40,6	6,3
2014	78,5	*12,7*	65,8	77,1	*38,7*	38,4	27,4
2015	65,7	*9,1*	56,6	78,7	*30,8*	47,9	8,7
2016	50,3	*13,7*	36,6	63,9	*16,7*	47,2	-10,6
2017	49,8	*14,0*	35,8	68,5	*15,6*	52,9	-17,1

Table 7: France and Germany exchange evolution

[17] Strangely, Fraunhofer reduces France's overall exports by about 5 TWh for each year from 2011 to 2014 (See Appendix C2) an anomaly that is corrected in the table. Is this because of energy taken by EnBW which participates in Fessenheim? And why is the reduction no longer applied after 2014?

For all that, over these 8 years, French electricity exports to Germany have declined (-14.1 TWh) more than French imports from Germany have increased (+2.1 TWh). What part have Germany's "green electrons" had in this?

The case for Switzerland is even more striking:

- exports from Germany to Switzerland first decreased (a consequence of nuclear power phase-out?)
- but have strongly increased as of 2014 (+6.6 TWh or 57%)

And, in 2017, Germany imports practically no electrons from Switzerland (only 384 GWh).

TWh / y exchange	Switz.--> Germany	Germany --> Switz.	Germ/Swi balance
2011	2,8	14,0	11,2
2012	3,1	12,7	9,6
2013	3,7	11,7	8,0
2014	**4,6**	**11,5**	**6,9**
2015	2,9	13,6	10,7
2016	1,0	15,6	14,6
2017	**0,4**	**18,1**	**17,7**

At the same time, the overall Swiss exports have dropped by about 25 % (nearly 8 TWh since 2015).

Table 8: Switzerland and Germany exchange evolution

	Swiss exports			
2011	30,3			
2012	**31,8**			
2013	30,7	Average	30,7	TWh
2014	30,0			
2015	30,8			
2016	22,8	then	-7,9	TWh
2017	23,1	then	-7,6	TWh

One cannot claim that this situation had not been anticipated: with a parable[18] reported by Enerpresse (dated 24 July 2012) "*Samuel Leupold, CEO of BKW International [...] aimed at emphasizing the competition between the two renewable energies particularly on the German market, stating* 'these two energies are sold at the same time, the noon peak, on the same wholesale markets'. ***The Swiss PHES[19] plants thus see their competitive edge diminish, confronted as they are to the intense development of PV in Germany***..."
This view was confirmed (Enerpresse dated 8 June, 2017) by Torbjörn Wahlborg, head of Vattenfall's pumped storage hydroelectricity division for Germany "*This restructuring program provides the only realistic chance to keep most of Vattenfall's German pumped storage plants in long-term operation*."

As for Europe as a whole, it appears (refer to the full table of 2017 vs 2011 gaps in Appendix C3) that its export capacities have... declined. Indeed:

- while **Germany gains ground with a 12.5 TWh (or +22.3 %) increase**
- **the rest of Europe declines by 55.4 TWh** (or -15.8 %) in spite of Sweden's and Norway's progression (they serve as outlets thanks to their hydro storage capacities) and that of the Netherlands (bridgehead for loop flows, i.e. bypassing Northern Germany to feed Southern Germany via Belgium and France, owing to Germany's insufficient transport infrastructures[20]).

Thus, we witness the **massive dumping of Germany's excess energy** (most of the time) to **the neighboring countries** among which some, as we will see, seek to establish protective measures (see Appendix C4).

9. Do the Negative Prices Propagate to Neighboring Countries?

The prologue of the "Market data" section on the "*eco2mix*" RTE web site explains that "*the spot prices in Europe mirror not only the exchange needs expressed by the market but also the available interconnection capacities.* ***As long as the interconnection limits are not reached, the price spread between countries is nil whereas insufficient interconnection capacities induce price differences among the wholesale markets****. The data taken up by the eCO2mix application show how important the interconnected European grid is* ["European copper plate"] *and in particular its interconnections, by way of the market wholesale prices of electricity."*
Needless to say it is tempting to verify the validity of this declaration of faith in the "M*arket*" by comparing the price data (with hourly resolution, for lack of better) on either side of the Rhine river (even further, beyond the Alps and the Pyrenees).
Regarding RTE, "*they originate from:*

- *EPEX SPOT SE for Germany, Austria, Belgium, France, the UK, the Netherlands and Switzerland*
- *The various exchanges involved via the ENTSOE-E Transparency Platform for the other countries.*

Italy having several price zones, only the Northern zone (that is interconnected with France) is posted on "éCO2mix".

The table below compares prices <u>at the same time</u> in Germany, France, Belgium, Switzerland when they are available (not the case on March 18, April 15 and June 24, dates for which RTE indicates "ND", i.e. *non disponible* equivalent to N/A, not available).

[18] ... *"Imagine two farmers going to the same market to sell their milk: the production of one of them is subsidized, not the other's. The first one will always be in a position to sell at a lower price than his competitor. With PV and hydro-power, it is the same."*
[19] *Pumped Hydroelectric Energy Storage,* the only large scale energy storage method available today.
[20] The same holds for the Eastern border, where the electricity transits through Poland, the Czech Republic and Austria.

From Fraunhofer ISE data delivered on www.energy-charts.de							From RTE-France.com/fr/eco2mix.fr				France to Germany difference	F.ISE to RTE difference (germ. price)
Day(s) of 2017	BH	EH	€/MWh	15 mn hollow max	Duration (hours)	Average €/MWh	Average €/MWh	Average €/MWh	Average €/MWh	Average €/MWh		
22/2	3	5	-1,42	-29,61	3	-1,42	33,25	7,66	27,35	35,95	25,59	9,08
24/2	2	2	-3,12	-21,55	1	-3,12	38,02	-27,08	29,00	36,84	65,10	-23,96
26/2	13	15	-12,86	-61,99	3	-12,86	26,80	9,75	28,84	37,76	17,05	22,61
18/3	6	8	-0,63	-20,48	3	-0,35	ND	ND	ND	ND		
15/4	11	14	-7,00	-55,95	4	-6,20	32,30	7,65	32,99	ND	38,49	13,85
24/4	12	13	-4,80	-50,92	2	-2,81	32,56	14,54	32,56	34,78	35,37	17,35
30/04-01/05	8	9	-2,16	-193,02	26	-34,22	12,73	-27,47	27,86	7,75	46,95	6,75
4/6	14	17	-10,14	-36,49	4	-7,91	11,86	8,51	14,45	10,59	19,77	16,42
7/6	3	4	-4,19	-19,93	2	-5,26	1,92	1,92	1,92	7,97	7,18	7,18
7/6	15	15	-1,11	-24,24	1	-1,11	21,09	9,71	25,40	27,05	22,20	10,82
12/6	14	14	-0,07	-8,88	1	-0,07	38,93	10,92	34,90	36,80	39,00	10,99
24/6	14	16	-24,35	-64,49	3	-23,46	25,34	9,93	30,92	ND	48,80	33,39
30/7	11	17	-12,55	-137,80	7	-56,64	7,12	-26,79	-1,48	7,67	63,76	29,85
20/8	4	15	-1,10	-23,39	10	-1,03	5,18	1,11	7,57	6,80	6,21	2,13
10/9	16	16	-0,39	-30,55	1	-0,39	10,51	10,51	13,64	18,23	10,90	10,90
10-11/09	23	5	-0,79	-21,54	7	-3,94	9,84	1,27	7,60	17,53	13,78	5,21
13/9	1	4	-1,60	-35,98	4	-4,63	9,19	9,15	9,86	9,40	13,82	13,78
13/9	14	15	-5,82	-27,46	2	-6,06	27,04	9,64	24,09	29,84	33,10	15,70
4-5/10	23	1	-1,65	-49,87	3	-2,21	50,11	2,22	40,90	48,55	52,33	4,44
5/10	12	15	-8,51	-32,20	4	-12,11	45,12	10,89	53,05	53,81	57,23	22,99
7/10	10	15	-0,06	-17,08	6	-4,07	41,41	3,88	41,14	41,21	45,48	7,95
22/10	6	7	-1,75	-20,57	2	-2,27	32,95	9,86	28,33	43,80	35,22	12,12
28-29/10	12	15	-5,65	-100,90	29	-44,36	38,73	-52,63	31,91	46,86	83,09	-8,27
29/10	21	21	-0,95	-17,31	1	-0,95	54,72	17,00	54,72	52,32	55,67	17,95
20/11	0	3	-3,89	-37,77	4	-7,28	59,76	11,65	54,30	57,01	67,05	18,93
10/12	0	2	-1,37	-45,41	3	-2,69	58,34	11,80	58,34	63,10	61,03	14,49
14/12	3	3	-9,18	-29,06	1	-9,18	23,52	9,01	32,40	59,62	32,70	18,19
23-24/12	23	14	-2,19	-45,96	16	-29,26	42,54	-19,18	33,31	36,29	71,80	10,08
24-25/12	20	6	-18,61	-85,74	11	-13,49	38,76	-13,82	33,11	39,98	52,25	-0,33
26/12	12	13	-3,76	-24,00	2	-4,42	47,26	-53,12	47,26	37,42	51,68	-48,70
28-29/12	22	4	-1,61	-35,10	7	-4,36	42,78	5,24	38,61	40,70	47,14	9,60
30/12	21	23	-0,38	-29,12	3	-0,16	18,59	3,02	23,71	46,99	18,76	3,18
31/12	11	16	-1,99	-38,40	6	-4,24	13,07	2,93	20,90	40,78	17,31	7,17

Table 9: Spot prices published by Fraunhofer ISE and the French GRT, "RTE"

This table does not provide clear information, with, in particular, surprising inconsistencies: in the 182 hours documented in it **RTE quotes prices for Germany that are on average 6 € higher than the prices quoted by Fraunhofer also for Germany**; moreover, we observe disparities that are beyond understanding[21].

Below, without comment, the **price for these 4 countries as averaged over the comparable 172 hours[22]** is displayed.

€/MWh from RTE				
	29,30	-14,08	29,11	30,51

Is it possible to conclude that Germany's negative prices do not propagate to the neighboring countries? We will not be so bold because some negative prices are observed outside of Germany (see detail in Appendix D):

- On Sunday April 30, from 3 pm to 4 pm in **France** and in **Switzerland** from noon to 4 pm.
- on Sunday July 30 in **Belgium** from noon to 2 pm
- again on a Sunday, August 20, in **France** from 2 pm to 3 pm

Unsurprisingly, the first two of these dates coincide with the most striking "plummeting" on EPEX/Fraunhofer, down to -193.02 €/MWh and -137.80 €/MWh (15 minutes block) respectively.

As for August 20, the prices crawled everywhere, with an average at -1.03 €/MWh (according to Fraunhofer) or +1.11 €/MWh (according to RTE) in Germany, +5.18 €/MWh in France, +7.57 €/MWh in Belgium and 6.80 €/MWh in Switzerland. Why such consistency?

It seems RTE's postulate "*Insufficient cross border interconnections induce price differences on the wholesale markets*" is being transformed into a theorem: **the German negative prices are very likely related to insufficient export possibilities.**

[21] On April 30, at 5 pm RTE quotes -6.00 €/MWh while Frauhofer displays -62.71 €/MWh. On the contrary, on October 29 at 11 am, RTE finds -81.95 €/MWh while Fraunhofer posts -16.26 €/MWh. However, October 28-29 Was the date for the change from Daylight Saving Time to Standard Time.

[22] Meaning the global 182 hours from which we remove the ND hours mentioned above (March 18, April 15, June 24) as well as the 2 hours with very small positive prices in the August 20 series and the "second" hour due to the change to standard time of October 29.

10. Some Neighbors Resort to Barricading Themselves

One thing is for sure, the onset of deeply negative prices in Germany has an impact at its borders. Thus, on July 30, Germany did not import from 9 am to 4 pm but exported continuously some 11 GW to all the neighboring countries, as illustrated in the graphs on the right.

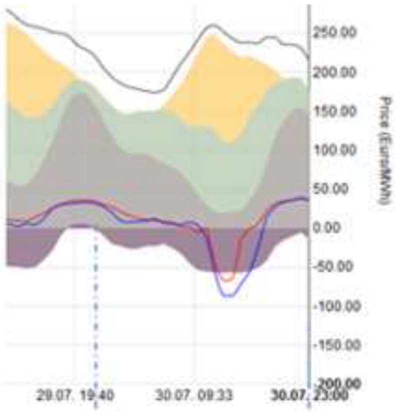
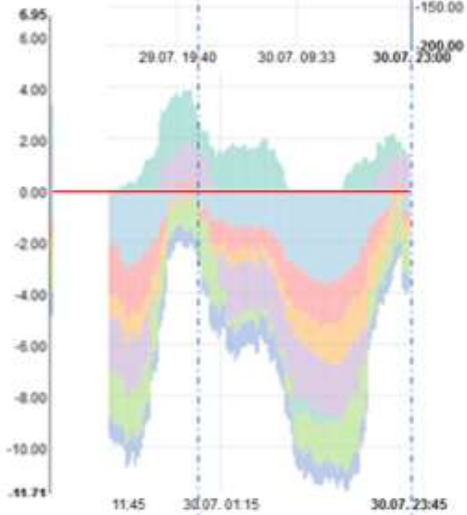


Figure 12 : Saturated export, July 30, 2017



Similarly, on April 30, Germany had continuously exported from 11 am to 4 pm, at a rate of more than 13 GW.
Thus, it is not surprising that 3 neighboring countries have come to installing “switches”, more specifically **phase angle regulators** (PAR) to protect themselves from unwanted green electron imports (see Appendix E). The 3 countries are **Poland**, the **Czech Republic** and, downstream from the Netherlands, **Belgium**[23].

These mechanisms seem to have a noticeable effect on German exports which have clearly declined since 2014-2015:

	Exchanges with Poland		Export bal.	Exchanges with Czech Rep		Export bal.	Exchanges with Netherl.		Export bal.
	Ger. --> Pol.	Pol. --> Ger.	Germ. - Pol.	Ger. --> Cz	Cz --> Ger.	Germ. - Cz.	Ger. --> NL	NL --> Ger.	Germ. - NL
2011	5,1	0,433	4,67	9,4	1,900	7,50	9,6	3,200	6,40
2012	5,5	0,167	5,33	7,4	3,500	3,90	20,5	1,600	18,90
2013	5,5	0,542	4,96	9,4	2,400	7,00	24,6	0,340	24,26
2014	9,2	0,051	9,15	6,3	3,800	2,50	24,3	0,348	23,95
2015	10,7	0,016	10,68	6,3	6,100	0,20	24,0	0,338	23,66
2016	8,8	0,002	8,80	3,5	2,100	1,40	15,8	0,189	15,61
2017	7,4	0,001	7,40	5,3	1,800	3,50	14,2	0,422	13,78

Table 10 : Evolution of german exchanges with three neighbours

However, we do not understand why Holland has apparently not undergone jolts on its own spot wholesale prices (according to the RTE market data).

11. What Can We Infer?

11.1 A first reaction dominates, one of amazement: how can it be in an organized market, that a product is sold not only at a loss (dumping is forbidden in France under the "*Code de Commerce*" even if exceptions are tolerated) but, more extravagant, that **customers are paid to consume a product they do not need or want**? From these "customers'" perspective **Germany is the land of plenty!**
Not that the amounts involved are huge. As a matter of fact, it is hard to have a clear idea of these amounts, they depend on the size of the energy blocks concerned and that is something we have no information about.

[23] It seems Belgium has no direct interconnection with Germany (but, strangely, the 2012 exchange rose mentions exchanges between Belgium and … the Czech Republic !).

Can we estimate the amount by attributing each negative price to the entire conventional production at that moment? This does not seem legitimate, the less so that the sale price collapse associated to the transgression is not limited to its negative part. In any case, we may thus obtain an upper limit for the bonus (we will call it monetary compensation -*soulte* in French- for want of a better term) granted for the April 30-May 1, 2017 long week-end:

30/04-1/05 Hour	Conv. power *GW (hourly)*	Hourly price €/MWh	"Soulte" M€	Export(> 0) *GW (hourly)*	Conv. Power *- Export*
08:00	21,79	-2,16	-0,05	7,08	14,70
09:00	19,78	-9,14	-0,18	9,05	10,73
10:00	18,07	-16,16	-0,29	11,32	6,75
11:00	17,24	-37,85	-0,65	13,20	4,04
12:00	16,32	-58,30	**-0,95**	13,34	2,99
13:00	15,53	-94,55	-1,47	13,33	2,20
14:00	15,37	-100,57	-1,55	12,88	2,49
15:00	15,53	-103,53	-1,61	12,98	2,55
16:00	15,95	-110,94	-1,77	13,14	2,82
17:00	16,74	-68,71	-1,15	10,91	5,84
18:00	18,72	-41,26	**-0,77**	9,27	9,45
19:00	21,50	-32,68	-0,70	8,77	12,73
20:00	22,84	-22,92	-0,52	9,83	13,01
21:00	22,28	-23,80	-0,53	9,77	12,51
22:00	20,90	-28,54	-0,60	9,19	11,70
23:00	19,59	-64,93	-1,27	9,13	10,46
00:00	18,66	-20,32	-0,38	9,61	9,05
01:00	18,28	-13,38	-0,24	8,73	9,55
02:00	18,19	-13,32	-0,24	9,52	8,67
03:00	18,40	-11,93	-0,22	8,99	9,41
04:00	18,68	-0,99	-0,02	8,79	9,89
05:00	18,81	-0,31	-0,01	8,80	10,01
06:00	18,66	-2,13	-0,04	7,91	10,75
07:00	18,84	-1,25	-0,02	8,17	10,67
08:00	19,54	-7,52	-0,15	8,43	11,11
09:00	20,20	-2,44	-0,05	8,77	11,43

Table 11 : *Over these 26 hours, the « soulte » would reach -15,43 M€*

When applied to the 182 hours with a negative price of 2017, this ratio would yield a global compensation amounting to some 100 M€. Does this number make any sense (it seems, by the way, that these transactions are not conducted on the open market but Over-The-Counter[24])? In addition, a large part of this conventional power is exported, as was the case on the afternoon of Sunday April 30 (more than 80%). Is this bonus, then, a godsend for Germany's neighboring countries? We hardly believe so, particularly if we think of the German consumers whose electricity is twice as expensive as that of their French counterparts.

11.2. Aside from the monetary aspect, shouldn't we stress how **grotesque** this situation is: a country at the cutting edge of ecology which advocates resorting to renewable energies, yet does not hesitate to "**warm the little birdies**" in order to do away with its excess fossil and even nuclear power production, on some days, at least! While the obvious solution would be to resort to the storage of electricity, an avenue that is not being traveled by Europe (for the record, Germany has numerous small PHES plants, totaling 9 GW but they cannot store more than 0.05 TWh, i.e. half of what France can store with its 5 GW capacity distributed among 5 PHES plants that enjoy larger water retention capacities).

11.3. Beyond these quantitative considerations, the deceptive nature of the supposedly "*free and undistorted*" European market must be decried: it places **controllable energy production, delivered as needed**, in competition with **inevitable and intermittent**

[24] Here, there is good reason to quote an expert of the German power grid (H. Lauer in a personal communication on May 1, 2018). "*The volume negotiated on the EPEX SPOT market is rather small relative to the total volume. In 2016, of the 3920 TWh negotiated on the exchange market, only 535 TWh (13.6 %) were negotiated on the EPEX SPOT market, of which 474 TWh on the 'Day-Ahead' and 61 TWh on the 'Intraday'. Do not forget that a large amount of electricity is negotiated 'Over-The-Counter', not on the exchange market*". In a June 13, 2018 communication, H. Lauer refers to a study by the Technical University of Freiberg which states that this negative price market, namely what we call the monetary compensation or *soulte*, is thought to be equal to the hourly negative price multiplied by the quantity of electricity negotiated and would amount to **180 M€ for the sole year 2017**, totaling half of the sum paid for the equivalent compensation during the years 2008 to 2016.

productions whose producers have already been paid! Yet, *"negative prices were first introduced in 2008 on the EPEX SPOT exchange to stimulate the flexibility of the electricity system, flexibility being considered as a major vector towards a successful energy transition, in particular to accommodate the intermittent character of the renewable energies. Negative prices, then,* seen *as an indicator of the flexibility of the conventional fleet."*[25] This is much like a *reversal of the proof* that can make one smile.
In reality, recurring negative prices disown an exchange system bearing on a product as volatile as electricity as V. Le Billon wrote in the daily *Les Échos* dated 18 June 2013, "*if the energy buyers can take advantage of these good deals to optimize their short term costs on small volumes [...] the long term message is much more negative, in particular because it deteriorates the return on investments in production plants",* investments in dispatchable power plants, that is.
In the same publication, Fabien Choné, deputy CEO of *Direct Énergie* (now *Total*) considered that "t*he short term impact may amount to a few million Euros, a ridiculously small sum compared to the long term stakes".* In other words, **this market delivers price information only for short sighted speculators.**
But it also generates a price counter-signal, to which conventional producers react by not investing, witness the owners of Swiss PHES plants or the owner of the Irsching power plant as we shall see.
The same conclusion is reached implicitly by "*Alternatives Économiques*" a monthly economy journal that is not usually inclined to disparage the energy transition. In the 19 January 2018 issue, it published an article titled **"*Destruction of the Electricity Market*"** by François Lévêque, professor of economy at *Mines ParisTech* in which he lets fly at these "*negative prices which pertain to heresy since they mean that producers of electricity pay money out to those who agree to 'purchase' it from them*."

11.4 François Lévêque also states that "*the end of the convergence between national prices, for example the prices on either side of the Rhine river, is related to the traffic jam on the cross-border thruways for electricity. When the wind blows strong in Germany and the sun shines, the excess electrons produced do not all manage to escape successfully to France: the transport capacities saturate. As a consequence, the wholesale price in France can be higher than in Germany because it is more rarely determined by very low cost renewable production*." The table of paragraph 9 partly confirms this but, in Appendix H, we show that things are seemingly not as mathematical as this. To the "*wind blows strong in Germany*", not the sole cause, by the way, of disturbances on the exchange market, other hypotheses can be put forward: interconnection breach (at the border or upstream from it), unavailability of production means in the neighboring countries[26], recurrent under-consumption (in particular during week-ends), erroneous analysis[27], in particular due to poor expertise on how the exchange market operates.
And we see:

- On one hand, the Brussels body doing its best to promote the development of cross-border interconnections or, at least, to prohibit any hindrance to the free circulation of electrons, whether with phase angle regulators, as we saw, or with direct current lines (now being considered by the Belgians and the Dutch).
- On the other hand, a form of revolt, as reported by Enerpresse in its March 2, 2018 edition: "*On Wednesday 28 February, Elia and 50Hertz announced having signed an inter-GRT agreement with TenneT, RTE, and Swissgrid to create a reflection group on a European market model for the future power system. The main objective is to* "contribute to a shared understanding of the most promising market model solutions for a **reliable, sustainable and affordable energy system for the future**. The process also aims to identify the steps necessary to achieve these," *explained the Belgian GRT in a press release. The group will have 2050 as its horizon, several States having declared their decision to decarbonize their society by that time [....]*". **Manner of stating that the present energy system is not reliable**.

11.5 In the short term, Europe's electricity system is living dangerously, the only real price signal being formed from the subsidies attributed to the renewable energies, whether as *ex-ante* bonuses, namely the former "*feed-in tariffs*", or *ex-post* as the new "*additional remuneration*" relative to a "*free market* [but ... structurally] *distorted*".
That said, the risk exposure on either side of the Rhine is different:

- France is shutting down its coal and oil fueled power plants (and is thinking about reducing its nuclear power) and RTE is basing its national grid balance forecast on the possibility of importing from neighboring countries, while **it has received no commitment to that effect from its large neighbor**.

- As for Germany, it ensures its energy supply security by backing up its inexorable production (wind + photovoltaic) with a more than equivalent dispatchable production fleet: 98.4 GW and 104.1 GW respectively in order to face up to a

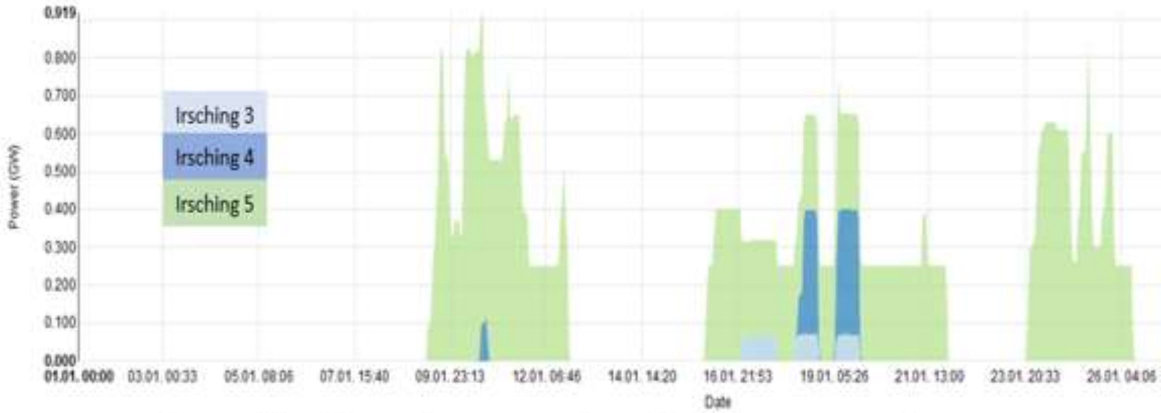
[25] H. Lauer, personal communication.
[26] How can one not think of the drop in the French nuclear power production in 2017 (5 TWh or -1.3 % relative to 2016) because of multiple reactor shutdowns dictated by the French *Autorité de Sûreté Nucléaire (nuclear safety authority)* all along the year.
[27] For a reliable analysis, it would be necessary to gain access to the Fraunhofer ISE data base, and also that of ENTSO-E, and, why not, that of EPEX...and develop investigative software.

domestic demand peak amounting to a mere 82 GW (versus the historical 102 GW peak in France). In Appendix F we give an illustration of this fundamental strategy, despite the "loss" of some 8 GW nuclear power in 2011.
Here, we have one of the frequently ignored causes of the high cost of electricity on the other side of the Rhine river: the need to fund a double production fleet, its green component in conjunction with the famous EEG tax (threefold the French CSPE), and its conventional component whose load factor, additionally, has fallen from 54.5% to 43.7% in 15 years.
Meanwhile, the failure of this *Energiewende* in terms of greenhouse gas emissions reductions cannot be denied: replacing uranium with fossil fuels can only increase carbon dioxide emissions.

But it is the whole of Europe that is walking a tightrope, putting its electricity production at the mercy of meteorological contingencies or of technical hazards (transmission lines[28] or production facilities). These risks are taken knowingly since it is evident that, in Germany, the forging ahead of solar and wind has not made an industrial scale iREL storage solution surface, despite regularly observed excess production and a mothballing of dispatchable production facilities. Witness "*the gas fueled power plant at Irsching on the Danube. Brand new cutting edge units start production at the very beginning of the 2010s. Confronted to the competition of coal fueled power plants and renewables, they are operated at half their capacity leading to a loss of several million Euros per year. The owners, seeing no hope for improvement in the near term, decide to shut them down. But this is refused by the grid operator, considering that these modern units must remain open to ensure the operational reserve that can supplement insufficient renewable electricity production on some days and times in the year in Southern Germany"*[29].

This is confirmed by

- a news flash from Enerpresse dated May 4, 2018: "*Units 4 and 5 of the Irsching gas-fueled power plant in Bavaria will be put in cold reserve from May 2019 to end of September 2020 for failing profitability, their owners announced on Thursday April 26* [...]. *The backup role for renewable energies that these units play* "is not adequately compensated", *these operators claim.* "The legal environment compels us to offer this service at prices that do not cover the costs"*, say the operators. Irsching 4 (561 MW) started operation in 2011. Irsching 5 (846 MW) in 2010. It is the third time that the latter has been placed in cold reserve since the beginning of its operation".*
- and the "*stop and go*" contribution of this power plant during the extreme strain on wholesale prices, beyond 300 €/MWh in the 4th week of January 2017 (see Appendix I) despite a considerable demand on gas-fueled plants (up to ~9 GW)[30].



<u>Figure 13 :</u> « Stop and go » *operation of Irsching gas power plant*

The German electricity system, then, is not shielded from strained circumstances, the more so when the nuclear power shutdown of the last 9.5 GW planned for 2020 becomes effective.

Neither is RTE which clearly counts on the support of its neighbors (Germany first)...

28 The continent wide incident of November 4, 2006 due to the untimely disconnection of a high voltage line in Northern Germany.
29 F. Lévêque paper referenced above.
30 In the rest of the year, this facility's contribution is limited to a few 2 to 3 hour peaks:
6 February: 336 MW Irsching 5
27 March: 1 (sic?) MW Irsching 4
3 May: 457 MW Irsching 4
17 May 321 MW Irsching 5
19 May: 143 MW Irsching 3
19 July: 470 MW Irsching 4
17 October: 174 MW: Irsching 3

Appendix A

The Role of EPEX

Excerpts from http://www.epexspot.com/en/company-info/epex_spot_in_the_power_market

EPEX provides a market place where exchange members send their orders to buy or sell electricity in determined delivery areas. The role of EPEX SPOT consists in matching these orders in a transparent manner, according to the public Exchange rules which among others describe the priorities and algorithms used for the matching of the orders. As a result of the order matching, EPEX SPOT produces trades which are legally binding agreements to purchase or sell a determined quantity of electricity to a defined delivery area for the matched (or "cleared") price. ***This price is never higher than the purchase price fixed by the buyer or lower than the sale price offered by the seller****.*

[...]

As an important result of this process, EPEX SPOT broadcasts the prices resulting from the trades. Since the trades result from a large, open and transparent competition between the orders of the exchange members, they reflect the best information available at the time on the market conditions. They are hence the most reliable prices available for the short-term electricity, either day-ahead for the day-ahead auctions or intraday for the continuous intraday trading.

These prices serve as a benchmark for the transactions of the wholesale market. {...]

The free trade of power thus insures competitive prices for the end consumers which have the freedom to choose between numerous suppliers. Independently of the production facilities that the suppliers may or may not have, they are dependent on the wholesale market to deliver the supply of power to their consumers. Moreover, since power cannot be stored, all users of the transmission grids must be balanced in real-time between their resources and consumption of power.

EPEX SPOT provides a critical liquidity outlet for the producers, the suppliers and the transmission system operators, as well as for the industrial consumers, to fulfill their sales or their purchases in short term power. Meeting these needs balances supply and demand, generating relevant prices for short term power.

In Wikipedia among others, it is specified that "***the price signal of 15-minute contracts contributes to the added value of flexibility and provides at the same time incentives for system stabilization".***

News Flash Compilation of Past "*Anomalies*"

September 11, 2012 Centre d'Analyses Stratégiques N° 281 excerpt on *negative prices*
http://archives.strategie.gouv.fr/cas/system/files/2012-09-11_-_transition_eunergeutique_allemande-na281-7_en_0.pdf

PREMIER MINISTRE

Centre d'analyse stratégique

September 2012 no. 281
LA NOTE D'ANALYSE
Sustainable development

Is the German energy transition sustainable?

In 2011, Germany began a radical energy policy, or "*Energiewende*", with the aim of completely abandoning nuclear power by 2022 and then achieving an 80-95% reduction in the country's greenhouse gas emissions by 2050. By this date, the country will therefore have to be producing its electricity almost completely without the use of gas, oil and coal, having replaced 80% of these sources with renewable ... opment of the national power grid, the cost and financing of the necessary investments, improved electricity storage techniques, the acceptability of the planned increases in the price of electricity or the financial difficulties experienced by solar panel manufacturers as a result of the sharp reduction in subsidies and competition from Asia. In addition, recent political dissent within the government

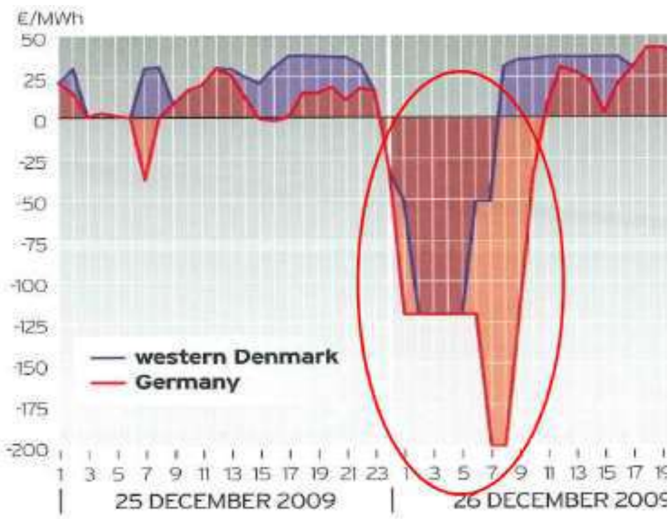
Box on Page 12:

Negative prices per MWh: an anomaly due to the priority injection of renewable energies into the grid

The intermittence of renewable energies can oddly generate negative prices on the electricity markets. In Germany, this occurred on 17 days in 2010, 15 days in 2011 and 6 days in the first quarter of 2012. The phenomenon recently spread to France: 5 days in 2011 and 2 days at the beginning of 2012. It is due to the fact that the production of renewable energy takes precedence on the grid [67] and that it is more cost-effective for a producer to pay a consumer to use his production rather than to bear the costs of shutting down/starting up his thermal power plants and cause premature wear. From the economic point of view, renewable energy which has zero marginal generation cost should not be offered on the market when prices are negative (and therefore less than the generation costs). The electricity exchange EPEX also notes episodes where peak prices were below **basic prices, another anomaly due to the same causes.**

(67) In economic terms, the marginal cost of wind or solar energy is zero and in the event of negative prices on the market, these methods of production should be dismissed.

March 25, 2013 "*Save the Climate*" workshop on PHESs



Negative price peak observed in December 2009 on the German exchange

March 18, 2013 Les Echos Newspaper by Véronique Le Billon : France grappling with negative electricity prices

The MWh price was being negotiated at -40€ last Sunday on the Epex Spot market

This paradox will not help the French understand their electricity bill. While the energy regulator considers that the tariffs should increase by nearly 10% in July to cover the costs of EDF this year, the megawatt-hour (MWh) delivered on the electricity market Sunday was being traded at a negative price, namely -40.99 euros. It even fell to -200 euros for a few hours in the morning.

The MWh was being traded at around 8.60 euros for delivery on Saturday and around 28 euros the previous days, these being already very low prices; "*It seems that a relatively low demand, resulting from mild temperatures during the week-end and a large production volume from non flexible sources (nuclear power, hydroelectricity, wind and photovoltaic) in France, Germany and Belgium have led to excess production in these countries*" Epex Spot, the electricity exchange market for intraday trading, indicated in a statement published on its internet site. In Germany the the MWh base price settled at -3.33 euros on Sunday.

In accordance with its market monitoring mission, the Energy Regulatory Body (*Commission de régulation de l'énergie* - CRE) will, in the coming weeks, conduct a thorough analysis of these price movements and identify possible dysfunctions. It appears that during that week-end, wind and solar productions were massive particularly in Germany. The alternative for the other energy producers was then to lower their production or to pay out to offload their MWhs for a few hours and get rid of this excess production, thus avoiding the extra costs entailed in putting their plants on cold reserve. In December, EDF had thus reduced the power output of its nuclear reactors.

But the producers of solar and wind power who enjoy fixed feed-in tariffs for the electricity they produce regardless of the demand, have no motivation to adjust their production, whether in France or in Germany. As soon as the demand increased on Monday, the electricity prices in France returned to positive values. The MWh traded at around 35 euros for same day delivery.

Last year, negative prices had already been registered during ten hours on the day ahead exchange and during seventeen hours on the intraday market, but this was only during Christmas and New Year holidays when the demand is particularly low. This time, the prices were negative during fifteen hours.

A new hazard for this market

While this phenomenon is still rare, it is perceived as a new hazard for the electricity market operation. If energy consumers can take advantage of good deals to optimize their costs in the short term, and on small volumes (115 000 MWh on Sunday) the long term signal is much more negative, particularly because it erodes the profitability of investments in production plants. "*The short term impact may represent a few million euros but that is peanuts compared to the long term stakes"* says Fabien Choné, deputy general manager of Direct Energie.

June 19, 2013 - Liberation Daily Newspaper by AFP : As the price of electricity fluctuates around negative values

A record-breaking negative price, -200 euros per Megawatt-hour was observed Sunday.

With subsidies and priority access to the grid of renewable energies, some producers of electricity generated from natural gas or nuclear power have to temporarily pay their customers to offload their production. A consulting firm points to a destabilization risk.

France too is caught up by negative prices on the wholesale electricity markets, threatening the profitability of its gas fueled plants and consequently its security of electricity supply warns the Sia Partners consulting firm. Last week-end, negative prices occurred during 14 hours in mainland France on the Epex-Spot electricity exchange market, more than the 10 hours of negative prices noted over the entire year 2012. Moreover, a record-breaking -200 €/MWh was observed on Sunday, says Sia.

This phenomenon which has already been seen among the major wind and photovoltaic power producers such as Spain, Germany, and Denmark is attributed to the growth of renewable energies. Solar and wind electricity enjoy "priority grid access" so that they are offloaded on the electricity grids before other production sources (hydroelectric dams, nuclear power plants, fossil-fueled power plants whether oil, natural gas or coal). Additionally, they are subsidized with fixed feed-in tariffs and produced at fixed costs, so that operators are encouraged to overproduce. As a result, the wholesale electricity prices in Europe collapse in the event of wind and solar production peaks, occasionally to the point of becoming negative.

According to Sia Partners, this phenomenon "*threatens the fragile balance of the European electricity markets*", in particular the profitability of gas fueled power plants as illustrated with the growing shutdown or mothballing of these facilities (including three GDF Suez owned plants in France) victims of an economic "massacre".

Indeed, at times of negative prices, the owners have to pay out to offload their electrons, or put their facilities on cold reserve, thus reducing their number of operating hours (load factor). Yet, "*when there is no wind or sun, production will have to be ensured with backup plants and if they all shutdown, there is a risk of being faced with an unsolvable problem*" warns Cédric Jeancolas of Sia Partners.

Certainly, wind and solar, whose production is intermittent require, by definition, backup production means whether hydro-power or conventional power plants (nuclear power plants being less dispatchable) to take over when they are not available.

Moreover, this is not really beneficial to the consumers, according to him. On one hand, they fund the subsidies for the renewables and on the other, when the producers have to pay out to offload their production, that eventually shows up on the consumer electricity bill.

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18 March, 2014 Enerpresse : Germany **New negative price episode on the market**

***European Power Exchange* (EPEX), the electricity exchange spot market based in Paris, has registered, this Sunday, a new negative price episode on the German (and Austrian) market.** The day ahead base load price (price for Sunday negotiated on Saturday) settled at an average -4.13 €/MWh but this pricing decreased to -37.71 €/MWh for the "early morning" (5 am to 8 am) hours. The per hour negative price record settles at -60.26 €/MWh with a strong thrust on exchanges during these periods, the producers attempting to offload much more power than the demand on the grid. Main cause of this "anomaly" in today's terminology: the strong power surge of the German wind turbines (up to 25 GW output during the hours considered while solar PV rose to 5 GW at solar maximum) and a very low demand on a pleasant almost springlike Sunday as early as daybreak (and after all it is a Sunday morning!). Note that the prices were negative during 10 of the day's 24 hours. Also, we note that the cross-border exchanges show Germany exporting to France during that time, France itself exporting all day long to other countries. As usual, one should recall that these are commercial exchanges. In other words, the fact that an entity imports electricity that is "on sale" is no indication that this entity's supply is insufficient.

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12 May, 2015 Enerpresse EUROPE The wholesale prices remain low in April

The electricity wholesale prices on the Western European exchange markets remained at very low levels in April, because of good solar production in Germany, according to the data published by the Platts Company on May 7. In France, the prices averaged at 38.97 €/MWh, 9% lower than in March because of good hydro and nuclear productions but 20% higher than in April 2014. In Germany, the prices averaged 30.22 €/MWh, 2% lower than in March and 3% lower than in April 2014. The German prices remain low because of the continuous development of renewable production in the country. The renewable production reached 40 GW on average in April, leading to a negative price episode on the market on April 22. Solar energy, in particular, reached a high level with a mean power output at 13.5 GW, an amount much larger than the country's 10 GW nuclear capacity. Only in the UK did the wholesale prices increase in April at 43.6 £/MWh (60.2 €/MWh) compared to 40.3 £/MWh (55.7 €/MWh) in March. There are two reasons for this relatively large increase: the carbon price increase from 9.55 £/t CO_2 to 18.08 £/t CO_2, and a receding wind production.

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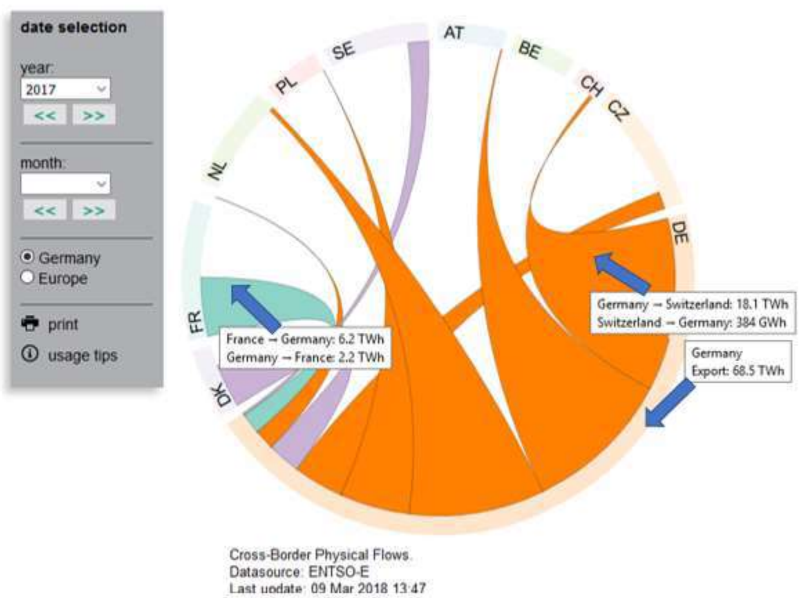
28 December 2016 Enerpresse : GERMANY Sharp downturn of spot prices on Christmas Holidays.

On the Epex Spot market, the base day ahead prices for the Germany/Austria zone dropped as of December 22. The price shifted from 45.23 €/MWh for delivery on December 22 to -12.25 €/MWh for delivery on December 26. The slack demand during the Christmas holidays in conjunction with a very strong wind production explain this spot price evolution. The contracts for delivery on December 27 came back up to a positive 4.48 €/MWh. Contracts for peak demand delivery also dropped to reach a negative -4.24 €/MWh for the product delivered on December 26.

Transcription of the Fraunhofer Data from its "Roses"...

Electricity exchange of Germany with its neighbours in 2017



Assembly of 3 screen shots: the blue arrows show the appropriate pointer direction on the Fraunhofer graph to get the insert of the exchanges between two countries for a given year, or the annual exports of a single country.

... to the summary chart below:

Echanges d'énergie électrique entre l'Allemagne, la France et leurs voisins, sur l'année 2017

en TWh/an   Src : www.energy-charts.de/exchange.html   Last update : 13 Jan 2018

de ... à ...	Allem.	Autr.	Belg.	Dan.	Esp.	Franc.	Gr-Br.*	Italie	Lux.	P.-Bas	Polog.	Suède	Suis.	Tch.	*Total*	Export
Allemagne		15,40		3,40		2,20			2,20	14,20	7,40	0,25	18,10	5,30	*68,45*	68,50
Autriche	0,11												6,60	0,00	*6,71*	18,90
Belgique						4,50			0,01	0,00					*4,51*	4,50
Danemark	4,60											2,20			*6,80*	9,10
Espagne						2,90										5,80
France	6,2		2,90		15,20		10,10	10,90	0,00				4,60		*49,90*	49,80
Gr.-Bret.*						2,20				0,19						2,40
Italie																2,90
Luxembg.	0,00		0,04			0,00									*0,04*	0 ?
Pays-Bas	0,42		9,60				7,20								*17,22*	17,40
Pologne	0,00											0,15		5,40	*5,55*	10,40
Suède	2,10			5,10							3,10				*10,30*	30,80
Suisse	0,38	0,07				2,20		20,50							*23,15*	23,10
Tchéquie	1,80	11,00									0,03				*12,83*	24,00
Import total calculé	*15,6*					*14,0*			*2,2*						*Total des exports*	*267,60*

Allemagne	Autriche	Belgique	Danemark	Espagne	France	Grande-Bret.	Italie	Luxembourg	Pays-Bas	Pologne	Suède	Suisse	Tchéquie
DE	AT	BE	DK	SP	FR	UK	IT	LU	NL	PO	SE	CH	CZ
Deutschland	Österreich	Belgien	Dänemark	Spanien	Frankreich	Verinnigtes Königreich	Italien	Luxemburg	Nieder-lande	Polen	Schweden	Schweiz	Tschechien
Germany	Austria	Belgium	Denmark	Spain	France	Un. Kingdom	Italy	Luxemburg	Netherlands	Poland	Sweden	Switzerland	Czech Rep.

On Fraunhofer "roses", countries are identified by their initials and alphabetically classified (except Spain, between Estonia and Finland !)

In our "naval battles", countries are classified in french alphabetical order (1st line)

This chart along with the chart on the next pages reproduce the Fraunhofer data in regular print. The *italicized* numbers of this chart give the total imports (bottom line - sum of the values in the column) and the total exports (right hand column -sum of the values in the line). This is supposed to match the exports of each country obtained on the Fraunhofer rose, by placing the pointer on its external band for each country.

Electricity Trading in European Union (plus Norway, Russia and Switzerland) during 2017, **in TWh**

(data from www.energy-chart.de/exchange.html Last update : 13 Jan 2018)

From ... to ...	Germ.	Austr.	Belg.	Bulg.	Den.	Spain	Eston.	Finl.	Franc.	G-Br.*	Greec	Hung.	Irel.	Italy	Latvia	Lithua	Lux.	Norw.	N-L	Pola.	Port.	Rom.	Russ.	Slova.	Slove.	Swed.	Switz.	Czch.	*Total*	Export
Germany		15,40			3,40				2,20								2,20		14,20	7,40						0,25	18,10	5,30	*68,45*	68,50
Austria	0,11											5,00		1,30											5,90		6,60	0,00	*18,91*	18,90
Belgium									4,50								0,01		0,00										*4,51*	4,50
Bulgaria											2,00											0,27							*2,27*	6,60
Denmark	4,60																	2,40								2,20			*9,20*	9,10
Spain									2,90												2,90								*5,80*	5,80
Estonia								0,84							2,30								1,50						*4,64*	4,70
Finland							1,60											0,04					0,00			0,08			*1,72*	1,80
France	6,2		2,90			15,20				10,1				10,90			0 ?										4,60		*49,90*	49,80
Gr.-Britt. *									2,2				0 ?						0,191										*2,39*	2,40
Greece				0,02										1,60															*1,62*	2,00
Hungary		0,07																				0,82		0,00					*0,89*	6,70
Ireland										0 ?																			*0,00*	?
Italy		0,11							0,28		0,33														0,02		0,01		*0,74*	2,90
Latvia							0,11									3,30							0,04						*3,45*	3,40
Lithuania															0,07					1,50			0,03			0,11			*1,72*	2,10
Luxembg.			0,04						0,00																				*0,04*	0 ?
Norway					5,30			0,29											5,00				0 ?			8,90			*19,49*	19,40
Netherlands	0,42		9,60							7,2								0,11											*17,33*	17,40
Poland	0,00															0,49								4,40		0,15		5,40	*10,45*	10,40
Portugal						5,60																							*5,60*	5,60
Romania				3,40								0,27																	*3,67*	5,80
Russia							0,19	5,80							0,94	2,70		0 ?											*9,63*	9,70
Slovakia												9,50								0,00								0,00	*9,50*	10,20
Slovenia		0,09												5,50															*5,59*	7,40
Sweden	2,10				5,10			15,00								3,20		2,30		3,10									*30,80*	30,80
Switzerland	0,38	0,07							2,20					20,50															*23,15*	23,10
Czech Repu.	1,80	11,00																		0,03				11,10					*23,93*	24,00
Total imported ***	*15,6*	*26,7*	*12,5*	*3,4*	*13,8*	*20,8*	*1,9*	*21,9*	*14,3*	*17,3*	*2,3*	*14,8*	*0,0*	*39,8*	*3,3*	*9,7*	*2,2*	*4,9*	*19,4*	*12,0*	*2,9*	*1,1*	*1,6*	*15,5*	*5,9*	*11,7*	*29,3*	*10,7*	*335,4*	

* **Northern Ireland** included

** Following nations (with their 2017 export) have not been included in upper table, even though they appear in the "big" Fraunhofer rose:

Albania	0,43
Bosnia-Herzegovin	3,5
Belarus	1,4
Croatia	2,0
Macedonia	2,1

Malta	?
Montenegro	1,6
Serbia	4,9
Turkey	3,3
Ukraine	2,0

neither Morocco ...

*** **Italics come from personal computation**

Overview of European Electricity Trading

limited to France's and Germany's Neighbors from 2011 to 2016 [31]

Year 2016 (Last update : 13 Jan 2018)

from ... to ...	Germ.	Austr.	Belg.	Denm.	Spain	Franc.	G-Br.*	Itay	Lux.	N-L	Poland	Swed.	Switz.	Czech	*Total*	Export
Germany		12,80		4,60		2,00			0,00	15,80	8,80	0,80	15,60	3,50	*63,90*	63,90
Austria	0,35															14,90
Belgium						4,40			0,00							6,30
Denmark	2,10															7,80
Spain						4,10										5,90
France	7,5		3,90		11,80		11,2	11,10	0 ?				4,70		*50,20*	50,30
Great Brit. *						1,1										1,20
Italy						0,29										3,80
Luxembg.	?		0,00			0,00									*0,00*	0 ?
Netherlands	0,19															16,90
Poland	2,00															11,50
Sweden	1,50															25,90
Switzerland	1,00					1,80										22,80
Czech Rep.	2,10															21,20
Computed total import	*16,7*					*13,7*			*0,0*						*Sum of exports*	*252,4*

Year 2015 (Last update : 7 Sept. 2016)

from ... to ...	Germ.	Austr.	Belg.	Denm.	Spain	Franc.	G-Br.*	Itay	Lux.	N-L	Poland	Swed.	Switz.	Czech	*Total*	Export
Germany		15,60		5,30		1,30			5,10	22,50	9,70	0,16	13,60	5,30	*78,56*	78,70
Austria	3,30															17,80
Belgium						1,20			0,21							2,30
Denmark	4,90															9,40
Spain						1,80										14,20
France	10,8		9,40		7,40		13,50	14,90	0,98				8,70		*65,68*	65,70
Great Brit. *						0,15										2,10
Italy						0,71										3,20
Luxembg.	1,20		0,49			0,00									*1,69*	1,70
Netherlands	0,28															18,30
Poland	0,02															13,10
Sweden	1,80															32,30
Switzerland	2,90					3,90										30,80
Czech Rep.	5,60															25,80
Computed total import	*30,8*					9,1			6,3						*Sum of exports*	*315,4*

Year 2014 (Last update : 11 March 2015)

from ... to ...	Germ.	Austr.	Belg.	Denm.	Spain	Franc.	G-Br.*	Itay	Lux.	N-L	Poland	Swed.	Switz.	Czech	*Total*	Export	
Germany		14,50		8,00		0,83			4,20	24,30	9,20	0,77	11,50	3,80	*77,10*	77,10	
Austria	5,50															18,00	
Belgium						0,97			0,18							4,20	
Denmark	4,50															8,30	
Spain						2,40										15,50	
France	14,8		11,10		6,00		15	15,50	1,10				10,00		*78,50*	73,50	erreur !
Great Brit. *						0,014										3,70	
Italy						0,63										2,70	
Luxembg.	0,78		0,83			0,00									*1,61*	1,60	
Netherlands	0,35															17,60	
Poland	0,05															11,30	
Sweden	1,80															32,50	
Switzerland	4,60					2,90										30,00	
Czech Rep.	6,30															28,10	
Computed total import	*38,7*					*12,7*			*5,5*						*Sum of exports*	*324,1*	

[31] Countries are classified in French alphabetical order

Year 2013 (Last update : 11 March 2015)

from ... to ...	Germ.	Austr.	Belg.	Denm.	Spain	Franc.	G-Br.*	Itay	Lux.	N-L	Poland	Swed.	Switz.	Czech	*Total*	Export	
Germany		14,50		11,50		1,20			5,60	24,60	5,50	1,00	11,70	2,40	*78,00*	78,00	
Austria	7,30															19,80	
Belgium						2,40			0,79							7,60	
Denmark	3,20															11,20	
Spain						3,20										16,60	
France	11,8		8,70		4,90		10,9	12,70	0,29				9,30		*63,59*	58,50	erreur
Great Brit. *						0,542										4,50	
Italy						0,86										2,20	
Luxembg.	0,00		0,70			0,00									*0,70*	1,70	erreur
Netherlands	0,34															14,90	
Poland	0,54															12,30	
Sweden	1,10															24,70	
Switzerland	3,70					3,40										30,70	
Czech Rep.	9,40															27,50	
Computed total import	*37,4*					*16,6*			*6,7*						*Sum of exports*	*310,2*	

Year 2012 (Last update : 11 March 2015)

from ... to ...	Germ.	Austr.	Belg.	Denm.	Spain	Franc.	G-Br.*	Itay	Lux.	N-L	Poland	Swed.	Switz.	Czech	*Total*	Export	
Germany		15,10		2,60		0,78			5,70	20,40	6,10	0,30	12,70	2,70	*66,38*	66,20	
Austria	6,30															22,60	
Belgium						2,30			0,18							6,50	
Denmark	8,20															10,50	
Spain						2,80										17,20	
France	13,2		6,70		4,40		7,6	12,60	0,00				9,60		*59,10*	54,10	erreur
Great Brit. *						1,2										3,60	
Italy						1,10										2,20	
Luxembg.	1,10		0,83			0,00									*1,93*	2,30	erreur
Netherlands	0,74															13,40	
Poland	0,17															12,60	
Sweden	2,90															32,40	
Switzerland	3,10					2,30										31,80	
Czech Rep.	8,40															28,70	
Computed total import	*44,1*					*15,5*			*5,9*						*Sum of exports*	*304,1*	

Year 2011 (Last update : 11 March 2015)

from ... to ...	Germ.	Austr.	Belg.	Denm.	Spain	Franc.	G-Br.*	Itay	Lux.	N-L	Poland	Swed.	Switz.	Czech	*Total*	Export	
Germany		15,90		2,90		0,14			5,80	9,60	5,10	0,63	14,00	1,90	*55,97*	56,00	
Austria	5,40															17,90	
Belgium						2,30			1,30							10,70	
Denmark	5,10															10,30	
Spain						2,50										13,70	
France	20,3		7,10		4,00		6,2	14,30	0,00				12,30		*69,20*	64,20	erreur
Great Brit. *						1,4										3,80	
Italy						0,94										2,10	
Luxembg.	1,10		1,50			0,00									*2,60*	2,70	
Netherlands	3,20															11,80	
Poland	0,43															12,00	
Sweden	2,00															21,40	
Switzerland	2,80					1,80										30,30	
Czech Rep.	9,40															27,50	
Computed total import	*49,7*					*14,1*			*7,1*						*Sum of exports*	*284,4*	

[31] **Countries are classified in French alphabetical order**

Evolution from 2011 to 2017 of the Export Capacity of European Countries

In red, countries trading directly with Germany ("small" rose of Fraunhofer site)

Country *	2011	2017	Δ 2017-2011	
			in TWh	in %
Albania	0,21	0,43	0,2	104,8
Austria	17,9	18,9	1,0	5,6
Belarus	2,9	1,4	-1,5	-51,7
Belgium	10,7	6,1	-4,6	-43,0
Bosnia-Herzegov.	3,9	3,5	-0,4	-10,3
Bulgaria	12	6,6	-5,4	-45,0
Croatia	6,3	2,0	-4,3	-68,3
Czech Rep.	27,5	12,8	-14,7	-53,5
Denmark	10,3	9,1	-1,2	-11,7
Estonia	5,0	4,7	-0,3	-6,0
Finland	4,6	1,8	-2,8	-60,9
France	69,2	49,8	-19,4	-28,0
Germany	56	68,5	12,5	22,3
Greece	3,9	2,0	-1,9	-48,7
Hungary	8,1	6,7	-1,4	-17,3
Ireland **	0,24	?	?	?
Italy	2,1	2,9	0,8	38,1
Latvia	2,8	3,4	0,6	21,4
Lithuania	1,3	2,1	0,8	61,5
Luxemburg	2,7	?	?	?

Country	2011	2017	Δ 2017-2011	
			in TWh	in %
Macedonia	1,5	2,1	0,6	40,0
Moldavia ***	0,5	?	?	?
Montenegro****	?	1,6	?	?
	11,8	17,4	5,6	47,5
North-Irel. **	0,73	?	?	?
Norway	13,6	19,4	5,8	42,6
Poland	12	10,4	-1,6	-13,3
Portugal	3,9	5,6	1,7	43,6
Romania	5,0	5,8	0,8	16,0
Russia	15,4	9,7	-5,7	-37,0
Serbia	5,1	4,9	-0,2	-3,9
Slovakia	12,2	10,2	-2,0	-16,4
Slovenia	7,9	7,4	-0,5	-6,3
Spain	13,7	5,8	-7,9	-57,7
Sweden	21,4	30,8	9,4	43,9
Switzerland	30,3	23,1	-7,2	-23,8
Turkey	2,6	3,3	0,7	26,9
United-Kingdom	3,8	2,4	-1,4	-36,8
Ukrain *****	5,5	2	-3,5	-63,6
w/o incompletes	411	363	-47,9	-11,7%
Overall sum	415	365		
w/o Germany	355	295	-60,4	-17,0%

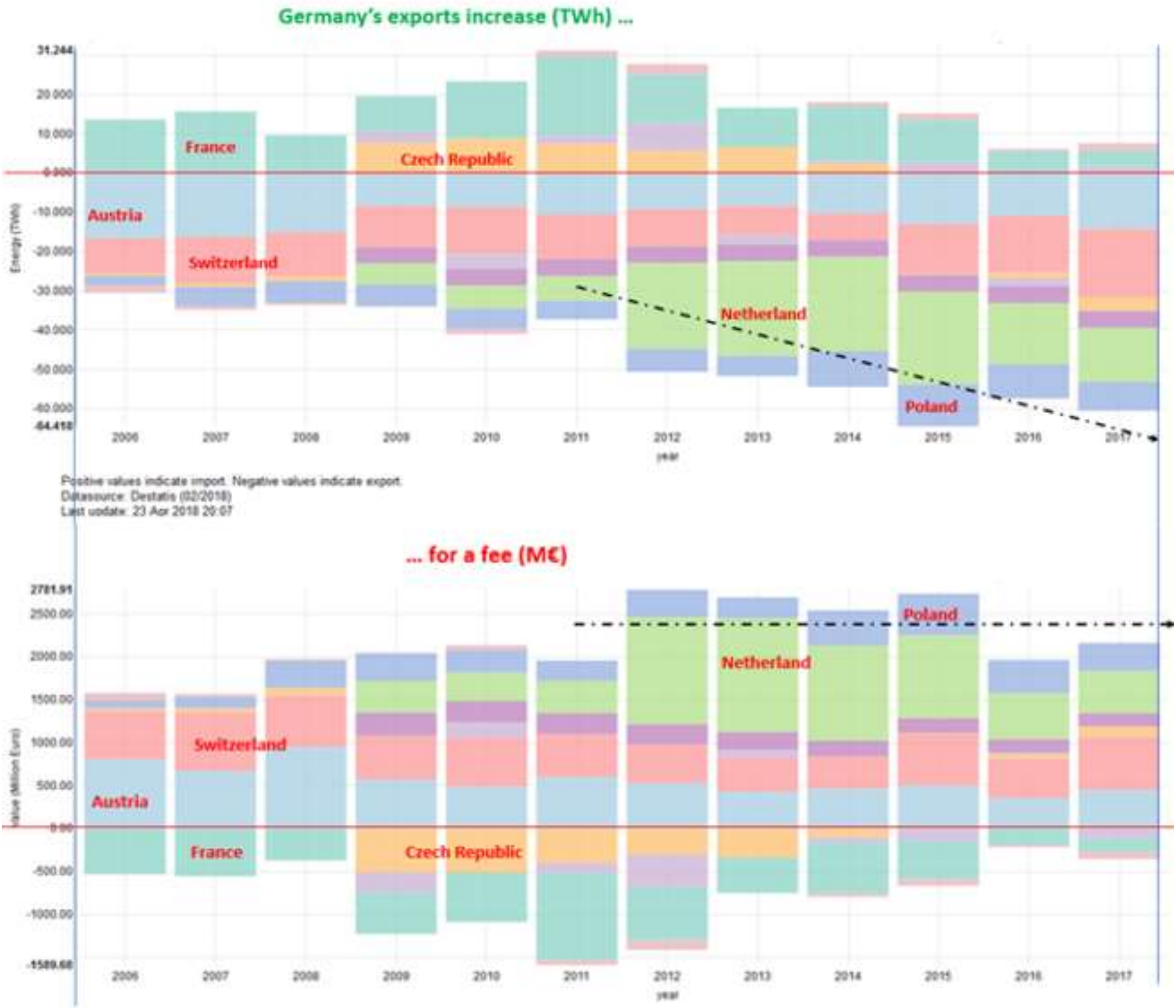
* Missing from the chart: Andorra and Morocco (even Spain?), Malta (non interconnected)

** Could both Irelands be integrated to the UK?

*** Why does Moldavia disappear (trading only with Romania, in 2017) ?

**** Why has Montenegro disappeared (exchanging with only Serbia in 2017) ?

***** Ukraine appears twice on the 2011 Fraunhofer rose (5,5 and 4,8 TWh) !



From these two graphs also provided by Fraunhofer, it appears that in terms of import/export balance:

- **Austria imports permanently**: from 16.7 TWh in 2007 to 14.1 TWh in 2017;

- ditto **Switzerland**, from 7.4 TWh in 2013 to 17.5 TWh in 2017;

- **Poland** too (up to 10.6 TWh in 2015) but clearly decreasing since then (7.3 TWh in 2017);

- ditto the **Netherlands**: 5.4 TWh in 2009, 24 TWh in 2014, merely 13.7 TWh in 2017.

- the **Czech Republic**, small importer up to 2008 became exporter (2.4 TWh in 2015) before reverting to being a small importer.

- **France** alone (with Sweden) **exports continuously**, but less and less since the 2011 peak (20.2 TWh).

Three Negative Price Episodes Observed Outside of Germany

Fraunhofer hourly data			Simultaneous Eco2mix (RTE) hourly data			
Day(s) of 2017	H	€/MWh	€/MWh	€/MWh	€/MWh	€/MWh
30/04 et 01/05	8	-2,16	14,98	9,56	21,29	12,72
	9	-9,14	15,61	8,71	21,75	10,54
	10	-16,16	12,12	3,23	19,97	1,12
	11	-37,85	10,00	-1,90	21,01	1,04
	12	-58,30	10,29	-1,18	20,90	-1,18
	13	-94,55	7,09	-70,01	25,00	-43,58
	14	-100,57	1,70	-74,92	30,00	-49,91
	15	-103,53	-2,17	-71,96	3,16	-49,95
	16	-110,94	-1,00	-49,97	22,00	-20,52
	17	-68,71	5,01	-6,00	15,20	2,36
	18	-41,26	8,70	-1,21	17,61	12,28
	19	-32,68	15,67	8,86	21,75	21,35
	20	-22,92	20,15	10,08	29,16	25,99
	21	-23,80	21,23	8,87	30,00	30,02
	22	-28,54	33,00	-0,54	33,00	30,67
	23	-64,93	35,81	-70,01	32,54	30,51
1/5	0	-20,32	19,54	-26,94	36,00	25,65
	1	-13,38	16,76	-25,00	36,00	17,82
	2	-13,32	12,87	-30,11	36,00	17,82
	3	-11,93	6,02	-30,03	36,00	12,83
	4	-0,99	7,02	-24,90	36,00	12,98
	5	-0,31	11,38	-30,05	36,00	14,62
	6	-2,13	12,18	-62,95	36,00	18,34
	7	-1,25	12,02	-53,85	36,00	18,80
	8	-7,52	12,56	-67,02	36,00	21,94
	9	-2,44	12,45	-65,00	36,00	27,35
30/7	11	-12,55	8,17	-0,02	13,90	8,51
	12	-57,71	10,53	-45,42	-41,31	7,09
	13	-86,12	8,54	-67,05	-11,49	7,00
	14	-86,41	5,77	-64,90	-9,59	5,97
	15	-71,65	2,51	-14,23	13,78	5,44
	16	-56,41	5,22	-0,91	11,00	8,52
	17	-25,62	9,09	5,01	13,34	11,13
20/8	4	-1,10	7,07	5,18	8,60	8,05
	5	-1,85	6,21	8,51	6,16	8,70
	6	-0,99	5,31	8,17	5,28	9,12
	7	-1,94	4,07	5,06	5,21	9,07
	8	-1,10	6,16	9,65	6,17	8,52
	9	1,72	6,80	5,59	8,80	9,96
	10	-2,02	6,91	2,66	10,23	6,00
	11	-2,94	6,54	2,10	10,05	7,42
	12	0,41	8,25	-0,01	11,65	5,10
	13	-1,95	5,76	-14,35	9,42	4,95
	14	-0,56	-0,87	-12,93	4,28	2,35
	15	-0,01	-0,05	-6,37	4,97	2,36

Doubtful values ...

Actions Taken by Germany's Neighboring Countries to Protect their Grid

<u>April 6, 2012 Enerpresse:</u> Prague will not block German electricity flow

The Czech Republic **does not plan to install phase-shifting transformers at its border with Germany**, to block excess electric power, in particular wind power, from Germany, the Czech Prime Minister, Petr Necas, assured this Tuesday in Prague. "O*ur policy is not to build phase-shifting transformers to split our electric grids,* ***although the flow of electricity originating from renewable sources in the north of Germany does create problems***", he said.

On windy days, the German North-South transport network saturates and the electricity is automatically redirected Eastward, to Poland and the Czech Republic. Such flows threaten the Czech grid's stability according to the CEPS Company which handles the Czech transport network. This company intends to invest some 63 billion crowns (2.57 billion euros) between now and 2024, in improvements of the network. **By contrast, Poland does plan to install phase-shifting transformers** in order to accept only the electricity it needs.

<u>October 31, 2012 Enerpresse:</u> German wind power bypasses Germany's interconnected neighbors

As opposed to oil, electric renewable energies cannot be stored. There's the rub in the German energy reform (Energiewende) focused on the rejection of the atom. At present, a more ecological mix is paradoxically akin to energy wasting. **And the neighboring Polish and Czech networks undergo the consequences**: owing to their interconnection with Germany, the sudden and fleeting electricity flow surges due to the wind farms in the north of the country (8 885 MW capacity connected since 2007) strain these crossborder networks. To a point where the operators have to put their coal fired plants on cold reserve momentarily and shoulder the extra cost to restart them, or pay customers to offload this "excess" production. It seems that these solutions are insufficient since the PGE operator has revised its production planning for the Dolna Odra and Turow power plants. "*Germany is aware of the problem. But the political will is not strong enough to solve it because of the large expense entailed*" says Pavel Solc, the Czech Deputy Minister of Commerce and Industry (reported by Bloomberg).

Although on the German side, the "*50Hertz Transmission Gmbh*" grid operator, (one of the 4 grid operators in Germany) ensures succinctly that it is "*looking for a constructive solution*", Pavel Solc reaches the conclusion that his country is "*forced to move forward unilaterally to protect the grid and prevent accidents and destructive events*". The more so that the seasonal clock is sounding the approach of winter. A prospect that is leading the Czech operator to consider the solution of installing switches of a sort in the vicinity of the border so as to turn off the connection when necessary. A more thorough action, to be taken in coordination with Poland, that consists in installing phase-shifting transformers in the areas bordering Germany is planned, with 4 installations by 2017. The possible creation of smaller exchange zones that would be easier to handle is being discussed with Berlin.

<u>In December 2013</u> **Pierre Audigier,** Ingénieur Général des Mines, wrote in *ParisTech Review* "*It is, then, to considerable inexorable electricity spillage from Germany that its neighboring countries must be prepared. The Czech Republic decided to install in 2016 a phase-shifting transformer at its border with Germany (such a transformer will allow it to reject any unwanted electricity arriving from Germany). Other countries - Poland, the Netherlands already mentioned and, more recently, Slovakia - are seriously considering doing the same so as to protect their grid stability; and, Kirchhoff's law being as it is - France will not be spared.*"

<u>May 20, 2014 Enerpresse:</u> A busy beginning of year for Elia[32]

On last May 16, Elia, the electricity transmission system operator in Belgium (Elia Transmission) and in Germany (50Hertz) presented its activities during the first quarter of 2014 [...].

Moreover, 50Hertz and the operator of the Polish grid have reached a solution to the unplanned cross border power flow problem between Germany and Poland. They have signed an agreement on the operation of phase-shifting transformers (PST) last March. "*the agreed measures will help to improve power system security in both countries and increase capacities between Germany and Poland to exchange electricity*" said the operator [...].

<u>ELIA[33] press release of November 2, 2016:</u> Commissioning of second phase-shifting transformer in Zandvliet

"One phase-shifting transformer already commissioned at the end of 2015. A transformer of this type is rather like a tap that regulates the supply of electricity. This transformer will spread power imported from the Netherlands across the grid more efficiently.

In total there are now 4 phase-shifting transformers on the Belgian-Dutch border. This is a major improvement in the reliability of the high voltage grid"

32 https://www.pse.pl/web/pse-eng/news/news/-/asset_publisher/6OMoxwXL8Emh/content/agreement-between-polish-pse-and-german-50hertz-transmission-system-operators-on-phase-shifting-transformers-marks-important-step-towards-completion-of-the-european-energy-market/pop_up?

33 http://www.elia.be/~/media/files/Elia/PressReleases/2016/02112016_Elia-completes-phase-one-of-the-Brabo-project.pdf

Evolution of the German Production Fleet Between 2002 and 2017

Data from *https://www.energy-charts.de/power_inst.htm* (*inferences in italics*)

Net installed electricity generation capacities (in GW)

End of year ...	Hydro Power	Biomass	Uranium	Brown Coal	Hard Coal	Mineral Oil	Gas	Wind onshore	Wind offshore	Solar	Σ	including *iREL*	*Convent.*
2017	5,60	7,38	10,80	21,29	25,05	4,44	29,50	50,29	5,26	42,82	*202,43*	*98,37*	*104,06*
2016	5,60	7,35	10,80	21,36	27,42	4,69	29,61	45,46	4,13	40,72	*197,14*	*90,31*	*106,83*
2015	5,59	7,17	10,80	21,42	28,65	4,20	28,36	41,30	3,28	39,22	*189,99*	*83,80*	*106,19*
2011	5,63	5,80	12,07	19,85	25,72	4,17	27,25	28,58		25,43	*154,50*	*54,01*	*100,49*
2010	5,41	6,23	20,43	21,34	28,39	5,90	23,80	26,82		17,94	*156,26*	*44,76*	*111,50*
2003	4,95	1,88	21,00	20,87	28,67	5,10	19,50	14,38		0,43	*116,78*	*14,81*	*101,97*
2002	4,94	1,32	22,43	20,30	28,29	5,30	20,30	11,98		0,30	*115,16*	*12,28*	*102,88*

Annual productions and matching load factors (f_c)

2017	Hydro Power	Biomass	Uranium	Bro. Coal	Hard Coal	Min. Oil	Gas	Wind onshore	Wind offshore	Solar	Σ	*iREL*	*Convent*
GW aver.	*5,6*	*7,365*	*10,8*	*21,325*	*26,235*	*4,565*	*29,555*	*47,875*	*4,695*	*41,77*	*199,79*	*94,34*	*105,45*
TWh	20,87	47,61	72,14	133,81	82,88	?	46,71	103,65		38,39	*546,06*	*142,04*	*404,02*
f_c	*42,5%*	*73,8%*	*76,3%*	*71,6%*	*36,1%*		*18,0%*	*22,5%*		*10,5%*	*31,2%*	*17,2%*	*43,7%*

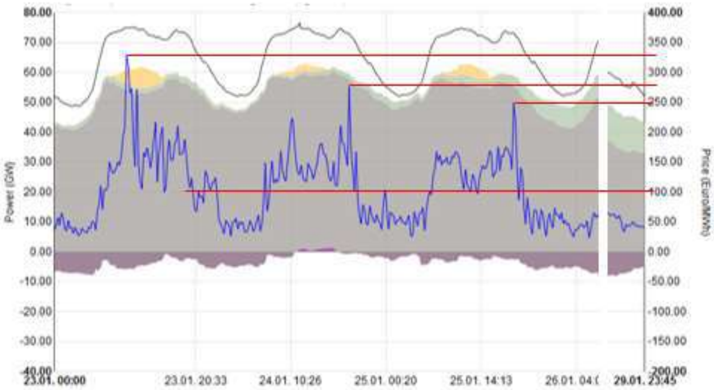
2016													
GW aver.	*5,60*	*7,26*	*10,80*	*21,39*	*28,04*	*4,445*	*28,985*	*43,38*	*3,705*	*39,97*	*193,57*	*87,06*	*106,51*
TWh	20,66	47,56	80,04	134,89	99,77	?	46,50	78,60		38,09	*546,11*	*116,69*	*429,42*
f_c	*42,0%*	*74,6%*	*84,4%*	*71,8%*	*40,5%*		*18,3%*	*19,0%*		*10,8%*	*32,1%*	*15,3%*	*45,9%*

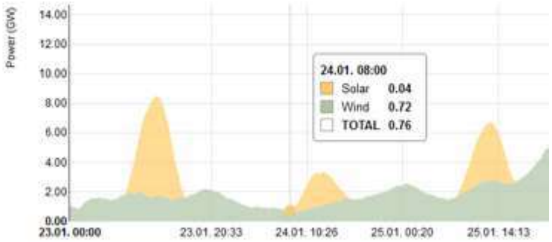
2011													
GW aver.	*5,52*	*6,015*	*16,25*	*20,595*	*27,055*	*5,035*	*25,525*	*27,7*	*0*	*21,685*	*155,38*	*49,39*	*106,00*
TWh	17,70	37,60	102,24	134,06	96,50	?	59,76	48,32		19,60	*515,78*	*67,92*	*447,86*
f_c	*36,6%*	*71,4%*	*71,8%*	*74,3%*	*40,7%*		*26,7%*	*19,9%*		*10,3%*	*37,9%*	*15,7%*	*48,2%*

2003													
GW aver.	*4,945*	*1,60*	*21,715*	*20,585*	*28,48*	*5,20*	*19,90*	*13,18*	*0*	*0,365*	*115,97*	*13,55*	*102,43*
TWh	17,70	6,55	156,46	141,73	121,83	?	44,97	18,71		0	*507,95*	*18,71*	*489,24*
f_c	*40,9%*	*46,7%*	*82,3%*	*78,6%*	*48,8%*		*25,8%*	*16,2%*			*50,0%*	*15,8%*	*54,5%*

A Complicated Week

Week 4 of 2017 starts out with 3 days of 15 minutes wholesale prices soaring to great heights: **329.81 €/MWh** on January 23 at 10:30 am, **276.04 €/MWh** on the 24th at 7:00 pm and **248.62 €/MWh** on the 25th at 7:00 pm. Between **7:00 am and 8:00 pm on each of those days, this wholesale price remained consistently above 100 €/MWh**.



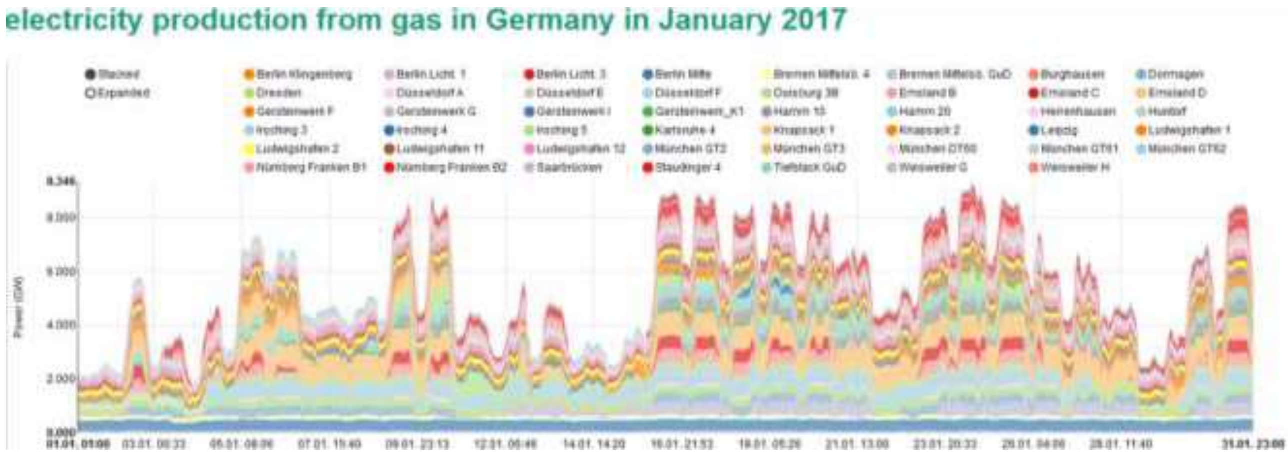


Analysis:

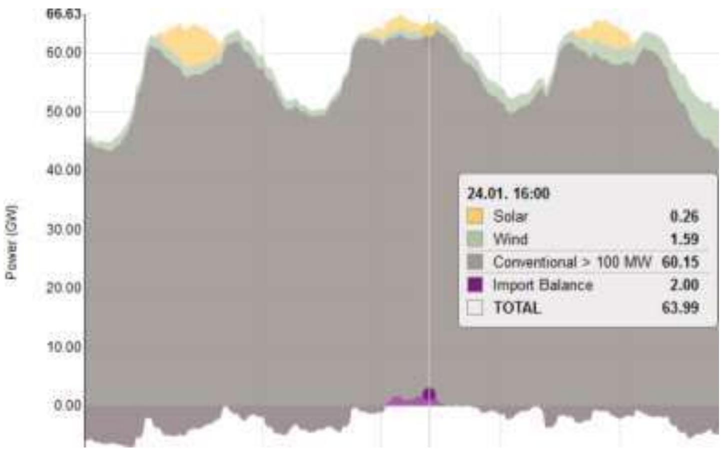
- no wind and not much sun (at best 6.8 GW on Monday the 23rd at half past noon). The contribution of these two intermittent energies collapsed to **0.76 GW** (with 90.31 GW installed capacity at the end of 2016), corresponding to a **0.85% capacity factor** ...
- with these measly resources it was not possible to face up to activity pickup at the very beginning of the week on Monday the 23rd:

  1.84 GW at 8:00 am, 6.58 GW at 10:30 am (coincides with the first price peak) and 8.52 GW at noon.

  Wind power was not much help, once the sun had set, in supplying the evening demand peaks on the following evenings at 7:00 pm (1.66 GW on Tuesday and 3.53 GW on Wednesday) with their impact on the price of electricity.
- the conventional power plants were "going full throttle": **7.6 GW for nuclear power**, around **17 GW brown coal, 22 GW hard coal, 0.3 GW oil, and 0.1 GW run of the river hydro.**
- **gas fired plant production did not rise above 9.4 GW**:



It is no surprise, then, that **Germany had to import 2 GW in the afternoon of January 24** :



Export Peaks Concomitant with Negative Prices?

The table on the next page deals with the **export maxima during each of the 52 weeks** of 2017 (Column a):

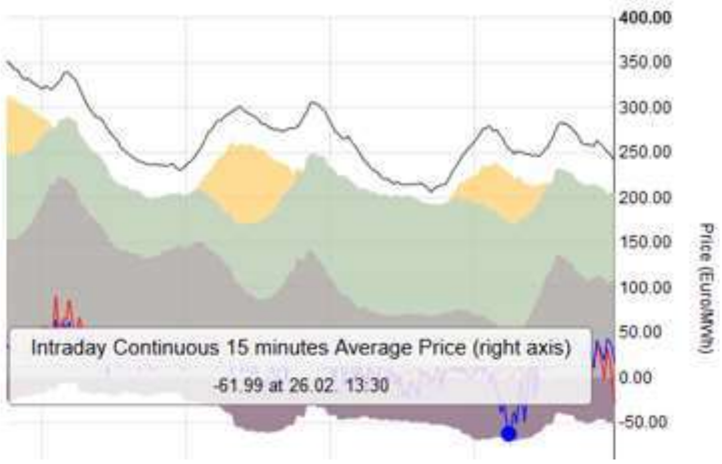
- Column f gives the maximum export, as it is displayed at the bottom of the ordinate axis on the "**import, export**" tab under **Power/Electricity production in Germany**. But we give the absolute value.

- Column g quotes the "*import balance*" as it is given when one browses the "**conv. > 100 MW**" in a graph insert under **Power/Electricity production in Germany**.

- Columns j/k locate the negative price in time, assumed to be coincidental while column l gives the time gap between the export peak and the negative price (e.g. 15 minutes for week 2).

- In column h, we infer the import coincidental with the export maximum, result of (f-g). Immediately, we note errors: **weeks 7, 8, 21, 31, 32, 43 yield negative imports** and this does not fit with the imports and exports detailed with each neighboring country, as shown in the figures above corresponding to February 26, 2017. There are, it seems, **discrepancies between the power graphs on one hand, and the detailed exports on the other hand**.

Be that as it may, we have limited the table below to the days on which the export maxima coincide with at least a negative price episode (15 minutes price). These are shown in column i which gives, as everywhere in this study, the price posted in the insert that pops up when browsing the "**quarter-hourly**" graph of the **Prices/Spot market prices in Germany** tab



Clearly, the 28 occurrences of an export maximum coincidental with negative prices happen on 3 week days, 8 Saturdays, and 17 Sundays, i.e. nearly **90% of the occurrences happen on week-ends**. And the 24 other weeks (with no coincidental negative prices) are systematically on week days.

a	b	c	d	e	f	g	h	i	j	k	l
Maximal weekly export					Export	Balance E - I	*Import ?*	15 mn price < 0			Time gap
W	Day	Date *	hh	mm	GW (> 0)	GW	*GW (> 0)*	€/MWh	hh	mm	price-export
2	Saturday	14-janv.	07	45	13,56	-12,10	*1,46*	-18,86	3	45	- 4:00
7	Sunday	19-févr.	10	15	10,83	-12,69	*-1,86*	-8,46	10	30	+ 15
8	Sunday	26-févr.	14	00	12,06	-13,92	*-1,86*	-61,99	13	30	-30
10	Sunday	12-mars	10	45	14,31	-14,31	*0*	-22,55	15	00	+ 2:15
11	Saturday	18-mars	06	45	14,49	-12,75	*1,74*	-20,48	16	00	+ 9:15
12	Saturday	25-mars	14	15	12,98	-11,33	*1,65*	-26,99	15	00	+ 45
14	Sunday	9-avr.	12	30	11,95	-11,95	*0*	-20,43	16	00	+ 3:30
15	Good Frid.	14-avr.	13	30	12,02	-12,02	*0*	-2,60	12	45	- 45
17	Sunday	30-avr.	12	00	13,48	-13,48	*0*	-193,02	16	00	+ 4:00
21	Saturday	27-mai	14	30	12,81	-13,40	*-0,59*	-14,18	16	00	- 1:30
23	Sunday	11-juin	11	45	13,59	-13,59	*0*	-2,43	16	00	+ 4:15
25	Saturday	24-juin	13	00	12,20	-12,18	*0,02*	-64,49	15	15	+ 2:15
29	Sunday	23-juil.	14	45	11,62	-10,38	*1,24*	-0,08	11	45	- 3:00
30	Sunday	30-juil.	16	15	11,71	-11,20	*0,51*	-137,78	14	00	- 2:15
31	Sunday	6-août	12	45	10,62	-10,75	*-0,13*	-19,39	16	00	+ 3:15
32	Sunday	13-août	00	00	9,77	-9,95	*-0,18*	-13,05	16	00	+ 16:00
33	Saturday	19-août	12	45	12,07	-12,02	*0,05*	-9,42	15	00	+ 15
34	Sunday	27-août	14	00	12,95	-12,95	*0*	-18,40	10	45	- 3:15
36	Sunday	10-sept.	22	00	7,45	-7,21	*0,24*	-30,85	16	00	- 6:00
37		11-sept.	04	45	7,82	-7,05	*0,77*	-21,50	04	00	- 45
40		3-oct.	13	30	13,53	-13,53	*0*	-20,23	14	30	+ 1:00
42	Sunday	22-oct.	02	30	12,99	-12,99	*0*	-20,60	06	15	+ 3:45
43	Saturday	28-oct.	15	15	9,79	-10,48	*-0,69*	-100,90	20	45	+ 5:30
46	Sunday	19-nov.	10	30	14,57	-11,51	*3,06*	-24,70	23	30	+ 13:15
47	Sunday	26-nov.	10	00	15,05	-11,41	*3,64*	-7,66	01	45	- 8:15
49	Sunday	10-déc.	08	30	15,53	-15,26	*0,27*	-45,41	00	45	+ 7:45
51	Saturday	23-déc.	08	45	13,99	-13,12	*0,87*	-45,96	06	15	- 2:30
52	Sunday	31-déc.	01	00	16,00	-16,00	*0*	-38,40	11	45	+ 10:45

** The dates have not been translated ...*

The coincidence sought is not as fine as could be imagined; not only the maximum exports and negative prices never occur at the same time but also the price dip can occur:

- 16 hours later (August 13)
- as well as 8 hours earlier (November 26)

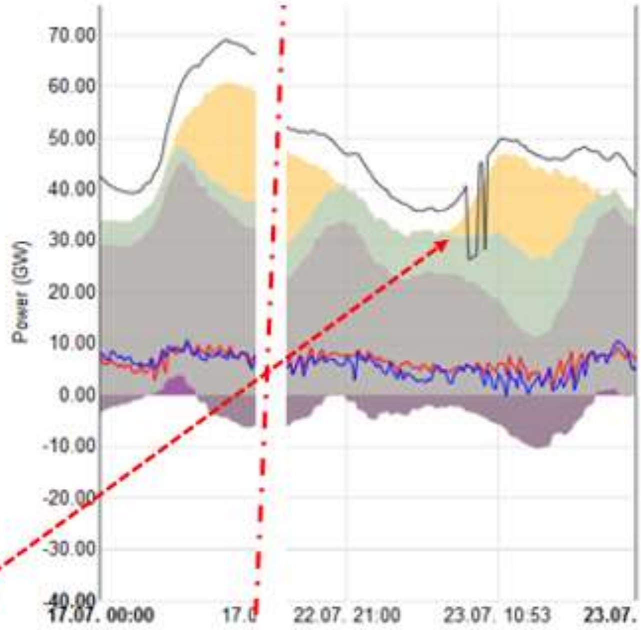
The average time gap amounts to 311 minutes later, 490 minutes earlier, a total (absolute value) amounting to 259 minutes (i.e. 2.5 hours)!!! With no apparent justification to this variability.

As for the mean export ratio, it is 12.49 GW in the first case (w-e) and 11.78 GW in the second, a not very significant difference except in that it contradicts the "*RTE postulate*" that declares that "*sufficient cross-border exchange capacity*" would countervail the emergence of negative prices (see end of §9 in the main body of this paper).

Discrepancies Observed in the Fraunhofer ISE graphs (probably incomplete list)

Week	Day *	HH	MM	Discrepancy (or hypothesis)
2	12-janv	08	45	wind discontinuity: ~ 11 GW
2	13-janv	19	45	"load" discontinuity: ~ 22 GW
3	21-janv	06	45	"load" discontinuity: ~ 14 GW
3	22-janv	08	15	"load" discontinuity: ~ 14 GW
6	08-févr	13	00	wind discontinuity: 5,5 GW
9	28-févr	23	45	**problem with Poland and Czech Republic?**
9	01-mars	18	30	"load" discontinuity: ~ 21 GW & 100 €/MW
10	06-mars	01	45	"load" discontinuity: ~ 8 GW
10	12-mars	09	30	"load" discontinuity: ~ 17 GW
12	26-mars	00	00	"load" discontinuity
13	27-mars	17	30	"load" discontinuity: ~ 18 GW
14	04-avr	04	45	"load" discontinuity
16	20-avr	12	00	"load" discontinuity: ~ 20 GW
18	06-mai	14	30	"load" discontinuity: ~ 15 GW
21	26-mai	15	15	"load" discontinuity: ~ 18 GW
23	11-juin	15	15	"load" discontinuity: ~ 15 GW
24	14-juin	15	15	isolated price peak, at ~ 73 €/MWh
24	14-juin	18	30	"load" discontinuity: ~ 19 GW
28	11-juil	08	30	"load" discontinuity: ~ 21 GW
29	23-juil	08	45	double "load" discontinuity
31	06-août	03	30	"load" discontinuity
32	07-août	20	00	"load" discontinuity
32	08-août	12	30	isolated price peak, at 116,96 €/MWh
38	20-sept	07	30	ditto, with 105 €/MWh
42	22-oct	01	00	2 consecutive "load" discontinuities
43	**29-oct**	**02**	**00**	**switch to the standard time (see appendix J)**
44	01-nov	23	45	problem with Switzerland?
44	**05-nov**	**07**	**45**	**surprising: 3 reactors out of service?**
46	15-nov	11	30	unlikely price sequence
48	01-déc	00	00	sudden 5 GW export increase
51	18-déc	23	00	problem with Switzerland ?

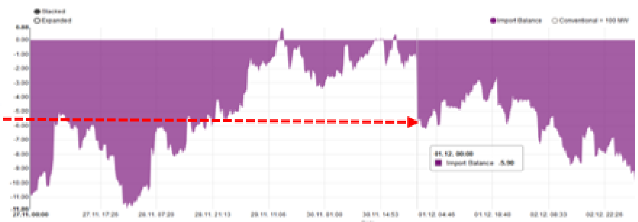
** The dates have not been translated ...*



15 GW "load" discontinuity, with no impact, on domestic production or on exports?

Neither exactly what the "*load*" represents nor how it is elaborated are explained on the Fraunhofer ISE site.

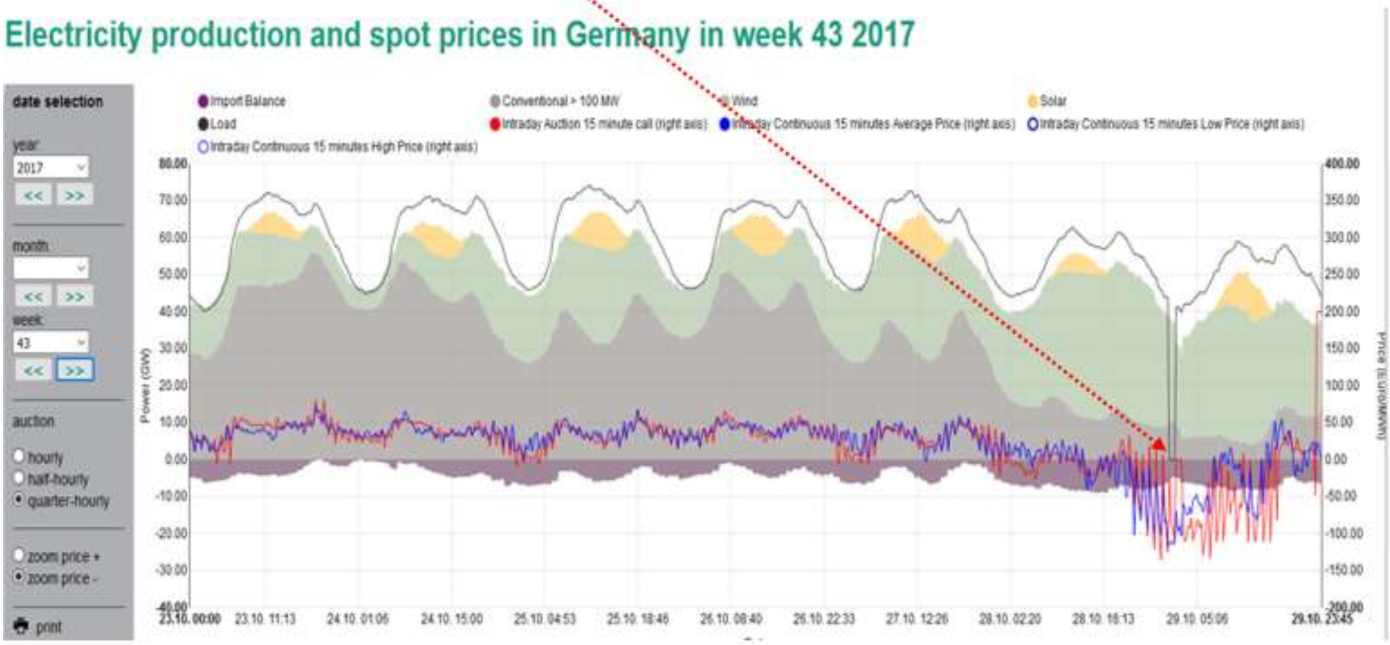
Date	Hour	Import balance	Gap
28-févr	23:15	-6,49	
	23:30	-6,75	-0,26
	23:45	**-4,06**	**2,69**
01-mars	00:00	-6,53	-2,47
	00:15	-7,85	-1,32
01-nov	23:00	-10,36	
	23:15	-9,74	0,62
	23:30	-9,34	0,40
	23:45	**-6,61**	**2,73**
02-nov	00:00	-10,79	-4,18
	00:15	-10,98	-0,19
30-nov	23:30	-0,93	
	23:45	-1,39	-0,46
01-déc	00:00	-5,90	-4,51
	00:15	-5,51	0,39
	00:30	-5,66	-0,15
18-déc	22:30	-4,62	
	22:45	-4,64	-0,02
	23:00	**-1,63**	**3,01**
	23:15	-1,22	0,41
	23:30	-1,05	0,17



As for the many "*import discontinuities*", they are not explained either.

Did the Switch to Standard Time Cause Panic on the Exchange Market?

29th of october, 2017 at 14:00 : very delicate (?) switch to standard time



Arduous Fraunhofer ISE report

According to "*solar, wind*" page

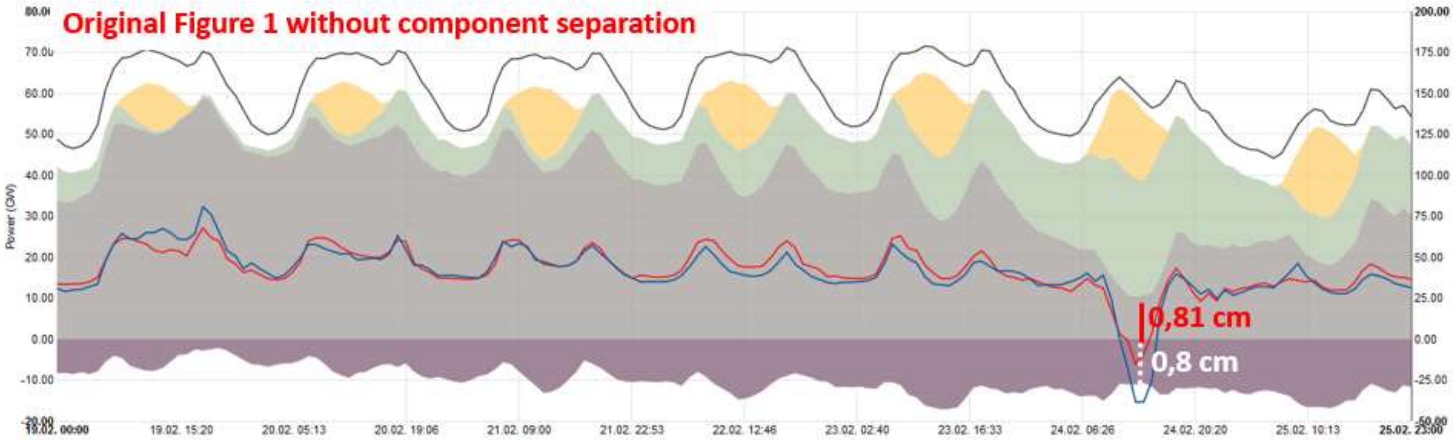
	October 29th	Wind (GW)*	
	02:00	28,39	
	02:15	26,98	Transnet BW (1 GW) exit
summer time	02:30	26,60	
	02:45	**26,47**	Amprion (5,1 GW) exit
winter time	02:00	**21,41**	
	02:15	22,24	
	02:30	21,98	
	02:45	**21,76**	
	03:00	**26,76**	Transnet/Amprion back
	03:15	26,78	
	03:30	26,97	
	03:45	26,92	
	04:00	27,37	

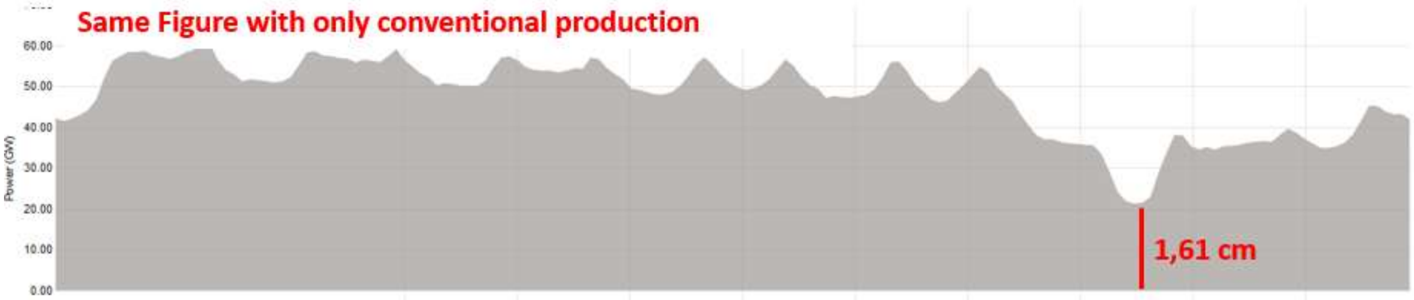
* By night, no photovoltaic production

According to "*conv. > 100 MW*" page

	October 29th	Wind (GW)*	Conventionnal (GW)	Import (GW)	Total consomtion ?	*Total production*
	02:00	28,78	15,32	-4,61	39,49	*44,10*
	02:15	27,34	15,12	-4,83	37,63	*42,46*
summer time	02:30	26,95	14,93	-4,60	37,28	*41,88*
	02:45	**26,83**	14,73	*-4,60*	**36,95**	*41,56*
winter time	02:00	**21,70**	14,53	-4,96	**31,27**	*36,23*
	02:15	22,54	13,94	-4,99	31,49	*36,48*
	02:30	22,28	13,35	-4,85	30,78	*35,63*
	02:45	**22,06**	12,76	-6,36	**28,46**	*34,82*
	03:00	**27,12**	12,17	-6,14	**33,15**	*39,29*
	03:15	27,14	12,24	-6,09	33,29	*39,38*
	03:30	27,34	12,30	-6,24	33,40	*39,64*
	03:45	27,29	12,37	-6,18	33,48	*39,66*
	04:00	27,74	12,43	-6,25	33,93	*40,17*

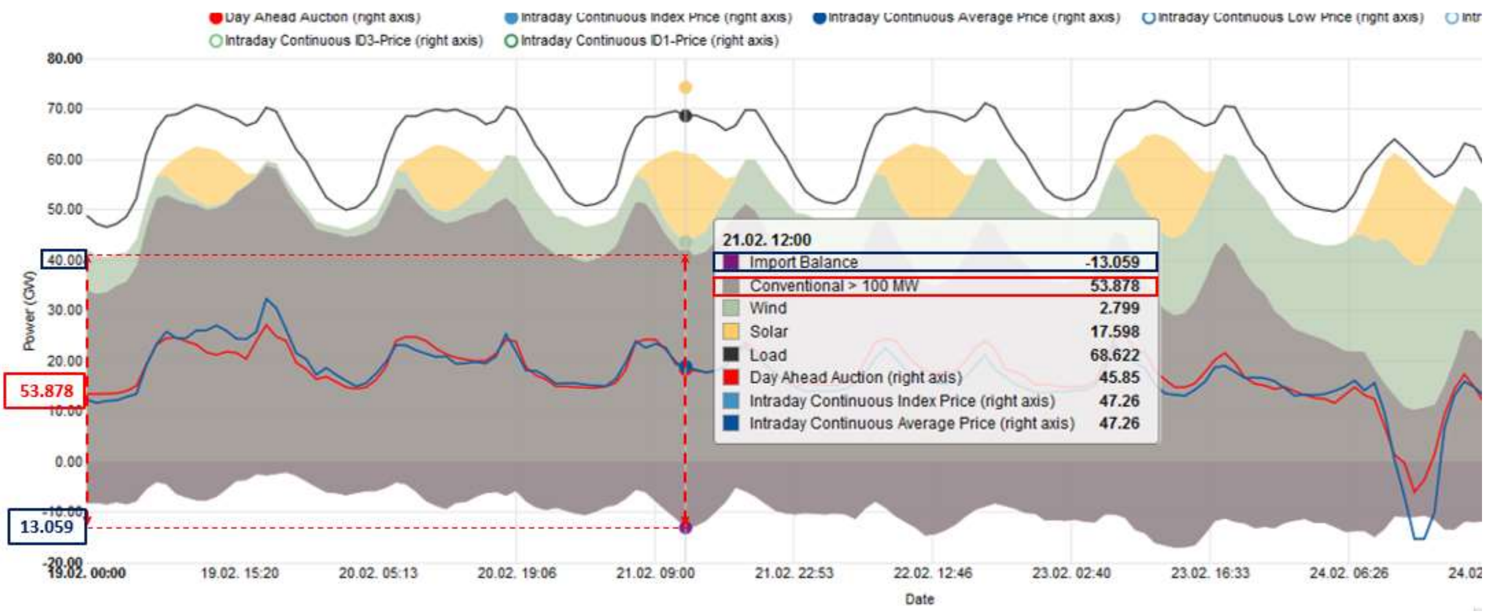
Optical illusion





A **German** reader can be delighted to "see" that his production on Saturday February 24 is essentially "**green**", the conventional production seeming reduced by half (the other half being entirely "exported").

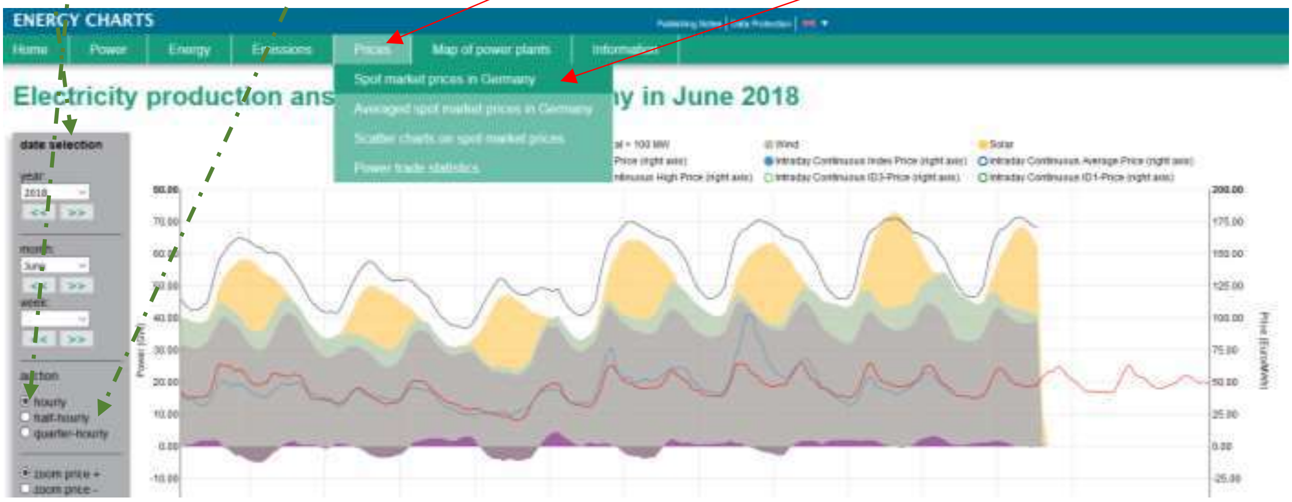
Another illustration: on February 21, 2017 at noon



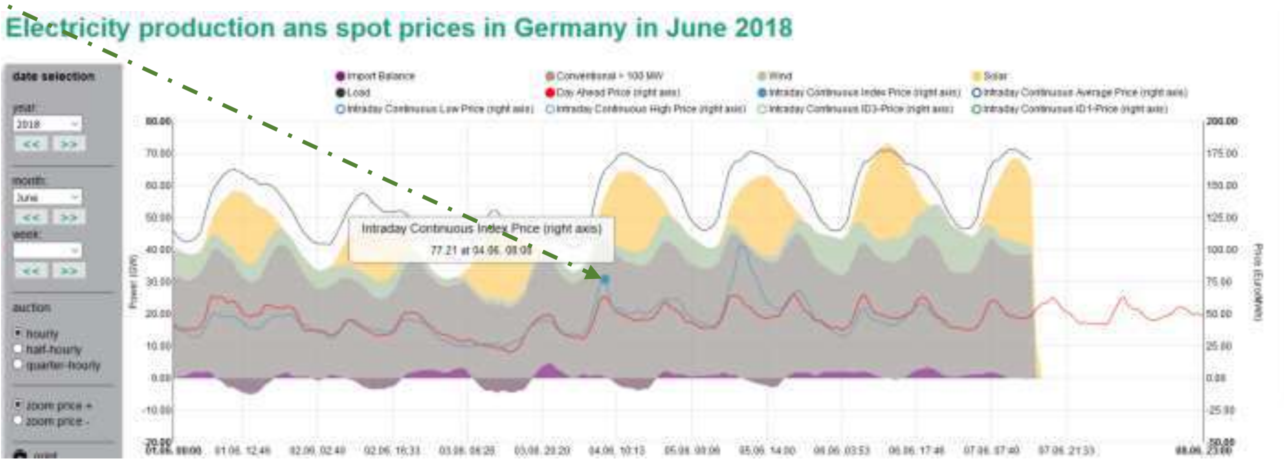
Fraunhofer ISE Site Navigation Tutorial

A little advice on how to navigate the www.energy-charts.de site will likely prove useful, if not vital:
For non German speakers, the English language version is accessible by clicking the flag in the upper right:

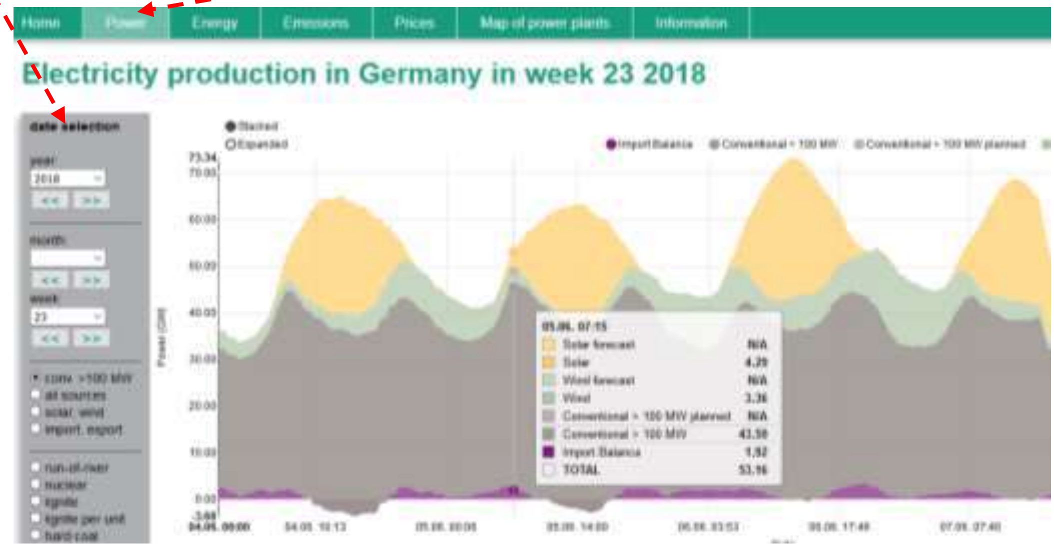
A) If the data of interest is the **real time spot price in €/MWh**, select the "*Prices*" tab, then the "*Spot market prices in Germany*" tab.
The desired time period can be specified in the left panel, by selecting the <u>month</u> or the <u>week</u> (via the week number).
Finally, select "*Hourly*" or "*Quarter-hourly*" according to the time resolution desired.



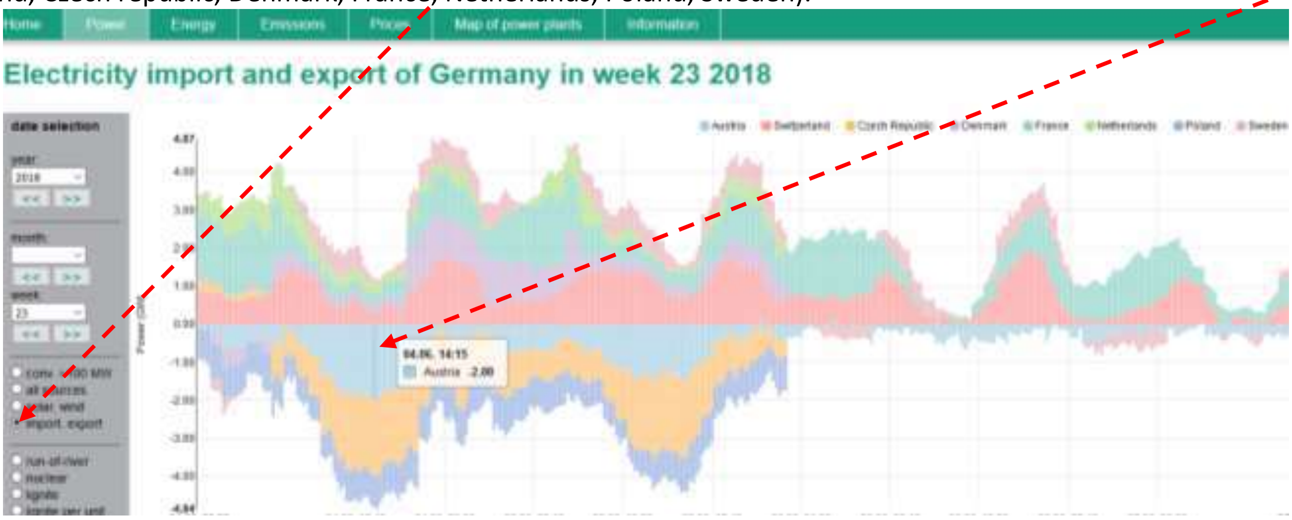
Price values are given on the right hand ordinate axis which can be more or less zoomed. To obtain a precise value, move the pointer to the corresponding location on the price curve.



B) If the data of interest is the **real time power output in GW** (fifteen minutes only) select the "*Power*" tab, then the "*Electricity production in Germany*" tab. On the left panel, select "***conv. > 100 MW***" which also gives the wind and PV power along with the "*import-export*" balance (positive when imports exceed exports). The popup window displays these values at the time corresponding to the pointer position.



On the left panel, if the pointer is placed on "import-export" the exchanges between the neighboring countries are displayed in real time (fifteen minutes), the pointer giving the detail of one of the 7 countries, these being recognizable by the color: Austria, Switzerland, Czech republic, Denmark, France, Netherlands, Poland, Sweden):



And, in general, refer to the "usage tips" in the left hand panel, to get help on how to use the mouse to access numerical values.