

Just, Sebastian

Working Paper

The German market for system reserve capacity and balancing energy

EWL Working Paper, No. 06/15

Provided in Cooperation with:

University of Duisburg-Essen, Chair for Management Science and Energy Economics

Suggested Citation: Just, Sebastian (2015) : The German market for system reserve capacity and balancing energy, EWL Working Paper, No. 06/15, University of Duisburg-Essen, Chair for Management Science and Energy Economics, Essen

This Version is available at:

<https://hdl.handle.net/10419/148213>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

Chair for Management Sciences and Energy Economics

University of Duisburg-Essen

EWL Working Paper No. 06/15

The German Market for System Reserve Capacity
and Balancing Energy

by

Sebastian Just

August 2015

THE GERMAN MARKET FOR SYSTEM RESERVE CAPACITY AND BALANCING ENERGY

by Sebastian Just

Abstract

This paper provides the technical background, describes the market design and its development as well as summarizes the market results of the German system reserve capacity market and the balancing energy mechanism, which are the key tools for required balancing the of the electricity system.

Keywords: system reserve capacity, balancing energy mechanism, German electricity market, market design

Sebastian Just

Chair for Management Sciences and Energy Economics,

University of Duisburg-Essen (Campus Essen)

Universitätsstr. 11, 45117 Essen

www.ewl.wiwi.uni-due.de

just@k8.hhl.de

The author is solely responsible for the contents which do not necessarily represent the opinion of the Chair for Management Sciences and Energy Economics.

1 Introduction

The electricity system requires continuous balancing of the consumed and produced power as a direct implication from the basic laws of physics. Ensuring the imbalance is exacerbated by the virtually non-storability of electricity, by the frequent and instantaneous changes in consumption and intermittent production, by the large number of consumers and producers that need to be coordinated, and by the limited flexibility of the electricity system. In the Germany electricity system with a decentral bilateral market model, system reserve capacity and the balancing energy mechanism are the crucial tools to achieve the required balancing of the system and to provide the adequate incentives for the large number of market participants to facilitate the balancing.

This paper provides the technical background, describes the market design and its development as well as summarizes the market results of the German system reserve capacity market and the balancing energy mechanism. It was originally written as part of my dissertation "Three Essays on Markets for System Reserve Capacity and Balancing Energy". The paper provides a more comprehensive context for the three respectively published papers: Pricing of Reserves – Valuing System Reserve Capacity against Spot Prices in Electricity Markets (Just and Weber, 2008), Appropriate Contract Duration in the German Market of On-line Reserve Capacity (Just, 2011) and Strategic Behavior in the German Balancing Energy Mechanism: Incentives, Evidence, Costs and Solutions (Just and Weber, 2015). This version of the paper has been updated as of August 2015.

2 Technical background & requirements

Reserve capacity and system balancing serve an important function in the electricity system. They are a requirement that results from the technical properties of the system. The following descriptions are not primarily intended to provide full engineering details. They are rather supposed to give non-engineers a good understanding of the subject.

2.1 System frequency and power balance

In all power systems, maintaining the standardized system frequency and the load balance are some of the most crucial operational tasks. The European electricity system is designed to

operate in a small bandwidth around 50 Hertz. A range of $\pm 50\text{mHz}$ is considered as normal operating conditions (see UCTE, 2004). All equipment, devices, machines and systems depend on this defined standard.

In order to keep the system frequency, a balance between produced and consumed power is necessary. As a result of physical laws, frequency changes are proportional to the size of the imbalance. Any power deficit (i.e. produced power smaller than consumed power) directly leads to a frequency drop, and vice versa. A deficit of electrical energy supply is mainly compensated with kinetic energy of the generator shafts. This slows down the rotation speed and thus reduces the frequency of the alternating current (see Swider, 2006).

Due to its instantaneous and system-wide nature, the frequency is the main status indicator for operating the power system. If the system frequency deviates significantly from the nominal value, system instabilities and, in extreme cases, blackouts will occur. Maintaining a continuous load-supply balance is therefore of utmost importance for a well-functioning power system.

However, imbalances occur all the time. Consumption changes continuously and – more important – unpredictably. Residential customers are switching on and off appliances and large industrial customers might have sudden changes in their consumption pattern. Power plant failures occur, resulting in immediate supply deficits. With the increasing share of renewables (e.g. wind and solar), their intermittent output becomes a growing source of unexpected imbalances. Furthermore, transmission line failures might result in opposite imbalances on both sides of the failure. Such a transmission line incident happened on the evening of November 4, 2006, creating a large power deficit in Western Europe and a large surplus in Eastern Europe. About 15m households from Germany to Portugal were for some time without power, making this event one of the largest blackouts in European history (cf. UCTE, 2007 and BNetzA, 2007a).

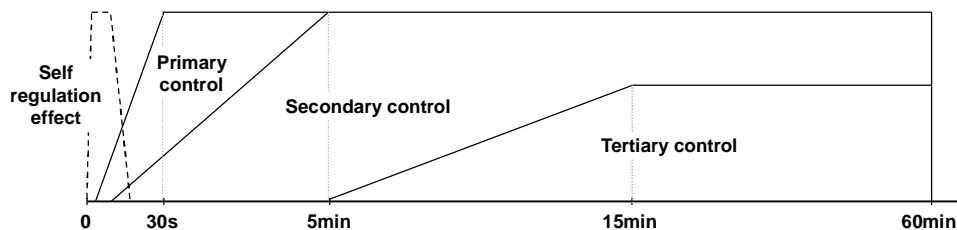
2.2 Frequency and imbalance control

Power systems are, to a limited extent, self-regulating. Frequency-dependent loads (e.g. motors) decline as the system frequency drops, and vice versa (see Al-Awaad, 2009). This reduces the imbalance and stabilizes the system frequency to some extent. However, this effect is insufficient for balancing the system.

The Union for the Co-ordination of Transmission of Electricity (UCTE)¹ has agreed standardized procedures to actively handle any system imbalance (see UCTE, 2004). Multiple control and

¹ The UCTE is the association of most Continental European electricity transmission system operators. It was merged into the European network of transmission system operators for electricity (ENTSO-E) in

defense actions are defined depending on the system frequency. Within a range of $\pm 20\text{mHz}$ no action is taken. When this threshold is exceeded, three hierarchical levels of load-frequency controls are employed: primary, secondary and tertiary control (see Figure 1). They differ by response time and control characteristics.



Source: Based on Swider (2006) with own adaptations

FIGURE 1: SEQUENCE OF LOAD-FREQUENCY CONTROL

Primary control activates the corresponding primary reserve capacity immediately to stabilize the system frequency in case of a disturbance. Full response has to be reached within 30 seconds. Activation is done automatically and decentrally through governor control by all generators in the UCTE system that provide primary reserve capacity. After the activation a quasi-steady frequency state is reached. The technical properties of the primary control process do not allow to restore the original load-supply balance and to bring the system back to the nominal system frequency of 50Hz.

This is done mainly by secondary control. Secondary reserves are activated by the centralized automatic generation control (AGC) at the level of the control zones to restore the scheduled load-flows between control zones and free the system-wide primary reserves. Activation also starts immediately after a disturbance and must reach full level within 5 minutes.

Tertiary control exists mainly for economic reasons. It restores and supports the faster responding secondary reserves. Tertiary reserves are usually activated automatically via re-scheduling by the TSO and should be fully available 15 minutes after activation. They are supposed to cover larger, more lasting imbalances at lower costs than secondary reserves.

When the frequency drops are too severe and the three load-frequency controls cannot react sufficiently, load shedding is used as a last resort. If the system frequency reaches 49.5Hz, pump loads of pumped-storage plants are automatically shed (see UCTE, 2007). Customer load is started to be shed automatically at a system frequency level of 49Hz, with further thresholds

below. Therefore protocols exist that, step-by-step, switch off local distribution grids at sub-stations.

The full series of control and defense measures was necessary during the system disturbance on the 4th of November 2006. They are well documented and described in UCTE (2007) and BNetzA (2007a).

It is important to catch “the falling knife”, even if it causes inconvenience and partial blackouts. As the system becomes more and more instable, generation units trip, which further increases the problem. At the frequency level of 47.5Hz, all generation units are disconnected and the power system is shut down. This would be the worst possible state – a full blackout. Recovery from such a situation is particularly difficult and can take days. Power stations need to be brought back online, while they themselves need power for operation. Therefore specific, so-called “black-start capable” plants are needed, which then help to restore the system step-by-step.

2.3 Sources of reserve capacity

The required reserve capacity can be provided from the supply-side as well as from the demand-side. It is only important that it can be provided reliably and fulfills the technical requirements (e.g. response time). This is ensured by a pre-qualification process.

So far, the supply-side has been by far the dominant source for reserve capacity, essentially thermal and hydro power plants. All thermal plants (gas, coal, lignite and nuclear) can provide all three reserve types when they are online (see Swider, 2006, also for more detailed technical explanation). However, the amount of reserve they can actually provide differs, as they have different ramp rates (% of capacity they can ramp up and/or down per minute). For incremental reserve, the plants need to run below their maximum capacity. For decremental reserve, they must run above their minimum stable operation limit. Due to their fast start-up times, gas turbines are the only thermal plants that can provide tertiary reserve capacity when they are offline. All other thermal plants need far more than 15min to start and ramp up.

Hydro power plants have different properties and abilities for reserve provision. Run-of-river plants have only limited capacity to hold back water for regulation. Therefore, they can only be used to provide primary reserve since primary control relies more on flexible up and down regulation capability than generating more or less energy over some longer time, which is important for secondary and tertiary reserves.

Storage and pumped-storage hydro plants have very high ramp rates and can start up very quickly. This makes them an ideal source for any type of reserve capacity. Incremental

secondary and tertiary reserve capacity can be provided even if they are offline. In pump mode, most pumped-storage plants are not flexible. Most pumps can be operated only at full speed. However, a hydrological short-circuit (using part of the pumped water in the turbine) can be implemented to overcome this shortcoming.

Recently, additional sources for supply-side reserve capacity became available. The increasing capacity of decentralized generation (e.g. Small-Scale CHP) can provide reserve capacity when pooled in virtual power plants (see Erge et al., 2010). Upspring aggregators like Next Kraftwerke, Energy2market or Grundgrün have entered the German reserve capacity market and operate virtual power plants that are prequalified to supply reserve capacity (see Regelleistung, 2015). Also storage technologies like batteries have the technical and economic potential to provide reserve capacity (see VDE, 2009). The German regional utility WEMAG started to provide primary reserve capacity from its 5 MW lithium-ion battery plant (see WEMAG, 2014).

In the mid-term future, reserve capacity might also be supplied by renewables like wind. Technically, wind turbines are able to provide all three types of reserve capacity (see Al-Awaad, 2009). Changing the pitch of the blades allows to regulate the output. However, the intermittency problem partly remains. If there is no wind, reserve cannot be provided. Over a foreseeable period with sufficient wind, the amount of reserve capacity that can be provided depends on the expected wind pattern and its minimum. Hence, large off-shore parks might provide reserve capacity over short periods of time that can be predicted with high accuracy. The analysis of Al-Awaad shows, though, that the reserve provision is not economical under the so far prevailing feed-in tariffs. This might change with the increasing market integration of renewables as a result of the recent amendments of the German renewable energy law (cf. EEG, 2014).

System reserve capacity can be provided from the demand-side (usually large industrial customers, e.g. large refrigerated warehouses) as well, but due to different restrictions, mainly technical ones, there had been difficulties to implement these measures widely in Germany (see Heise, 2007). However, these restrictions have been recently overcome. Trimet, an aluminum producer, supplies primary reserve capacity from its electrolysis facilities (Trimet, 2014). The utility Stadtwerke Schwerin, among others, provides decremental secondary reserve using electro boilers (Stadtwerke Schwerin, 2013), a technology widely referred to as power-to-heat. It is generally expected that the demand-side participation in the reserve capacity market will increase. As part of the demand-side, electric vehicles are expected to play a role as a source of flexibility and reserve capacity in the mid-term future (see Galus et al., 2010).

2.4 Demand for reserve capacity

System reserve capacity is basically an insurance against instabilities of the power system. The required volume is determined by the trade-off between security (as large as necessary) and costs (as small as possible).

In the UCTE network, a primary reserve capacity of $\pm 3,000$ MW is required (see UCTE, 2004). This corresponds roughly to the breakdown of two large power plants. The provision of the $\pm 3,000$ MW is distributed among the individual TSOs proportional to the share of generated power within their respective control zone. The German TSOs had to have ± 578 MW primary reserves at their disposal as of mid-2015 (see Figure 2).² Over the last 10 years the required primary reserve capacity decreased slightly, mainly driven by a higher growth of electricity generation outside Germany and extension of the UCTE control zone.

The demand for secondary and tertiary reserve capacity is determined by a probabilistic analysis and an acceptable shortfall probability. The Graf-Haubrich method is generally used (see Consentec, 2008). The German TSOs had to obtain 2,076 MW incremental and 2,103 MW decremental secondary reserves as well as 1,513 MW incremental and 1,782 MW decremental tertiary reserves mid of 2015 (see Regelleistung, 2015).

The demand for secondary and tertiary reserve capacity significantly declined over the last decade. The amendment of the Energiewirtschaftsgesetz (EnWG) in 2005 empowered the German regulator Bundesnetzagentur to refine and monitor the reserve capacity market. The active challenging of required reserve capacity as well as market design changes (e.g. the operational cooperation of the four German TSOs in 2009/10, see Section 3.2 for further details) increased the usage effectiveness of the reserve capacity and therefore ultimately reduced its demand. As a result, the required incremental and decremental secondary reserves declined by 37% and 19%, respectively, compared to the 2005 level. While the demand for incremental tertiary reserves declined significantly, the demand for decremental tertiary reserves generally increased over last decade. The German regulator attributes this inverse trend to the change in the German generation structure and the increase of renewable production (see BNetzA, 2013). Furthermore, there is a trend to harmonize the amount of incremental and decremental reserve capacity.

In the auctions themselves, demand for reserve capacity is fixed and price-inelastic.

² The primary reserve capacity auction via the internet platform www.regelleistung.net tenders additionally ± 71 MW of the Swiss, ± 67 MW of the Austrian and ± 67 MW of Dutch primary reserve requirements as part of the ± 783 MW to be procured in the joint auction (see Regelleistung, 2015 and cf. footnote 13)

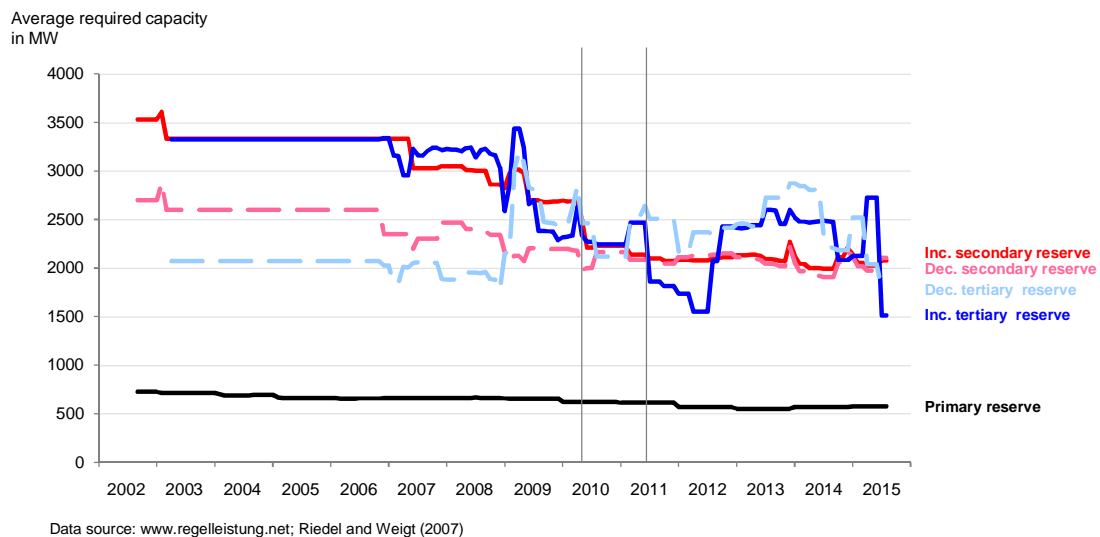


FIGURE 2: DEMAND FOR RESERVE CAPACITY BY GERMAN TSOs

3 Market design in Germany

Following the EU directive 96/92/EC (see EU, 1996) and its translation into the German energy law EnWG (1998), the German electricity market was liberalized in 1998. The main innovations were the suspension of the regional monopolies, the negotiated non-discriminating third party access (TPA) to the electricity grid, and the formal unbundling of the TSOs. This paved the way for competitive electricity markets.

The EU directive gave the individual member states a choice between three models for network access: negotiated open access, regulated open access to the system or a single buyer model. The first two models are essentially sub-forms of what is known as the decentralized bilateral market model. The single buyer model is often referred to as being similar to or a more general form of a centralized pool model (see Harris, 2006; Meeus et al, 2005). In a pool model all physical power transactions are centrally coordinated and administered by the system operator. All power generation capacity has to be offered into the pool. The system operator co-optimizes the generation dispatch, the reserve capacity provision, and partly even the required transmission capacity through a computational algorithm. The most prominent example of a pool model is the PJM-system in US states of Pennsylvania, New Jersey and Maryland.

The German legislative authorities – like most European counterparts – decided to implement a decentralized bilateral market model that relies on various not explicitly coordinated markets. The main idea behind the bilateral market model is that the open non-discriminatory TPA creates a level playing field for market-based interactions. The individual market participants can freely decide how to interact, e.g. via bilateral trades or via an exchange. As a result,

separate markets for scheduled energy, reserve capacity, and balancing energy exist in Germany.

In the following, an overview of the electricity markets in Germany is provided and the development of the reserve capacity market and balancing mechanism design is summarized.

3.1 Overview of electricity markets in Germany

Broadly, three types of markets or mechanisms can be distinguished in Germany (see Figure 3). The first one is the scheduled energy market, in which the actual output of power plants is traded and administrated in schedules.³ It is often also referred to as wholesale energy market. Thereby, forward and (day-ahead and intraday) spot energy markets are distinguished.⁴

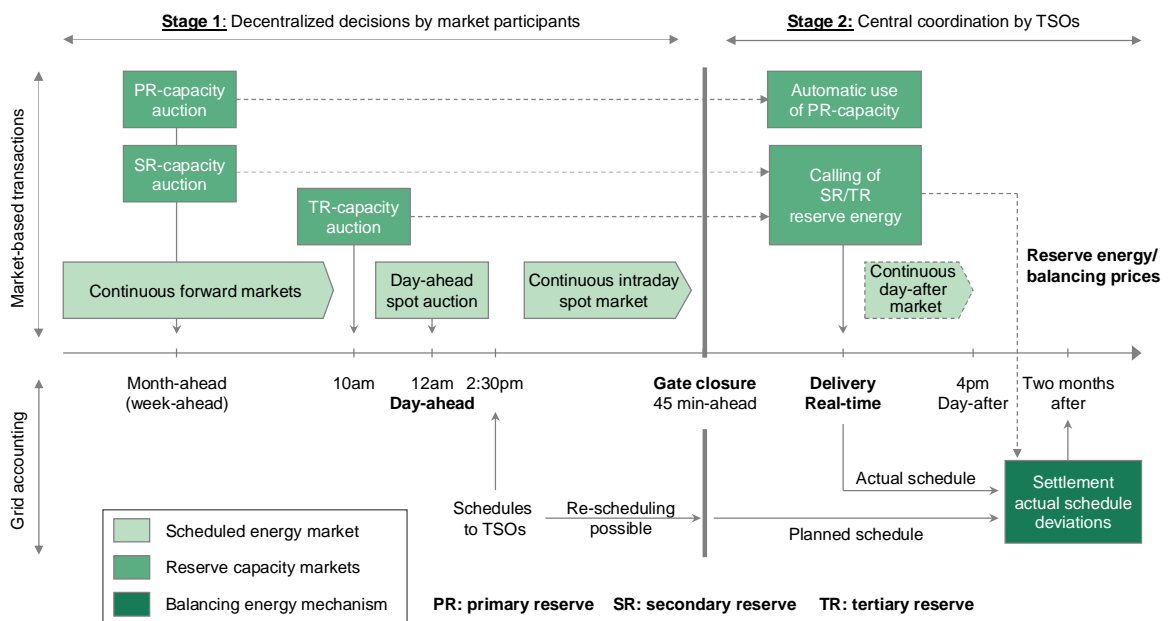


FIGURE 3: CURRENT SEQUENCE OF ELECTRICITY MARKETS IN GERMANY

Second, in the reserve capacity markets, the TSOs procure reserve capacity via one-sided auctions some time ahead of its contingent use. The contracted capacity is called in real-time as required to balance the system, when a difference between the planned energy schedule and the

³ An energy schedule describes the energy supplied, transported or consumed over a certain period of time in ¼-hourly increments.

⁴ Forward (or future) markets exist mainly for hedging purposes (see Hunt, 2002). Some time ahead of delivery, energy is continuously traded in forward markets either on the European Energy Exchange (EEX) or over-the-counter (OTC). Most of these trades are purely financial and only part of the OTC deals are physical. The financial forward contracts are generally settled at the day-ahead spot price.

required load arises in real-time. The option-like character of reserve capacity is reflected in the two-part pricing. The provision of reserve capacity is remunerated with a reservation price (€/MW) for reserving the capacity, and a reserve energy price (€/MWh) is paid for exercising the reserve option to generate the required energy in real-time. The incremental and decremental reserve energy supplements the scheduled energy.

Third, the costs for supplemental reserve or balancing energy are distributed among the market participants responsible for imbalances. This procedure is called the balancing mechanism and administrated by the TSOs (see Section 3.3 for details).

The first two – the scheduled energy and the reserve capacity market – are market-based transactions, whereas the third – the balancing mechanism – is an accounting procedure.

In an ideal world, the required energy could be traded in a real-time market. This would mean that all power plant dispatch decisions are continuously made in real-time, responding to the instantaneous consumption and setting a real-time price for the consumed energy. In such an ideal world, there would be no need for these three types of markets. However in reality, three main factors impede a true real-time market. First, a large number of transactions would be required every moment in a decentralized electricity system. Second, the operation of power plants is path-dependent. The efficient dispatch depends on the operation status in the preceding and subsequent hours (see Weber, 2005). Third, the grid infrastructure must technically be able to transmit the energy.

For these reasons, the European electricity system is administrated in two essential phases separated by the so-called gate closure. Decentralized decisions are characteristic for the first phase before gate closure whereas central coordination prevails after gate closure. In the first phase, the day-ahead spot market has the crucial function to align the demand expectations and the system-wide dispatching decisions of the various generators. Physical energy is traded for individual hours (or blocks of hours) of the following day for all locations in Germany.⁵ After the EEX day-ahead spot market is held, all market participants (technically all balancing groups) have to submit their ¼-hourly energy schedules for the following day to the TSOs. At this stage, the system is theoretically in balance as all expected generation schedules must equal the expected consumption schedules. The TSOs monitor the schedule balance and the feasibility of the expected power flows. These schedules can be adjusted until gate closure 45 minutes ahead of delivery. There is a continuous intraday spot market to facilitate physical energy transactions necessary for those re-schedulings. At the EEX and OTC hourly and ¼-hourly products are

⁵ Even if four control zones exist in Germany, they are managed as a single price zone for all energy transactions. Congestions – if they occur – are handled by the TSOs through re-dispatch on their account. Currently, there is no market for transmission capacity in Germany.

traded. These are the last market-based transactions and decentralized decisions before the energy schedules are fixed and economically binding.

After gate closure, the second phase starts and the TSOs take over the responsibility for any further action. If necessary, the TSOs call the contracted reserve capacity based on the reserve energy price merit order to balance the system in real-time. Furthermore, the TSOs collect the metering data on the actual consumption and generation schedules. The imbalance between the planned and actual schedules for every balancing group is settled at the balancing price. The settlement of these costs has to occur at the latest two month after the operation. This procedure is called the balancing mechanism. Pricing of the actual imbalances caused by each balancing group shall ensure the right incentive for effective decentralized planning before gate closure and thus minimize the actually arising balancing requirements in real-time.

The specific design of the reserve capacity market and the balancing mechanism are detailed in the following.

3.2 Reserve capacity markets – design and development

During the first years after the liberalization, the TSOs continued their established practice to obtain the necessary reserve capacity exclusively from their associated generation companies.⁶ Besides the intransparency, this opened ample opportunities for profit-shifting.

The German Federal Cartel Office (Bundeskartellamt) recognized this uncompetitive behavior and ordered the implementation of transparent public tenders for reserve capacity as part of the conditions for merger clearance between RWE and VEW as well as between E.ON and Heingas (see BKartA, 2000a,b). Formally, the orders applied only to the TSOs of RWE and E.ON. In addition, the Cartel Office opened abuse control proceedings against the other two TSOs in 2001, resulting in identical orders against EnBW and Vattenfall (see BKartA, 2002a,b).

To increase efficiency, RWE as well as Vattenfall had to consolidate their respective control zones, reducing the total number to four control zones in Germany.⁷ The Cartel Office ordered further

- to establish a pre-qualification process for all potential suppliers based on technical requirements only,

⁶ As the German authorities decided to implement the negotiated TPA, all network-related issues were negotiated and recorded in the *Verbändevereinbarung* (association agreement). Both *Verbändevereinbarungen* I and II did not contain any specification about the procurement of reserve capacity. Hence, it was a largely unregulated space.

⁷ RWE had to combine its original with the VEW control zone. Similarly, the former Bewag, HEW and VEAG control zones had to be consolidated by Vattenfall.

- to tender primary and secondary reserve capacity for a period of maximum six months,
- to tender tertiary reserve capacity daily (applying after a transition period),
- to distinguish between separate incremental and decremental products as well as separate prices for capacity provision and reserve energy delivery when procuring secondary and tertiary reserves⁸, and
- to publish the results in anonymous form shortly after the auctions.

The limited preciseness in the Cartel Office order led to a very heterogeneous implementation by the four TSOs. Table 1 is based on Swider (2004) and shows that the auctions differed by the auction timing, the offer periods, the minimum offer capacity, the bid selection and remuneration. This made a comparison among the auction results difficult and led to a splitting into four distinct markets. The heterogeneous market design certainly favored the incumbent suppliers and thus caused much criticism (see Swider and Weber, 2003; Swider and Ellersdorfer, 2005; Wawer, 2005). As a consequence, the Cartel Office started an investigation into excessive prices in the markets for reserve capacity (see BKartA, 2003).

The European as well as the German authorities recognized that not only the reserve capacity design, but the overall electricity market design was insufficient and launched a new series of legislations with the directive 2003/54/EC (see EU, 2003) and the second amendment of the EnWG (2005). The main implications for the reserve capacity markets were fourfold:

- the codification of the reserve capacity market fundamentals (§22 EnWG, 2005 and §6-10 StromNZV, 2005) – essentially specifying and codifying the Bundeskartellamt orders,
- the implementation of one common web-based auction platform for the four control zones,
- the obligation for cooperation among the TSOs to reduce the costs for reserve capacity and energy as long as the security and network conditions are not compromised, and
- most importantly, empowering the German regulator Bundesnetzagentur to refine and monitor the market design for reserve capacity and balancing energy.

⁸ Primary reserve capacity is tendered as a power bandwidth comprising incremental as well as decremental regulation. It is tendered at a reservation price only. The actual use of the capacity is not rewarded separately as it is assumed that the incremental and decremental primary energy offset each other.

TABLE 1: MAIN CHARACTERISTICS OF RESERVE CAPACITY AUCTION 2001-2006 BY TSO

		RWE Net AG	E.ON Netz GmbH	EnBW Transportnetze AG	Vattenfall Europe Transmission GmbH
Primary reserve capacity	Auction timing	Biannual (Feb-Jul & Aug-Jan)	Biannual (Jun-Nov & Dec-May)	Biannual (Feb-Jul & Aug-Jan)	Biannual (Mar-Aug & Sep-Feb)
	Offer periods	Only working days/ weekend possible	Peak/base periods ^a	Only working days/ weekend possible	Only working days/ weekend possible
	Min. offer capacity	+/- 2 MW	+/- 10 MW	+/- 10MW	+/- 10MW
Secondary reserve capacity	Auction timing	Biannual (Feb-Jul & Aug-Jan)	Biannual (Jun-Nov & Dec-May)	Biannual (Feb-Jul & Aug-Jan)	Biannual (Mar-Aug & Sep-Feb)
	Offer periods	Peak/base periods ^b	Peak/base periods ^a	Peak/base periods ^c	Peak/base periods ^c
	Min. offer capacity	+30MW / -30MW	+30MW / -30MW	+30 MW / -30MW	+20MW / -20MW
	Bid selection	Mix of reservation and energy price ^f	Reservation price only	Reservation price only	Reservation price only
	Bid remuneration	Pay-as-bid	Uniform pricing	Pay-as-bid	Pay-as-bid
Tertiary reserve capacity	Auction timing	Daily (day-ahead 2pm)	Daily (day-ahead 10.30am)	Daily (day-ahead 1.30pm)	Daily (Day-ahead 9.00am)
	Offer periods	5 periods ^d	Peak/base periods ^a	Peak/base periods ^c	Peak/base periods ^e
	Min. offer capacity	+ 30MW / -30MW	+50MW / -50MW	+ 30MW / -30MW	+30MW / -30MW
	Bid selection	Mix of reservation and energy price ^f	Reservation price only	Reservation price only	Mix of reservation and energy price ^f
	Bid remuneration	Pay-as-bid	Uniform pricing	Pay-as-bid	Pay-as-bid

a. Peak periods Mon-Fri 6am-10pm & Sat, Sun 8am-1pm

b. Peak periods 8am-8pm

c. Peak periods Mon-Fri 8am-8pm

d. 0-4am, 4-8am, 8am-4pm, 4-8pm, 8-12pm

e. 0-4am, 4-8am, 8-12am, 12am-4pm, 4-8pm, 8-12pm

f. Bid selection changed over time; partly selection by capacity price only

Source: based on Swider (2004), Albers (2001) and Wawer (2005)

The Bundesnetzagentur practically assumed its responsibility for the reserve capacity market in 2006, when harmonizing and refining the design for tertiary reserve capacity (see BNetzA, 2006). The objective was to enhance competition and to align the design among the four control zones. The main refinements starting December 2006 were

- to tender incremental as well as decremental tertiary reserves daily with six 4-hour time slots (0-4am, ..., 8-12pm),
- to hold the auction day-ahead at 11am (one hour before the day-ahead spot auction),
- to reduce the minimum offer capacity for tertiary reserve from 30MW to 15MW,
- to allow pooling of capacities within a control zone to reach the minimum offer capacity,
- to select the bids by reservation price only and to remunerate the successful bids pay-as-bid (capacity provision and energy),

- to procure at most 50% of the (secondary plus tertiary) reserve capacity⁹ exclusively from within the respective control zone and at least 50% from a regionally-unrestricted tender, and
- to administer the auction procedure and to publish the results via a common internet platform (www.regelleistung.net).

The penultimate item is also called the “Kernanteil”. It was the first step towards a cross-control zone auction. Before, the TSOs procured the required reserve capacity exclusively from within their control zone, arguing that it is technically inevitable. The 50% “Kernanteil” was the practical compromise between reaching a higher efficiency in an unrestricted market and technical concerns.

Similarly, the Bundesnetzagentur refined the rules for the primary and secondary reserve capacity auctions one year later, effectively applying in December 2007 (see BNetzA, 2007b,c). The main refinements were

- to auction primary reserves monthly without sub-segments and secondary reserves monthly with two time segments (peak: Mon-Fri 8am-8pm; off-peak: otherwise, including public holidays),
- to set the minimum offer capacity to +/-5MW for primary reserves and 10MW for incremental and decremental secondary reserves,
- to allow pooling of capacities to reach the minimum offer capacity,
- to select the primary reserve bids by the reservation price with a pay-as-bid remuneration (no energy bids for primary reserves),
- to select the secondary reserve bids by reservation price only and to remunerate the successful bids pay-as-bid (capacity provision and energy), and
- to procure the reserve capacity unrestricted to specific control zones (i.e. repealing the “Kernanteile” for secondary as well as for tertiary reserves)¹⁰.

The removal of the “Kernanteile” meant that the TSOs procured the reserve capacity jointly and then assigned individual capacities to specific TSOs for usage.¹¹ The control zones were still

⁹ Thereby at least 2/3 of the secondary reserve capacity had to be provided from within the control zone.

¹⁰ The TSO Vattenfall Europe Transmission GmbH (now 50Hertz Transmission GmbH) was granted an exception of 520MW decremental secondary reserve capacity due to specific network congestions.

administered separately. This could mean that one control zone was undersupplied and had to use incremental reserves, whereas another control zone was oversupplied and had to use decremental reserves. This inefficiency was criticized by many market participants as well as in the academic literature (see Nailis, 2006; Riedel and Weigt, 2007; LBD, 2008; Consentec, 2008; Flinkerbusch and Heuterkes, 2010).

The Bundesnetzagentur started a determination procedure into this issue in July 2008 (see BNetzA, 2008). As an intermediate result, the three TSOs EnBW Transportnetze AG (TransnetBW GmbH since March 2012), Transpower Stromübertragungs GmbH (the former E.ON Netz GmbH)¹² and 50Hertz Transmission GmbH (former Vattenfall Europe Transmission GmbH) formed the Grid Control Coordination (GCC, or Netzregelverbund in German) in May 2009 with the objective of netting the existing imbalances of the three control zones. Hence, only the remaining imbalances need to be countered using reserve capacity in each control zone (see E-Bridge, 2009). The GCC managed the three control zones de facto as one zone for all balancing issues. Following an order by the Bundesnetzagentur, the fourth TSO Amprion GmbH (former RWE Net AG) had to join the GCC in May 2010 (see BNetzA, 2010).

The GCC adjusted also the control concept for secondary reserves. Every plant needs only one data connection to the central AGC to provide secondary reserve in all four control zones. Hence, this created a true common market without technical separations.¹³

In a further and most recent step, the Bundesnetzagentur refined the market design for primary and secondary reserves effective as of July 2011 (see BNetzA, 2011a,b) and for tertiary reserves effective as of Dec 2011 (see BNetzA, 2011c). The main refinements are

- to auction primary and secondary reserves weekly (with the earlier defined time segments unchanged),
- to reduce the minimum offer capacity to +/-1MW for primary reserves and to +/-5MW for secondary and tertiary reserves,

¹¹ The joint market applied only to primary and tertiary reserves. To offer secondary reserve in all four control zones, a power plant had to be directly connected to the AGCs of each TSO. This technical restriction resulted in the continuous separation of the secondary reserve market. See also Section 4.2 for the impact on competition.

¹² After the sale of Transpower Stromübertragungs GmbH from E.ON to TenneT, the company was renamed TenneT TSO GmbH as of October 5, 2010 (see TenneT-TSO, 2010).

¹³ The GCC has been continuously internationally extended since 2011 and the Danish TSO Energinet.dk, the Dutch TSO Tennet TSO BV, the Swiss TSO Swissgrid, the Czech TSO CEPS, the Belgium TSO Elia and the Austrian TSO APG have joined the GCC. They are using free cross boarder transmission capacities to net existing imbalances and thus reduce the overall reserve capacity requirements. The Austrian, Dutch and Swiss TSOs even procure partly primary reserve capacity together with the German TSO during the internet platform www.regelleistung.net.

- to automatize the control and activation of tertiary reserves, and
- to further increase the transparency and breadth of the information published via the web-based platform www.regelleistung.net.

The main properties of the current market design as of August 2015 are summarized in table 2.

TABLE 2: MAIN CHARACTERISTICS OF RESERVE CAPACITY AUCTIONS AS OF AUG 2015

	Primary reserve capacity	Secondary reserve capacity	Tertiary reserve capacity
Auction timing	Weekly	Weekly	Daily (day-ahead 10am)
Offer periods	1 period	2 periods (Peak/base)	6 periods of 4 hours (0-4am, ..., 8-12pm)
Min. offer capacity	+/- 1MW	+5MW / -5MW	+ 5MW / -5MW
Pooling of capacity	Possible	Possible	Possible
Offer price components	Reservation price	Reservation & energy price	Reservation & energy price
Bid selection	Reservation price only	Reservation price only	Reservation price only
Bid remuneration	Pay-as-bid	Pay-as-bid	Pay-as-bid
Calling of capacity	All proportionally depending on frequency	By reserve energy price	By reserve energy price
Control mechanism	Automatic decentral control via governor control	Automatic central control via direct data connection	Automatic central control via direct data connection

Source: based on BNetzA (2011a,b,c)

3.3 Balancing energy mechanism and its development

The administration of the electricity system is a complex task. Millions of customers and suppliers are withdrawing and injecting electricity from the grid infrastructure. The TSOs as the responsible system operators keep track of all the transactions and the economic accountabilities with an accounting procedure called balancing groups. Simply speaking, these are virtual accounts collecting the supply as well as the withdrawal of power schedules.

Every market participant (e.g. generators, supply companies with all withdrawal points of its end customers, larger customers with wholesale market access, traders) with its injection and withdrawal points needs to be part of a balancing group, one for every one of the four control zones it has transactions in. A balancing group can consist of multiple market participants and is steered by the balancing responsible party (BRP). The BRP is economically accountable for keeping the balance between all power supplies and withdrawals in every ¼-hour within its balancing group.

At the planning stage between handing in the schedules day-ahead at 2.30pm and gate closure, all balancing groups are balanced by definition. Otherwise, the schedules are not accepted by the TSOs. Imbalances may arise in real-time between planned and actual schedules, both for power supplies and withdrawals.

A simple example will help the understanding. A supply company, supplying end customers with electricity in only one control zone, needs to forecast all withdrawals for the next day, resulting in a withdrawal schedule with 96 ¼-hourly power volumes. The matching supply schedule is sourced from a generation company. This sourced schedule is booked in the balancing groups of both the supply and of the generation company. The balancing group of the supply company is theoretically balanced after this transaction. The forecasted withdrawal schedule and the sourced supply schedule are submitted to the TSO and are binding after gate closure. Deviations occur when the actual metered withdrawal schedule does not match the forecasted withdrawal schedule.¹⁴ The sourced supply schedule does not change. Any change in the planned generation is a deviation in the balancing group of the generation company.

In this way, the balancing group procedure assigns and tracks accountabilities for any power transaction in the system. Part of the overall accounting procedure is the balancing mechanism that settles the actual imbalances at the balancing price.

After the liberalization and in the framework of the negotiated TPA, the TSOs implemented a balancing mechanism that was widely regarded as intransparent and discriminating (see BKartA, 2000a,b; Müller-Kirchenbauer and Zenke, 2001). For every balancing group, a tolerance range of $\pm 5\%$ of maximum monthly load was defined. Within that range, imbalances could be partly accumulated and netted over a week. A limited part of the remaining imbalance could be carried over into the next week and the remainder was charged or respectively remunerated at the balancing energy price. Outside the tolerance range, the imbalances were charged/remunerated directly at a relatively high price (see VVII, 1999). This mechanism favored large balancing groups (usually the large utilities affiliated with TSOs), as portfolio effects generally lead to smaller relative imbalances. Furthermore, the balancing prices were regarded as prohibitive (see Müller-Kirchenbauer and Zenke, 2001).

The Bundeskartellamt recognized the inadequate design and ordered the implementation of major changes in the balancing mechanism during the RWE/VEW and E.ON/HeinGas merger clearance (see BKartA, 2000a,b). The balancing prices were directly linked to the effective energy prices of the reserve capacity market. The average price paid for the required secondary

¹⁴ Thereby, only deviations of the average volume of the ¼-hour are relevant. Within the ¼-hour all deviations are netted (see StromNZV, 2005).

and tertiary reserve energy during a ¼-hour sets the respective balancing price. The balancing price depends on the status of the control zone – either the decremental balancing price when the control zone is long/oversupplied or the incremental balancing price when the control zone is short/undersupplied. All balancing groups with a positive imbalance (an oversupply of energy) receive this balancing energy price and all undersupplied balancing groups have to pay for the missing energy. The balancing mechanism is summarized in Figure 4.

		Status of control zone	
		Long/ oversupplied	Short/ undersupplied
Status of own balancing group	Long/ oversupplied	Receive decremental reserve energy price	Receive incremental reserve energy price
	Short/ undersupplied	Pay decremental reserve energy price	Pay incremental reserve energy price

FIGURE 4: SUMMARY OF THE REMUNERATION OF THE BALANCING MECHANISM

The mechanism distributes the reserve energy costs among the originators of the imbalance.¹⁵ Additionally, it redistributes payments between balancing groups with opposite imbalances. Under this design, it is hence a zero-sum activity for the TSOs.

As the balancing price is the same for over- and undersupplied balancing groups (only the payment direction differs), it is called a one-price system. It does not provide portfolio effects and does not discriminate against smaller balancing groups.

However, as shown by Just and Weber (2015), the mechanism is prone to strategic behavior. Balancing energy is a substitute for any electricity traded in the scheduled energy markets. As the spot and balancing prices are disconnected, statistical arbitrage opportunities exist.

Critical grid situations with significant imbalances in winter 2011/12 raised the attention of the regulator Bundesnetzagentur. It initiated a detailed investigation (see Consentec, 2012), which pointed out insufficiencies in the balancing mechanism. As a result, the Bundesnetzagentur

¹⁵ The costs, incurred by the TSOs, for reserving the capacity are distributed to all customers via the grid fees.

stipulated two amendments of the balancing mechanism in December 2012 to curb the strategic behavior (see BNetzA, 2012):

- Using the higher of the intraday spot price and the balancing price as balancing payment in case of undersupply, and vice versa,
- Using a surcharge if the imbalance is larger than 80% of the contracted reserve capacity: the balancing price is increased by 50% (at least by 100 €/MWh) in undersupply situation, or reduced by 50% (at least by 100 €/MWh) in oversupply situations.

The first modification eliminates arbitrage opportunities when the balancing price is lower than the intraday spot price in case of an undersupplied control zone, and when the balancing price is higher than the intraday spot price in case of an oversupplied control zone. The second modification reduces arbitrage opportunities in the most severe system situations when remaining reserve capacity is short and increases the incentive for better forecasting. Both modifications are certainly a step in the right direction, but they do not completely solve the problem with strategic behavior (cf. Just and Weber, 2015).

For completeness, the balancing groups have the possibility to adjust their planned and submitted schedules retroactively until 4pm the day-after. This does not change anything physically, yet modifies the grid accounting. Theoretically, energy can be traded retroactively on paper between two balancing groups to change their respective planned schedules. In other words, individual imbalances can be traded in the day-after market, which is basically an OTC market. However, given the design of the balancing mechanism as a one-price system, there are no win-win situations between balancing groups with opposite imbalances that could be facilitated by trading, if the balancing prices are known. Only reducing the uncertainty until the balancing prices are known two months later, provides an incentive for market participants to exchange their imbalances (see Andor et al., 2010a). As shown in Just and Weber (2015), there is a rather high ex ante predictability of the balancing prices. Thus, the day-after market exists, but it is largely irrelevant in practice.

4 Market results

The market results are reviewed along three major dimensions. The overall market size for reserve capacity and energy is presented, followed by a discussion of the competitive structure in terms of number of market participants and by a review of the resulting market prices.

4.1 Market size of reserve capacity and energy

The overall market size of reserve capacity and energy slightly increased between 2005 and 2009 in Germany, from about €1.0bn to €1.2bn per year (see Figure 5). The market size significantly decreased in the following years to an expected level of ~€550m in 2015. Besides a reduction in required reserve capacity volume, prices for capacity reservation decreased significantly (see Section 4.3). The significantly reduced overall costs can be at least partly attributed to the various changes in the market design that fostered a higher efficiency and increased competition.

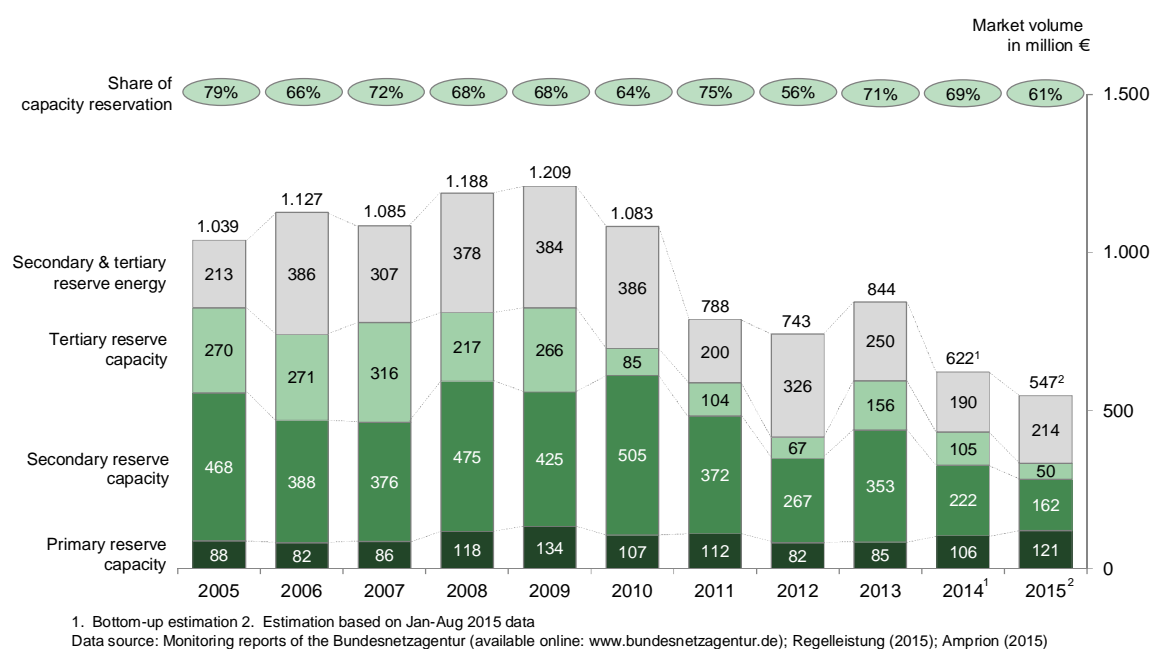


FIGURE 5: MARKET SIZE OF THE GERMAN RESERVE CAPACITY AND ENERGY MARKET

The insurance character of reserve power is highlighted by the fact that capacity reservation makes up about 70% of the overall costs. The actual reserve and balancing energy costs comprise only about 30% of the costs.

Secondary reserve is the dominant reserve type with a share of about 50-60% of the reservation costs. Primary and tertiary reserves contribute about 10-20% and 20-40%, respectively.

4.2 Market participants in reserve capacity markets

In general, there has been an extensive debate about the market concentration and potential oligopolistic clout in the German electricity market (see among others Monopolkommission, 2009, 2011, 2013). Even though, the large four incumbents RWE, E.ON, EnBW and Vattenfall Europe reduced their share of conventional generation capacity from about 90% in the early

2000's to 68%¹⁶ in 2013, they are still the dominant generators (see Monopolkommission, 2013).

Since large conventional power plants are the main source of reserve capacity, the situation has been very similar in the reserve capacity market, especially for primary and secondary reserves. Apart from the large four incumbents, only one other player, Steag, offered into these markets until 2007 (see Figure 6). Due to the technical requirements and their limited generation fleet, independent power producer and municipalities were practically excluded from these markets. The situation improved mainly with the sale and swap of generation capacity to/with large European players like Electrabel/GdF Suez and Statkraft. At the end of 2009, seven companies offered primary and nine offered secondary reserve capacity into the market. As the technical requirements (e.g. minimum offer capacity, capacity pooling and shorter contract durations) were reduced by the Bundesnetzagentur and the GCC was internationally expanded (cf. footnote 13), the number of suppliers increased to 18 for primary and 31 for secondary reserve capacity in 2015.

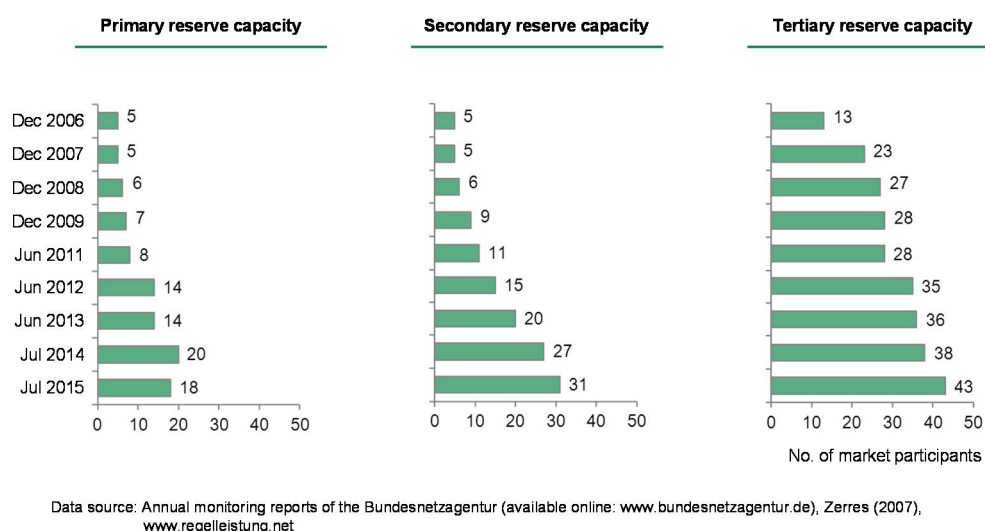


FIGURE 6: DEVELOPMENT OF NUMBER OF MARKET PARTICIPANTS

There is one additional factor that significantly increased the competition – the implementation of the Grid Control Coordination (GCC). Previously, power plants offering secondary reserve had to have a direct connection to the AGC of the control zone. This led effectively to the situation that three of the four control zones had only two potential suppliers, while the fourth control zone had three suppliers (see Zerres, 2007). The implementation of the GCC also changed the control process, resulting effectively in one secondary reserve market without any separation.

¹⁶ The market share of 68% refers only to the installed conventional generation capacity of about 104 GW. Considering the total installed capacity of 174 GW including renewables, the market share of the Big Four is below 50%.

The market for tertiary reserve capacity naturally has a higher number of potential suppliers. The technical requirements are lower (e.g. off-line gas turbines can provide only incremental tertiary reserve capacity) and the market is held daily with a contract duration of only four hours. Mid of 2015, 43 suppliers were active in the market, 15 suppliers more than in 2009 and 30 suppliers more than in 2006 (see BNetzA, 2010, Regelleistung, 2015).

Growitsch et al. (2010) studied the supplier structure and the opportunities to exercise market power in the tertiary reserve market. They found that the market is “best characterized as tight oligopolies with a (competitive) fringe”. For incremental tertiary reserve, the fringe suppliers have a market share of about 30% (see Figure 7), which keeps the market power of the four incumbents limited. The picture is different for decremental tertiary reserves. Not only have the fringe suppliers a smaller market share of about 10%, but also the opportunity of the incumbents to exercise market power rises significantly during the night hours (0-8am).¹⁷ This result is not surprising as the opportunity to lower the output of power plants during night times with low consumption is generally very limited.¹⁸ During such times, decremental tertiary reserve is largely supplied by nuclear, lignite and coal power plants (mostly in part load), which belong predominantly to the four incumbents.

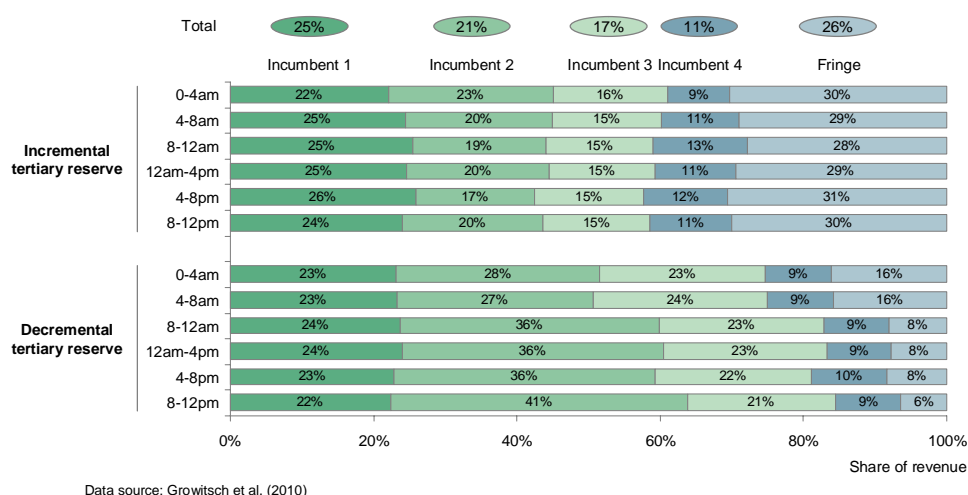


FIGURE 7: MARKET SHARES IN THE TERTIARY RESERVE CAPACITY MARKET

¹⁷ Growitsch et al. (2010) reached this conclusion by using the pivotal supplier index (cf. Bushnell et al, 1999) among other concentration measures, despite the fact that the night hours have a relatively higher market share of the fringe suppliers (see Figure 7). They found that one of the incumbents could have potentially exercised market power in 12 and 14% of the days during the analyzed year. This result was further confirmed by an analysis of the residual supply index (cf. Twomey et al, 2005).

¹⁸ These technical limitations have direct implications for the expected market prices as seen in the next sub-section.

4.3 Market prices for reserve capacity and balancing energy

The following section on market prices aims to provide an overview of the price levels and price development over time.

Primary reserve capacity

The average reservation prices for primary reserve capacity have historically been in a range between €12 and €30 per MW per hour (see Figure 8).¹⁹ The price applies to the capability of both up- and downward regulation. This is different to the auctions for secondary and tertiary reserves, in which the reservation price applies either to upward or downward reserve power. Therefore, reservation prices of the different reserve qualities are difficult to compare.

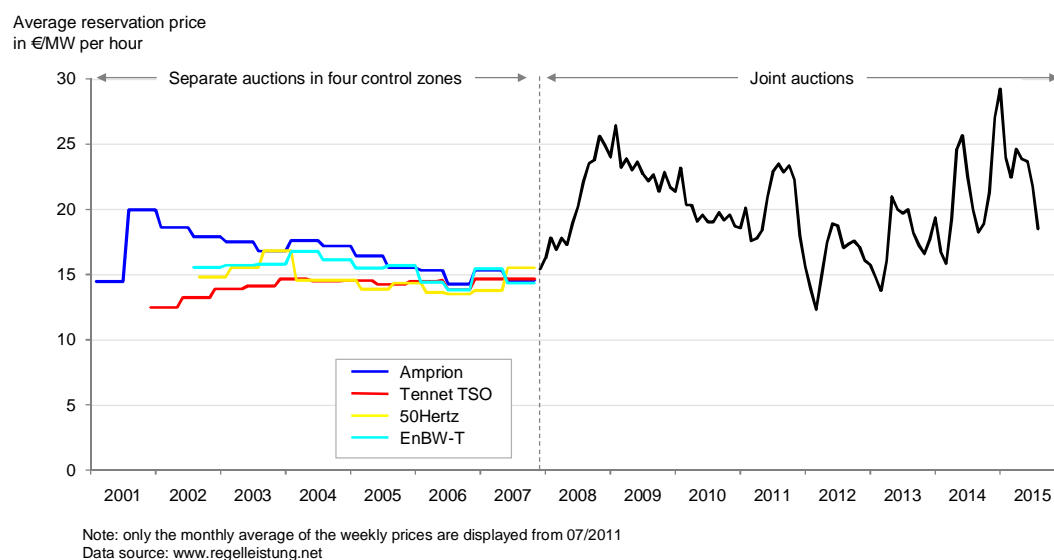


FIGURE 8: DEVELOPMENT OF AVERAGE RESERVATION PRICES FOR PRIMARY RESERVE CAPACITY

Initially, primary reserve capacity was tendered separately in the four control zones for periods of six months. The implementation of the auctions started at different points during 2001 and 2002. The prices were relatively stable and converged among the control zones at a level of about €15/MW per hour. Since December 2007, primary reserve capacity has been tendered monthly in one common auction. Shortly after, the prices increased steeply to about €26/MW per hour in 2008, before decreasing again in the following years to a level of about €18/MW per hour at the beginning of 2011. During the last years 2011-15, the prices were very volatile with steep increases and decreases within a short period, reaching a level of about €18/MW per hour

¹⁹ The reservation prices are expressed in €/MW per hour to compare them more easily with wholesale energy prices, spreads and generation margins that are conventionally quoted in €/MWh.

in mid-2015. The volatility might be explained partly by bidding behavior (see following Excursus).

At first sight, this steep increase in 2008 seems counterintuitive as removing the market segmentation should increase competition and consequently lower prices. Yet the year 2008 was marked by steeply increasing spot electricity prices, which certainly also changed the economics of providing reserve capacity. However, for a qualified discussion, the price and cost drivers have to be understood. This issue is discussed in more depth in Just and Weber (2008).

Excursus: bidding behavior

Pay-as-bid remuneration is used in the reserve capacity market. Thus, theoretically in multi-part auctions with known demand, bidders try to guess the price of the marginally accepted offer to bid as closely as possible while controlling the risk of overbidding. In repeated markets with stable economics, this should lead generally to a convergence of bids. This can be observed in Figure 9, depicting the range of accepted offers (minimum and maximum) and the average price of these bids. Initially after starting the common auction in December 2007, there was presumably relatively large uncertainty about the bidding strategies and the marginal offer. In the following months, the bidding range narrowed somewhat or remained relatively stable. The bidding range significantly widened when the fundamental economics changed.²⁰ Once the uncertainty about the economics disappeared, the bidding range diminished again to a very small margin – as it would be theoretically expected. Similar recurring pattern with “price shocks” can be observed also in spring 2011 (after the Fukushima disaster, resulting in a partial shutdown of nuclear capacity in Germany), spring 2012, and in 2015. Market participants react with a short time delay and adjust to the bidding behavior of the other market participants. This bidding behavior, which is largely impacted by the pay-as-bid remuneration, at least partly explains the price volatility of the average primary reserve capacity prices during the years 2011-15.

²⁰ Following a tremendous increase of oil prices in 2008, natural gas and electricity prices surged to new record levels in the second half of 2008. This certainly changed the economics of providing reserve capacity as well.

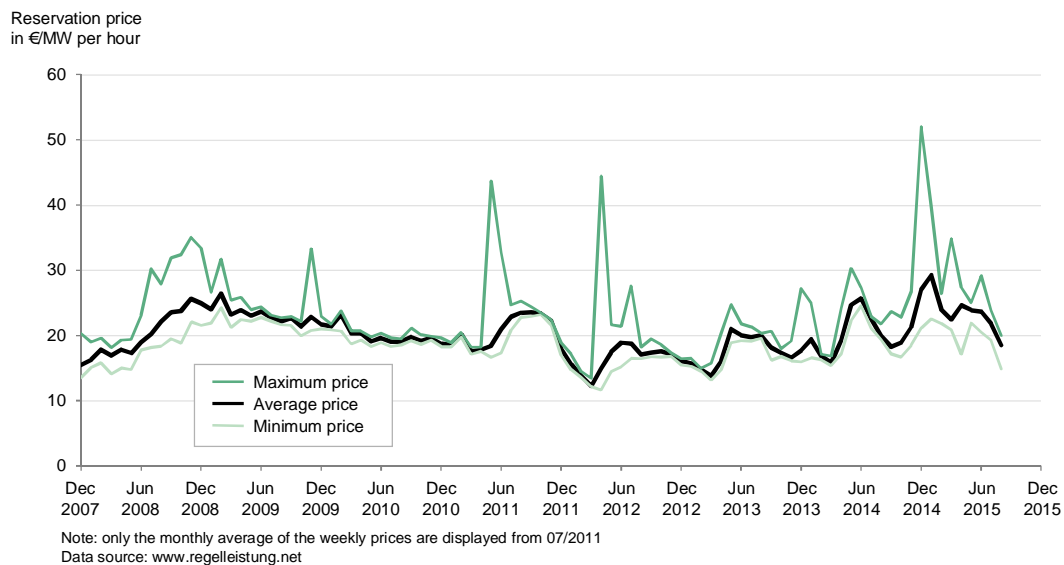


FIGURE 9: RESERVATION PRICE OFFERS FOR PRIMARY RESERVE CAPACITY

Secondary reserve capacity

More than one price exists for secondary reserve capacity – compared to the single price for primary reserves. Secondary reserves are tendered in four products: incremental peak and off-peak as well as decremental peak and off-peak. Furthermore, the auctions consist of a reservation price and an energy price. Energy prices for secondary reserves are considered later in this section jointly with the tertiary reserve energy prices.

Reservation prices for incremental and decremental secondary reserves evolved very differently over time (see Figure 10, which depicts the time-weighted monthly average between the respective peak and off-peak products). Prices for incremental reserve were relatively stable since 2002, moving mainly in a range of €8-12/MW per hour. After the introduction of the common auction in December 2007, the reservation price increased shortly to €14/MW per hour, before steadily declining to a level of about €2/MW per hour during 2012. Only in summer 2011 after the closure of several nuclear power stations in Germany in the Fukushima aftermath, the price for incremental secondary reserve capacity shortly increased, only to decline afterwards steeply to a historically low level in 2012. During 2013 the average price for incremental capacity increased to around €12/MW per hour before returning to a level of about €5-8/MW per hour in 2014/15.

On the other hand, average reservation prices for decremental secondary reserve were initially lower, but have surged significantly from a level of about €5/MW per hour at the end of 2007 up to about €19/MW per hour in the second half of 2010. Afterwards prices were very volatile in a range between €8-16/MW per hour until 2013. In 2014/15 the prices for decremental secondary reserves steeply declined to about €1-4/MW per hour (with another spike end of

2014/beginning of 2015). The general increase of decremental secondary capacity prices is partly attributable to the increasing stress in the German electricity system due to the rising volume of renewables and the short-term limitations to lower the output of the inflexible coal plants. The same rigidities cause negative prices in the spot markets (see Andor et al., 2010b).

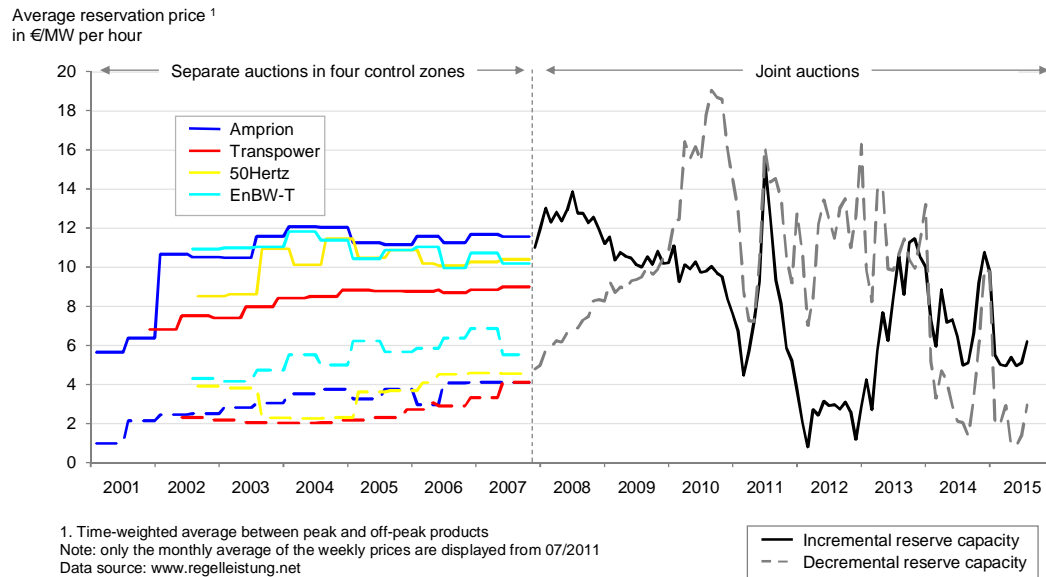


FIGURE 10: DEVELOPMENT OF AVERAGE RESERVATION PRICES FOR SECONDARY RESERVE CAPACITY

Heim and Götz (2013) analyzed the market structure and bidding behavior in the decremental secondary reserve market in 2009/10. Using non-public firm-level data from the Bundesnetzagentur, they identified significant market concentration with highly pivotal suppliers. Their results suggest that the reduction of the offer volume by the most dominant supplier coincides with the price increases, pointing toward collusive behavior. They further argue that the price increase is supported by the pay-as-bid remuneration mechanism as this led to a mirroring of the bids of the dominant supplier by the other suppliers in the next auction period and thus resulted in a price spiral.²¹ However, Heim and Götz did not analyze how much of the price increase was influenced by the actual cost drivers (i.e. increasing expected must-run costs to keep the capacity online in order to provide decremental secondary reserve).

The relative shift of incremental and decremental secondary reserve prices illustrates the recent change in the German electricity system. With the significant increase of renewables over the last few years, conventional generation capacity became abundant and the opportunity costs of providing incremental reserve capacity significantly decreased. At the same time there

²¹ Similar behavior of following the marginally accepted offer in the following periods can be also observed for primary reserve capacity in Figure 9.

is generally less conventional generation capacity online that can be reduced to provide decremental secondary reserve capacity. This created the visible upward price pressure.

A significant change is also visible while looking at peak and off-peak products and prices (see Figure 11). Incremental peak prices were historically significantly above off-peak prices, since conventional generation capacity was generally in high demand during peak periods and in low demand during off-peak periods. Since the beginning of 2008²², the incremental peak prices declined significantly and the peak and off-peak prices basically converged in the first quarter of 2011. They moved largely in line afterwards.

Decremental peak and off-peak prices diverged significantly from beginning of 2008 until mid of 2011. This was likely driven by the increasing rigidities in the system during off-peak periods. However, the clear divergence disappeared almost completely over the last three years. Decremental peak and off-peak prices are generally moving in line similarly as the peak and off-peak incremental reserve capacity prices. The reason is presumably that the clear distinction between night and day time characteristics of the electricity system disappeared with the increasing solar power generation. Peak and off-peak situations of the electricity system still exist but they are no longer linked with day and night time anymore as the peak (8am-8pm Monday to Friday) and off-peak (otherwise) product definition assumes.

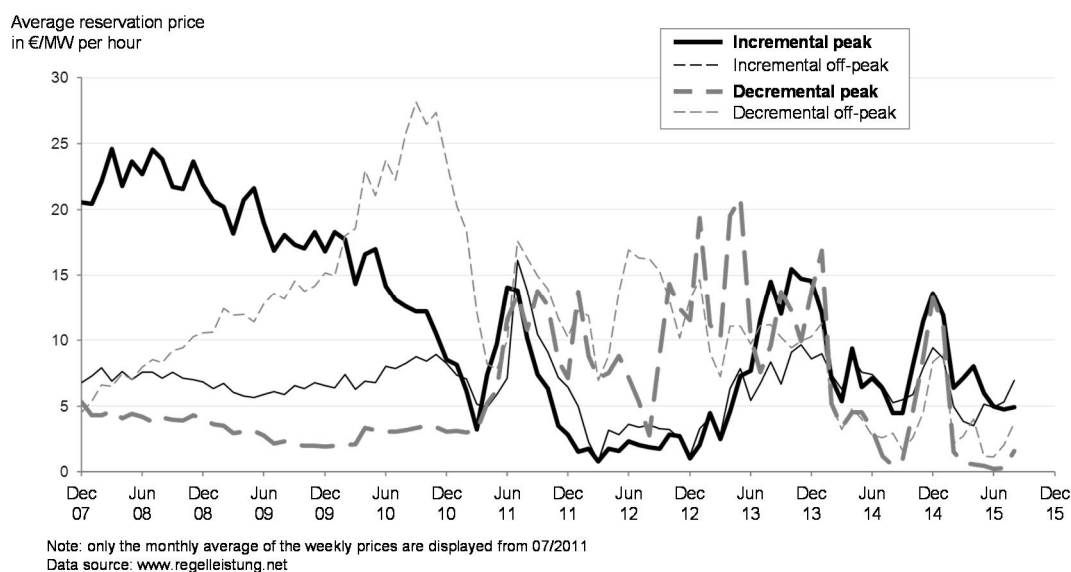


FIGURE 11: DEVELOPMENT OF PEAK AND OFF-PEAK SECONDARY RESERVE PRICES

²² Peak and off-peak secondary reserve capacity prices are only publicly available since December 2007, when the Bundesnetzagentur ordered a more transparent publication (see BNetzA, 2007b,c).

Tertiary reserve capacity

Reservation prices for tertiary reserve capacity have been historically very volatile – especially for incremental reserve (see Figure 12). In November 2007, average daily incremental prices fluctuated between €3 and €83/MW per hour within two consecutive days. In individual 4-hour periods prices peaked even at about €220/MW per hour. During the recent years the volatility as well as the absolute level of incremental tertiary reservation prices have declined significantly (see also Figure 13 for average monthly prices). The volatility and absolute level of decremental tertiary reserve have not changed significantly over time, though periods with higher volatility are clearly visible.

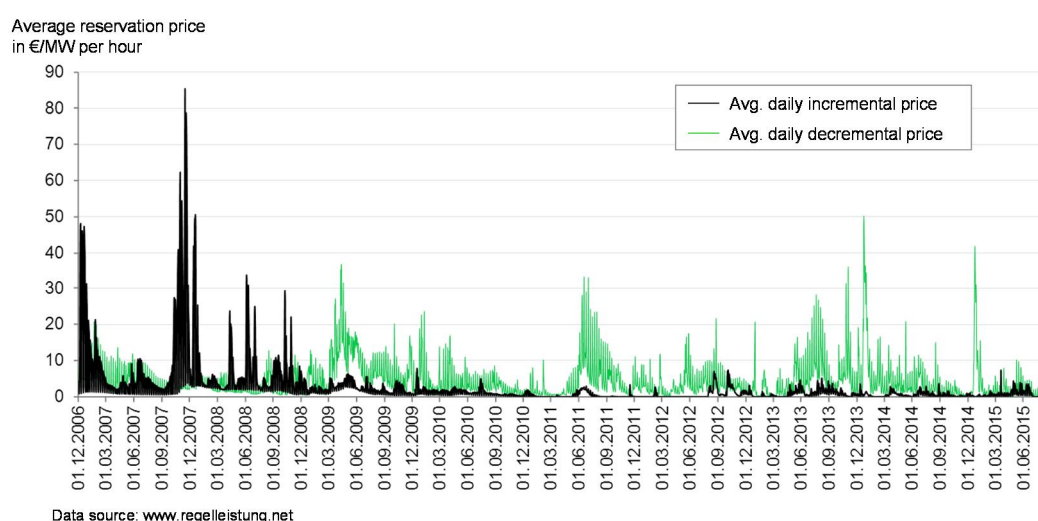


FIGURE 12: DAILY AVERAGE RESERVATION PRICES FOR TERTIARY RESERVE CAPACITY

The average price of incremental tertiary reserve capacity has decreased constantly over time, from almost €9/MW per hour on average during 2007 to below €1/MW per hour on average in the years since 2011. Reservation prices for incremental tertiary capacity are on average significantly below the prices for primary and secondary reserves, mainly as a result of the lower technical requirements.

The yearly average price for decremental reserve capacity has been largely in the range between €2/MW per hour and €6/MW per hour. As for secondary reserves, reservation prices for decremental tertiary capacity surpassed the incremental prices in the last years.

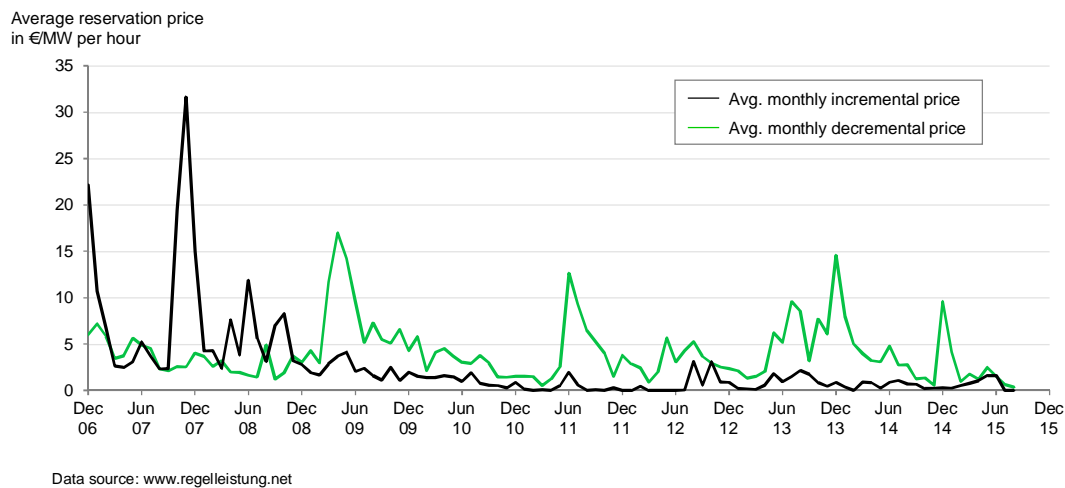


FIGURE 13: MONTHLY AVERAGE RESERVATION PRICES FOR TERTIARY RESERVE CAPACITY

When looking at the individual four-hourly products, similar patterns as for secondary reserves can be observed (see Figure 14). For incremental tertiary reserve, day-time (peak) products used to be generally more expensive than night-time (off-peak) products, but the difference disappeared from 2010 onwards. For decremental tertiary reserves, only the products 0-4am and 4-8am had a significant price. The reservation price for the other four products (8am-12pm) was mostly negligible until 2012. During the last years, the clear distinction of more pricy night-time products disappeared. The relevant system conditions depend less on differing load between night and day but rather on intermittent renewables supply.

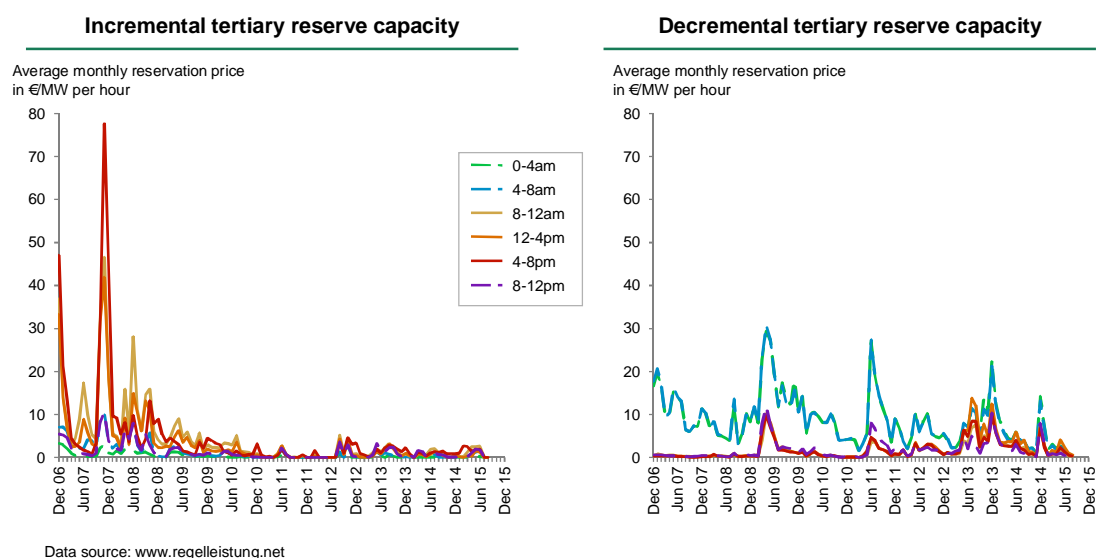


FIGURE 141: RESERVATION PRICES OF FOUR-HOURLY TERTIARY RESERVE CAPACITY PRODUCTS

Reserve and balancing energy

The TSOs call the contracted secondary and tertiary reserves according to the respective energy bid merit orders to counter the instantaneous imbalance. The resulting accumulated costs over a ¼-hour period divided by the reserve energy amount called constitute the respective balancing price. Depending on the imbalance of the overall control zone, it is either called incremental or decremental balancing price.

Figure 15 summarizes the overall evolution of the yearly average balancing prices from 2004 to 2015.²³ The prices for incremental balancing energy increased until 2008 by approximately 50% and remained largely stable afterwards with a further price drop after 2012. This price evolution was only partly in line with the EEX spot energy prices. The most recent incremental balancing prices in the GCC were on average ~€70/MWh during the first half of 2015.

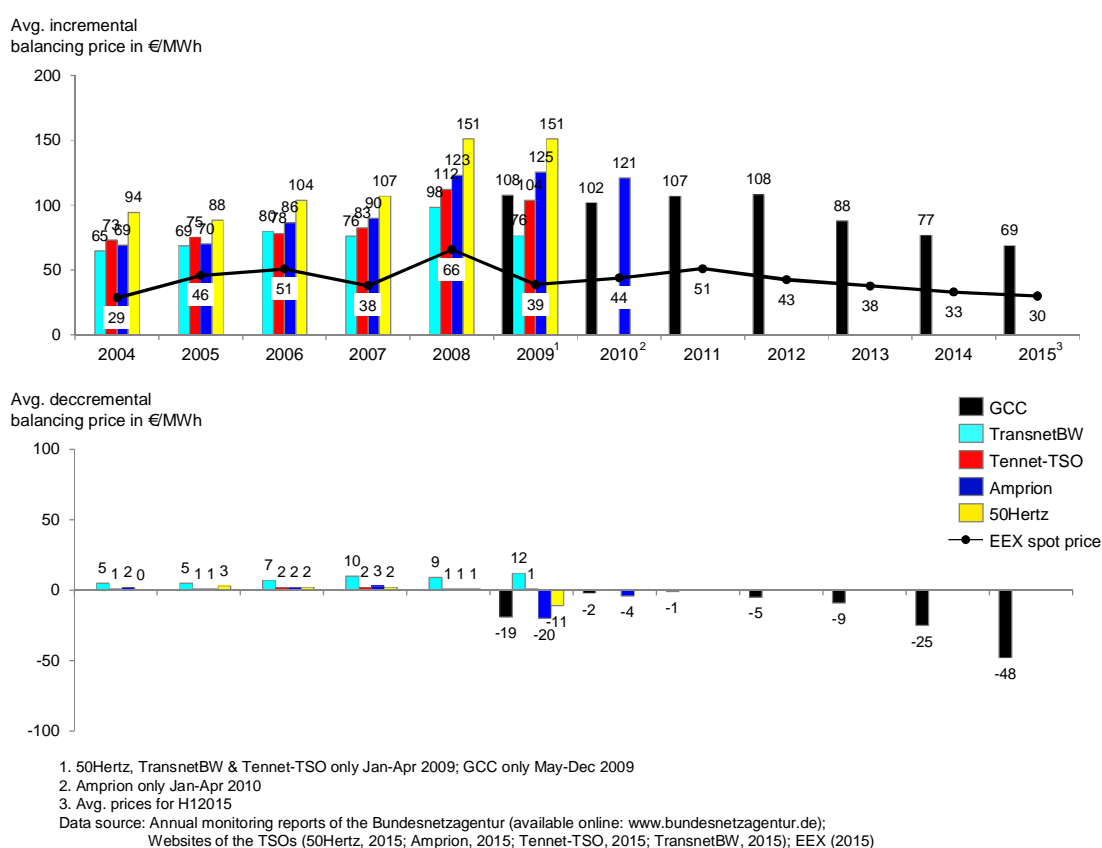


FIGURE 15: AVERAGE YEARLY BALANCING PRICES

Decremental balancing prices have historically been very low – in a range of €0-10/MWh. Since the beginning of 2009, offers for reserve energy can be negative. As a result, most bidders

²³ There were separate balancing prices in each of the four control zones until April 2009. With the implementation of the GCC, the number of balancing areas and thus applicable balancing prices reduced to two in May 2009 and to only one in May 2010 (cf. Section 3.2).

requested a payment when they reduce the output of their plant. Average prices for decremental energy dropped to a range between -50 and 0 €/MWh.²⁴

Figure 16 shows average monthly incremental and decremental balancing prices, distinguishing between peak and off-peak periods. In general, the difference between peak and off-peak balancing prices has been relatively small, with off-peak prices trading generally below peak prices. Only the Amprion control zone showed a significant, relatively constant delta between peak and off-peak for incremental balancing energy during the years 2006-2009.

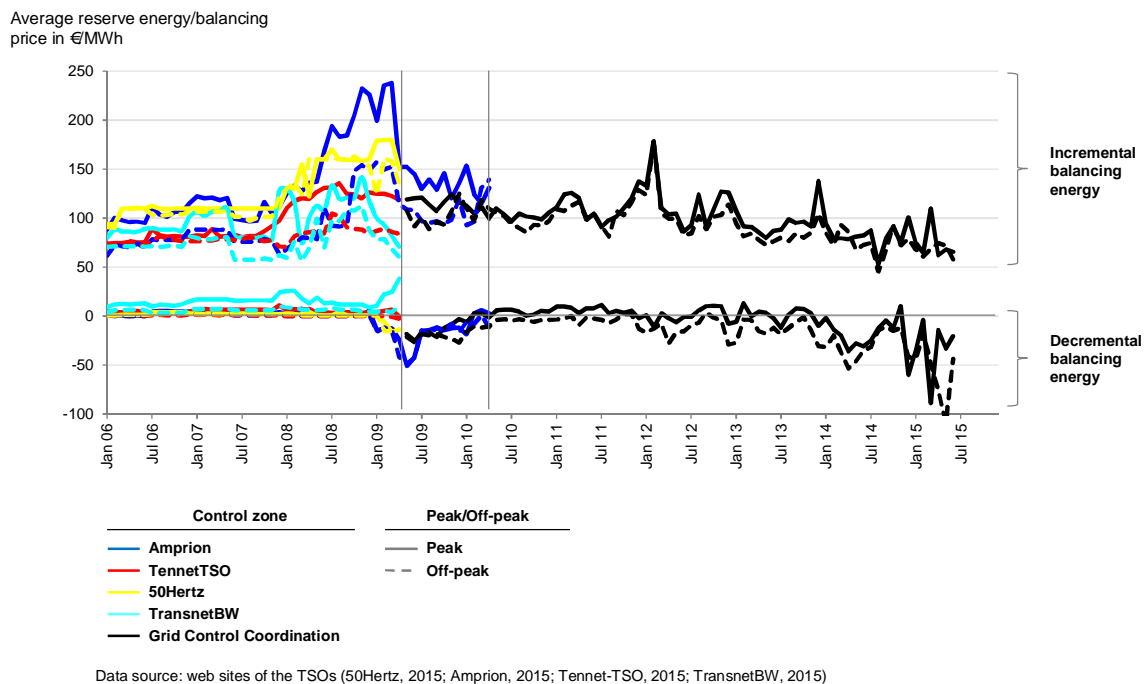
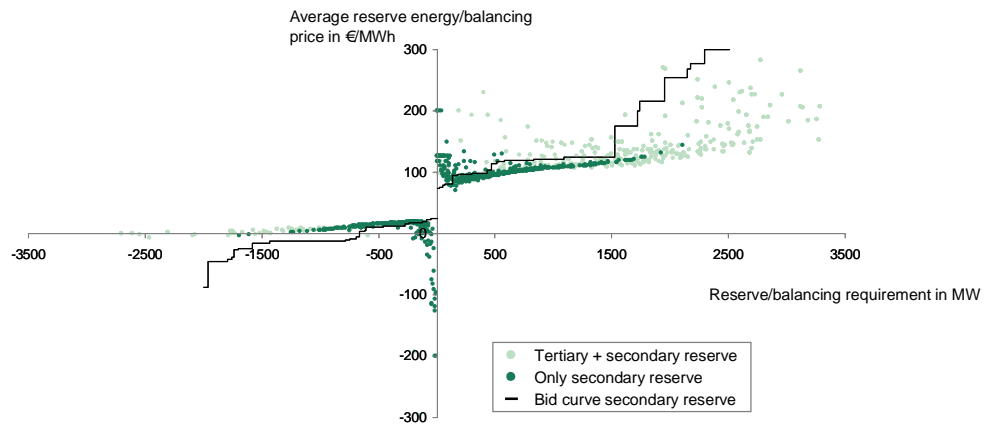


FIGURE 16: AVERAGE MONTHLY BALANCING PRICES

For a more detailed consideration, individual balancing prices are exemplary depicted in Figure 17 for the peak periods in May 2010, the first month after the complete implementation of the GCC. The depiction distinguishes between ¼-hourly periods in which only secondary reserve energy (dark dots) is called and periods in which also tertiary reserve energy (light dots) is called. The secondary only prices generally follow the distinct pattern of the secondary energy

²⁴ This offering behavior is likely rather a result of the absence of competition and/or a result of the specific design of the bid selection than caused by technical constraints. Negative prices appeared in the German day-ahead spot market in the last years in periods with relatively low demand and high wind generation. In such periods coal power plants are usually already in part-load, which makes further reduction very costly, especially when the full load is needed again in a few hours. The situation in the secondary reserve market is different, especially in peak periods. While providing decremental reserve energy, plants lower their output level and save on fuel costs, but do not hand off the contracted income from the unreduced output. Hence, under competitive conditions a positive payment towards the TSO should be expected – as seen in the TransnetBW control zone before 2009.

bid curves (black lines). The actual prices deviate from the bid curves mainly for two reasons. Firstly, the pay-as-bid remuneration leads to lower average costs compared to the marginally called bid. Secondly, the balancing price is determined by all cost for reserve energy called, divided by the average imbalance during the $\frac{1}{4}$ -hour period. This may result in large deviations from the bid curve in all $\frac{1}{4}$ -hours when incremental as well as decremental energy is called – usually periods with small average imbalances.



Data source: www.regelleistung.net; Amprion (2014)

FIGURE 17: RESERVE ENERGY/BALANCING PRICES FOR PEAK PERIODS IN MAY 2010

The prices for tertiary energy tend to be in a similar range as the secondary reserve energy prices. Furthermore, the balancing prices are mainly determined by the monthly secondary reserve capacity auctions. For that reason, incremental and decremental balancing prices are widely predictable throughout the respective month. This fact plays a crucial role for the gaming opportunities in the German balancing mechanism investigated in Just and Weber (2015).

5 References

- 50Hertz, 2015. Balancing Price and Imbalance Data. Online: www.50hertz-transmission.net.
- Al-Awaad, A. K., 2009. Beitrag von Windenergieanlagen zu den Systemdienstleistungen in Hoch- und Höchstspannungsnetzen (Contribution of Wind Generation towards Ancillary Services for the High-voltage Transmission Grid). PhD dissertation, University of Wuppertal.
- Amprion, 2015. Balancing Price and Imbalance Data. Online: www.amprion.net.
- Andor, M., Flinkerbusch, K., Janssen, M., Liebau, B., Wobben, M., 2010a. Handeln am Day-After Strommarkt (Trading at the Day-After Electricity Market). *Energiewirtschaftliche Tagesfragen* 60 (5), 46-50.
- Andor, M., Flinkerbusch, K., Janssen, M., Liebau, B., Wobben, M., 2010b. Negative Strompreise und der Vorrang Erneuerbarer Energien (Negative Electricity Prices and Priority of Renewables). *Zeitschrift für Energiewirtschaft* 34 (2), 91-99.
- BKartA, 2000a. Beschluss im Fusionsverfahren RWE/VEW (Ruling about RWE/VEW Merger). B8-40000-U-309/99 from July 03, 2000.
- BKartA, 2000b. Beschluss im Fusionsverfahren E.ON/HeinGas/HEW (Ruling about E.ON/HeinGas/HEW Merger). B8-40200-U-132/00 from September 04, 2000.
- BKartA, 2002a. Abuse Proceedings against EnBW in the Balancing Energy Sector Discontinued. Press release from February 21, 2002. Online: www.bundeskartellamt.de.
- BKartA, 2002b. Abuse Proceedings against Bewag, HEW and VEAG the Balancing Energy Discontinued. Press release from August 19, 2002. Online: www.bundeskartellamt.de.
- BKartA, 2003. Bundeskartellamt Initiates Abuse Proceedings against RWE and E.ON on Account of Excessive Balancing Energy Fees. Press release from February 26, 2003. Online: www.bundeskartellamt.de.
- BNetzA, 2006. Festlegung zur Ausschreibungspraxis in der Minutenreserve (Ruling on the Auction Procedures for Tertiary Reserve Capacity). BK6-06-012 from August 29, 2006. Online: www.bundesnetzagentur.de.
- BNetzA, 2007a. Report on the Disturbance in the German and European Power System on the 4th of November 2006. Online: www.bundesnetzagentur.de.
- BNetzA, 2007b. Festlegung zu Verfahren zur Ausschreibung von Regelenergie in Gestalt von Primärregelleistung (Ruling on the Auction Procedures for Primary Reserve Capacity). BK6-06-065 from August 31, 2007. Online: www.bundesnetzagentur.de.
- BNetzA, 2007c. Festlegung zu Verfahren zur Ausschreibung von Regelenergie in Gestalt von Sekundärregelleistung (Ruling on the Auction Procedures for Secondary Reserve Capacity). BK6-06-066 from August 31, 2007. Online: www.bundesnetzagentur.de.
- BNetzA, 2008. Introduction of a Determination Procedure to Avoid Contradirectional Non-Harmonised Use of Balancing Energy. Press release from July 25, 2008. Online: www.bundesnetzagentur.de.
- BNetzA, 2010. Festlegung zum Einsatz von Regelenergie (Ruling on Grid Control Cooperation among the German TSOs). BK6-08-111 from March 16, 2010. Online: www.bundesnetzagentur.de.

- BNetzA, 2011a. Festlegung zu Verfahren zur Ausschreibung von Regelenergie in Gestalt von Primärregelleistung (Ruling on the Auction Procedures for Primary Reserve Capacity). BK6-10-097 from April 12, 2011. Online: www.bundesnetzagentur.de.
- BNetzA, 2011b. Festlegung zu Verfahren zur Ausschreibung von Regelenergie in Gestalt von Sekundärregelleistung (Ruling on the Auction Procedures for Secondary Reserve Capacity). BK6-10-098 from April 12, 2011. Online: www.bundesnetzagentur.de.
- BNetzA, 2011c. Festlegung zu Verfahren zur Ausschreibung von Regelenergie in Gestalt von Minutenreserve (Ruling on the Auction Procedures for Minute Reserve Capacity). BK6-10-099 from October 18, 2011. Online: www.bundesnetzagentur.de.
- BNetzA, 2012. Festlegung zu Verfahren zur Weiterentwicklung des Ausgleichsenergiepreis-Abrechnungssystems (Ruling on enhancements in the German balancing mechanism). B6-12-024 from October 25, 2012. Online: www.bundesnetzagentur.de.
- BNetzA, 2013. Monitoringbericht 2012 (Monitoring report 2012). Online: www.bundesnetzagentur.de.
- Bower, J., Bunn, D., 2000. Model-Based Comparisons of Pool and Bilateral Markets for Electricity. Energy Journal 21, 1-29.
- Bushnell, J., Knittel, C.R., Wolak, F., 1999. Estimating the Opportunities for Market Power in a Deregulated Wisconsin Electricity Market. Working paper. Online: www.customersfirst.org/pdf/MarketPowerPaper.pdf.
- Consentec, 2008. Gutachten zur Höhe des Regelenergiebedarfs (Report on the Required Amount of System Reserve Capacity). Report for the Bundesnetzagentur. Online: www.bundesnetzagentur.de.
- Consentec, 2012. Gutachten zur Weiterentwicklung des Ausgleichsenergie-Preissystems im Rahmen des Verfahrens BK6-12-024 der Bundesnetzagentur (Report on the Further Development of Balancing Mechanism as part of the Ruling BK6-12-024). Report for the Bundesnetzagentur. Online: www.bundesnetzagentur.de.
- E-Bridge, 2009. Gutachten zur Optimierung der Ausregelung von Leistungsungleichgewichten (Report on the Optimized Balancing of System Imbalances). Report for the Bundesnetzagentur. Online: www.bundesnetzagentur.de.
- EEG, 2014. Gesetz für den Ausbau erneuerbarer Energien, Erneuerbare-Energien-Gesetz – EEG 2014 (German Renewable Energy Law) from July 21, 2014. BGBl. I, S. 1066-1132.
- EEX, 2015. Market data on day-ahead spot prices. Online: www.eex.de.
- EnWG, 1998. Gesetz über die Elektrizitäts- und Gasversorgung (Energiewirtschaftsgesetz (EnWG)) (German Energy Law) from April 24, 1998. BGBl. I, S. 730-736.
- EnWG, 2005. Gesetz über die Elektrizitäts- und Gasversorgung (Energiewirtschaftsgesetz (EnWG)) (German Energy Law) from July 07, 2005. BGBl. I, S. 1970-2018.
- Erge, T., Sauer, C., Preiser, K., Barnsteiner, M., Rösch, J., Andersen, A., Mutale, J., Romanovsky, G., Watts, M., Giovanetti, E., Siewierski, T., Obersteiner, C., 2010. Market Access for Smaller Size Intelligent Electricity Generation – Final Public Report. Online: http://www.iee-massig.eu/papers_public/MASSIG_Brochure_Final_c.pdf.
- EU, 1996. Directive 96/92/EC of the European Parliament and of the Council of 19 December 1996 Concerning Common Rules for the Internal Market in Electricity. Official Journal L 27, 20-29.

- EU, 2003. Directive 2003/54/EC of the European Parliament and of the Council of 26 June 2003 Concerning Common Rules for the Internal Market in Electricity and Repealing Directive 96/92/EC. Official Journal L 176, 37-56.
- Flinkerbusch, K., Heuterkes, M., 2010. Cost Reduction Potentials in the German Market for Balancing Power. *Energy Policy* 38, 4712-4718.
- Galus, M.D., Zima, M., Andersson, G., 2010. On Integration of Plug-in Hybrid Electric Vehicles into Existing Power System Structures. *Energy Policy* 38, 6736-6745.
- Growitsch, C., Höffler, F., Wissner, M., 2010. Marktkonzentration und Marktmachtanalyse für den deutschen Regellestenergiemarkt (Analysis of Market Concentration and Market Power in the German Reserve Capacity Market). *Zeitschrift für Energiewirtschaft* 34, 209-222.
- Harris, C., 2006. *Electricity Markets: Pricing, Structures and Economics*. Wiley, Chichester.
- Heim, S., Götz, G., 2013. Do pay-as-bid auctions favor collusion? Evidence from Germany's market for reserve power. ZEW Discussion Papers, No. 13-035. Online: <http://ftp.zew.de/pub/zew-docs/dp/dp13035.pdf>.
- Heise, J., 2007. The Role and Potential of Interruptible Load as Tertiary Reserve in the German Reserve Market: A Survey among Industrial Consumers. Presentation, 9th IAAE European Energy Conference, Florence.
- Hogan, W., 1995. To Pool or Not to Pool: A Distracting Debate. *Public Utility Fortnightly* 133 (1). Online: <http://www.fortnightly.com/fortnightly/1995/01/pool-or-not-pool-distracting-debate>.
- Hunt, S., 2002. *Making Competition Work in Electricity*. Wiley Finance, New York.
- Just, S., 2011. Appropriate Contract Durations in the German Markets for On-line Reserve Capacity. *Journal of Regulatory Economics* 39, 194-220.
- Just, S., Weber, C., 2008, Pricing of Reserves: Valuing System Reserve Capacity against Spot Prices in Electricity Markets, *Energy Economics* 30, 3198-3221.
- Just, S., Weber, C., 2015, Strategic Behavior in the German Balancing Energy Mechanism: Incentives, Evidence, Costs and Solutions, *Journal of Regulatory Economics* 48, 218-243.
- LBD, 2008. Untersuchung des Einsparpotenzials bei der regelzonenübergreifenden Saldierung (Investigation of Possible Savings from Common Balancing across Control Zones). Report for Lichtblick. Online: www.lbd.de/cms/pdf-gutachten-und-studien/0804-LBD-Gutachten-Regelzonenubergreifende-Saldierung.pdf.
- Mansur, E.T., White, M. W., 2012. Market Organization and Efficiency in Electricity Markets. Working paper. Online: http://www.dartmouth.edu/~mansur/papers/mansur_white_pjmaep.pdf.
- Meeus, L., Purchala, K., Belmans, R., 2005. Development of the Internal Electricity Market in Europe. *The Electricity Journal* 18 (6), 25-35.
- Monopolkommission, 2009. Strom und Gas 2009: Energiemärkte im Spannungsfeld von Politik und Wettbewerb – Sondergutachten 54 (Special Opinion on the German Electricity and Gas Markets 2009). Online: www.monopolkommission.de.
- Monopolkommission, 2011. Strom und Gas 2011: Wettbewerbsentwicklung mit Licht und Schatten – Sondergutachten 59 (Special Opinion on the German Electricity and Gas Markets 2011). Online: www.monopolkommission.de.

- Monopolkommission, 2013. Energie 2013: Wettbewerb in Zeiten der Energiewende – Sondergutachten 65 (Special Opinion on the German Electricity and Gas Markets 2013). Online: www.monopolkommission.de.
- Müller-Kirchenbauer, J., Zenke, I., 2001. Wettbewerbsmarkt für Regel- und Ausgleichsenergie (Competitive Market for Reserve and Balancing Energy). *Energiewirtschaftliche Tagesfragen* 51, 696-702.
- Nailis, D., 2006. Steht der Regelenergiemarkt vor dem Umbruch? Auswirkungen des EnWG und der Netzzugangsverordnung auf Regel- und Ausgleichsenergie (Market for System Reserve Capacity at the Turning Point? Repercussions of the EnWG and StromNZV for the Reserve and Balancing Energy). *Energiewirtschaftliche Tagesfragen* 56(1/2), 56-60.
- Ockenfels, A., Grimm, V., Zoettl, G., 2008. Electricity Market Design. Report for the Saxon Exchange Supervisory Authority. Online: http://cdn.eex.com/document/38615/gutachten_eex_ockenfels_e.pdf.
- Regelleistung, 2015. Common Internet Platform of Reserve Power Auctions of the Four German TSOs. Online: www.regelleistung.net.
- Riedel, S., Weigt, H., 2007. German Electricity Reserve Markets. Working paper WP-EM-20, Technical University of Dresden. Online: http://hannesweigt.de/paper/wp_em_20_riedel_weigt_Germany_reserve_markets.pdf.
- Stadtwerke Schwerin, 2013. Inbetriebnahme der neuen Sekundär-Regelenergie-Anlage (Commissioning new secondary reserve power facility). Press release as of October 23, 2013. Online: www.stadtwerke-schwerin.de.
- StromNZV, 2005. Verordnung über den Zugang zu Elektrizitätsversorgungsnetzen (Stromnetzzugangsverordnung – StromNZV) (Ordinance on the Access to Electricity Networks) from July 25, 2005. BGBl. I, S. 2243-2251.
- Swider, D.J., 2004. Background study – Balancing system in Germany, Working Package 4 of the GreenNet Project "Pushing a Least Cost Integration of Green Electricity into the European Grid". Online: www.greennet.at.
- Swider, D.J., 2006. Handel an Regelenergie- und Spotmärkten (Trading on Markets for Power Systems Reserve and Spot Energy). PhD dissertation, University of Stuttgart.
- Swider, D.J., Ellersdorfer, I., 2005. Kosteneffizienz am deutschen Regelenergiemarkt (Cost Efficiency in the German Market for Power Systems Reserve). *Energiewirtschaftliche Tagesfragen* 55 (11), 802-806.
- Swider, D.J., Weber, C., 2003. Ausgestaltung des deutschen Regelenergiemarktes (Design of German Markets for Power Systems Reserve). *Energiewirtschaftliche Tagesfragen* 53 (7), 448-453.
- TenneT-TSO, 2010. Aus transpower wird TenneT (Transpower becomes TenneT). Press release of October 8, 2010. Online: www.tennet.eu.
- TenneT-TSO, 2015. Balancing price and imbalance data. Online: www.tennetso.de.
- TransnetBW, 2015. Balancing Price and Imbalance Data. Online: www.transnetbw.de.
- Trimet, 2014. Geschäftsbericht 2013/14 (Annual report 2013/14). Online: www.trimet.eu.
- Twomey, P., Green, R., Neuhoﬀ, K., Newbery, D., 2005. A Review of the Monitoring of Market Power: The Possible Roles of Transmission System Operators in Monitoring for Market Power Issues in Congested Transmission Systems. *Journal of Energy Literature* 11 (2), 3-54.

- UCTE, 2004. Operation Handbook. Online: www.entsoe.eu.
- UCTE, 2007. Final Report – System Disturbance on 4 November 2006. Online: www.entsoe.eu.
- VDE, 2009. Energiespeicher in Stromversorgungssystemen mit hohem Anteil erneuerbarer Energieträger (Energy Storage in Power Supply Systems with a High Share of Renewable Energy Sources). Online: <http://www.vde.com/de/fg/ETG/Arbeitsgebiete/V1/Aktuelles/Oeffentlich/Seiten/Studie-Energiespeicher.aspx>.
- VVII, 1999. Verbändevereinbarung über Kriterien zur Bestimmung von Netznutzungsentgelten für elektrische Energie (Association Agreement on Criteria to Determine the Electrical Grid Charges) from December 13, 1999. Online: www.loy-energie.de/download/verb_v_2.pdf.
- Wawer, T., 2005. Effiziente Ausgestaltung von Regelennergieauktionen zur Verringerung der Netznutzungsentgelte (Efficient Design of Auction for Power System Reserve to Reduce Transmission Charges). Proceedings of 4th IEWT Conference, Vienna, 2005.
- Weber, C., 2005. Uncertainty in the Electric Power Industry - Methods and Models for Decision Support. Springer Verlag, Berlin.
- WEMAG, 2014. Europaweit erstes kommerzielles Batteriekraftwerk eröffnet (First commercial electrical battery plant opened in Europe). Press release of September 09, 2014. Online: www.wemag.com.
- Wilson, R., 2002. Architecture of Power Markets. Econometrica 70, 1229-1241.
- Zerres, A., 2007. Die Entwicklung des Regelenenergiemarktes aus Sicht der Bundesnetzagentur (Development of the Market for Power System Reserve from the Perspective of the Bundesnetzagentur). Presentation given at the Information Day "Regelenenergie", Mörfelden, 2007.