A Balancing Act

Developments in Dutch and German balancing markets and the impact of variable renewable generation.

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07-04-2018
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Abstract

Injections to and withdrawals from the electricity grid should continuously be in balance to avoid large deviations from the reference grid frequency. In case of grid imbalance, transmission system operators (TSOs) activate balancing reserves to correct the imbalance. With increasing variable renewable generation, different model studies expect that balancing reserve capacity should increase to cover the larger forecast errors of variable renewable generation. However, different studies identified that balancing reserve capacity has decreased in the past, while variable renewable generation has increased. The goal of this study was 1) to provide an overview of developments in the Dutch and German balancing markets 2) study the relationship between different possible contributors, including variable renewable generation, and system imbalance, using 15-minute data between 2015 and 2017 for the Netherlands and Germany.

The results showed that in both the Netherlands and Germany the penalty for being in imbalance has decreased over time. Imbalance volumes increased in the Netherlands, but stayed relatively constant in Germany. Market design seemed to have a major impact on these developments. Regression analyses were performed to study the relationship between variable renewable generation, total generation, total load, and the forecast errors of these factors on the one hand and system imbalance on the other hand. All regression analyses followed the expected trends (e.g. higher system imbalance with higher variable renewable generation), but the correlation values were weak. This indicated that the impact of variable renewable generation on imbalance volumes is limited.

List of abbreviations

aFRR	:	automatic frequency restoration reserves
DSO	:	distribution system operator
ENTSO-E	:	European Network of Transmission System Operators for Electricity
FCR	:	frequency containment reserves
FRR	:	frequency restoration reserves
IGCC	:	international grid control cooperation
ISP	:	imbalance settlement period
LFC	:	load frequency control
mFRR	:	manual frequency restoration reserves
mFRRda	:	manual frequency restoration reserves, directly activated
mFRRsa	:	manual frequency restoration reserves, schedule activated
RR	:	restoration reserves
TSO	:	transmission system operator
UCTE	:	Union for the Coordination of the Transmission of Electricity
VRES	:	variable renewable energy systems

1. Introduction

Balancing the electricity grid is one of the main responsibilities of European Transmission System Operators (TSOs). The alternating current grid frequency in Continental Europe should not deviate too much from 50 Hz to avoid damage to electrical appliances connected to the grid. To maintain this frequency, the electricity injected to the grid should be equal to the sum of electricity withdrawals and grid losses (Hirth & Ziegenhagen, 2015). In a situation where supply does not match demand, grid imbalance occurs. TSOs generally cover this imbalance by utilising flexibility options to compensate for under- or oversupply to the grid.

The electricity market could face major developments in the coming years, which might influence TSOs balancing practices. Firstly, the size of the balancing market could change. Some studies expect that increasing penetration of variable renewable electricity technologies in the energy system can result in more and higher grid imbalances, because of their intermittent nature (Lund et al., 2015; Bird et al., 2013). This intermittent nature could make generation forecasts less robust, causing that renewable energy sources supply more or less electricity to the grid than sold in the market, resulting in grid imbalance.

In addition, the technologies providing flexibility could change drastically. The implementation of variable renewable energy technologies reorganises the merit order. Due to its low marginal costs, renewable sources push out different fossil generation plants from the merit order, reducing the average load factor of power plants (Brunekreeft et al., 2015). The merit order effect also results in a lower average electricity price (Sensfuß et al., 2008, Clò et al., 2015, Nicolosi & Fürsch, 2009; Brunekreeft et al., 2015). Both effects have a negative impact on the business case of power plants, resulting in potential decommissioning or mothballing of conventional power plants which could provide reserve capacity (International Energy Agency, 2014; Brunekreeft et al., 2015).

Commercial parties see this as an opportunity to introduce new types of flexibility for resolving grid imbalances to the market. In the past years different (pilot) projects have been set up to test the suitability of these techniques to provide reserve capacity. These projects include projects with electric vehicle batteries (The New Motion, n.d.; Breuning, 2017), Lithium-ion batteries (AES Energy Storage, April 30 2015), and ammonia (Nuon, n.d.) as providers of balancing energy. Different studies have shown that providing balancing energy could be profitable for some of these technologies (Hoogvliet et al., 2017; Camus et al., 2009; Kahlen & Ketter, 2015; Guinot et al., 2015).

1.1. Problem definition & research questions

Different authors have already looked into the developments of the balancing market. Despite the previous work on this topic, there is still much ambiguity about the current state of the balancing market. Studies either addressed specific products on the balancing market (De Jong et al., 2017), or only looked at the contracted reserve capacity (Hirth & Ziegenhagen, 2013). Therefore, a comprehensive, recent and in-depth overview of developments in the balancing market in the Netherlands and Germany is lacking.

Therefore, the first of goal of this research is to answer the following research question:

How have the balancing markets in the Netherlands and Germany developed since 2013?

In this analysis, imbalance developments in general will be addressed, as well as developments in the balancing products in the Netherlands and Germany: Frequency Containment Reserves (FCR), automatic Frequency Restoration Reserves (aFRR) and manual

Frequency Restoration Reserves (mFRR) (Lampropoulos et al., 2016). The analysis is divided into three aspects:

- Volume developments
- Price developments
- Market developments

Moreover, some possible effects of variable renewable generation on imbalance volumes are still understudied. Brouwer et al. (2014) provided an overview of the increase in balancing reserve requirements in different model studies when moving from a scenario with low variable renewable generation to a scenario with high variable renewable generation. In all studies except one, an increase in balancing reserves is expected. The increase in required primary balancing reserves ranged between 2-12% in different studies, while the expected increase in required secondary balancing reserves ranged between 0-21% between different studies (Brouwer et al., 2014). However, different retrospective studies showed different trends. Hirth and Ziegenhagen (2013) did observed a decrease in the reserve requirements when looking at German data between 2008 and 2012, although variable renewable generation increased significantly in Germany in this time period. Similarly, Holttinen et al. (2006) found that the reserve requirements did not increase in West-Denmark, Germany and Spain with increasing variable renewable generation, a similar conclusion which was made by Kling et al. (2011) when looking at Irish, Danish, Spanish and Portuguese data. On the other hand, Bal (2013) noted that imbalance volumes increase when the variable renewable energy sources make up at least 20% of the installed capacity in a country.

Altogether, it is visible that there is a discrepancy between different studies on the impact of variable renewable generation on system imbalance. Therefore, additional research on this relationship is necessary. Most studies either looked at the annual reserve requirements (Hirth & Ziegenhagen, 2013; Holttinen et al, 2006; Brouwer et al., 2014), or annual imbalance volumes (Bal, 2013). However, studies on a shorter timescale are lacking; it has not been studied whether the moments with high variable renewable generation are the moments with the highest imbalance volumes. To create a better understanding about the role of variable renewable generation on imbalance volumes, a study on smaller time scales is required.

Similarly, the effect of other possible contributors, including total generation and load and forecast errors, on system imbalance will be studied. Thus, the second research question that will be answered is the following:

What is the influence of possible contributors to system imbalance on imbalance volumes?

This analysis will mainly focus on the influence of variable renewable energy systems on imbalance volumes. It will address the relationship between variable renewable generation and imbalance volumes on a 15-minute basis, as well as the relationship between installed variable renewable capacity and imbalance volumes. Also, the variable renewable generation forecast error will be estimated, and the relationship between these forecast errors and imbalance volumes will be examined. Lastly, this study will address the relationship between total generation, load, generation forecast errors and load forecast errors on the one hand, and imbalance volumes on the other hand.

1.2. Relevance

The results of this research are relevant for different stakeholders. Firstly, the results are relevant for stakeholders interested in entering the balancing market or others interested in understanding the balancing market. It will provide a clear overview of the balancing market for these stakeholders. By indicating the price, volume and market size developments and by linking it to the variable renewable energy share, market parties can determine the potential and risk of stepping into one of the balancing markets.

In addition, the effect of variable renewable generation on imbalance volumes is relevant for TSOs and policy makers. The results of these studies gives an indication in future imbalance volumes and balancing reserve requirements with increasing variable renewable generation, and provides insight in whether the current balancing system design is suitable for a situation with high variable renewable generation, and whether changes in balancing market design are necessary to assure a robust balancing system in the future.

1.3. Background

This internship report is the end product of an internship performed at TenneT TSO B.V.

1.4. Document outline

The report will start with detailed background information on the Dutch and German electricity transmission system landscape in chapter 2 and the Dutch and German balancing markets in chapter 3. Subsequently, chapter 4 will elaborate on the methods used in answering the research questions. Chapter 5 to 7 will provide results of the first research question; chapter 5 will discuss volume developments in the balancing market, chapter 6 price developments and chapter 7 market developments. Chapter 8 will look at the impact of different possible contributors on imbalance volumes. This report will be concluded with a discussion in chapter 9 and a conclusion in chapter 10.

2. Electricity transmission in the Netherlands and Germany

In an electricity system based on (partly) centralised electricity generation, electricity transmission is crucial to ensure security of supply. After the liberalisation of the European electricity sector, electricity generators were no longer allowed to both manage generation and transmission of electricity (Directive 96/92/EC)[1]. The transmission of electricity became the responsibility of distribution system operators (DSOs) and transmission system operators (TSOs). DSOs are responsible for maintaining and managing the low voltage grid and for investing in this grid. TSOs have the same responsibilities for the high voltage grid and are also responsible for maintaining grid balance and facilitating an integrated European electricity market (Elektriciteitswet, 1998). As this report focusses on balancing, DSOs will not be further addressed in this report.

The Netherlands knows one TSO: TenneT TSO B.V. TenneT owns and manages the whole electricity grid of 110 kV and above in the Netherlands, as displayed in Figure 1 – The TenneT grid in the Netherlands. Source: TenneTFigure 1. TenneT is, together with other TSOs, current owner of the NorNed interconnection line and the future owner of the COBRA interconnector line (TenneT, n.d.a., TenneT n.d.b). TenneT is 50% shareholder in the BritNed TSO, which is responsible for the BritNed interconnector line between the Netherlands and the United Kingdom (TenneT, n.d.c). Since 2016, TenneT is also assigned as the Dutch offshore TSO (Nugteren, 2016). The Dutch state is the sole shareholder of TenneT.

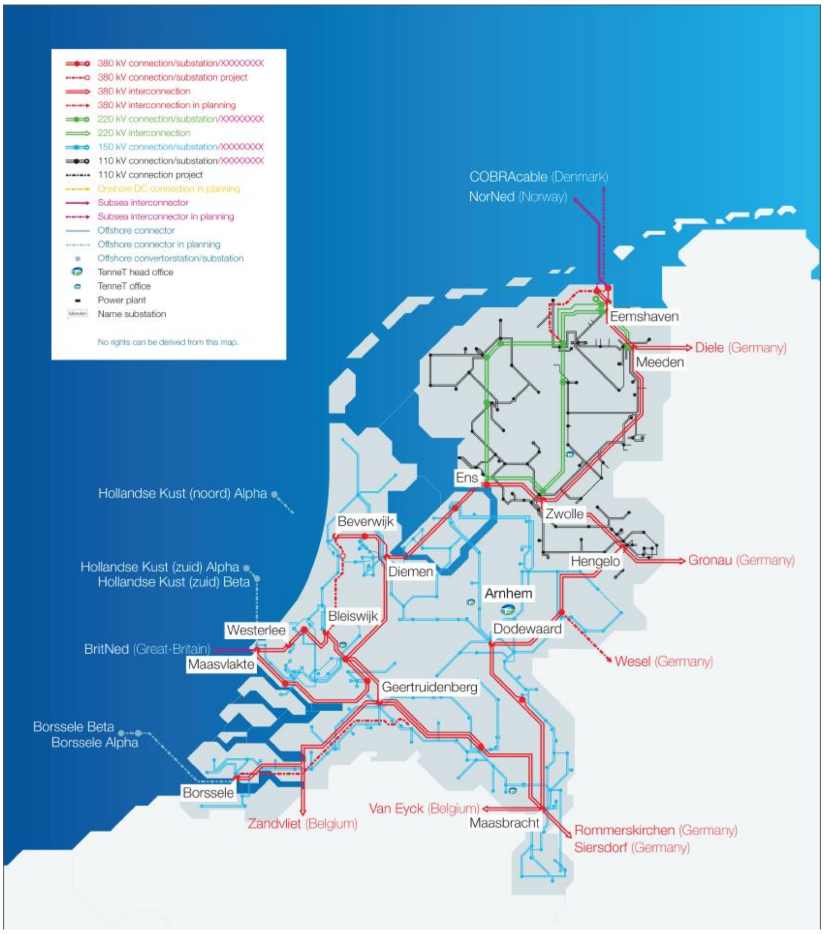


Figure 1 – The TenneT grid in the Netherlands. Source: TenneT NL

[1] 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, OJ L27/20

The German high voltage grid has been divided among four TSOs: Amprion, 50 Hertz, Transnet and TenneT TSO GMBh, as displayed in Figure 2. TenneT TSO GMBh is owned by TenneT TSO B.V, making TenneT the first transnational TSO. German TSOs are responsible for 220 kV and 380 kV grids.

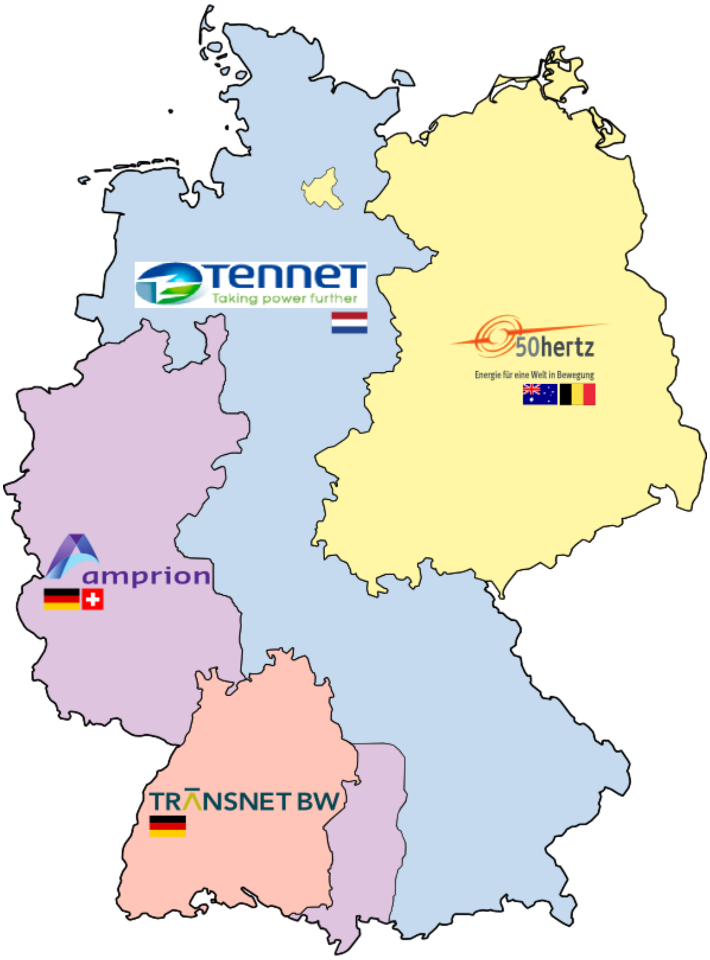


Figure 2 – TSO areas in Germany. Source: Wikimedia commons

3. Grid imbalance and the balancing market

Grid imbalance and the different products of the balancing market are interrelated and relatively complex to understand. In this report, Figure 3 will be used to illustrate how the different products of the balancing market are deployed in case of grid imbalance. The process of grid imbalance and the use of balancing power in Europe can generally be divided into six steps, although the specific procedures for each step may differ per country. Each of these steps will be discussed separately.

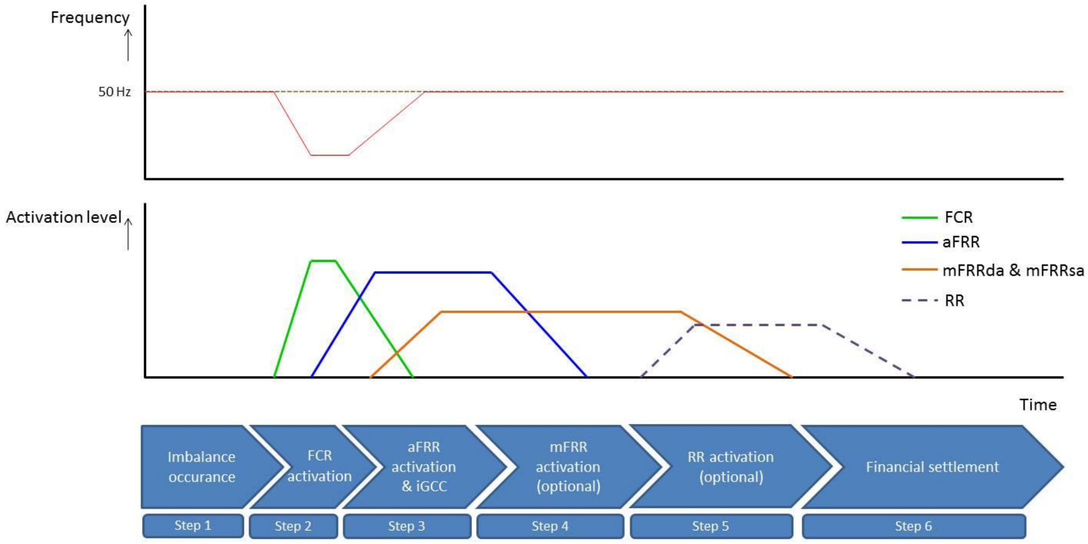
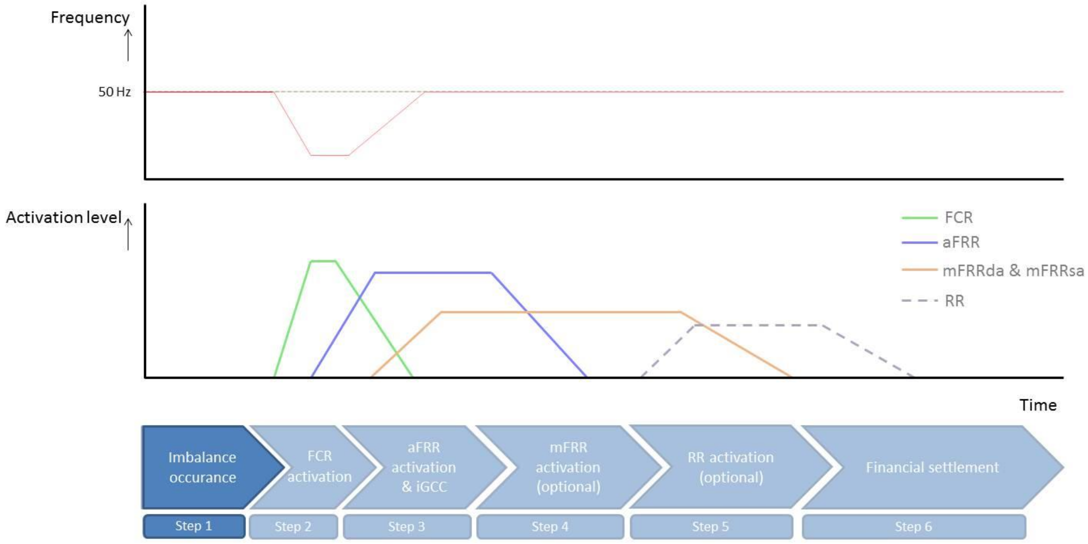


Figure 3 – Overview of the balancing process (based on ENTSO-E, 2009)

3.1. Step 1: Occurrence of grid imbalance



Suppliers and buyers of electricity trade in the future, day-ahead and intraday market before the actual production and delivery of electricity. After closure of the long-term, day-ahead and intraday markets, the trade schedules of all market participants are in balance (Borggrefe & Neuhoff, 2011)[2]. Each supplier or buyer on the wholesale electricity market has to subject to certain requirements and is referred to as a balance responsible party (BRP). A

[2] Market participants can buy products ranging from years before actual delivery to two days before actual delivery in the future market. Market participants can make bids on the day-ahead market one day before delivery at 12:00, after which the trading schedules are determined. Market participants can make bids in the intraday market 5 minutes prior delivery (EPEX Spot, 2017)

BRP monitors the balance of one or multiple access points to the electricity grid. Every generator and offtaker in the grid is obliged to have a contract with a BRP (typically via the electricity supplier), or alternatively be their own balance responsible party. In general, BRPs have a large portfolio consisting of many generators and/or offtakers. Each BRP is responsible for informing TSOs of their planned electricity production, consumption and transport needs. If the actual production or consumption differs from the agreed production or consumption (i.e. electricity sold/bought on the electricity markets), a BRP is in imbalance.

An electricity system consists of all BRPs and TSOs connecting BRPs in a synchronous area. The alternating current (AC) frequency in a synchronous area is always the same. The Netherlands and Germany are part of the synchronous grid of Continental Europe, usually referred to as the UCTE synchronous area, and has a nominal frequency of 50 Hz (ENTSO-E, 2009). This grid covers the majority of continental Europe, as displayed in Figure 4. ENTSO-E is the consultative body of the TSOs in the synchronous area. The synchronous area is divided in different Load Frequency Control (LFC) blocks, usually covering one country. A LFC block is in imbalance if the sum of production and import does not equal the sum of consumption and export. The LFC system imbalance is also equal to the netted BRP imbalances in the LFC block. The difference between supply and demand in case of system imbalance is captured in rotating masses connected to the grid, which accelerate in case of oversupply of electricity to the system and deaccelerate in case of undersupply of electricity to the system. This change in rotating speed causes a deviation of the AC frequency, which will be experienced across the whole synchronous area (Consentec, 2014).

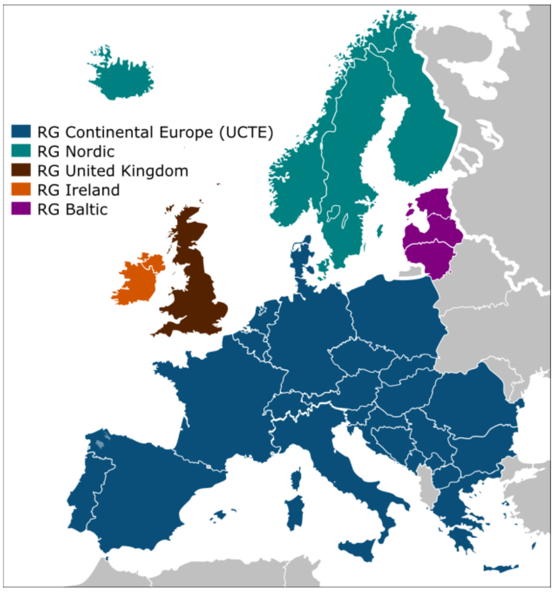
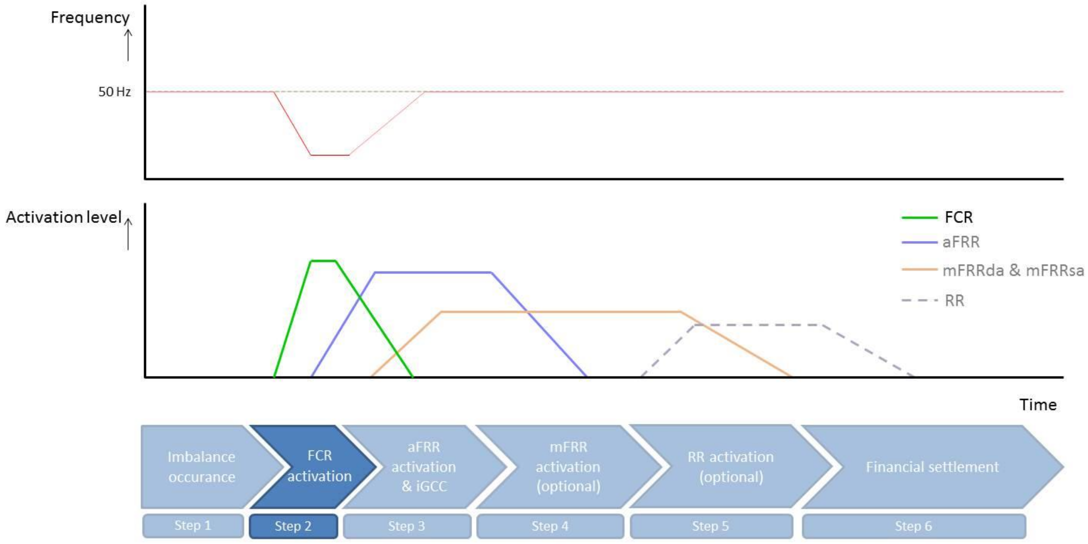


Figure 4 - Synchronous area of Continental Europe
Source: Wikimedia commons

BRPs have the opportunity to correct their own imbalance before the imbalance settlement period (ISP) ends, without facing financial consequences. The ISP timeframe can differ amongst LFC blocks. Within the Netherlands and Germany, it is 15 minutes. A TSO is responsible for both resolving power imbalances within one ISP and resolving residual energy imbalances over ISPs that are left unsolved by the market.

3.2. Step 2: Frequency Containment Reserve (FCR) activation



The first priority for TSOs in case of a system imbalance is to avoid further frequency deviation and limit damage to appliances connected to the grid. The frequency is stabilised using frequency containment reserves (FCR). Activation of FCR causes a change in production or load, restoring the balance between supply and demand. Triggered by frequency activation, FCR is activated automatically (i.e. through a computer signal based on frequency deviation) in the synchronous grid of Continental Europe. All providers of FCR capacity are able to quickly change their power output or load, as 50% of the FCR capacity should be activated within 15 seconds after frequency deviation and full activation should occur within 30 seconds (ENTSO-E, 2009). Conventional providers of FCR are large scale thermal power plants (using steam storage capacity) or hydro power plants (Consentec, 2014).

ENTSO-E uses a reference incident[3] (i.e. the largest likely imbalance event) in the synchronous grid of Continental Europe in determining the FCR capacity requirements (ENTSO-E, 2009). The capacity requirements for the whole synchronous area have remained relatively constant at around 3000 MW in the past years. Every LFC block area should contract part of this capacity according to its share in total generation and consumption in the synchronous grid (ENTSO-E, 2009). All capacity is contracted using auctions. Every LFC block needs to contract 30% of its allocated part within its own LFC block, while the rest can be contracted in other LFC blocks. The German, Austrian, French, Danish, German, Dutch and Swiss TSOs do this by conducting a jointly auction on Regelleistung.net. FCR capacity is contracted for one week, based on the merit order of the offered capacities and associated capacity price, with a minimum bid size of 1 MW. This auction happens six days before the actual delivery of FCR capacity. Providers of FCR will be remunerated for capacity provision, but not for electricity generation.

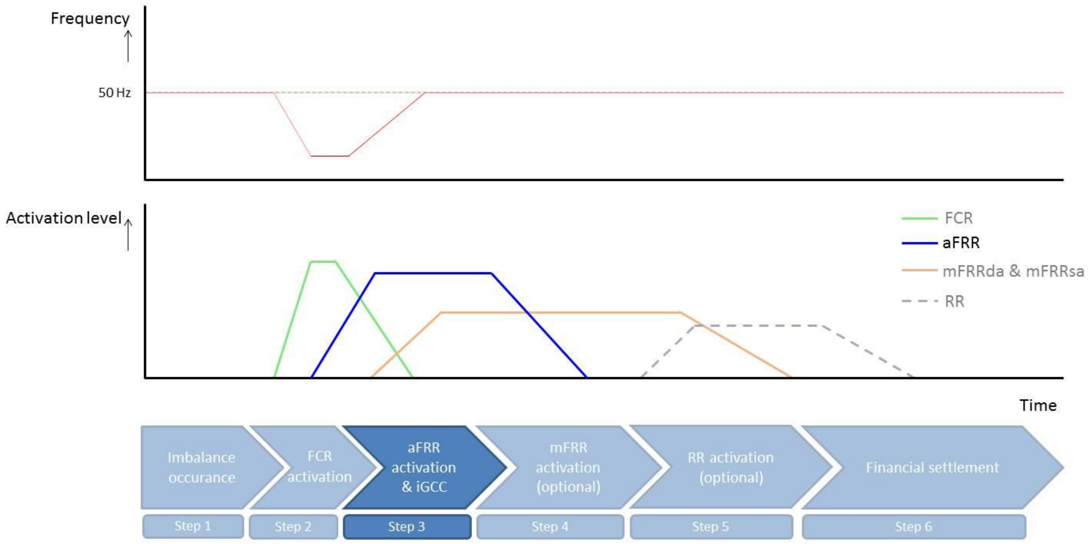
Table 1 - FCR product specifications (Lampropoulos et al., 2016; ENTSO-E, 2009, Regelleistung.net)

Technical requirements	Should be able to provide the same amount reserve capacity in both directions. 50% of its contracted capacity should be activated within 15 seconds after imbalance occurs, full activation within 30 seconds.

[3] The reference incident is based on a simultaneous outage of the two largest production facilities within the synchronous area.

Method of activation	An imbalance situation in one LFC block leads to automatic FCR activation based on a frequency deviation of at least 20 mHz within the whole synchronous area.
Market structure	Capacity auctioned on weekly basis. Only auctioned capacity will be used for FCR.
Capacity requirements	3000 MW for synchronous grid of Continental Europe. Contracting responsibility divided amongst LFC blocks according to its share in total generation and consumption in the synchronous grid. In 2017, the Netherlands was responsible for 96 MW and Germany for 600 MW. 30% of this FCR capacity should be contracted within the LFC block.
Settlement method	Capacity payment (€/MW/week). No compensation for electricity production.
Minimum bid size	1 MW

3.3. Step 3: aFRR activation & IGCC



After FCR activation, TSOs focus on freeing FCR capacity again. This is mainly to be able to deploy this capacity in other imbalance situations. FCR capacity is generally replaced by automatic Frequency Restoration Reserves (aFRR). aFRR capacity is activated to restore the frequency to its nominal 50 Hz frequency. The maximum start up and full activation time for aFRR providers are respectively 30 seconds and 15 minutes after the imbalance situation (ENTSO-E, 2009). While imbalance in one LFC block leads to FCR activation within all LFC blocks in the synchronous region, aFRR should be activated within the LFC block with the original imbalance situation. As aFRR and FCR have different technical requirements regarding start-up time and minimum activation duration, not the same type of power plants are used for both types of reserve. Typical conventional aFRR providers are thermal power plants in dispatchable operation, as such plants are capable of changing their operating point within a short period (Consentec, 2014).

European guidelines demand a minimum contracted FRR capacity (aFRR and mFRR, which will be discussed later) in each LFC block, to assure sufficient FRR capacity is available in case of a major imbalance situation. The required amount of FRR capacity is determined using the deterministic and probabilistic method. The deterministic method looks at loss of power if the biggest generation unit or interconnection line fails (n-1 method). The probabilistic method looks at the FRR capacity requirements to cover 99% of the major imbalance events. Whichever is highest will be the minimum contracted capacity. As TSOs use different processes for activating aFRR and mFRR, TSOs are free to divide the minimum contracted FRR capacity between aFRR and mFRR.

In the Netherlands, contracting occurs through auctions. Before 2016, Dutch aFRR capacity was only contracted through yearly auctions, but since 2016 this happens through quarterly (until July 2017), monthly (since July 2017) and yearly auctions. From 2018 onwards, all capacity will be auctioned using monthly auctions. Participants in the aFRR capacity auctions should be 100% available and should be able to provide both upward and downward capacity. The minimum bid size is 1 MW and plants with a capacity of more than 60 MW are obliged to make a bid. The aFRR providers receive capacity compensation. In Germany aFRR capacity auctions happen on a weekly-basis, using separate auctions for upward and downward aFRR, and for peak and off-peak hours.

The actual deployment of aFRR is based on the sorted balancing energy bid price (merit order list). In Germany, this merit order list consists of all parties that won the aFRR capacity auction, based on the energy price bidded in this auction. All participants that won an aFRR capacity auction in the Netherlands are obliged to make a bid for aFRR energy. Providers of aFRR energy without a capacity contract are also allowed to make a bid in the Netherlands, called a 'free bid'. Bids should be made 30 minutes before the ISP starts. The opportunity to make free bids relatively short before the auction also allows providers of aFRR with less certainty about their long-term availability (e.g. renewables) to provide aFRR energy. The outcome of the energy auction is determined using a merit order list, without distinguishing between free bids and bids from parties with a capacity contract. The German balancing system does not allow free bids.

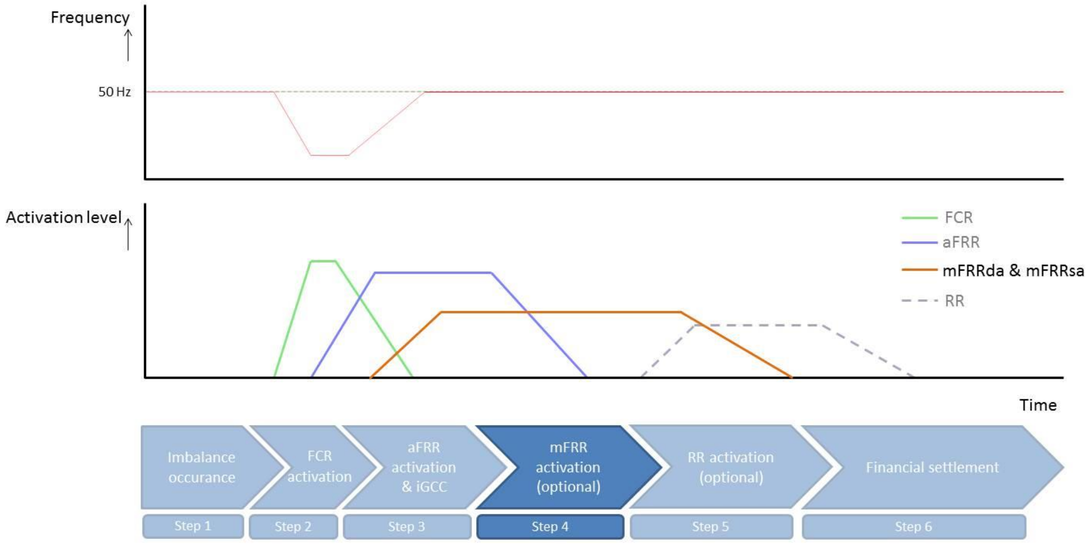
Some TSOs apply International Grid Control Cooperation (IGCC) before activating aFRR. IGCC is a cooperation between TSOs of at least two LFC blocks. Currently, TSOs from Austria, Belgium, Czech Republic, Denmark, Germany, France, the Netherlands and Switzerland are involved in the IGCC project. The goal of IGCC is to avoid simultaneous aFRR activation in opposite direction. Without IGCC, situations with an imbalance surplus in one TSO area and an imbalance shortage in another TSO area were balanced independently from each other. IGCC causes that the TSO with an imbalance surplus can provide energy to the TSO with negative imbalance, reducing aFRR activation. The extent to which IGCC can be utilised depends on the available cross-border capacity and the grid congestion levels.

Table 2 aFRR product specifications (Lampropoulos et al., 2016; ENTSO-E, 2009, Regelleistung.net)

Technical requirements	Maximum start up time of 30 seconds. Full activation time of maximum 15 minutes. In the Netherlands, aFRR provided should be capacity-symmetrical
Method of activation	Automatic activation through a computer algorithm based on imbalance volumes and frequency deviation
Market structure	Minimum capacity auctioned (yearly & monthly basis NL/weekly basis DE) per LFC block. Market participants which have won the aFRR capacity auction are obliged to bid for providing aFRR energy every ISP. In the Netherlands, 'free bids' of parties not providing capacity are possible, up to one hour before aFRR activation. Deployment based on merit order list, without distinguishing between contracted bids and free bids.
Capacity requirements	340 MW (symmetrical) for the Netherlands in 2017. The German capacity requirements differ per quarter. The capacity

	requirements in the last quarter of 2017 were 2048 MW negative control reserve and 1131 MW upward control reserve.
Method of remuneration	Capacity remuneration for capacity auctioned (€/MW/year, €/MW/quarter, €/MW/month or €/MW/week). Financial settlement for electricity provided or consumed (€/MWh) according to imbalance price (discussed in section 3.6).
Minimum bid size	1 MW for both contracted and free bids

3.4. Step 4: mFRR activation (optional)



In situations of large system imbalance, manual Frequency Restoration Reserves (mFRR) will be activated. In contrast to aFRR activation, mFRR activation is not activated by computer algorithms but by operators in the control room. mFRR activation aims to free-up the aFRR reserves, which should be available for new imbalance situations (ENTSO-E, 2009). mFRR is activated only in case of sustained aFRR activation, which occurs infrequently. Contrary to aFRR reserves, mFRR reserves are not activated automatically. The decision process regarding mFRR activation differs per TSO. Some TSOs (e.g. German TSOs) have relatively strict criteria regarding mFRR activation, while other TSOs (e.g. TenneT NL) leave the relevant decisions to the insights of operators in the TSO control room. Gas turbines with a short start up time or demand side management projects are common providers of mFRR (Consentec, 2014).

A distinction can be made between directly activated mFRR (mFRRda) and schedule activated mFRR (mFRRsa). The main differences between both products are their technical requirements. Both types of mFRR must provide energy during the whole ISP after the ISP in which the activation signal has been sent out. mFRRda must directly provide energy in the ISP when the signal was sent out according to a specific ramp rate, while mFRRsa does not need to provide energy in the ISP in which this signal was sent out. What types of mFRR is activated happens based on the nature of the imbalance situation.

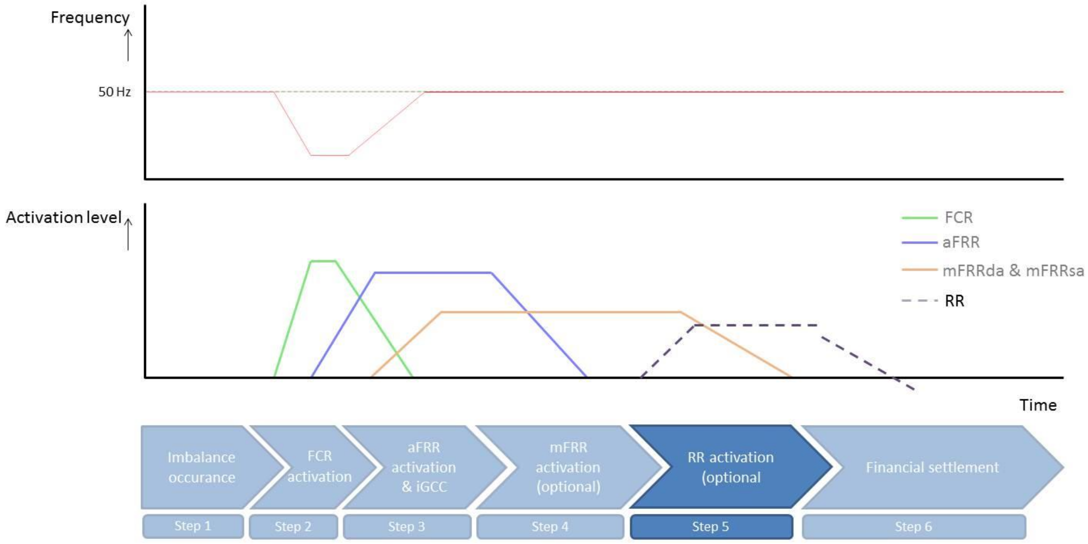
As previously described, a minimum capacity of FRR should be contracted by the TSO. The Netherlands contracts mFRRda to partly fulfil this requirement, this happens through quarterly (50%) and half yearly (50%) auctions. In Germany, all contracted mFRR should be able to provide mFRRsa or mFRRda. Whether the contracted capacity will be used as mFRRsa or mFRRda depends on the nature of the system imbalance. Contracting happens through daily auctions on Regelleistung.net.

mFRRda providers receive a capacity remuneration, as well as an energy remuneration. In the Netherlands, the energy remuneration is generally 10% percent higher than the imbalance price, with a minimum price of 200 euro/MWh. Providers of mFRRsa bid on the same merit order as aFRR providers, but are only activated in case mFRR is activated. The highest mFRRsa or aFRR bid sets the imbalance price. This imbalance price will also be used for the financial settlement for all mFRRsa and aFRR energy in the Netherlands (see section 3.6 for a detailed explanation). Germany uses a pay-as-bid system for mFRR, which means that market participants that provided mFRR energy receive the bidded energy price.

Table 3 mFRR product specifications (Lampropoulos et al., 2016; ENTSO-E, 2009, Regelleistung.net, TenneT, n.d.d)

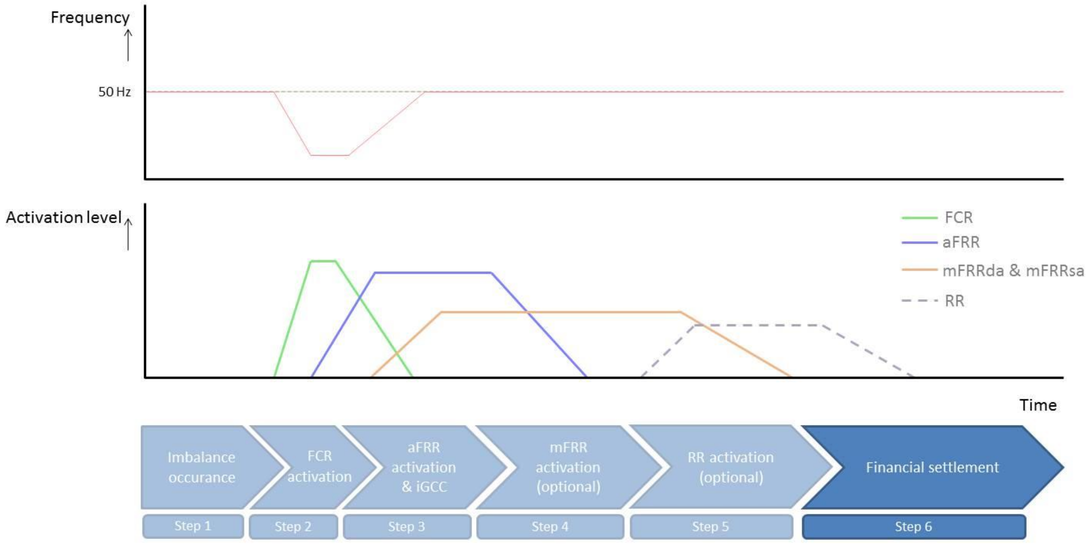
	mFRRda	mFRRsa
Technical requirements	Maximum 100% start-up time of 15 minutes. Minimum total activation duration of 15 minutes.	Maximum full activation time of 15 minutes. Minimum total activation time of 15 minutes.
Method of activation	Manual activation	Manual activation
Market structure	Minimum capacity contracted through quarter and half yearly auctions in the Netherlands and through daily auctions in Germany.	Only free bids
Capacity requirements	the Netherlands: 350 MW upwards, 200 MW downwards in 2017. Germany: Differs per quarter. 2048 MW upwards, 1131 MW downwards in the last quarter of 2017.	n.a.
Method of remuneration	Capacity remuneration and an energy remuneration which is 10% higher than imbalance price and at least 200 euro/MWh,.	Financial settlement for electricity provided or consumed (€/MWh) according to imbalance price (discussed in section 3.6).
Minimum bid size	4 MW	4 MW

3.5. Step 5: Reserve replacement (optional)



Some TSOs also contract Reserve Replacement (RR) capacity. RR frees up mFRR capacity and is generally activated in time spans of at least one hour. Many TSOs, including all Dutch and German TSOs, do not make use of RR, as it competes with the intraday trading market. For this reason, RR will not be further discussed in this study.

3.6. Step 6: Financial settlement



The electricity price received by a producer and paid by a consumer of electricity is dependent on the moment of trade; electricity traded in the intraday market has a different price than the electricity traded in the forward or day-ahead market. Balancing can be seen as real-time buying or selling electricity by a TSO. The price of this real time market is the imbalance price.

Germany and the Netherlands use different methods to determine the imbalance price. A pay-as-bid system is used for aFRR and mFRR in Germany, meaning that the price that applies to activated aFRR and mFRR providers is equal to the price they bid in. The German imbalance price for BRPs is determined by dividing the total balancing costs by the total imbalance volumes in an ISP. In the Netherlands, a marginal pricing system is used for financial settlement. The price of the highest activated aFRR or mFRR bid in an ISP determines the imbalance price for that ISP. This imbalance price applies to BRPs in imbalance, as well as to all activated aFRR/mFRR bids.

A high system imbalance leads to a big price difference with the intraday or day-ahead price. This price difference is called the imbalance delta and can be seen as a penalty for contributing to system imbalance. A high imbalance delta incentivises BRPs to avoid having a negative contribution to the system imbalance. In the Netherlands, TenneT provides BRPs with live updates on imbalance volumes and prices to financially stimulate BRPs to have beneficial contributions to reduce the system balance, by having a positive BRP imbalance in case of a negative system imbalance and vice versa. This mechanism is called 'passive balancing'.

Generally, the imbalance price is higher than spot market price with a short system (imbalance shortage/negative system imbalance), while it is lower than the day-ahead or intraday price with a long system (imbalance surplus/positive system imbalance). This is further explained in Figure 5 & Figure 6 on page 16 & 17.

The Dutch balancing market knows two extra elements. Firstly, it has introduced a dual pricing system (TenneT, 2016). In a situation with both relatively high negative and positive imbalances within one ISP, a separate imbalance price for positive and negative imbalance applies, to motivate market participants to refrain from being in imbalance in either direction. Secondly, an 'incentive component' is introduced in some situations to encourage market parties to refrain from portfolio deviations. It can be seen as an extra penalty upon the imbalance price. It will be increased for one week if one of the following events occur:

- the number of five minute blocks in a week with a change in imbalance volume greater than 300 MW is higher than 40.
- the weekly average change of imbalance volume per 5 minutes is higher than 20 MW.. (TenneT, 2017b)

The incentive component is zero the majority of the time.

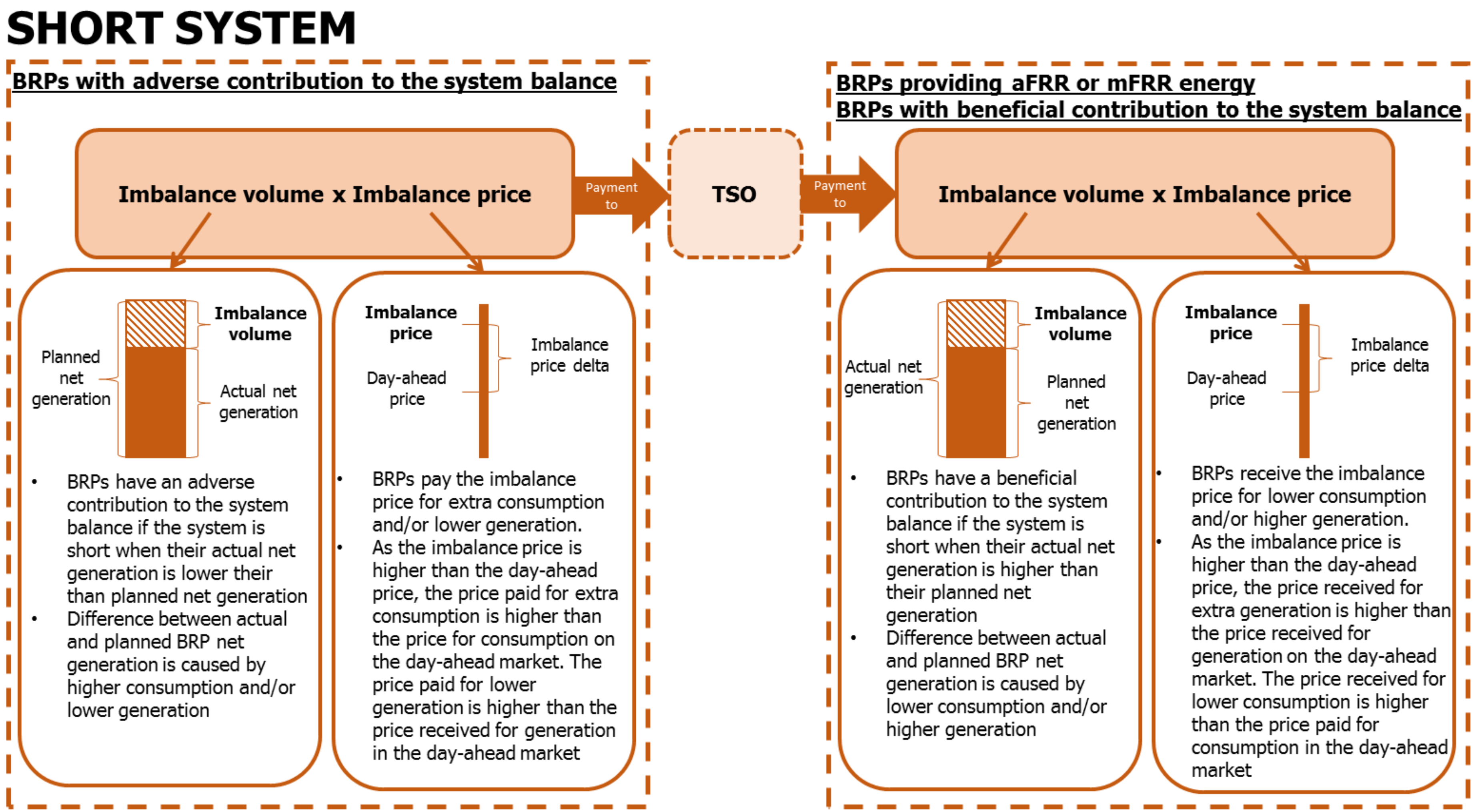


Figure 5 - Schematic explanation of the imbalance price in case of a short system.

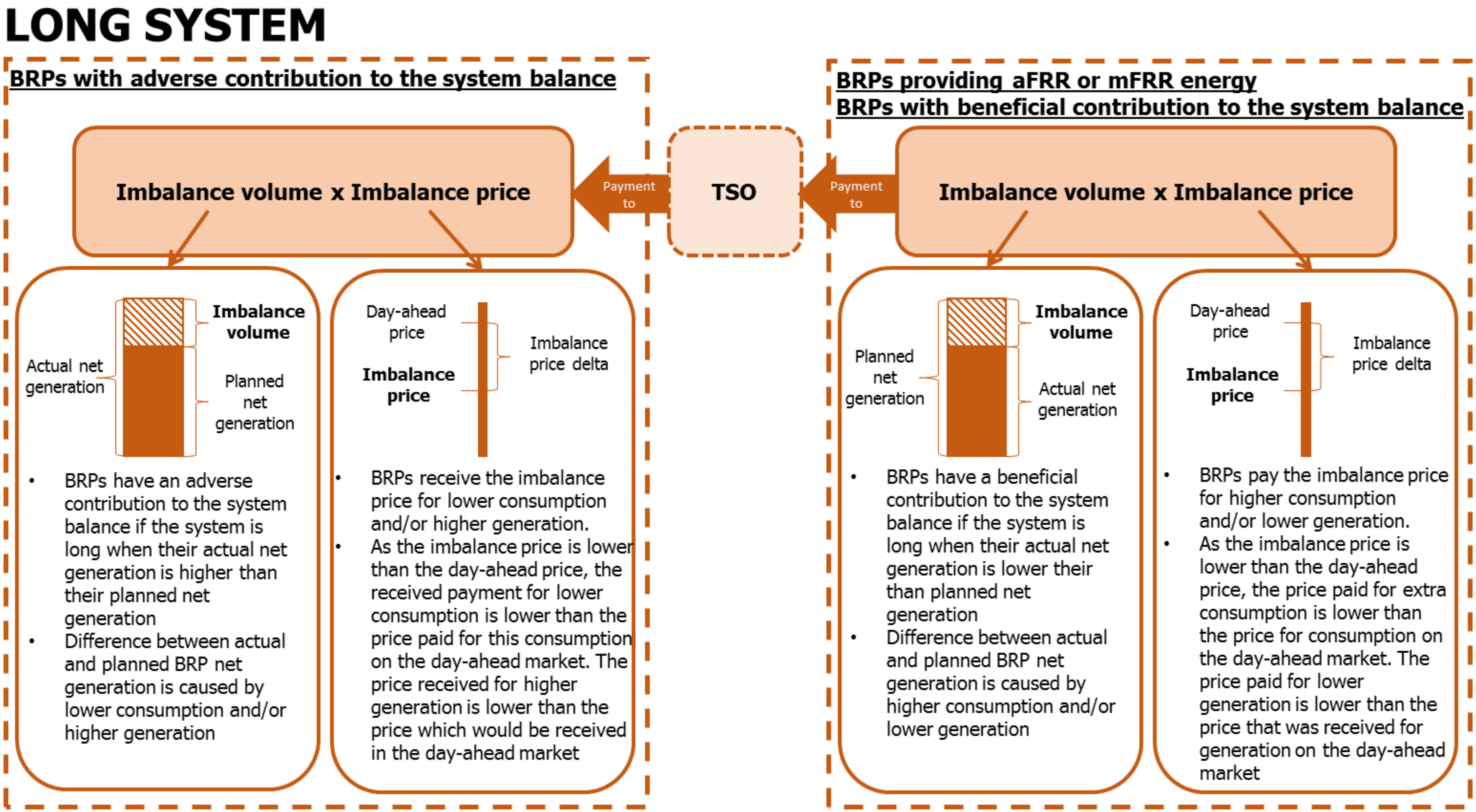


Figure 6 - Schematic explanation of the imbalance price in case of a long system.

4. Methodology

The methods used for answering each of the research questions of this report are discussed separately.

4.1. Developments in balancing markets

The first research question focuses on volume, price and market developments in balancing markets between 2013 and 2017.

4.1.1. Volume developments

Volume developments in the balancing markets will be studied by looking at BRP imbalance volumes, as well as activation volumes of different balancing products. In addition, developments in contracted volumes of different balancing products will be analysed.

Net BRP imbalance volumes are available on a 15-minute basis on the TenneT NL website (for the Netherlands) and on Regelleistung.net (for Germany). The Netherlands and Germany use a different configuration for short and long imbalance volumes. This is harmonized by converting imbalance volumes with a short system to negative values, while imbalance volumes with a long system are converted to positive values. While the published Dutch BRP imbalance values are exact measurements, the published German imbalance volumes equal the summed IGCC and FRR activation volumes, and are thus an approximation of the net BRP imbalance volumes.

aFRR and mFRR activation volumes are also published on a quarter-hourly time scale on the TenneT NL website and Regelleistung.net for the Netherlands and Germany respectively. Developments in contracted volumes of FCR, aFRR and mFRR in Germany are determined using data from Regelleistung.net. Contracted volumes in the Netherlands are obtained from Regelleistung.net for FCR, and internal TenneT NL data for aFRR and mFRR.

4.1.2. Price developments

Developments of both imbalance prices and capacity prices will be studied when examining price developments in the balancing market.

Imbalance prices are published by TenneT NL for the Netherlands and by Regelleistung.net for Germany. Regelleistung.net also publishes weekly Dutch and German FCR prices and German aFRR capacity prices. Dutch aFRR prices are published on ENTSO-E Transparency Platform.

Imbalance price developments will be studied using imbalance price deltas instead of absolute imbalance prices, as the difference between the spot market price and the imbalance price is the incentive for market participants to stay balanced (see section 3.6).

The imbalance price delta can be calculated using the day-ahead price or the intraday price as a reference price. The day-ahead price will be used as a reference price in this study for different reasons. Firstly, the traded volumes on the day-ahead market are much higher than on the intraday market, especially in the Netherlands. The German intraday market is relatively big, but is still much smaller than the intraday market. In addition, most trading in the intraday market in Germany is done by TSOs, which cannot be in imbalance. Therefore, most market participants look at the difference between imbalance price and day-ahead price when determining the penalty of being in imbalance. Secondly, there is not one single German intraday price for an hour, since part of the German intraday trading takes place in a continuous auction. The 'intraday price' for a specific hour is often determined by taking the weighted average price of the continuous auction, based on trading volumes. However, as this represents an artificial price, this intraday price is not used as a reference price.

The imbalance price delta will calculated differently for short and long systems, as both systems require different incentives, as described in Figure 5 & 6. For short systems the imbalance price delta has been calculated as:

$$imbalance\ price\ delta = imbalance\ price - day\ ahead\ price$$

The imbalance price delta has been calculated as follows for long systems:

$$imbalance\ price\ delta = day\ ahead\ price - imbalance\ price$$

As reserve capacity is auctioned for different timeframes for different balancing products, capacity prices will be standardized to be able to make a comparison. This standardization takes place by dividing capacity prices by the number of hours for which capacity needs to be provided.

German aFRR capacity is auctioned in four products: off-peak downward capacity, peak downward capacity, off-peak upward capacity and peak upward capacity. Peak products should provide capacity between 08:00-20:00 on weekdays, while off-peak products should offer capacity between 20:00-08:00 on weekdays and 24 hours/day on weekends and holidays. The combined German aFRR capacity price has been determined by taking the weighted average standardized capacity prices of the four products, based on contracted capacity.

In the Netherlands, aFRR is partly contracted in yearly auctions and partly in quarterly/monthly auctions. The Dutch aFRR capacity price has also been determined by taking the weighted average standardized capacity price.

4.1.3. Market developments

Market developments will be examined by looking at the market revenue in different markets over years, aFRR merit order developments and by monitoring the providers of balancing energy.

The market revenue of a specific market is the sum of revenue made by market participants from providing capacity and the revenue made by market participants for providing balancing energy.

The capacity revenue (CR) for a specific market has been determined as follows:

$$CR = \sum_{n}^{\#\ auctions} capacity\ price_n * contracted\ volume_n$$

The imbalance price delta instead of absolute imbalance prices will be used to determine the revenue made with providing balancing energy, as market participants generally see the extra money made compared to the day-ahead price as balancing revenue. The following formula has been used in determining the balancing energy revenue (BER) if the system was short and if the system was long:

$$BER\ (short) = \sum_{n}^{\#ISPs} balancing\ energy\ offered_n * (imbalance\ price_n - day\ ahead\ price_n)$$

$$BER\ (long) = \sum_{n}^{\#ISPs} balancing\ energy\ offered_n * (day\ ahead\ price_n - imbalance\ price_n)$$

The aFRR merit order will be analysed by looking at the merit order size per ISP for the Netherlands, data which is published on the TenneT website. This analysis will not be performed for Germany, as the German balancing system does not allow free bids and the German merit order size thus does not fluctuate over time. The activation levels of the aFRR merit order will be studied by looking at aFRR activation volumes and the aFRR merit order size per ISP.

Lastly, the market composition of aFRR providers will be studied by looking at the fuel types of prequalified capacity in Germany, based on Regelleistung.net data. In the Netherlands, fuel types are not registered when prequalifying reserve capacity, so such an analysis was not possible. The installed battery capacity will be discussed in depth, based on the DOE Global Energy Storage database.

4.2. Contributors to system imbalance

The impact of different possible contributors to system imbalance will be studied: installed variable renewable capacity, variable renewable generation, total generation, total load, and the forecast errors of the last three possible contributors.

4.2.1. Data collection and data quality

The installed variable renewable capacity in the Netherlands will be obtained from the Nationale Energieverkenning. These values are not measured but represent estimations of the installed variable renewable capacity. Data from Bundesnetzagentur will be used to identify developments in the installed variable renewable capacity. This is also mostly based on estimations and does not represent measured values.

The variable renewable generation for both Germany and the Netherlands are obtained from ENTSO-E Transparency Platform, which are uploaded by TSOs. Also these numbers are not exact measurements, as not all renewable generation can be measured on TSO grids. The numbers on ENTSO-E Transparency Platform are based on measurements on the variable renewable generation on the TSO grids, and these measurements are extrapolated for the rest of the country.

Total generation and load data are also obtained from ENTSO-E Transparency Platform. For the Netherlands, total generation data is not available on ENTSO-E Transparency Platform. Internal TenneT data is used instead, but is only available on a 15-minute basis for 2017. ENTSO-E Transparency Platform also publishes day-ahead forecasts regarding wind, solar, total generation and load. Variable renewable generation forecasts are based on weather forecasts, while generation and load forecasts on ENTSO-E Transparency Platform are based on the actual situations on the same weekday in the three weeks before, as the deviation with day-ahead BRP transportation schedules proved to be too big in the past.

The forecast error is determined by the following formula:

$$forecast\ error = actual\ situation - forecasted\ situation$$

The generation forecast error in the Netherlands will not be determined, as the internal generation data corresponds with the measured infeed on the TenneT grid, while the forecasted generation on ENTSO-E Transparency Platform corresponds with the total generation in the Netherlands.

4.2.2. Data analysis

The impact of possible contributors to system imbalance to the system imbalance will be determined by comparing the system imbalance with the value of the possible contributor for every ISP. Subsequently, a regression analysis using all data points will be performed in SPSS to find if there is a correlation between the contributor and system imbalance. An exception is the correlation analysis with the installed variable renewable capacity. The variable renewable capacity is only available on a yearly basis. Therefore, too limited data points are available to perform a regression analysis.

Linear, quadratic and cubic regression analyses will be performed. For most contributors to be studied, a linear regression analysis is not necessarily the most logical correlation. For instance, imbalance volumes are not necessarily highest at the highest renewable generation volumes. The power curve of wind turbines is flat at high wind speeds, causing that imbalance caused by slight deviations in wind speed could be higher at medium wind speeds. To take such effects into account, quadratic and cubic regressions are performed next to linear regressions.

The ENTSO-E Transparency Platform exists since 2015. Therefore, this analysis can only be performed using data from 2015 onwards. Internal TenneT experts indicated that the data quality regarding forecasts and renewable generation estimates on the ENTSO-E Transparency Platform have improved since 2015. For this reason, the correlation analyses will also be performed using 2017 data only.

There is no clear expected relationship between (variable renewable) generation or load and whether the system imbalance is long or short; higher generation or load could both result in a long or short system. Therefore, the regression analysis for these possible contributors will be performed with absolute imbalance volumes. On the other hand, a direct relationship between forecast errors and whether the system is long or short is expected; e.g. an underestimation of actual (variable renewable) generation is likely to result in a long system and vice versa. Therefore, the correlation analyses with forecast errors will be performed with non-absolute imbalance data.

The level of correlation between the contributors to the system imbalance and the system imbalance will be studied using the R^2 value. For every data point, the difference between the observed imbalance volume and the expected imbalance volume according to the model (trend line) is determined, and these differences are squared. Adding these up makes up the *sum of squares of the model* (SS_M). Similarly, the difference between the observed imbalance volume and the average imbalance volumes is determined to create the *total sum of squares* (SS_T). The R^2 value is calculated as follows:

$$R^2 = SS_M/SS_T \text{ (Field, 2009)}$$

The R^2 value is a value between 0 and 1, which measures the amount of variability in one variable that is shared by another variable (Field, 2009). It measures how tightly the data points fit to the regression line. There is discussion among scholars what R^2 is acceptable to talk about a correlation. Cohen (1992) states that R^2 value of at least 0.01 denotes a small effect, a R^2 value of 0.09 denotes a medium effect and a R^2 value of 0.25 as a strong effect. However, other scholars, such as Falk & Miller (1992) & Plonsky & Oswald (2014) propose higher R^2 values to speak about small, medium and strong effects. Most scholars agree that an R^2 value lower than 0.10 should be considered as a weak correlation (Larson-Hall, 2015).

5. Volume developments in balancing markets

The first step in answering the first research question is to look at volume developments in the balancing markets. A distinction can be made between three types of volume developments: imbalance volumes, contracted capacity of different balancing products and activation levels of different balancing products. Each of these developments will be discussed separately.

5.1. Imbalance volumes

The total imbalance volumes in the Netherlands and Germany show different trends, as exhibited in Figure 7.

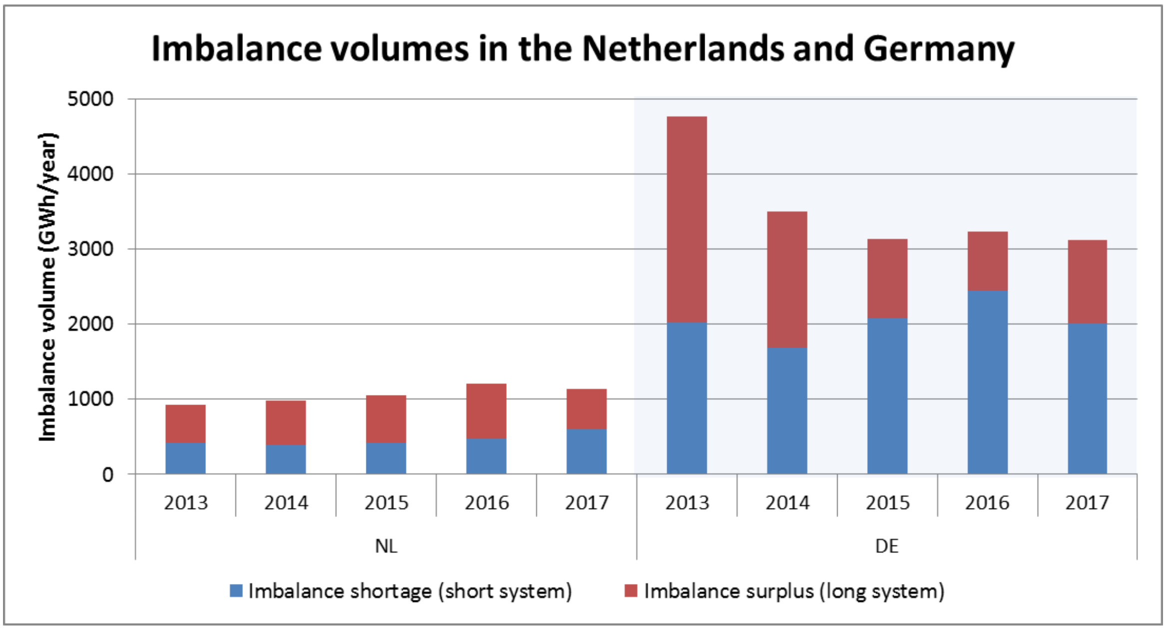


Figure 7 - Summed net ISP imbalance volumes for the Netherlands and Germany between 2013 and 2017. Source: ENTSO-E Transparency Platform, Regelleistung.net, TenneT NL

While the imbalance volume in the Netherlands has increased by 22% from 929 GWh in 2013 to 1136 GWh in 2017, the German imbalance volume has decreased by 35% from 4760 GWh in 2013 to 3116 GWh in 2017. This trend is also visible in Figure 8 & 9, which show a count of the number of ISPs in which the net imbalance volume fell within a certain range.

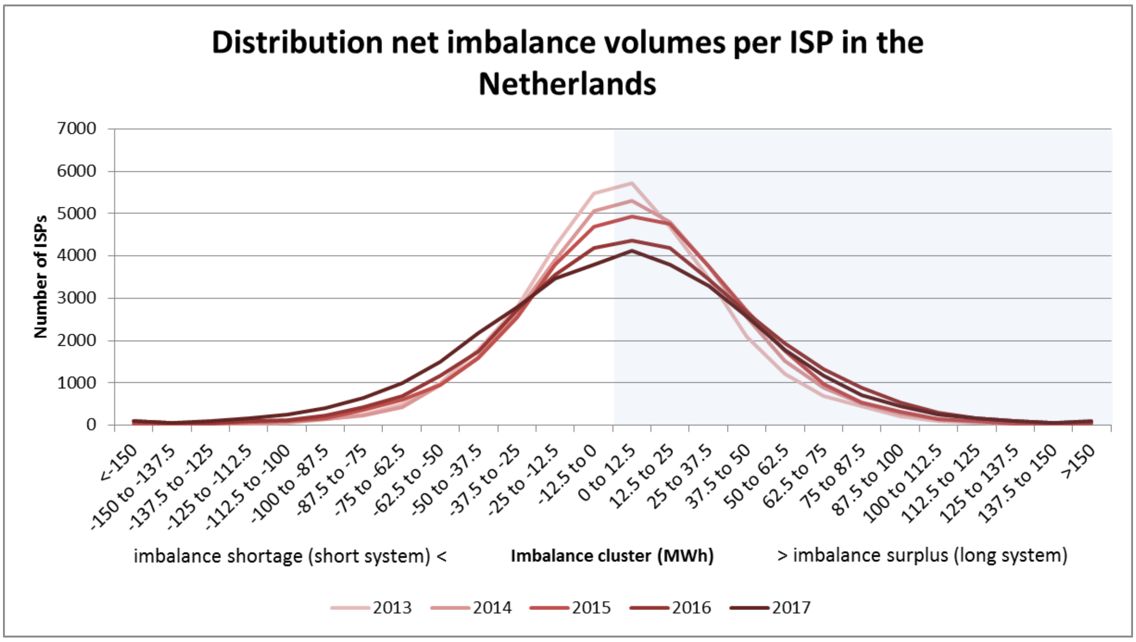


Figure 8 – Distribution of net imbalance volumes per ISP in the Netherlands between 2013 and 2017. Source: TenneT NL

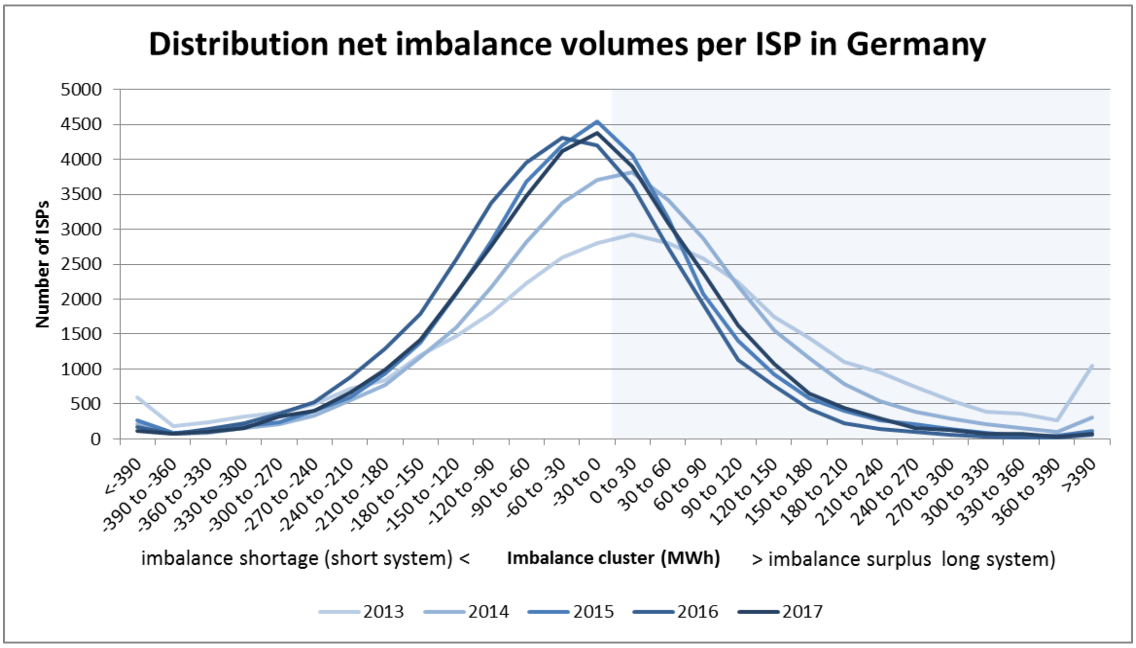


Figure 9 - Distribution of net imbalance volumes per ISP in Germany between 2013 and 2017. Source: Regelleistung.net

For the Netherlands, the lines are continuously shifting downwards over the years, indicating that low imbalance volumes occurred less frequently and extreme imbalance volumes occurred more frequently than in in previous years. In contrast, it is visible in Figure 9 that in Germany the graph has shifter onwards from 2015 onwards, indicating that in a larger share of the ISPs imbalance volumes were low.

Some of these trends could be attributed to developments in the imbalance price delta, which can be seen as the penalty for imbalance. The average imbalance price delta has decreased for both countries, which will be addressed in detail in section 6.1. In the Netherlands, this decrease reduced the incentive for market participants to stay balanced or to provide passive balancing services. However, this trend did not result in higher imbalance values in Germany. The imbalance price delta in Germany is generally higher and Germany has faced extreme imbalance prices in recent years. These higher imbalance prices, together with the fact that the German balancing system does not provide live updates on imbalance volumes and prices, makes the risk of being in imbalance in the wrong direction much higher in Germany. In addition, the liquidity of the German intraday market has increased over the years (see TenneT Market Review 2017), causing that market participants might have settled their imbalance in the German intraday market.

Another observation that can be made in the figures above is that the Dutch system is generally more often long than short, while the German system is more often short than long. An explanation for this trend can also be found in the imbalance price delta, which is higher for short systems in the Netherlands and higher for long systems in German, as discussed in section 6.1.

The average imbalance volumes per month have been studied to identify if there is a seasonal pattern in imbalance volumes. The results are displayed in Figure 10.

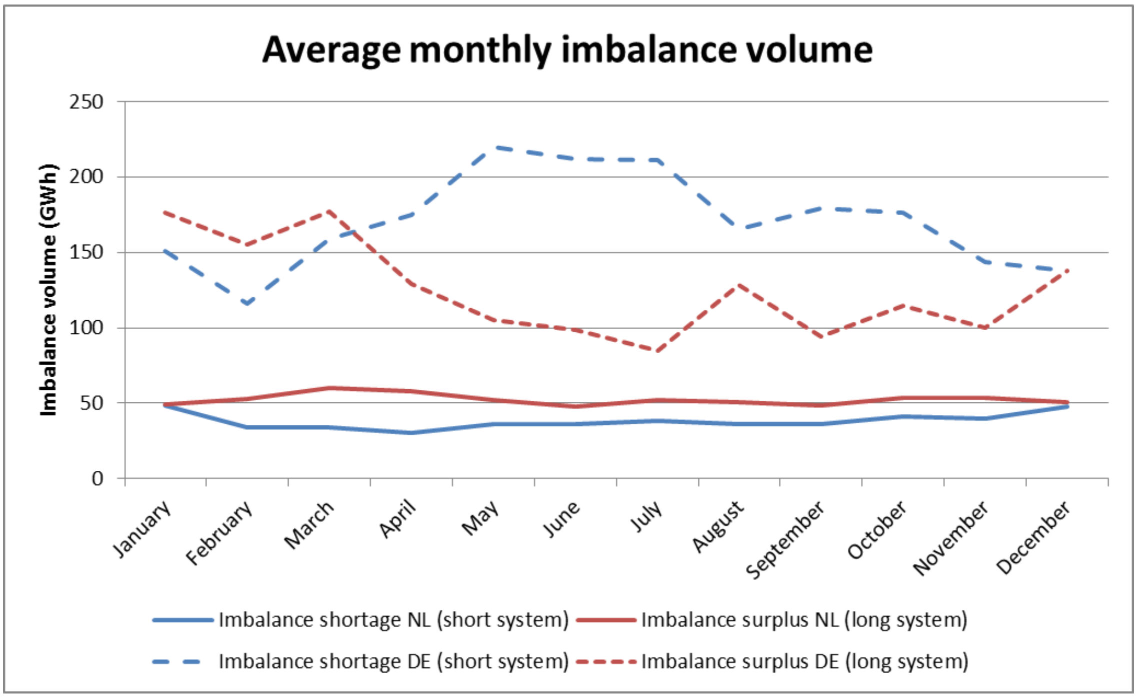


Figure 10 - Average monthly imbalance volumes between 2013 and 2017 in the Netherlands and Germany.
Source: ENTSO-E Transparency Platform, Regelleistung.net, TenneT NL

The imbalance volumes in the Netherlands do not vary significantly throughout the year. However, a seasonal trend is visible for German imbalance volumes; there are more imbalance shortages during summer and more imbalance surpluses during winter.

In addition, the average hourly imbalance has been identified in Figure 11to see if there is a daily pattern observable.

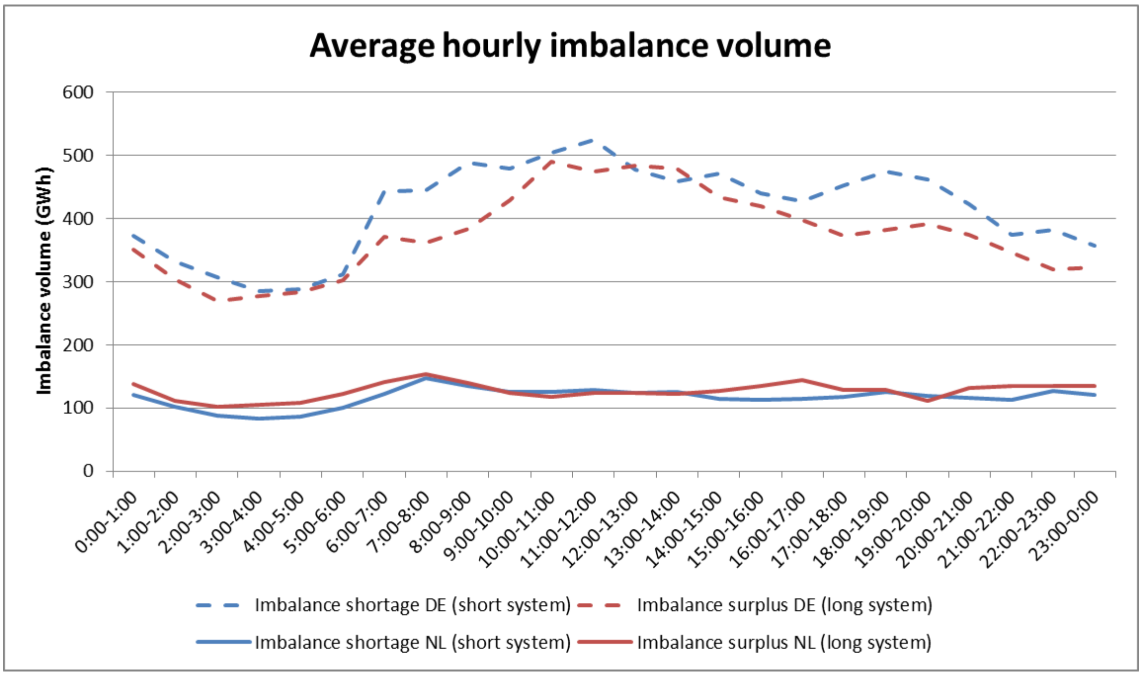


Figure 11 - Average hourly imbalance volumes between 2013-2017 for the Netherlands and Germany. Source: Regelleistung.net, ENTSO-E Transparency Platform, TenneT NL

It is visible that throughout the day, the imbalance volumes remain relatively constant in the Netherlands and Germany. During night hours, the imbalance volumes are slightly lower, after which these imbalance volumes increase in the early morning (between 6:00-7:00 in Germany, between 7:00-8:00 in the Netherlands). These lower imbalance volumes are caused by lower generation volumes and lower load during night hours, which causes that the chance of high imbalances is lower.

5.2. Activation volumes of balancing products

The aFRR and mFRR activation volumes of the Netherlands are displayed in Figure 12. Figure 13 shows the aFRR and mFRR activation volumes in Germany.

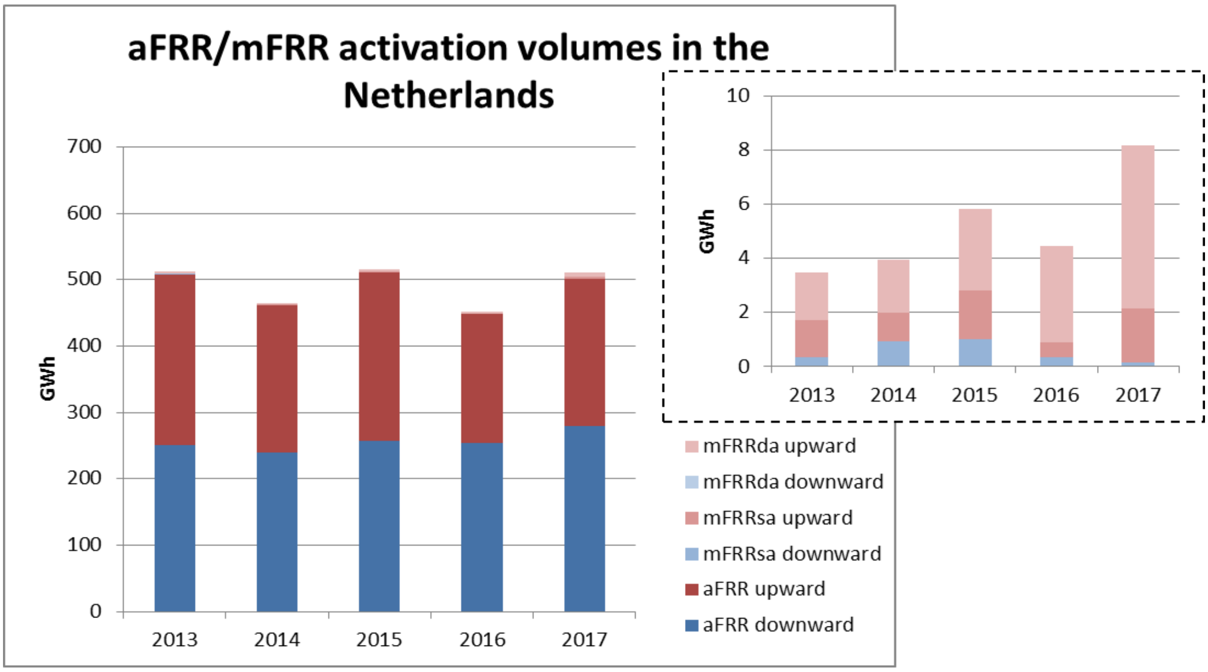


Figure 12 – aFRR and mFRR activation volumes in the Netherlands, with a zoom-in on mFRR volumes. Source: TenneT NL

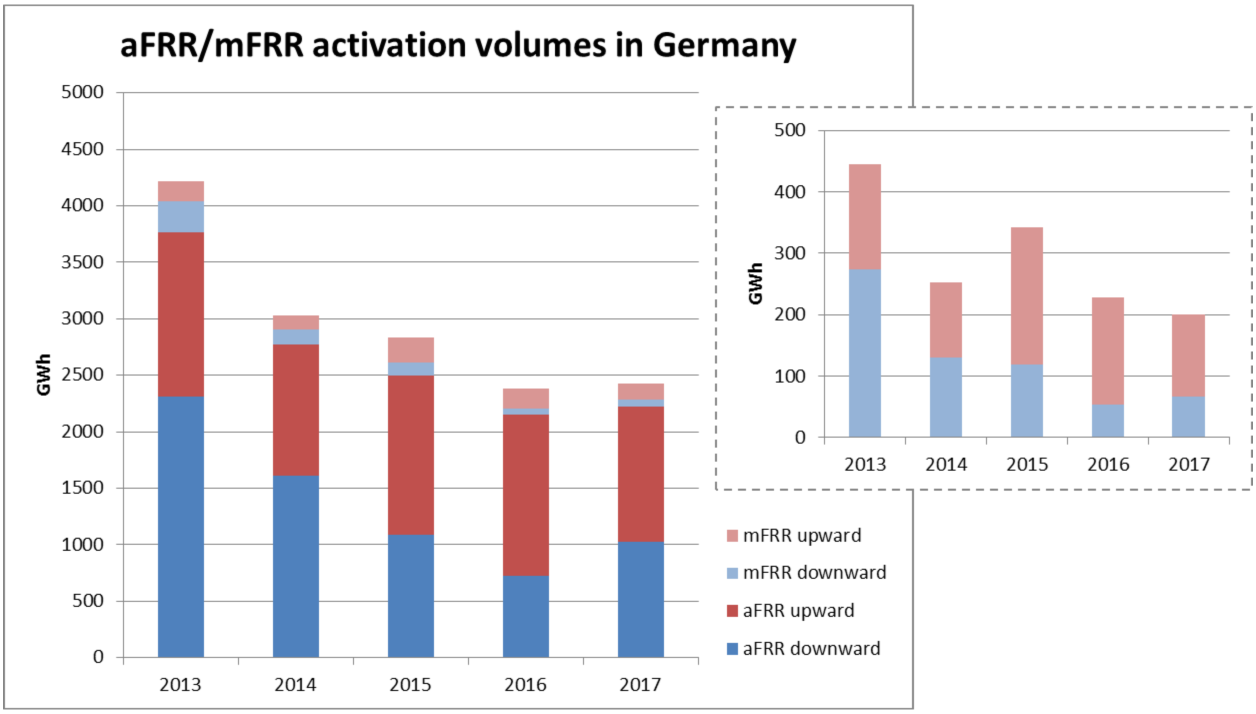


Figure 13 – Annual aFRR and mFRR activation volumes in Germany, with a zoom-in on mFRR volumes. Source: Regelleistung.net

Generally, developments in imbalance volumes should be reflected in FCR, aFRR and mFRR activation volumes. However, Figure 12 & 13 do not support this hypothesis. Figure 12 shows that the aFRR activation volumes in the Netherlands remained relatively constant since 2013, while section 5.1 showed that the imbalance volume in the Netherlands has increased in this time period. Similarly, the German imbalance volume has remained relatively constant since 2015, but Figure 13 shows that the activated aFRR volumes reduced significantly between 2015 and 2017.

The mFRR volumes in the Netherlands show an upward trend, in line with the developments in the imbalance volumes, as shown in Figure 12. Especially the increase between 2016 and 2017 is significant, which is due to an incident with prolonged mFRR activation on July 28th 2017. The mFRR activation volumes in Germany in Figure 13 follow a similar downward trend as the aFRR activation volumes.

Germany uses relatively much more mFRR energy compared to the Netherlands. This difference is caused by a different strategy used by balancing operators in the Netherlands and Germany. Where Dutch operators only activate mFRR in extreme situations, mFRR is used with less extreme imbalance situations in Germany.

This difference in strategy also explains why the ratio between activated upward and downward mFRR volumes is different between both countries. In the Netherlands, the upward activated mFRR volumes are much higher than the downward activated mFRR volumes, while these volumes are more equal in Germany. As described above, mFRR in the Netherlands is only activated in situations of extreme imbalance. Most extreme imbalance volumes occur because of the outage of a power plant. This requires upward mFRR balancing energy. In Germany, mFRR is also activated with less extreme imbalance events, which are not necessarily caused by outages and might require downward mFRR activation.

One explanation for the different trend between activated aFRR/mFRR volumes and imbalance volumes could be IGCC, of which the volumes are displayed in Figure 14.

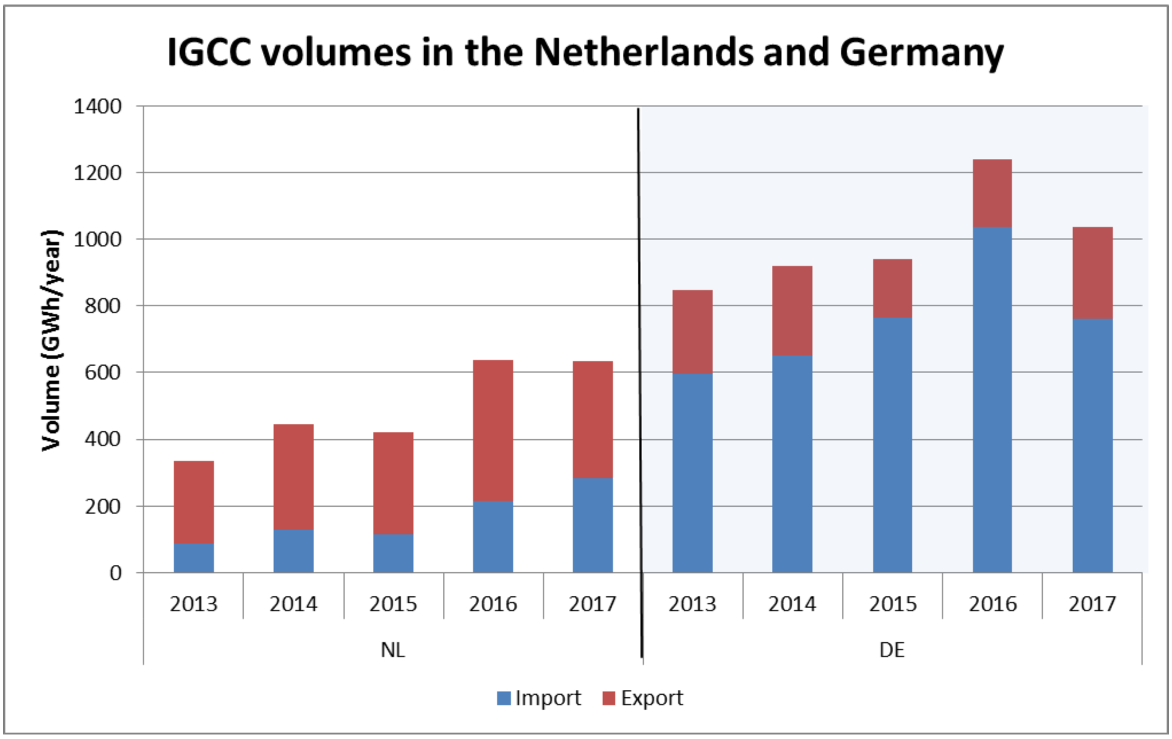


Figure 14 - International Grid Control Cooperation (IGCC) volume developments in the Netherlands and Germany between 2013 and 2017.
Source: Regelleistung.net

As explained in section 3.3, imbalance volumes in different directions are exchanged with IGCC, resulting in lower imbalance volumes which need to be corrected with reserve activation. Figure 14 shows that the IGCC exchanges in the Netherlands and Germany have increased significantly. This is mainly induced by the participation of RTE (French TSO) in February 2016, which caused that the options for exchange grew significantly.

The Netherlands is mainly an exporter of IGCC energy, while Germany is an importer. IGCC volumes are restricted by the interconnector capacities. The interconnector capacity to the Netherlands and the interconnector capacity from Germany are more often constrained than the capacity in reverse direction. Consequently, IGCC utilisation is regularly limited when the Netherlands is has an imbalance shortage (short system) and wants to import through IGCC, and when Germany has an imbalance surplus (long) and wants to export through IGCC.

5.3. Contracted volumes of balancing products

Lastly, the volume developments of different balancing products contracted by TSOs to assure sufficient reserves are available are discussed. FCR developments are displayed in

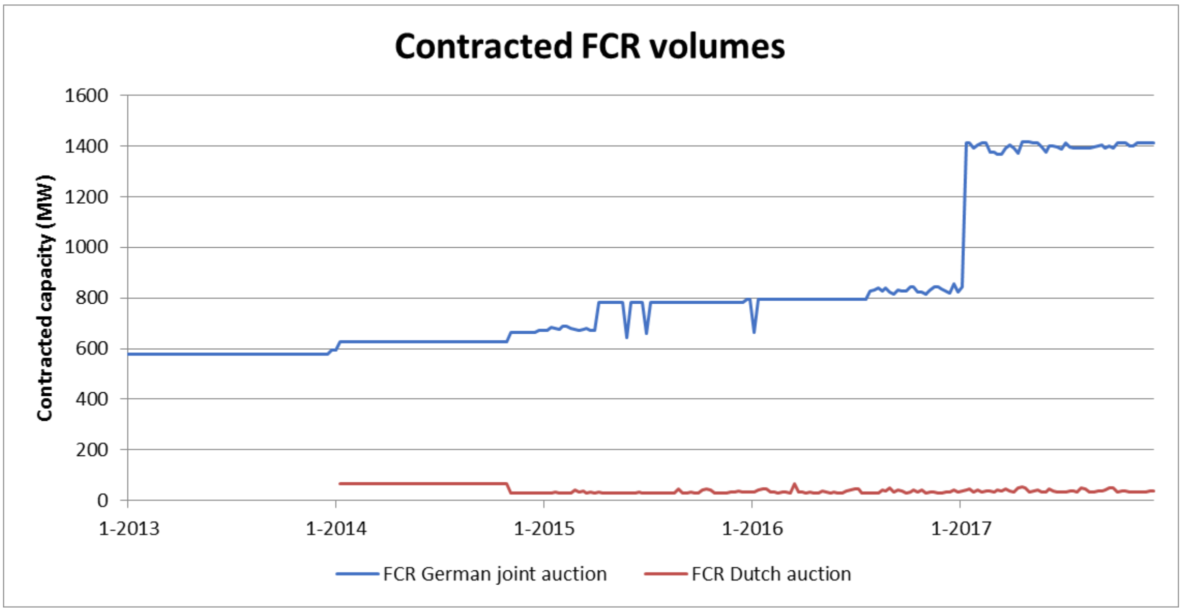


Figure 15 - Contracted FCR volumes in the Netherlands and the joint German auction. Source: Regelleistung.net

Figure 15 shows that the contracted capacity in the joint German FCR auction, which is accessible to German, Dutch, Austrian, Belgian, French and Swiss FCR providers, has shown an upward trend since 2013. Therefore, Dutch and German FCR providers have access to a bigger market.

This increase is caused by increased participation from TSOs in the joint auction, which each are obliged to contract a minimum capacity of FCR (see section 3.2). The Dutch branch of TenneT joined the auction in 2014. APG (Austrian TSO) and Swissgrid (Swiss TSO) joined the auction in the second quarter of 2015 and Elia (Belgian TSO) decided to participate halfway 2016. The major increase in contracted capacity in the beginning of 2017 comes from participation of RTE (French TSO).

The joint auction suffices for the German TSOs to meet the ENTSOE-E requirement to contract 30% within the TSO area. This is not the case for the Dutch branch of TenneT. Therefore, additionally a separate Dutch FCR auction is organised in the Netherlands. The capacity contracted in this auction remained relatively constant around 30 MW.

In addition, TSOs are obliged to contract a minimum amount of FRR within their TSO control area. The Netherlands contracts aFRR and mFRRda, mFRRsa is not contracted. The contracted volumes are determined once per year. Germany contracts aFRR and mFRR. The contracted mFRR should be able to provide both mFRRda and mFRRsa energy. The contracted volumes change throughout the year. Figure 16 & 17 display the contracted FRR volumes for respectively the Netherlands and Germany.

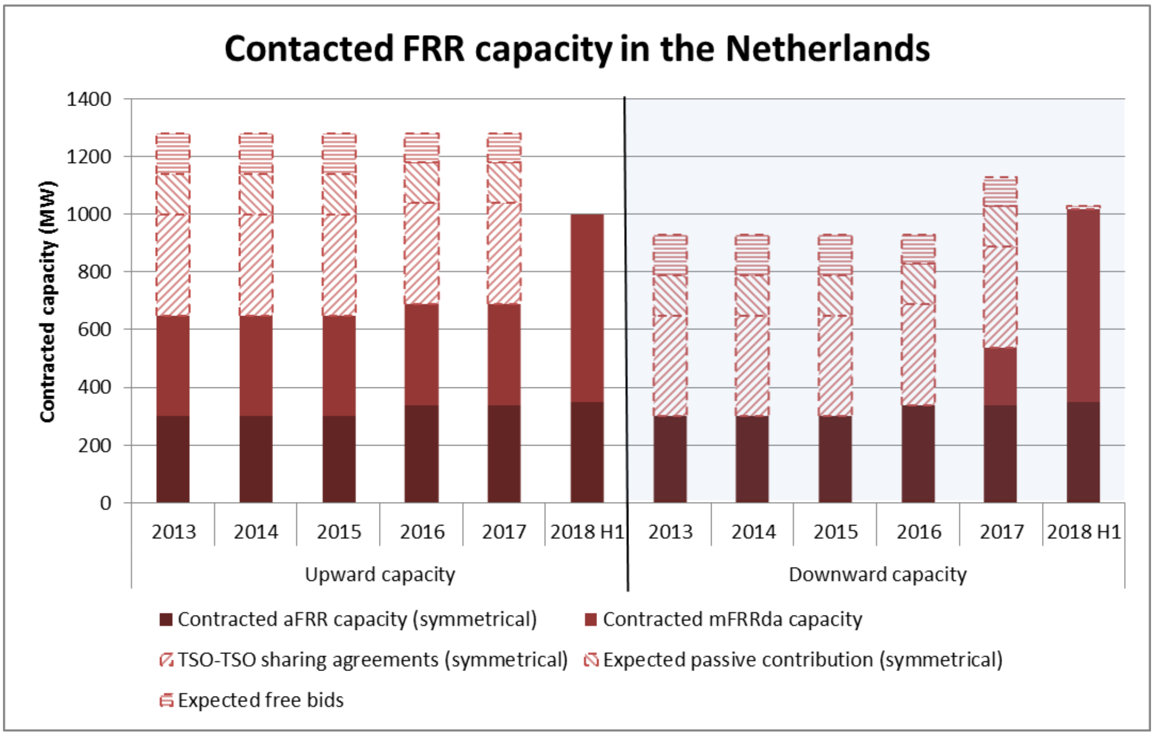


Figure 16 - FRR dimensioning in the Netherlands.
Source: TenneT NL

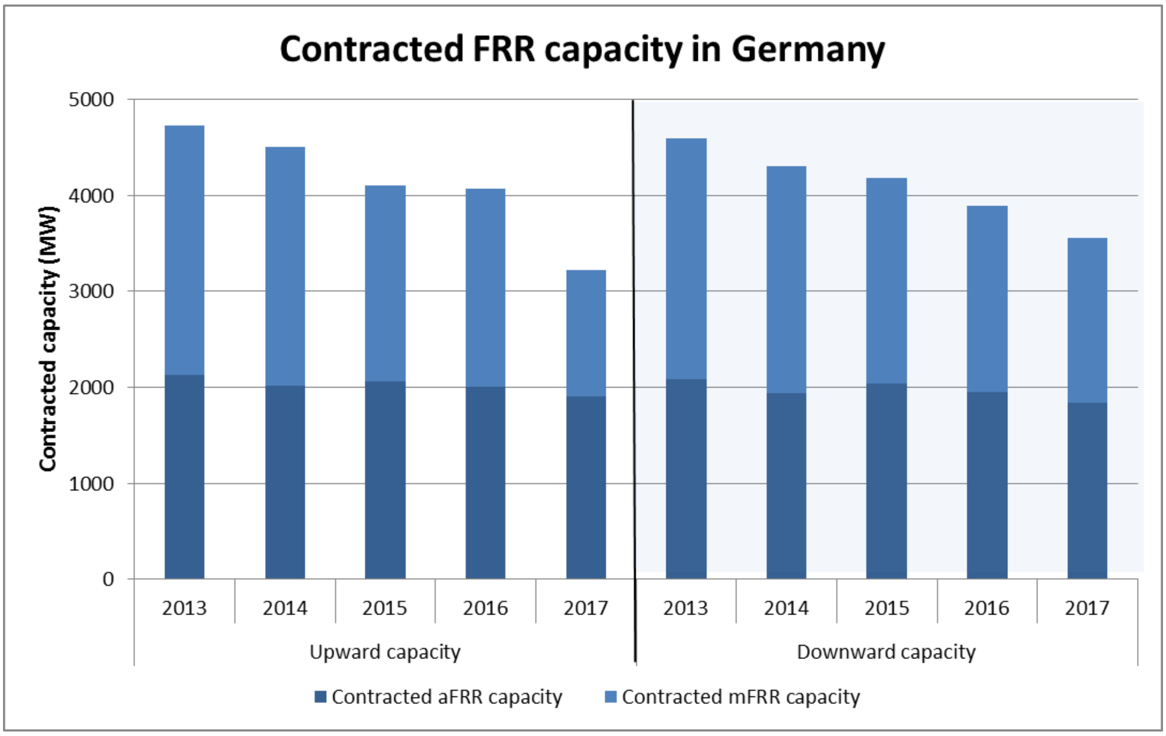


Figure 17 – Average yearly FRR dimensioning in Germany.
Source: ENTSO-E Transparency Platform

The contracted FRR volumes in the Netherlands remained relatively constant between 2013 and 2017, except for the introduction of the downward mFRRda capacity product in 2016. In 2018, the contracted mFRRda products will increase significantly. Until 2017, part of the dimensioned FRR requirement was fulfilled through expected free bids, expected passive contributions and exchange with other TSOs (i.e. TSO-TSO sharing agreements). TenneT decided to contract more reserve capacity in 2018 because of insufficient free bids and passive contributions in the recent years. In addition, TSO-TSO sharing agreements are not taken into account in 2018 because of increasing interconnector capacity constraints.

In contrast, the contracted FRR volumes in Germany have decreased since 2013. This decrease is mostly visible in the contracted mFRR volumes. The cause of this decrease is a lower outcome of the probabilistic calculations used for determining the dimensioned FRR requirements.

6. Price developments in the balancing markets

Next to volume developments, price developments in the balancing markets will also be studied. The first part of this section will zoom-in on imbalance prices, followed by a look at capacity prices of different balancing products.

6.1. Imbalance prices

As described in section 4.1.2, developments in the imbalance price will be studied by looking at the imbalance price delta (i.e. the difference between the imbalance price and the day-ahead price). The development of the average imbalance price delta in the Netherlands and Germany is displayed in Figure 18 & 19.

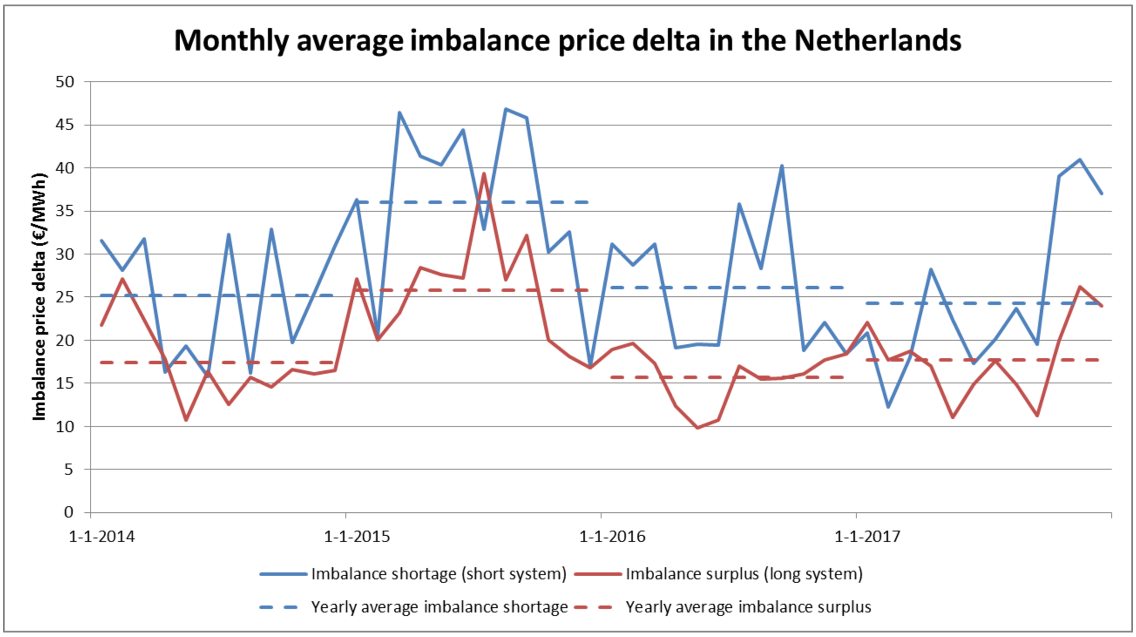


Figure 18 - Monthly average imbalance price delta in the Netherlands.
Source: TenneT NL, EPEX Spot

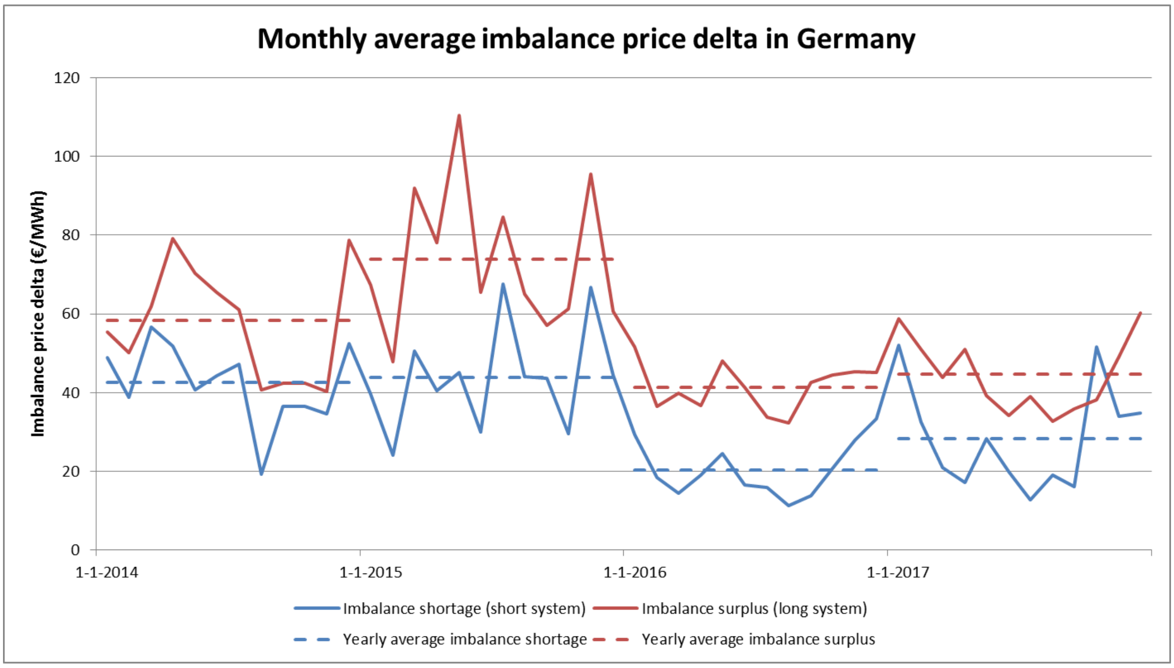


Figure 19 - Monthly average imbalance price delta in the Netherlands.
Source: Regelleistung.net, ENTSO-E Transparency Platform, EPEX Spot

These figures show that the imbalance price delta increased for both countries between 2014 and 2015, but decreased significantly since 2015. The increase in IGCC volumes can be one factor contributing to this development, as IGCC leads to lower aFRR/mFRR activation and therefore to lower imbalance prices. The German decrease can also be attributed to the lower imbalance volumes, as reported in the previous section.

Providing downward balancing energy is more attractive for market participants than providing upward balancing energy. Market participants save fuel costs when providing downward balancing energy, while their fuel costs increase when providing upward balancing energy. In addition, the number of market participants that can provide downward balancing energy is generally higher than the number of market participants that can provide upward balancing energy, as market participants generally want to sell their full capacity on the day-ahead market. When operating at full capacity, this market participant cannot ramp up to provide upward balancing energy, while all flexible power plants can ramp down to provide downward balancing energy. This is explains why the imbalance price delta is higher when there is an imbalance shortage, which requires upward balancing energy.

This trend is not observable in Germany for two reasons. Firstly, the structure of the German generation fleet plays a role. Baseload conventional generation makes up a large share of the German generation, as well as renewable. By law, renewables may not be ramped down in Germany, while it is not always technically possible to ramp down baseload conventional generation. Therefore, the options for ramping down in Germany are more limited. In addition, IGCC plays a role, as IGCC exchanges are limited by the available interconnection capacity (see section 5.2). This section showed that the Netherlands is generally an exporter of IGCC, which occurs when there is an imbalance surplus, while Germany is an importer of IGCC energy, which occurs when there is an imbalance shortage. As IGCC avoids reserve activation, the aFRR and mFRR activation volumes and thus imbalance prices are generally higher when there is an imbalance shortage in the Netherlands and an imbalance surplus in Germany.

The figures also show that the imbalance price delta in Germany is higher compared to the Netherlands. This can be ascribed to the difference in balancing market design between Germany and the Netherlands. The German system does not allow for passive balancing and free bids. Both effects have an upward effect on the imbalance price; passive balancing limits reserve activation, while free bids enhance competition between aFRR and mFRR providers.

The distribution of imbalance price delta's among imbalance volumes in the Netherlands and Germany in 2017 are shown in respectively Figure 20 & 21. These figures for 2015 and 2016 for both countries can be found in Appendix I.

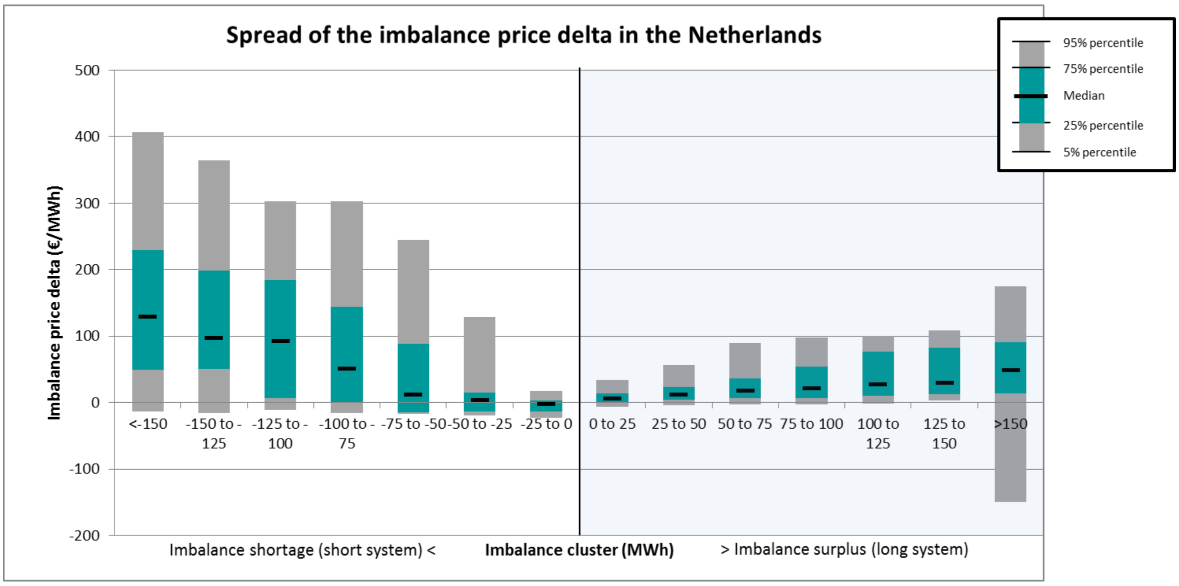


Figure 20 - Spread of imbalance price delta at different imbalance volumes in the Netherlands in 2017. Source: TenneT NL, EPEX Spot.

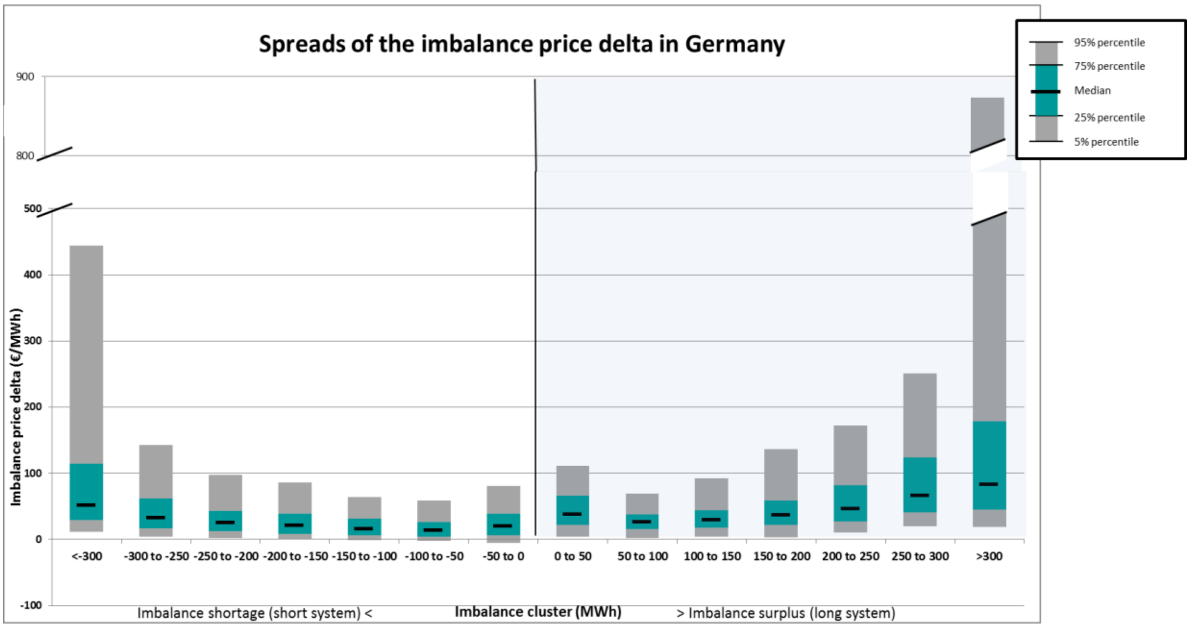


Figure 21 - Spread of imbalance price delta at different imbalance volumes in Germany in 2017. Source: ENTSO-E Transparency Platform, EPEX Spot.

As the incentive to stay balanced should be larger with high system imbalance volumes, one expects the imbalance price delta to be higher in such situations. The figures above show that in both countries, the imbalance price delta spreads at high imbalance volumes are higher compared to low imbalance volumes. In contrast to previous years (see Appendix I), the 5% percentile of the imbalance price delta at high imbalance volumes in the Netherlands has periodically been very low or even negative, which can be attributed to the depressing effect of IGCC on imbalance prices.

Germany experienced an increasing occurrence of extreme imbalance prices, with a record-high imbalance price of 24,455 euro/MWh on October 17th 2017. Figure 21 reflects this with high 95% percentile imbalance price delta values, which increased enormously for some imbalance volumes compared to 2015 and 2016 (see Appendix I). The absence of free bids in the German balancing system limits competition for aFRR activation. This motivated contracted market participants to make very high bids, which resulted in the high 95% percentile values. The negative spike in the Netherlands for imbalance volumes of at least 150 MWh can be attributed to a prolonged incident with sustained mFRRda activation with an inexplicably high passive BRP contribution.

The design of the German balancing system induces the higher spreads in imbalance price delta around an imbalance volume of 0, which is even more evident in Appendix I. Around an imbalance volume of 0, the chance of counter activations, in which both upward and downward aFRR is activated by TSOs, is relatively high. The German imbalance price is set by dividing the total imbalance costs by the imbalance volume. As the imbalance costs are relatively high due to counter activation, while the net imbalance volume is relatively low, the imbalance price is relatively high at low imbalance volumes.

6.2. Capacity prices

The development of the FCR and aFRR capacity prices in Germany and the Netherlands are displayed in Figure 22 on page 35.

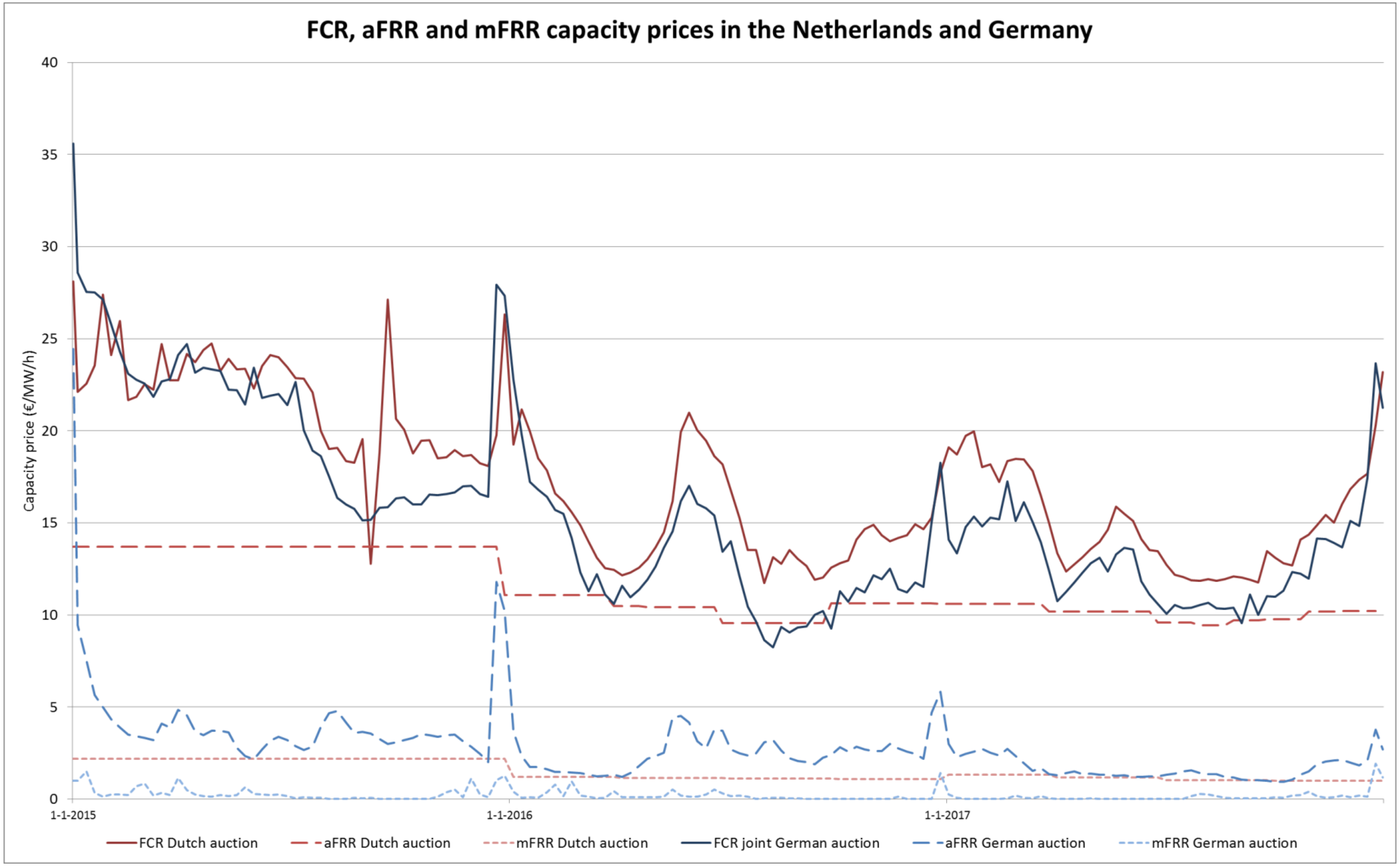


Figure 22 – Average FCR, aFRR and mFRR capacity prices in the Netherlands and Germany.
Source: Regelleistung.net, ENTSO-E Transparency Platform

The figure indicates that the FCR capacity price is higher than the aFRR capacity price in the Netherlands and Germany, while the mFRR capacity price is lower than the aFRR capacity price. This difference can be attributed to the higher technical requirements of FCR and aFRR compared to respectively aFRR and mFRR. Furthermore the difference between the FCR capacity price and the aFRR and mFRR capacity prices can be explained by the fact that aFRR and mFRR capacity providers receive an energy price for providing balancing energy, in contrast to FCR capacity providers.

Germany contracts all its FCR capacity through a joint auction with TSOs from Austria, Belgium, France, the Netherlands and Switzerland. The Netherlands has an additional national auction to meet the ENTSO-E requirement to contract 30% of FCR within the TSO region. As more FCR providers can participate in the joint auction, the competition in this auction is higher. Therefore, the average capacity price in the Dutch FCR auction is generally higher compared to the average capacity price in the joint auction.

The different nature of the balancing system in Germany and the Netherlands induces the large difference between the average aFRR and mFRR capacity price in both countries. The Dutch system allows free bids into the aFRR and mFRR merit order, while the German aFRR merit order only comprises contracted providers. Due to the absence of free bids in the merit order, competition for aFRR and mFRR activation is lower in Germany, causing aFRR providers to bid in high energy prices. This motivates German market participants to make low aFRR capacity bids to assure inclusion in the merit order.

A clear decrease in the average capacity price for the German aFRR auction and both FCR auctions since 2015 is visible, indicating a growingly competitive market. During Christmas period in 2015 and 2016 the average German aFRR capacity price peaked, which are the consequence of higher contracted volumes during this period. The lower average capacity price from 2016 onwards in the Dutch aFRR market is caused by a change in market design. Before 2016, Dutch aFRR capacity was only contracted through yearly auctions, but since 2016 this happens through quarterly (50%, until July 2017), monthly (50%, since July 2017) and yearly (50%) auctions. This demands shorter commitment from aFRR providers and thus results in lower average capacity prices.

The competitiveness of different markets can be analysed by looking at the difference between the maximum and average accepted capacity price, as high convergence between the maximum and average price indicates that market participants bid similar prices. 37, shows this difference for aFRR in Germany and FCR in Germany and the Netherlands. For all other products, only the average accepted capacity prices are published.

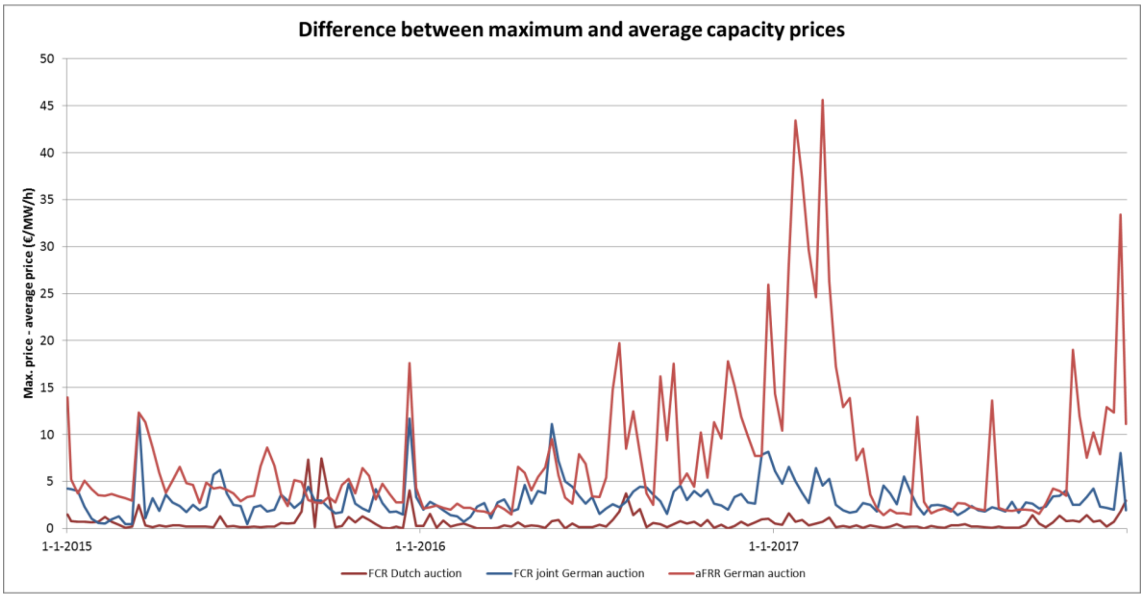


Figure 23 - Difference between maximum and average accepted capacity prices in the Netherlands and Germany.
Source: Regelleistung.net

Different trends can be observed. First of all, it shows that the difference between the average and maximum FCR price of the joint German auction has is relatively low. This might indicate that the market is mature and competitive. This competitiveness is even higher in the Dutch FCR auction, where the difference between the maximum and average capacity price is often close to 0. Remarkable is the high difference between the maximum and average German aFRR capacity price at the end of 2016 and the beginning of 2017, which was in some occasions higher than the highest accepted FCR bid. This could indicate that the competition between suppliers of aFRR capacity is limited. A detailed analysis of this peak is performed in Appendix II.

7. Balancing market developments

The previous two chapters mostly focussed activated balancing products, and their corresponding volumes and prices. However, information about non-activated balancing bids, as well as the composition of the balancing markets, is also relevant for market participants, as it provides them with insight in the level of competition in the different balancing markets and the opportunities for entering these markets. For this reason, the market revenue in the different balancing markets, as well as the aFRR merit order will be studied.

7.1. Market revenue in balancing markets

Figure 24 and 25 show money earned by market participants in respectively for FCR, aFRR and mFRR in respectively the Netherlands and Germany.

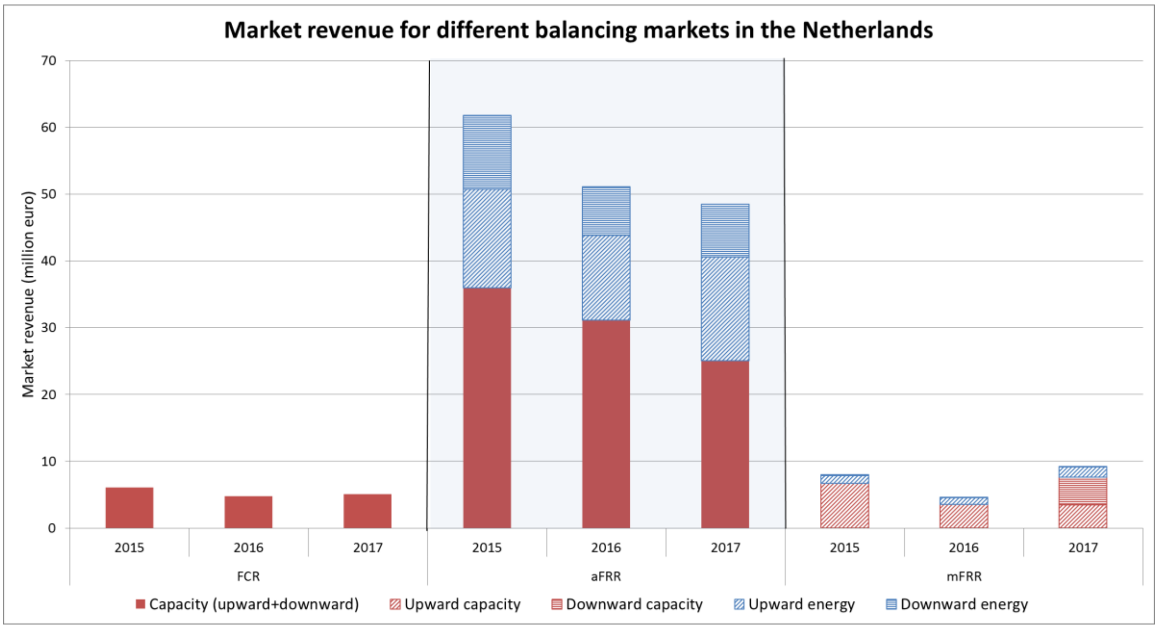


Figure 24 - Market revenue for different balancing markets in the Netherlands.
Source: TenneT NL, ENTSO-E Transparency Platform, EPEX Spot, Regelleistung.net

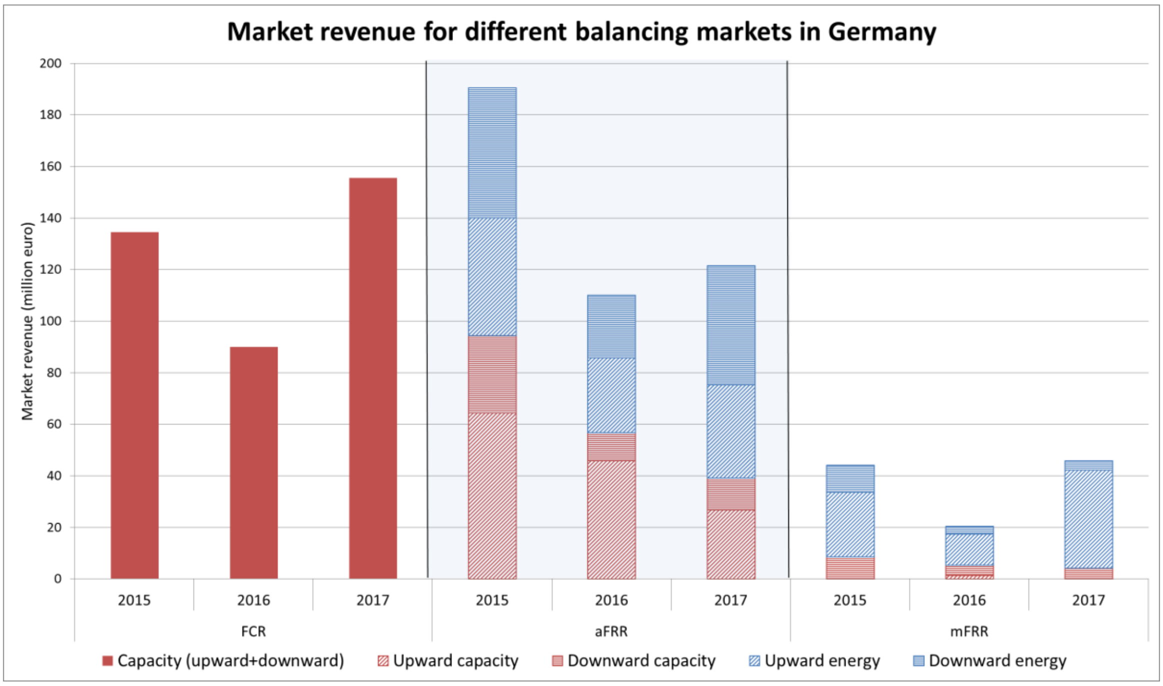


Figure 25 - Market revenue for different balancing markets in Germany.
Source: ENTSO-E Transparency Platform, EPEX Spot, Regelleistung.net

A significant difference between the Netherlands and Germany is the contribution of the FCR market in the total revenue by market participants in all balancing markets. While the FCR market is the smallest market in the Netherlands, the FCR market was the biggest market in Germany in 2017. This is caused by the fact that FCR capacity for surrounding countries is contracted in the German FCR auction.

In both the Netherlands and Germany the aFRR market is responsible for a large share of the total profit in all balancing markets, as aFRR is used relatively often and for a relatively long time period compared to the other balancing products. In comparison to the money made in the aFRR market, the money made in the mFRR market is relatively bigger in Germany. This is caused by the higher mFRR activation volumes in Germany.

Market participants receive a large their balancing revenue by offering capacity. In the Netherlands and Germany this share is around 50% for aFRR, while it is 100% of the money received for FCR by market participants as FCR providers do not receive an energy remuneration. Due to the low mFRR activation levels in the Netherlands, most of the money received by market participants for mFRR is for offering capacity. In contrast, most of the money made by German mFRR providers is for mFRR activation. This is caused by the higher mFRR activation levels, together with the low mFRR capacity prices offered to assure inclusion in the mFRR merit order, as described in section 6.2.

7.2. aFRR merit order developments

Information on the merit order for balancing energy bids provides potential future market participants with insight in the level of competition and market potential in the different balancing markets. As the aFRR merit order is the most frequently used merit order for balancing energy bids, this merit order will be examined in detail.

Whereas the German aFRR merit order only consists of contracted market participants, non-contracted market participants can also be included in the Dutch aFRR merit order. The Dutch aFRR merit order size therefore fluctuates every ISP, while the merit order size in Germany remains relatively constant. For this reason, Figure 26 shows the monthly average aFRR merit order size in the Netherlands.

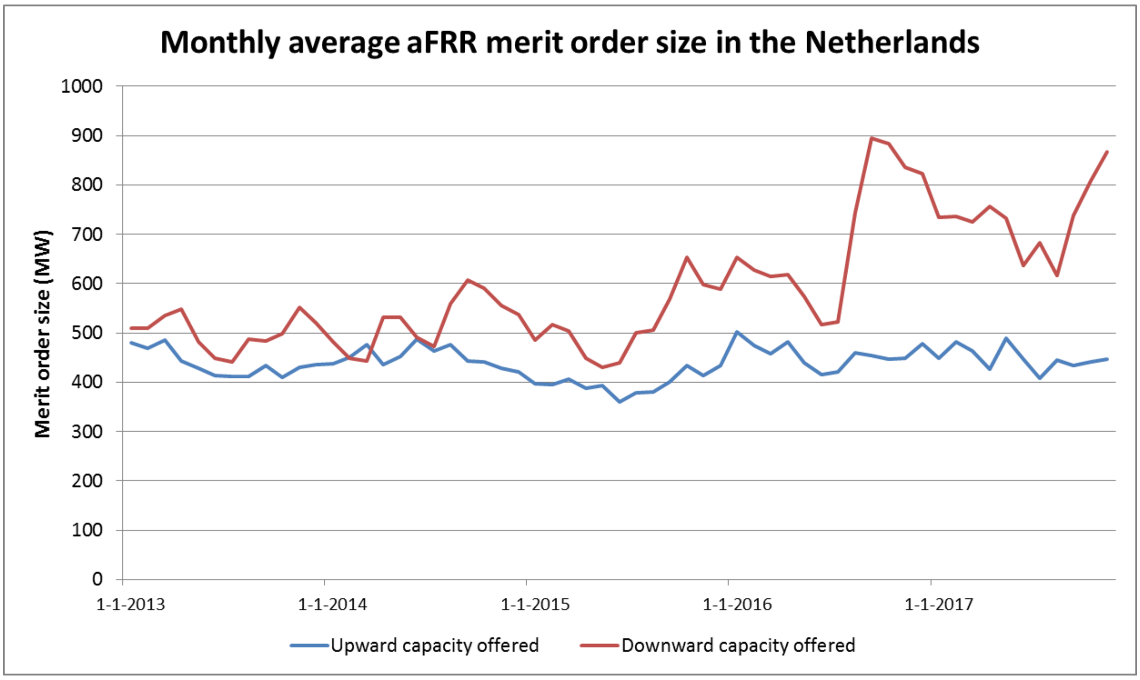


Figure 26 - Monthly average aFRR merit order size.
Source: TenneT NL

The figure also shows that the downward aFRR merit order size is bigger than the upward merit order size in the Netherlands, just like **Fout! Verwijzingsbron niet gevonden.**. The upward merit order size remained relatively constant since 2013, while the downward merit order size has grown significantly in 2017, indicating that multiple market participants have joined this market.

Figure 27 & 28 show the average, maximum and 95% percentile aFRR merit order activation levels per month in the Netherlands and Germany. This gives insight in whether the merit order size in these countries is sufficiently large.

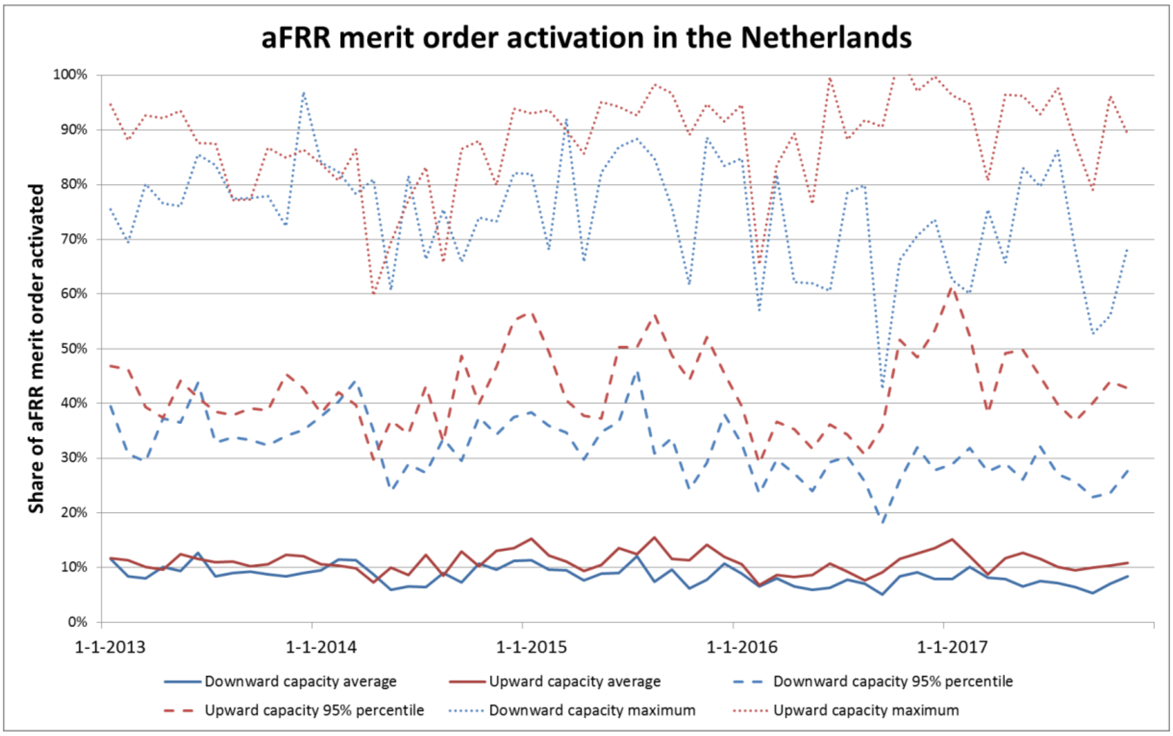


Figure 27 - Share of aFRR merit order activated in the Netherlands
Source: TenneT NL

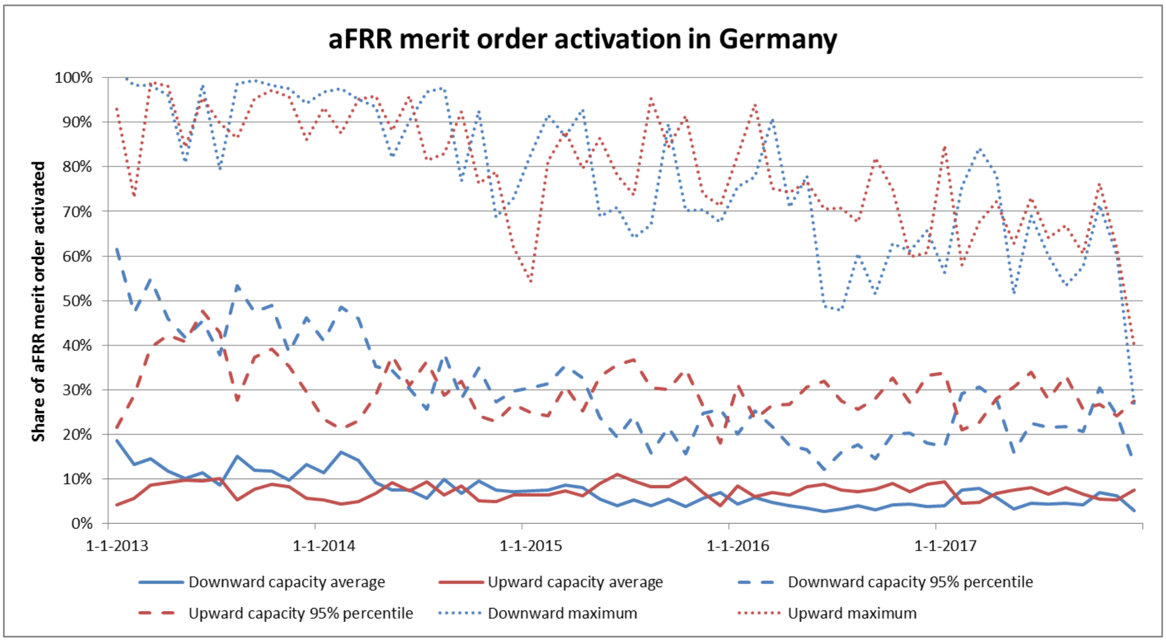


Figure 28 – Share of aFRR merit order activated in Germany
Source: ENTSO-E Transparency Platform, Regelleistung.net

Figure 27 shows that the average aFRR merit order activation in the Netherlands is relatively low; around 10%, and that in all months the activation levels were 95% of the time below 60%. However, in some months the aFRR upward activation levels were for one or more ISPs just below or equal to 100%, indicating that in such situations the upward aFRR merit order is tight. This is less an issue for the downward aFRR merit order, mainly due to the larger merit order size since the end of 2016.

In contrast to the Netherlands, the aFRR merit order list has become less tight in Germany, as shown in Figure 28. There are two likely explanations for this development. First of all, the German imbalance volumes have decreased, which requires less aFRR activation. Secondly, German operators activate mFRR at lower imbalance volumes, which reduces the aFRR activation levels and thus reduces the tightness in the German aFRR merit order.

7.3. Market composition

German providers of balancing energy must be prequalified to proof they are able to provide balancing energy. Figure 29 gives insight in the technologies that are active in the different balancing markets in Germany. In the Netherlands, the fuel type is not registered when prequalifying power plants.

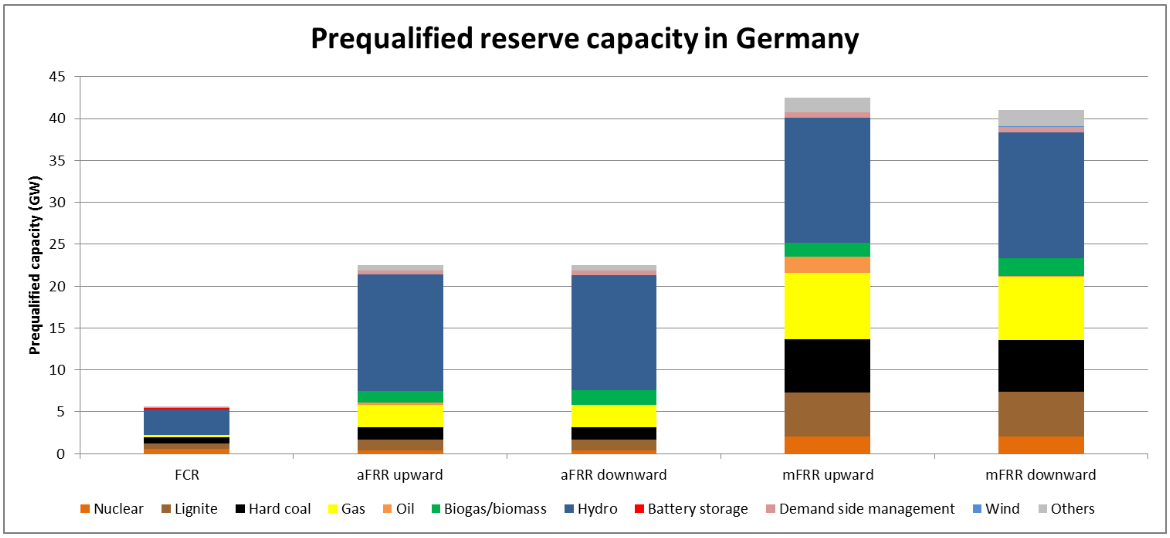


Figure 29 - Prequalified reserve capacity in Germany - reference date November 2017. Source: Regelleistung.net

The prequalified capacity is highest for mFRR and lowest for FCR, as FCR has the most stringent technical requirements, followed by aFRR. It is visible that hydro power plants are responsible for the majority of the prequalified capacity in Germany, mainly due to their quick reaction time. Although the installed lignite capacity and hard coal capacity in Germany is higher than the installed natural gas capacity, the natural gas prequalified reserve capacity is larger than the lignite and hard coal prequalified capacity, mainly caused by the higher flexibility of natural plants.

It is also visible in Figure 29 that batteries are prequalified for providing FCR. This is a recent development, which could significantly affect the balancing markets. Figure 30 shows that the battery market is emerging in Germany, in particular the installed lithium-ion capacity.

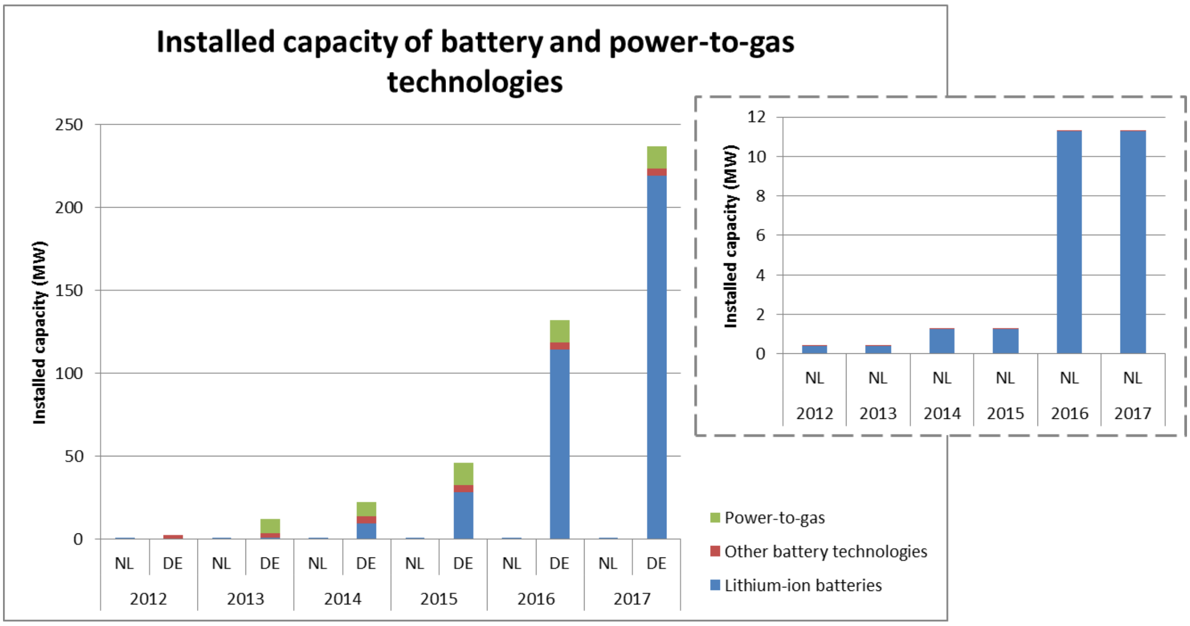


Figure 30 - Installed capacity of battery and power-to-gas technologies in Germany and the Netherlands (zoom in on the Netherlands).
Source: DOE Global Energy Storage Database

The installed capacity has increased from below 1 MW in 2012 to over 219 MW in 2017, mainly induced by the cost reductions and technical improvements made in lithium-ion batteries (Bromgren, 2017). Storage lobby parties in Germany expect this growth to continue, to an expected installed capacity of 700 MW at the end of 2018 (Franke, 2018). The battery market in the Netherlands is much less developed; the only large battery system in the Netherlands is the 10 MW AES battery in the province of Zeeland.

8. Contributors to system imbalance

In this section, the contribution of factors which could influence the system imbalance is studied. The development of each of the possible contributors between 2015 and 2017 is displayed, after which the correlation with system imbalance will be studied.

8.1. Installed variable renewable capacity

Due to the intermittency of variable renewable generation, a higher installed variable renewable capacity could lead to more forecast errors, possible resulting in higher imbalance volumes.

Figure 31 & 32 show the installed variable renewable capacity in the Netherlands and Germany respectively.

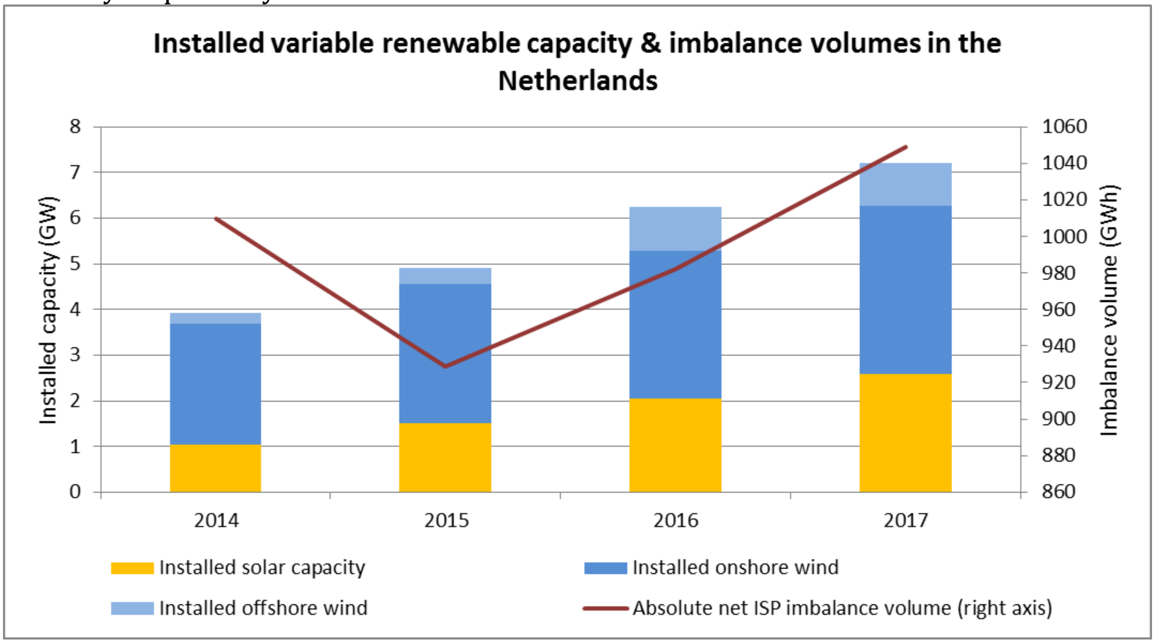


Figure 31 - Installed variable renewable capacity and imbalance volumes in the Netherlands Source: Nationale Energieverkenning, TenneT NL

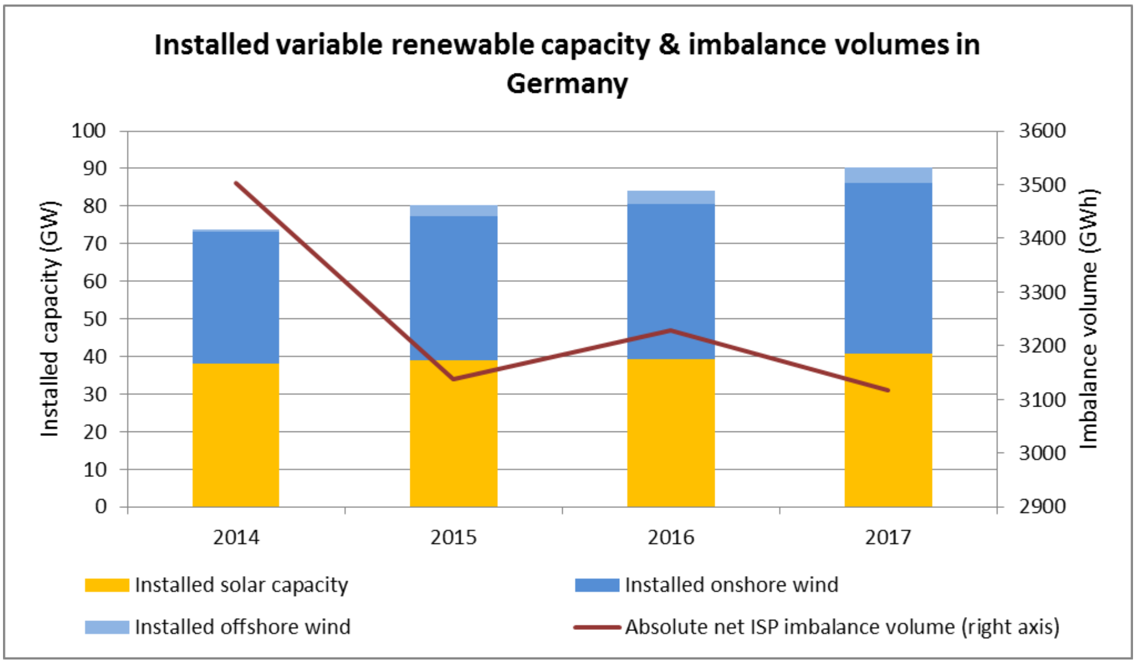


Figure 32 - Installed variable renewable capacity and imbalance volumes in Germany Source: BNetZA, ENTSO-E Transparency Platform

It is visible that the installed VRES capacity in both the Netherlands and Germany is growing, but that the Dutch VRES capacity is growing at a relatively faster rate than in Germany. This is mainly induced by the fact that Germany already had a relatively much higher installed VRES capacity in 2012, which makes fast growth harder. The share of solar in the total VRES capacity is higher in Germany compared to the Netherlands, mostly caused by more beneficial weather conditions for solar generation in southern Germany. Offshore wind in the Netherlands has grown significantly since 2012, and this growth will continue when the planned offshore wind farms by the Dutch government will be realized (Wiebes, 2018).

Next to the installed VRES capacity, the figures also show the development of the absolute imbalance volumes[4]. In the Netherlands, the imbalance volumes have risen continuously since 2015, together with a rising installed VRES capacity. However, imbalance volumes decreased between 2014 and 2015, while the VRES capacity increased in this year. In Germany, a very different trend is visible. The imbalance volumes have almost continuously decreased since 2014, while the VRES capacity has increased. These developments together indicate that a higher VRES capacity does not automatically result in higher imbalance volumes.

8.2. Variable renewable generation

A slight change in weather conditions can already significantly affect the power output of variable renewable energy systems (VRES). This sometimes results in quick ramp rates of the power output, making VRES generation hard to predict. Therefore, high VRES generation volumes could possibly lead to higher imbalance volumes, as the chance of sudden changes in power output is higher if VRES generation is higher.

[4] As described in the methodology, the correlation between VRES capacity and imbalance volumes can only be studied on an annual basis, as the VRES capacity is only monitored on this timescale. Therefore, no statistical analyses were be used to study this correlation.

8.2.1. Development of variable renewable generation

The Dutch and German VRES generation volumes between 2015 and 2017 are displayed in Figure 33 & 34 respectively.

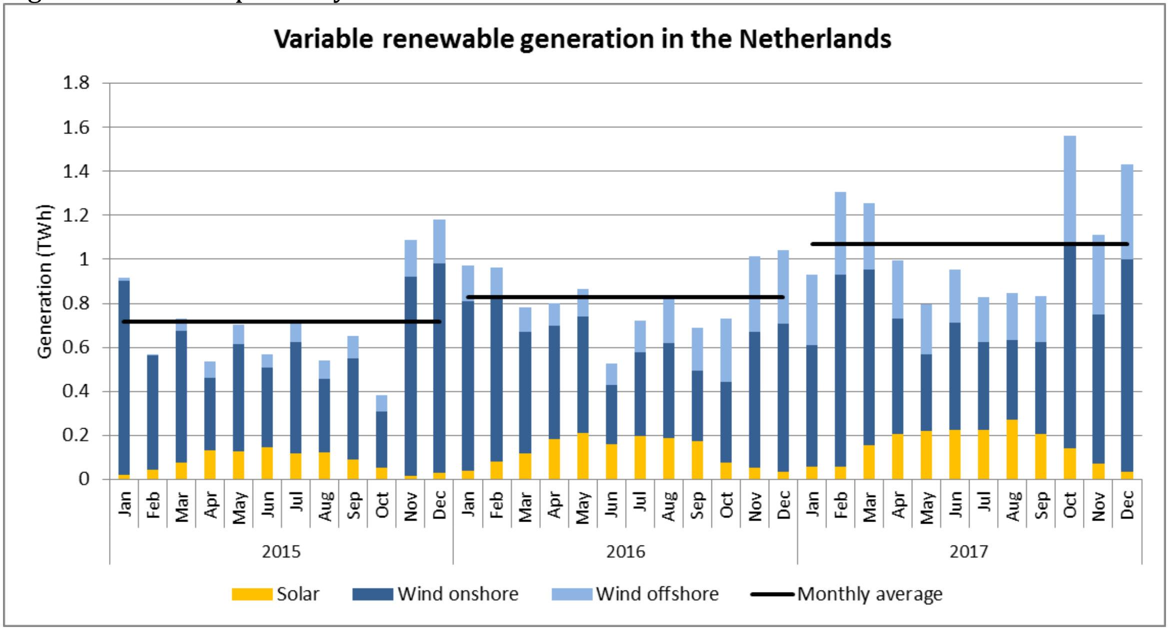


Figure 33 - Variable renewable generation in the Netherlands.
Source: ENTSO-E Transparency Platform

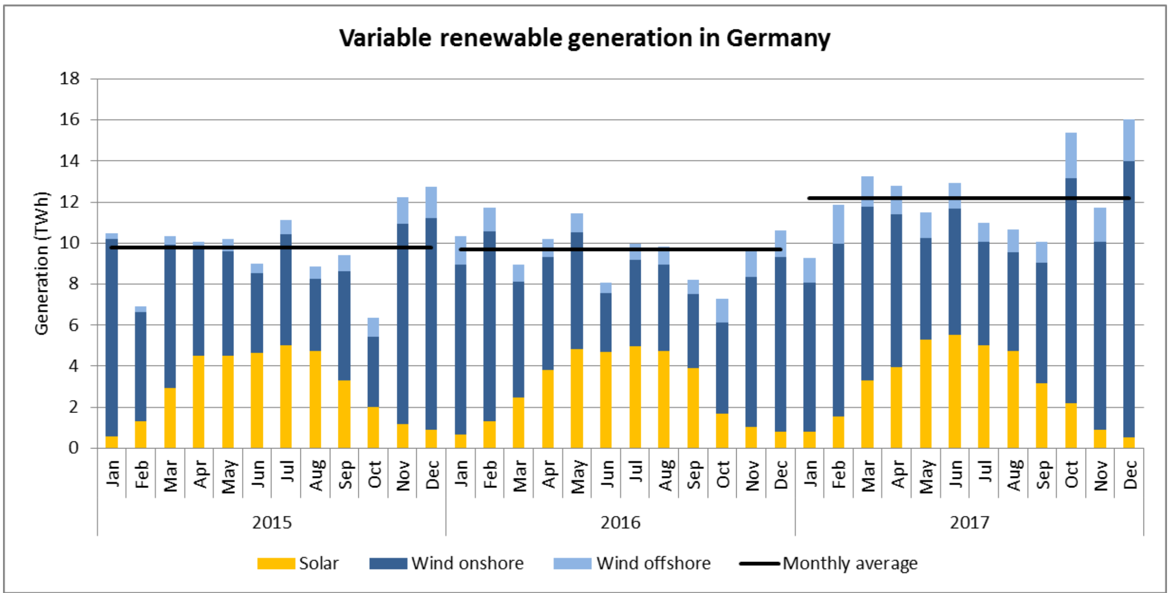


Figure 34 – Variable renewable generation in Germany.
Source: ENTSO-E Transparency Platform

It is visible that in both countries, the VRES generation volumes are higher in 2017 compared to 2015, in line with the increase in installed VRES capacity. However, the impact of weather conditions on the VRES output is visible in Germany; although the installed VRES capacity increased between 2015 and 2016, the VRES generation did not increase.

The share of solar generation in the total VRES generation is larger in Germany compared to the Netherlands, caused by a higher installed capacity and sunnier weather conditions in Germany. The offshore wind generation volumes increased significantly between 2015 and

2017 in the Netherlands, caused by the realisation of new offshore wind farms (Gemini in 2017), and the high number of full load hours of offshore wind turbines.

8.2.2. Relationship between variable renewable generation and system imbalance

As discussed in the methodology (section 4.2.2), the correlation between variable renewable generation and system imbalance will be studied using absolute imbalance data on a 15-minute scale, for both Germany and the Netherlands for 2015-2017 and 2017 only using a linear, quadratic and cubic regression. The results are displayed in Figure 37.

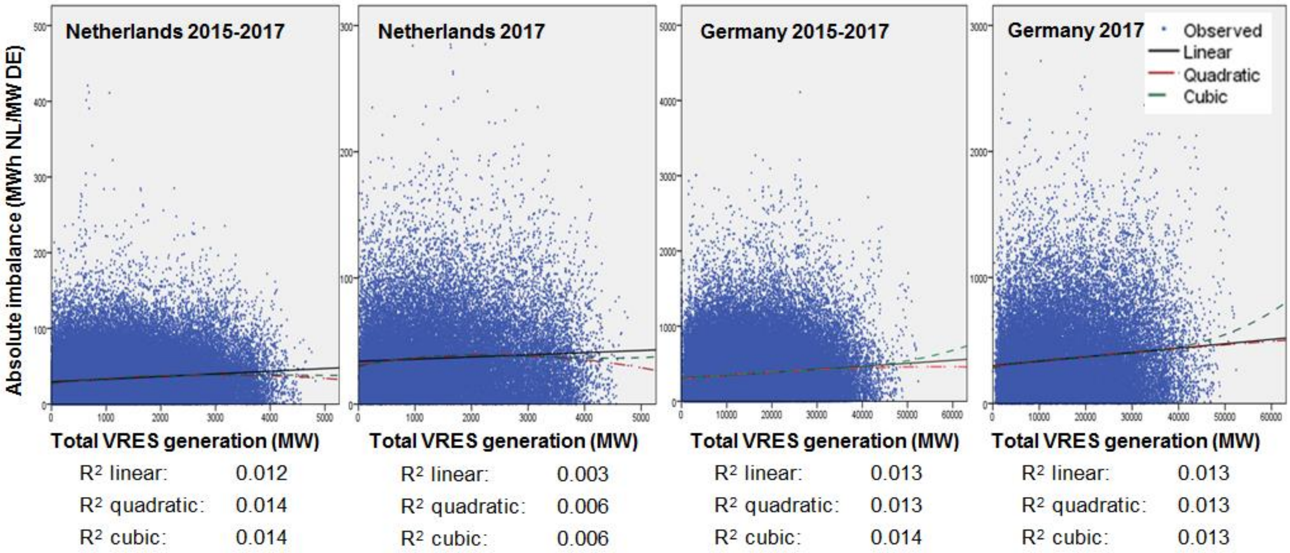


Figure 35 - Relationship between Total Variable Renewable Energy System (VRES) generation and absolute imbalance volumes per ISP in Germany and the Netherlands. Significance for all trend lines <0.000.
Source: TenneT NL, Regelleistung.net, ENTSO-E Transparency Platform

All trend lines (linear, quadratic and cubic) in Figure 37 follow a similar trend; they move relatively linear upwards. This means that higher renewable generation results in higher absolute imbalance volumes.

However, these trends show a weak correlation. The R^2 value is highest for the Netherlands using 2015-2017 data, but this R^2 value of 0.014 indicates that variable renewable generation can only account for 1.4% of the deviations in the imbalance volumes. The maximum R^2 value of 0.006 indicates that this correlation in the Netherlands is even lower in 2017 compared to the years before. The differences between the correlation values for Germany and the Netherlands are low. The correlation analyses have also been performed using non-absolute imbalance volume in Appendix III. Also these R^2 values were low.

When zooming in on the relationship between generation volumes of specific VRES and imbalance volumes in Figure 38 on page 50, a similar trend is visible; all trend lines show a relatively linear upward trend, but the correlation is weak. This correlation is strongest for onshore wind, indicating that onshore wind generation has more impact on imbalance volumes than solar and offshore wind generation. One possible explanation for this phenomenon is the fact that onshore wind is responsible for the majority of VRES generation in the Netherlands and Germany. However, also onshore wind is only a minor contributor to imbalance volumes, with a maximum R^2 value of 0.019. There are no clear differences between the Netherlands and Germany visible.

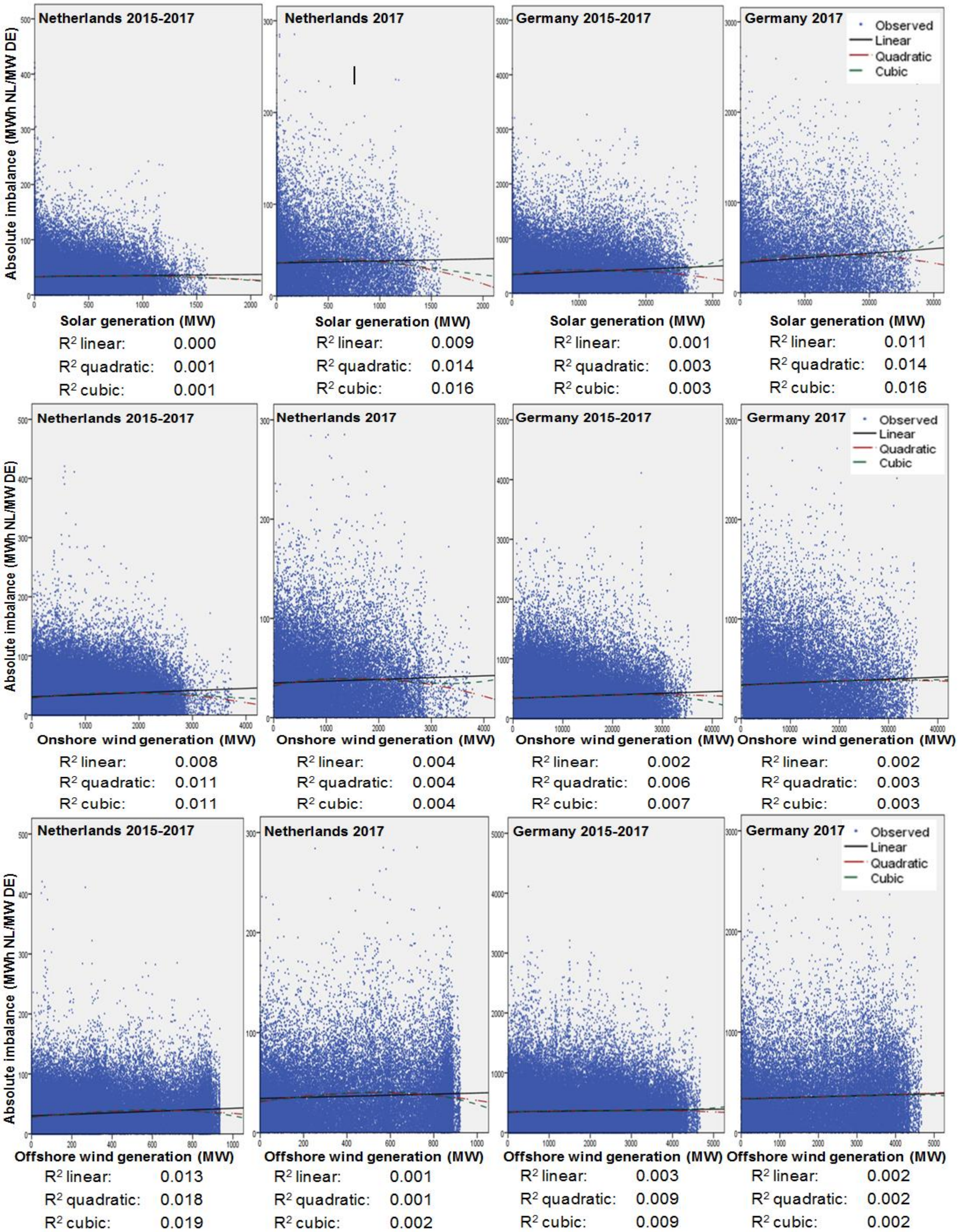


Figure 36 - Relationship between solar, onshore wind and offshore wind generation and (absolute) imbalance volumes per ISP in Germany and the Netherlands. Significance for all trend lines <0.000.
Source: TenneT NL, Regelleistung.net, ENTSO-E Transparency Platform

8.3. Generation and load

Next to variable renewable energy sources, conventional power plants could also be a source of imbalance. In case of an unexpected plant outage, inaccurate measurement of the power output or unexpected behaviour of generators connected to a BRP, the generation schedule sent to the TSO by a BRP could deviate from its actual generation. The same applies to the load; a discrepancy between the expected load and the actual load can occur because of unexpected behaviour of customers connected to a BRP, which results in a deviation from the trading schedule of the BRP. Therefore, total generation and load could be other possible contributors to imbalance volumes.

8.3.1. Development of total generation and load

The Dutch generation and load is displayed on a yearly basis in Figure 37.

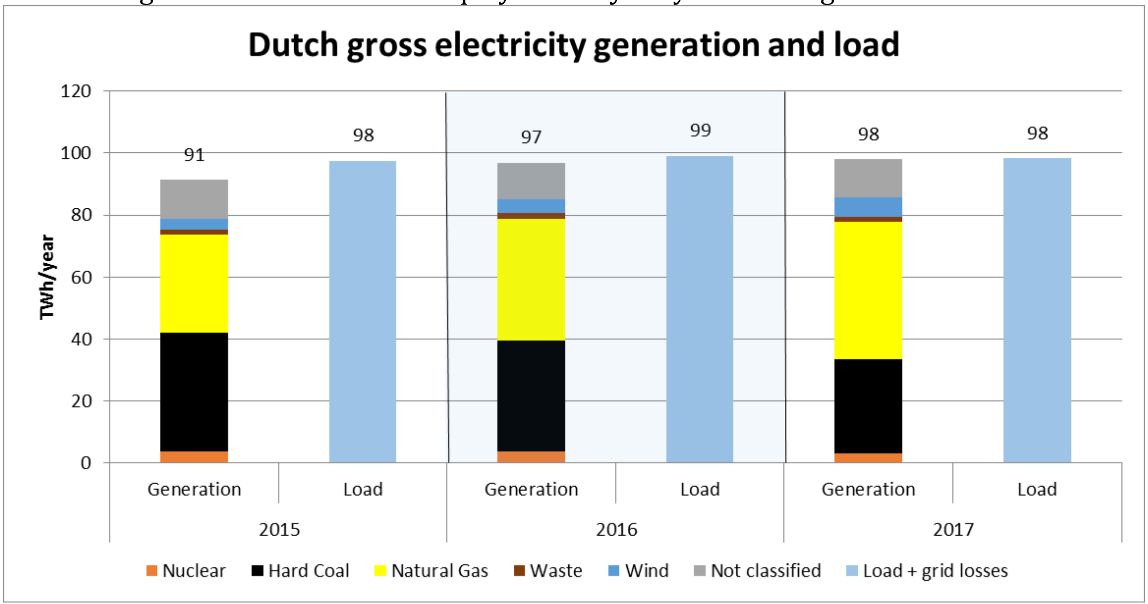


Figure 37 - Gross electricity generation and load in the Netherlands.[5] Source: TenneT NL

It is visible that the generation in the Netherlands has increased significantly since 2015. This is mainly triggered by a higher profitability of power plants in the Netherlands, as can be read in the TenneT Market Review 2017. The share of different fuel types in the total electricity generation has changed considerably. Generation from hard coal has decreased considerably from 38 TWh in 2015 to 30 TWh in 2017, which was mainly caused by the closure of the four coal power plants (Amer, Borssele, Gelderland and Maasvlakte), as agreed upon in the Energy Agreement on Sustainable Growth. The lower coal generation has been mainly taken over by natural gas plants, of which the generation volumes rose from 32 TWh in 2015 to 44 TWh in 2017. Wind generation doubled from 3.2 TWh in 2015 to 6.4 TWh in 2017, caused by a higher installed wind capacity and beneficial weather conditions in 2017.

The load remained relatively constant between 2015 and 2017. It is visible that the difference between the load and generation volumes decreased over time, indicating that the net importing position of the Netherlands has decreased.

Figure 38 shows the generation, load and imports/exports on a monthly basis.

[5] The generation and load values represent the infeed and withdrawals measured on the TenneT grid. Unclassified generation consists of generation from units with a capacity lower than 10 MW.

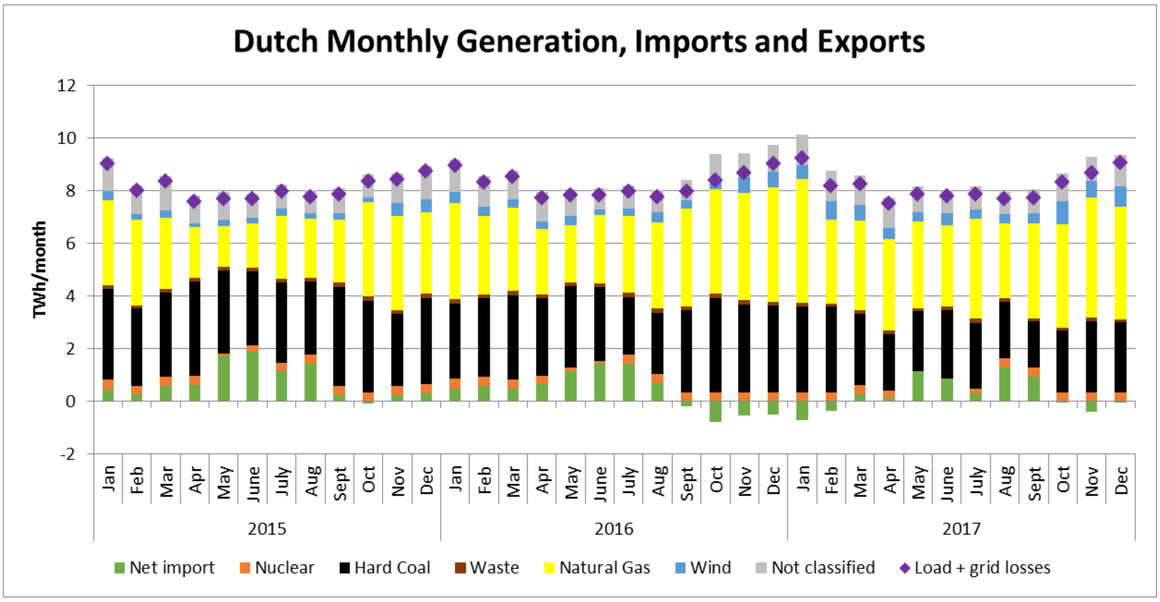


Figure 38 - Monthly electricity generation, imports/exports and load in the Netherlands. Source: TenneT NL

A few trends are visible. Load is higher in winter, caused by higher electricity consumption with low temperatures induced by among others electric heating systems. It is also visible that the imports are lower in winter months (in some occasions even exports). Countries like France have a very high share of electric heating systems, causing that demand peaks with low temperatures. The increase in demand resulted in a tight market situation, resulting in high prices. This resulted in higher Dutch generation volumes, to serve the French market.

In particular generation from natural gas increased in winter months. This is induced by a higher profit margin for natural gas generation in these months, caused by higher electricity prices. Although profit margin for coal plants also increases with higher electricity prices during winter months, coal generation only increased slightly as coal plants generally operate at full capacity throughout the year.

Similarly, the German generation volumes and load are depicted in Figure 39.

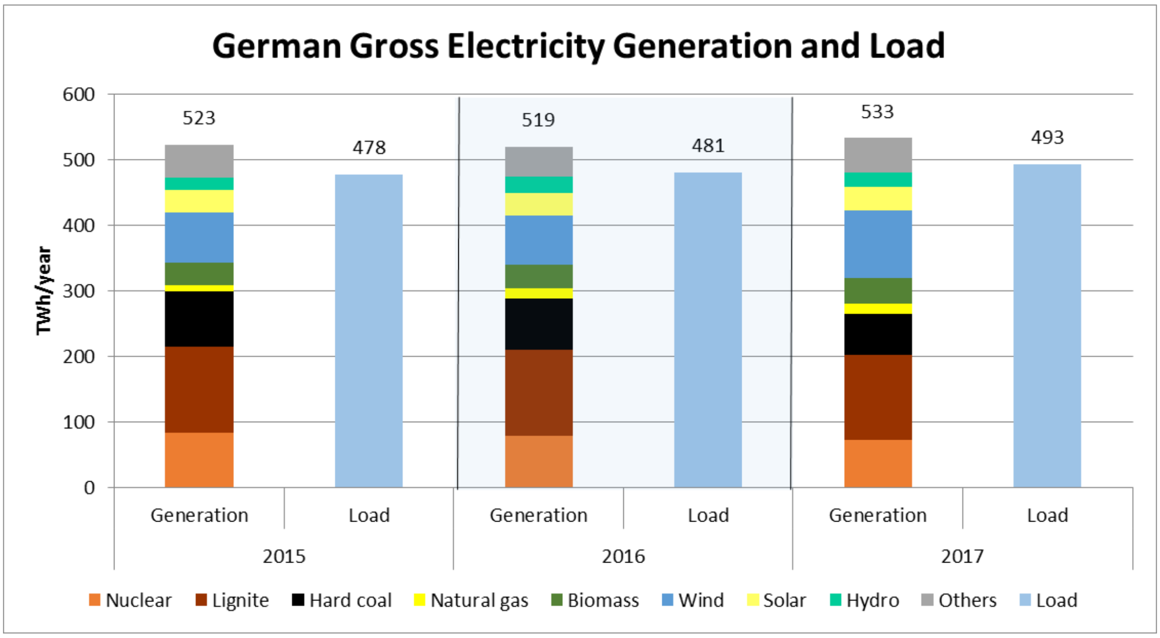


Figure 39 - Gross electricity generation and load in Germany. Source: SMARD, BNetzA

The load increased between 2015 and 2017, while the generation decreased between 2015 and 2016 but increased from 2016 to 2017. The large difference between the generation and load underlines that Germany has a big exporting position. This is caused by low prices in Germany, induced by the large share of renewables in Germany.

As previously described, renewable generation has increased significantly. In 2017, wind became the largest electricity source after lignite, surpassing hard coal and nuclear. In particular the hard coal generation decreased in Germany, as different coal plants were phased out of the market between 2015 and 2017.

The monthly generation pattern in Germany is similar compared to the Netherlands, as depicted in Figure 40.

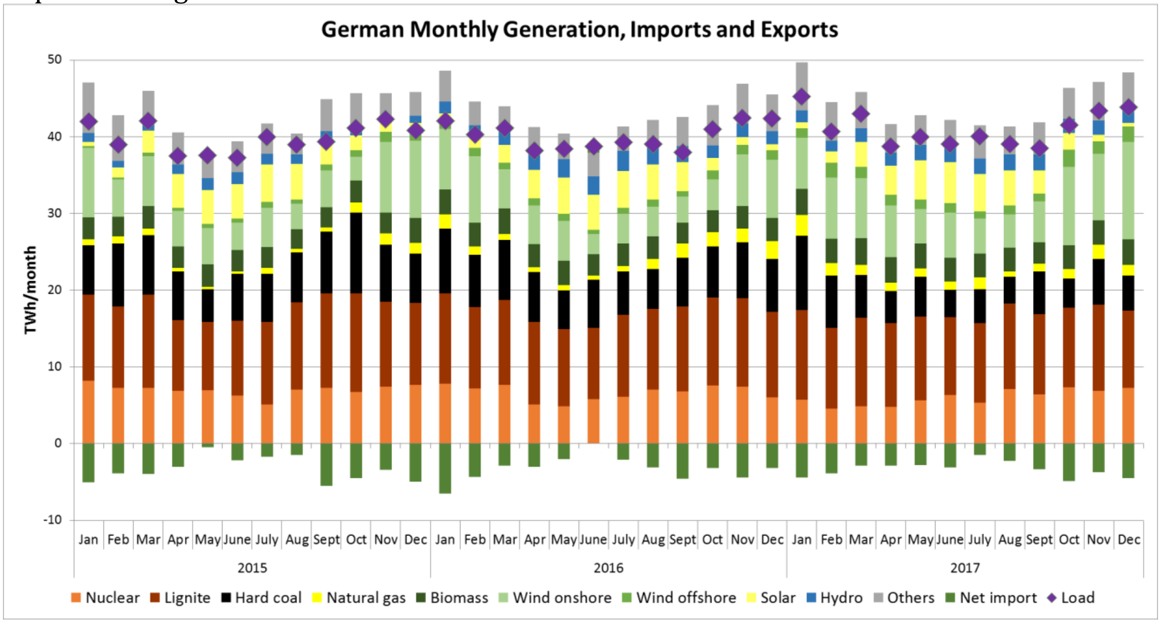


Figure 40 - Monthly electricity generation, import/exports and load in Germany. Source: SMARD, BNetzA.

Generation is higher in winter to meet the higher domestic demand with low temperatures, but also to serve the French market which has a more temperature-sensitive load profile. Different than in the Netherlands, a change in total generation especially comes from a change in hard coal generation, indicating that hard coal plants in Germany still have the flexibility to ramp up or ramp down.

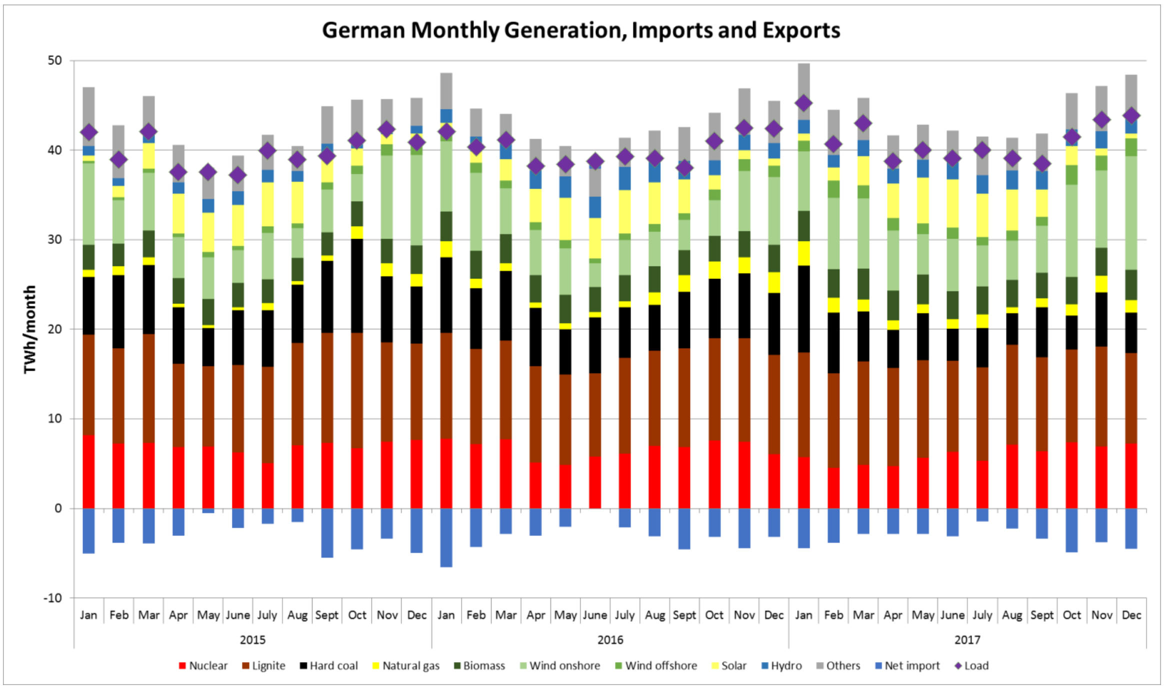


Figure 41 - Monthly electricity generation, import/exports and load in Germany. Source: SMARD, BNetzA.

8.3.2. Relationship between generation/load and system imbalance

Figure 42 shows the relationship between total generation volumes and imbalance volumes in the Netherlands and Germany.

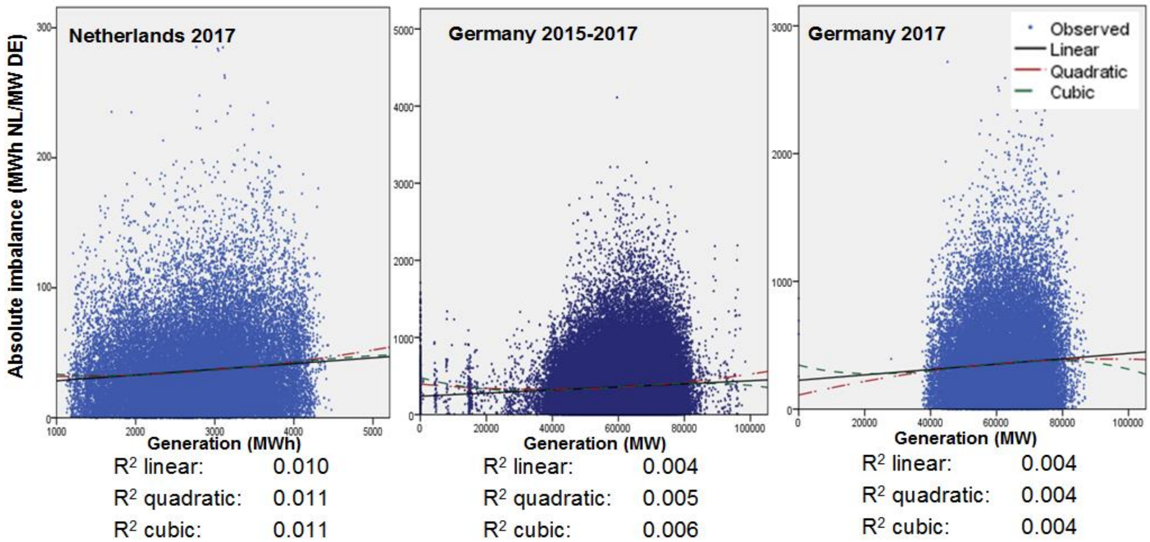


Figure 42 - Generation volumes versus absolute imbalance volumes per ISP in the Netherlands (2017)[6] and Germany (2015-2017, 2017). Significance for all trend lines <0.000
Source: TenneT NL, Regelleistung.net; ENTSO-E Transparency Platform

The trend line shows a positive relationship between generation volumes and absolute imbalance volumes for both the Netherlands and Germany; higher generation volumes generally result in higher imbalance volumes. This is in line with expectations; the chance of forecast errors is higher when generation volumes are higher.

Nonetheless, the correlation between generation and absolute imbalance volumes is poor; the highest R^2 is 0.011 for the Netherlands. The R^2 values in Germany are even lower, with a maximum R^2 value of 0.006. This low correlation is also visible in the Figure 42; the data points are widely scattered around the trend lines.

Similarly, the correlation between load and imbalance volumes in Germany and the Netherlands is displayed in Figure 43.

[6] 15-minute generation data for the Netherlands is only available for 2017. Therefore, 2015 and 2016 were not included in this analysis.

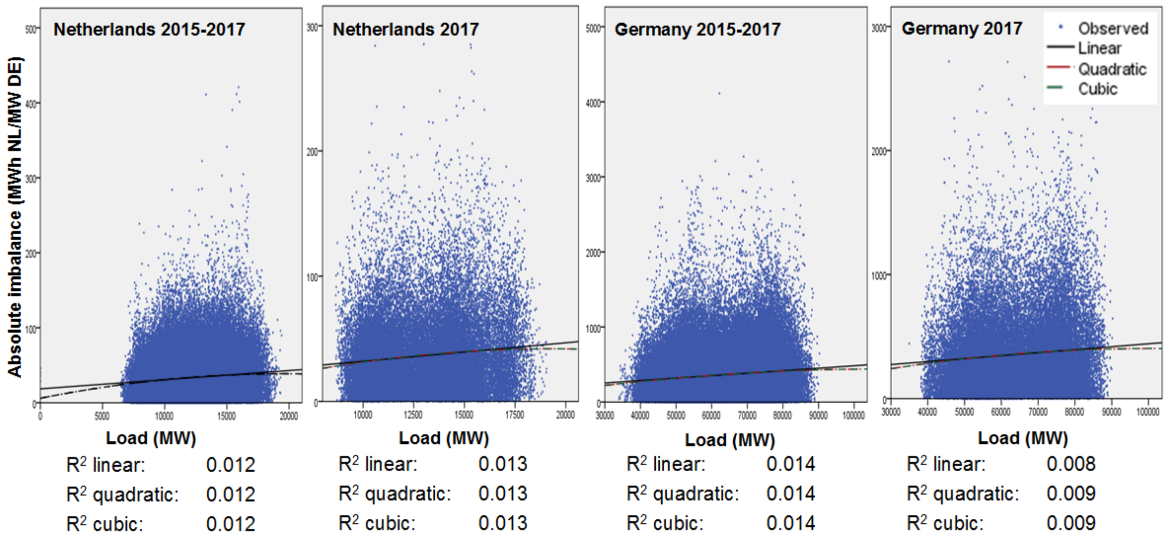


Figure 43 - Load versus absolute imbalance volumes per ISP in the Netherlands (2017) and Germany (2015-2017, 2017). Significance for all trend lines: <0.000
Source: TenneT NL, Regelleistung.net; ENTSO-E Transparency Platform

The trend lines in Figure 43 also show an upward trend for both the Netherlands and Germany; absolute imbalance volumes are higher with higher load. This is a possibly caused by a higher chance of load deviations with higher load.

Also the correlation between load and absolute imbalance volumes is far from strong; the maximum R^2 value is equal to 0.014. The correlation between load and absolute imbalance volumes in Germany is higher than the correlation between generation and absolute imbalance. There is no large difference between these correlations for the Netherlands.

The scatter plots with generation and load versus non-absolute imbalance volumes can be found in Appendix III. It is visible that the trend lines are more flat, and that correlation values are lower.

8.4. Variable renewable forecast errors

The low correlation between variable renewable capacity and generation and imbalance volumes indicated that the effect of variable renewable generation on imbalance volumes is limited. One explanation for this low correlation could be that the moments with high variable renewable generation are not the moments with the highest forecast errors. Therefore, high variable renewable forecast errors are possibly a better explanation for the high imbalance volumes.

Dutch and German TSOs publish day-ahead generation forecasts and actual generation for all variable renewable generation technologies on a 15-minute basis. The difference between the day-ahead generation forecast and the actual generation forecast gives insight in the forecast error. However, generation forecast of the TSO, which is based on weather forecasts, could be different from aggregated generation forecasts of BRPs, as they might use different methods or data sources when forecasting VRES generation.

8.4.1. Development of variable renewable forecast errors

The development of the average generation forecast error in case of overestimation (actual generation is lower than forecasted generation) and underestimation (actual generation is higher than forecasted generation) is depicted for respectively the Netherlands and Germany in Figure 44 & 45[7].

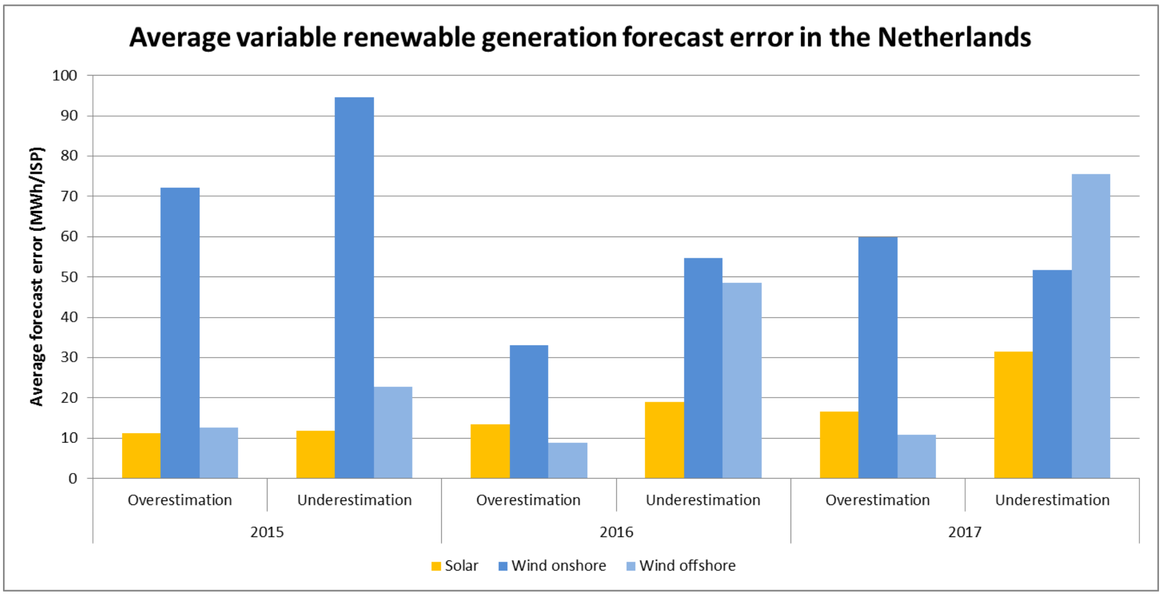


Figure 44 – Development of average renewable generation forecast error in the Netherlands. Source: ENTSO-E Transparency Platform

[7] Due to a high number of hours with no available data in 2015 and part of 2016, the sum of forecast errors could not be calculated.

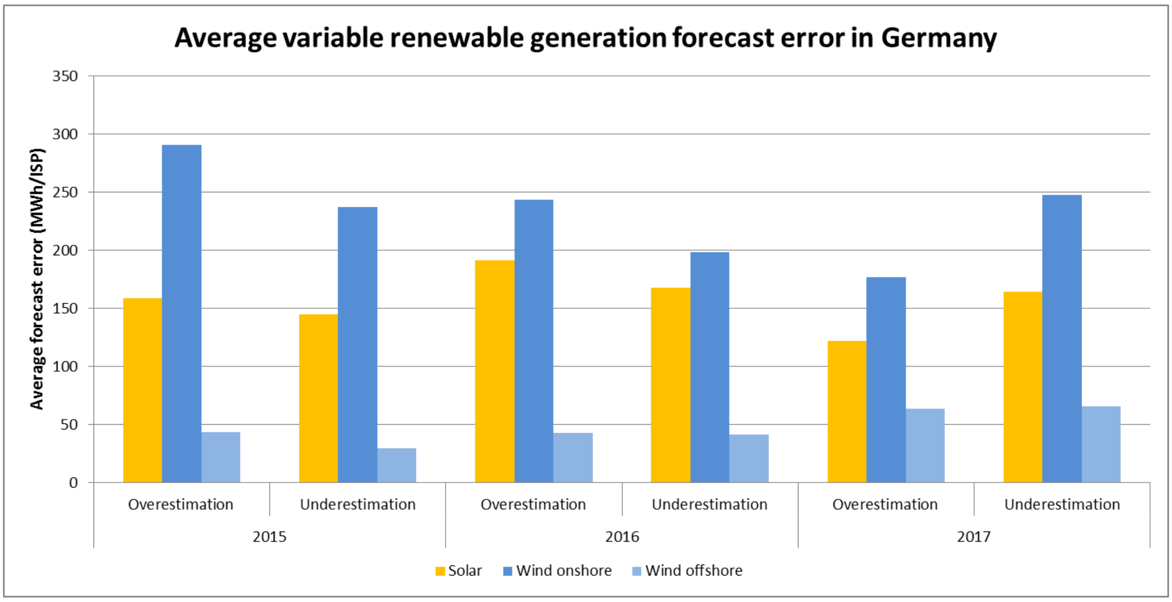


Figure 45 - Development of average renewable generation forecast error in Germany. Source: ENTSO-E Transparency Platform

Major differences between the Netherlands and Germany are observable. The solar forecast error is relatively much larger in Germany, as the share of solar generation in the total variable renewable generation in Germany is much larger. In addition, the forecast error for offshore wind is the largest contributor to the total VRES forecast error in the Netherlands in 2017, while it is only a minor contributor in Germany. This is caused by the relatively much larger installed offshore wind capacity in the Netherlands compared to Germany. The realisation of the Gemini wind farm in 2016 and 2017 caused the major increase in the offshore wind forecast error between 2015 and 2017 in the Netherlands. However, as onshore generation volumes in the Netherlands are still higher than offshore generation volumes, the average TSO forecast error for offshore generation is higher than the average forecast error for onshore generation.

For most technologies, there does not seem to be a systematic difference between the size of under- or overestimations in both Germany and the Netherlands, except for offshore wind in the Netherlands. The forecast error is significantly higher for offshore wind when there is an underestimation compared to an overestimation, implying that the generation forecast methods used for offshore wind tend to overestimate the generation.

8.4.2. Relationship between VRES generation forecast error and system imbalance

Figure 48 shows the correlation between VRES generation forecast error and non-absolute imbalance volumes per ISP.

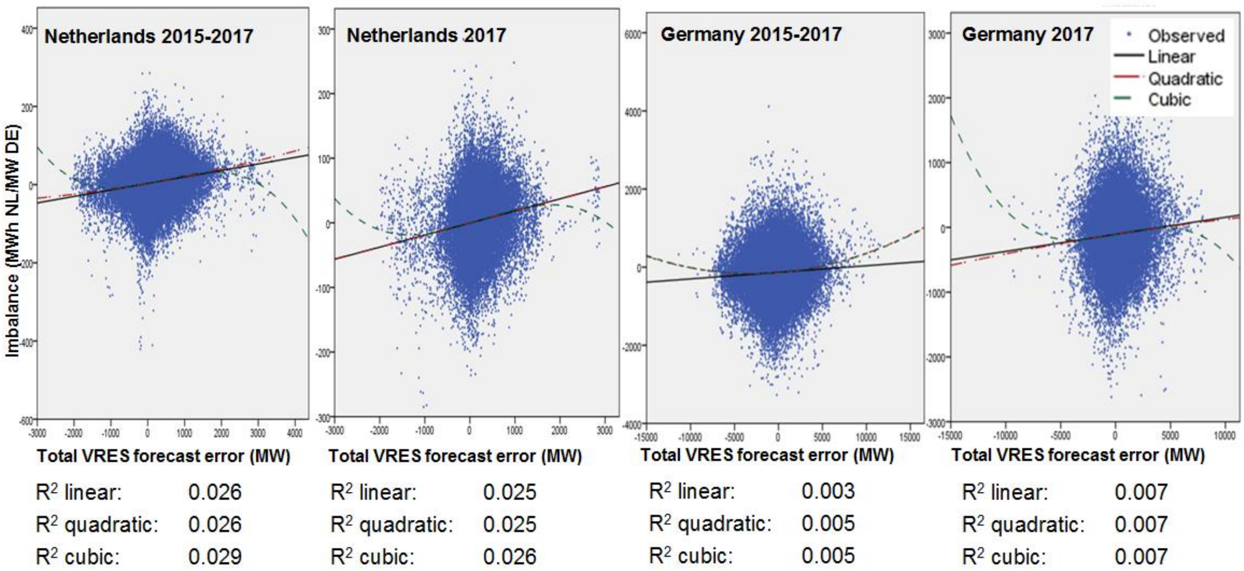


Figure 46 – Variable Renewable Energy System generation forecast error versus non-absolute imbalance volumes per ISP in the Netherlands and Germany. Significance for all trend lines <0.000
Source: TenneT NL, Regelleistung.net, ENTSO-E Transparency Platform

All trend lines show a rising trend. With negative forecast error values (overestimation of actual generation), there are generally more negative imbalance volumes (short system/imbalance shortage), while there are more positive imbalance volumes (long system/imbalance surplus) with positive forecast error values (underestimation of actual generation). This is in line with expectations; lower VRES generation than the forecasted generation results in a generation deficit and a short system. Similarly, underestimation of VRES generation results in a generation surplus and a long system.

The correlation values differ significantly between the Netherlands and Germany. The R^2 values with VRES forecast errors in the Netherlands are higher than the R^2 values of VRES generation volumes, which implies that the VRES forecast errors are better explanations for imbalance volumes than VRES generation volumes. Conversely, the R^2 values of VRES forecast errors are lower than these values for VRES generation volumes in Germany. However, the maximum R^2 value of 0.029 for the relationship between VRES forecast error and imbalance volumes is still far too low to talk about a strong correlation.

The relationship between forecast error of specific VRES technologies and imbalance volumes is portrayed in Figure 49 on page 60. It is visible that the trend line shows a rising trend in all figures, although the steepness differs among figures. The correlation is highest for onshore wind forecast errors in the Netherlands and Germany with 2015-2017 data. In all other cases, the correlation is negligibly low. This indicates that the onshore wind forecast error has the highest influence on imbalance volumes, but that this influence has decreased over the years.

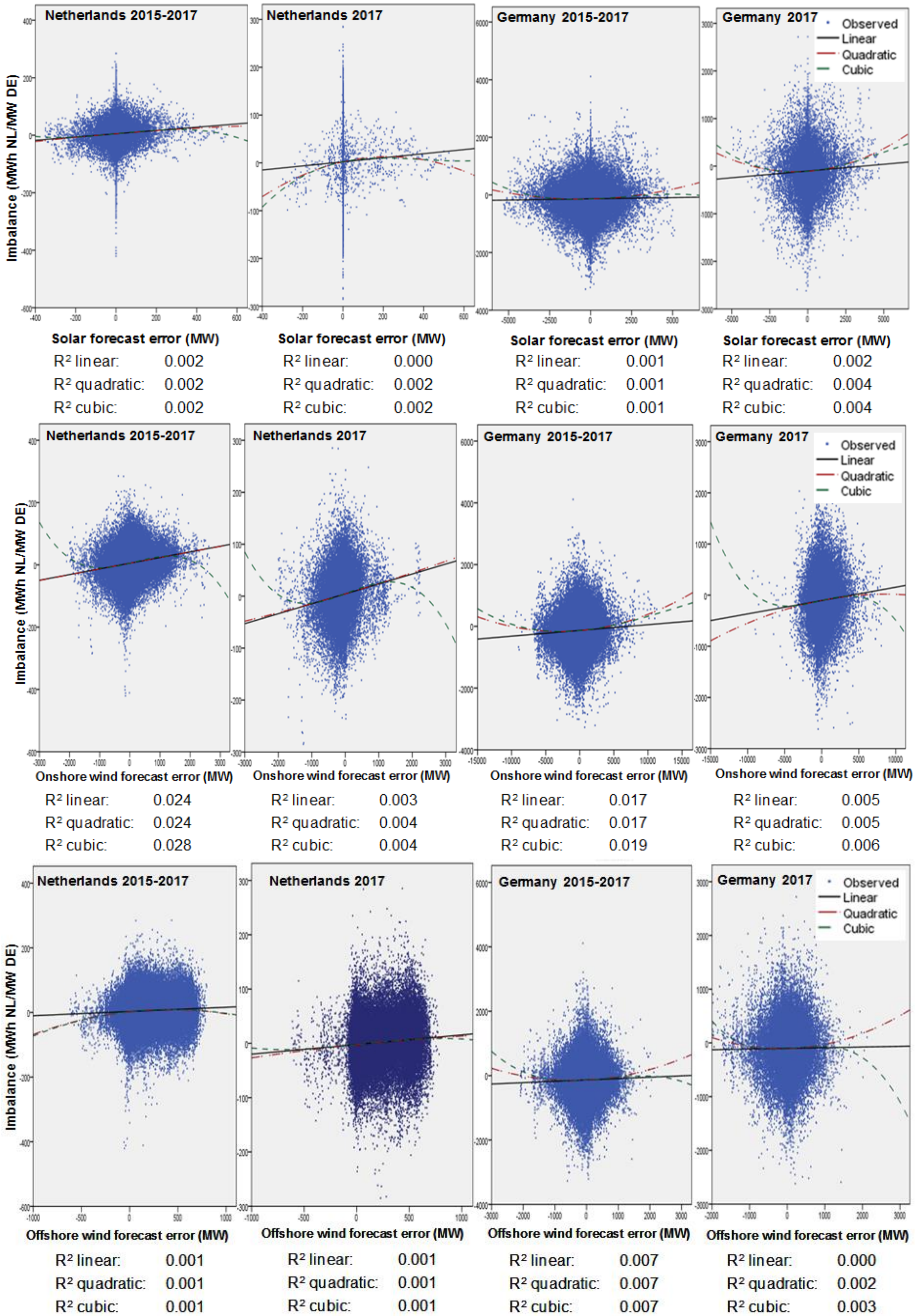


Figure 47 – Solar, onshore wind and offshore wind generation forecast error versus non-absolute imbalance volumes per ISP in the Netherlands and Germany. Significance for all trend lines <0.000. Source: TenneT NL, Regelleistung.net, ENTSO-E Transparency Platform

8.5. Generation and load forecast errors

The low correlation between generation and load could also be caused by a low correlation between forecast errors and generation volumes. Therefore, the effect of generation and load on imbalance will also be studied using forecast errors.

The TSO publishes day-ahead generation and consumption forecasts on a 15-minute basis, based on the realised generation and load on the same weekday in the three weeks before. The forecast published by the TSO is not equal to the BRP generation and consumption schedule, as the deviation between the actual generation/load and the BRP energy programmes sent to the TSO was too large. The deviation between the actual generation/load and forecasted generation/load by the TSO can therefore be seen as a proxy for the forecast error and can indicate unexpected generation/load volumes, for instance due to the tripping of a generator, but is not equal to the BRP forecast error.

8.5.1. Development of generation and load forecast errors

Figure 48 shows the development of the load forecast error in the Netherlands[8].

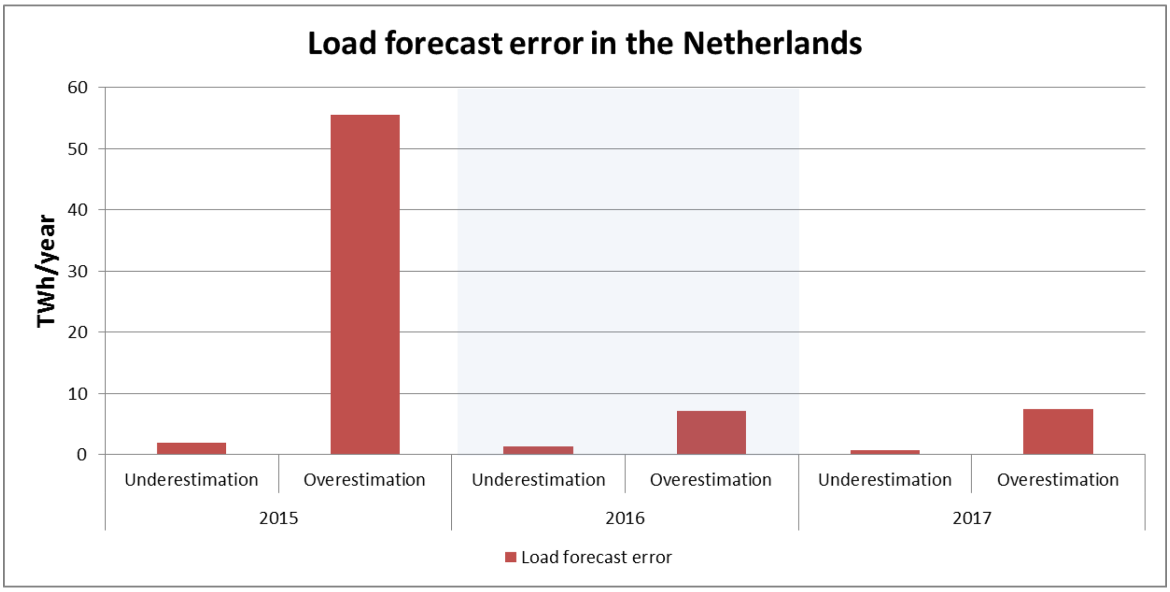


Figure 48 - Development of load forecast error in the Netherlands
Source: ENTSO-E Transparency Platform

It is visible that the load forecasts as published on ENTSO-E Transparency Platform generally overestimate the actual load. This overestimation was immense in 2015. Since 2015, the forecasts have improved and the forecast errors have reduced. However, load forecasts still tend to overestimate the actual load.

Figure 49 shows the total generation and load forecast error in Germany.

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[8] It was not possible to determine the generation forecast errors for the Netherlands, as the Dutch generation volumes are not, like the generation forecasts, published on ENTSO-E Transparency Platform. The discrepancy between internal TenneT generation data (which does not contain all grid connections in the Netherlands) and generation forecasts on ENTSO-E Transparency Platform was very large, causing that the data quality was insufficient for publication.

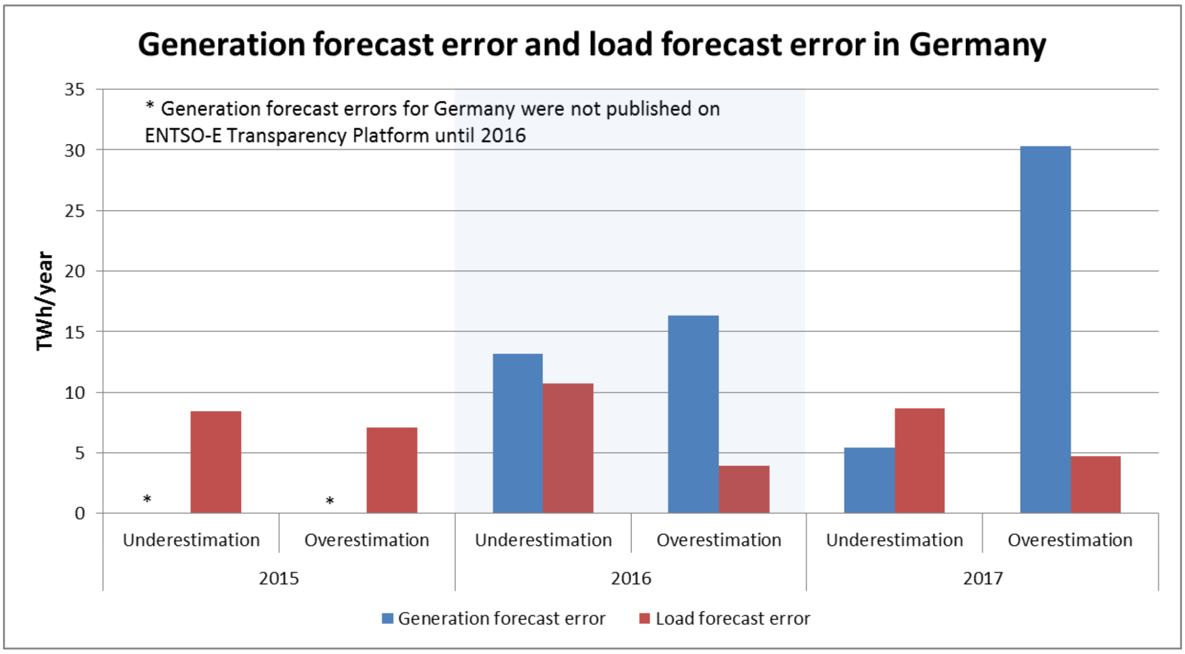

Figure 49 - Development of generation forecast errors and load forecast errors in Germany. Source: ENTSO-E Transparency Platform

The load forecasts are generally better than the generation forecasts in Germany. The generation forecast errors in Germany have significantly increased in Germany, while the load forecast errors remained relatively constant.

8.5.2. Relationship between generation and load forecast errors and system imbalance

The German generation forecast errors and the corresponding imbalance volume per ISP are displayed in Figure 50. The trend lines follow a horizontal trend. In addition, the correlation values are extremely low. This indicates that the correlation between generation forecast errors (based on TSO data) and imbalance volumes is negligible.

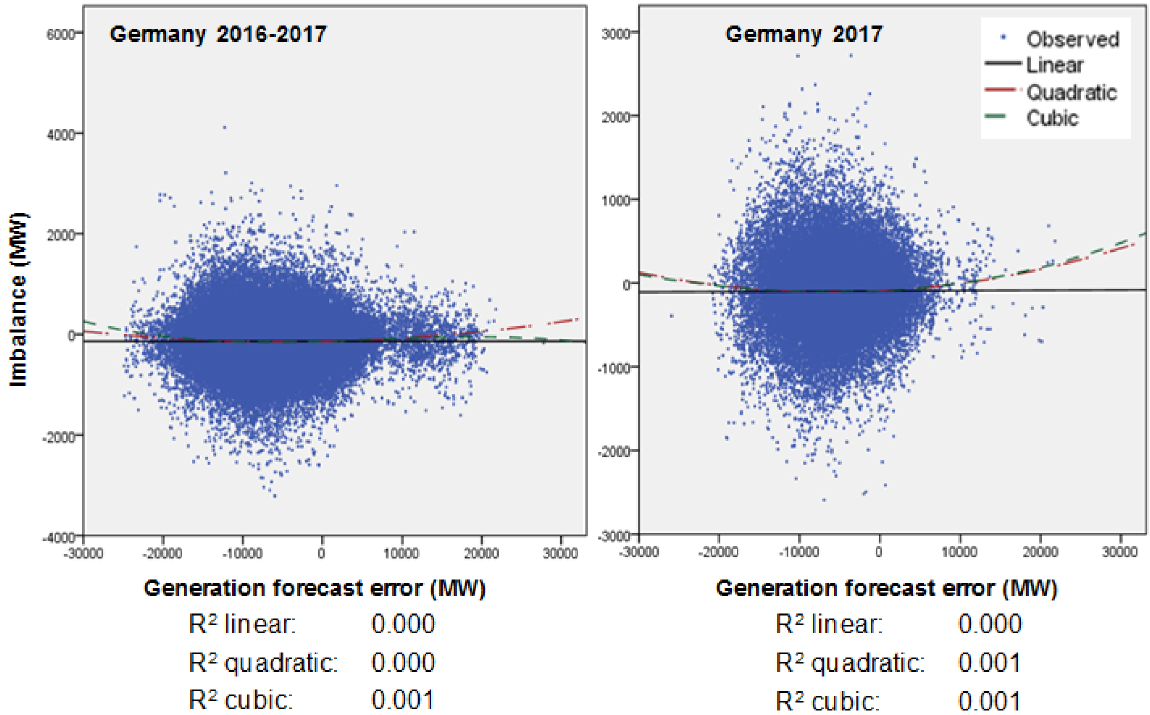

Figure 50 - Generation forecast errors versus non-absolute imbalance volumes in Germany. Significance linear regression 2015-2017 data equals 0.110. quadratic regression 2015-2017 data 0.277, linear regression 2017 data 0.393. All other trend lines have a significance of 0.000.
Source: Regelleistung.net, ENTSO-E Transparency Platform

The relationship between Dutch and German (TSO) load forecast errors and imbalance volumes is displayed in Figure 51.

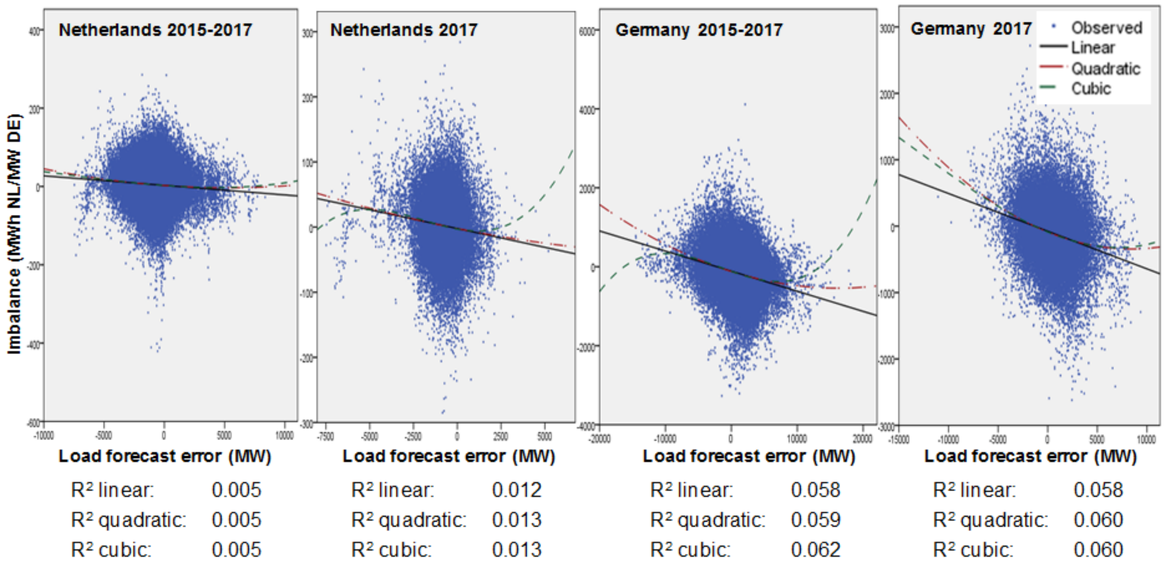

Figure 51 - Load forecast errors versus non-absolute imbalance volumes in the Netherlands and Germany. Significance linear regression NL 2015-2017 data 0.220. All other trend lines have a significance <0.000
Source: TenneT NL, Regelleistung.net, ENTSO-E Transparency Platform

The trend lines follow a downward trend inFigure 51; negative load forecast errors (higher actual load than forecasted load) result in positive imbalance volumes (long system, imbalance surplus), while positive load forecast errors (higher forecasted load than actual load) result in negative imbalance volumes (short system, imbalance shortage). This is the expected trend. As extra load leads to insufficient generation, and thus an imbalance shortage, and vice versa, the trend lines follow the expected trends.

The correlation values differ significantly between the Netherlands and Germany. While the R^2 values for the Netherlands are relatively low, the R^2 values in Germany are the highest for all correlation analyses performed in this report, reaching values of 0.062. However a R^2 value of 0.062 is still considered as a weak correlation.

9. Discussion

This research looked at the developments in the Dutch and German balancing markets, and looked at the impact of different possible contributors, including variable renewable generation, on system imbalance. Before the conclusions of this research will be presented, this section will discuss the limitations and implications of this study.

9.1. Methodological considerations

One point of consideration in the first part of the study is the method used for determining the imbalance price delta. The imbalance price delta has been calculated using the day-ahead price, However, one could argue that it would be more logical to use the average intraday price, as some market participants also trade in the intraday market and use the intraday price as a reference. The reasons why the day-ahead price was used instead of the intraday price are discussed in section 4.1.2. The impact of this decision is minor. The TenneT Market Review 2017 showed that the difference between the German day-ahead price and the intraday price is 95% of the time below 10 €/MWh, and most of the time close to zero. Also, the price analyses for Germany have been performed using the weighted average intraday price as well, and the differences were negligible.

One methodological aspect that could influence the first and second part of the study is that the data used for German imbalance volumes are not equal to the net BRP imbalance volumes, but are equal to the summed aFRR, mFRR and IGCC volumes. This since the net BRP imbalance volumes are not published for all four TSOs Germany. Although the net BRP imbalance volumes and the summed aFRR, mFRR and IGCC volumes are not always equal, the difference is relatively small (Frank Nobel, personal communication, 10 January 2018). Therefore, the used data still gives an indication of the imbalance volumes, and thus can still be used for the regression analysis.

Similarly, the data used for total generation in the Netherlands does not represent the actual generation in the Netherlands, as it only measures generation on the TenneT grid. The total variable renewable generation data in the Netherlands and Germany is also based on measurements on specific wind farms and solar generation sites, and are therefore not perfectly accurate. Although the absolute values for total generation and variable renewable generation might not be completely accurate, the used data does give an indication in the size of the total generation and total variable renewable generation in an ISP, and can thus be used in a regression analysis.

Lastly, the imbalance volumes used in the Netherlands represent the net BRP imbalance volumes per ISP. This means that if market participants provided passive balancing services in an ISP, this is also included in the net BRP imbalance volumes. Therefore, imbalance volumes caused by one of the contributors studied in this study could be less evident, as passive balancing services reduced the net BRP imbalance. However, passive balancing happens on a much smaller scale in Germany, as passive balancing is not promoted through live updates. As the German regression analyses have similar outcomes as the Dutch regression analyses, it is expected that this did not significantly affect the results.

9.2. Theoretical embedding

The results in this study are in line with previous studies on the relationship between variable renewable penetration and imbalance volumes. These studies showed that the balancing reserve requirements decreased (Hirth & Ziegenhagen, 2015) or did not change (Holttinen et al., 2006; Kling et al., 2011) with increased installed variable renewable capacity. Although this report did not look into reserve requirements, which depends on the most extreme imbalance situation, the conclusion is the same; increasing variable renewable generation has only limited impact on the balancing market..

Previous research has identified different causes for the low impact of variable renewable generation on system imbalance. One of the most-addressed aspects is the role of balancing market design. Different authors that BRPs should be economically incentivised to be balanced (Nobel, 2016; Van der Veen, 2012; Hirth & Ziegenhagen, 2009). Hirth & Ziegenhagen (2015) states that the imbalance price has a role as "an economic incentive to BRPs is to avoid (or not avoid) imbalances" (p. 1047). If these incentives are right, it is expected market participants improve VRES forecasts, compensate their own imbalance using other generators from their generation portfolio or correct their imbalance in the intraday market.

The impact of balancing market design on imbalance volumes was also visible in the first section of this report. The introduction of IGCC in the TSO balancing practices reduced the difference between imbalance prices and the day-ahead prices, reducing the incentive for BRPs to stay in balance. This resulted in higher imbalance volumes in the Netherlands, but in similar imbalance volumes in Germany. The German balancing market has faced extreme price peaks, due to its market design, which could have triggered market participants to avoid being in imbalance. This indicates that the balancing market design and events like the implementation of IGCC have more impact on imbalance volumes than an increase in VRES generation.

The intraday market is also mentioned as a possible cause for the low correlation between variable renewable generation and system imbalance (Hirth & Ziegenhagen, 2015). Borggreve & Neuhoff (2011) indicate that a well-designed and liquid intraday market can significantly reduce the system balancing costs. A liquid intraday market allows market participants to make more short-term forecasts and reduce their forecast error. For instance, the wind generation forecast error reduced from 5.9% 24 hours before delivery to 3.8% 2 hours before delivery (Borggrefe & Neuhoff, 2011). The liquidity of the German intraday market is much higher than the Dutch intraday market; the German intraday trading volumes are equal to 20% of the day-ahead trading volumes in 2017, compared to 4% for the Netherlands. This could explain the lower imbalance volumes in Germany. However, Borggreve & Neuhoff (2011) point out that there is significant room of improvement in the German intraday market, which could further allow market participants to avoid being in imbalance.

9.3. Implications and recommendations

It is uncertain how imbalance volumes will develop with higher penetration rates of variable renewable energy systems in the future, as the gradient of the trend lines in the correlation analyses were positive (higher VRES generation resulted in higher imbalance volumes), but the correlation was weak. As described above, balancing and intraday market design can play an important role in incentivizing market participants to refrain from adverse contributions to the system balance, for instance by improving forecast errors. In the short run, Germany is moving towards a balancing system with 'free bids' in 2018 (Bundesnetzagentur, 2017), while different European TSOs are working on projects to share aFRR (PICASSO project; Genêt & Bos, 2017) and mFRR (MARI project, Møller et al., 2017), resulting in more efficient reserve utilisation. Both effects result in lower imbalance price delta's, which reduces the incentive for market participants to stay in balance. Therefore, in the short term, the changes in market design could result in higher imbalance volumes, irrespective of higher variable renewable energy generation.

However, this development could be different with very high variable renewable penetration rates (>80%) in the future. Although the trend lines in the regression analyses showed a positive relationship between variable renewable generation and system imbalance, the correlation was too weak for renewable generation to be the main contributing factor to system imbalance. Unless a capacity mechanism is introduced by governments in Europe, it is very likely that most of the conventional power plants will be phased out of the market in such a situation. This means that the number of plants that can provide balancing energy will be reduced, leading to higher imbalance price deltas. Whether this leads to higher imbalance volumes depends on developments in other providers of balancing energy, such as battery systems, as well as on improvements in forecast errors of variable renewable energy generation. The forecast error for wind generation has decreased over years, although the balancing market design has not changed considerably (Ernst et al., 2007). However, it is unsure whether the wind generation forecast errors can become lower than the current conventional generation forecast errors, thus reducing imbalance volumes. As both upward and downward effects on system imbalance are possible with high VRES generation, it cannot be predicted how the system imbalance will develop in the long-term future.

It also remains questionable whether the TSOs will need to contract more reserve capacity as a direct consequence of a higher VRES share, as model studies summarized in Brouwer et al. (2014) concluded. As explained in section 3.3, the reserve requirements are based on the deterministic method, which looks at the highest power loss in case of a contingency, or the probabilistic method, which looks at the reserve capacity to cover 99% of the imbalance events. As discussed above, the imbalance volumes might increase, depending on the market design, which might increase the reserve requirements based on the probabilistic method. However, TSOs are currently working on large scale market integration and renewable integration projects, such as the North Sea Wind Power Hub. Multiple direct-current (DC) connection lines of 2 GW are considered in this project to transport the high generation volumes of offshore wind power (around 70 GW) to land (TenneT, 2017c), which will significantly affect the outcome of the deterministic method. It is therefore very likely that the required reserve capacity will increase, but that this is mostly because of the introduction of connection lines with high capacity, rather than higher imbalance volumes caused by the intermittency of renewables.

However, it is likely that a larger VRES share in total generation will affect the ratio between required aFRR and mFRR capacity. aFRR is currently mostly used to quickly correct small imbalance volumes, while mFRR is generally used in case of a large scale contingency, such as the outage of a large power plant. With higher small-scale variable renewable generation and lower generation from large conventional power plants, the chance of a large scale outage is smaller, while fast-changing, small-scale imbalance volumes will occur more often due to the intermittency of the variable renewable generation. Therefore, relatively more aFRR and less mFRR will be required to ensure system adequacy with a high share of variable renewable generation.

As the design of the balancing market seem to have a major influence on imbalance volumes, further studies should further look into this. These studies could look at the balancing market design in other countries than the Netherlands and Germany, to find the ideal balancing market design which limits system imbalance.

In addition, it is recommended that future studies study the relationship between variable renewable generation and imbalance volumes by looking at specific BRP portfolio's with high VRES generation, instead of looking at the overall system imbalance. Looking at the relationship between VRES generation of a BRP and BRP imbalance has two advantages. Firstly, this filters out passive balancing from other BRPs which now distort the imbalance volumes, as previously discussed in this section. Secondly, if a BRP with a very high share of VRES in their portfolio is studied, it could give better insight in the development of imbalance volumes very high variable renewable generation (>80%).

10. Conclusion

The goal of this study was twofold: to address recent developments in the Dutch and German balancing markets and to identify the impact of different possible contributors to system imbalance in the Netherlands and Germany.

The first aspect of the study was performed by looking at volume, price and market developments in the balancing markets. The incentive to stay in balance – the difference between the imbalance price and the day-ahead price – has decreased for both the Netherlands and Germany, which caused that the Dutch imbalance volumes continuously increased since 2013. This trend was not visible in Germany; imbalance volumes decreased since 2013 and remained relatively stable between 2015 and 2017. In both countries, the activation volumes of balancing products did not show the same trends as the imbalance volumes. In both countries, no clear seasonal or hourly trends regarding imbalance volumes could be observed.

Most of the developments in imbalance volumes and imbalance prices could be attributed to market design. The introduction of International Grid Control Cooperation had a significant downward effect on the imbalance prices, as it avoided balancing reserve activation. In addition, the different trends regarding imbalance volumes in the Netherlands and Germany can also be attributed to market design; the intraday market in Germany has a higher liquidity, and the German balancing system contains different mechanisms which sometimes results in very high imbalance prices. This, together with the absence of live updates on imbalance volumes and prices in the German balancing system, make the risk of being imbalance in the wrong direction high, resulting in lower imbalance volumes. This indicates that market design is one of the main drivers for system imbalance.

The different design of the German and Dutch balancing market is reflected in the market revenue for each of the balancing products in both countries. aFRR is in both countries the market with most revenue in the past years, but the mFRR market revenue is relatively much bigger in Germany compared to the Netherlands due to different usage of this balancing product. The Dutch merit order for aFRR energy has become much larger in the past years. However, this merit order seems to be tighter than the German equivalent. Hydro power is the most prequalified technology for providing balancing energy in Germany, but battery systems are emerging rapidly.

The second aspect of the study, the impact of different possible contributors on system imbalance, has been studied by performing regression analysis between the following possible contributors and system balance using 15-minute data: variable renewable generation, total generation, total load, variable renewable forecast error, generation forecast error and load forecast error. Also, the installed variable renewable capacity and imbalance volumes have been compared annually. The trend lines in all regression analyses followed the expected trends; higher variable renewable generation, total generation and total load result in higher imbalance volumes. Also the trend lines in the regression analyses between (variable renewable) generation/load forecast error and system imbalance followed the expected trend. However, the correlation in all regression analyses were weak; the R^2 values were in all cases low (0.062 was the highest R^2 value), and the data points were widely scattered around the trend lines. Therefore, it can be concluded that the contributors studied in this paper on their own only have a very minor impact on system imbalance.

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12. Appendix I

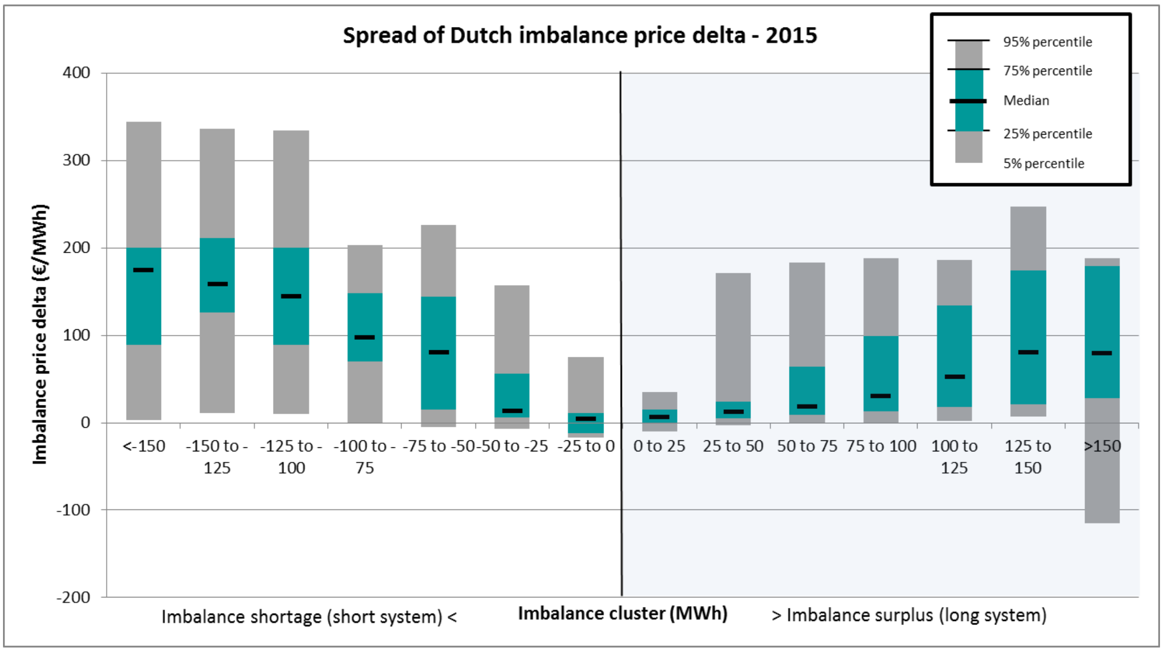

Figure 52 - Spread of imbalance price delta at different imbalance volumes in the Netherlands in 2015. Source: TenneT NL, EPEX Spot.

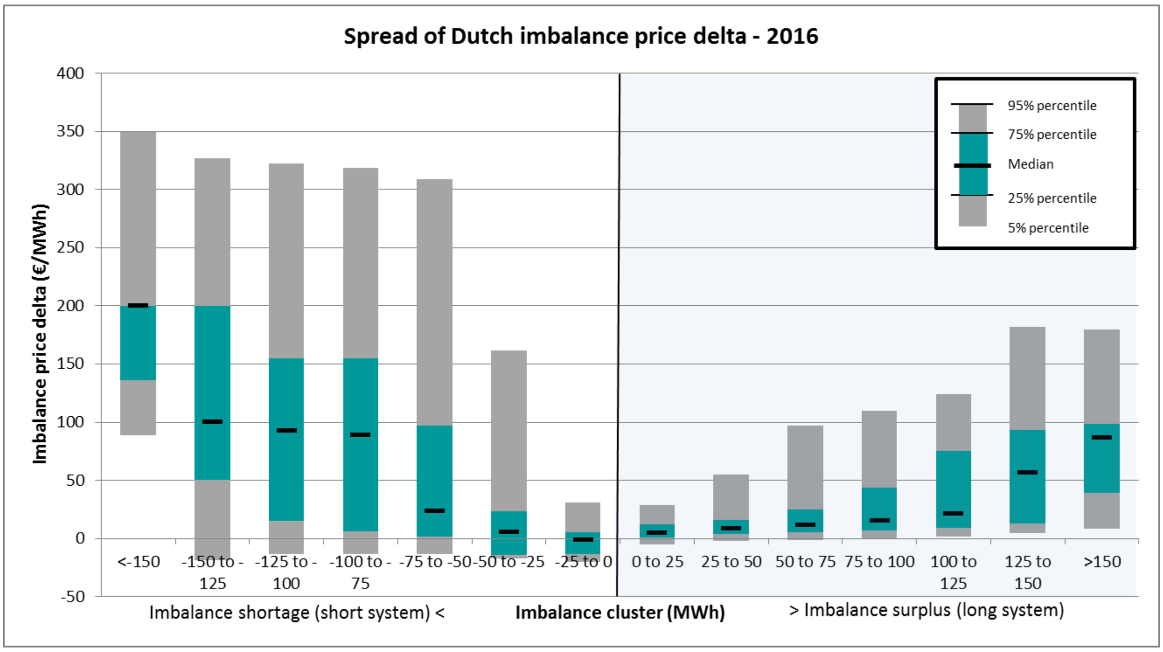

Figure 53 - Spread of imbalance price delta at different imbalance volumes in the Netherlands in 2016. Source: TenneT NL, EPEX Spot.

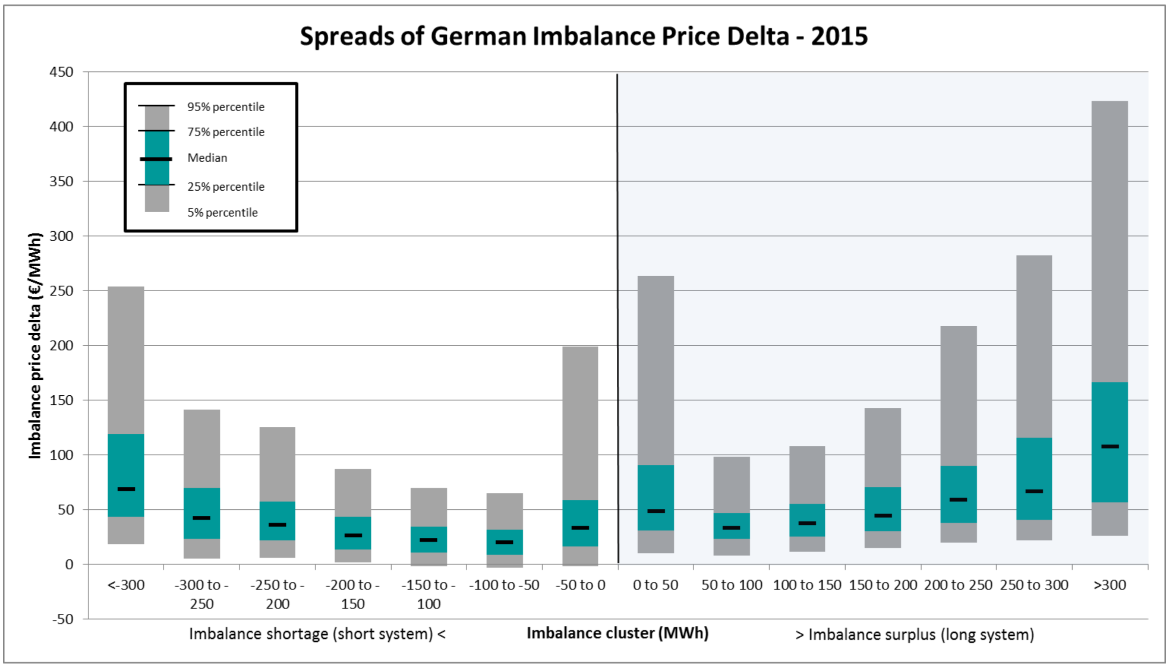

Figure 54 - Spread of imbalance price delta at different imbalance volumes in Germany in 2015. Source: ENTSO-E Transparency Platform, EPEX Spot.

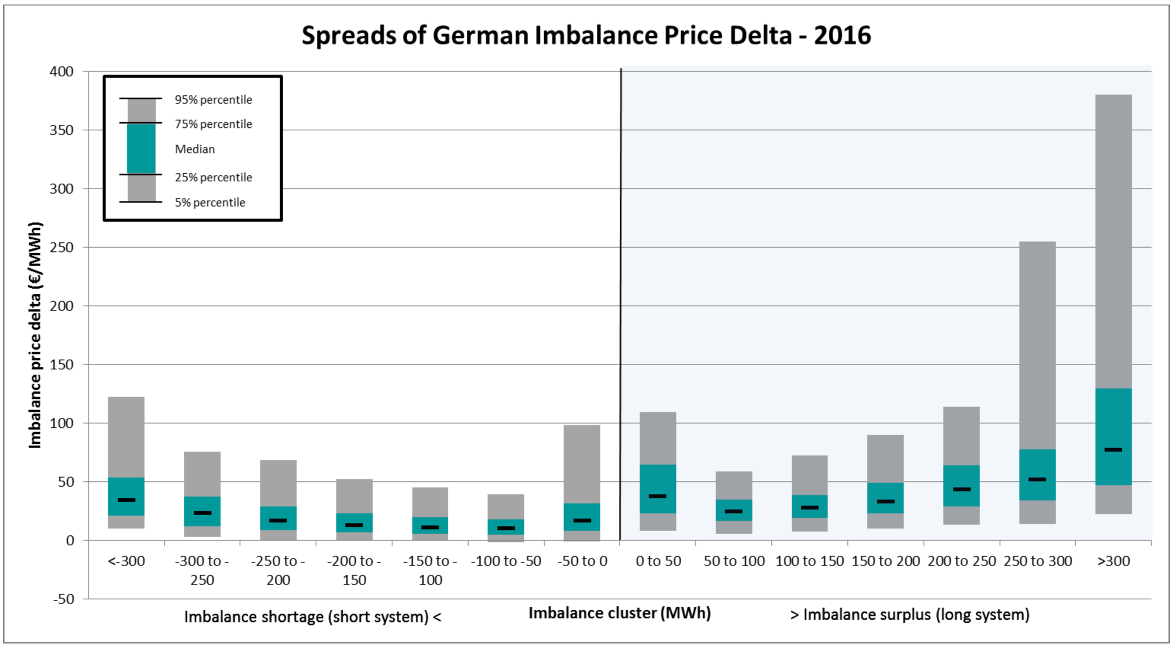

Figure 55 - Spread of imbalance price delta at different imbalance volumes in Germany in 2016. Source: ENTSO-E Transparency Platform, EPEX Spot.

13. Appendix II

The section zooms in on the capacity price developments of the four different aFRR products contracted in Germany. A distinction is made between upward and downward aFRR capacity, and between aFRR capacity during peak (08:00-20:00 during weekdays) and during off-peak hours (20:00-00:00 and 00:00-08:00 during weekdays and all day during weekends and holidays).

Figure 56 shows the development of capacity prices of these four products.

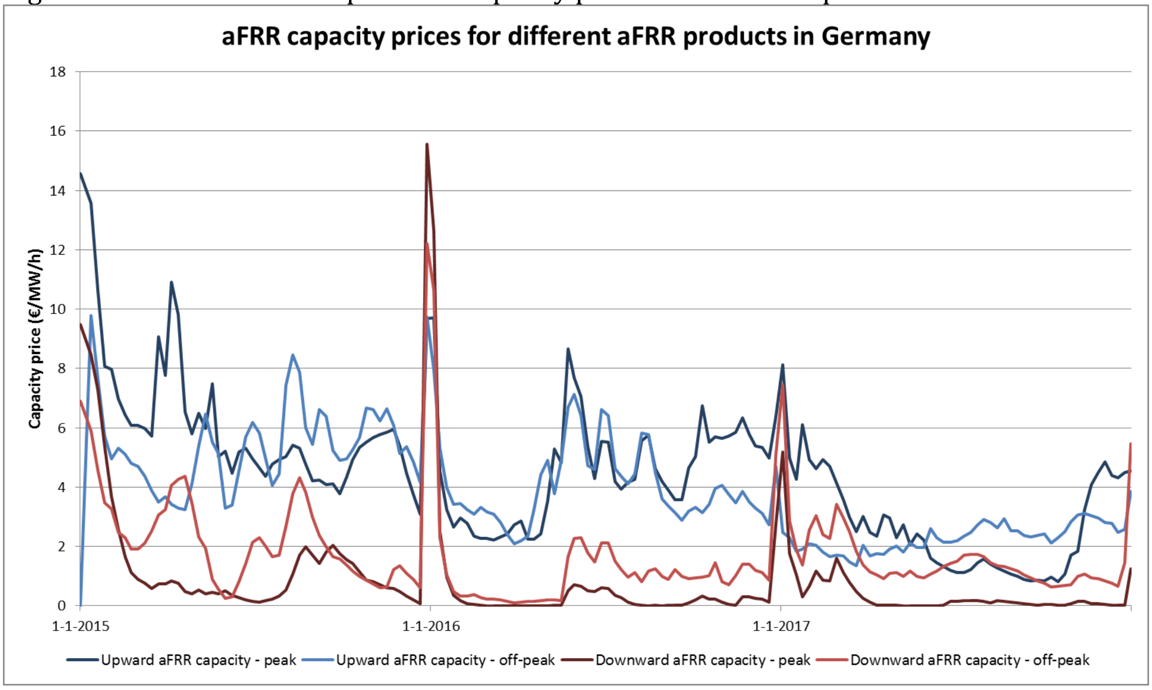

Figure 56 - Capacity prices of four different aFRR products in Germany.
Source: Regelleistung.net

The provision of downward aFRR capacity is more attractive than the provision of upward aFRR capacity for market participants, because a market participant cannot sell its full production capacity in the day-ahead market if it provides upward aFRR capacity. This explains why Figure 56 shows that the average capacity price for upward capacity is generally higher than for downward capacity. The average downward off-peak capacity price is higher than the average downward peak capacity price, as producers are forced to operate during off-peak hours to be able to provide downward aFRR capacity. During off-peak hours the demand and thus the price is generally lower, making power plant operation less profitable.

Figure 57 looks at the difference between the average and maximum accepted bid for the different products.

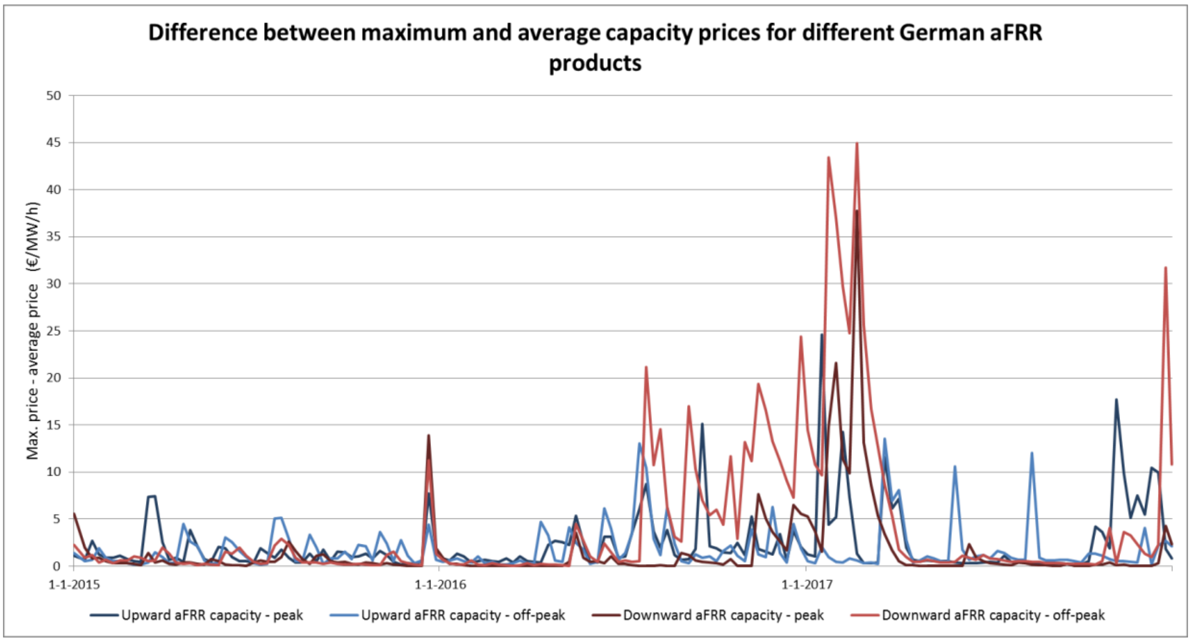

Figure 57 – Difference between the maximum and average accepted capacity bid price for different German aFRR products.
Source: Regelleistung.net

As described in section 6.2, the difference between the average and maximum accepted German aFRR bids was large during the start of 2017. These peaks were mainly for the downward aFRR products, both peak and off-peak. This indicates that the competition for this product was lower. A possible cause is maintenance of generators, which reduces the options for downward aFRR capacity.

14. Appendix III

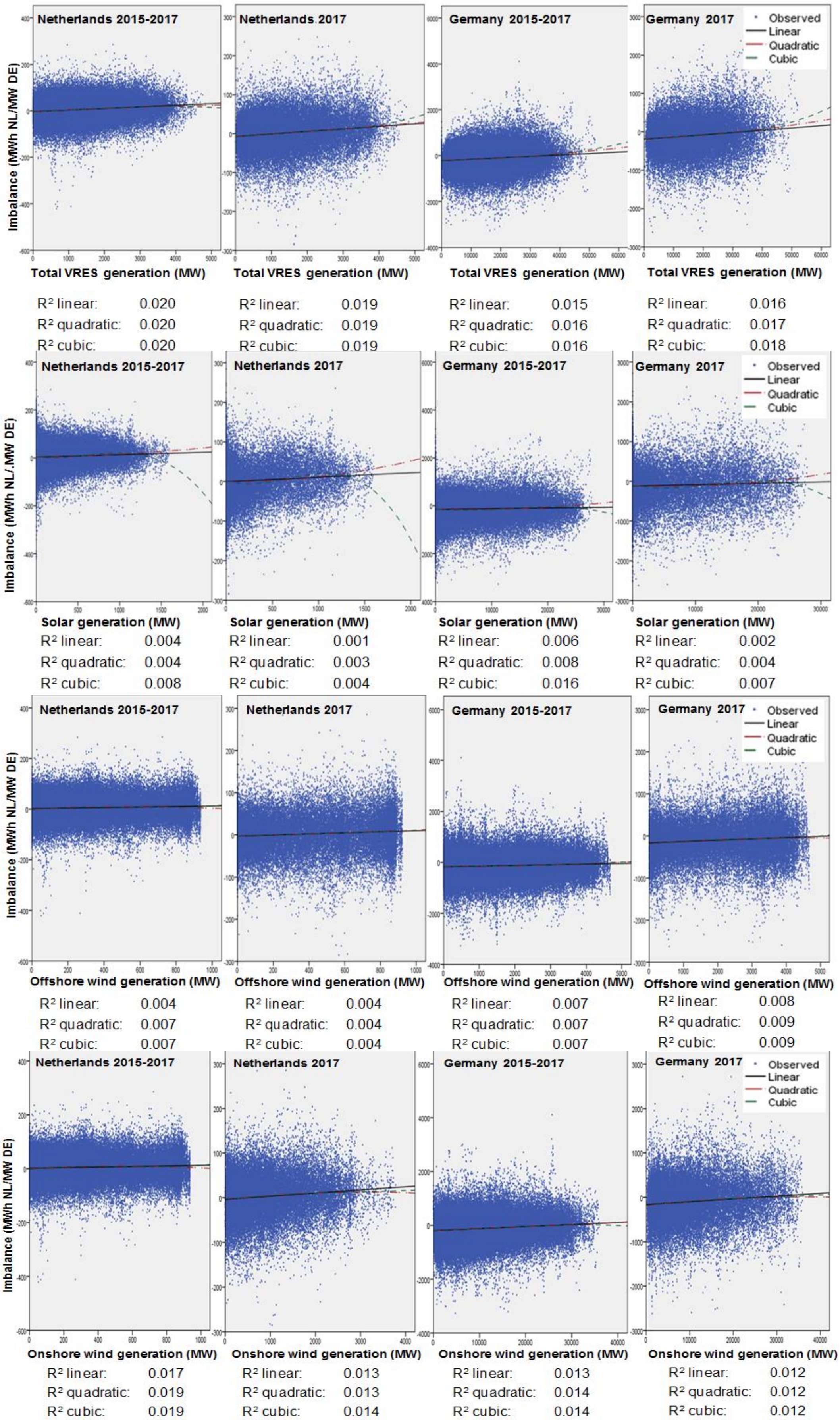

Figure 58 – Total VRES, solar, onshore wind and offshore wind generation versus non-absolute imbalance volumes per ISP in the Netherlands and Germany. Significance for all trend lines <0.000.
Source: TenneT NL, Regelleistung.net, ENTSO-E Transparency Platform

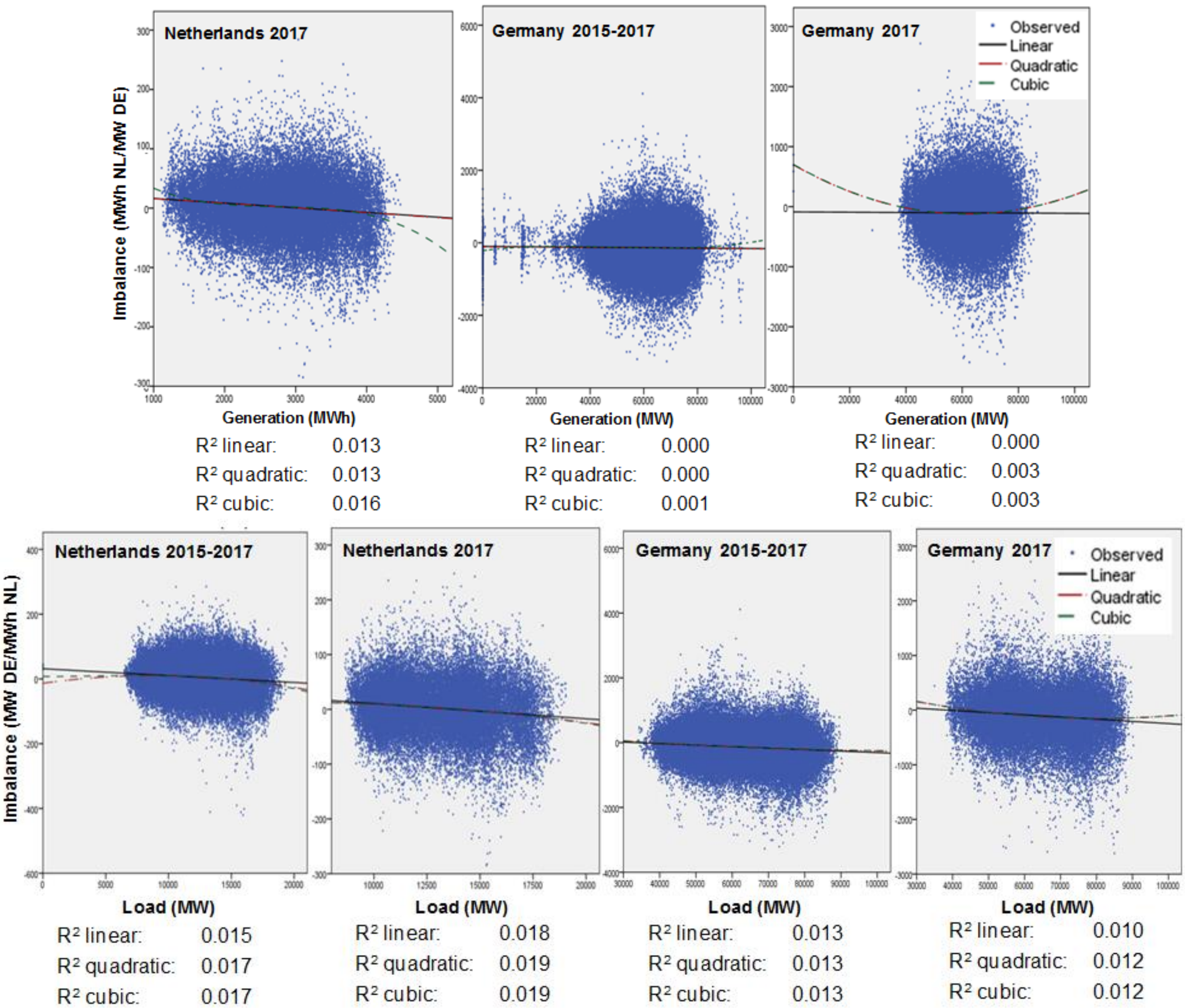

Figure 59 - Total generation and load versus non-absolute imbalance volumes per ISP in the Netherlands and Germany. Significance for all trend lines <0.000.
Source: TenneT NL, Regelleistung.net, ENTSO-E Transparency Platform