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Impacts of Germany's nuclear phase-out on electricity imports and exports

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Executive Summary

After the decision to return to the accelerated phase-out of nuclear energy in Germany in 2011, the development of electricity imports and exports between Germany and its neighboring countries has become a sensitive matter in energy and nuclear policy. Both in Germany and in other countries it has been repeatedly postulated that after the shutdown of nuclear power plants in March 2011 additional power would have to be imported from foreign nuclear power plants in order to make up for the loss of domestic nuclear energy, and that as a result the integrity of Germany's nuclear phase-out would ultimately be compromised.

Against this background comprehensive data analysis was conducted for the development of electricity imports and exports with neighboring countries and for the development of power generation of German and foreign nuclear power plants.

In 2011 the power generation of nuclear energy plants in Germany fell by 23% compared to the previous year. Nevertheless, in 2011 and the first nine months of 2012, Germany exported more electricity than it imported. Two thirds of the fall in nuclear power generation was replaced in the overall balance for 2011 by the expansion of the use of renewable energies and one third by a reduction of export surpluses.

A detailed analysis of electricity imports and exports since 2003 has shown that Germany has historically always exported electricity in winter and imported it in summer. This already shows that power is not imported due to a (technical) shortage of power plant capacity since domestic demand is at its highest in winter. In the winter months sufficient power plant capacities are evidently available in Germany not only to cover the high domestic demand but also to export electricity. In contrast, power is traditionally imported in the summer months when domestic demand is lower than in winter. This can be traced back to, among other things, snow melting on the Alps in spring and summer. During these months hydro power plants in the Alpine countries can produce large quantities of electricity, and more expensive fossil-fired power plants in Germany are shut down. A second reason for this seasonal pattern is the French nuclear power plants, which are operated as conventional base load power plants. If demand in France is low in summer, electricity is exported. Nuclear power plants are not operated for export purposes; rather, surplus power is only sold abroad if it would otherwise have to be curtailed. In winter power generation from nuclear power plants in France is often not sufficient to cover French load. As a result Germany exports electricity to France during this season.

When nuclear power plants in Germany are switched off, it does not influence the quantity of surplus electricity in France, which comes about as a result of nuclear power plants not decreasing their output. On the basis of economic mechanisms in the power market on a theoretical level and as a result of the analysis of empirical production data it can be ruled out that additional electricity production from French nuclear power plants are imported due to the decommissioning of German nuclear power plants.

The typical shift from net exports in winter to net imports in summer coincided with the decommissioning of substantial nuclear power plant capacities in Germany in mid-March 2011 and the additional decommissioning of German (nuclear) power plants in May 2011 when the phase-out was further revised. Thus, the increase of electricity imports in spring and summer is attributable not to the phase-out of nuclear power in Germany, but rather mostly to the typical seasonal effect described above.

Generally, electricity is not imported and exported on the basis of (technical) scarcity situations in security of supply; rather, power imports and exports are the result of transnational optimisation of supply and demand on the electricity market. This is also demonstrated by the following results of the present analysis:

- More electricity was imported from France in 2011 than in 2010. In absolute terms, the additional imports from France only constitute approx. 1% of the annual electricity production in Germany; this level had already been reached in previous years and was not accompanied by an increased production of French nuclear power plants. It should be noted, however, that the trading of electricity and the physical imports between Germany and France diverge significantly from each other: systematically more electricity is physically transported from France to Germany than is actually commercially traded. In 2011 the German physical electricity imports from France were mostly transits to neighboring countries. These were chiefly transit flows from France to Switzerland (and sometimes from there on to Italy) via Germany.
- The availability of renewable energies has a large impact on imports and exports. In 2010 there were low levels of precipitation in Scandinavia, as a result of which electricity was exported from Germany to the region. Following very strong rainfall in 2011 there was surplus electricity production in Scandinavia, and Germany was able to import electricity from the region. This explains a large share of the decrease in surplus German exports.
- The expansion of the use of renewable energies in Germany also has an impact on its electricity imports and exports, and significant changes are taking place in this respect. Prior to 2012 Germany imported electricity in summer. However, in July, August and September 2012, Germany actually exported electricity. Currently Germany is exporting electricity – in particular when a lot of solar power is being generated. Evidently fossil-fired power plants are not being shut down when electricity production from photovoltaics is high; rather, this electricity production is being sold to other countries. This is another example of imports and exports chiefly being the result of optimisation processes that manifest themselves daily on the electricity market.

The two key findings resulting from this critical assessment of the accelerated phase-out of nuclear energy in Germany are as follows:

- The existence of power imports is not an indication that the (domestic) security of supply is in jeopardy.

- The shutdown of nuclear power plants has not resulted in increased imports of power from foreign nuclear power plants and thus has not been counterbalanced by foreign power imports.

Rather, the structures of foreign power imports are an indicator of the cost structures that can be found in the particular market situation of the various domestic power plant fleets in the internal European electricity market. To this extent the international power exchange can provide considerable flexibility for integration of renewable energies into the German and European power supply system. However, at the same time it is observed that the complex interaction of cost structures in power generation, of domestic and international infrastructural bottlenecks and of market design increasingly requires analysis and activities which go beyond national borders.

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1 Introduction and Points of Departure

By the middle of March 2011 – and as a consequence of the reactor catastrophe in Fukushima, Japan – significant nuclear power plant capacity on the German electric power market was decommissioned, which created a new situation comparatively quickly. Five nuclear power plants were taken off the grid within a few days (Brunsbüttel, Krümmel and Biblis B were not in operation for other reasons when the moratorium began). And this changed the supply and the source of electric power on the market. Other power generation options replaced the loss of nuclear energy production.

Since then, the effects of this shutdown have been a topic of discussion by various sides. The development of the transnational electricity exchange plays a central role in this matter. It has been repeatedly postulated that after the shutdown of nuclear power plants in March 2011 Germany would have to import additional power from foreign nuclear power plants in order to make up for the loss of domestic nuclear energy.[1]

Sometimes different aspects become confused in the discussion of the development of electricity imports and exports within the context of energy transformation (*Energiewende*):

- From a technical perspective the question arises of what the consequences of the very sudden shutdowns are for the security of supply (Öko-Institut, 2011a). The observed power imports are interpreted in the debate as being technically necessary and an indication that the (domestic) security of supply is jeopardized by the shutdowns.
- Based on that, it is being asked, in the case of power imports from countries which themselves operate nuclear power plants, whether it is morally acceptable to dispense with domestic nuclear energy and its associated risks if the result is that other countries (have to) operate nuclear power plants.

Substantial power exports and imports and even significant changes in the volume of power transported across borders are by no means a new phenomenon. The existence of power imports and exports, and their developments with respect to volumes and structures, are the result of changes in the power industry (e.g. changes in fuel prices), infrastructure changes (expansion and operation of cross-border interconnectors, etc.), but also political endeavors (strengthening the internal European market through market coupling, etc.). The increased integration of the European market through a strengthening of electricity imports and exports can increase the efficiency of the power supply system, provides additional flexibility (for the expansion of renewable energies as well) and can contribute towards increasing security of supply – though only to a limited extent due to the infrastructural bottlenecks.

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[1] Cf. for example: "Imports of nuclear power from France are implicitly accepted. Energy policy without self-delusion still seems impossible" (Manfred Köhler, FAZ, 1 September 2011), "We should not simply accept that we are now importing more nuclear energy" (Rainer Brüderle, FAZ, 5 June 2012).

Therefore it is useful in all analyses on the developments in transnational power exchange to differentiate between two specific aspects:

- Power supply as a technical system in which certain – technical – criteria are to be satisfied in order to ensure the security of supply, such as the provision of sufficiently large generation capacities.
- Power supply as a liberalized, transnational market in which economic criteria are decisive for investments and for the operation of nuclear power plant capacities.

The effects of the second aspect – i.e. Europe-wide optimization of power plant dispatch and of power imports and exports between European countries arising from this, are often and improperly excluded of the debate on energy policy. However, an assessment of power imports and exports often only concentrates on the first, technical aspect. In an evaluation of this kind problematic interpretations arise when economically motivated power imports are taken as evidence of technical bottlenecks, or power exports per se are interpreted as a successful energy policy.

The postulates described above of the security of supply being jeopardized by the German phase-out of nuclear energy and of Germany's phase-out policy being counterbalanced by nuclear energy imports must therefore be examined within the context of an already complex state of affairs.

To be able to adequately assess the consequences of the German phase-out of nuclear power on the European generation structure and thus also on the import-export situation between Germany and other European counties, it is necessary firstly to make a distinction between technical and financial drivers for the use of power plants and commercial flows observed.

Secondly, it is also necessary to analyze the developments over time, that is, the physical and commercial transnational power flows before and after the nuclear energy moratorium in March 2011. In doing so, seasonal and intra-day effects (e.g. the relationship with fluctuating renewable power generation) need to be taken into account based on comparative data from previous years.

The purpose of the present report is to bring the debate on the relationship of Germany's nuclear phase-out and the development of electricity imports and exports on to a more objective level based on well-founded data analysis, and thus also to provide a critical analysis of the hypothesis that Germany's nuclear phase-out would be counterbalanced by increasing nuclear energy imports.

The present report provides a more thorough analysis of various questions on the development of electricity imports and exports. It builds on an initial analysis of this topic from 2011 (Öko-Institut 2011b), but takes into account a much broader data inventory which extends more closely up to the present time. The report is structured as follows:

In Chapter 2 the basic mode of operation of the German power market is explained, together with its interaction with neighboring countries. In addition, the various data sources for imports to and exports from the German power system and their respective boundaries are presented.

The development of power generation and of electricity prices is shown in Chapter 3. In particular, the operation and decommissioning of nuclear power plants over time is documented as a basis for the following analyses. In addition, the fluctuation in spot prices in important European neighboring countries is discussed.

Various quantitative analyses of international electricity imports and exports are conducted in Chapter 4.

- The starting point for the analysis is the annual and monthly data for the net power exchange in Germany, together with its historical development.
- In a second step, the annual and monthly power exchange between Germany and neighboring countries is differentiated according to country.
- Finally, Germany's hourly load flows are compared to its neighboring countries. This covers both the commercial and the physical load flows. Fluctuations in the daily profile and seasonal effects are illustrated based on hourly averages for power exchange for days in the summer and winter seasons.

Chapter 5 comprises two specialized analyses: Firstly the particular transit flows from France through Germany into Switzerland, and the relationship between the French import-export balance and the production of French power plants are examined. Secondly, loop flows from north Germany through neighboring east European countries and Austria to south Germany are analyzed.

The concluding Chapter 6 contains several key conclusions from the preceding analyses.

The Annex contains supplementary data and selected graphs relating to the net power exchange of various countries and electricity imports and exports between Germany and its neighboring countries.

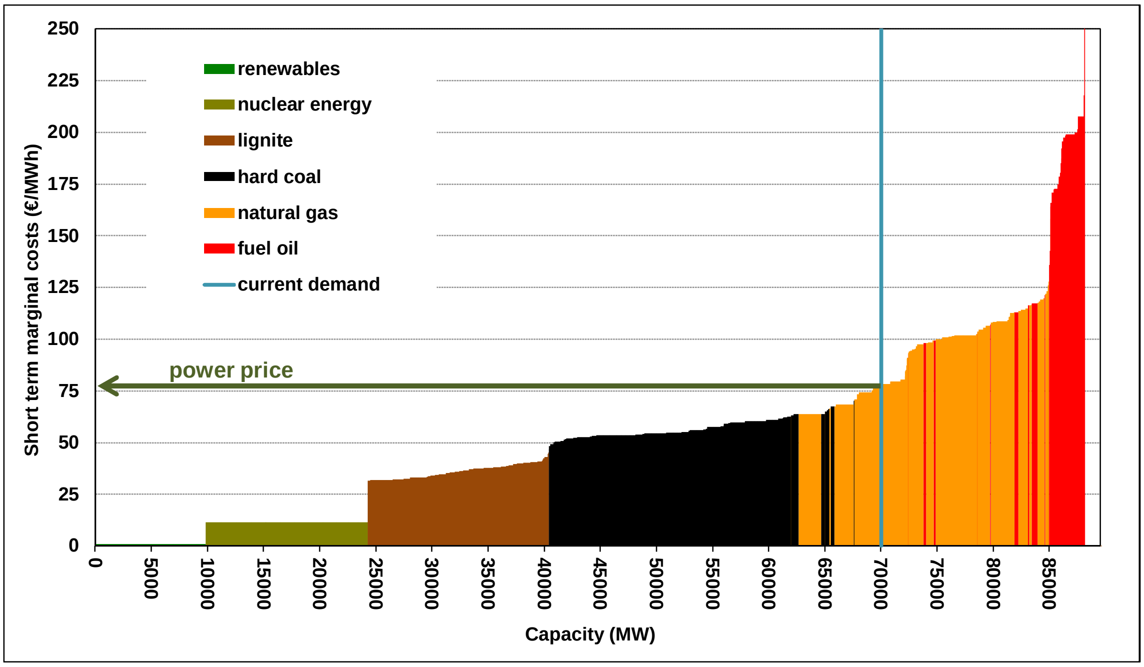
2 Introductory Comments on Methodology

2.1 Operation of the Power Market and how Decisions are made on Imports and Exports

In liberalized power markets the pricing and employment of power plants on the spot market generally occurs by means of an energy exchange. In Germany, France and Switzerland, this energy exchange is the EPEX Spot with headquarters in Paris, which emerged from a fusion of the EEX (Germany) and the Powernext (France) spot markets.

Pricing is handled on the EPEX Spot energy exchange based on supply and demand. The power plants offer their electricity at short-term marginal costs. These costs are composed essentially of fuel costs and any CO_2 costs, plus in small measure any additional, variable operating costs. The resulting offer curve is called the "Merit Order." The final power plant needed to meet the demand, sets the electricity price (marginal power plant) for all needed power plants. All more expensive power plants are then not involved. The Merit Order for the German power plant park is presented, for example, in Figure 1.

Figure 1 Presentation of the Merit Order for German power plants (example)



Source: Öko-Institut

The renewable energies with their short-term marginal costs of near zero are included here, since they have either no fuel costs (e.g. wind, PV) or appear with factual marginal costs of zero due to EC subsidy and ranking controls. Among the conventional power plants, the short-term marginal costs of the nuclear power plants are the lowest. They are followed by power plants operating with lignite, hard coal, natural gas and oil, and these are ranked depending on their efficiency and the ratio of fuel to CO_2-costs. So if nuclear power plants are available, then they will always be fully utilized if the demand is there, before the next more expensive power plants come into play.

Daily at 12:00 hours an auction is held on the EPEX for the following day, at which the prices are determined for each hour of the following day.

Formerly, the transmission capacities between two countries were auctioned and then the transmission capacities could be used by the successful bidders to transport electricity from one country into another (explicit auction). The auctioning of transmission capacities is presently being replaced step by step by a market linkage in which the transmission capacities are being integrated into the commercial power auction. On 09 November 2010 the CWE[2]-Market-Coupling mechanism was introduced. It includes Germany, France and the Benelux countries. At the same time, a linkage with Scandinavia was introduced through the ITVC (Interim-Tight-Volume-Coupling).

At present, only a (smaller) percentage of the transmission capacity between Germany, France and the Benelux countries is auctioned in annual and monthly auctions, the remaining transmission capacity is employed automatically within the framework of market coupling by the EPEX energy exchange. In 2010 an additional transmission capacity of 3500 MW from France to Germany was auctioned in the annual auction. In 2011 the transmission capacity auctioned for the entire year fell to 900 MW and in 2012 it fell to 800 MW.[3]

After issuing the offers for the daily Day-ahead spot auction, the EPEX Spot energy exchange prepares a joint Merit Order for the French and the German market (and for all other linked markets). The marginal offer and the power price needed to meet the load (demand) are computed. An additional result of the calculations is the imports/exports between the two market areas. Provided the calculated load flows are smaller than the transmission capacities, there will be one price, for example, in the French and in the German markets. In a large portion of the hours, the spot prices are the same in Germany and France. In 2011 this was the case in 70% of the hours.[4] If the transmission capacity is not sufficient, then the Merit Order breaks down into a German and a French Merit Order. Then the transmission capacity is fully utilized to move power from the market area with the lower price into the market area with the higher price. This is illustrated in Figure 2. Without market linkage, the market price in the particular hours would have been 200 € / MWh in the market area in question. Now if 1500 MW is exported from one price zone with low prices into a zone with higher prices, then the offer curve will shift to the right. This will result in a lower price on the

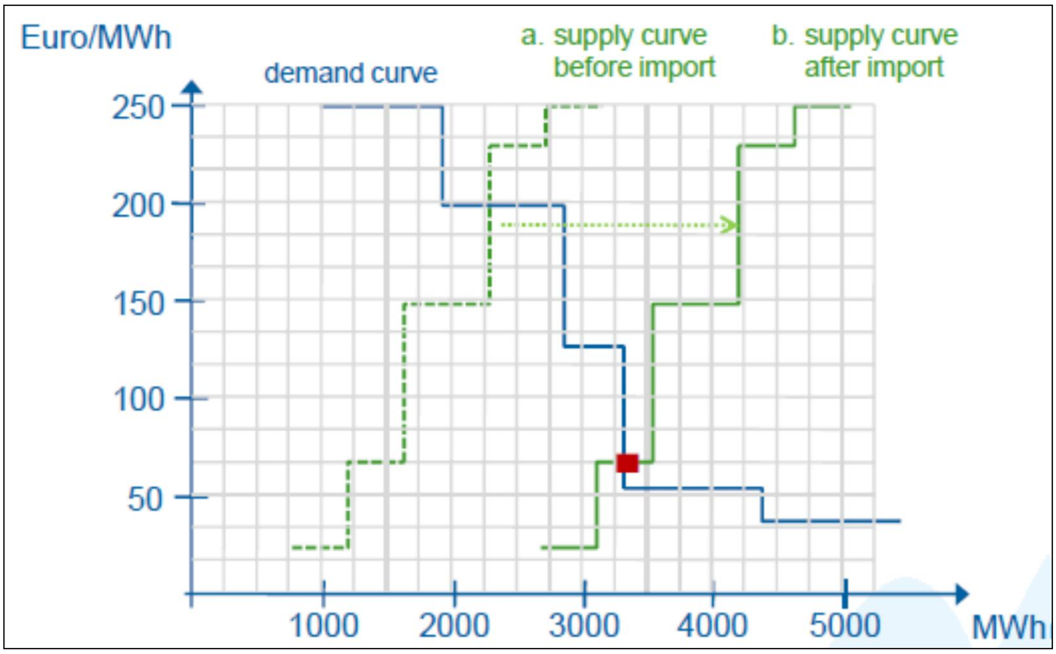
2 Central Western European.

3 http://www.casc.eu/en/Market-data/Cumulative-curves/Allocated-Capacity#%20FR%20%3E%3E%20DE.

4 Calculations by Öko-Institut based on EPEX Spot data.

spot market, which in the example used here, will be only 66 € / MWh. Conversely, the price of power in the exporting price zone will increase (not illustrated).

Figure 2 Example of market coupling – explanation of mechanisms



Source: EMCC (2009)

It is very interesting that physical transmission capacities having no regulations for power transport are used automatically by the exchange for the market coupling. The owner of the transmission right then receives a fee in the amount of the price differences between the two market areas which are defined in the market coupling (Article 4.01 (c) CWE Auction Rules). This fee can also be zero if the prices are the same. For example, if a power dealer has purchased transmission capacity from France to Germany but then after the auction the power flows from Germany to France, he likewise will receive no fee. In this case the owner of the transmission capacity from Germany to France will receive the fee. This means that power dealers employ the acquired transmission capacities according to the energy exchange.[5] The level of imports and exports is thus determined primarily by means of optimizing on the energy exchange, and no longer through the decision of individual power suppliers to trade power from one country to another. A market coupling mechanism has not yet been introduced for Switzerland and the eastern neighbors of Poland and the Czech Republic. The transmission capacities are auctioned and the results are published on the internet at www.central-ao.com. Publication of the results of the auction of transmission capacities between Germany and Switzerland likewise appears on www.casc.eu.

5 It should be pointed out that the price for the auction of annual transmission capacities is set in an efficient market which corresponds to the price difference between the scheduled market in the two participating countries.

2.2 Data Sources and Delineation

2.2.1 Definition and Delineation of Monthly Imports and Exports at ENTSO-E

The monthly load flows published on www.ENTSO-E.eu for the power exchange between Germany and neighboring countries are physical load flows. The delimitation of power exchange areas coincides with the international boundaries. These published, monthly load flows thus also correspond to the values stated in domestic statistics for imports and exports. Since these data are published at a delay of several months, this study was only able to include monthly import-export data through September 2012.

2.2.2 Definition and Delineation of Hourly Imports and Exports at ENTSO-E

The hourly physical and commercial load flows for Germany's power exchange with neighboring countries is published on www.ENTSO-E.net and does not coincide with the load flows across international borders, but rather reflects the boundaries of the control zones.

Thus, deviations appear in the monthly data which balance out along the international borders, because sometimes foreign power plants or grids belong to German control zones. By the end of 2010 the "German control bloc" comprised the four German transmission grid operators, the Luxemburg transmission grid operator Cegedel Net S.A., the Austrian TIWAG and the Austrian Vorarlberger Energienetze GmbH (VKW).

At the beginning of 2011 the TIWAG grid was assigned to the "Austrian control bloc" under the leadership of the Austrian transmission grid operator APG. At the beginning of 2012 the grid operated by the Vorarlberger Energienetze Gmbh (VKW) was likewise allocated to the "Austrian control bloc."

Thus at the beginning of 2012 the "German control bloc" consisted only of the four German transmission grid operators and the Luxemburg transmission grid operator Cegedel Net S.A. (www.ENTSO-E.net).

Whereas the monthly data published by ENTSO-E represent only physical load flows, the hourly break down provides both the physical and also the commercial load flows.

Fundamentally a distinction is to be drawn between these two: The commercial load flows are those load flows which result from the energy trade between the authority responsible for the circular balance or that calculated by the energy exchange in the case of a market coupling. A prognosis is prepared for the commercial load flows (D-1 Cross-Border Commercial Schedules) on the evening before the day of delivery; this prognosis is based on the results of the Day-ahead auctions which likewise occur on the previous day. The final commercial load flows (Final Cross-Border Schedules) are each published after a seven-day delay and contain any needed corrections (FAQ www.ENTSO-E.net).

In the case of physical load flows we are dealing with load flows measured at the interconnection sites. The physical load flows can differ from the commercial ones for a number of reasons.

- Loop flows
- Cross-border re-dispatch
- Use of balancing power

The so-called “loop flows” are of particular importance. These occur because the power does not flow automatically along the shortest geographic path, but rather is divided according to Ohm's law and the Kirchhoff laws along several parallel conductors commensurate with the electrical resistance of the conductors. Germany is affected by loop flows because, for example, during periods of high wind energy feed-in in north Germany, power flows via Poland and the Czech Republic to south Germany. In addition, there may also be loop flows due to French exports to Switzerland, for instance.

3 Development of Power Generation

3.1 Development of Annual Power Generation in Germany

Figure 3 shows the development of the fuel mix for gross power generation in Germany from 1990 to 2011. From 1993 to 2007 the domestic consumption and power generation increased, and then after a collapse in 2009, in the last two years again nearly returned to the high level of previous years. Until 2006 the nuclear power plants provided a stable contribution of 150 TWh to 170 TWh, which decreased in years 2007 to 2010 to values of around 140 TWh and in 2011 to 108 TWh. Power generation from lignite during the period remained roughly constant, while power generation from hard coal fell slightly and that from natural gas increased.

Power generation from renewable energies rose steadily in the period in question, and due to the likewise increasing power consumption this by no means led to a reduction in conventional power generation. Not until years 2009 and 2011 was less conventional power generated than in the early 1990s, when conventional power generation had reached its 1990 minimum. Shifts between fuels and changes to gross power generation overall have thus occurred to a varying extent in past years.

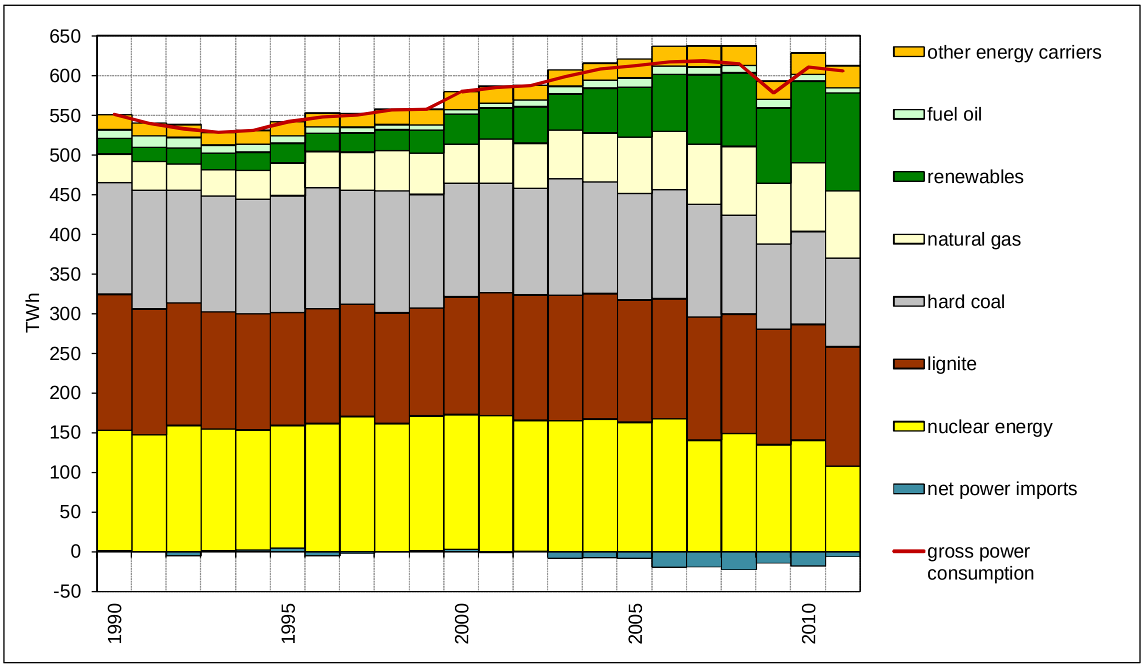
The shutdown of several nuclear power plants in 2011 means a definite reduction in gross power generation from nuclear energy in comparison to the previous year. It declined from 140.6 TWh in 2010 to 108.0 TWh in 2011. Thus compared to the previous year there was a loss of 32.6 TWh of power generation from nuclear energy.

At the same time, in 2011 the gross power generation from renewable energies rose by 20.2 TWh from 103.3 to today’s 123.5 TWh in comparison to last year. The exported excess fell in the same period by 11.4 TWh from 17.7 TWh in 2010 to 6.3 TWh in 2011. Thus in a purely computational manner, the sum from additional renewable energy and the reduced exports totaling 31.6 TWh already corresponds nearly to the amount of power production lost from nuclear energy.

But also there were additional, minor changes in fossil fuel power generation. Power generation from lignite increased by 4.2 TWh, whereas power generation from hard coal (-4.6 TWh), natural gas (-4.3 TWh) and fuel oil (-1.6 TWh) decreased. And thus fossil fuel generation fell by a total of 6.3 TWh.

Furthermore, overall less power was produced and consumed: Gross power generation in 2010 fell by 19.8 TWh from 628.6 TWh to 608.8 TWh in 2011. The gross domestic consumption also declined by 8.3 TWh from 610.9 TWh (2010) to 602.6 TWh (2011).

Figure 3 Development of Power Generation in Germany, 1990-2011



Source: AG Energiebilanzen, graph by Öko-Institut

Thus in sum, the power generation from nuclear energy, hard coal, natural gas, petroleum products and other energy carriers (totaling 38.9 TWh) which fell in comparison to the previous year, was half replaced in 2011 by the increased power production from renewable energies (+20.2 TWh) and in smaller part by lignite power generation (+4.2 TWh), or could simply be ignored because the exported excess also decreased (-11.4 TWh) and domestic consumption dropped (-8.3 TWh).

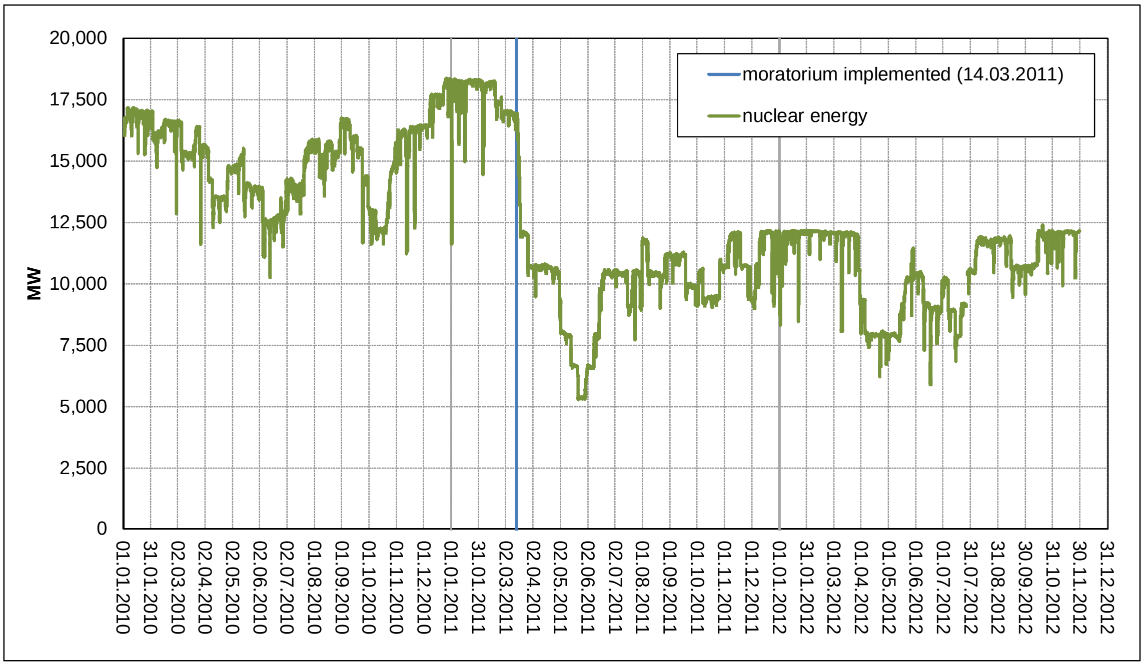
The illustrated shifts in the power mix for 2011 in comparison to the previous year are attributable to various factors which are partly independent of the shutdown of the nuclear power plants. For instance, about half of the greater power generation from lignite, amounting to about 2 TWh[6] , is attributable to trial operation of the new RWE power plant blocks BoA 2 & BoA 3, which are operated for a limited period in parallel to the old lignite power plant units which are, in turn, to be decommissioned. The expansion of renewable energies has already been decided policy, regardless of the decision for shutdown of the nuclear power plants in 2011, and is well underway.

6 In a press report the RWE states that power production from power plant blocks BoA 2&3 was 1.5 TWh starting from 29 Nov. 2011 through 16 Dec. 2011. Scaled up to the end of year 2011 the power production is calculated as 2 TWh. http://www.rwe.com/web/cms/de/2320/rwe-power-ag/presse-downloads/pressemitteilungen/pressemitteilungen/?pmid=4007273

3.2 Generation from Nuclear Power Plants in Germany, hourly breakdown

On 14 March 2011 as a result of the reactor catastrophe in Fukushima, Japan, the German Federal Government issued a 3-month moratorium deferring the service extension for German nuclear power plants approved by the 11th amendment to the German Atomic Energy Act, and announced a reassessment of the safety of all German nuclear power plants. On 17 March 2011 as a consequence of this moratorium or change in course, three nuclear power plant blocks (Neckarwestheim 1, Philippsburg 1, Isar 1) were taken out of operation, and on 18 March 2011 two additional power plant blocks (Unterweser, Biblis A) were taken offline. Under consideration of the situation that the Brunsbüttel and Krümmel nuclear power plants (NPP) had already been entirely out of operation since the summer of 2007 due to technical problems, and the Biblis B NPP had been shut down since the end of February 2011 for scheduled inspections, a total of eight NPPs were out of operation for the long term. Therefore since 18 March 2011 only about 60% of the net power capacity of German NPPs has been on the grid.

Figure 4 Power generation by German NPPs from 2010 to 30 November 2012



Source: EEX Transparency data, calculations by Öko-Institut

By May of 2011 additional nuclear power plants went off the grid due to inspections scheduled with long lead times. The following nuclear power plants were involved:

- Grafenrheinfeld NPP from 26 March 2011 through 16 June 2011;
- Gundremmingen B NPP from 1 May 2011 through 31 May 2011;
- Grohnde NPP from 2 May 2011 through 14 June 2011;

- Lingen NPP from 21 May 2011 through 8 June 2011;
- Phillippsburg 2 NPP from 15 May 2011 through 14 June 2011;

In the period from 21 May through 31 May 2011 only about one-quarter (26%) of the German NPP capacity was available to the German power market. Only the four nuclear power plants at Brokdorf, Neckarwestheim 2, Gundremmingen C and Isar 2 were still on the grid.

The power generation situation in 2011 and in the first half of 2012 can be characterized as follows:

- In January 2011 the generation from nuclear power plants still amounted to 18 GW.
- Due to the inspection of Biblis B, generation fell to 17 GW starting in the second half of February.
- Since 19 March 2011, generation amounted to only 12 GW.
- Due to the inspections the generation from nuclear power plants fell steadily and hit its nadir of only 5 GW in the period from 21 May through 31 May.
- Beginning on 17 June, generation from nuclear power plants again reached 10 GW.
- From December 2011 until March 2012, again 12 GW of power was available.
- Due to inspections in April and May 2012, the capacity during this period fell to 7.5 GW.

Against this background the factor of primary significance for the following analyses is what were the effects on the international energy exchange resulting from the short-term shutdown of about 5 GW of NPP power (17/18 March 2011) or of the more than 12 GW total power loss (starting on 21 May 2011).[7]

3.3 Development of Spot Prices in Germany and in Neighboring Countries

Imports and exports in a liberalized market are affected primarily by the level of electricity prices on the spot market. Therefore, the spot market electricity prices in Germany are compared below with the prices in various other European countries in the peri-

[7] The EEX Transparency data provide implausible figures for several days for total nuclear energy production: On 27 July 2012, on 12 Oct. 2012, on 26 Oct. 2012, on 4 Nov. 2012, on 9 Nov. 2012 and on 30 Nov. 2012 a production reduced by 3.9 GW or 5.4 GW compared to the preceding and subsequent days, respectively, was reported to the EEX. These spikes correspond to the power obtained from three or four nuclear plants with an output of 1.3 GW to 1.4 GW each. From an engineering standpoint such spikes are implausible; thus it has to be assumed that data errors are present and that one of the large operators did not report on that day. The production data from these days is thus not presented in the diagrams.

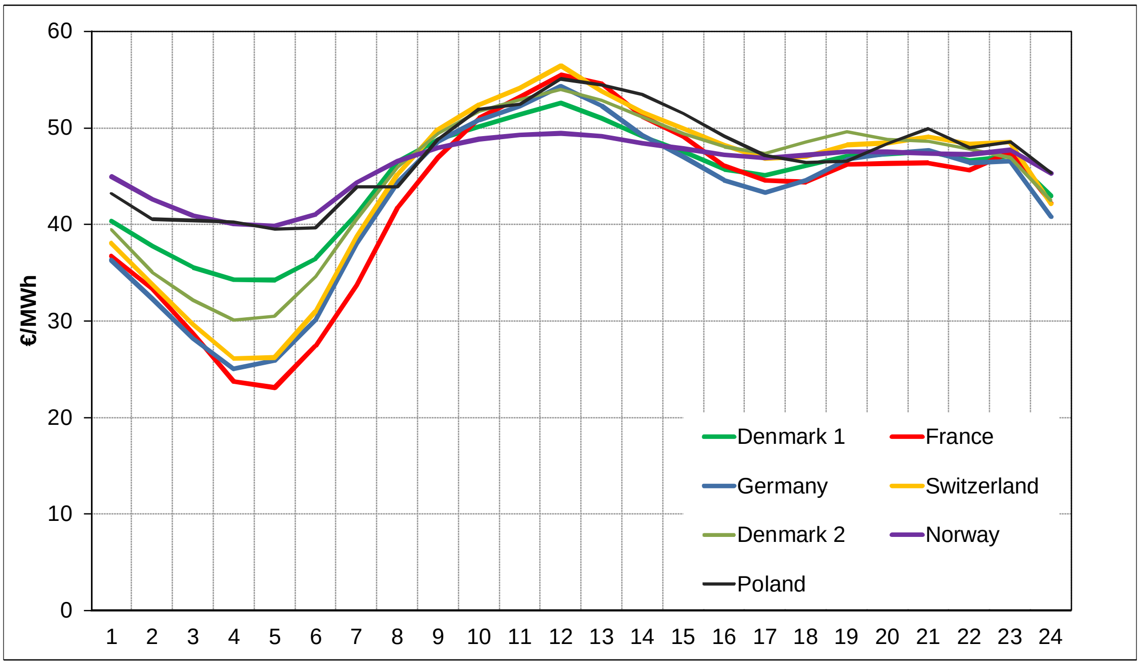
od from summer 2010 through summer 2012. Energy prices on the spot market are affected by numerous factors, for example, the supply of renewable energy, the availability of power plants, the prices for fossil fuels and the load. The load here varies both with the time of year and also with the time of day: The load is greatest by day, and low at night; in winter the load is usually greater than in summer. At the same time, generation from hydro power plants is usually greater in summer due to the snow melt.

For this reason the average spot prices during the day are viewed separately for the summer and winter periods in the analysis of spot prices.

For Norway the spot price for Region 2 was chosen because it is connected by sea cables to Denmark and to the Netherlands. In Denmark there are two price zones: Denmark 1 covers the peninsula and Denmark 2 covers the Copenhagen region.

Figure 5 shows the average daily progression of spot prices in summer 2010. The classical price profile for Germany is also visible. At night the prices are low, and reach their minimum average of 25 € / MWh in the 4th hour. The highest prices of 55 € / MWh are reached at the midday peak. A similar profile is observed in most neighboring countries. In France the average electricity price minimum appears in the 5th hour and at 23 € / MWh is slightly below the German price minimum. Prices in Switzerland run parallel to the German spot price.

Figure 5 Average hourly spot prices during the day in summer 2010 (1 April 2010 to 30 September 2010)



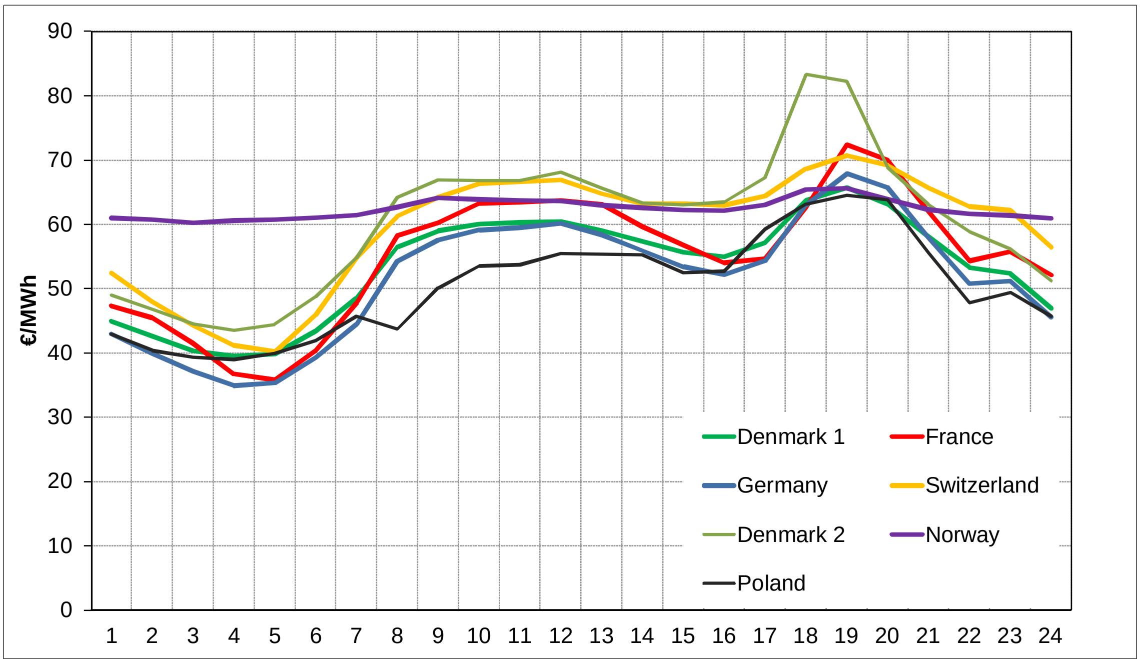
Source: EPEX/EEX, NordpoolSpot, PolPX, calculations by Öko-Institut

Norway displays a strikingly flat profile. At night the prices are higher; by day they do not quite reach the continental European level. On average the spot prices in Norway do extend approximately up to the level of continental Europe.

Figure 6 presents the average daily progression of spot prices in winter 2010/2011. Again, the classical price profile is observed for Germany. At night the prices are low, and reach their minimum average of 35 € / MWh in the 4th hour. The highest prices of 68 € / MWh are reached at the evening peak. For France it is striking that the level of electricity prices in winter is structurally higher during the day than in Germany (e.g. by 4 € / MWh in the period from 08:00 until 20:00 hours). Prices in Switzerland are about 7 € / MWh higher than in Germany. This can be explained in all probability by exports to Italy and by the low production of hydro power in winter.

For Norway a higher price level of over 60 € / MWh is observed throughout. Thus the spot prices in Norway are at the level of peak load in continental Europe.

Figure 6 Average hourly spot prices during the day in winter 2010/2011 (1 October 2010 to 31 March 2011)

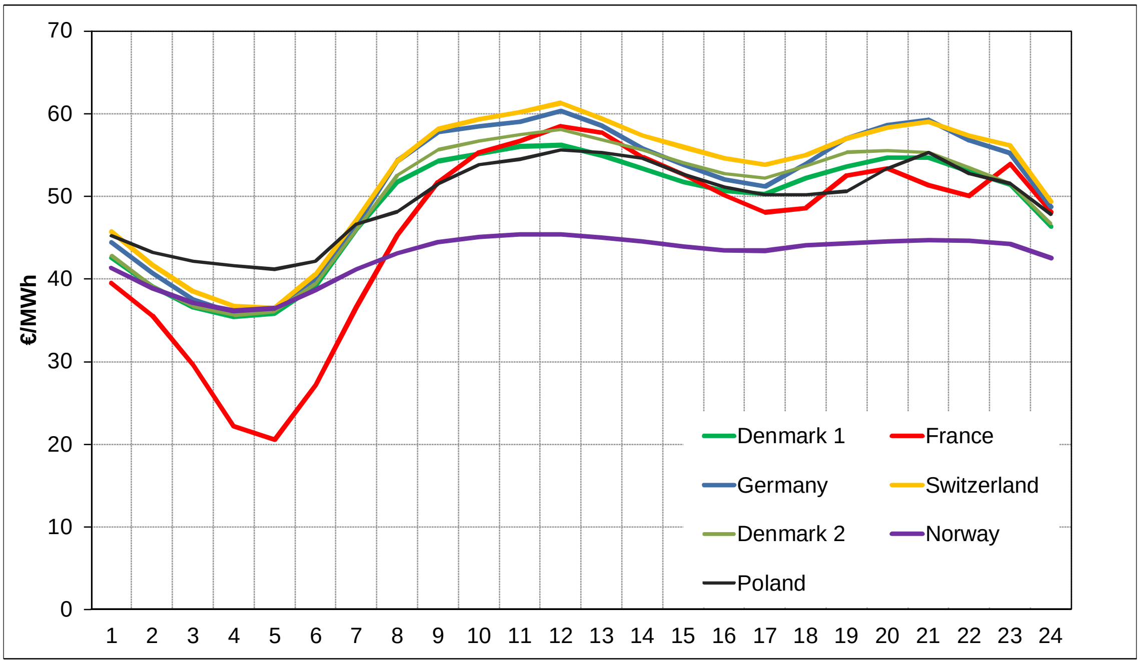


Source: EPEX/EEX, NordpoolSpot, PolPX, calculations by Öko-Institut

Figure 7 shows the average daily progression of spot prices in summer 2011. For Germany nighttime prices on average of 36 € / MWh were noted in the 4th and 5th hours. Prices of up to 60 € / MWh were attained in the midday and evening peaks. In summer 2011 the price level in France was on average 20 € / MWh lower at night, especially in the 5th hour. Prices in Switzerland in the summer of 2010 again run parallel to the German spot price.

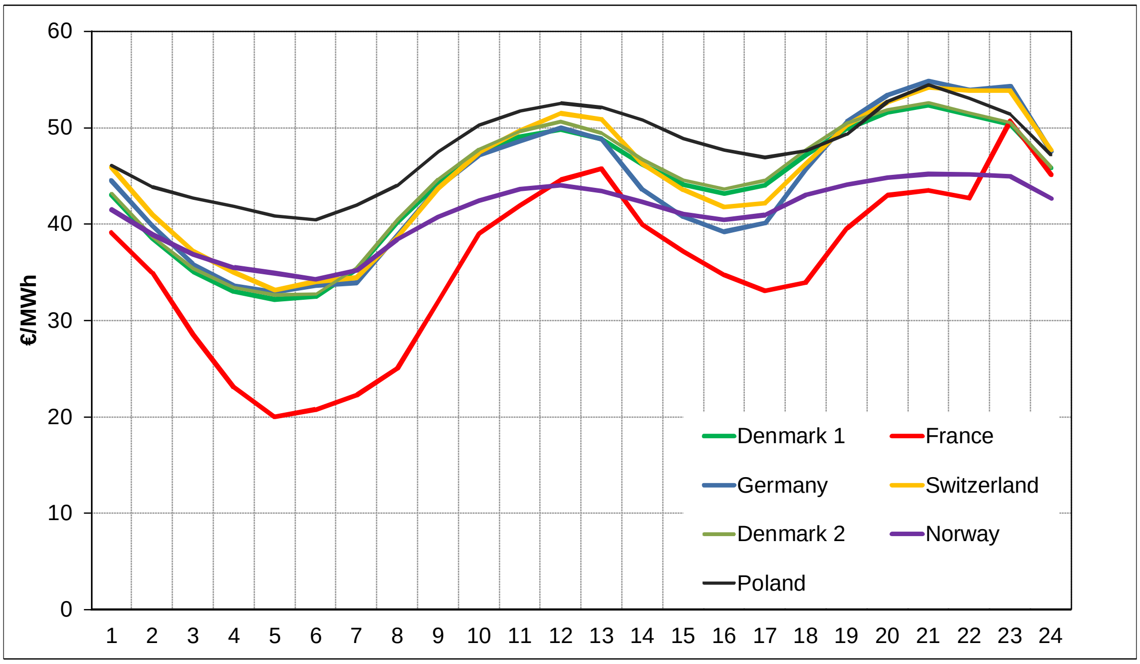
The price level in Norway has fallen considerably in comparison to winter 2010/2011 and in off-peak times, that is, at low-demand times, approaches the German price level. Figure 8 likewise shows for the summer of 2011 the average daily progression of spot prices on weekends and holidays. In contrast to Figure 7 it is clear that electricity prices on weekends are lower and fluctuate less severely over the day. This is attributable primarily to the fact that the load on weekends is lower and the power demand can be covered with lower-cost power plants. On weekends the price difference between France and Germany is clearly greater than on average across all days. This is an indication that a lot of power is exported from France, especially in periods of low load.

Figure 7 Average hourly spot prices during the day in summer 2011 (1 April 2011 to 30 September 2011)



Source: EPEX/EEX, NordpoolSpot, PolPX, calculations by Öko-Institut

Figure 8 Average hourly spot prices during the day in summer 2011 (1 April 2011 to 30 September 2011) on Saturdays, Sundays and holidays



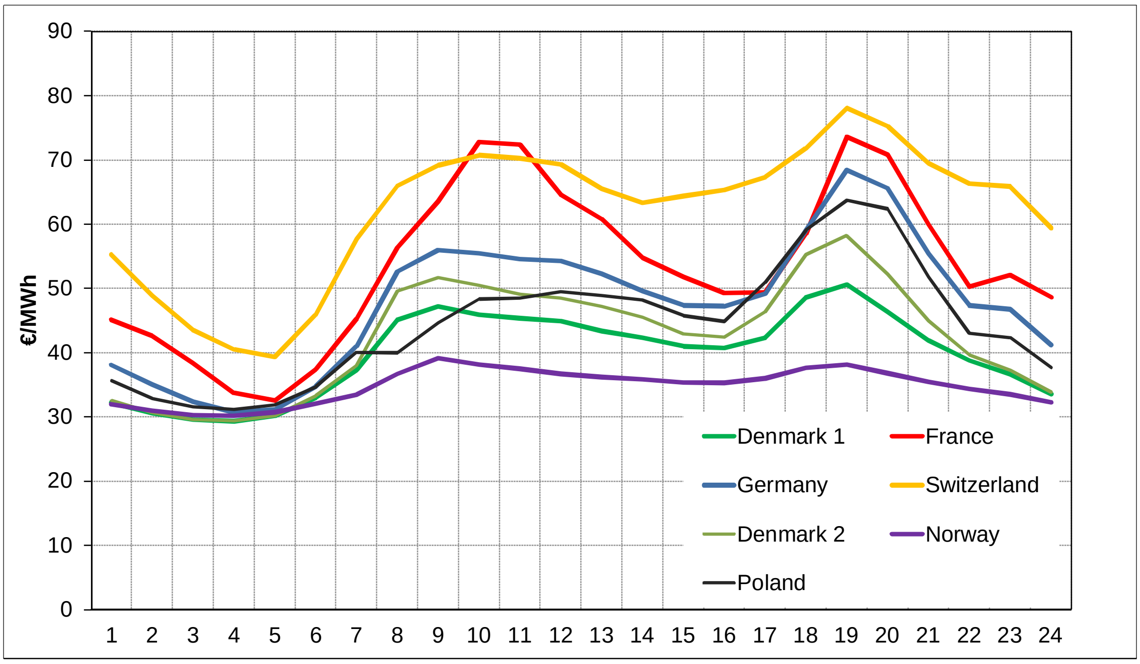
Source: EPEX/EEX, NordpoolSpot, PolPX, calculations by Öko-Institut

Figure 9 represents the average daily progression of spot prices in winter 2011/2012. As in the winter 2010/2011, prices in France are again slightly above the German level. It is interesting that in France a price peak appears at midday which is not observed in Germany. This is probably attributable to the effect of photovoltaics.

Prices in Switzerland are about 14 € / MWh higher than in Germany. This can be explained in all probability by exports to Italy and by the low production of hydro power in winter.

The price level in Norway is at the level of German off-peak price – as was also the case in summer 2011.

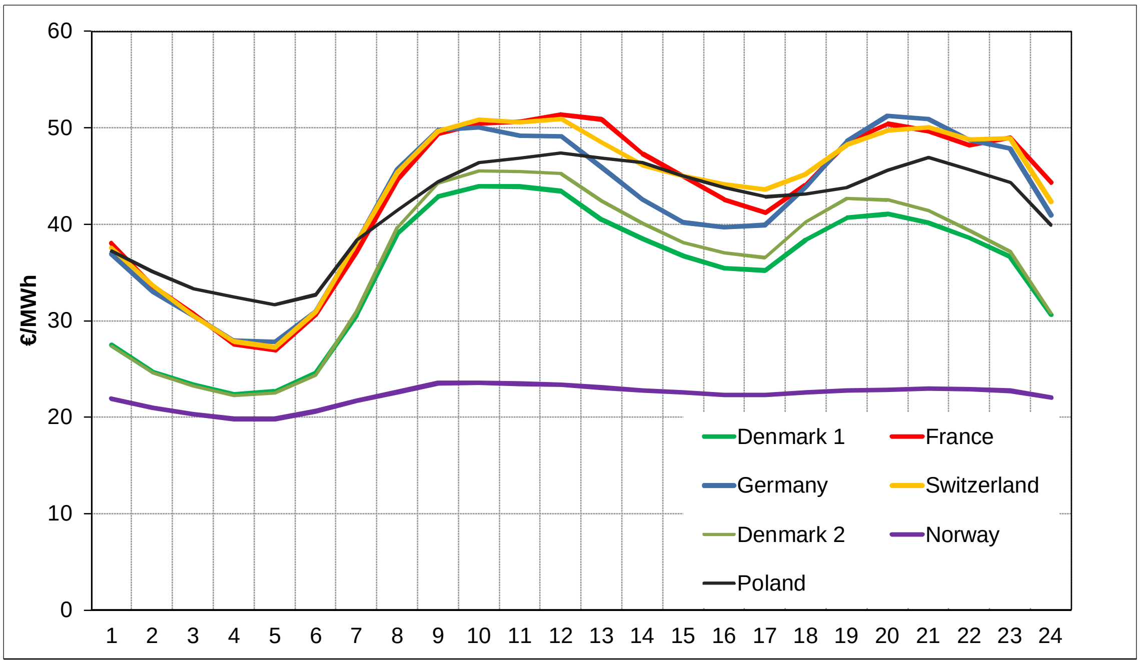
Figure 9 Average hourly spot prices during the day in winter 2011/12 (1 October 2011 to 31 March 2012)



Source: EPEX/EEX, NordpoolSpot, PolPX, calculations by Öko-Institut

Figure 10 shows the average daily progression of spot prices in summer 2012. Compared to the previous year, the price level in France is higher and is now at the same level as in Germany. In the afternoon prices in Germany fall below the French level (which is indicative of PV effects). Nighttime and afternoon prices in Poland are higher than in Germany. In the morning and evening, prices in Poland are lower. Compared to summer 2011 the price level in Norway has fallen and is now clearly below the German level.

Figure 10 Average hourly spot prices during the day in summer 2012 (1 April 2012 to 30 September 2012)



Source: EPEX/EEX, NordpoolSpot, PolPX, calculations by Öko-Institut

In summary the following conclusions can be drawn overall with respect to the development of spot prices:

- In winter 2010/11 and again in winter 2011/12 the electricity prices in Germany were lower than in France. In summer 2011 the electricity prices in Germany were higher than in France; in the summers of 2010 and 2012 the average prices in Germany and France were similar, but the price trend for power in France was increasing.
- In the two winter periods in question, the electricity prices in Switzerland were greater than in Germany, and in summer the electricity prices are equivalent to the German level. Evidently the spot prices in Switzerland in winter are equivalent to the (high) level in Italy and decrease in summer to the (lower) German level.

- In Norway electricity prices were very high in winter 2010/2011. This can be explained by the fact that in 2010 very low precipitation was recorded, so that power had to be imported. Therefore a high price level was the result. After the heavy precipitation over the course of the summer 2011 the price level in Norway had fallen to the German off-peak price and in winter 2011/2012 was again at this level.
- Regarding prices in Denmark it was found that as a rule they fluctuate between the Norwegian and German price level.
- In Poland the spot prices exhibit a similar structure as in Denmark. In summer 2010 the spot prices in Poland were higher than in Germany, especially in the off-peak hours. In winter 2010/2011, in summer 2011 and in winter 2011/2012 the off-peak spot prices in Poland were higher than in Germany, and during the day were lower than in Germany. This might be explained because in Poland hard coal-fired power plants set the prices by day and also by night.

4 Imports and Exports

4.1 Historical Development of Germany's Overall Imports and Exports

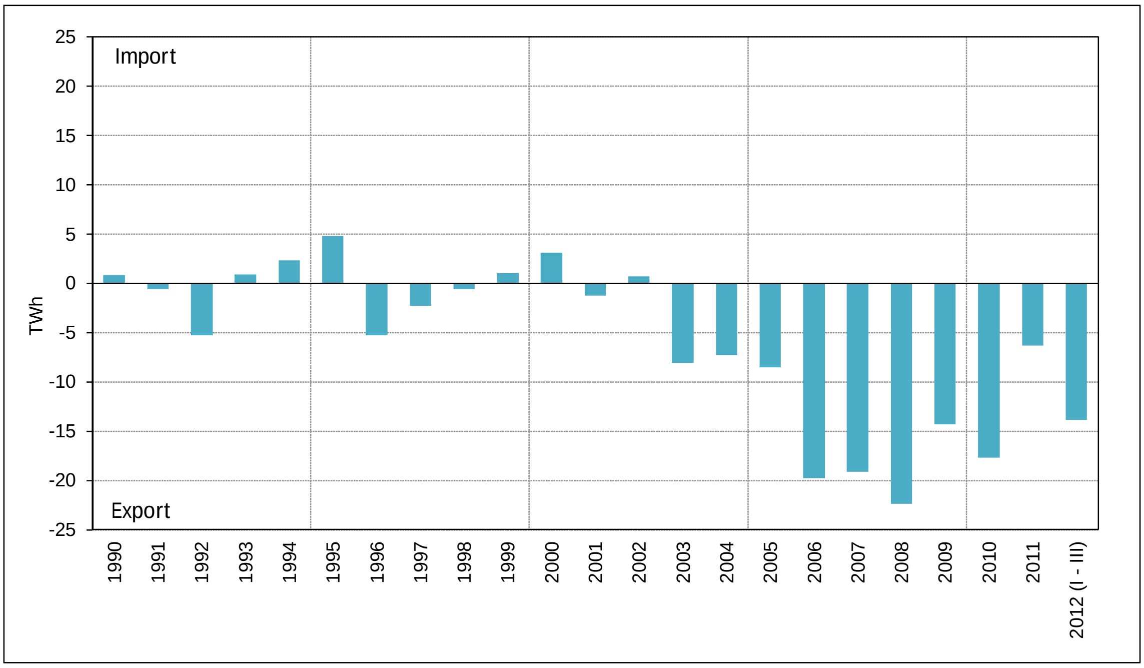
4.1.1 Germany's annual import and export balance

As is readily evident in Section 2 in Figure 3 the net import-export balance changed in the period between 1990 and 2011. This is shown in detail in Figure 11 and Table 1.

In the period between 1990 and 2002 both annual net imports and also annual net exports occurred, which amounted to a maximum of about 5 TWh. Starting in 2003, Germany became a net overall exporter, and on balance for the years 2003 to 2010, annual exports were between 7 TWh and 22 TWh.

Thus 2011 with its export balance of 6 TWh does not represent any particularly exceptional situation in an historical perspective since 1990. For 2012 so far only data from the first three quarters is available. After a decrease in the export balance in 2011, net exports rose again in the first three quarters of 2012 to nearly 14 TWh. Since Germany is a traditional power exporter in winter, it can be assumed that the export balance by the end of 2012 will continue to rise.

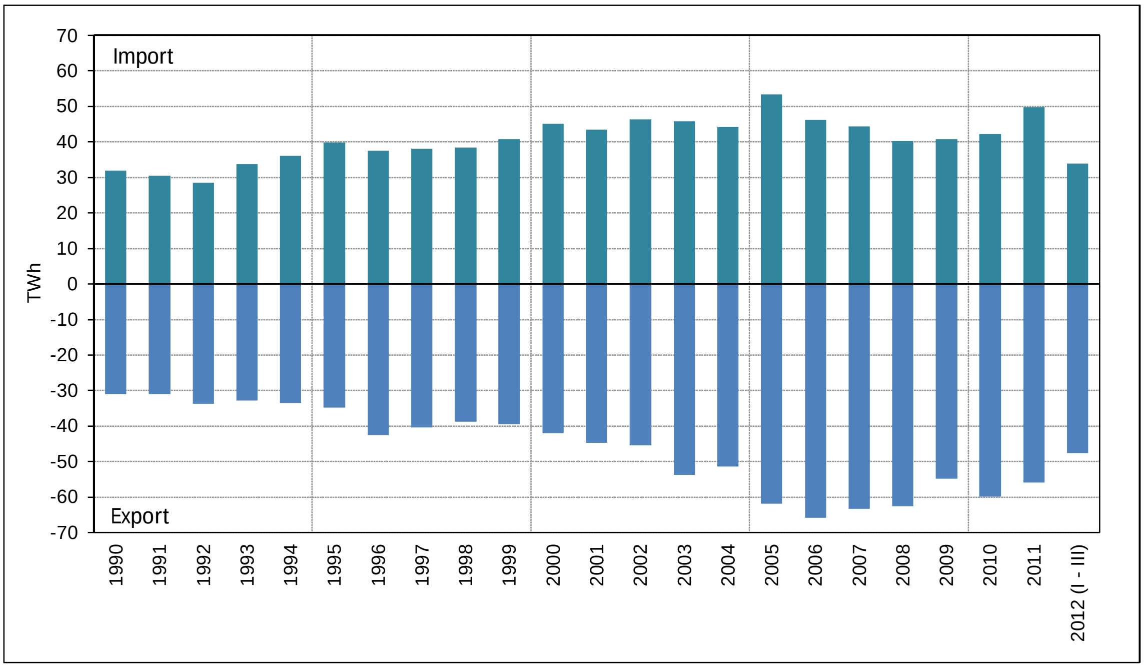
Figure 11 Development of Germany's net power imports from 1990 to 2011 and quarters I-III for 2012.



Source: AG Energiebilanzen, Quarters I-III 2012 ENTSO-E, diagram by Öko-Institut

Figure 12 shows the annual power imports and exports separately. In 2011 an amount of 49.7 TWh was imported and 56.0 TWh was exported. Thus imports in 2011 attained their second-highest value since 1990, but did not reach the import maximum of 2005. Exports for 2011, in spite of a decrease compared to the previous year, are still in the range of the large power exports which have been observed in the last seven years. Regarding the data available at this point for 2012 it should be noted that imports have decreased more significantly and the exports continue to remain at a high level.

Figure 12 Development of Germany's annual power imports and exports from 1990 to 2011 and quarters I-III for 2012



Source: AG Energiebilanzen, Quarters I-III 2012 ENTSO-E, diagram by Öko-Institut

Table 1 Development of Germany's annual power imports and exports from 1990 to 2011 and quarters I-III for 2012

year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
power imports (TWh)	31.9	30.4	28.4	33.6	35.9	39.7	37.4	38.0	38.3	40.6	45.1	43.5
power exports (TWh)	31.1	31.0	33.7	32.8	33.6	34.9	42.7	40.4	38.9	39.6	42.1	44.8
net power imports (TWh)	0.8	-0.6	-5.3	0.9	2.3	4.8	-5.3	-2.3	-0.6	1.0	3.1	-1.3

year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	*2012 (I-III)*
power imports (TWh)	46.2	45.8	44.2	53.4	46.1	44.3	40.2	40.6	42.2	49.7	*33.9*
power exports (TWh)	45.5	53.8	51.5	61.9	65.9	63.4	62.7	54.9	59.9	56.0	*47.8*
net power imports (TWh)	0.7	-8.1	-7.3	-8.5	-19.8	-19.1	-22.4	-14.3	-17.7	-6.3	*-13.8*

Source: AG Energiebilanzen, Quarters I-III 2012 ENTSO-E

4.1.2 Germany's monthly import and exports

Now while Germany was always a net exporter over the last 9 years when looking at the **annual** balance, this was not always the case for each individual month of any particular year.

Figure 13 shows the monthly values for Germany's import-export balance in the period from 2003 to March 2012. Positive values denote imports, negative values denote exports. A seasonal pattern is clearly in evidence: On balance, Germany regularly exports power in winter and imports in summer.

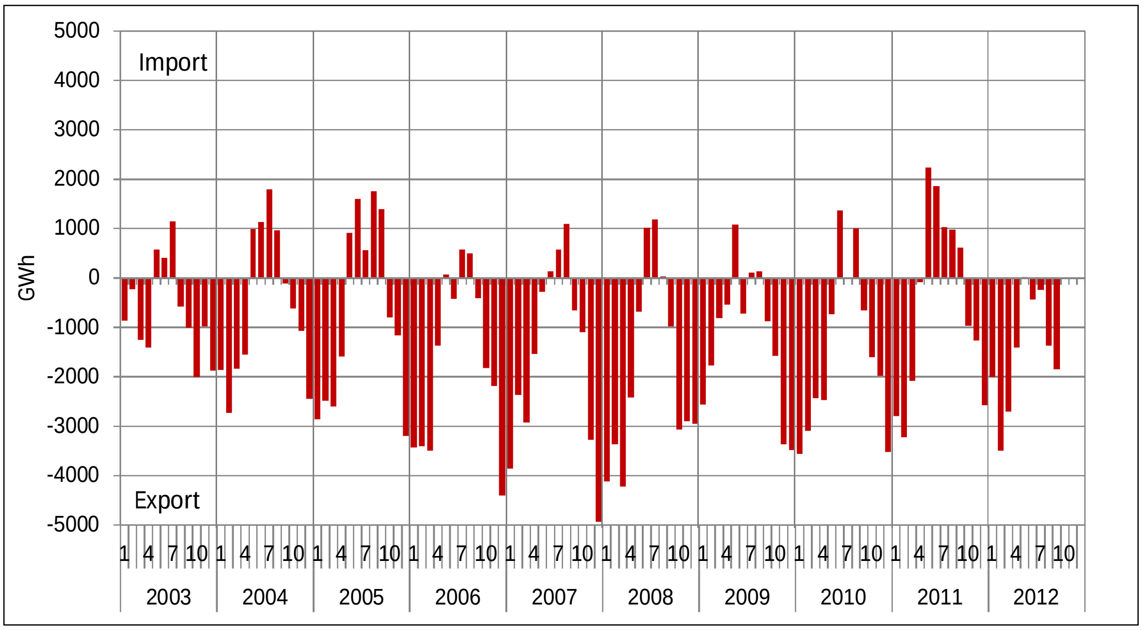
This shows that imports do not occur due to any (specific) deficiency in power plant capacity – precisely because the domestic demand is greatest in winter. In these months there are evidently sufficient power plant capacities available in Germany to cover not only the high domestic demand, but also to export – on a competitive basis – electricity. However, imports occur on balance precisely in the summer months when domestic demand tends to be lower than in winter. In these months power plant capacity abroad appears to be available at lower cost than domestically, so that on a monthly balance the result is market-driven imports.

Year 2011 also exhibits this seasonal structure, and imports were greater especially in the months of May and June than in preceding years since 2003, and imports now also occurred in September 2011. In the months of October, November and December 2011, and also in January to April 2012, net monthly exports were again observed. The only month in 2012 in which net imports – although very minor – occurred, was May 2012. In the subsequent months of June, July, August and September, net exports are again noted.

So Germany was a net exporter in the winter 2011/2012, just as in previous years. But in contrast to previous years, in the summer of 2012 Germany was virtually not a net importer, but rather on balance exported power throughout.

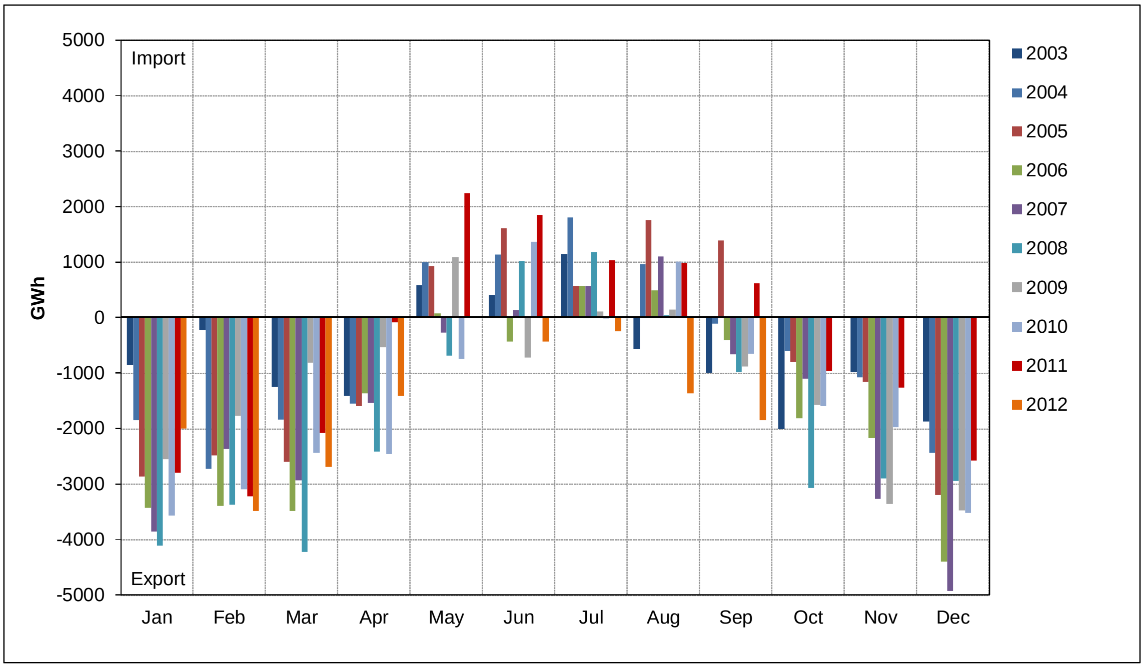
Figure 14 shows the same values for the monthly import-export balance as Figure 13, but not in chronological order, rather sorted by months. Again this clearly shows the elevated import balance in the months of May 2011 and (to a lesser extent) June 2011, compared to the same months from prior years since 2003. But since July 2011 the values for the monthly import-export balance again return to the range of values observed since 2003, with the exception of the situation in September 2011, when power was imported. The last time this happened was in 2005. Figure 14 shows the seasonal profile of the import-export balance particularly clearly.

Figure 13 Monthly import-export balance (physical flows) for Germany, 2003 to September 2012



Source: ENTSO-E, calculations by Öko-Institut

Figure 14 Monthly comparison of the import-export balance (physical flows) for Germany, 2003 to September 2012

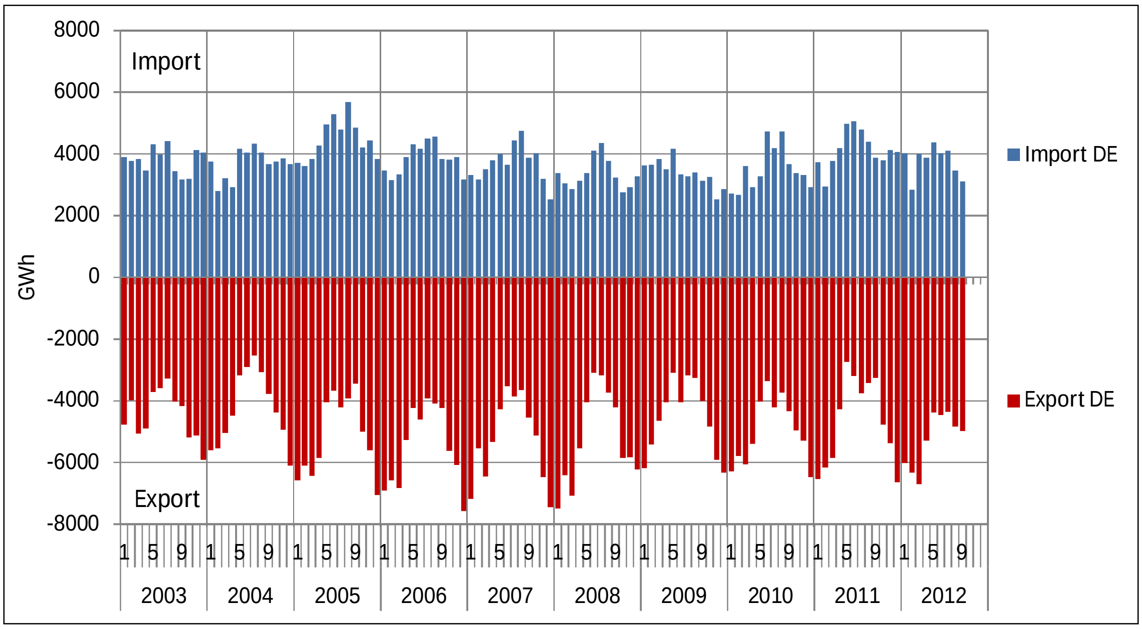


Source: ENTSO-E, calculations by Öko-Institut

Figure 15 shows the monthly imports and exports for Germany from 2003 to March 2012, not as a net balance, but rather each one separately. Both imports and exports occur in all months. And both show a seasonal pattern: Imports in the summer months tend to be greater than in the winter months, but there are clear differences between the years in the chronological structure of monthly imports. Exports follow the seasonal pattern more clearly: In winter significantly greater exports are regularly noted than in the summer months.

Year 2011 is characterized by comparatively elevated imports in the months of May to August, but historically this does not represent a unique situation because the values were even exceeded in 2005. Exports in 2011 are comparatively low, especially in May and September, and are exceeded by the imports. In summer 2012 the imports are still comparatively high. But at the same time, exports clearly increased in comparison to the previous year.

Figure 15 Monthly imports and exports (physical flows) for Germany, 2003 to September 2012



Source: ENTSO-E, calculations by Öko-Institut

4.2 Germany's Power Exchange with Individual Neighboring Countries

4.2.1 Annual power exchange with neighboring countries

The physical power exchange between Germany and neighboring countries is discussed in detail in the following section. Table 2 and Figure 16 show Germany's annual import balance with various countries from 2003 through September 2012. There are classical importing and classical exporting countries: During the period in question, imports occurred from France and the Czech Republic in all years; exports went to the following countries, in order: Netherlands, Switzerland, Austria, Luxemburg and Poland. In most years the power exchange with Denmark amounted to a net import, in many years there were net imports from Sweden, but in other years a net export.

In 2011 the physical net power imports for Germany arrived from France, the Czech Republic, Denmark and Sweden. Net exports went to Austria, Switzerland, the Netherlands, Poland and Luxemburg. In 2012 German net physical power imports increased from Denmark and Sweden. In the first nine months of 2012, already 4 TWh more power was imported than in the entire year 2011.

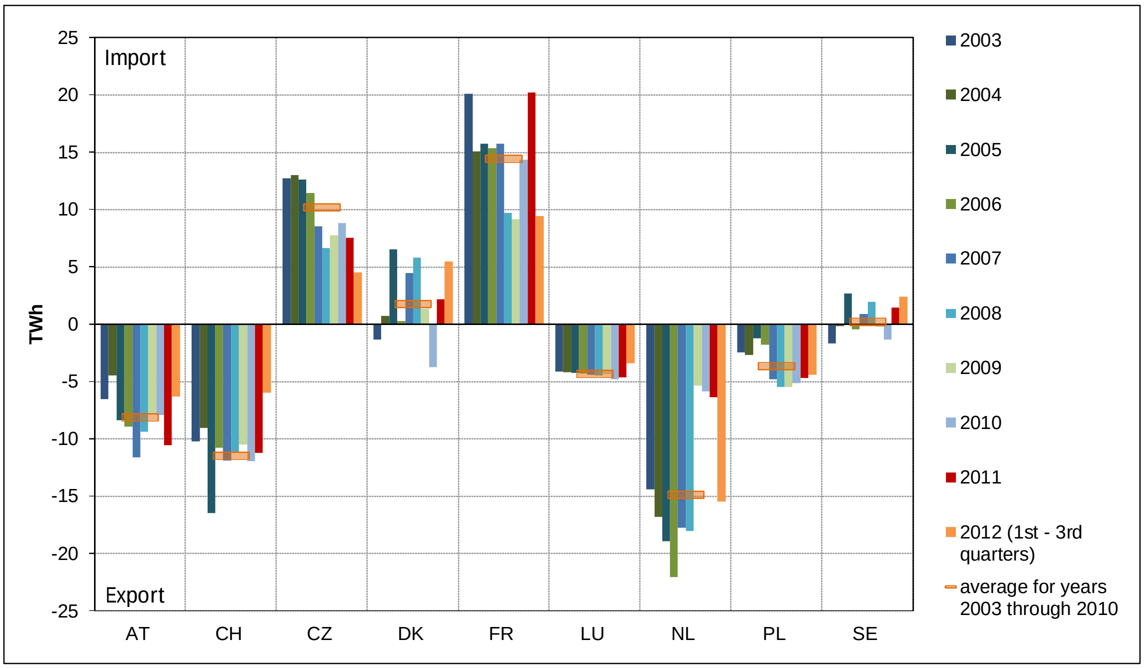
Table 2 Germany's annual physical import balance from different countries from 2003 through September 2012

	AT	CH	CZ	DK	FR	LU	NL	PL	SE	sum
					TWh					
2003	-6.6	-10.2	12.7	-1.4	20.1	-4.1	-14.4	-2.5	-1.7	-8.0
2004	-4.5	-9.0	13.0	0.7	15.1	-4.2	-16.8	-2.7	-0.2	-8.6
2005	-8.4	-16.5	12.6	6.5	15.7	-4.2	-18.9	-1.2	2.7	-11.8
2006	-9.0	-10.8	11.4	0.3	15.3	-4.3	-22.1	-1.8	-0.5	-21.4
2007	-11.6	-11.9	8.5	4.4	15.7	-4.4	-17.8	-4.8	0.9	-21.0
2008	-9.4	-11.1	6.6	5.8	9.7	-4.5	-18.0	-5.5	2.0	-24.4
2009	-7.9	-10.5	7.7	1.3	9.2	-4.4	-5.4	-5.5	-0.2	-15.6
2010	-8.0	-12.0	8.8	-3.8	14.3	-4.8	-5.9	-5.2	-1.3	-17.7
2011	-10.6	-11.2	7.5	2.1	20.2	-4.7	-6.4	-4.7	1.4	-6.3
2012 (1st - 3rd quarters)	-6.3	-6.0	4.5	5.4	9.4	-3.4	-15.5	-4.4	2.4	-13.8
average for years 2003 through 2010	-8.2	-11.5	10.2	1.7	14.4	-4.4	-14.9	-3.7	0.2	-16.1
year 2011 difference from the average	-2.4	0.3	-2.7	0.4	5.8	-0.3	8.5	-1.1	1.2	9.8
year 2012 difference from the average	1.8	5.5	-5.7	3.7	-5.0	1.0	-0.6	-0.8	2.2	2.2

Source: ENTSO-E, calculations by Öko-Institut

The average value for years 2003 to 2010 and also the deviations of year 2011 from this average are presented in Table 2 in order to gain a starting point for an assessment of the import-export situation for year 2011. It is particularly striking in this context that the net physical imports from France in 2011 were 5 TWh higher than the average of previous years, and that exports to the Netherlands in 2011 were 8.5 TWh lower than the average of previous years.

Figure 16 Germany's annual physical import balance from different countries from 2003 to 2011 and quarters I-III of 2012



Source: ENTSO-E, calculations by Öko-Institut

However, the level of imports and/or exports varied for several countries in the particular period, sometimes significantly between the years, as Figure 16 shows: For example, the annual balance of imports from France ranged between 9 TWh and 20 TWh. In 2011 the net annual balance with France again reached the maximum of 20 TWh. In the first nine months of 2011, imports from France clearly fell again and are more than 6 TWh below the imports in the first nine months of 2011.

Net exports from Germany to the Netherlands of 14 to 22 TWh through 2008 represented the greatest export values. However, since 2009 these exports have been reduced to one-third, so that year 2011 with 6 TWh of net exports to the Netherlands merely continues this trend. Various factors come into consideration to explain the decrease in net exports since 2009: New power plant construction and a decrease in consumption in the Netherlands, the laying of a cable between the Netherlands and Norway, and also low gas prices after the beginning of the economic crisis. In 2012 exports to the Netherlands again rose quickly and reached the level before the economic crisis. The background for this is probably the now rapidly rising gas prices and the associated loss of competition on the part of the Dutch gas power plants.

Net imports from the Czech Republic since 2007 ranged over a lower level than in years 2003 to 2006, and the 7.5 TWh in 2011 held the second-lowest position in the period in question.

Germany's net annual power exports to Poland likewise changed in the studied period: Since 2007, on balance, about twice as much was exported to Poland as in previous years.

4.2.2 Monthly power exchange with neighboring countries

The following figures show the monthly physical power exchange between Germany and neighboring countries in years 2003 through September 2012. In sum, the overall imports, exports and net balance illustrated in the proceeding Section are indicated there. The monthly net balance between Germany and various other countries is illustrated in Figure 17. Figure 18 and Figure 19 show the exports to and imports from these countries in absolute terms.

In nearly all months there is on balance a net export to all the classical export countries, namely Austria, Switzerland, Luxemburg, Netherlands and Poland, where net exports are indicated in the annual balance. Likewise, net imports from the Czech Republic and France (with the exception of February 2006) are evident for all months throughout. Fluctuations between months with net imports and months with net exports are noted for Denmark and Sweden (cf. Figure 17), wherein net imports predominate especially from Denmark.

Net exports from Germany described in Section 4.1.2 in the winter months are reflected especially in the net exchange balance with Austria and Switzerland. The net balance in both countries indicates exports in nearly all months, with the greatest values appearing in the winter months. Small net imports do occur occasionally in summer months.

Until 2008 the net balance of power exchanged with the Netherlands followed a similar seasonal pattern: On balance, Germany exported power to the Netherlands, and increasingly so in the winter months. Since the middle of 2009, net imports from the Netherlands can also be observed in individual months. With the exception of the month of May 2011, in all other months on balance power was exported to the Netherlands, and this applies increasingly for the months of March through September 2012.

On a monthly balance, Poland pulls physical current from Germany. A low-level of exports is noted, and here, too, they are higher in the winter months than in summer. Monthly imports from Poland are very low, so that the level and structure of exports dominate the net balance (cf. Figure 18 and Figure 19).

A comparatively constant power exchange with Luxemburg is observed, and on balance a low-level, steady net-export from Germany is evident.

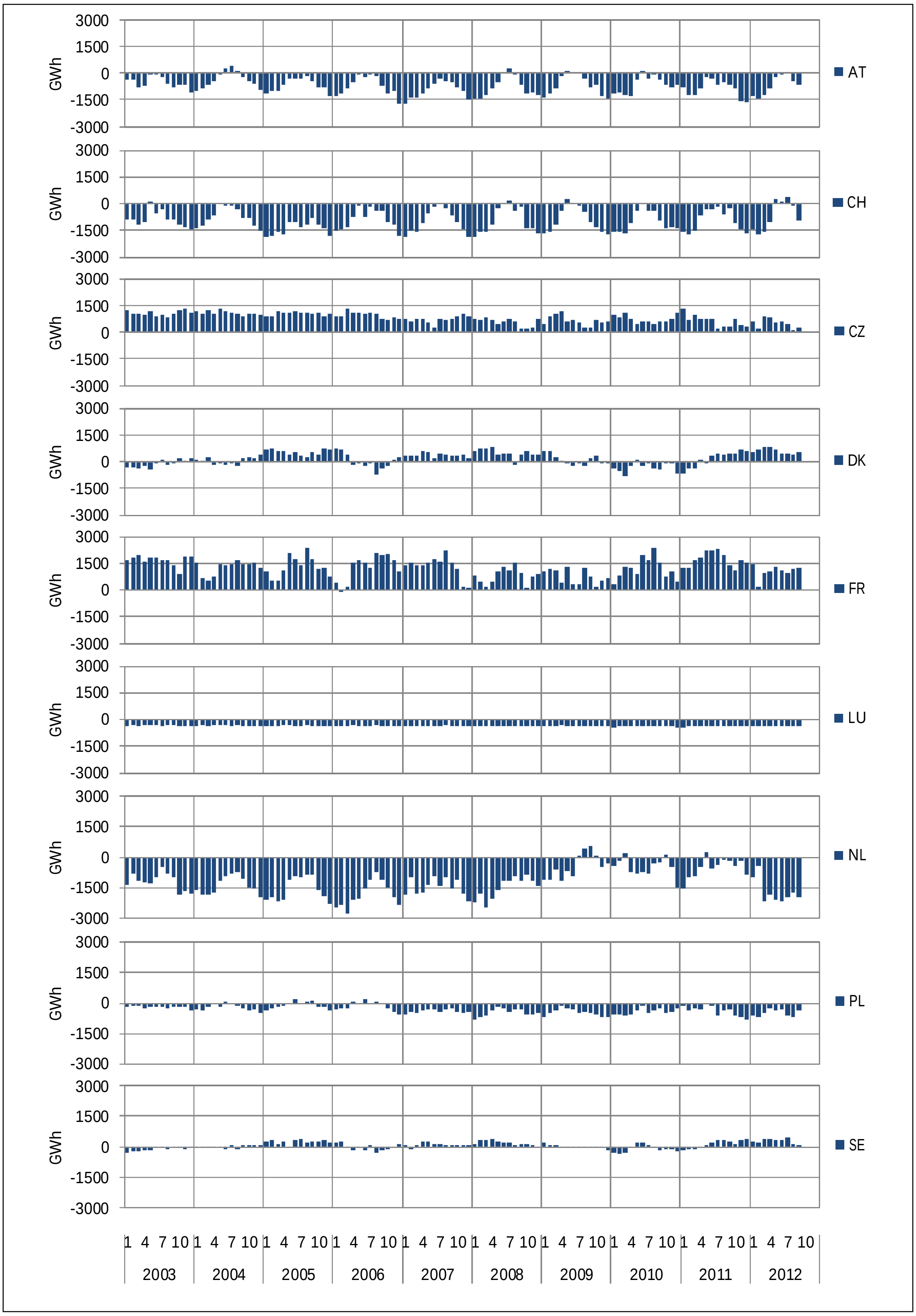
France traditionally exports (physical) power to Germany, and also to Italy, England, Spain, Belgium and Switzerland. Germany obtains its greatest power imports from France (cf. Figure 19), whereas – at least in the monthly aggregate – only minor exports to France are noted (cf. Figure 18). For example, there is throughout a comparatively high net monthly import balance from France. The net physical imports from France to Germany in 2011 of about 20 TWh have been at about the same level since 2003. Seasonal fluctuations are not quite regular, but especially in 2011 the development is toward greater net imports from France in summer months than in winter months. This is sometimes also observed in previous years (see the special assessment for France in Section 5.1).

In the studied period we find exclusively net imports to Germany from the Czech Republic in the monthly balance; in recent years there is a declining development and in the period from the middle of 2011 through May 2012 it is rather low compared to the historical average. However, the separate illustration of imports (Figure 19) and exports (Figure 18) between the Czech Republic and Germany, shows both rising exports in winter 2011/2012, and also rising imports, which in sum produce a low net balance.

The monthly net power exchange with Denmark is positive in most months, that is, on balance Germany imports power from Denmark. This applies in particular since June 2011, after a longer period from mid-2009 through the middle of 2011 when there were also minor exports to Denmark.

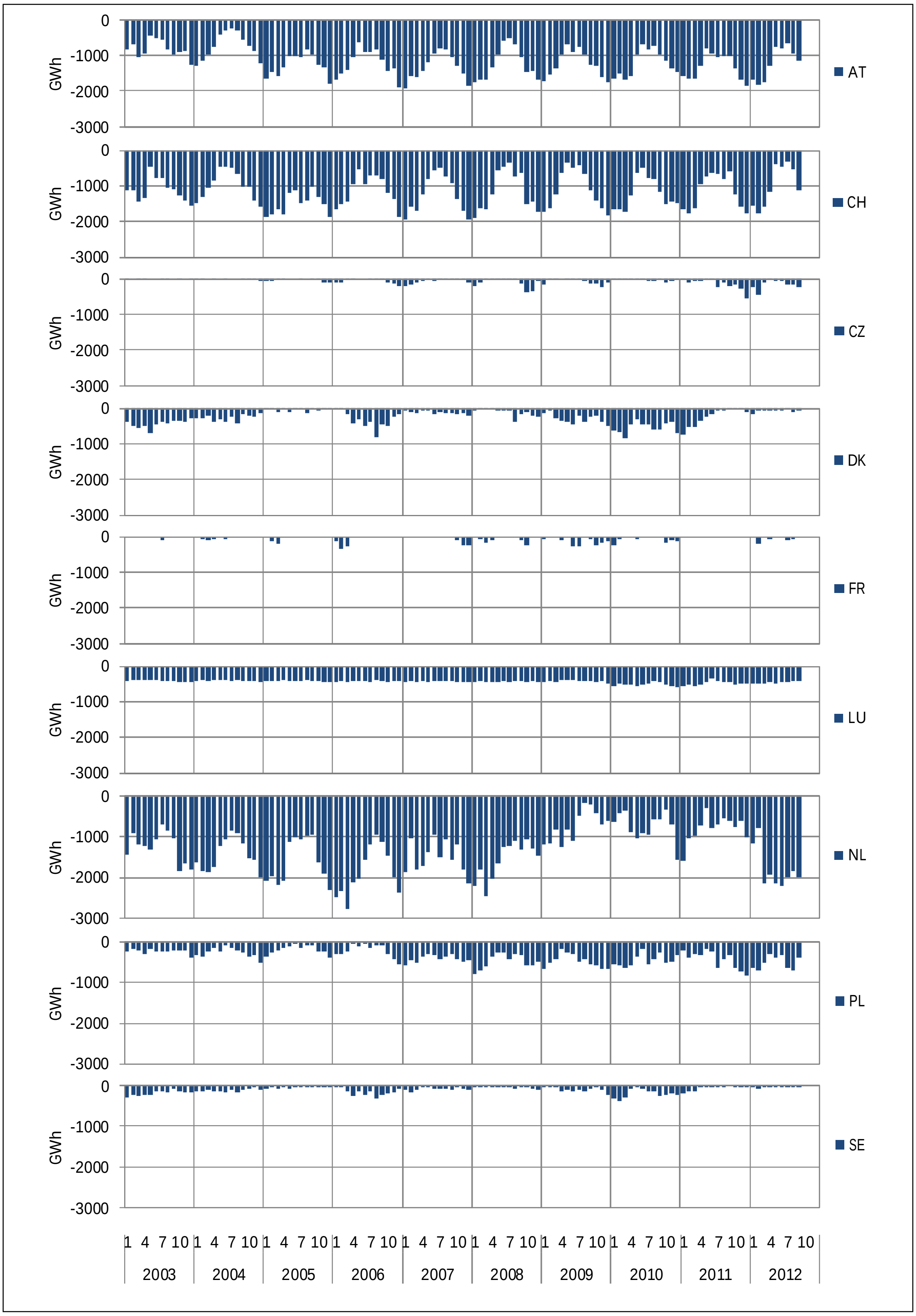
The situation with Sweden is similar: Since May 2011 the net monthly balance indicates net imports from Sweden to Germany throughout, whereas the annual net balance in years 2009 and 2010 was roughly even. Exports from Denmark and Sweden are correlated with the water levels in Scandinavian hydro power plants which are published at nordpoolspot.com.

Figure 17 Monthly import balance (physical) between Germany and neighboring countries, 2003-2012 (positive = net imports)



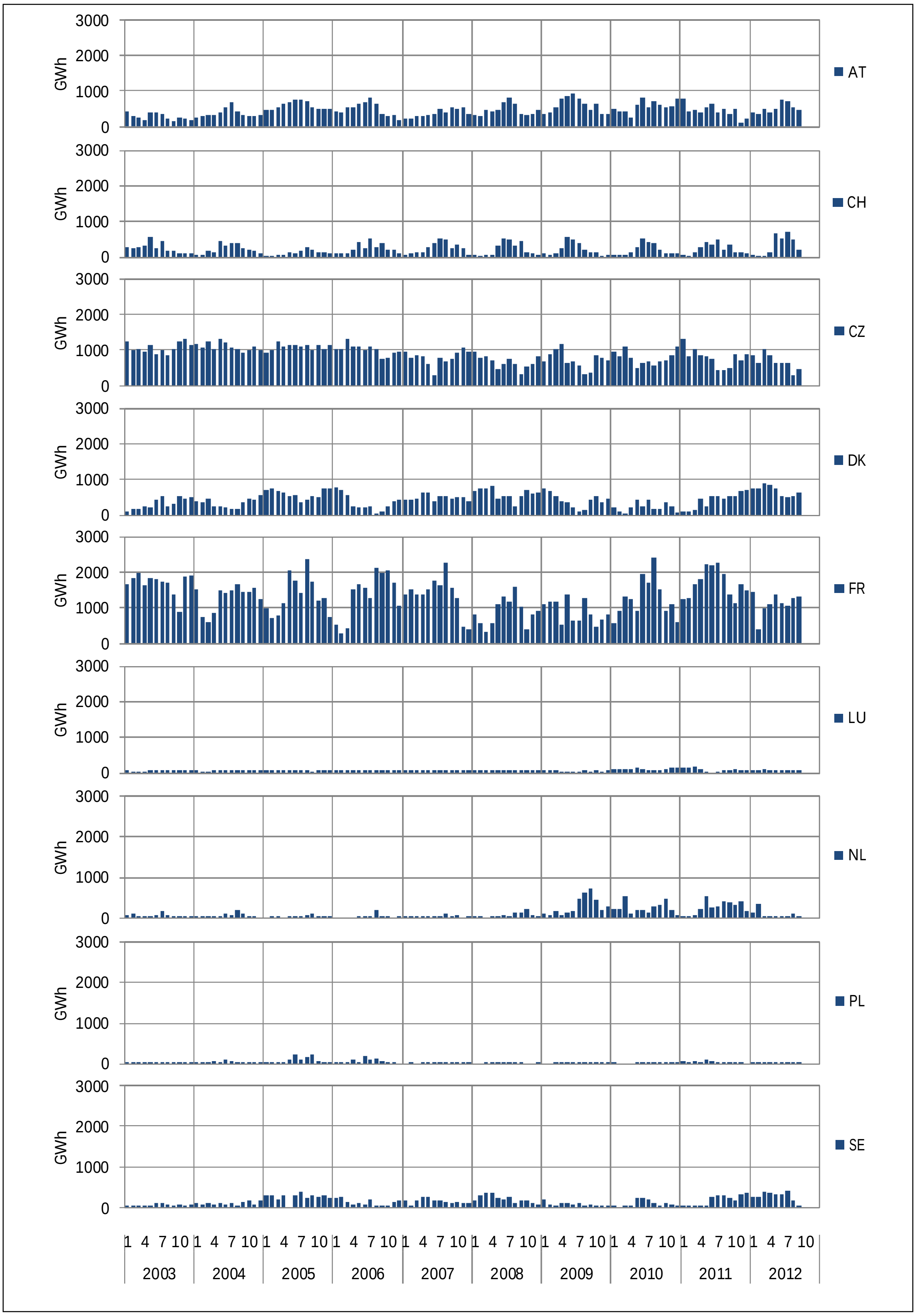
Source: ENTSO-E, diagram by Öko-Institut

Figure 18 Monthly physical exports from Germany to neighboring countries 2003-2012



Source: ENTSO-E, diagram by Öko-Institut

Figure 19 Monthly physical imports to Germany from neighboring countries 2003-2012



Source: ENTSO-E, diagram by Öko-Institut

4.3 Hourly Import-Export Balance and Seasonal Development of Imports and Exports throughout the Day

In this Section we will now examine the period from 2010 through November 2012 in a somewhat greater temporal resolution in order to ascertain any potential changes occurring as a result of the shutdown of nuclear power plants in March 2011. It must be noted here that the used hourly data on net power flow is balanced across control zone boundaries and not across international borders, which results in minor deviations in comparison to the monthly data (cf. Section 4.1.2).

The analysis of monthly data on imports and exports in the preceding Sections has already shown: On balance, Germany imports power in the summer months and exports in the winter months. The change-over from net imports to net exports typically takes place roughly in the month of May, and in many years in the past, May has had a positive balance, and in many other years a negative import balance (cf. Figure 14). The transition to net exports usually begins historically in September.

Figure 20 shows both the power production by German nuclear power plants and also the physical and commercial import balance, presented in an hourly break-down, and also the 24-hour moving average for the period 2010 through mid-2012. Here too, the described trend of exports in winter, imports in summer, is clearly evident. Moreover, the hourly values show that there are hours of net imports even in winter, and conversely also in summer there are several hours with a net export balance.

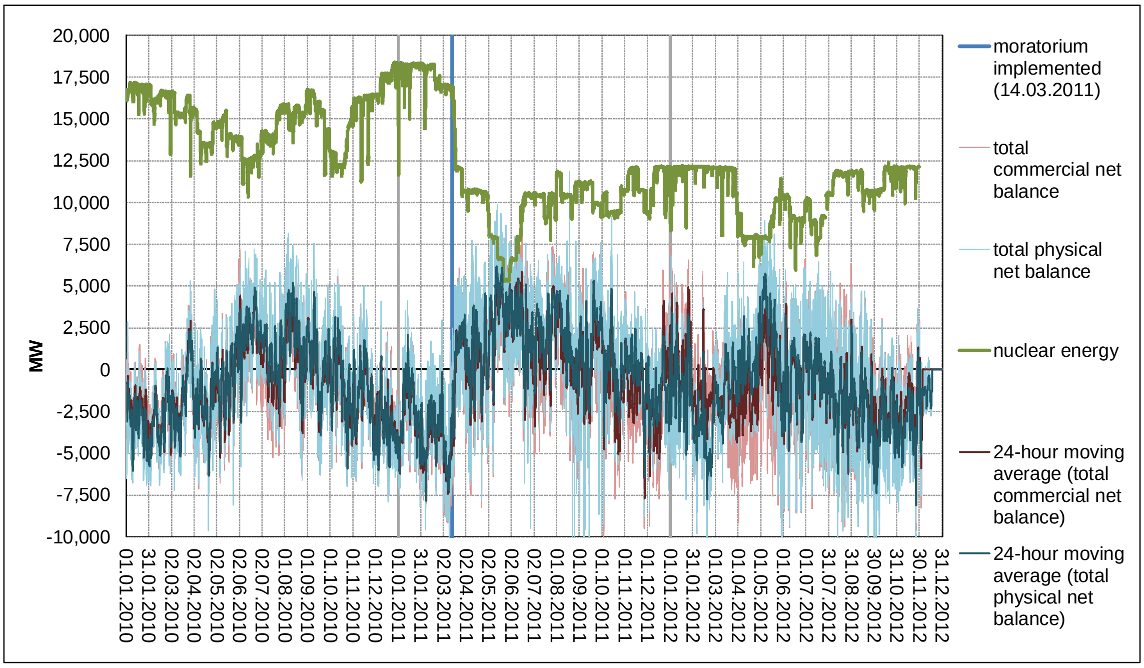
In 2010 as well, approximately in May there is a transition from net exports to net imports, and even in the months of March and April 2010 there are occasionally positive net imports in the 24-hour average. In 2011 net positive imports were even observed in March (using a moving 24-hour average), but there were also individual hours with net exports. In the first half of 2012 again the transition from net exports to net imports can be observed.

Both 2010 and also 2011 exhibit a temporary summer reduction in net imports in the month of July (2010) and in June/July (2011), followed by another increase in August (2010) and in July/August (2011). In 2012 net imports occur primarily in May – as was already described in the previous Sections – but by contrast in the other summer months there were net exports.[8]

In September 2010 the balance again goes back to net exports, whereas in September 2011 the net imports predominate. As the winter begins in 2012 we find mostly exports, as is the case in previous years.

[8] The data on power exchange with several countries – as cited for several hours in January 2012 – are in part implausible. They are, for example, greater than the physical capacity of the lines, so that Germany's listed, total net power exchange with all countries for January 2012 cannot be evaluated in the analysis.

Figure 20 Hourly import balance and 24-hour moving average (commercial and physical) for Germany and generation from German nuclear power plants from January 2010 through November 2012



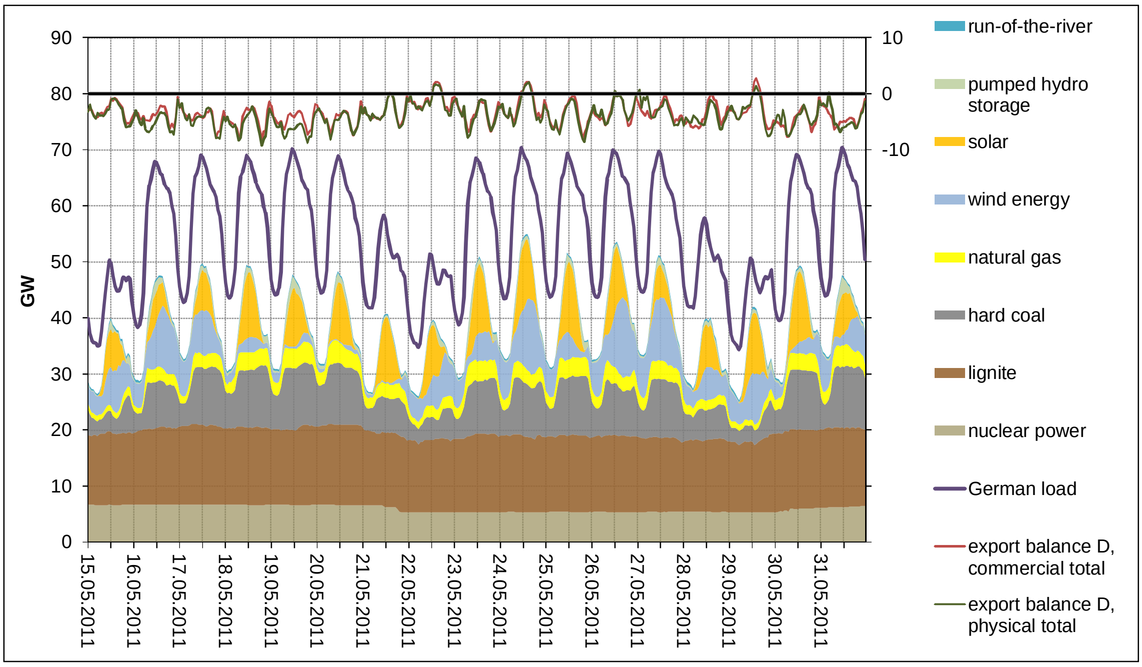
Source: EEX Transparency data, ENTSO-E, calculation by Öko-Institut

Note: Data for January 2012 is somewhat implausible, data for power exchange with Austria between January and March 2012 not available

The period in the second half of May 2011 is presented in greater resolution in Figure 21 because the production from nuclear energy reached a minimum due to long-planned inspections. Power production by various energy sources is presented based on EEX-transparency data; this does not cover all power generation, but provides a good level of coverage in particular for the large power plants, and also the grid load stated by the ENTSO-E. Germany's export balance (physical and commercial) is presented on a second, upper axis, using the same scale, and positive values pertain to net exports, negative values to net imports.

During this period there are primarily net imports, and these are greatest at about 08:00 in the morning and at about 20:00 in the evening. But there are some hours when net imports are low or net exports even occur. In these hours of the weeks of May in question, the domestic load is also high, nonetheless exports still occur. This is due chiefly to the production of solar power which reaches its daily peak at midday or early afternoon.

Figure 21 Power production in Germany according to energy carriers, grid load; on the second axis the export balance (commercial and physical) in May 2011



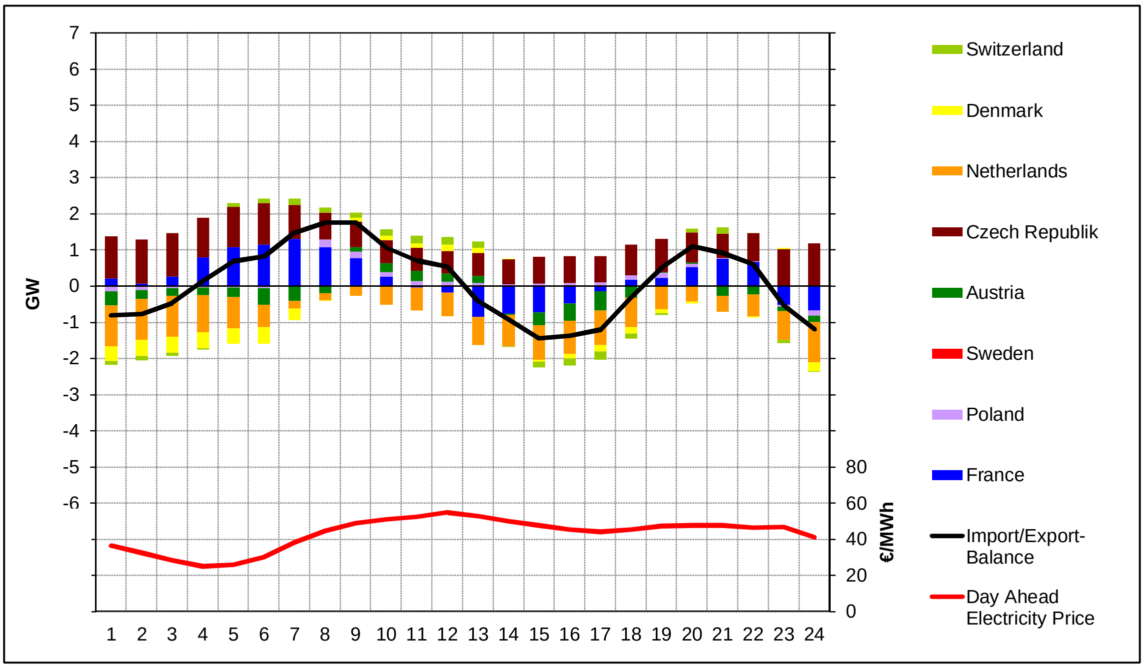
Source: EEX Transparency data, ENTSO-E, calculation by Öko-Institut

If we examine the average daily profile for different seasons in the period from summer 2010 through summer 2012, then we see typical changes in the import-export balance both in the daily profile and also between the summer and winter months.

Figure 22 shows the average daily progression of imports and exports in summer 2010. Positive values represent imports and negative values represent exports. In summer 2010 Germany exported power at night and in the afternoon. In the early morning and in the evening, on average Germany imports power. France in particular appears as a flexible trade partner. In the early morning hours power is imported from France, in the early afternoon power is exported from Germany to France, and then is imported again in the evening.

German power pricing on the spot market is likewise presented in Figure 22 and exhibits a clear minimum, especially in the early morning hours.

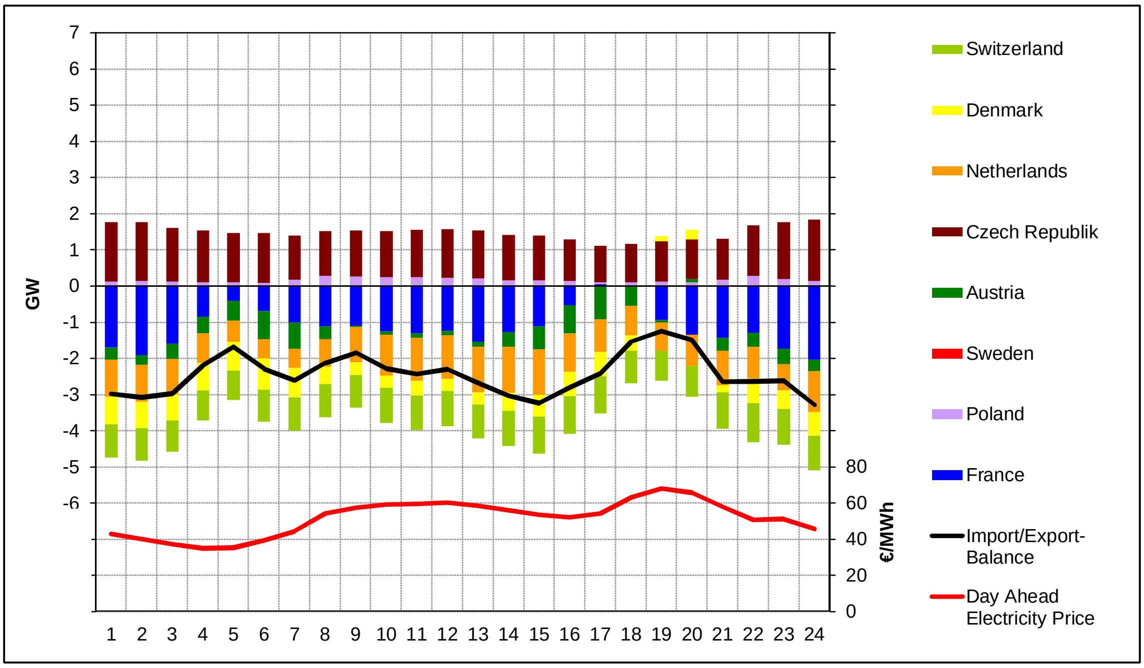
Figure 22 Development of net imports (commercial trade) using a daily average in summer 2010 (13 April 2010 through 30 September 2010)



Source: EEX, EPEX/EEX, ENTSO-E, calculations by Öko-Institut

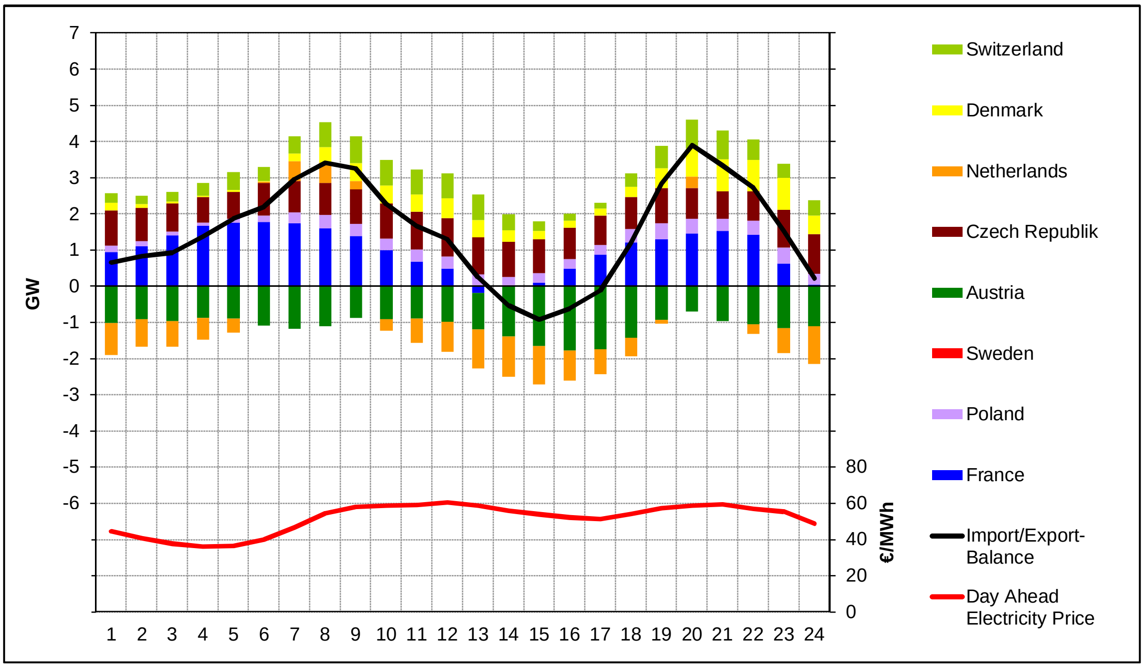
Figure 23 shows the average daily progression of imports and exports in winter 2010/2011. In winter 2010/2011 Germany had an average hourly net export of 3 GW. The exports decrease significantly, especially during the evening peak from 18:00 to 20:00 hours. It is assumed that during this time hydro power plants abroad increase their production.

Figure 23 Development of net imports (commercial trade) using a daily average in winter 2010/11 (1 Oct. 2010 through 31 March 2011)



Source: EEX, EPEX/EEX, ENTSO-E, calculations by Öko-Institut

Figure 24 Development of net imports (commercial trade) using a daily average in summer 2011 (1 April 2011 through 30 September 2011)

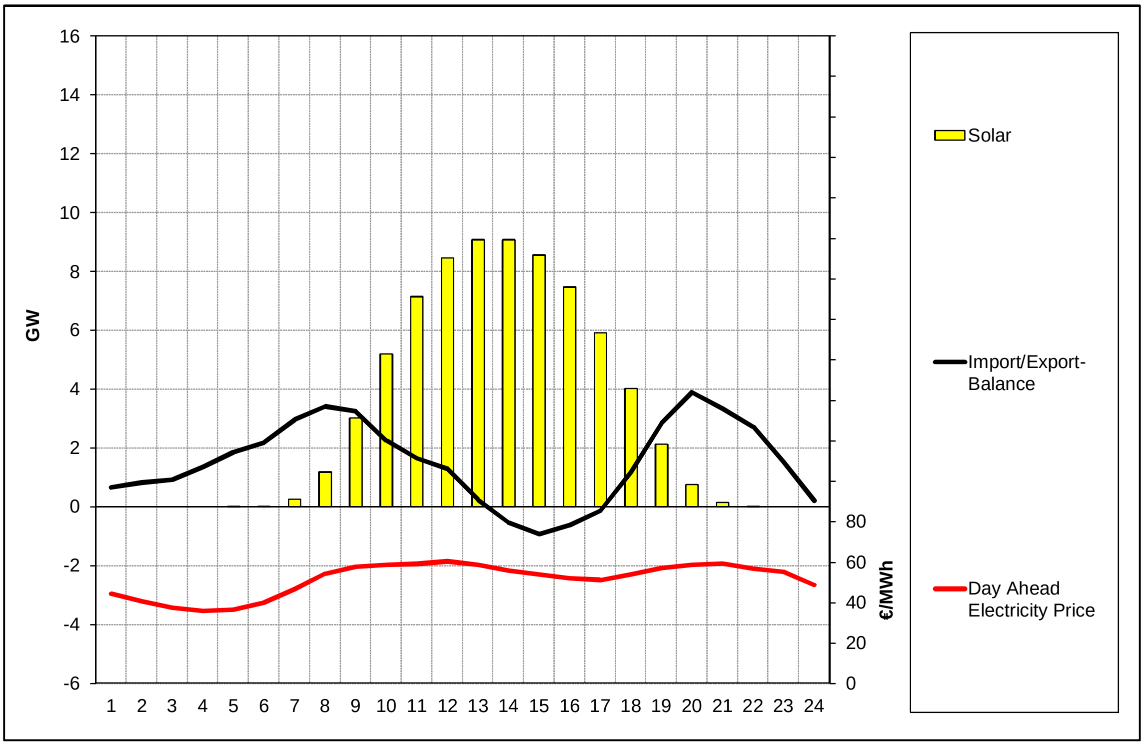


Source: EEX, EPEX/EEX, ENTSO-E, calculations by Öko-Institut

Figure 24 shows the average daily progression of imports and exports in summer 2011. Positive values represent imports and negative values represent exports. On balance, power is exported in the afternoon. Figure 25 makes clear that Germany's imports and exports in summer are very greatly affected by photovoltaic production.

The import balance (imports reduced by exports) attains two peaks in the daily profile. In the morning from 07:00 to 09:00 hours and again in the evening from 19:00 to 22:00 hours, average net imports of up to 4 GW are noted. At night, the net imports fall to below 1 GW, and in the afternoon power is sometimes exported.

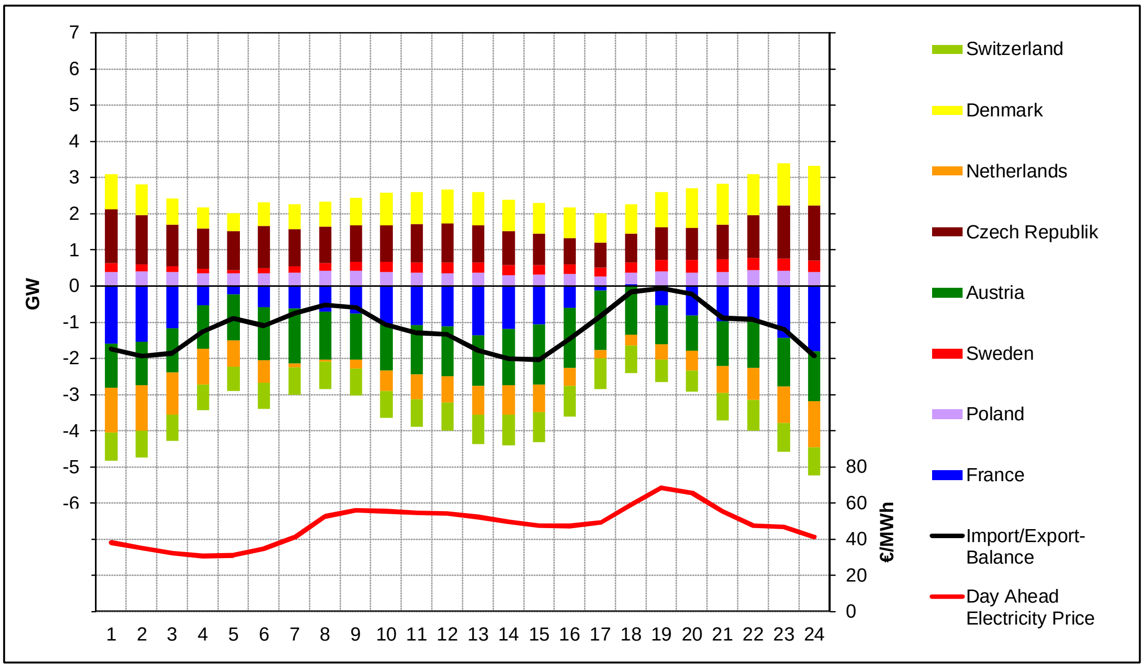
Figure 25 Effect of power generation from photovoltaics on the development of commercial trade in summer 2011 (1 April 2011 through 30 September 2011, each using a daily average)



Source: EEX, EPEX/EEX, ENTSO-E, calculations by Öko-Institut

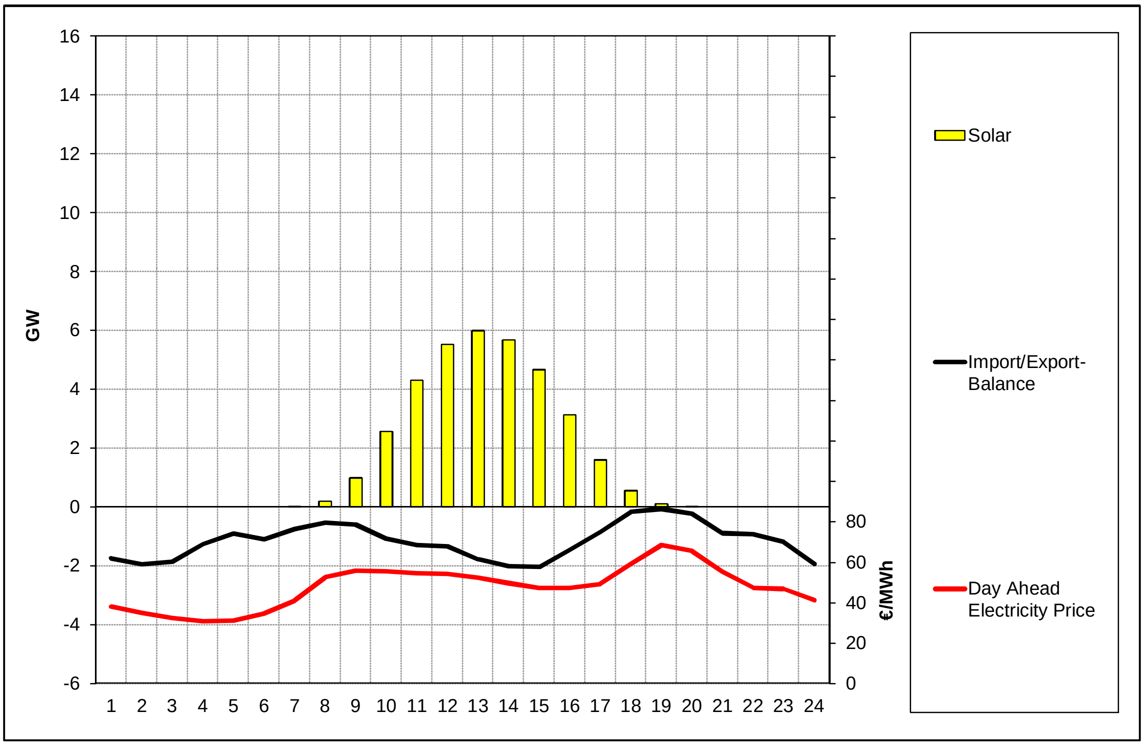
Figure 26 shows the average daily progression of imports and exports in winter 2011/2012. In winter 2010/2011 Germany had an average net export of 1 GW. In comparison to winter 2010/2011 it can be observed in particular that Denmark and Sweden no longer appear as importers, but rather as exporters. This is probably attributable primarily to the greater availability of hydro power plants in Norway and Sweden. Exports to the Netherlands have fallen, whereas exports to Austria have risen. Even though power generation from photovoltaics is less in the winter half year, Figure 27 shows that power generation from photovoltaics is easily correlated with the export balance even in winter.

Figure 26 Development of commercial trade in winter 2011/2012 (1 October 2011 through 31 March 2012)



Source: EEX, EPEX/EEX, ENTSO-E, calculations by Öko-Institut

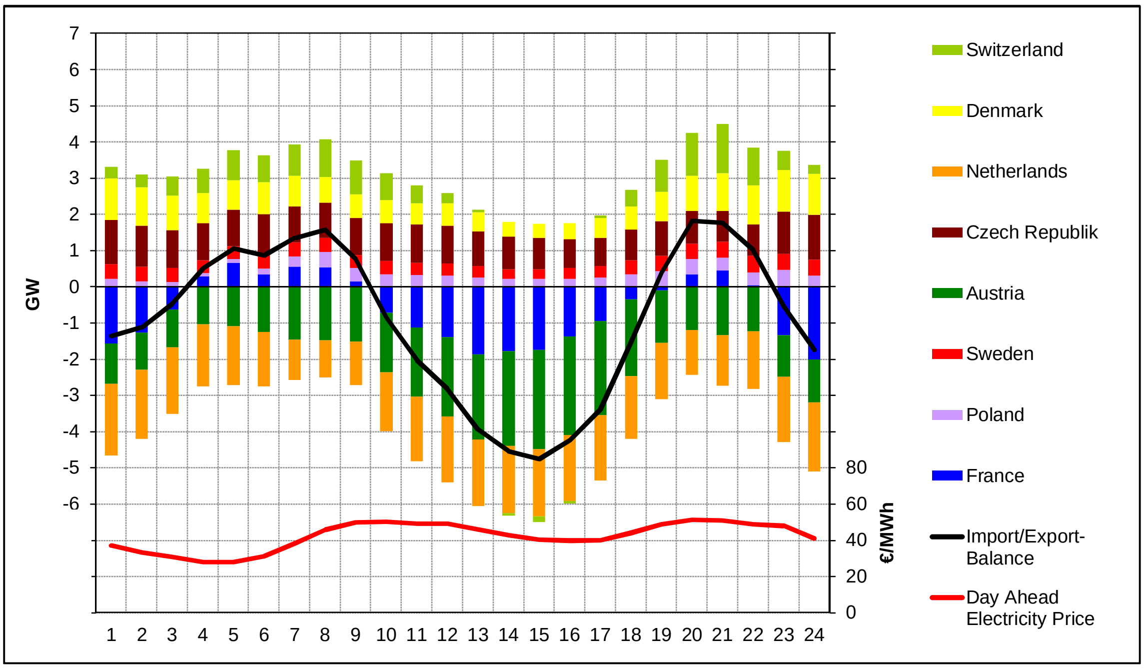
Figure 27 Effect of power generation from photovoltaics on the development of commercial trade in winter 2011/2012 (1 October through 31 March 2012, each using a daily average)



Source: EEX, EPEX/EEX, ENTSO-E, calculations by Öko-Institut

Figure 28 shows the average daily progression of imports and exports in summer 2012. In comparison to summer 2011 it is striking that France in particular is now importing commercial power from Germany in the midday hours.

Figure 28 Development of net imports (commercial trade) using a daily average in summer 2012 (1 April 2012 through 30 September 2012)

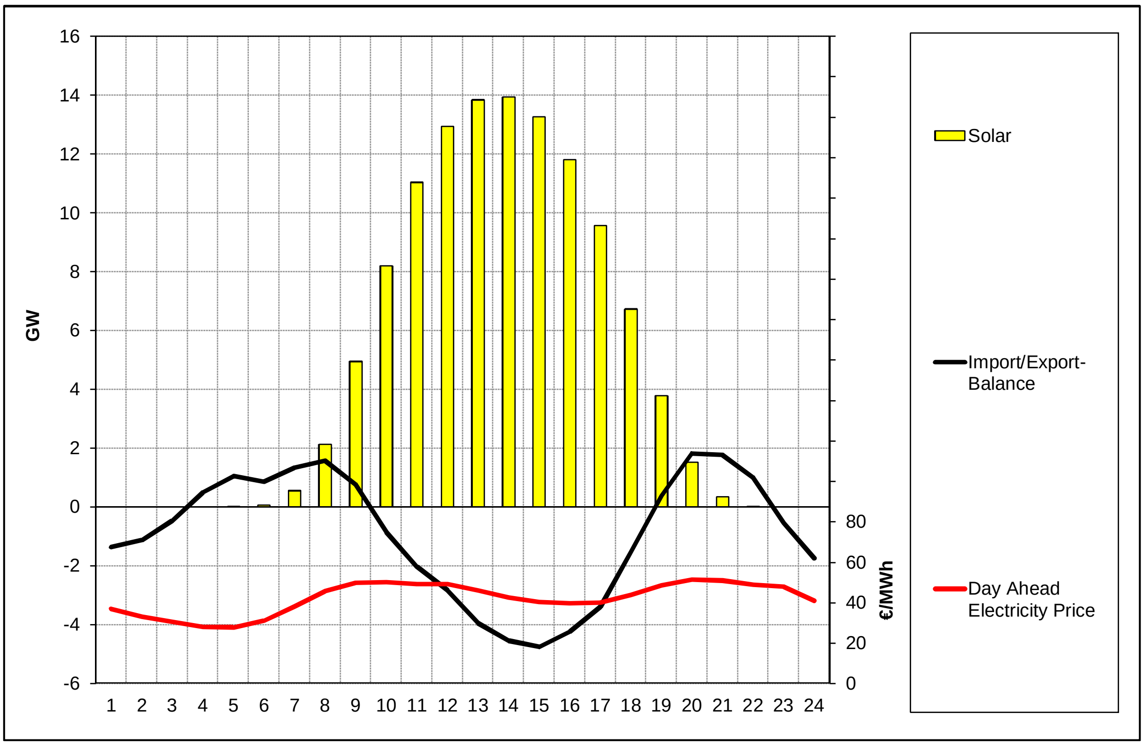


Source: EEX, EPEX/EEX, ENTSO-E, calculations by Öko-Institut

Due to the significant expansion of photovoltaics, the daily average power generation from this source in summer 2012 is clearly greater even than in summer 2011. Figure 29 illustrates that photovoltaics in summer 2012 had a powerful effect on Germany's export balance. Germany is no longer a classical exporter of base load current at night, but rather exports power during the day. In spite of a greater production from photovoltaics, fossil power plants are not stepped down, but rather sell their power production abroad. The financial optimizing of the European power market means that the integration of photovoltaics is occurring partly also in neighboring European states. Thus for German energy suppliers it is less expensive to import power in the morning and evening, than to keep fossil power plants in operation for a few hours. At the same time it appears to be less expensive for foreign operators to import solar power at midday and not to operate their own peak load power plants – or to shift their production to the morning or to the evening.

The effect of photovoltaics also shows up in the electricity prices: The peak price which occurred at 12:00 hours in summer 2011 was shifted to 09:00 in summer 2012 because the electricity prices are already falling again in the midday hours.

Figure 29 *Effect of power generation from photovoltaics on the development of commercial trade in summer 2012 (1 April 2012 through 30 September 2012, each using a daily average)*



Source: *EEX, EPEX/EEX, ENTSO-E, calculations by Öko-Institut*

5 Special Analyses

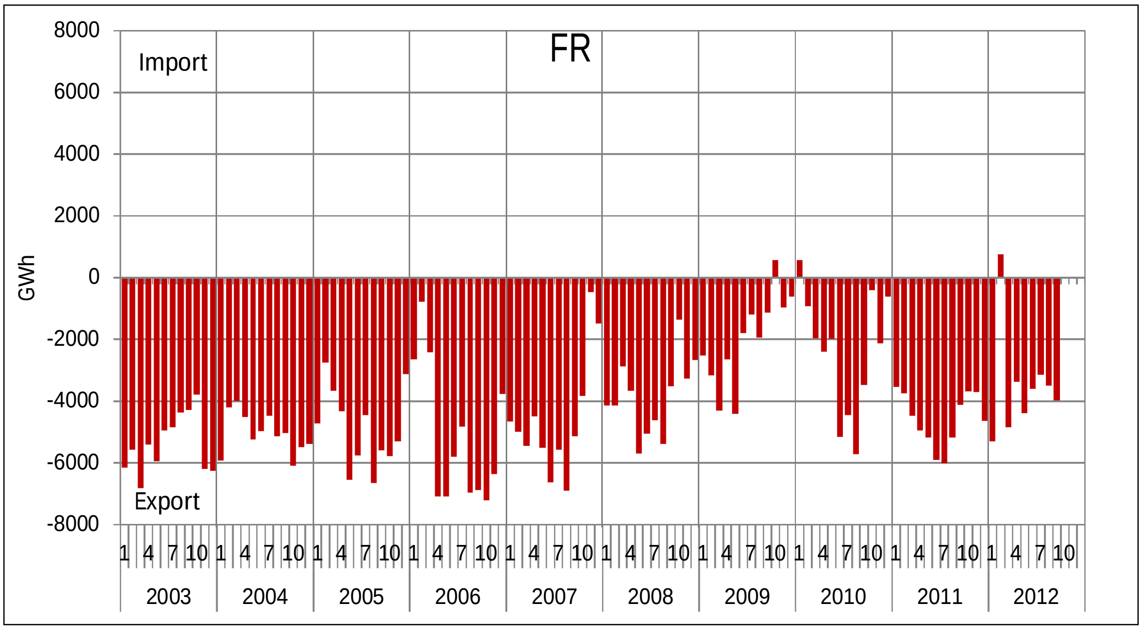
5.1 France

The question of whether "additional nuclear power is being imported from France" plays a central role in the debate on imports and the shutdown of several German nuclear power plants. Upon closer consideration two different questions are relevant, namely that of "power from France" and the question of "nuclear power." First we will present below a detailed analysis of the power exchange with France.

France is traditionally a power exporting country: Figure 30 shows the monthly balance of all power imports and exports by France with its neighbors (Spain, England, Belgium, Germany, Switzerland, Italy) from January 2003 until September 2012. France was a net exported for nearly every month during this period. In a historical perspective, 2011 does not represent any particular exception; however, comparatively large net exports were noted in the winter months of 2011. In contrast, both preceding years 2009 and 2010 display comparatively small exports and the months of October 2009, January 2010 and February 2012 are even the only ones with net imports to France.

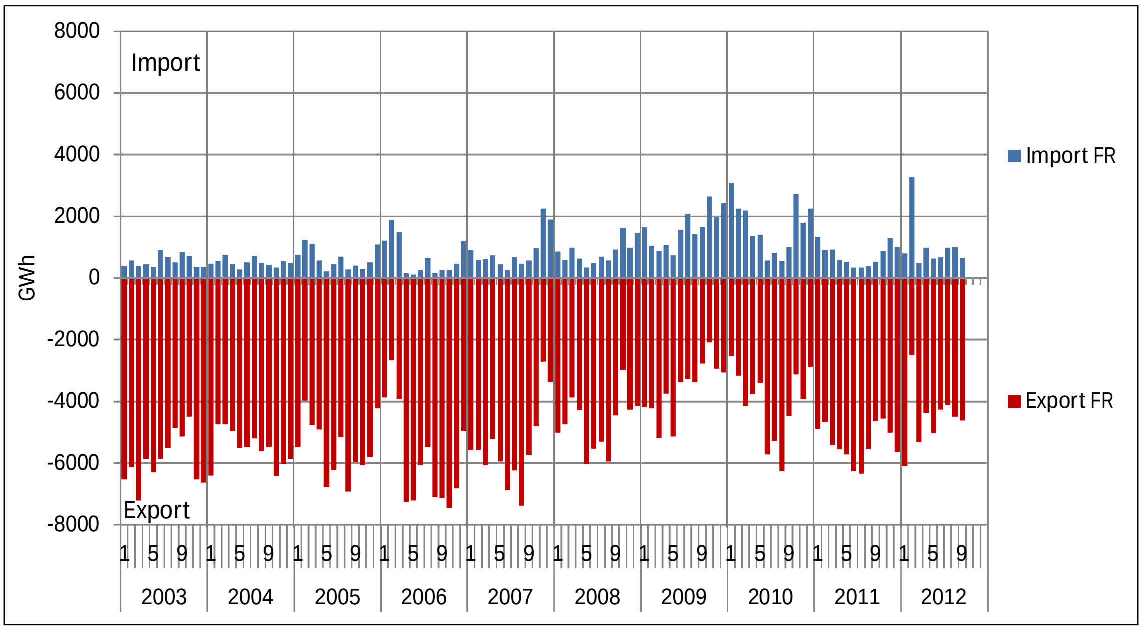
A seasonal pattern is not so greatly pronounced as in Germany. However, beginning in 2005 developments of particularly low exports can be observed in individual winter months. During the increasing power demand in winter, France uses its power plants in most years primarily to cover its domestic consumption.

Figure 30 Monthly import-export balance (physical flows) from/to France, 2003 through September 2012



Source: ENTSO-E, calculations by Öko-Institut

Figure 31 Monthly imports and exports (physical flows) from/to France, 2003 through September 2012



Source: ENTSO-E, calculations by Öko-Institut

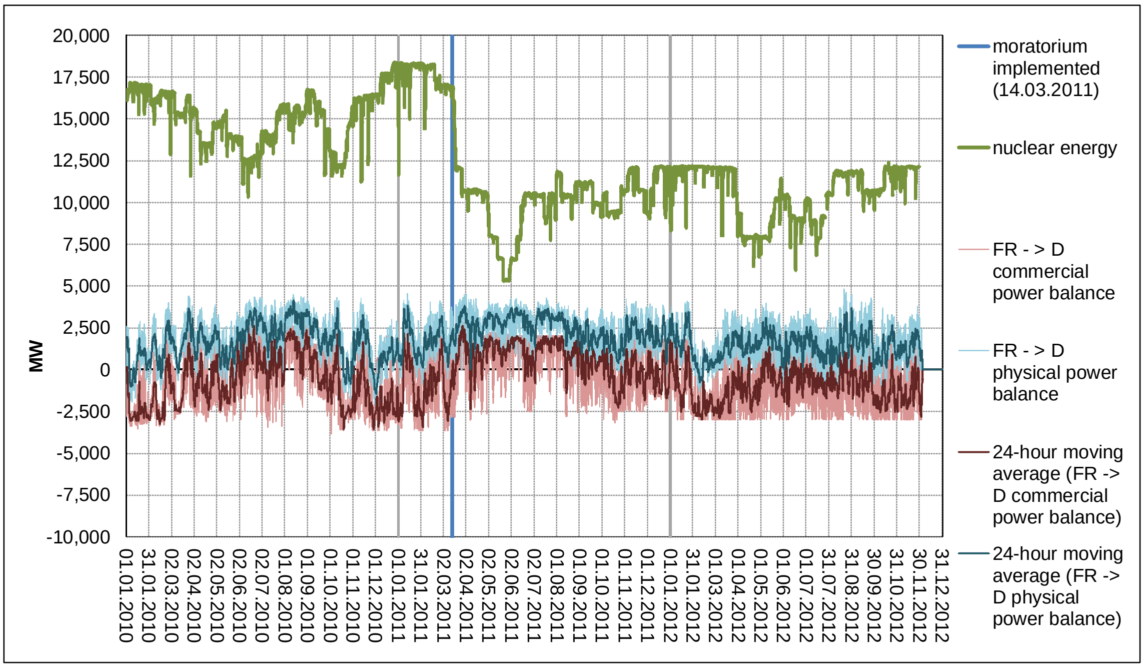
The separate representations of France's imports and exports in Figure 31 shows that in recent years between 2000 GWh and as much as 7000 GWh have been exported. However, physical power imports also flow to France, and increasingly so in winter months in recent years. An import maximum is observed in February 2012. But even in these months power exports still continue.

5.1.1 Transit flows from France through Germany to Switzerland

Figure 32 shows the production of German nuclear power plants together with the physical and commercial net power balance between Germany and France from January 2010 until November 2012. Positive values mean net imports from France to Germany, and negative ones mean net exports from Germany to France. As for the overall net power balance in Germany, there is a net development in the balance with France toward greater imports from France to Germany in the summer months and toward smaller imports or even exports in winter.

It is striking that the commercial net exchange differs throughout from the physical power flow. It appears systematically lower than the physical flow, on average by about 2.2 GW. For example, here are hours when physical power is indeed flowing from France to Germany, but at the same time, commercial power is sold from Germany to France.

Figure 32 Hourly net power flows ***from France to Germany*** *and moving average over 24 hours (commercial and physical) and generation from nuclear power plants from January 2010 through November 2012*



Source: EEX Transparency data, ENTSO-E, calculations by Öko-Institut

Table 3 shows the annual total of physical and commercial net power exchanges. Accordingly, in 2010 an amount of 14 TWh flowed physically from France to Germany, but commercially just barely 7 TWh was sold in the other direction from Germany to France. In 2011 net commercial imports of 2.4 TWh were noted from France, but this value was an order of magnitude smaller than the net physical imports of 20 TWh. In the months of January to November of 2012 on balance there were 11 TWh of physical flows from France to Germany, whereas 8 TWh was traded from Germany to France.

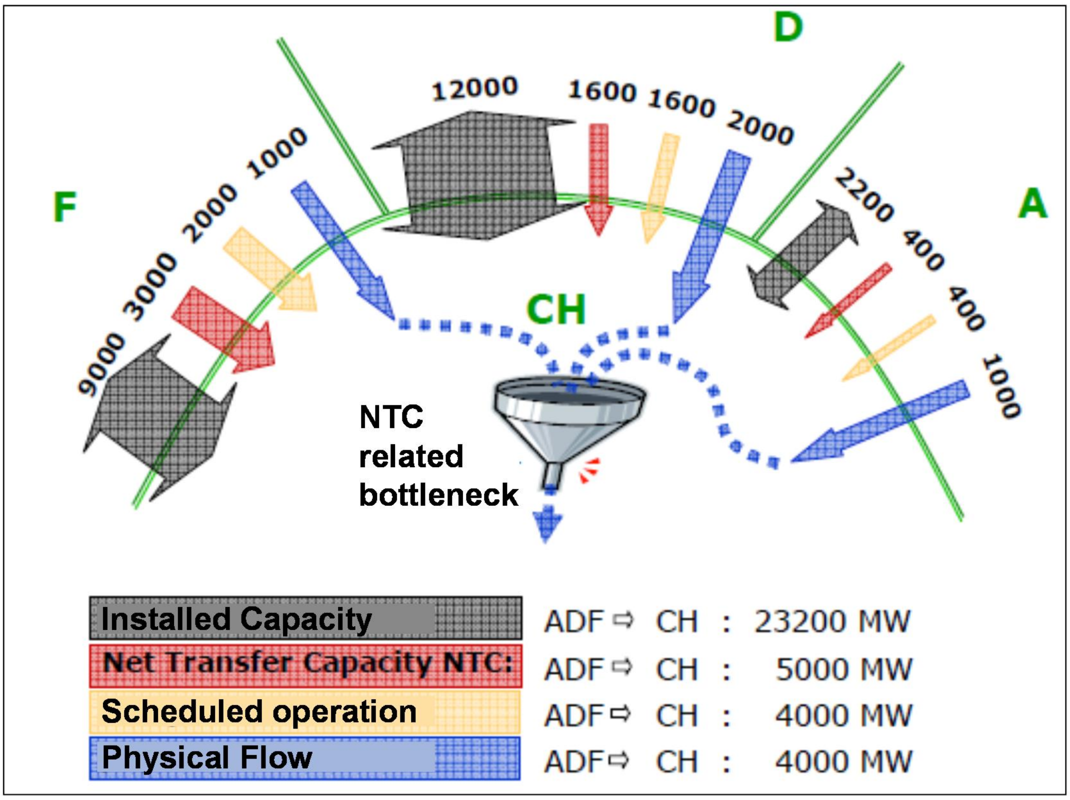
Table 3 Annual physical and commercial net imports from France to Germany based on hourly values from ENTSO-E

Year	**Net power exchanges France - Germany**	
	physical *GWh*	**commercial** *GWh*
2010	14,242	-6,716
2011	20,006	2,396
Jan. - Nov. 2012	11,237	-8,070

Source: ENTSO-E, calculations by Öko-Institut

These differences can be explained by the interaction of several circumstances.

Figure 33 Difference between commercial and physical transmission capacity between Germany and Switzerland



Source: Swissgrid (2007), translation by Öko-Institut

When all interconnectors with neighboring countries are fully utilized, internal bottlenecks appear in the grid in Switzerland. In particular, the transmission capacity over the Alps to the south is limited.[9] Thus to prevent internal grid overloads imports to Switzerland from the north are limited. As illustrated in Figure 33, the “NTC-related bottleneck” within Switzerland amounts to 5 GW. This means that 5 GW can be reliably transported through Switzerland. Thus the total sum of imports from France, Germany and Austria into Switzerland is limited to 5 GW. The transmission grid operators have divided this available transport capacity as follows: From France to Switzerland a value of 3 GW may be imported, from Germany to Switzerland the value is 1.6 GW and from Austria to Switzerland 0.4 GW. The physical transmission capacity of a total 23.2 GW (with 12 GW of this between Germany and Switzerland, 9 GW between France and Switzerland, and 2.2 GW between Austria and Switzerland) is much greater than the transmission capacity available for commercial trade. Thus France is allocated over 60% of the transport capacity for commercial trade, whereas France’s proportion of the physical transmission capacity amounts to only 40%. Germany is allocated only over 32% of the transport capacity for commercial trade, whereas the proportion of the physical trans-

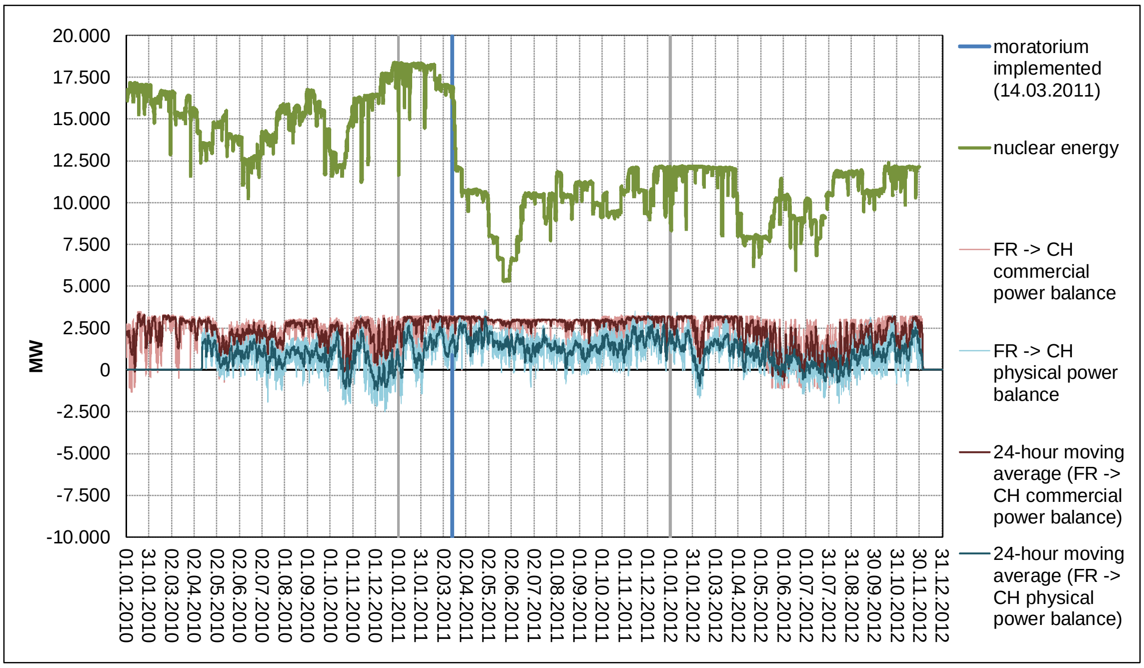
9 Thus the grid expansion currently planned in Switzerland concentrates on increasing the internal north-south transmission capacity (Swissgrid 2012).

mission capacity amounts to 52%. It is readily apparent here that France can use a disproportionately large share of the import capacity into Switzerland, whereas Germany has available only a sub-proportionate share.

This disequilibrium in the allocation of available transport capacities results in transit flows. This means that the flow of power is divided to several parallel conductors so that the resistance is minimized. Therefore the power does not flow directly from France to Switzerland, but rather partly also flows over a longer transport route. This mechanism of transit flows is also evident in the historical data. Figure 34 shows the physical and the commercial balance between France and Switzerland since 2010. In most hours, France is exporting to Switzerland. The physical and commercial power flows differ here as do those between France and Germany. On average, approx. 1.5 GW more power is sold hourly from France to Switzerland than flows physically.

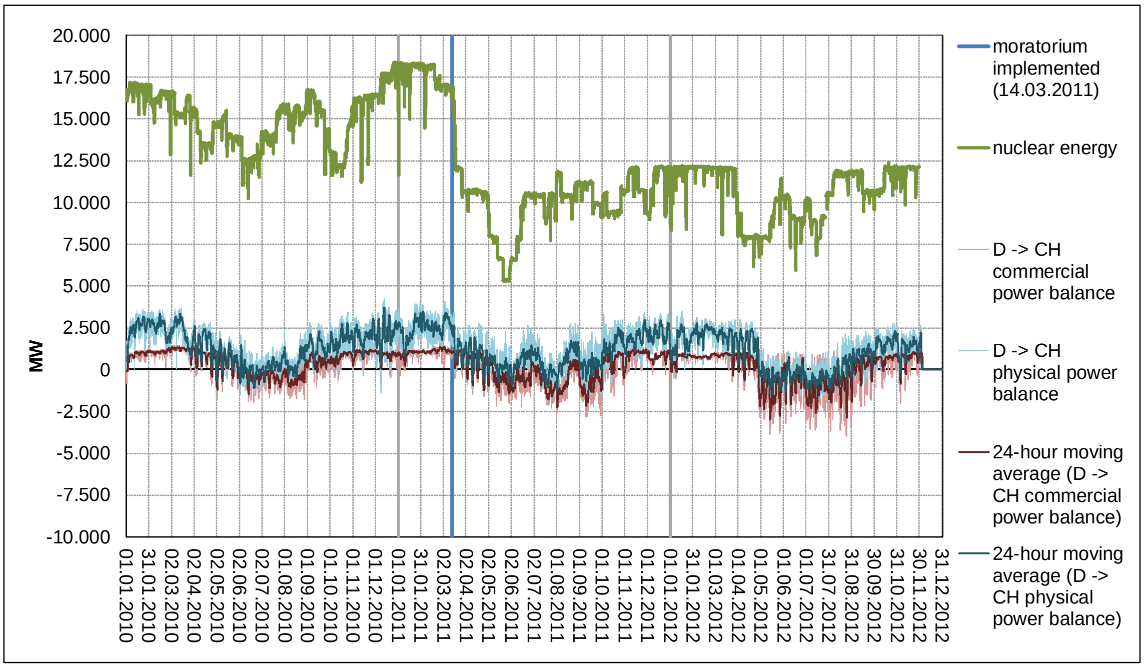
Also the physical and the commercial balances for the power exchange between Germany and Switzerland, represented in Figure 35, differ from each other. On average since 2010 about 1 GW more flows physically from Germany to Switzerland than is traded.

*Figure 34 Hourly net power flows **from France to Switzerland** and 24-hour moving average (commercial and physical) and generation from nuclear power plants from Jan. 2010 through Nov. 2012*



Source: EEX Transparency data, ENTSO-E, calculations by Öko-Institut

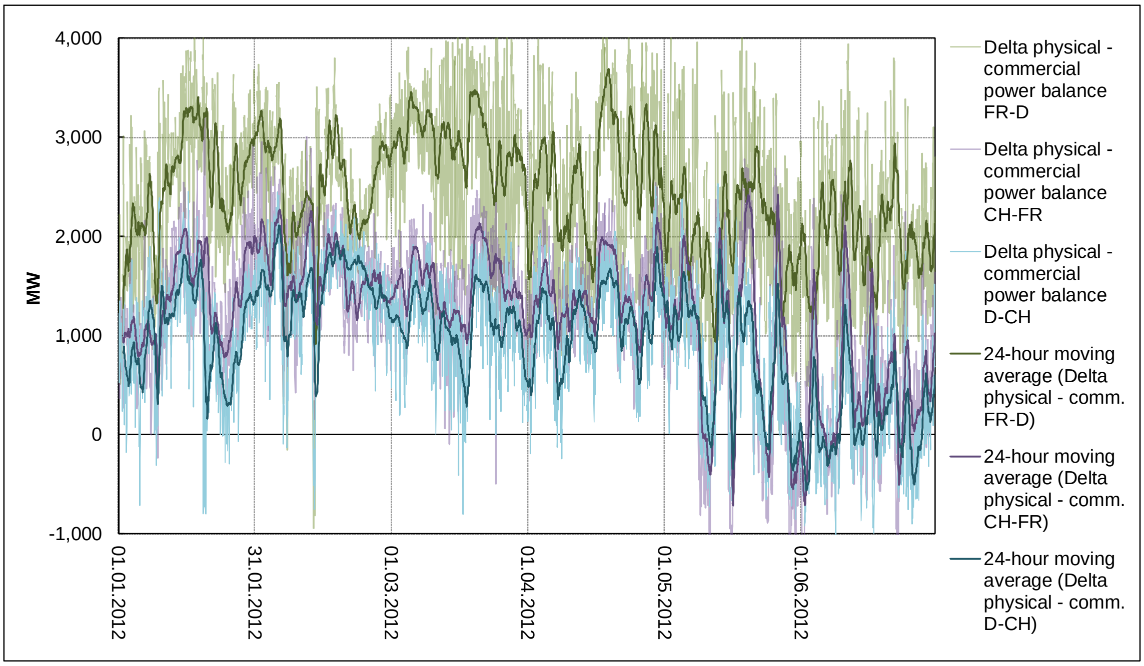
Figure 35 *Hourly net power flows* ***from Germany to Switzerland*** *and 24-hour moving average (commercial and physical) and generation from nuclear power plants from Jan. 2010 through Nov. 2012*



Source: *EEX Transparency data, ENTSO-E, calculations by Öko-Institut*

Figure 36 presents an example for the first half of 2012 showing the difference between net commercial and net physical balance for the three previously discussed borders of France/Germany, Germany/Switzerland and Switzerland/France. Evidently there is a definite correlation between the differences at the Switzerland/France border and the Switzerland/German border: The difference between the amount of electricity sold and the amount which physically flows from France to Switzerland, corresponds in quantity and profile to the difference between the amount traded and the amount which flows physically from Germany to Switzerland.

Figure 36 Delta between commercial and physical power flows for France-Germany, Germany-Switzerland and Switzerland-France in the first half of 2012

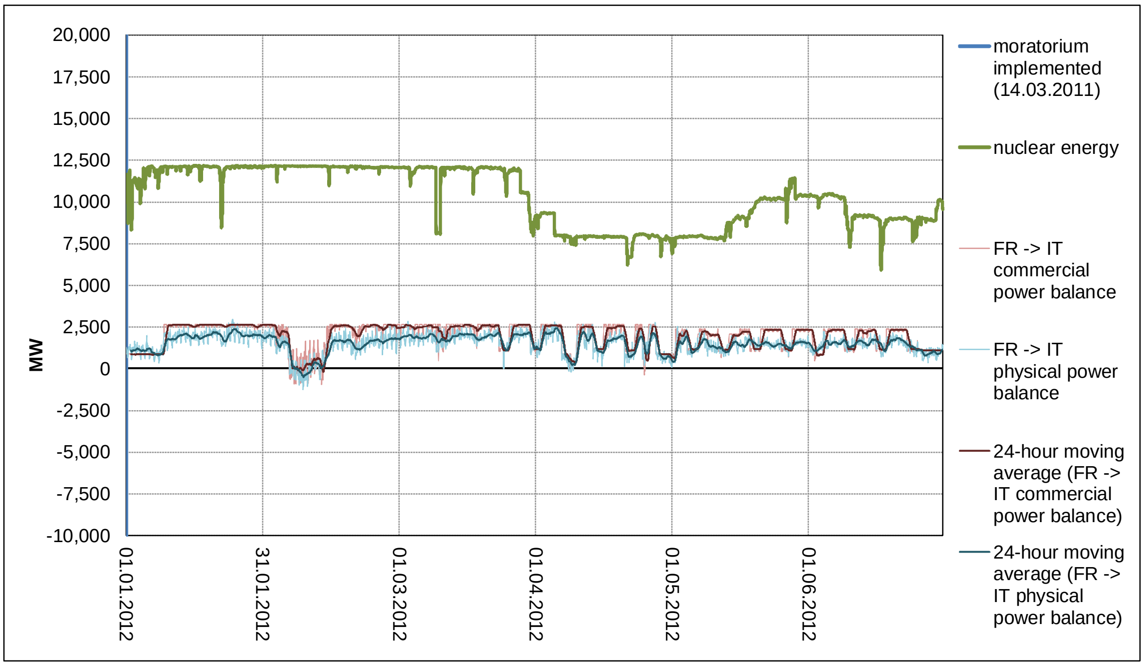


Source: ENTSO-E, calculations by Öko-Institut

The deviation between physical and commercial flow at the German-French border interconnectors is thus only partly explained. Its profile does indeed resemble the time profile of the differences at the Swiss/French and Swiss/German borders, but it is higher throughout. An additional analysis would be needed here.

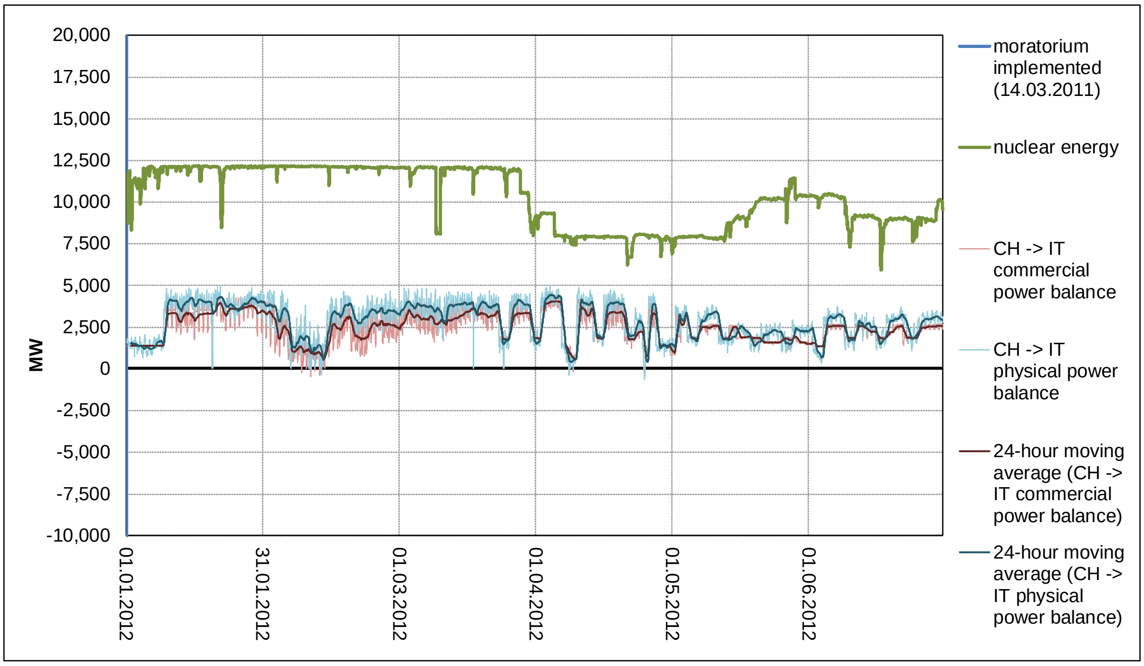
By the way, a similar correlation also exists for the differences between the physical and commercial power flows at the France/Italy and Switzerland/Italy borders, but at a lower level. Figure 37 shows as an example the balance of commercial and physical power flows from France to Italy for the first half of 2012. France systematically sells more power to Italy than flows physically. A similar deviation in the opposite directly occurs between Switzerland and Italy. Switzerland exports physically more power to Italy than it trades, as shown in Figure 38.

Figure 37 Hourly net balance of power flows ***from France to Italy*** *and also 24-hour moving average (commercial and physical) and generation from nuclear power plants in the first half of 2012*



Source: EEX Transparency data, ENTSO-E, calculations by Öko-Institut

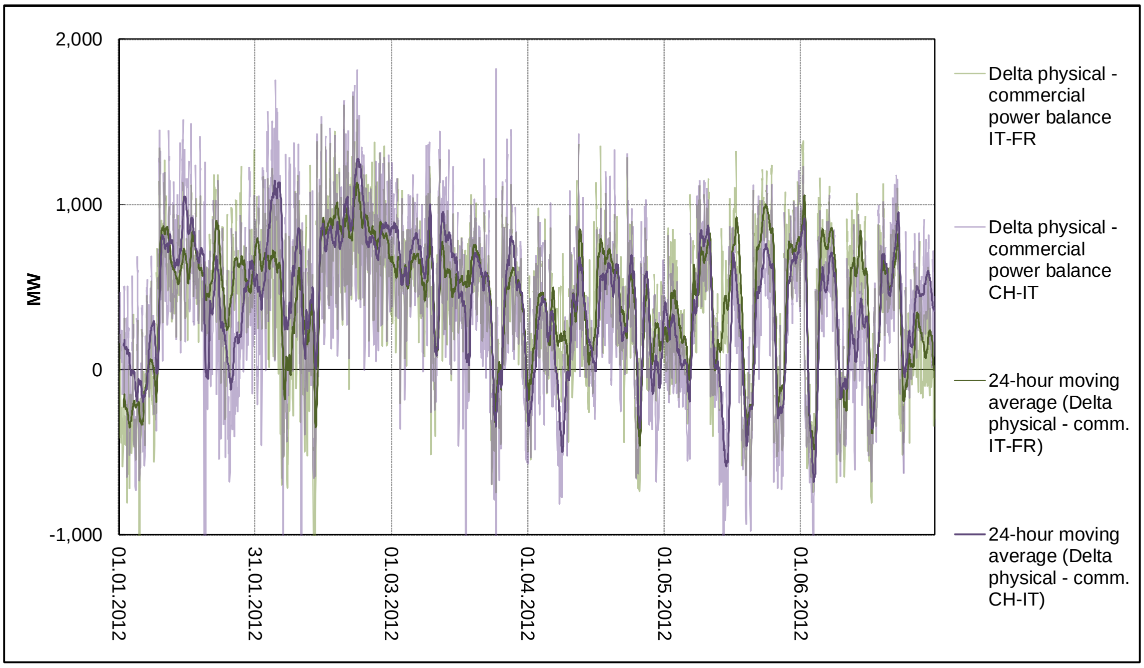
Figure 38 Hourly net balance of power flows ***from Switzerland to Italy*** *and also 24-hour moving average (commercial and physical) and generation from nuclear power plants in the first half of 2012*



Source: EEX Transparency data, ENTSO-E, calculations by Öko-Institut

The differences between physical and commercial power flow at the France-Italy and Switzerland-Italy borders are likewise found in Figure 39 for the first half of 2012 and exhibit a definite correlation. And thus there are also physical transit flows of power through Switzerland which were sold by France to Italy. However, these hourly transit flows of at least 400 MW on average for both borders are lower than the previously indicated transit flows from France via Germany to Switzerland of roughly 1 GW on average.

Figure 39 Difference between commercial and physical power flows for France-Italy and Switzerland-Italy in the first half of 2012



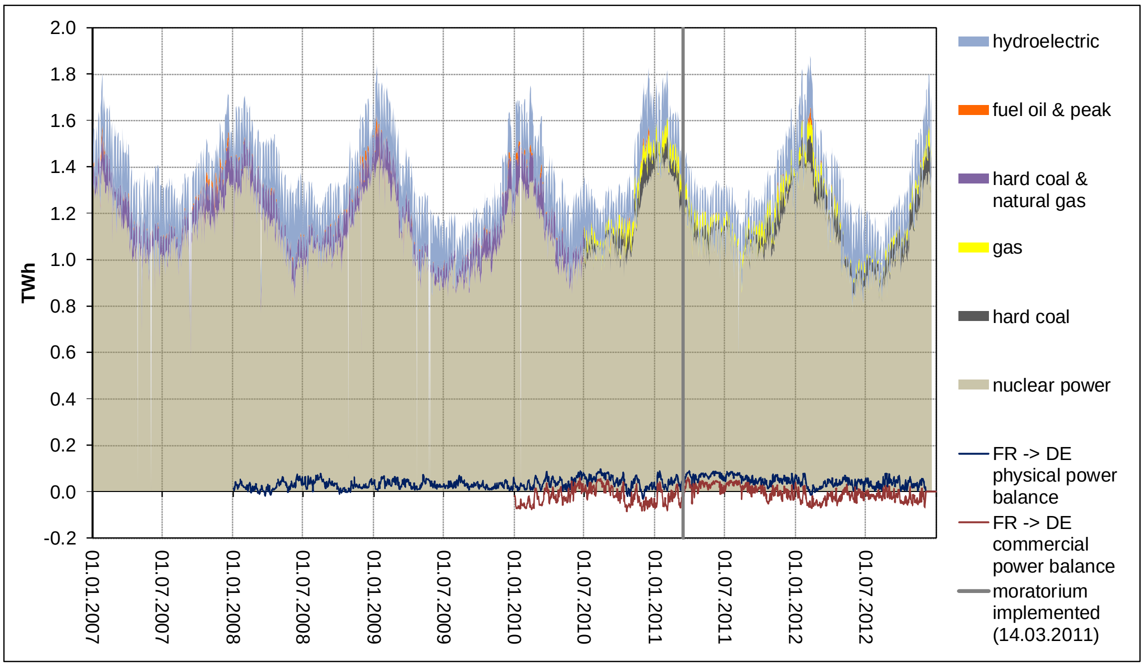
Source: ENTSO-E, calculations by Öko-Institut

5.1.2 Production of French power plants and import-export balance

Associated with the question of imports from France there is always the question of whether such imports pertain to French “nuclear power.” In order to analyze this more precisely, the production of the French nuclear power group will be discussed below in connection with French imports and exports.

Figure 40 shows the daily power production in France since 2007 based on various fuels. The majority originates from nuclear power plants which also follows a clear seasonal development: In winter the French nuclear power plants produce up to about 1.4 TWh of power daily, the maximum output in the period under discussion is a bit more than 61 GW. In summer the power production drops significantly, down to about 1 TWh per day. The physical and the commercial import-export balance between France and Germany is likewise shown in Figure 40.

Figure 40 Daily production data from French power plants from 2007 through November 2012 and physical and commercial import balance for France - Germany



Source: RTE, calculations by Öko-Institut

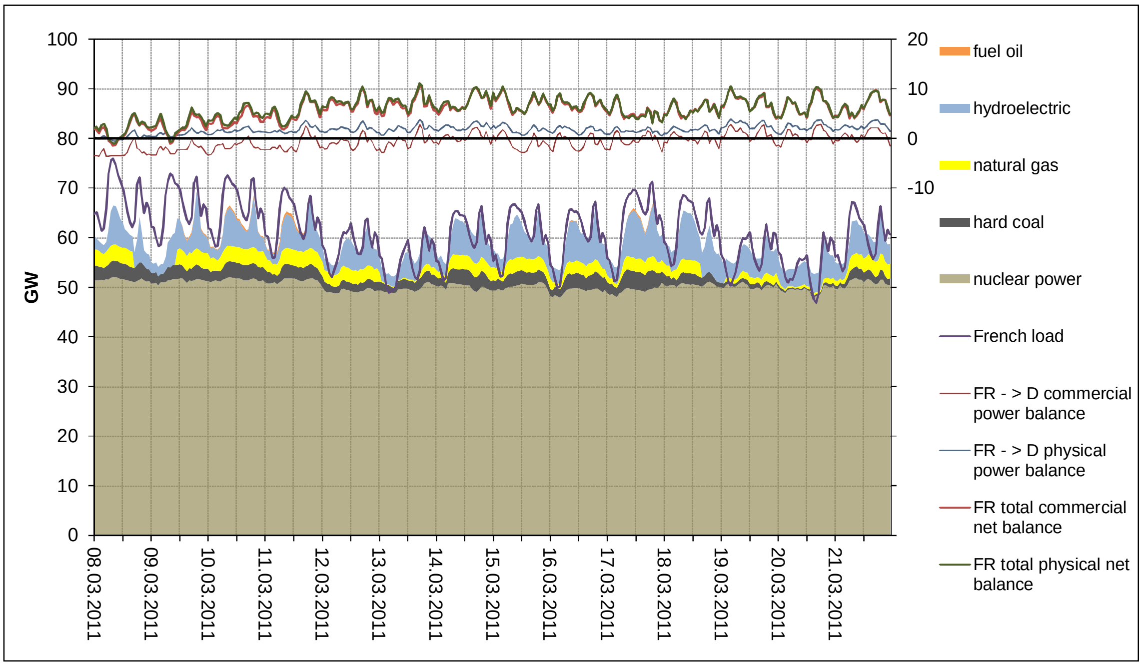
For a somewhat more detailed analysis, Figure 41 presents a period of two weeks before and after the decision for the moratorium in Germany in March 2011. In addition to the production by French power plants, the Figure also shows the French net power exchange overall, and the net exchange from France to Germany is presented on a second axis. The daily course of French production is easily discernible: A decrease at night is followed by a morning peak, a midday drop and an evening peak. The higher level of production on the four sequential weekdays compared to the weekends (12/13 March and 19/20 March) is clearly visible.

Three different aspects are prominent: Firstly, the physical and the commercial net power flow from France to Germany actually rose slightly in the period in question. But even in the week of the moratorium, commercial power was traded in peak load hours from Germany to France.

Secondly, French exports increase when the production in France decreases. The export balance mainly shows peaks during the nighttime valleys and the afternoon valleys of power production. In these hours the production from all power plants decreases, even in the nuclear power plants, in comparison to the preceding hours. Therefore the power plants are not brought online for exporting, but rather the power which is exported, has its origin in power plants that were not powered down as much as would actually have been possible if it were solely a matter of meeting domestic demand. This can be explained through the interaction of technical-economic parameters of the power plants, such as start-up and shutdown gradients, costs for start-up and shutdown procedures, and the position of these power plants in the combined merit-order of the countries participating in market coupling (cf. Section 2).

Thirdly, in all the hours in question, other conventional power plants are also in operation which are more expensive in the merit order than nuclear power plants. If these power plants likewise respond to the regular power market, then the fact that they are in operation at all will mean that the (short-term lower-cost) nuclear power plants will be producing as much power as possible, but will not be enough to cover the load. This also means: Additional load would not be covered from nuclear power plants in this situation, rather by the next available bordering power plant, which is a gas, hydro- or oil-fired power plant, depending on the situation in the two weeks under consideration. Activities in the power market alone cannot explain that the production by nuclear power plants *in toto* displays any hourly fluctuations; rather it is probably attributable to the offering of system services.

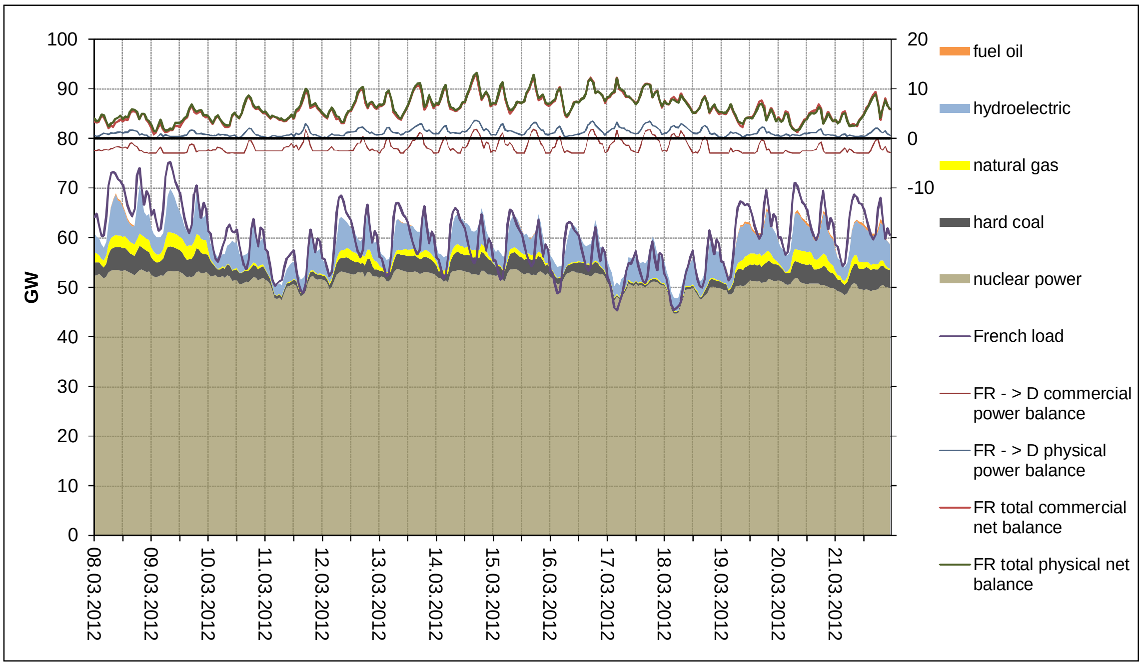
Figure 41 *Hourly power production in France according to energy carriers; on the second axis the total export balance for France and the net power exchange with Germany in March 2011*



Source: *RTE, ENTSO-E, calculations by Öko-Institut*

Note: *Data for gas power plants from 8 March 18.00 hours through 9 March 11.00 hours and for 18 March 17.00 hours to 19 March 02.00 hours is not available.*

Figure 42 Hourly power production in France according to energy carriers; on the second axis the total export balance for France and the net power exchange with Germany in March 2012

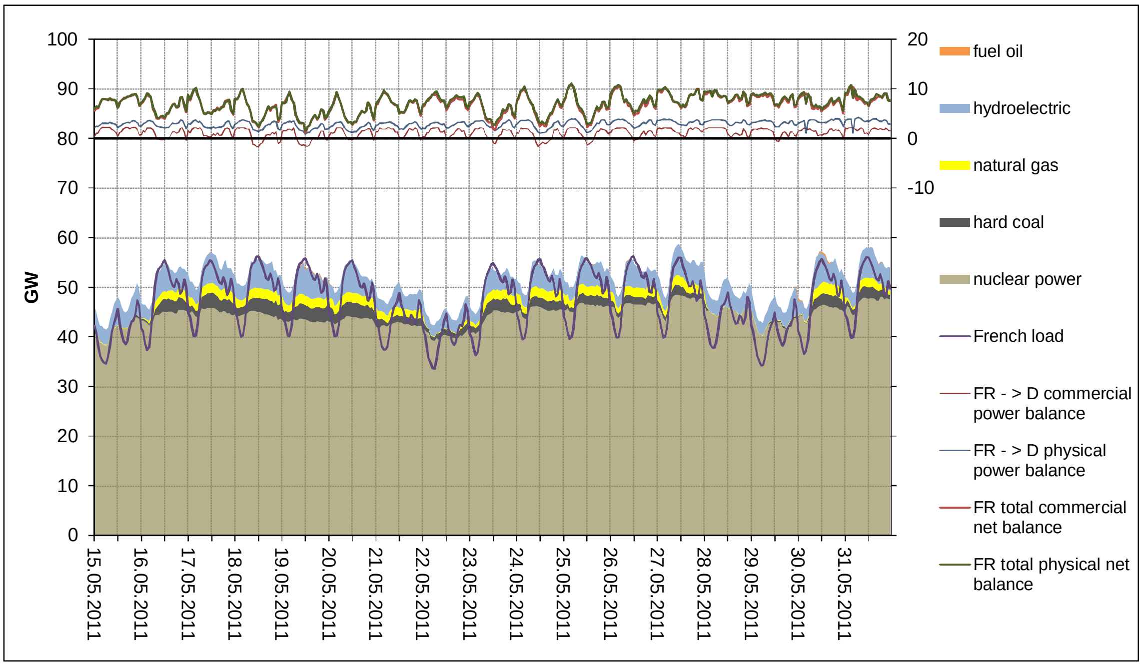


Source: RTE, ENTSO-E, calculations by Öko-Institut

For comparison, the same time period is also presented in Figure 42 for 2012. In principle, the same effects can be observed as in the previous year: France buys power from Germany when their own consumption – and thus also their own production – is high. In those hours when French power production drops, the physical exports and the direction of commercial power flows reverses from being imports from Germany, to an export to Germany.

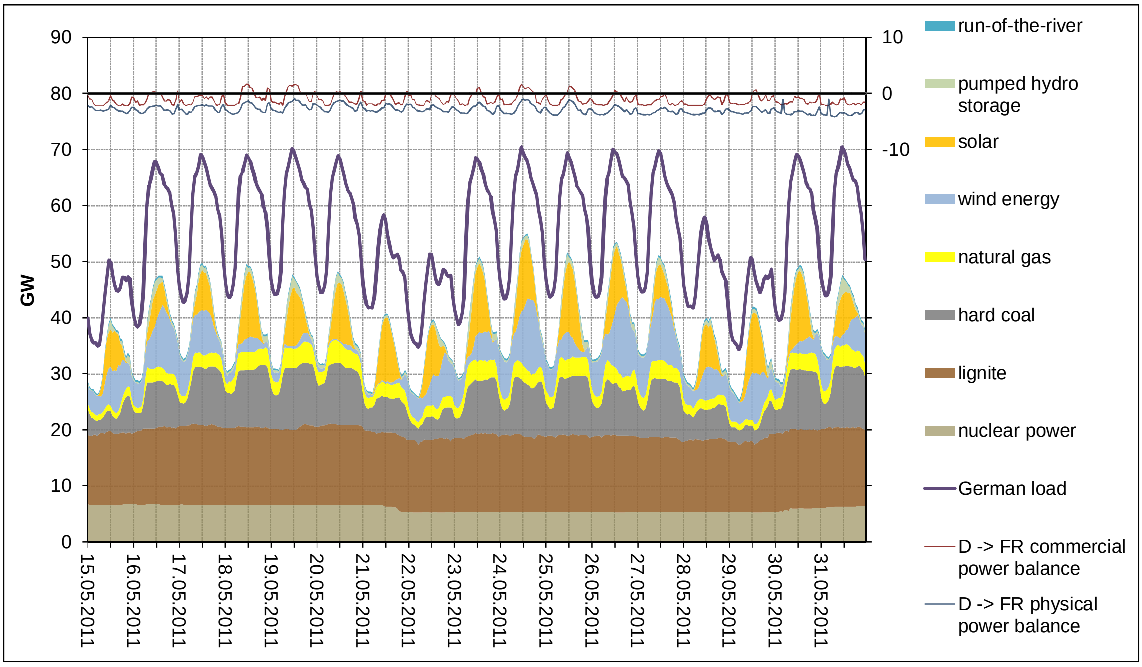
The minimum power production from German nuclear power plants in 2011 occurred, as indicated in Section 3.2, due to long-planned service-related work conducted from 21 May through 31 May when total capacity of approx. 5 GW was in operation. The production from French power plants and the development of the French net import-export balance and the net exchange with Germany is also illustrated for this time period in Figure 43. For comparison, the power production in Germany and the net exchange with France – here with a reverse sign – is presented in Figure 44 for the same time period.

Figure 43 Hourly power production in France according to energy carriers; on the second axis the total export balance for France and the net power exchange with Germany in May 2011 (exports positive)



Source: RTE, ENTSO-E, calculations by Öko-Institut

Figure 44 Hourly power production in Germany according to energy carriers, grid load; and on the second axis the total export balance with France in May 2011 (exports positive)



Source: EEX Transparency data, ENTSO-E, calculations by Öko-Institut

Thus, although from 21 May onwards only 5 GW of nuclear power plant power were still in operation in Germany, electricity was still traded commercially from Germany to France during several hours in this time frame – especially when French demand, and thus also the production, was particularly high. In Germany these were likewise hours of high demand. However, in these hours in the period in question a lot of solar and/or wind power is also in production, in addition to conventional power.

Net imports from France to Germany reached their greatest values in the second half of May 2011 in the hours from 4 to 5 in the morning, and in the hours between 20 and 21 at night. But in particular these early morning hours are ones with low to average demand and power production in Germany, when domestic power plant capacities are still widely available.

In France during those two weeks, fossil power plants were also in operation in all hours, except on the weekends. The French marginal power plant thus cannot have been a nuclear power plant during these hours. On weekends this cannot be precluded; indeed hydro power plants also supplied power here, but it is possible that their short-term marginal costs are below those of nuclear power plants if we are dealing, for example, with run-of-river power plants or reservoir hydro power plants (without pump) with full water reservoirs.

Overall the following conclusion can be drawn from the preceding analyses:

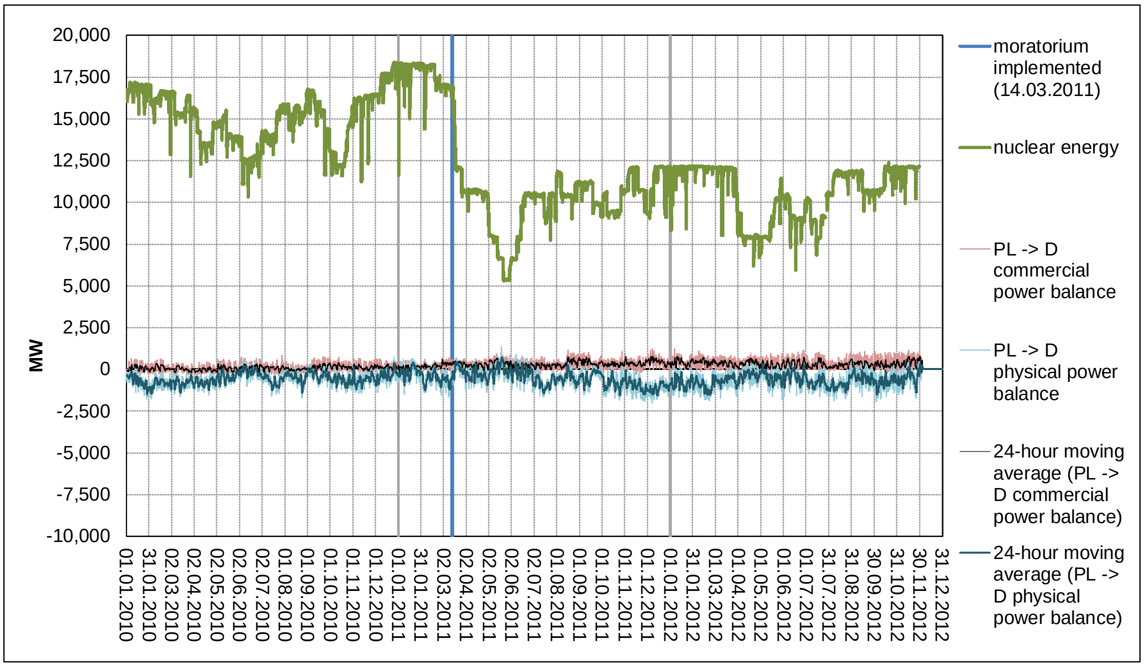
Power deliveries from France to Germany do not occur based on any particular deficit of power plant capacities in Germany. Physical and also commercial power flows from France to Germany occur increasingly in situations when French power plants have already reduced their production. Conversely, reduced physical flow from France to Germany, or even commercial power flow from Germany to France occurs in situations of high French demand, or respectively high French power production. In Germany these are chiefly hours with high solar power production.

5.2 Loop Flows from north Germany via Poland, Czech Republic and Austria to south Germany

In conjunction with the phase-out of nuclear energy there is also a discussion of power imports from the Czech Republic which likewise has substantial nuclear power plant capacities in operation. In addition, the expansion of renewable energies brings up the question of how the power exchange with all east European neighboring states will change due to the energy transformation. In particular the phenomenon of loop flows comes up; this question will be discussed in greater detail below.

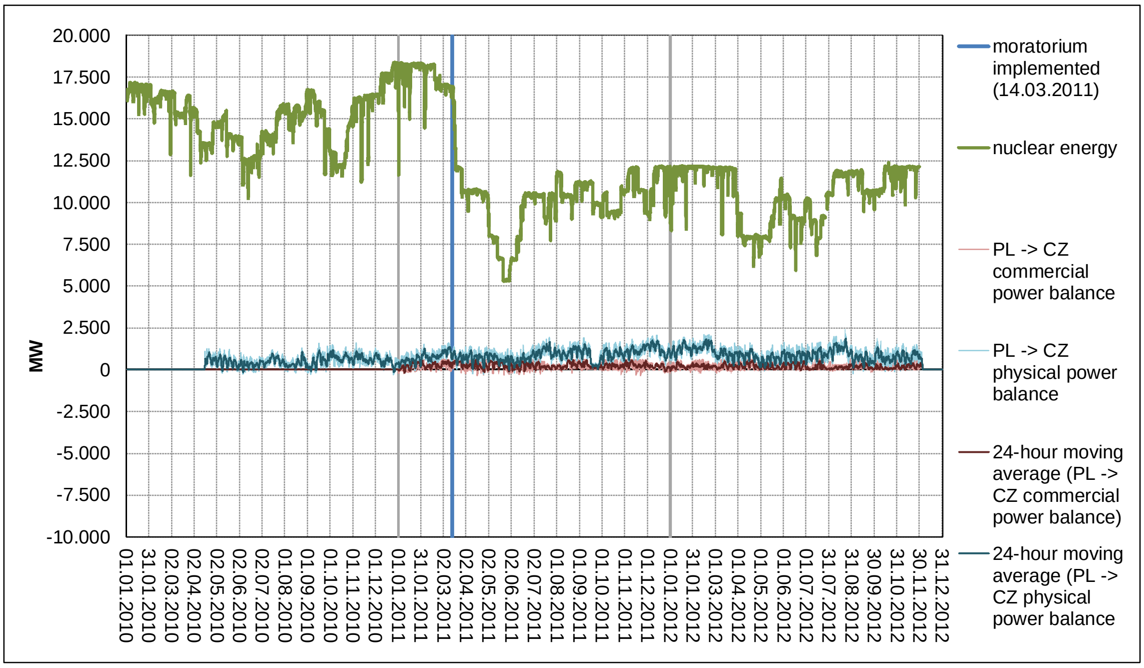
Figure 45 shows the physical and commercial net balance between Germany and Poland. Here too, there is a deviation between commercial and physical power flows in the order of 1 GW. Whereas generally a low level of power is imported from Poland to Germany, the physical flow is frequently from Germany to Poland. This was the case in particular in December 2011 and also again in 2012.

*Figure 45 Hourly net power flows **from Poland to Germany** and 24-hour moving average (commercial and physical) and production from nuclear power plants from January 2010 through November 2012*



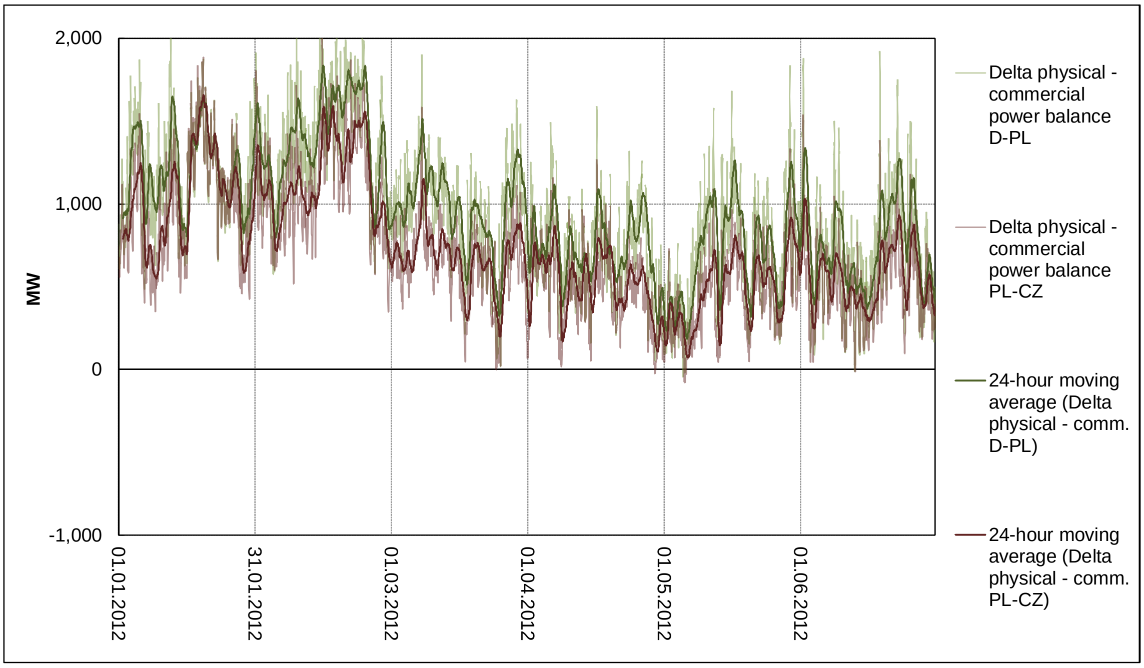
Source: EEX Transparency data, ENTSO-E, Calculations by Öko-Institut

*Figure 46 Hourly net power flows **from Poland to the Czech Republic** and 24-hour moving average (commercial and physical) and production from nuclear power plants from January 2010 through November 2012*



Source: EEX Transparency data, ENTSO-E, calculations by Öko-Institut

Figure 47 Delta between commercial and physical power flows for Germany-Poland and Poland-Czech Republic in the first half of 2012



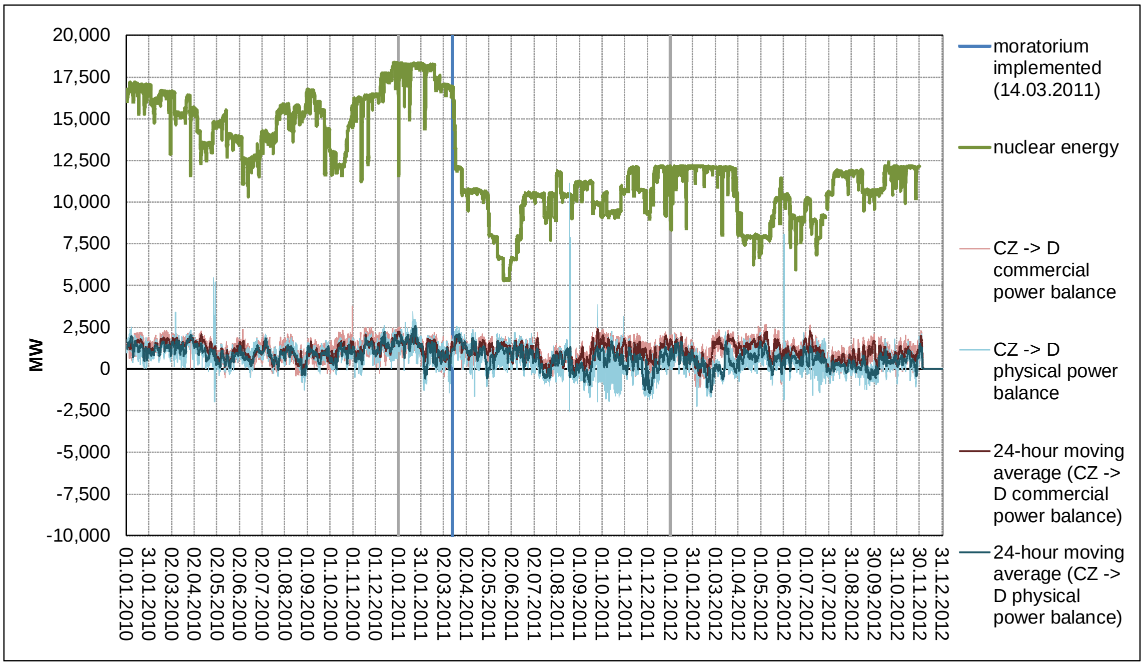
Source: ENTSO-E, calculations by Öko-Institut

A difference between physical and commercial flows is also observed at the Polish-Czech border (Figure 46). Whereas a low commercial balance is evident from Poland to the Czech Republic, physically more power clearly flows in this direction. The difference between commercial and physical power flow at the Polish-Czech border exhibits a clear correlation with the difference at the German-Polish border, as indicated in Figure 45 for the first half of 2012. The power which flows physically from Germany to Poland, without having been traded in this direction, flows on balance from Poland on to the Czech Republic.

Does this power now flow back from the Czech Republic to Germany? Figure 47 shows the import balance of power flowing from the Czech Republic to Germany. Actually, Germany imports physical power from the Czech Republic. Firstly, it turns out that the imports from the Czech Republic are not correlated with the production of nuclear power plants in Germany. Thus there was no visible response to the German shutdown by additional imports from the Czech Republic.

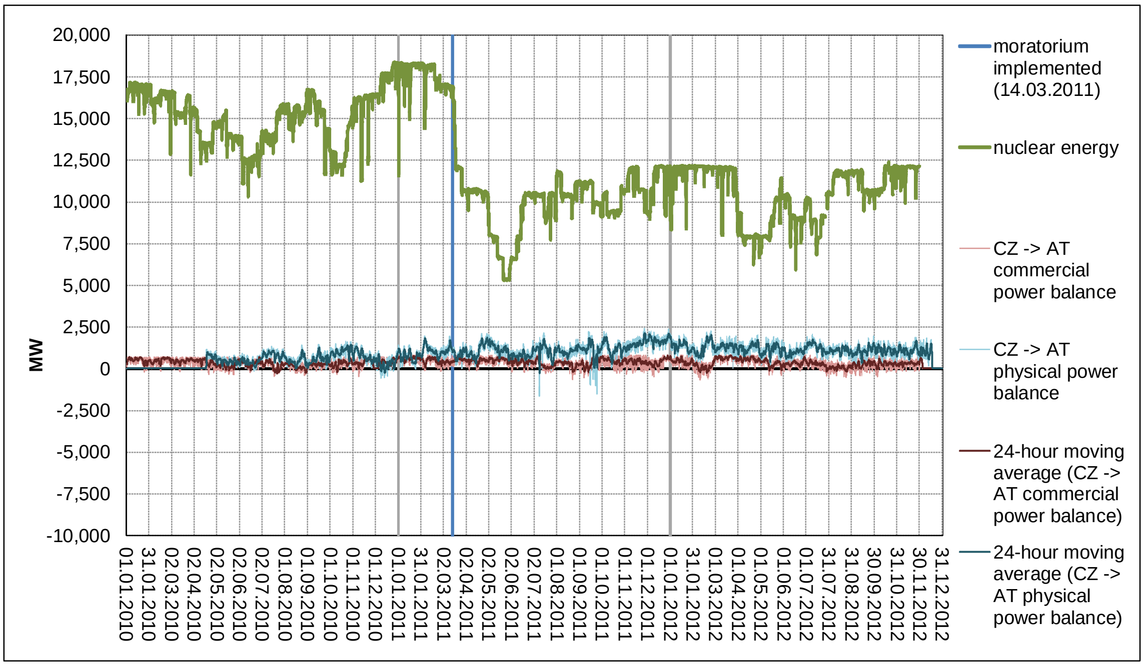
Secondly, the following conclusion can be drawn for the question of loop flows: In particular since September 2011 more power is traded commercially from the Czech Republic to Germany than flows physically. If the physical imports from the Czech Republic pertained to loop flows, then it would be expected that the commercial flow of power is less than the physical.

Figure 48 Hourly net power flowing ***from the Czech Republic to Germany*** *and 24-hour moving average (commercial and physical) and production from nuclear power plants 2010 through November 2012*



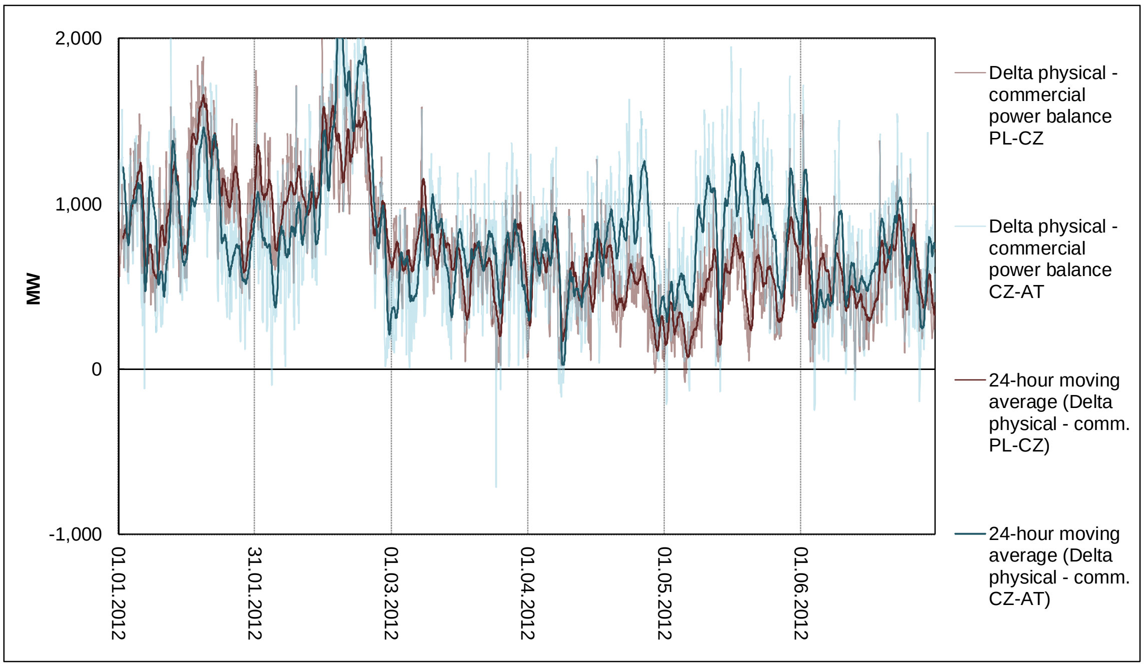
Source: EEX Transparency data, ENTSO-E, calculations by Öko-Institut

Figure 49 Hourly net power flowing ***from the Czech Republic to Austria*** *and 24-hour moving average (commercial and physical) and production from nuclear power plants 2010 through November 2012*



Source: EEX Transparency data, ENTSO-E, calculations by Öko-Institut

Figure 50 Delta between commercial and physical power flows for Poland-Czech Republic and Czech Republic-Austria in the first half of 2012

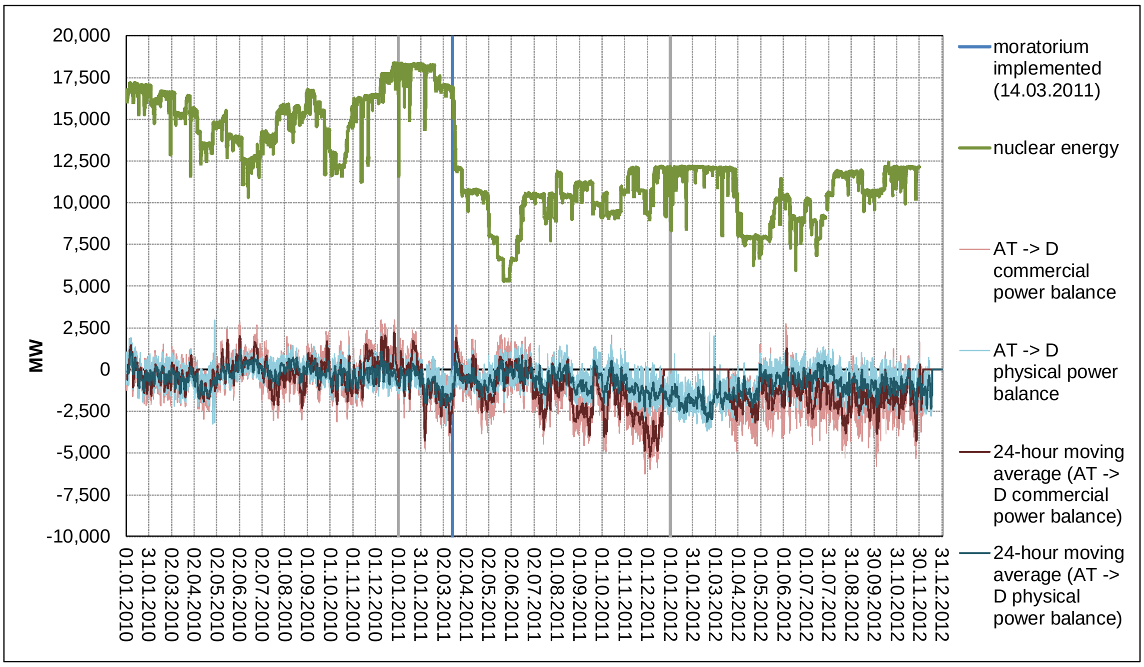


Source: ENTSO-E, calculations by Öko-Institut

Actually the difference between physical and commercial flow from Germany to Poland, from Poland to the Czech Republic and from the Czech Republic to Austria can be tracked as shown in Figure 47 and Figure 49.

The physical electricity flows from Germany to Austria are lower than the commercial power flows (Figure 51).

*Figure 51 Hourly net power flowing **from Austria to Germany** and 24-hour moving average (commercial and physical) and production from nuclear power plants 2010 through June 2012*



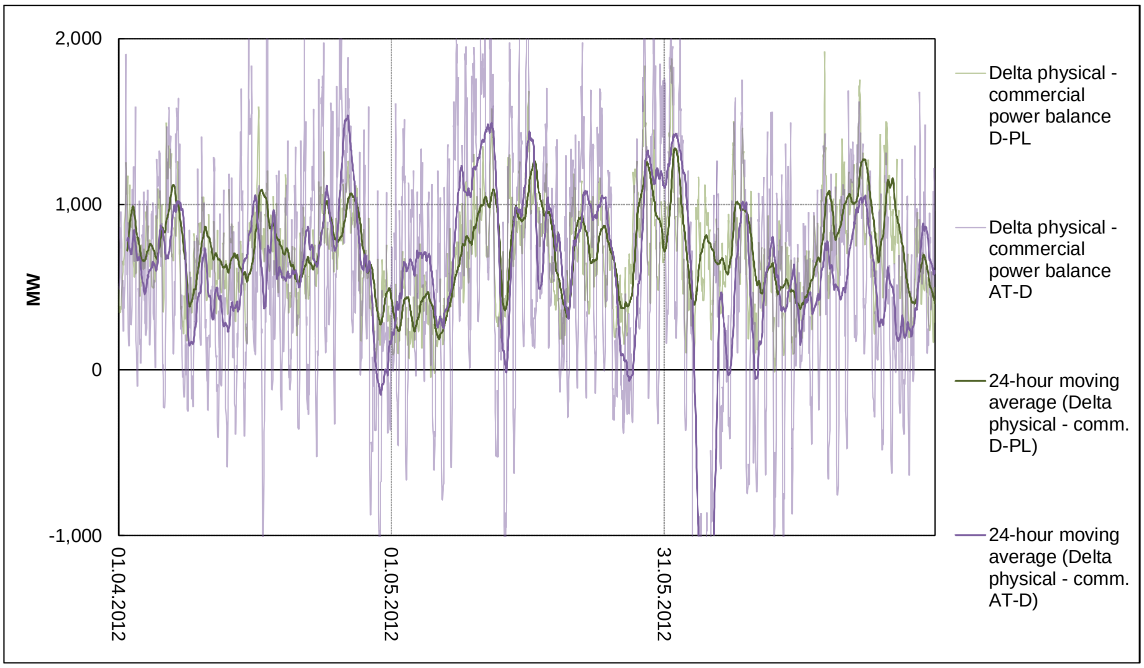
Source: EEX Transparency data, ENTSO-E, calculations by Öko-Institut

Note: Missing data for commercial power flows from January to March 2012; delimitation of Austria follows the tariff zones here, not the international border.

The difference between commercial and physical flows for the German-Austrian border is compared in Figure 52 to the difference at the German-Polish border where the described circular flow begins. Only the period from April to June 2012 is shown here, since the data for the coupling stations to Austria are missing from January to March. The difference at the German-Austrian border varies very much more on an hourly basis than was the case for the power flows discussed above (Germany/Poland, Poland/Czech Republic, Czech Republic/Austria). Nonetheless, a similar profile can be found on a moving 24-hour average like that observed for the difference in flows from Poland to Germany.

This means that power sold commercially from Germany to Austria either flows in part via Poland and the Czech Republic to Austria, or that the described circular flow moves via Poland, Czech Republic and Austria back to Germany, and on balance compensates for a portion of the exports to Austria.

Figure 52 Difference between commercial and physical power flows for Germany-Poland and Austria-Germany from April through June 2012



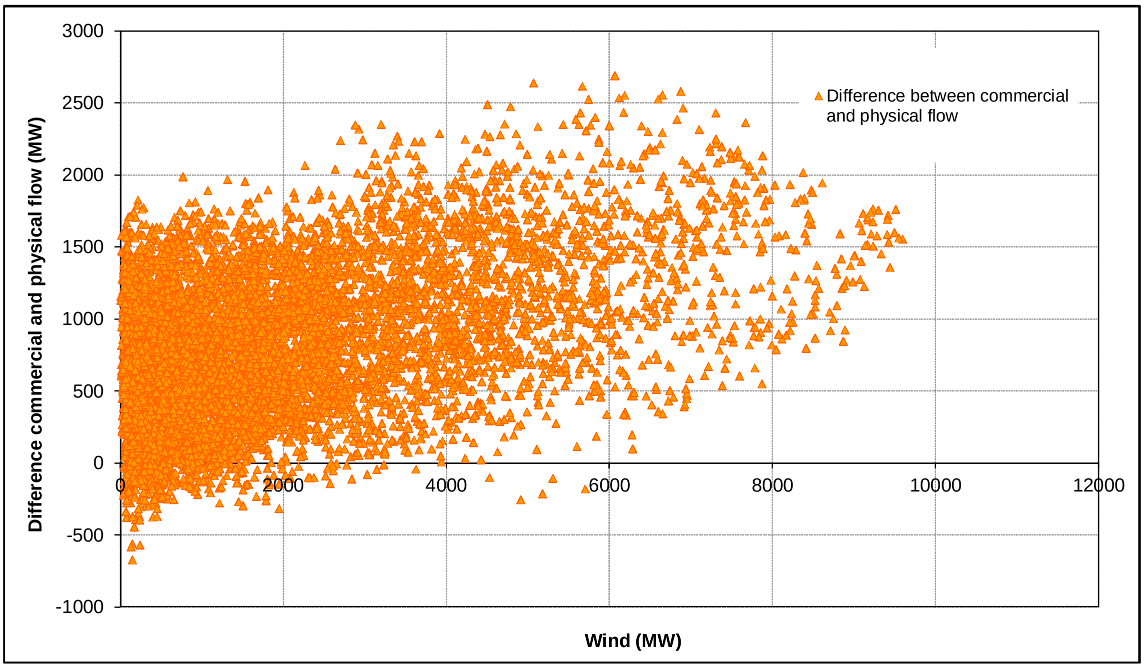
Source: ENTSO-E, Calculations by Öko-Institut

So how do the described loop flows to Poland come about?

In Figure 53 a correlation analysis was conducted between the loop flows (in the form of the difference between commercial and physical power flows) from Germany to Poland and the feed-in of wind energy into the 50-Hertz control zone. Firstly, loop flows in an amount greater than 2,500 MW only occurred in 2011 when the generation from wind power plants was between 4,000 MW and 8,000 MW. Secondly, significant loop flows of up to 2,000 MW also occurred when the generation from wind power plants was virtually negligible.

Therefore loop flows occur not only with high wind energy feed-in, but rather also are attributable to other factors (e.g. to high conventional generation in the 50-Hertz control zone).

Figure 53 Correlation of wind power feed-in into the 50 Hertz control zone and differences between commercial and physical flows between Germany and Poland in 2011



Source: Transparency data der EEX, ENTSO-E.

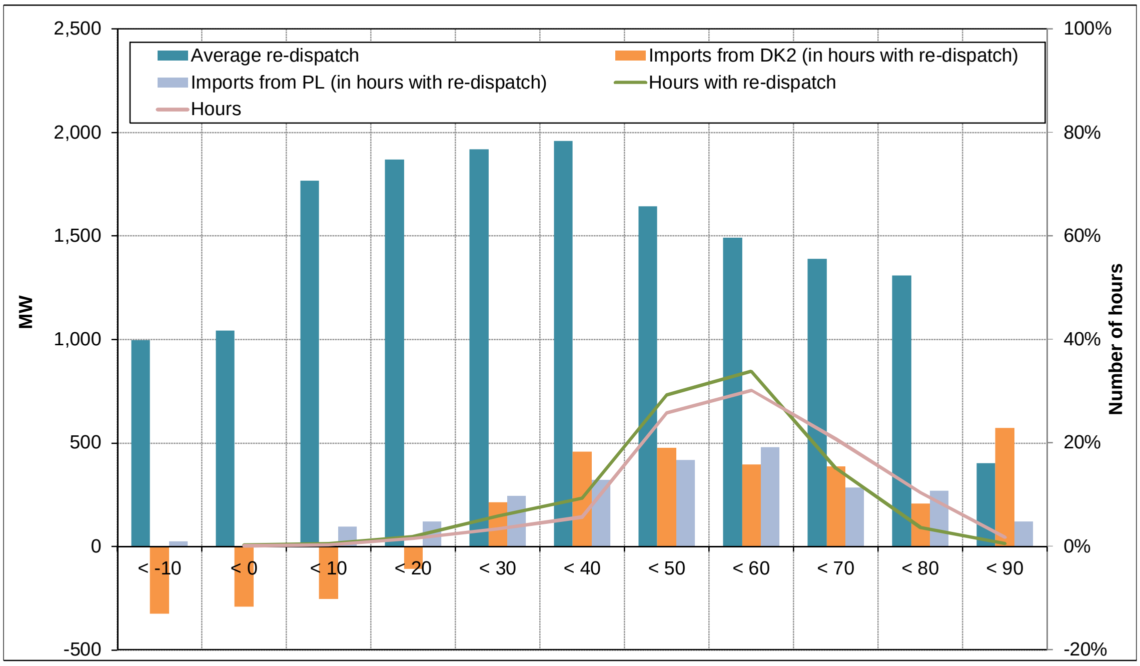
Since it was shown in Figure 53 that the loop flows also occur even with low wind power feed-in in the 50-Hertz control zone, it is suggested that the loop flows are not attributable to a high wind energy feed-in in the 50-Hertz control zone, but rather to the used market design, for example.

To test this thesis we studied when re-dispatch occurs in the 50-Hertz control zone. Re-dispatch is an indicator that too much generation is occurring in one market area, so that production has to be stepped down to attain a safe network operation. The violet line in Figure 54 represents the distribution of all hours above the particular power-price interval. For example, the electricity price ranges between 50 € / MWh and 60 € / MWh in 30% of the hours. The green line denotes the distribution of hours when re-dispatch occurs. In 34% of the hours in which re-dispatch occurs the electricity price ranges between 50 € / MWh and 60 € / MWh. This means that in the interval between 50 € / MWh and 60 € / MWh, re-dispatch occurs super-proportionately. When prices are above 60 € / MWh re-dispatch occurs at disproportionately low levels.

The blue bars in Figure 54 represent the average re-dispatch as a function of electricity prices. It is evident that little re-dispatch is necessary at very low prices and at very high prices. The greatest re-dispatch amounting to almost 2,000 MW occurs at spot prices between 30 € / MWh and 40 € / MWh. At the same time, on average a power of 450 MW from Denmark and 320 MW of power from Poland is imported into the 50-Hertz control zone. Thus the following items occur in the 50-Hertz control zone:

- There is already an excess production and thus a re-dispatch must be carried out.
- But at the same time, the spot price in the German/Austrian market area is so high that it is worthwhile to import power from Denmark and Poland into the 50-Hertz control zone. This intensifies the problems in the 50-Hertz control zone where there is already an excess generation.
- Therefore the power does not flow into the 50-Hertz control zone (where there is already an excess generation), but rather the result is a circular flow in the direction of south Germany/Austria via Poland and Czech Republic.

Figure 54 Occurrence of re-dispatch in the 50 Hertz control zone and correlation with imports in the 50 Hertz control zone in the second half of year 2011



Source: EEX, Transparency data der EEX, ENTSO-E

An interesting analysis of this topic has been provided by the transmission grid operators of the Czech Republic, Hungary, Poland and Slovakia in which the introduction of a separate prize zone for Austria was requested (CEPS et al. 2012). This is in contradiction to an assessment conducted under contract to the Federal Grid Agency (Frontier Economics and Consentec 2011) which argued against splitting of the Germany/Austria price zone.

There are unambiguous indications that the loop flows through the neighboring east European states are caused primarily by an imperfect market design and not by the expansion of renewable energies or by the nuclear phase-out in Germany. The German spot market is based on the fiction of non-existent network bottlenecks ("copper plate"), which do not apply in reality. Since many generators with low marginal costs (lignite and wind) are installed in the 50-Hertz control zone, situations occur in which the spot market gives the signal to produce too much power in the 50-Hertz control zone or to import too much power into the 50-Hertz control zone. Since the excess production in the 50-Hertz control zone is evidently so great that it cannot be diminished with re-dispatch alone, loop flows will occur. A number of measures could be taken to reduce the occurring loop flows:

- In the event of a foreseeable production excess in the 50-Hertz control zone, lignite power plants could be stepped down. This could occur through increased grid usage fees (G-component) or by regulatory provisions.
- In the event of a foreseeable production excess in the 50-Hertz control zone, no additional power should be imported. In these hours the NTC-value for the import could be set to zero.
- The proposal of the CEPS et al. (2012) could be taken up and the Germany/Austria price zone could be split up. Then it would have to be thoroughly studied where the existing price zone should be divided. The previous results of the grid development plan 2012 found a significant need to expand the grid in north and south Germany. This indicates that splitting of the price zone between north and south Germany, for example at the level of Frankfurt (Main), probably makes more sense than between Germany and Austria.
- For the domestic economy it would be most efficient if power could be commercially exported from the 50-Hertz control zone to Poland and the Czech Republic. This would probably occur automatically after splitting of the German price zone. Alternatively, the NTC-values for exports from Poland and the Czech Republic to Germany could be set to zero, and the German transmission grid operators would buy transmission capacities for the affected interconnectors within the framework of the anticipated loop flows. This includes the acquisition of transmission capacities for exports from Germany to Poland, for exports from the 50-Hertz grid area to the Czech Republic, for exports from Poland to the Czech Republic, for exports from the Czech Republic to Austria and for exports from the Czech Republic into the TenneT grid area. Simplified the following loop flows would occur:
    - Power flows from the 50-Hertz grid area via Poland, Czech Republic to Austria.
    - Power flows from the 50-Hertz grid area to the Czech Republic and from there into the TenneT grid area.

However, a detailed discussion and assessment of these possibilities goes beyond the scope of this study and must be reserved for future analysis.

5.3 Interim Summary of Special Analyses

Power imports from France to Germany do not occur based on any particular deficit of power plant capacities in Germany. Physical and also commercial power flows from France to Germany occur increasingly in situations when French power plants have already reduced their production. Conversely, reduced physical flow from France to Germany, or even commercial power flow from Germany to France occurs in situations of high French demand, or respectively high French power production. In Germany these are chiefly hours with high solar power production.

The physical net balance of power exchanged between Germany and France, and the commercial net balance – which has resulted since the market coupling primarily due to optimizing on the common power exchange – differ significantly from each other. More power is systematically transported physically from France to Germany than is traded. In 2011 the commercial import balance with France amounted to only 2.4 TWh, in comparison to 20 TWh which was physically imported from France. Whereas physically the power mostly flows from France to Germany, commercially in 2010 and again in the first half of 2012, on balance power was sold from Germany to France. A significant portion of the physical power imports from France to Germany is attributable to transit flows from France via Germany to Switzerland (and from there partly continuing on to Italy).

Loop flows or transit flows also occur at the eastern border of Germany. Power flows from eastern Germany via Poland, the Czech Republic and Austria to south Germany.

The net exchange balance between Germany and Austria shows that most of the time in winter 2011/2012 more power was exported from Germany to Austria than was imported. This is particularly interesting under consideration of the discussion about Austrian back-up power plants to support German power demand last winter. Therefore the loop flows do not arise in order to meet demand in south Germany, but rather to ensure fulfillment of export contracts to Austria.

There are unambiguous indications that the loop flows through the neighboring east European states are caused primarily by an imperfect market design and not by the expansion of renewable energies or by the nuclear phase-out in Germany.

6 Conclusions

From the preceding analyses the following overall conclusions may be drawn:

- Historically it can be observed that on balance, Germany imports power in the summer months and exports in the winter months. This shows that imports do not occur due to any (specific) deficiency in power plant capacity – precisely because the domestic demand is greatest in winter. In these months there are evidently sufficient power capacities available in Germany to cover not only the high domestic demand, but also – and on a competitive basis – to export power. However, imports occur on balance precisely in the summer months when domestic demand is lower than in winter. In these months power plant capacity abroad appears to be available at lower cost than domestically, so that on a monthly balance the result is market-driven imports.
- The shutdown of several nuclear power plants in 2011 meant a significant reduction in gross power generation from nuclear energy in comparison to the previous year. It decreased from 140.6 TWh in 2010 to 108.0 TWh in 2011. Thus compared to the previous year there was a loss of 32.6 TWh of power generation from nuclear energy.
- The changes in the power mix from 2010 to 2011 can be summarized as follows: The lost power generation from nuclear energy was replaced in the annual balance largely through increased power generation from renewable energies (+20.2 TWh) and a decrease in the excess exports (-11.4 TWh).
- In 2011 Germany exported a total of 6.3 TWh more electricity than it imported. The decrease in the excess exports from 17.7 TWh to 6.3 TWh is attributable to various reasons. Firstly, in 2010 power was exported from Germany to Denmark and Sweden. After very plentiful rainfall in Scandinavia in 2011, power was imported from Denmark and Sweden in 2011. Thus overall the export excess decreased by nearly 9 TWh. In addition, the net physical imports from France increased by 6 TWh in 2011 compared to year 2010. The balance with other neighboring countries changed only very slightly, for example, more power was exported to Austria. The net power balance between Germany and the Czech Republic (where nuclear power plants are likewise in operation) displays no change in a historical perspective. In absolute terms, the additional imports from France amount to approx. only 1% of annual power generation in Germany; this level had already been reached in previous years and was not accompanied by an increased production of French nuclear power plants.
- The physical net power exchanged between Germany and France, and the commercial net balance differ significantly from each other. More power is systematically transported physically from France to Germany than is traded. In 2011 the commercial import balance with France amounted to only 2.4 TWh, in comparison to 20 TWh which was physically imported from France. A significant portion of the physical power imports from France to Germany is attributable to

transit flows from France via Germany to Switzerland (some of which then continues on to Italy).

- The structure of the power exchange between Germany and France is such that Germany has a tendency to import power from France when the load is low. Conversely, power exports from Germany to France take place in situations with high demand. Since the power generating system in France is characterized by base load power plants, it is easy to see that France always exports a lot when it does not need the power itself. Power imports from France to Germany do not take place due to any specific deficit in power plant capacity in Germany, but rather are a result of optimizing generation in the European power market.
- Based on the available data for the first three quarters of 2012, one can see that in 2012 the export balance for Germany has again risen to almost 14 TWh. Since Germany is a traditional power exporter in winter, it can be assumed that the export balance by the end of 2012 will continue to rise and again return to the level of the years 2006 to 2010. The increase in the export balance is attributable primarily to the increase in exports to the Netherlands (+10 TWh in the first 9 months of 2012 compared to the first 9 months of 2011) and to a decrease in imports from France (-6 TWh in the first 9 months of 2012 compared to the first 9 months of 2011). In particular the increasing exports to the Netherlands might be attributable to the currently high gas prices.
- Thus the German power market in the period from April to June 2011 gained a new equilibrium. It must be taken into account in this context in particular that the inspection plans for the nuclear and fossil power plants had not yet been adjusted to the new situation in energy policy. In May 2011 the available capacity of the nuclear power plants sometimes amounted to only 5 GW owing to previously planned inspections. In winter 2011/2012 Germany again exported power as in previous years.
- The expansion of renewable energies in Germany has an effect on its electricity imports and exports. Until recently Germany exported power most notably at night from base load power plants. In particular in summer 2012 it can be seen that Germany exports power primarily in the early afternoon when a lot of power was available from PV systems. Evidently the production of fossil-fired power plants is not being decreased, but rather their power production is being sold abroad, where power plants with higher marginal costs are being taken off the grid. Based on the possibility of exporting electricity to other countries in Europe additional flexibility for the integration of renewable energies is being tapped.
- The short-term increase in imports to Germany after the shutdown of considerable NPP capacity in mid-March 2011 is thus attributable primarily to a seasonal effect, since Germany's imports always increase in the spring. This seasonal effect was incidentally coincident with the shutdown of German nuclear power plants in mid-March 2011. However, the change-over from exports to imports in

the spring would have occurred even without the shutdown of significant NPP capacities in March 2011.

In summary the following conclusions are reached with regard to the interactions between the German phase-out of nuclear energy and the development of power imports and exports occurring between Germany and its neighboring countries:

- The existence of power imports is not an indication that the (domestic) security of supply is in jeopardy.
- The shutdown of nuclear power plants has not resulted in increased imports of power from foreign nuclear power plants and thus has not been counterbalanced by foreign power imports.

Rather, the structures of foreign power imports are an indicator of the cost structures that can be found in the particular market situation of the various domestic power plant fleets in the internal European power market. To this extent the international power exchange can provide considerable flexibility for integration of renewable energies into the German and European power supply system. However, at the same time it is observed that the complex interaction of cost structures in power generation, of domestic and international infrastructure bottlenecks and of market design increasingly requires analysis and activities which go beyond national borders.

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7.2 Databases used

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Nordpool Spot: Hourly Elspot Prices. Lysaker Norway

Oanda: Historical foreign exchange rates. Zloty / Euro

PolPX Spot: Historical Data. Market: DAM. Particular contracts. IRDN. Auction 2. PolishPowerExchange. Warsaw

Réseau de transport d‘ électricité (RTE): Operational Data. Generation in France. Actual Generation. Paris.

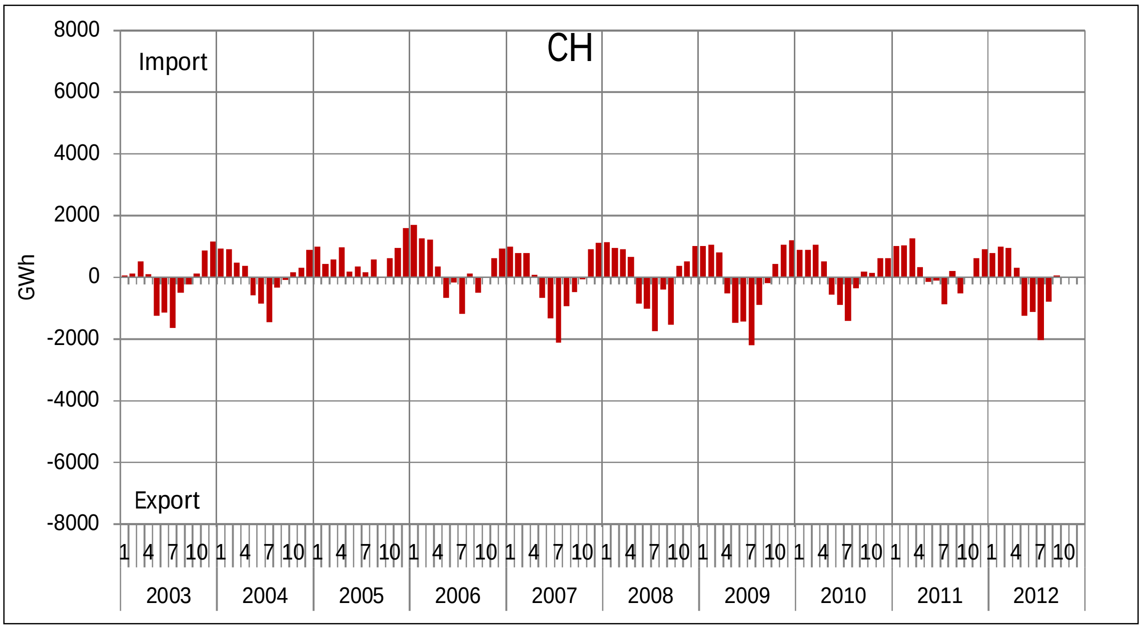
Annex

A1 Import-Export balance for other European countries

A1.1 Switzerland, Austria, Italy

Figure 55 shows the monthly import-export balance in Switzerland. A seasonal pattern is clearly evident here: In the summer months power is exported and then imported in winter. In 2011 the summer exports were comparatively low.

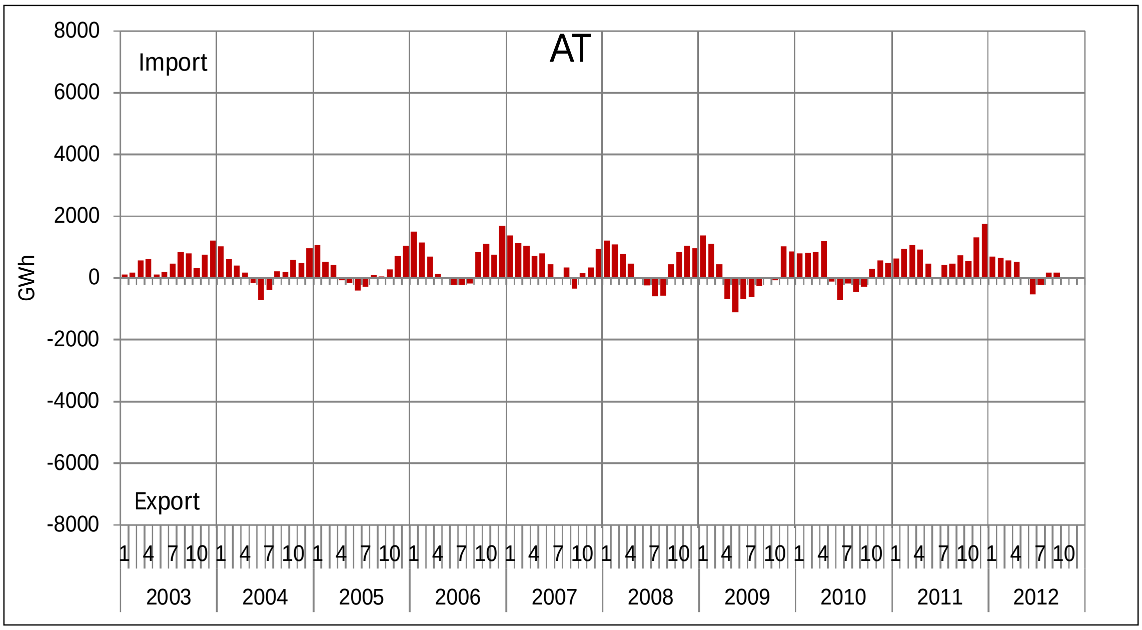
Figure 55 Monthly import-export balance (physical flows) for Switzerland, 2003 through September 2012



Source: ENTSO-E, calculations by Öko-Institut

A similar pattern is also observed for Austria (Figure 56). Here too, there are net imports in winter and then net exports – if any – in the summer months. In 2011 however, no net exports from Austria are observed in the monthly balance.

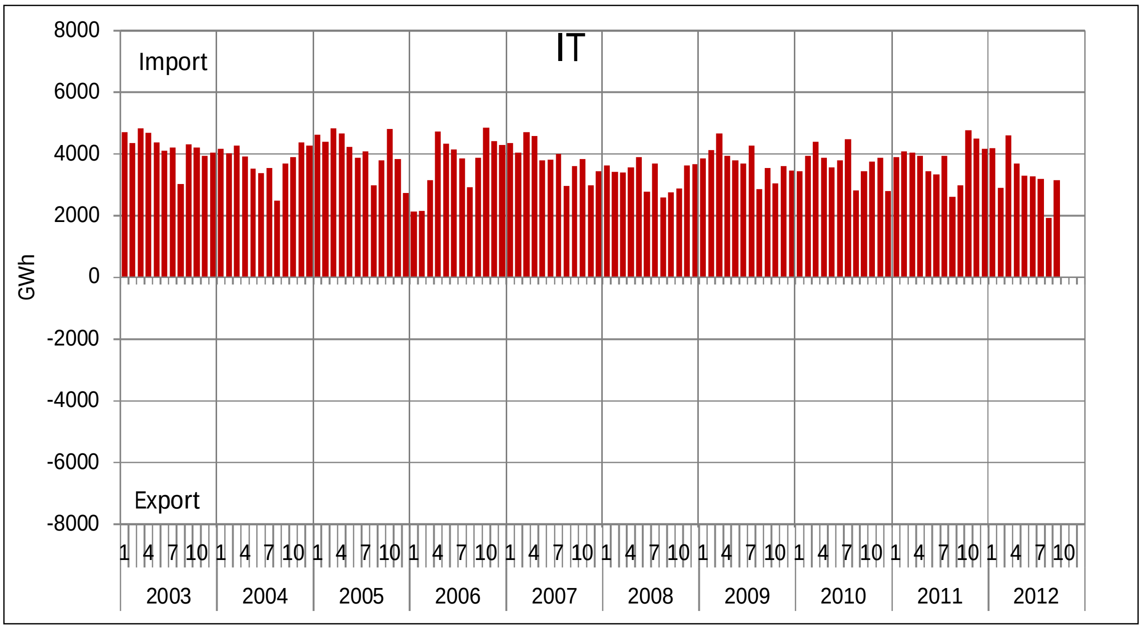
Figure 56 Monthly import-export balance (physical flows) for Austria, 2003 through September 2012



Source: ENTSO-E, calculations by Öko-Institut

Italy is historically a power importer. Imports in 2011 have a similar range of fluctuation as in previous years.

Figure 57 Monthly import-export balance (physical flows) for Italy, 2003 through September 2012



Source: ENTSO-E, calculations by Öko-Institut

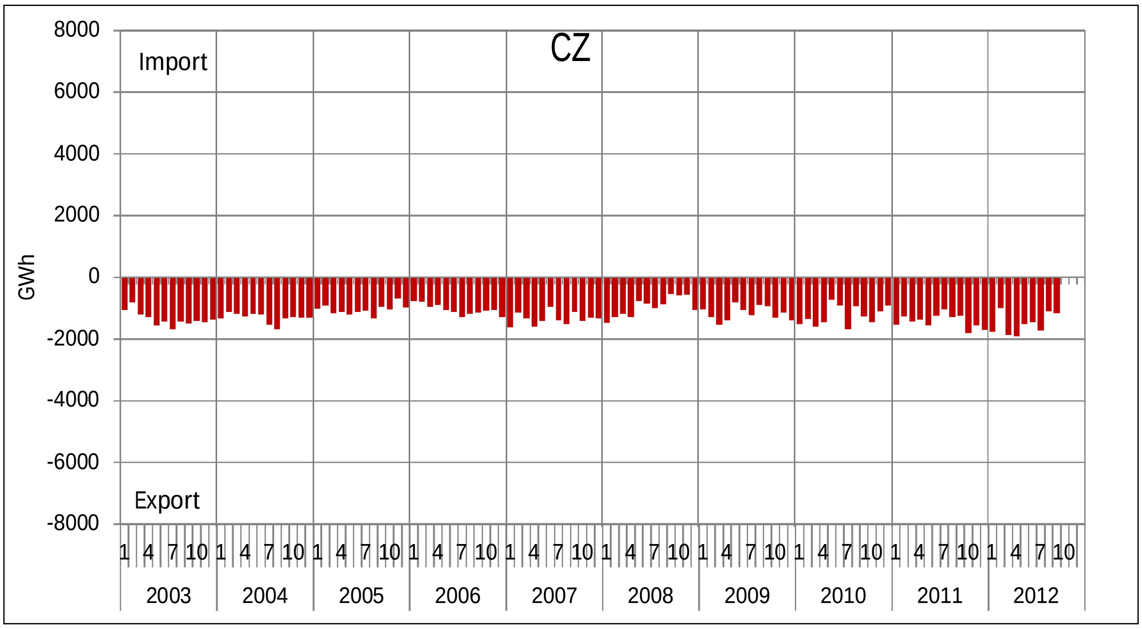
A1.2 Czech Republic

In years 2003 to 2011 the Czech Republic has been historically always a comparatively low-level net exporter on monthly balance, as indicated in Seasonal differences are not very highly pronounced. 2011 is among those years with a high export balance, but still remains on the same order of magnitude as the historical values.

Figure 58.

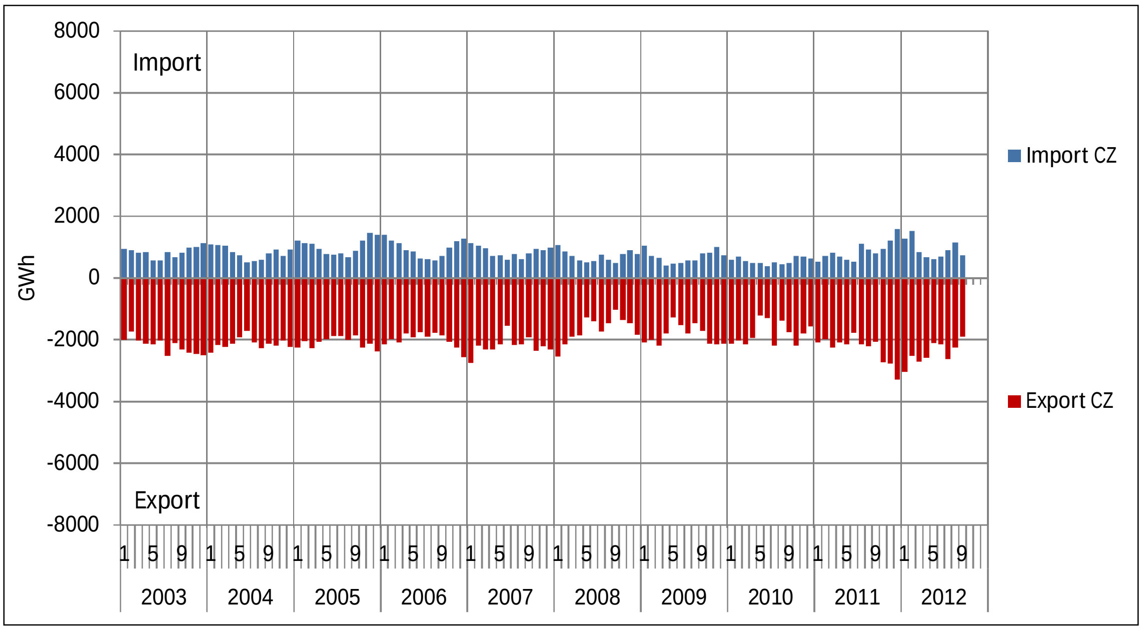
Seasonal differences are not very highly pronounced. 2011 is among those years with a high export balance, but still remains on the same order of magnitude as the historical values.

Figure 58 Monthly import-export balance (physical flows) for Czech Republic, 2003 through September 2012



Source: ENTSO-E, calculations by Öko-Institut

Figure 59 Monthly imports and exports (physical flows) for Czech Republic, 2003 through September 2012



Source: ENTSO-E, calculations by Öko-Institut

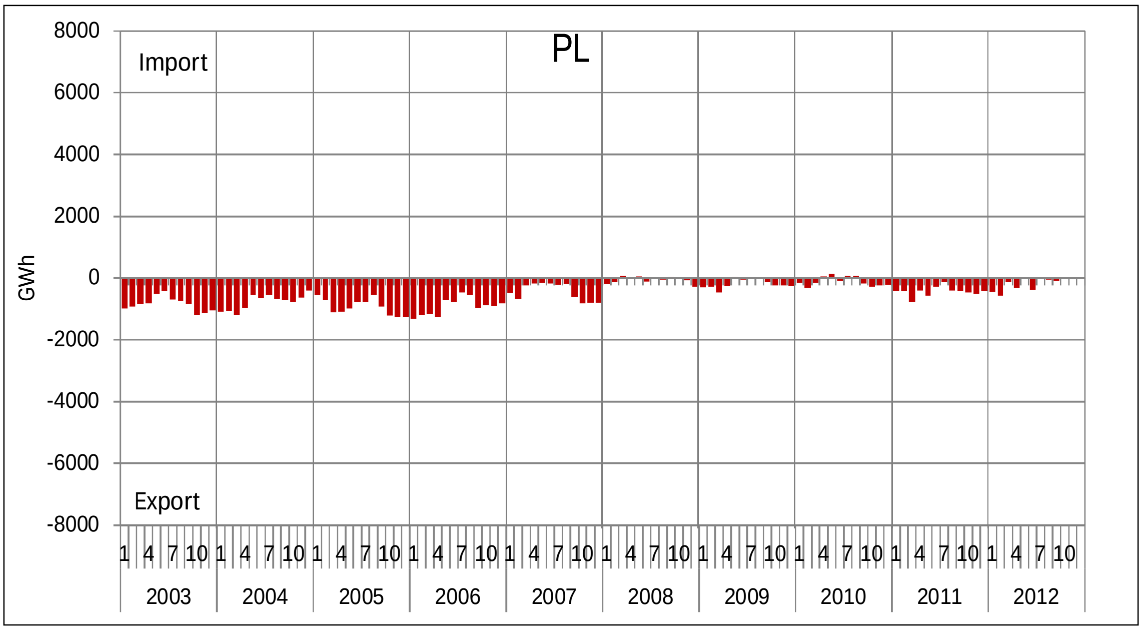
The separate presentation of the Czech Republic's exports and imports from 2003 onward in Figure 59 indicates a seasonal pattern of imports, especially in the initial years, which increases in the winter months. However, overall it is evident that the import-export activity in the winter months is greater than in the others. This applies in particular for import-export activity in the winter months of 2011 and 2012. Whereas in these months there were elevated exports, at the same time also increased imports can be observed in comparison to previous years, so that the net balance from these months is comparatively unremarkable.

A1.3 Poland

As Figure 60 shows, from 2003 to 2007 Poland was a net exporter in most months. Whereas the years 2008 to 2010 were characterized by very low monthly exports and occasional imports, in 2011 on balance Poland exported power again in all months, but at a low level.

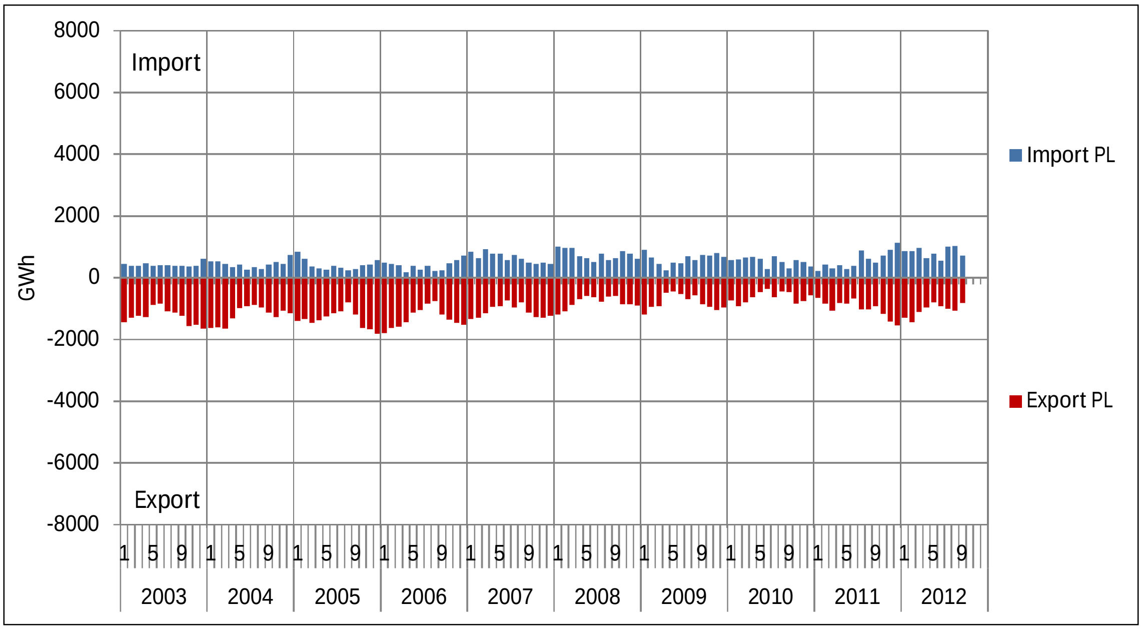
The separate presentation of imports and exports in Figure 61 shows that in the past Poland exported power chiefly in the winter months. Since 2010 this pattern has become somewhat less pronounced. 2011 and the first months of 2012 are by historical comparison unremarkable.

Figure 60 Monthly import-export balance (physical flows) for Poland, 2003 to September 2012



Source: ENTSO-E, calculations by Öko-Institut

Figure 61 Monthly imports and exports (physical flows) for Poland, 2003 to September 2012

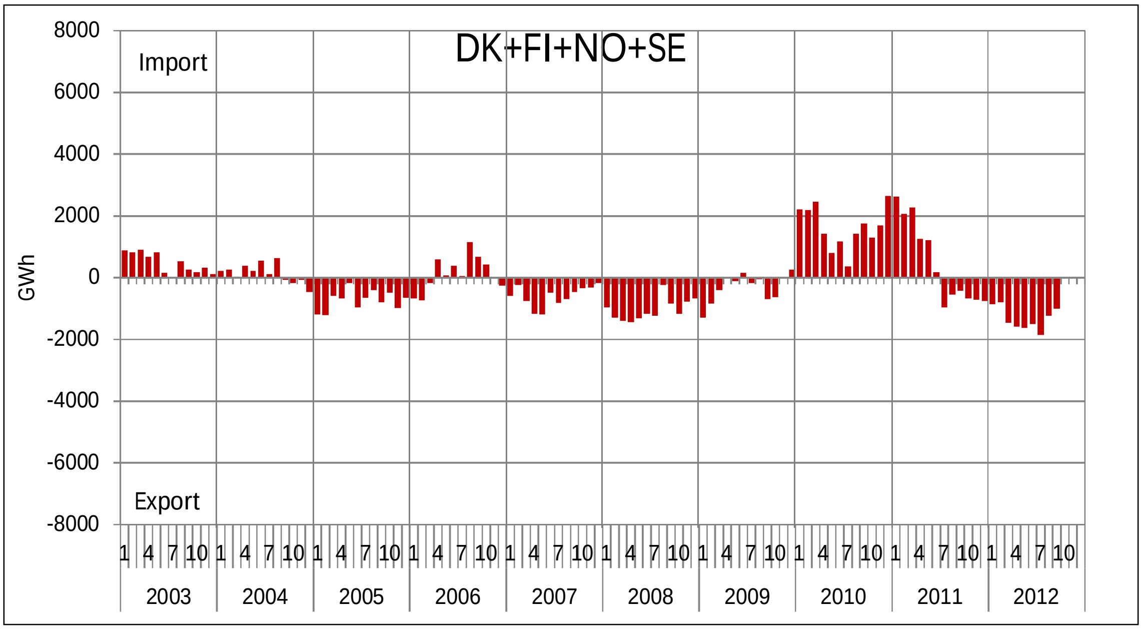


Source: ENTSO-E, calculations by Öko-Institut

A1.4 Scandinavia

Figure 62 shows the combined net monthly import-export balance for the Scandinavian countries of Denmark, Finland, Norway and Sweden as a whole. A consistent picture does not emerge for the period under consideration (since 2003). In years 2005, 2007, 2008 and 2009 there were predominately exports in the monthly balance. Imports were observed in years 2003, 2004, partly in 2006, and at a high level throughout 2010 and into the first half of year 2011. Beginning in July 2011 the monthly balance swung over again from imports to low-level exports.

Figure 62 Monthly import-export balance (physical flows) for Denmark, Finland, Norway and Sweden, 2003 through September 2012

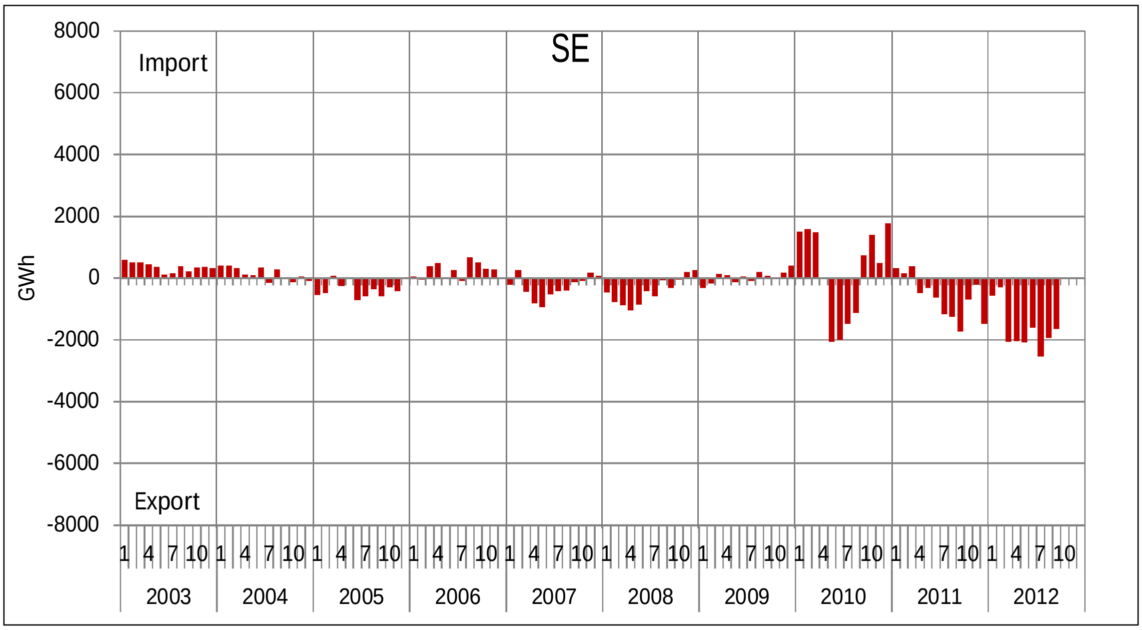


Source: ENTSO-E, calculations by Öko-Institut

The net balances for the individual Scandinavian countries overall differ from the combined balance for Scandinavia as a whole. Here we will consider Sweden and Denmark, which have power lines running to Germany. Whereas the Scandinavian countries on balance imported power in 2010 and the first half of year 2011, during this same period of time Sweden exported power, and specifically in the summer months of 2010 and again starting in April 2011.

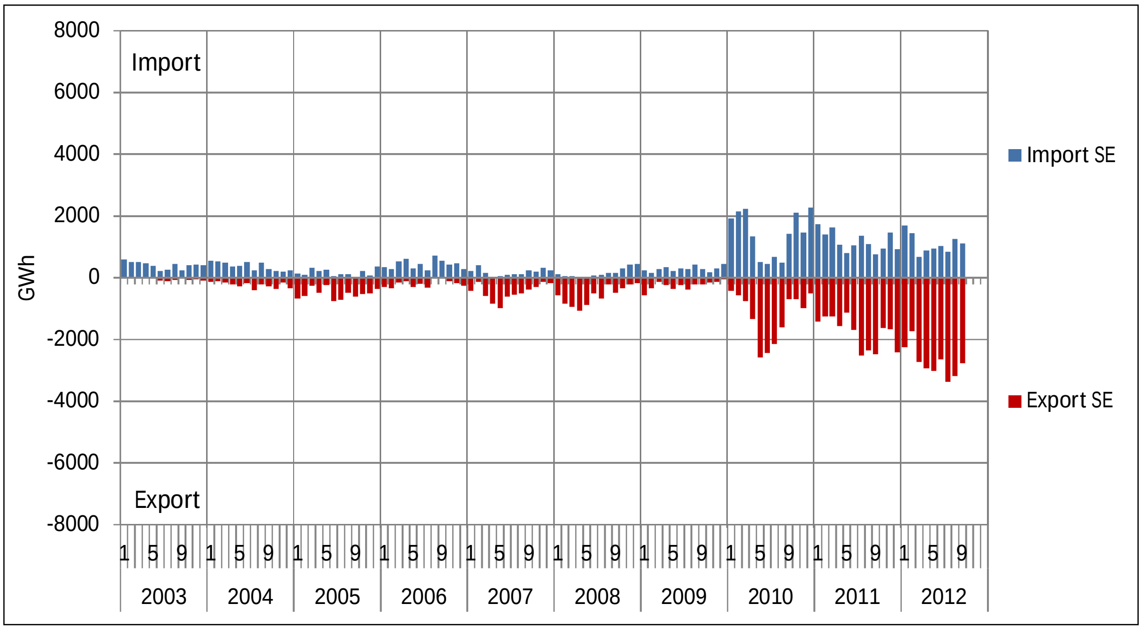
The absolute power exchange activity of Sweden is clearly greater since 2010 than in previous years, as is shown by the separate presentation of imports and exports in Figure 64 . A more precise analysis of the Swedish data shows that beginning in 2010 for the first time exports were sent to Poland, likewise beginning in 2010, increased imports from Finland and increased power exchange with Denmark and Norway were observed. In this case Sweden imports power from Denmark in winter and exports to Denmark in summer.

Figure 63 Monthly import-export balance (physical flows) for Sweden, 2003 to September 2012



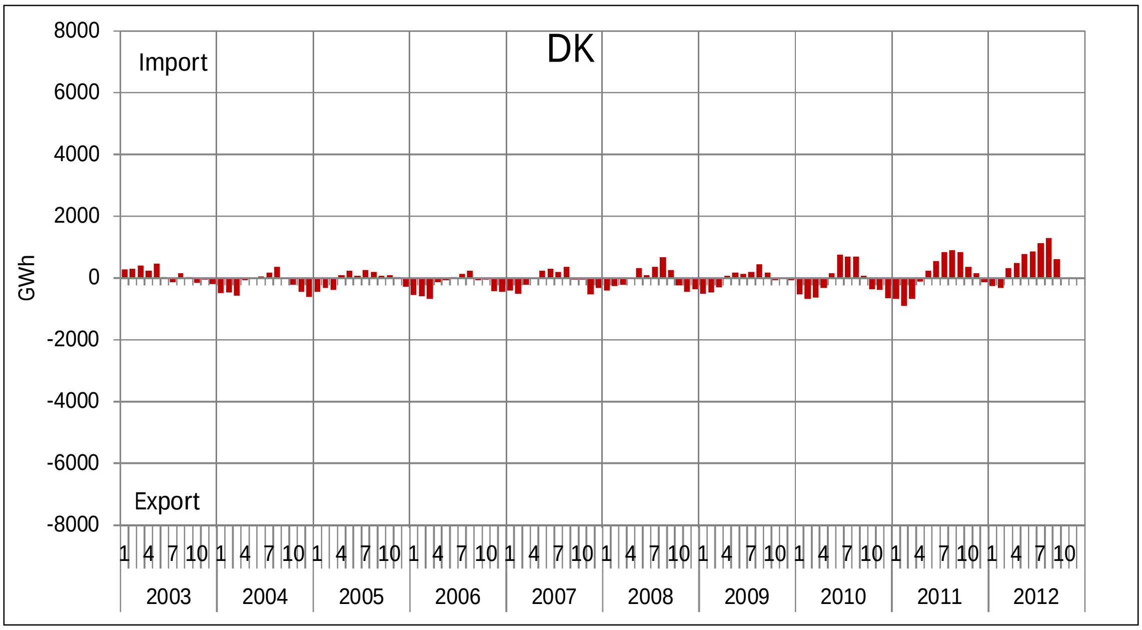
Source: ENTSO-E, calculations by Öko-Institut

Figure 64 Monthly imports and exports (physical flows) for Sweden, 2003 to September 2012



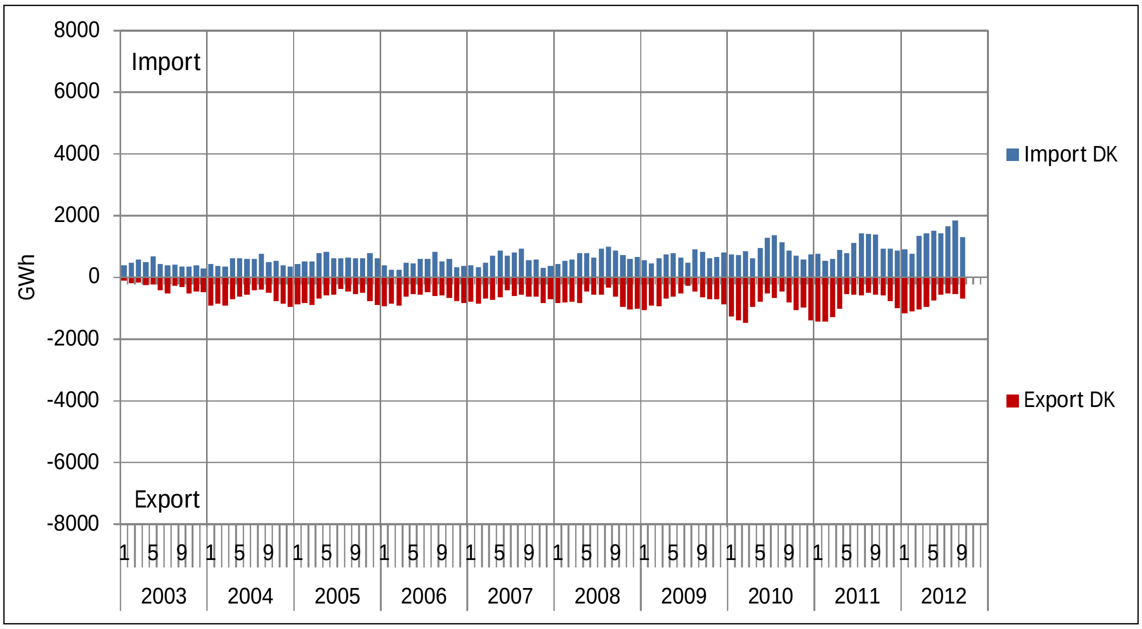
Source: ENTSO-E, calculations by Öko-Institut

Figure 65 Monthly import-export balance (physical flows) for Denmark, 2003 to September 2012



Source: ENTSO-E, calculations by Öko-Institut

Figure 66 Monthly imports and exports (physical flows) for Denmark, 2003 to September 2012

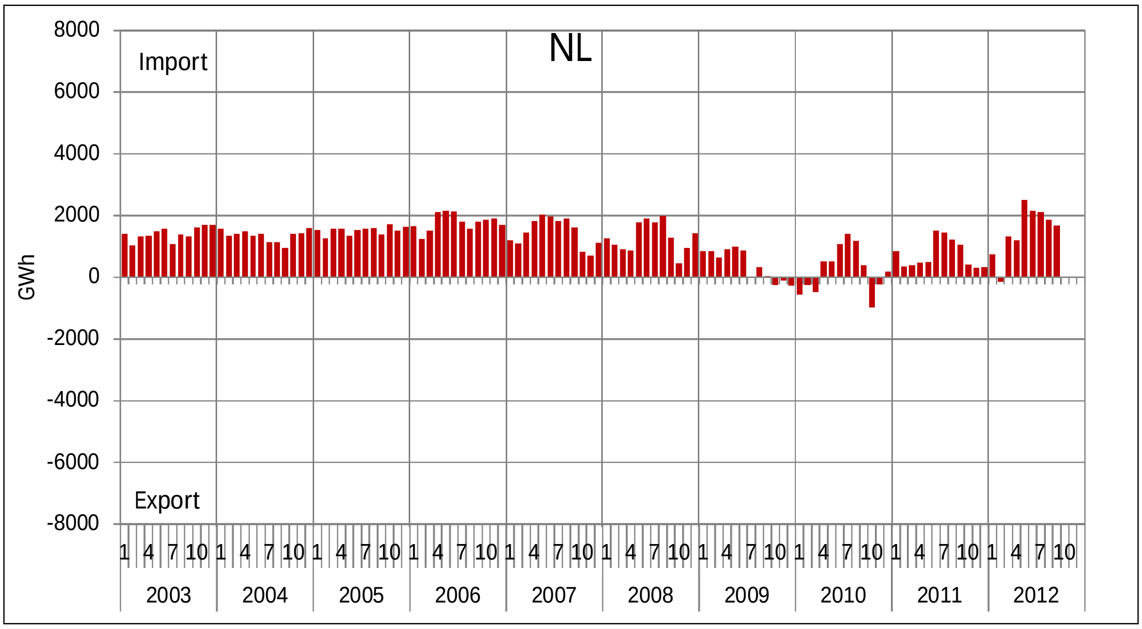


Source: ENTSO-E, calculations by Öko-Institut

A1.5 The Netherlands and Belgium

In most years in the past, the Netherlands imported power on balance, and this includes also all months in 2011 expect for December. Several months in years 2009 and 2010 exhibit minor net power exports.

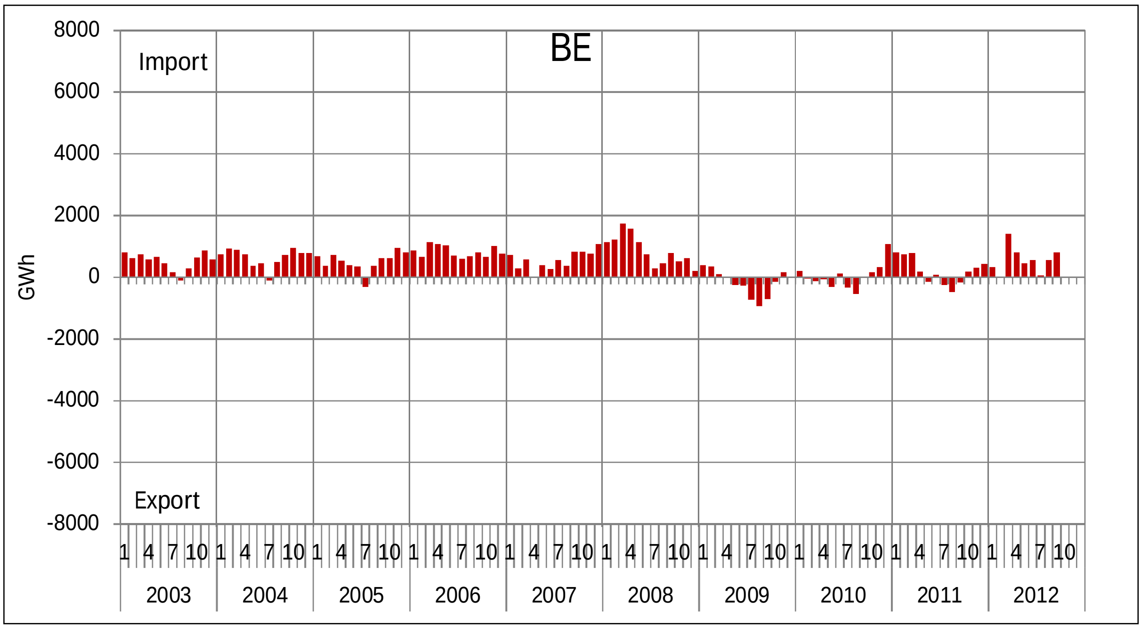
Figure 67 Monthly import-export balance (physical flows) for the Netherlands, 2003 to September 2012



Source: ENTSO-E, calculations by Öko-Institut

The power balance for Belgium appears similar; here too net imports are observed in nearly all months through 2008. Beginning in 2009 there are minor net exports in several months, for example, in the summer months of 2011. Belgium has no electrical connection to Germany, so the shown imports and exports are with the Netherlands, France, Norway, Luxemburg or the UK.

Figure 68 Monthly import-export balance (physical flows) for Belgium, 2003 through September 2012

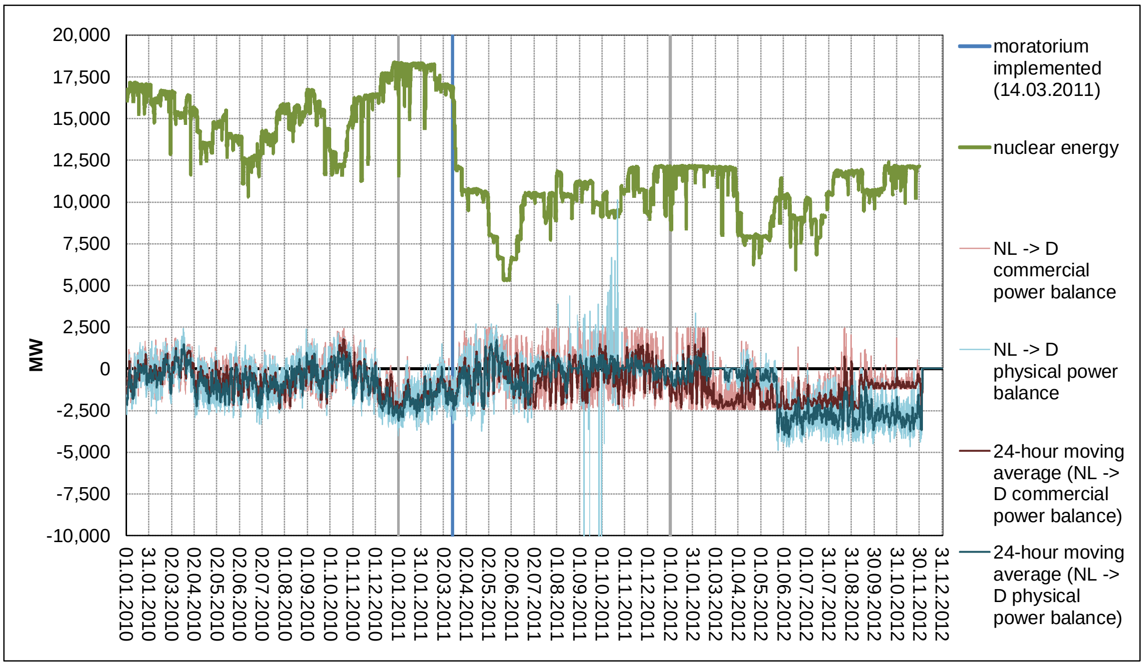


Source: ENTSO-E, calculations by Öko-Institut

A2 German import-export balance with European countries

A2.1 The Netherlands

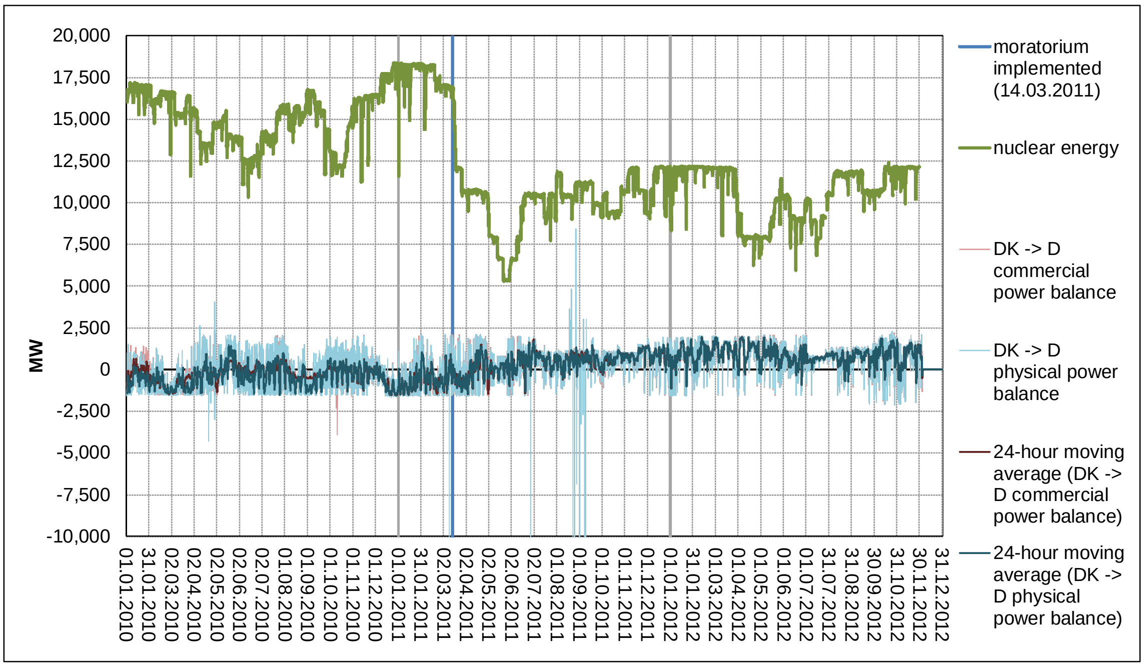
Figure 69 Hourly net power flows from the Netherlands to Germany and 24-hour moving average (commercial and physical) and generation from German nuclear power plants from January 2010 through November 2012



Source: EEX Transparency data, ENTSO-E, calculation by Öko-Institut

A2.2 Denmark

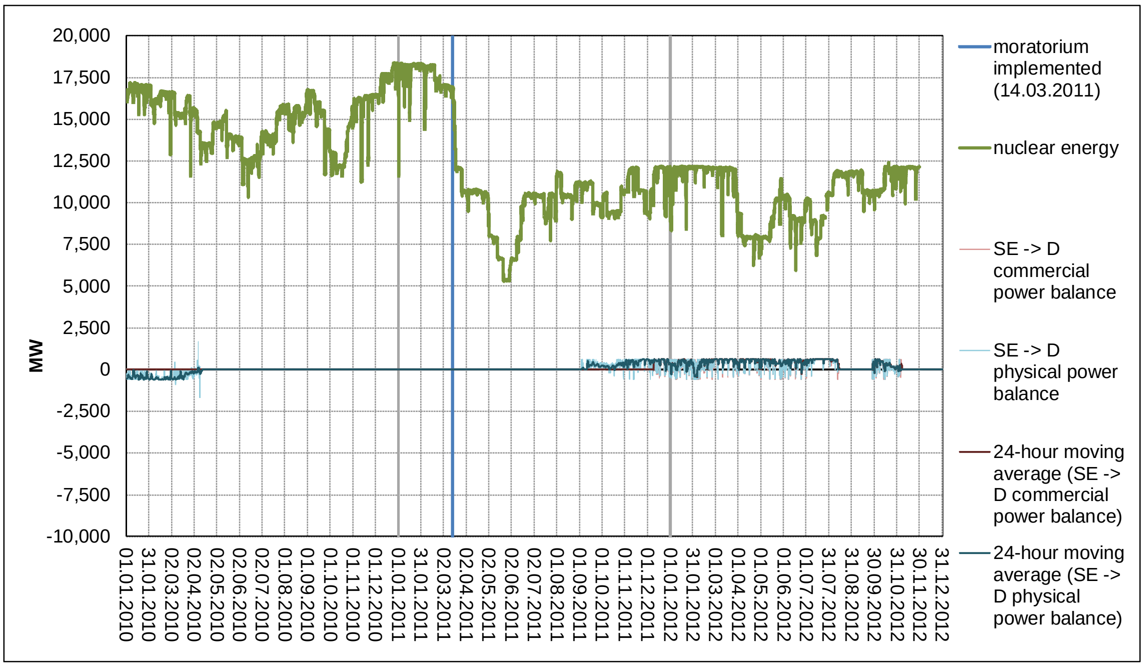
Figure 70 Hourly net power flows from Denmark to Germany and 24-hour moving average (commercial and physical) and generation from German nuclear power plants from January 2010 through November 2012



Source: EEX Transparency data, ENTSO-E, calculations by Öko-Institut

A2.3 Sweden

Figure 71 Hourly net power flows from Sweden to Germany and 24-hour moving average (commercial and physical) and generation from German nuclear power plants from January 2010 through November 2012



Source: EEX Transparency data, ENTSO-E, calculation by Öko-Institut

Note: Missing data from April 2010 to August 2011