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Mergers of Germany's natural gas market areas: Is transmission capacity booked efficiently?

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Abstract

In the past, networks of natural gas transmission system operators (TSOs) determined the gas market areas in the European Union. However, gas markets mergers introduce the possibility to book the transmission capacity of alternative TSOs. One necessary condition for competition among TSOs is the absence of restrictions in capacity booking. This paper analyses whether this holds for Germany. As German TSOs distinguish a number of capacity types to deal with network constraints, market mergers have created transport alternatives for only 32% of cross-border capacity products. In almost all cases, we find that gas transmission network users make efficient booking decisions.

Key Words

Gas market Regulation Market mergers Transmission networks

JEL Codes

Q48 L51 L95 L98 K23

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1 Introduction

As part of the European Union's (hereafter: EU) policy to establish an internal market, the EU aims to create a European internal gas market (European Union 2012). To achieve this, measures directed at national energy policies, regulatory frameworks, and the design of gas markets in Member States are laid out in three so-called *European Energy Packages* entering into force in 1998, 2003, and 2009, respectively. These regulations aim at liberalising the EU gas markets and establishing wholesale markets. In particular, they impose regulatory provisions to ensure non-discriminatory network access and network tariffs, and unbundling rules on network infrastructure companies. In gas wholesale markets, transmission system networks provide the key infrastructure. These networks are operated by transmission system operators (hereafter: TSOs), and are connected to networks of adjacent TSOs as well as to storage facilities and downstream distribution system networks. The networks are used by producers, traders, and suppliers (collectively, *network users*). Since transmission networks are the backbone of gas markets, regulating TSOs means regulating the entire gas market.

In the past, suppliers had to book network capacities according to the actual transport route in order to supply a customer. This changed after the introduction of entry-exit systems, also referred to as market areas, which decoupled the physical network from the commercial trade of gas.[1] Network users are now able to inject gas at any entry point of the physical network in a market area and withdraw gas at any exit point that belongs to the same market area. The management of physical gas flows within a market area is the responsibility of the TSOs. This decoupling also allows wholesale markets to arise because injecting and withdrawing gas are independent of each other and independent of any predefined transport routes (CEER 2011; Lohmann 2009). Nevertheless, wholesale markets have not fully developed (Frontier Economics Ltd., 2014), and integrating gas markets may improve their liquidity, and intensify the competition among gas market participants (ACER and CEER 2017).

Market integration can be achieved by merging markets. If two markets merge, the resulting single gas market is based on the infrastructure of two TSOs. Market mergers have taken place mainly in Germany, which consisted of 41 market areas in 2006 and which were eventually merged to two today (Monopolkommission 2009; Ströbele et al. 2012). According to regulatory authorities, most European markets are still not sufficiently developed, and there are doubts about whether this will happen without structural reforms (ACER and CEER 2015). Hence, further market mergers, even across national borders, are to be expected.

The integration of gas markets is widely discussed in the literature. For example, Asche et al. (2013) found a high integration of the gas markets in the UK, the Netherlands, and Belgium. Petrovich (2013) measured the degree of market integration for different EU gas wholesale markets using the wholesale prices. Kuper and Mulder (2016) focused on the integration of the German and Dutch gas market not only based on wholesale prices but also taking into account infrastructure utilisation and regulatory changes, including mergers of markets. Examining the performance of spatial arbitrage between the gas markets in Belgium and the UK, Massol and Banal-Estañol (2018) call for paying attention to possible market power of trading companies.

Market mergers, however, do not only have an impact on wholesale markets. Networks users also obtain transport alternatives. Merging two markets areas, which are entry-exit systems, results in a new joint market area, also organised as an entry-exit system. Therefore, gas injected into the network of one TSO may be withdrawn from the network of the other TSO belonging to the same integrated market area, and vice versa. If two market areas are merged, and both are connected to a third market area, the merger of the two market areas creates a choice for network users for gas flows

[1] The terms entry-exit system, entry-exit zone, and market area are used interchangeably.

between the merged market and the third market area. Since network users obtain a choice among routes, market mergers may imply competition among TSOs.

In the literature, TSOs are generally considered as natural monopolies, which need to be regulated in absence of effective competition (Sherman 2001). In the U.S. gas industry, wellhead, production, interstate pipeline transmission, and local utility distribution are separated (Chermak 1998; Makholm 2012). Market competition is among commodity suppliers to city gates, but not among infrastructure operators (Broadman 1986). Beukenkamp (2009) analyses pipeline competition in Europe, finding that some routes across Europe have the potential to compete. However, these are long-distance routes involving several countries and TSOs, whereas this paper focuses on adjacent markets. Von Hirschhausen et al. (2007) analysed competition among German TSOs and concluded that German TSOs are not exposed to effective competition and that there is no potential for such competition to arise. As several German TSOs asked to be granted an exemption from tariff regulation, the regulatory authority in charge also concluded that the companies were not exposed to effective existing or potential pipeline competition (Bundesnetzagentur 2008). However, the situation of Germany in 2007 and 2008, consisting of 16 market areas, indicated a significantly lower degree of market integration than today. The regulatory regime has also changed. For example, capacity products (defined by runtime) have been standardised, and are offered on a central booking platform.

This paper examines the impact of gas market mergers and the potential for competition among regulated TSOs by analysing the efficiency of the network users' behaviour in terms of booking gas transmission capacity. We focus on the demand for gas transport capacities to and from the two German gas markets. As Germany has been faced with a strong reduction in the number of market areas via market mergers, inferences drawn from this experience may contribute to shaping the future of the European regulatory regime and market design. This paper analyses whether the choices made by network users are efficient. We define booking behaviour as being efficient if network users choose the transport alternative with the lowest tariff. We use auction data from the capacity booking platform PRISMA for the calendar year 2016 to determine the efficiency of network users' booking behaviour. Our analysis looks at all capacity alternatives to and from the German gas markets, and compares the optimal costs of booking to the costs observed. The paper further provides explanations for inefficiencies.

For both German gas markets, the results show a fairly efficient booking behaviour of network users. We conclude that network users make efficient use of the transport alternatives obtained from market mergers. However, we also find that differences between capacity types in the European and the national German regulation need to be considered. This explains to a very large extent why in some cases apparently more expensive alternatives are preferred over less expensive ones. Although gas transport capacity is highly standardised, the quality differences, i.e., the differences in capacity types, matter to network users. As German TSOs distinguish a number of capacity types to deal with network constraints, market mergers have created transport alternatives for only 32% of cross-border capacity products. In almost all cases, we find that network users make efficient booking decisions.

Following this introduction, the paper starts with a concise description of the background and functioning of European gas markets, and the effect of market mergers. Section 3 continues with economic theory, which leads to our hypothesis. Section 4 introduces the data used and Section 5 explains our analysis. The results are reported in Section 6 and Section 7 provides our conclusions. Detailed results can be found in the Appendix.

2 Regulation and integration of European gas markets

2.1 Entry-exit regulation

EU Regulations and Directives determine the regulatory framework of European gas markets. Regulation (EC) No 715/2009, being part of the so-called *Third Energy Package* and also referred to as the *Gas Regulation*, prescribes a market design to be implemented by TSOs, referred to as the *entry-exit system.* The concept of entry-exit offers flexibility in gas transport, and allows for wholesale markets, so-called *virtual trading points*, in the market areas. In an entry-exit system, only two gas transport capacity contracts are necessary to supply a customer. A capacity contract at an entry point, e.g., a production facility, grants the right to inject gas into a TSO's network. Additionally, a contract for exit capacity is needed at the point where gas shall be withdrawn from the network, e.g., a customer (CEER 2011; Lohmann 2009). A network user only has to book and manage entry and exit capacity contracts to transport gas, and no specific physical transport routes in a network anymore, which reduces transaction costs (Vazquez et al. 2012). With entry-exit systems, a network user also obtains increased flexibility as every entry point can supply every exit point. The management of the physical gas flows is solely the responsibility of TSOs. Hence, commercial trading, based on entry and exit, and physical gas transport are decoupled. Since TSO networks are well connected, gas may exit one market area and enter an adjacent one. Therefore, the entry-exit system allows for cross-border trade.

As defined by the EU Gas Regulation, capacity offered by TSOs is either firm or interruptible, which refers to its quality (European Parliament and Council of the European Union 2009b). Firm capacity is without any risk to network users as it is contractually guaranteed as being non-interruptible. To guarantee the flow, the amount of firm capacity on offer is limited by the physical capability of the network. In addition to firm capacity, TSO's can offer interruptible capacity unlimitedly. However, this capacity may be interrupted by a TSO, for example, to ensure the security of supply in case the sum of intended gas flows would exceed the maximum flow possible.

2.2 Market integration

The introduction of entry-exit systems induced a major step towards completing the EU internal energy market for gas, but not a sufficient one (Frontier Economics Ltd., 2014). ACER and CEER (2015) conclude that for a number of markets even the full implementation of new market provisions, as foreseen by the third energy package,[2] will not lead to a well-functioning internal gas market, and structural reforms related to market mergers, are necessary.

Integrating markets can generally be referred to as abolishing barriers between single markets, such as tariffs (Belassa 1961). If (tariff) barriers are abolished completely, the single markets become one, and the *law of one price* applies (Li et al. 2014). The possibility for cross-border trade and, hence, also the degree of integration, is limited by the amount of interconnection capacity between the markets (Vazquez et al. 2012). As widely discussed in the literature, the European gas markets are already integrated to a large extent (Asche et al. 2013; Growitsch et al. 2013; Kuper and Mulder 2016; Petrovich 2013). However, further integration is considered necessary in order to obtain a well-functioning internal gas market with higher liquidity, wholesale market competition, and supply price convergence.[3]

[2] See the concept of network codes as stated in Article 6 of Regulation (EC) No 715/2009.
[3] For further information on gas market integration and implementation tools, see ACER and CEER (2015).

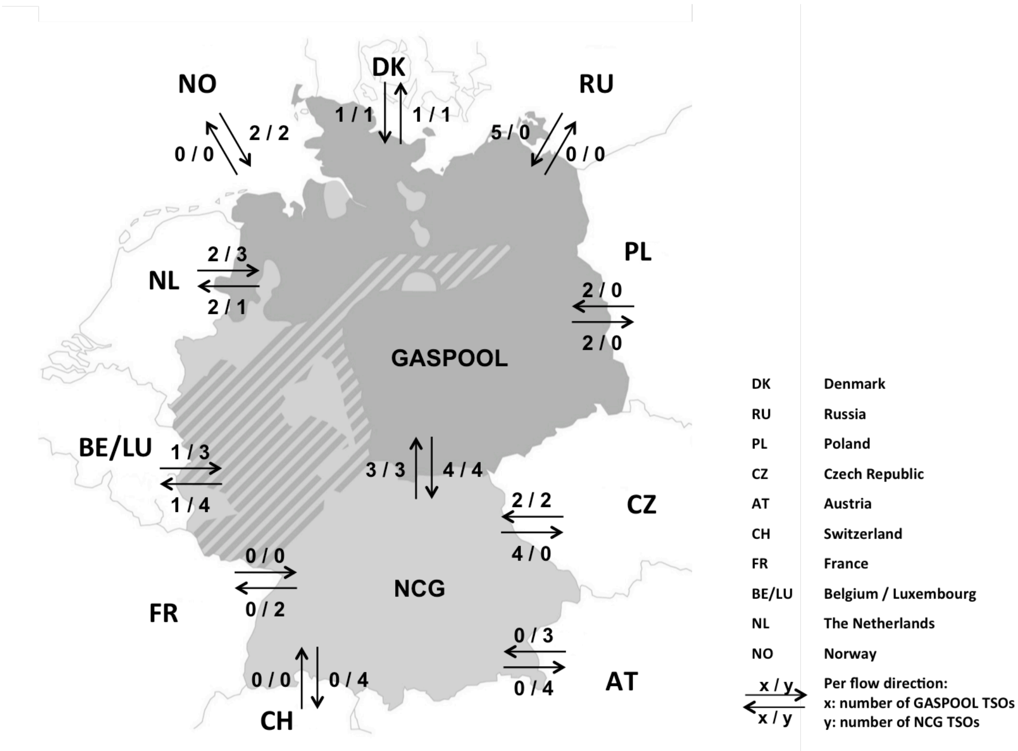
2.3 Mergers in the German gas market

Gas market mergers can be observed in Europe, particularly in Germany (Heather 2015; Lohmann 2009). Compared to other EU Member States, which usually have one or two TSOs, Germany today has 16 TSOs offering gas transport capacity.[4] In 2006, Germany consisted of 41 market areas, but due to market mergers, there are only two market areas left in Germany today, named "GASPOOL" and "Net Connect Germany (NCG)" (Monopolkommission 2009; Ströbele et al. 2012). As Germany has been faced a reduction in the number of market areas via market mergers, inferences drawn from this experience may contribute to shaping the future of the European regulatory regime and market design.

The impact of several market mergers on connections to and from Germany is shown in Figure 1. The map shows the two market areas in Germany with GASPOOL mainly in the north, and NCG in the south of the country. In the west, there is also a mixed area, where pipelines of both market areas exist. The map further shows the number of different TSOs a network user can choose from for importing gas to (entry) and exporting gas from (exit) the German market areas. The arrows indicate the flow direction. The first number refers to the number of GASPOOL-TSOs, the second to the number of NCG-TSOs offering capacities a network user could choose from. As the figure shows, the capacity between the two markets is often offered by more than one TSO. Thus, market mergers have led to transport alternatives for network users at the border between some market areas.

Fig. 1

Map of German and adjacent market areas, and the number of German TSOs offering firm capacity products per flow direction.**[a]** Source: ENTSOG (2017b), FNB Gas e.V. (2018); own calculations



[a] The national markets of Belgium and Luxembourg have already merged. France has two national gas markets. However, NCG is only connected to the northern part of France (PEG Nord).

[4] See https://platform.prisma-capacity.eu.

3 Theoretical framework

3.1 Impact of market mergers on the choice of network users

Consider three market areas, A, B, and C, that are geographically determined by the boundaries of the physical networks of TSO A, TSO B, and TSO C, respectively (see Figure 2). Each TSO's network has a number of entry and exit points. If, for example, A4 is a production facility where gas is to be injected, and A2 is a customer where gas is to be withdrawn, then in this entry-exit system a supplier would need to book entry capacity at A4 and exit capacity at A2. If B3 is a customer in an adjacent market area also to be supplied by gas from A4, then a network user needs four capacity contracts: entry at A4, exit at A1 at the border, entry at B1 at the border, and finally exit at B3. This customer needs two more contracts because an entry-exit system allows only combining entry and exit points that belong to the same market area (Lohmann 2009; Vazquez et al. 2012).

Fig. 2
Example of unmerged market areas with entry-exit system

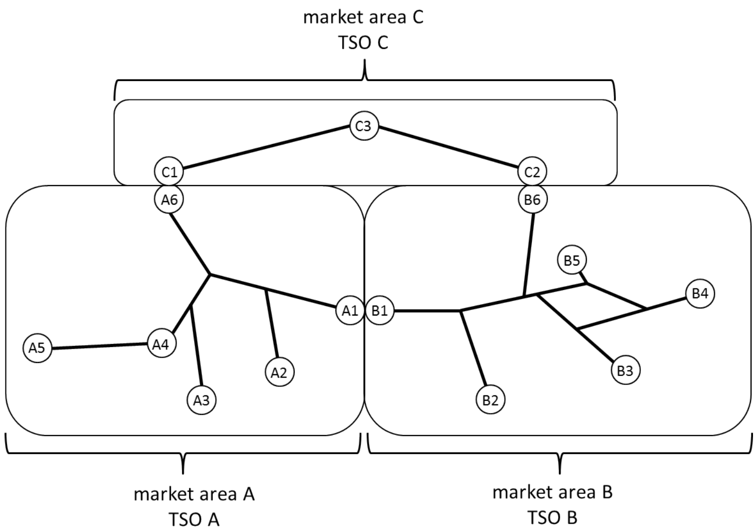


Fig. 3
Example of merged market areas with entry-exit system

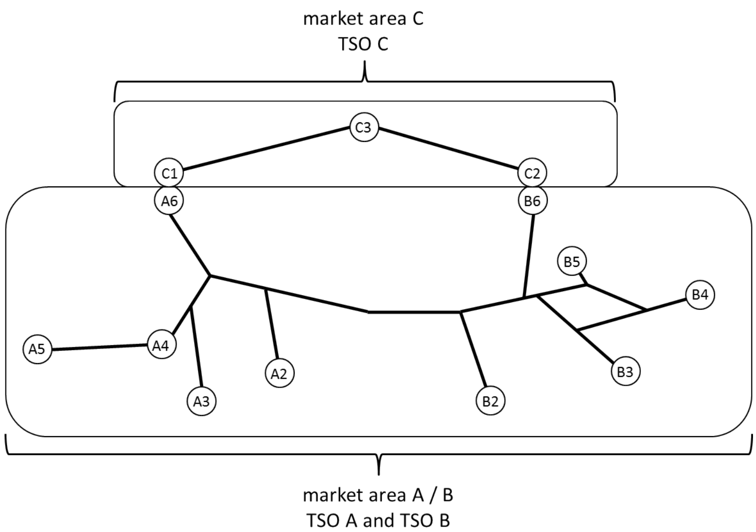


Figure 3 illustrates that after the merger of the market areas A and B, the commercial border, i.e., A1/B1, between the two markets disappears. The supplier of the customer located at B3, which receives its gas from A4, needs only two capacity contracts after the merger instead of four, i.e., entry at A4 and exit at B3. Note that only the market areas merge while the TSOs A and B remain independent companies operating their network. The difference is that gas flows within an entry-exit system without any border restrictions. Merging the market areas A and B creates opportunities for network users' gas flows between the merged market area A/B and the adjacent market area C; a network user can choose between TSO A and TSO B as illustrated by Figure 3. For example, a customer B3 is to be supplied by gas from the production facility C3. The respective supplier can choose gas to be transported either via C1/A6 or via C2/B6. The border points A6 and B6 are competing, and so are the TSOs A and B. Nevertheless, the merger has only an impact on the cross-border capacity. For example, the capacity on offer to distribution system operators, storage facilities, and industrial customers being connected to the transmission system is not affected by the merger. Referring to the example, the capacity to exit B3 in order to supply the customer needs to be booked at TSO B, whether or not the merger has taken place.

3.2 Network users' booking behaviour

Merging market areas requires network users to decide between different alternatives when booking gas transport capacity. Their decisions are supposed to be made in line with individual preferences based on utility and profit maximisation. If two (or more) capacity products differ in any of their characteristics, network users are supposed to choose the alternative in accordance with their preferences. Although capacity products are highly standardised by European regulation, a supplier still must choose between booking a yearly capacity contract and a profiled booking using multiple capacity products of shorter runtimes (European Commission 2017a). Additionally, capacity is either firm or interruptible. Interruptible capacity is associated with the risk of interruption as discussed in Section 2.1, which is why it is of a lower quality compared to firm capacity, and is offered at a discounted tariff reflecting the risk of interruption (European Commission 2017b). For this reason, a network user may have a preference to book capacity of lower quality if this is suitable for the underlying trade, and if the discount is subjectively perceived to outweigh the risk. Also, a network user may prefer to book a more expensive alternative at a certain TSO if, for example, both companies belong to the same corporate group. To avoid any kind of biased behaviour by vertically integrated companies, unbundling obligations were established (Bernaerts 2013; European Parliament and Council of the European Union 2009a).

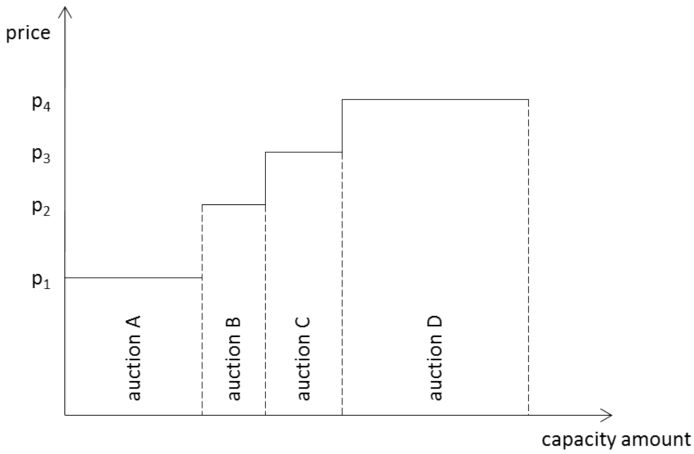
Besides costs for the capacity product, network users should consider any additional costs, such as those related to the booking procedure. For instance, a lack of transparency regarding available capacity may imply high costs of gathering additional information about the capacity products on offer, and how these can be booked. If more information about a specific capacity product is provided, the more expensive product may be preferred over a less expensive alternative. According to Kury (2015) increased transparency about the capacity on offer provided by an electricity TSO, can reduce information costs.

Here we compare the actual capacity booking behaviour of network users and optimal booking behaviour. The latter is defined as behaviour that results in the lowest cost for booking with all other product characteristics being equal. Hence, the optimal booking behaviour results from cost-minimisation. This allocative efficiency measure is, for instance, used in the analysis of the dispatch of power plants; given a variety of power plants using different technologies, an optimal dispatch needs to be determined to supply electricity to meet demand (Müsgens 2006).

The concept of a merit order analysis can also be used to measure the allocative efficiency of gas transport capacities. However, there are differences compared to power plants in the electricity sector. Gas transport capacities are booked via auctions on booking platforms. Alternatives of gas transport capacities are not offered in joint auctions, hence, unlike for electricity production capacity, there is no merit order created by the booking platform for gas transmission capacities. However, network users are able to compare the tariffs for standardised capacity products on offer and create merit orders themselves to decide which capacity to book. Another difference is that production capacity for electricity may be offered not only in one marketplace, but also in different marketplaces. Finally, in terms of prices, TSOs charge regulated tariffs, whereas power plants offer electricity at marginal costs (Morales and Pinedab 2017).

Figure 4 gives an example of a merit order for gas transport capacity auctions. Since all the auctions are independent of each other, a network user is able to book capacity from each of the auctions. If, for example, capacity is booked in auction C, then the network user has to pay the amount of capacity booked times the tariff of that particular auction. If another network user books capacity in auction A, then the tariff of auction A applies. Since the auctions are independent of each other, there is no single market price. In this example, booking capacity in auction C is not efficient in case capacity has been available in other auctions at lower tariffs. However, if all networks users would try to book capacity in auction A, and the demand for capacity in this auction exceeds the amount on offer, surcharges will be included in the actual costs of booking. These auction surcharges may result in capacity allocation at a tariff that is higher than the tariff at which capacity was offered, for instance, in auction B. Hence, it would have been more efficient for a network user to directly book capacity at auction B.

Fig. 4
Example of a merit order for gas transport capacity products



The comparison of the actual capacity allocation to the merit order determines the degree of allocative efficiency. Therefore, we can measure the allocative inefficiency by comparing the actual costs of booking observed with the optimal costs. The optimal costs are based on a merit order of all capacity products a network user could have chosen from. The actual costs observed refer to the booked capacity amount and the price to be paid including auction surcharges when applied.[5] Both the actual costs and the optimal costs are expressed as the average costs per unit.

Given a European regulatory framework with effective unbundling rules, harmonised capacity products, the entry-exit system, and an equal level of transparency and transaction costs, the tariff of capacity is expected to be the driving force for deciding between transport alternatives. In absence of restrictions, it is economically efficient for network users to choose the least expensive alternative available. Therefore, we hypothesise that if network users have the choice between gas transport alternatives for one and the same market area, they book those capacities that are associated with the lowest total costs.

4 Data

Gas transport capacities are offered by TSOs and booked by network users. Capacities are offered on booking platforms, and allocated via auction procedures in line with European network access provision stated in the so-called *network code on capacity allocation mechanisms* (hereafter: NC CAM), to be applied since 1 November 2015 (European Commission 2017a). We use publicly available auction data from the leading European capacity booking platform for gas transport capacity named PRISMA (PRISMA European Capacity Platform GmbH 2016) for Germany for the calendar year 2016 to determine the efficiency of network users' booking behaviour.[6] Except for capacity to and from Poland, all auctions for primary capacity[7] at German TSOs are auctioned via PRISMA. The auction results include, among others, entry and exit market area and network points, entry and exit TSO, capacity on offer and allocated, as well as all tariffs and additional fees that are charged to network users. The introduction of NC CAM implied a huge change to the regulatory framework, and the allocation procedure. Furthermore, before NC CAM, not all TSOs offered capacity via PRISMA. To ensure data consistency, the data set used in the analysis covers the calendar year 2016 in which no major regulatory changes, in particular to capacity allocation and network tariffs, were applied.

The data extracted from PRISMA for the calendar year 2016 delivers 2,089,914 single observations of auctions. However, data cleansing is necessary (see Table 1). For reasons discussed earlier, we focus on German markets; auctions not involving German markets were eliminated.

[5] By comparison, in electricity markets, the inefficiency is calculated on the basis of the market price (i.e., the actual system marginal costs) and the system marginal costs in case of optimal dispatch.
[6] The data are available on the PRISMA website: https://platform.prisma-capacity.eu/#/reporting/standard. At the point in time, the analysis was conducted, the available data only covered the calendar year 2016. Since then, no further mergers took place in Germany, nor has the regulatory framework changed significantly. Thus, we are confident that analysing 2016 data allows for general conclusions.
[7] According to the Gas Regulation, primary capacity refers to capacity that is directly booked at the TSO. As compared to this, secondary capacity may be offered by network users, who have acquired this as primary capacity before.

Table 1
Summary of PRISMA auction data for 2016, and data cleansing. Source: PRISMA European Capacity Platform GmbH (2016); own calculations

	Number of auctions
PRISMA auction data (1 Jan. 2016 – 1 Jan. 2017)	2,089,914
- auctions not involving German markets	1,087,388
- auctions where capacity is not bundled and not firm	472,753
+ auctions where capacity is unbundled firm and to or from non-EU country	116,138
- cancelled auctions	182
Remaining	645,729
of which auctions to or from EU countries	529,618
of which auctions to or from non-EU countries	116,111

As outlined in Section 2.1, capacity may be either firm or interruptible. NC CAM prescribes TSO to offer firm capacity as bundled capacity. Bundling refers a package of corresponding firm entry and exit capacity that is auctioned. Interruptible capacity is not offered bundled. Firm capacity may be offered unbundled, though. However, this is limited to the case where available capacity on one side of the border exceeds the available firm capacity on the other side. Network users who already hold corresponding capacity at the other side, e.g., due to an existing long-term contract, may book unbundled firm capacity. Also, network users who are willing to combine one firm capacity product with interruptible capacity may be interested in unbundled firm capacity. However, network users assess their demand for interruptible capacity differently. Although relevant data are publicly available, the assessment, for example of the probability of interruption, and the resulting consequences, differ per network user. The risk preference differs as well. As a consequence, only firm and bundled capacity is considered for the analysis. Data on unbundled and interruptible capacities are omitted to avoid a distortion of the results. Finally, a small number of auctions is cancelled, so there are 645,618 observations remaining, of which 82% involves connection to and from EU countries.

The NC CAM only applies to TSOs within the EU. However, TSOs in the EU may have connections to non-EU countries. German TSOs offer capacity to non-EU countries also via PRISMA in line with the same provisions that apply for connection to other EU Member States. However firm capacity to and from non-EU countries is marketed only unbundled. Since the analysis can identify these auction data, they are not omitted but taken into account with special caution.

NC CAM harmonises capacity products. A capacity product is defined by its runtime, which may be a year, a quarter, a month, a day, or a number of hours of a day. Table 2 shows the number of auctions according to these harmonised capacity products.

Table 2
Number of PRISMA auctions, offered capacity, and booked capacity per capacity product of German TSOs in 2016. Source: PRISMA European Capacity Platform GmbH (2016); own calculations

Capacity product	Number of auctions	Capacity on offer [GWh/h/runtime]	Capacity booked [GWh/h/runtime]	Booking rate [%]
Within-day	617,100	899,590	1,150	0.13
Day-ahead	27,426	40,820	617	1.51
Month	590	1,094	35	3.23
Quarter	214	392	4	1.05
Year	399	884	14	1.63

In general, the longer the runtime, the fewer auctions take place. This seems obvious as, for example, within the runtime of a yearly capacity product, 365 (366) day-ahead auctions take place. Table 2 compares the amount of capacity offered and booked. The booking rate indicates that the demand for capacity is fairly low. However, the data cover all auctions with German TSOs in 2016. A network user may hold a long-term contract concluded in the past, which is still valid. Hence, such a network user has no, or at least a lower demand, for new capacity. However, the capacity products are dependent on each other. For example, capacity that was offered but not booked in the auction for yearly capacity will be offered again as a quarterly product. The amount left unallocated will be reoffered as a monthly product, day-ahead and maybe within-day product. Hence, one unit of capacity, which is not booked, will be counted several times.

Tables 3 and 4 give an overview of the number of auctions held in 2016 for each gas transport connection to and from Germany. For each flow direction, more auctions involve the NCG market area compared to GASPOOL (approx. 63% entry, 59% exit). The number of auctions held in 2016 varies among the different connections for both entry and exit. Entry from the Dutch TTF shows by far the largest number of auctions.

Table 3
Number of PRISMA auctions for entry capacity to the German market areas in 2016. Source: PRISMA European Capacity Platform GmbH (2016); own calculations

Exit \ Entry	GASPOOL	NCG	Sum
internal borders			
GASPOOL	-	73,194	73,194
NCG	56,940	-	56,940
external borders			
Austria	-	20,712	20,712
Belgium / Luxembourg	8,679	25,799	34,478
Czech Republic	8,787	36,293	45,080
Denmark	8,711	8,457	17,168
The Netherlands	31,698	77,130	108,828
Norway	22,195	24,377	46,572
Russia	18,236	-	18,236
Sum	155,246	265,962	421,208

Table 4
Number of PRISMA auctions for exit capacity from the German market areas in 2016. Source: PRISMA European Capacity Platform GmbH (2016); own calculations

Entry \ Exit	GASPOOL	NCG	Sum
internal borders			
GASPOOL	-	56,940	56,940
NCG	73,194	-	73,194
external borders			
Austria	-	3,842	3,842
Belgium / Luxembourg	8,519	17,610	26,129
Czech Republic	19,553	13,123	32,676
Denmark	12,159	-	12,159
France	-	19,690	19,690
The Netherlands	21,915	56,807	78,722
Switzerland	-	26,311	26,311
Norway	8,754	16,238	24,992
Sum	144,094	210,561	354,655

5 Methodology

5.1 Constructing homogeneous groups of auctions

Using the data described, we test the hypothesis formulated in Section 3.2 regarding the booking behaviour of network users. Since the dataset contains auctions that are single observations, we need to group these observations in such a way that any group of observations represents an exhaustive list of all alternatives from which a network user, with a specific need for gas transport capacity, could choose. This will be called a homogeneous group of auctions. For every homogeneous group of auctions, we determine the efficiency of the network users' booking behaviour.

The following attributes are considered to guarantee that all auctions have equal characteristics, and thus are alternatives for network users:

- *Market area entry/exit:*
  To be an alternative for network users, capacity needs to connect the same two market areas. Since capacity is a means to fulfil a commodity trade, the commodity trade prescribes the capacity needed. Every auction offering capacity that allows for the trade to be physically fulfilled needs to connect the same market area in the entry as well as in the exit direction. Treating entry and exit as two different attributes ensures that all auctions of a homogeneous group of auctions have the same flow direction, which is a necessary condition.
- *Capacity product (runtime):*
  A network user may place a bid in an auction offering, for example, a monthly capacity product. However, he may also book day-ahead capacity on every day of the month. By placing a bid in an auction for monthly capacity, the network user reveals a preference for the monthly product over a month of day-ahead products. Hence, other capacity products may be an alternative but are not preferred, or were not auctioned at the time the network users

wanted to obtain capacity. Thus, only capacities with the same runtime are considered alternatives.

- *Start of auction:*
  A capacity product may not be auctioned at the same time as the capacity of another runtime. The timing of capacity auctioning follows the so-called auction calendar (ENTSOG 2017a; European Commission 2017a). If a network user wants to book capacity at a certain point in time, he can only choose from those auctions that are open at that point in time. In accordance with the auction calendar and the auction algorithms applied, the start of an auction is harmonised. Only if the start of auctions is equal, the auctions can be alternatives.
- *Runtime start:*
  The capacity product and the start of the auction are not sufficient to cover the time dimension. According to the auction calendar, there are two different within-day auctions taking place at 7:00 p.m. each day: First, within-day capacity is offered for the next gas day.[8] It has the same runtime as a day-ahead product, i.e., one gas day of 24 hours. As within-day capacity is sold after day-ahead capacity, the amount offered is the non-allocated amount of firm day-ahead capacity. The runtime of this capacity starts at the next gas day. Second, within-day capacity for the rest of the current gas day is also auctioned at 7:00 p.m. The runtime of this capacity starts four hours after the start of the respective auctions, and ends at the end of the same gas day (European Commission 2017a). This underlines that within-day capacity is, in fact, a "rest-of-the-day" capacity. Since these two within-day auctions are not alternatives, the runtime start of the capacity products on offer is needed to define homogeneous groups of auctions.
- *Gas quality:*
  The chemical composition of gas may vary within a certain range. A capacity product in Germany may be either high calorific gas (H-gas) capacity or low calorific gas (L-gas) capacity. H- and L-gas capacity are not substitutes and, hence, they are no alternatives for network users.

If auctions have equal characteristics defined by these attributes, they belong to the same homogeneous group of auctions and can be considered as alternatives for network users. According to this definition, a homogeneous group can contain auctions of several TSOs. As stated in Section 2, this is the result of market mergers that have taken place, and a reason why network users have a choice between alternatives in gas transport. It is a necessary condition to allow for infrastructure competition. To determine the efficiency of the homogeneous groups, two conditions must apply:

(1) The efficiency of booking behaviour may only be assessed if network users have a choice. In case a homogeneous group of auctions consists of only one auction, networks users do not have a choice between alternatives. Thus, as a condition, a homogeneous group needs to contain multiple auctions.
(2) Since we intend to measure allocative efficiency, capacity needs to be allocated. Therefore, as a second condition, the sum of capacity allocated in all the auctions of that group must be greater than zero.

[8] A gas day is defined as the period of 24 hours starting at 5.00 UTC in wintertime and starting at 4.00 UTC in daylight saving time (European Commission 2017a). Hence, in central Europe, a gas day is from 6.00 a.m. till 6.00 a.m. the next day. If not stated differently, the time refers to Central European (Summer) Time, CE(S)T.

Only those homogeneous groups of auctions fulfilling these conditions are considered in determining the efficiency of the network users' booking behaviour.

5.2 Inefficiency measure

In order to test the hypothesis, the efficiency of every homogeneous group of auctions is determined. For this purpose, we calculate for each homogeneous group an indicator IER that compares the actual costs of booking observed with the optimal costs of booking (see Equation 1). Hence, IER will have a minimum value of 1.00, in which case efficiency is 100%.

$$\text{IER} = \frac{\text{actual costs of booking}}{\text{optimal costs of booking}} \tag{1}$$

IER is calculated for each homogeneous group of auctions. To interpret and compare the results, a weighted IER for a cluster of homogeneous groups can be used. Such a cluster may consist of, for example, all homogeneous groups connecting two specific market areas, and its IER may be compared with those of another connection. The weighted IER calculates a weighted average of all the individual IERs of the relevant homogeneous groups. As a weight, we use the runtime of the capacity product normalised to days, as well as the capacity allocated in kWh/h/runtime of each homogeneous group (indexed i) as expressed by Equation (2).

$$\text{IER}_{\text{weighted}} = \frac{\sum_{i=1}^{n} (\text{IER}_i \times \text{runtime}_i \times \text{allocated capacity}_i)}{\sum_{i=1}^{n} (\text{runtime}_i \times \text{allocated capacity}_i)} \tag{2}$$

First, we determine the actual cost of booking, i.e., what network users actually had to pay to TSOs for the capacity allocated. In order to do so, we calculate for every auction what a network user had to pay for a single unit of capacity. These costs are based on regulated network tariffs, which are the starting prices for the capacity auctions. In the case of contractual congestions, in which the demand for capacity exceeds the quantity on offer, an auction surcharge is added, which is determined automatically during the auctioning process with the aim of finding an equilibrium. Thus, the auction surcharge represents the price for scarcity.[9] Furthermore, additional charges or fees are considered if applied by the respective TSO. These may be charged, for example, for metering services, billing services, or gas quality conversion. All this information is contained in the PRISMA data used (see Section 4). As the costs may be charged in different units, all these components are harmonised to cent/kWh/h/runtime. In case charges are not provided in Euros, daily exchange rates of the European Central Bank are used to convert to Euros. The actual costs of booking are then determined for every homogeneous group of auctions. This is done by multiplying for every auction the costs of a single unit of capacity by the amount of capacity allocated and aggregating them per each homogenous group.

In order to calculate the optimal costs per homogenous group of auctions, we create a merit order for every homogeneous group by ranking all auctions in ascending order of the costs per unit of

[9] See Article 16 to 18 of NC CAM for further details on the auction algorithms and auction surcharge, the so-called *price* steps. These price steps are predefined for the auctions, are transparent during the auction, and contained in the data set used, as it is an integral part of the auction results.

capacity (see Section 3.2). The optimal costs of booking are then determined for every homogeneous group of auctions by multiplying the total capacity allocation of each homogeneous group with the costs according to the respective merit order. After having calculated the actual costs as well as the optimal cost, an IER is calculated for every homogeneous group of auctions using Equation (1). Applying Equation (2) yields weighted IER for different clusters of homogenous groups of auctions.

6 Results

6.1 Efficiency of booking

The conditions of a mandatory capacity allocation and the minimum size appear to have a large impact on the number of homogenous groups of auctions. As reported in Table 5, 645,729 observations are allocated to 262,881 groups following the definition of homogeneous groups. Approximately 36% (93,546) of all homogeneous groups need to be omitted as they consist of only a single auction, and hence do not offer a choice to network users. The second condition has an even larger impact. Only 1.5% of all groups contain at least one auction where at least one unit of capacity was allocated. This means that in the vast majority of all auctions, capacity was offered but not booked (see also Table 2). After applying the two conditions only 3,003 out of 262,881 homogeneous groups remain.

Table 6 shows the impact of the conditions applied to homogenous groups of auctions per capacity product. Less than one percent of all within-day auction and groups of within-day auctions meet the conditions. However, for within-day capacity, auctions, as well as homogeneous groups, amounts to approximately 96% of all data in the data set. The size of homogeneous groups varies between one and eight auctions, as shown by Table 7. The number of auctions is obtained by multiplying the size of groups with the number of homogeneous groups. Omitting groups consisting of one auction, and applying the condition of a successful capacity allocation, about 30% of all remaining homogeneous groups contain two auctions, and about 55% contain three auctions.

To analyse the efficiency of network users' booking behaviour, we cluster the individual inefficiency ratios, and apply the weighted IER according to Equation (2) using the runtimes and capacity allocated as the weights. Table 8 summarises the results of the efficiency calculation and shows that GASPOOL capacity (weighted IER: 1.17) is booked less efficiently compared to NCG capacity (weighted IER: 1.05). However, about three-quarters of the loss in monetary terms is associated with NCG capacity. Although there may be restrictions regarding booking capacity to and from non-EU countries, those capacities are booked more efficiently (weighted IER: 1.05) compared to connections to and from EU countries (weighted IER: 1.07). The overall inefficiency is about 6%, which amounts to about four million Euros.

Tables 10 to 15 in the Appendix show detailed results for different clusters of connections. According to these, about 81% of all inefficiencies in monetary terms for GASPOOL connections result from an inefficient booking behaviour of entry capacity from Norway (20%) and Russia (61%). The respective weighted IERs are 1.09 and 2.10. GASPOOL entry from NCG shows a relatively high weighted IER of 1.16, whereas the inefficiency in monetary terms is relatively low with about 5 thousand Euros. In terms of NCG connections, in particular, import capacity for L-gas from The Netherlands (58%), from Norway (12%), and export capacity to Austria (21%) reveal the highest inefficiencies in monetary terms. The respective weighted IERs are 1.04, 1.02, and 1.51. These highlight that a high monetary share of inefficiency and a high or low IER may, but not necessarily have to, correlate. The reason is that the number of auctions associated with a certain cluster of connections influences the inefficiency in monetary terms. A specific inefficiency may be obtained by a few auctions with high inefficiency but also by a high number of auctions with low inefficiencies. Hence, the weighted IER shows where efficiency gains are possible, whereas the inefficiency in monetary terms shows the impact of potential efficiency gains.

Table 5
Number of homogeneous groups of auctions[a] based on PRISMA auction data for Germany TSOs in 2016 under conditions. Source: PRISMA European Capacity Platform GmbH (2016); own calculations

	Number of auctions and homogeneous groups
Single auctions after data cleansing	645,729
Homogeneous groups of auctions	262,881
of which containing one auction	93,546
of which containing multiple auctions	169,335
of which no capacity allocated	258,957
of which capacity allocated	3,924
of which unconditional	259,878
of which conditional	3,003

[a] The number of conditional homogeneous groups of auctions refers to those that contain multiple auctions as well as allocated capacity as stated in Section 5.1. Unconditional refers to those auctions and homogenous groups on which the two conditions are not imposed.

Table 6
Number of homogeneous groups of auctions[a] based on PRISMA auction data for Germany TSOs in 2016 under conditions per capacity product. Source: PRISMA European Capacity Platform GmbH (2016); own calculations

Capacity product	Unconditional		Conditional		Conditional / Unconditional	
	Auctions	Homogeneous groups	Auctions	Homogeneous groups	Auctions [%]	Homogeneous groups [%]
Within-day	617,100	251,293	5,260	1,528	0.85	0.61
Day-ahead	27,426	10,955	4,014	1,374	5.01	12.54
Month	590	287	216	70	36.61	24.39
Quarter	214	100	32	14	14.95	14.00
Year	399	246	47	17	11.78	6.91
Sum	645,729	262,881	6,929	3,003	1.07	1.14

[a] The number of conditional homogeneous groups of auctions refers to those that contain multiple auctions as well as allocated capacity as stated in Section 5.1. Unconditional refers to those auctions and homogenous groups on which the two conditions are not imposed.

Table 7
Number and size of homogeneous groups of auctions based on PRISMA auction data of Germany TSOs in 2016, and allocation of capacity. Source: PRISMA European Capacity Platform GmbH (2016); own calculations

Number of auctions per homogeneous group	Number of homogeneous groups	of which no capacity was allocated	of which capacity was allocated
1	93,546	92,625	921
2	68,272	67,374	898
3	56,367	54,790	1,577
4	13,268	13,228	40
5	7,963	7,797	166
6	11,591	11,381	210
7	10,887	10,783	104
8	987	979	8
Sum	262,881	258,957	3,924

Table 8
Inefficiency based on PRISMA auction data of German TSOs in 2016. Source: PRISMA European Capacity Platform GmbH (2016); own calculations

Cluster of connections	Weighted IER	Inefficiency [thousand Euros]
GASPOOL entry	1.22	731
GASPOOL exit	1.02	48
Total GASPOOL	**1.17**	**780**
NCG entry	1.03	2,389
NCG exit	1.31	894
Total NCG	**1.05**	**3,283**
EU	1.07	3,002
Non-EU	1.05	1,028
Overall	**1.06**	**4,030**

6.2 Explaining observed inefficiencies by national regulation

As elaborated in Section 4, the analysis takes into account only firm capacity. With reference to the European regulatory framework, it has been assumed that gas transport capacity offered by the TSOs is harmonised such that the quality of capacity is always either firm or interruptible. Besides the European regulation, however, there is also national regulation. German firm capacity, which is analysed here, also includes conditional firm capacities foreseen by national regulation and introduced by German TSO.

Markets mergers also affect the quality of capacity products offered by a TSO. Within an entry-exit system, every entry point may be used to supply every exit point, which also holds if an entry-exit system consists of more than one TSO. However, this flexibility is limited by the capacity connecting TSO networks. If the intended gas flows of network users induce a flow between two networks of the same market area that exceeds the technical capacity, no transport is possible. However, if the capacity used to transport the gas is firm capacity, the TSOs do not have the right to interrupt the gas flow, although this would be necessary. Whilst market mergers resolve barriers to commodity trading, market mergers can impose restrictions in terms of firmness and free allocability of capacity. To face these restrictions, the total capacity amount on offer may be reduced, investments in network expansions may be undertaken, or the restrictions are reflected in the quality of the capacity offered (Wagner & Elbling GmbH 2014). German TSOs chose the latter option and introduced additional capacity types reflecting the restrictions implied by the merger taken place. All of them are treated as firm capacity although they are firm only conditionally. These conditions may be linked, for example, to fluctuations in demand or specific point-to-point connections (Kooperationsvereinbarung Gas (Annex 1) 2016). Hence, compared to European regulation, there are multiple firm capacity types in Germany. These conditions imply a risk, which is reflected in the networks tariffs by granting a discount (Bundesnetzagentur 2015).

Multiple firm capacity types offered by German TSO may have an impact on the network users' booking behaviour. Although there might be a less expensive conditional firm capacity on offer, the capacity may not be suitable for a network user. This may be either because of the conditions or because of the discount that may not adequately reflect the risk as assessed by the network user. As an explanation of the inefficiencies measured initially, we hypothesise that capacity type has an impact on booking behaviour. For example, capacity that is always firm and capacity that is firm only in accordance with a certain demand reflect different quality, and therefore are not complete substitutes. Hence, a network user who might be completely risk averse may never book conditional firm capacity even in case it is offered at a lower tariff compared to non-conditional firm capacity. If the capacity type matters, then the analysis needs to control not only for firm and interruptible capacity but also for different firm capacity types. Thus, the definition of homogeneous groups will be extended by the type of firm capacity for both entry and exit capacity of a firm bundled capacity product.

A stricter definition of a homogeneous group increases the number of groups, because auctions must share common characteristics in order to belong to the same group. Table 9 compares the number of homogeneous groups for the two different definitions of firm capacity. The stricter definition leads to an increase from 262,881 to 448,822 groups. However, the number of groups with at least two single auctions decreases by approximately 16%. The condition that capacity must be allocated in at least one auction of a group is also very restrictive. The number of groups meeting this condition rises by about 19%, which is less than the increase in all homogeneous groups (+71%). Applying the German definition of firm capacity, the number of groups meeting both conditions declines by about 42% as compared to applying the weaker definition of a homogenous group.

Taking account of differences in capacity types, approximately 68% of all homogenous groups contain only one auction, and hence, do not offer alternatives of transport capacity to network users. However, about 32% of all homogenous groups offer alternatives as they consist of at least two auctions with equal characteristics. If there was a higher harmonisation of capacity types leading to a lower number of capacity types, network user could choose from even more transport alternatives.

Table 9

Comparison of the number of homogeneous groups of auctions[a] based on PRISMA auction data of Germany TSOs in 2016 under conditions and according to the EU and German definition of firm capacity. Source: PRISMA European Capacity Platform GmbH (2016); own calculations

	Number of auctions and homogeneous groups	
	according to EU firm capacity	according to German firm capacity
Single auctions after data cleansing	645,729	645,729
Homogeneous groups of auctions	262,881	448,822
of which containing one auction	93,546	305,764
of which containing multiple auctions	169,335	143,058
of which no capacity was allocated	258,957	444,162
of which capacity was allocated	3,924	4,660
of which unconditional	259,878	447,095
of which conditional	3,003	1,727

[a] The number of conditional homogeneous groups of auctions refers to those that contain multiple auctions as well as allocated capacity as stated in Section 5.1. Unconditional refers to those auctions and homogenous groups on which the two conditions are not imposed.

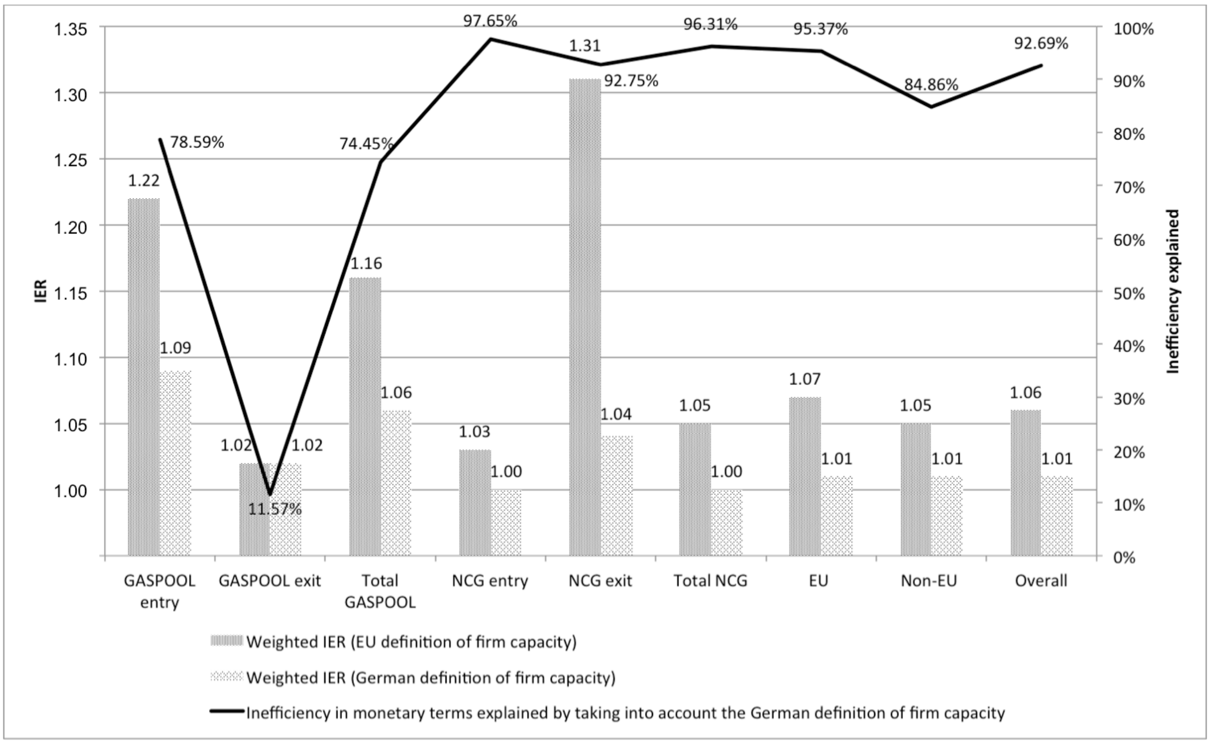
Figure 5 summarises the results of the adjusted efficiency calculation considering the German definition of firm capacity and compares it to the initial calculation using the EU definition of firm capacity. Initially, the weighted IER for GASPOOL entry and NCG exit show relatively high inefficiencies. Taking into account the different firm capacity types that exist in Germany results in a large decrease of these inefficiencies. Overall, GASPOOL has a weighted IER of 1.05 and NCG even of 1.00 compared to 1.17 and 1.05 initially calculated applying the EU definition of firm capacity. EU connections are at 1.01, falling from 1.07. Even though there may be additional restrictions influencing the booking behaviour at the border with non-EU countries, also these connections show a weighted IER of 1.01. Overall, the inefficiency measured is at about 1%. In monetary terms, approximately 93% of all inefficiencies can be explained by controlling for different firm capacity types as used in Germany. However, the reduction of the inefficiency in monetary terms explained by the different definition of firm capacity for GASPOOL exit is, compared to the other clusters of connections, relatively low (about 11.6%). Looking at the absolute numbers reveal that the inefficiency initially determined has already been relatively low for GASPOOL exit, and therefore, applying the different definition of firm capacity to explain inefficiencies only has a relatively small impact.

Tables 16 to 21 in the Appendix show detailed results for different clusters of connections. For GASPOOL connections, entry capacity from Norway shows the highest inefficiency (weighted IER: 1.09) accounting for about 78% of all the inefficiency measured for GASPOOL connections, which amounts to about 156 thousand Euros. For NCG connections, import from Norway has become full efficient with a weighted IER of 1.00 and no inefficiency in monetary terms. L-gas import capacity from The Netherlands to NCG also reveals a weighted IER of 1.00 but suggests an inefficiency of about 19 thousand Euros due to a relatively high number of auctions. This again shows that even small inefficiencies can lead to a certain amount in case the number of auctions is relatively high. Exit capacity from NCG to Austria is still relatively inefficient (weighted IER: 1.13) but the monetary impact is fairly low as the number of auctions is low as well. Exit capacity for H-gas from NCG to

The Netherlands, however, is booked relatively inefficiently (weighted IER: 1.21) causing an inefficiency of about 48 thousand Euros, which is approximately 39% of all inefficiencies for NCG connections.

Fig. 5

Inefficiency explained by taking account of the German definition of firm capacity based on PRISMA auction data of German TSOs in 2016. Source: PRISMA European Capacity Platform GmbH (2016); own calculations



7 Conclusions

European regulators aim at the higher integration of gas markets (ACER and CEER 2015). Merging gas markets could lead to competition among transmission system operators within the merged markets for cross-border transmission capacity. Assuming inter-TSO competition, it is expected that there are no constraints that prevent network users from making efficient choices, i.e., that they choose those network connections with the lowest network tariffs.

Analysing the booking behaviour of network users in the German gas markets in 2016, we find an inefficiency of approximately 6% when we only include one type of firm capacity as defined by European regulation. Most of the inefficiency can be explained by taking into account different types of firm capacity, which in Germany deal with network constraints. We find that market mergers have created transport alternatives for 32% of all cross-border capacity products, which are booked with an inefficiency of about 1%. Thus, we conclude that network users are sensitive to differences in gas transport capacity offered by TSOs, and that their booking behaviour is largely efficient. Our analysis underlines that network users making their booking decisions are not only sensitive to differences in network tariffs, but that differences in terms of the quality of capacity products also matter.

Our analysis differs from previous studies on market integration (e.g., Asche et al. 2013; Kuper and Mulder 2016; Petrovich 2013), as it does not focus on the degree of wholesale market integration but on the impact of gas market mergers on the competition among infrastructure operators. As we find that network users make efficient use of the booking alternatives that are created by merging markets, we conclude there are no constraints for network users to book the least expensive capacity on offer.

Our results reveal the possibility that market mergers have the potential to create infrastructure competition among TSOs for gas transport capacity. Such competition would be limited to specific cross-border capacity where capacity products have the same characteristics. In this respect, we find that taking into account the quality of capacity (the capacity type) is important. Further harmonisation of capacity types has the potential to increase the number of alternative capacity products at the border of merged gas markets. Since there is also capacity that is not affected by a market merger, a TSO regulation would still be necessary even if inter-TSO competition may be found for capacity at the border of merged gas markets. Nevertheless, changes to the regulatory framework may be economically reasonable to allow for the coexistence of regulation and competition. However, the question of whether or not inter-TSO competition for certain cross-border capacity exists cannot be answered conclusively from the results of our analysis. Such competition not only depends on the network users' behaviour but also on the behaviour of the TSOs. In this paper, we did not analyse how TSOs set the tariffs for access to their networks. TSOs set the tariffs based on the regulatory framework they are operating in. Therefore, before any conclusion about competition among TSOs within merged market areas can be drawn, it is necessary to investigate the TSOs behaviour, taking into account the constraints given by the regulatory framework.

The results of this analysis may be relevant to the debate over the European regulatory framework, which includes the means of harmonisation within the EU (European Parliament and Council of the European Union 2009b). One concept of harmonisation, for example, is the provision of so-called virtual interconnection points, which require TSOs to combine their network points that connect the same entry-exit systems into one virtual point for the sake of joint capacity marketing (European Commission 2017a). Our paper reveals that network users are able to choose among different capacity alternatives, and are making efficient booking decisions. Hence, restricting transport alternatives by introducing virtual interconnection points is not needed as a means to increase efficiency, at least not in the German gas market.

Appendix: Detailed results of inefficiency determination

Tables 10 to 15 show detailed results of the analysis for different clusters of connections: Tables 10 to 13 deal with connections to and from the German market areas; Table 10 (entry) and Table 11 (exit) with GASPOOL, Table 12 (entry) and Table 13 (exit) with NCG. The results are also shown separately for the borders of the German market areas with EU Member States (Table 14) and with non-EU countries (Table 15). In terms of the inefficiency ratio IER, the tables report the minimum, maximum, average ($\bar{x}$), standard deviation (σ) and coefficient of variation ($\sigma/\bar{x}$), and a capacity and runtime weighted average for each cluster of connection. All the calculations are based on auction data from PRISMA European Capacity Platform GmbH (2016). IER and costs are calculated as stated in Section 5.2. The number of conditional homogeneous groups and contained auctions refer to those groups that contain multiple auctions and allocated capacity as stated in Section 5.1. Unconditional refers to those auctions and homogenous groups on which the two conditions are not imposed.

Table 10
Inefficiency results for entry connections to GASPOOL based on PRISMA auction data for 2016

Exit	Gas quality	Unconditional: Homogeneous groups	Unconditional: Auctions	Conditional: Homogeneous groups	Conditional: Auctions	Efficiency ratio IER: Min.	Max.	$\bar{x}$	σ	$\frac{\sigma}{\bar{x}}$	Weighted	Actual costs [€]	Auction surcharge [€]	Optimal costs [€]	Inefficiency [€]
NCG	H	9,079	54,086	88	493	1.00	1.63	1.38	0.22	0,16	1.16	42,330	-	37,455	4,875
Norway	H	8,855	22,195	177	473	1.00	1.10	1.05	0.05	0.05	1.09	2,090,395	-	1,934,782	155,612
Russia	H	9,057	18,236	3	6	1.00	2.65	2.10	0.78	0.37	2.10	799,579	-	325,040	474,539
The Netherlands	L	9,016	22,895	368	1,025	1.00	1.92	1.07	0.16	0.15	1.02	3,409,200	10,843	3,323,662	96,381
Sum		36,007	117,412	636	1,997						1.22	6,341,504	10,843	5,620,939	731,407

Table 11
Inefficiency results for exit connections from GASPOOL based on PRISMA auction data for 2016

Entry	Gas quality	Unconditional: Homogeneous groups	Unconditional: Auctions	Conditional: Homogeneous groups	Conditional: Auctions	Efficiency ratio IER: Min.	Max.	$\bar{x}$	σ	$\frac{\sigma}{\bar{x}}$	Weighted	Actual costs [€]	Auction Surcharge [€]	Optimal costs [€]	Inefficiency [€]
Czech Republic	H	8,459	19,553	26	70	1.00	1.55	1.11	0.19	0.17	1.02	870,378	-	853,588	16,790
Denmark	H	8,642	12,159	65	130	1.00	1.03	1.00	0.01	0.01	1.00	10,548	-	10,507	41
NCG	H	9,082	56,724	117	723	1.00	1.61	1.06	0.15	0.14	1.01	1,418,425	-	1,397,795	20,630
The Netherlands	H	8,790	14,477	40	80	1.00	1.48	1.06	0.13	0.12	1.04	93,478	-	90,156	3,322
NCG	L	8,736	16,470	231	462	1.00	1.22	1.21	0.05	0.04	1.05	150,177	-	142,825	7,352
Sum		43,709	119,383	479	1,465						1.02	2,543,006	-	2,494,871	48,135

Table 12
Inefficiency results for entry connections to NCG based on PRISMA auction data for 2016

Exit	Gas quality	Unconditional		Conditional		Efficiency ratio IER						Actual costs [€]	Auction surcharge [€]	Optimal costs [€]	Inefficiency [€]
		Homogeneous groups	Auctions	Homogeneous groups	Auctions	Min.	Max.	$\bar{x}$	σ	$\frac{\sigma}{\bar{x}}$	Weighted				
Czech Republic	H	8,945	36,293	2	7	1.08	1.10	1.09	0.01	0.01	1.09	49	-	44	4
GASPOOL	H	9,082	56,724	117	723	1.00	1.61	1.06	0.15	0.14	1.01	1,418,425	-	1,397,795	20,630
Austria	H	5,479	20,712	10	35	1.38	2.01	1.60	0.23	0.14	1.49	6,449	-	4,372	2,077
Norway	H	8,985	24,377	201	581	1.00	1.31	1.16	0.08	0.07	1.02	21,785,433	-	21,387,847	397,586
The Netherlands	H	9,084	52,550	139	753	1.00	1.92	1.09	0.13	0.12	1.06	1,196,677	17,029	1,143,066	70,640
Belgium / Luxembourg	H	8,915	25,799	10	23	1.00	1.18	1.03	0.06	0.06	1.01	2,194	22	2,193	22
GASPOOL	L	8,736	16,470	231	462	1.00	1.22	1.21	0.05	0.04	1.05	150,177	-	142,825	7,352
The Netherlands	L	8,856	24,580	949	2,720	1.00	1.21	1.04	0.06	0.06	1.04	52,360,236	96,325	50,565,743	1,890,818
Sum		68,082	257,505	1,659	5,304						1.03	76,919,640	113,376	74,643,885	2,389,129

Table 13
Inefficiency results for exit connections from NCG based on PRISMA auction data for 2016

Entry	Gas quality	Unconditional		Conditional		Efficiency ratio IER						Actual costs [€]	Auction surcharge [€]	Optimal costs [€]	Inefficiency [€]
		Homogeneous groups	Auctions	Homogeneous groups	Auctions	Min.	Max.	$\bar{x}$	σ	$\frac{\sigma}{\bar{x}}$	Weighted				
Switzerland	H	9,019	26,311	35	87	1.00	1.00	1.00	-	-	1.00	1,149,916	-	1,149,916	-
Czech Republic	H	8,433	13,123	3	6	1.04	1.08	1.06	0.02	0.02	1.06	8,663	-	8,247	416
GASPOOL	H	9,079	54,086	88	493	1.00	1.63	1.38	0.22	0.16	1.16	42,330	-	37,455	4,875
France	H	6,855	19,690	55	153	1.00	1.16	1.03	0.03	0.03	1.04	631,453	-	611,244	20,209
Austria	H	2,990	3,842	196	402	1.00	10.05	3.01	2.24	0.74	1.51	2,356,379	284,590	1,961,632	679,338
The Netherlands	H	9,000	39,510	230	1,191	1.00	11.77	1.13	0.72	0.64	1.18	1,016,633	153,009	983,087	186,555
Belgium / Luxembourg	H	8,904	17,610	7	14	1.00	1.00	1.00	-	-	1.00	62,216	35	62,121	130
The Netherlands	L	8,183	17,297	51	135	1.00	1.21	1.03	0.07	0.07	1.02	176,781	16	174,162	2,635
Sum		62,463	191,469	665	2,481						1.31	5,444,371	437,650	4,987,864	894,158

Table 14
Inefficiency results for entry and exit connections to and from Germany and adjacent EU countries based on PRISMA auction data for 2016

Capacity product	Gas quality	Unconditional		Conditional		Efficiency ratio IER						Actual costs [€]	Auction surcharge [€]	Optimal costs [€]	Inefficiency [€]
		Homogeneous groups	Auctions	Homogeneous groups	Auctions	Min.	Max.	$\bar{x}$	σ	$\frac{\sigma}{\bar{x}}$	Weighted				
Within-day	H	157,261	418,522	473	2,314	1.00	11.77	1.11	0.52	0.47	1.13	2,649,957	164,698	2,541,032	273,623
Within-day	L	43,104	87,401	894	2,499	1.00	1.92	1.05	0.11	0.10	1.03	15,944,187	101,351	15,542,562	502,977
Day-ahead	H	6,883	18,671	469	1,606	1.00	10.05	1.92	1.72	0.90	1.98	1,776,639	289,987	1,359,291	707,334
Day-ahead	L	1,904	3,984	682	1,787	1.00	1.75	1.09	0.10	0.09	1.06	5,540,668	5,832	5,279,987	266,513
Month	H	204	420	34	127	1.00	1.61	1.23	0.22	0.18	1.01	1,696,906	-	1,678,617	18,289
Month	L	35	75	19	47	1.00	1.11	1.03	0.04	0.04	1.04	10,480,214	-	10,105,814	374,400
Quarter	H	72	156	5	12	1.00	1.00	1.00	-	-	1.00	1,300,800	-	1,300,800	-
Quarter	L	12	28	1	2	1.58	1.58	1.58	-	-	1.58	23,316	-	14,735	8,580
Year	H	193	315	7	21	1.00	1.58	1.18	0.21	0.18	1.02	291,569	-	285,767	5,802
Year	L	28	46	3	7	1.00	1.11	1.05	0.05	0.05	1.04	24,108,008	-	23,263,293	844,716
Sum		209,696	529,618	2,587	8,422						1.07	63,812,264	561,868	61,371,898	3,002,234

Table 15
Inefficiency results for entry and exit connections to and from Germany and adjacent non-EU countries based on PRISMA auction data for 2016

Capacity product	Gas quality	Unconditional		Conditional		Efficiency ratio IER						Actual costs [€]	Auction surcharge [€]	Optimal costs [€]	Inefficiency [€]
		Homogeneous groups	Auctions	Homogeneous groups	Auctions	Min.	Max.	$\bar{x}$	σ	$\frac{\sigma}{\bar{x}}$	Weighted				
Within-day	H	50,928	111,177	161	447	1.00	1.21	1.10	0.09	0.08	1.08	654,879	-	605,604	49,275
Day-ahead	H	2,168	4,771	223	621	1.00	1.31	1.10	0.09	0.08	1.09	851,493	-	784,673	66,820
Month	H	48	95	17	42	1.00	1.21	1.10	0.05	0.05	1.10	1,275,151	-	1,159,726	115,425
Quarter	H	16	30	8	18	1.00	2.65	1.50	0.67	0.45	1.57	1,672,401	-	1,107,524	564,878
Year	H	25	38	7	19	1.00	1.10	1.02	0.03	0.03	1.01	21,371,399	-	21,140,059	231,340
Sum		53,185	116,111	416	1,147						1.05	25,825,323	-	24,797,586	1,027,738

Tables 16 to 21 show detailed results of the analysis for different clusters of connections taking into account the German definition of firm capacity: Tables 16 to 19 deal with connections to and from the German market areas; Table 16 (entry) and Table 17 (exit) with GASPOOL, Table 18 (entry) and Table 19 (exit) with NCG. The results are also shown separately for the borders of the German market areas with EU Member States (Table 20) and with non-EU countries (Table 21). In terms of the inefficiency ratio IER, the tables report the minimum, maximum, average ($\bar{x}$), standard deviation (σ) and coefficient of variation ($\sigma/\bar{x}$), and a capacity and runtime weighted average for each cluster of connection. All the calculations are based on auction data from PRISMA European Capacity Platform GmbH (2016). IER and costs are calculated as stated in Section 5.2. The number of conditional homogeneous groups and contained auctions refer to those groups that contain multiple auctions and allocated capacity as stated in Section 5.1. Unconditional refers to those auctions and homogenous groups on which the two conditions are not imposed.

Table 16
Inefficiency results for entry connections to GASPOOL based on PRISMA auction data for 2016 considering German definition of firm capacity

Exit	Gas quality	Unconditional		Conditional		Efficiency ratio IER						Actual costs [€]	Auction surcharge [€]	Optimal costs [€]	Inefficiency [€]
		Homogeneous groups	Auctions	Homogeneous groups	Auctions	Min.	Max.	$\bar{x}$	σ	$\frac{\sigma}{\bar{x}}$	Weighted				
NCG	H	32,722	54,086	76	252	1.00	1.31	1.18	0.10	0.08	1.06	16,232	-	15,272	961
Norway	H	8,855	22,195	177	473	1.00	1.10	1.05	0.05	0.05	1.09	2,090,395	-	1,934,782	155,612
Russia	H	17,389	18,236	0	0	-	-	-	-	-	-	-	-	-	-
The Netherlands	L	22,895	22,895	0	0	-	-	-	-	-	-	-	-	-	-
Sum		81,861	117,412	253	725						1.09	2,106,627	-	1,950,054	156,573

Table 17
Inefficiency results for exit connections from GASPOOL based on PRISMA auction data for 2016 considering German definition of firm capacity

Entry	Gas quality	Unconditional		Conditional		Efficiency ratio IER						Actual costs [€]	Auction surcharge [€]	Optimal costs [€]	Inefficiency [€]
		Homogeneous groups	Auctions	Homogeneous groups	Auctions	Min.	Max.	$\bar{x}$	σ	$\frac{\sigma}{\bar{x}}$	Weighted				
Czech Republic	H	12,898	19,553	20	42	1.00	1.69	1.14	0.22	0.19	1.02	857,390	-	842,814	14,576
Denmark	H	12,159	12,159	0	0	-	-	-	-	-	-	-	-	-	-
NCG	H	25,119	56,724	118	452	1.00	1.61	1.06	0.14	0.13	1.01	1,411,302	-	1,393,986	17,315
The Netherlands	H	8,790	14,477	40	80	1.00	1.48	1.06	0.13	0.12	1.04	93,478	-	90,156	3,322
NCG	L	8,736	16,470	231	462	1.00	1.22	1.21	0.05	0.04	1.05	150,177	-	142,825	7,352
Sum		67,702	119,383	409	1,036						1.02	2,512,347	-	2,469,781	42,565

Table 18
Inefficiency results for entry connections to NCG based on PRISMA auction data for 2016 considering German definition of firm capacity

Exit	Gas quality	Unconditional		Conditional		Efficiency ratio IER						Actual costs [€]	Auction surcharge [€]	Optimal costs [€]	Inefficiency [€]
		Homogeneous groups	Auctions	Homogeneous groups	Auctions	Min.	Max.	$\bar{x}$	σ	$\frac{\sigma}{\bar{x}}$	Weighted				
Czech Republic	H	27,586	36,293	2	4	1.07	1.08	1.08	0.01	0.01	1.08	49	-	45	4
GASPOOL	H	25,119	56,724	118	452	1.00	1.61	1.06	0.14	0.13	1.01	1,411,302	-	1,393,986	17,315
Austria	H	12,370	20,712	10	24	1.00	1.23	1.06	0.08	0.08	1.02	6,449	-	6,350	99
Norway	H	16,746	24,377	161	322	1.00	1.00	1.00	-	-	1.00	14,993,504	-	14,993,504	0
The Netherlands	H	26,226	52,550	137	373	1.00	1.45	1.03	0.08	0.08	1.01	1,054,807	7,981	1,050,544	12,243
Belgium / Luxembourg	H	19,343	25,799	2	4	1.00	1.12	1.06	0.06	0.06	1.11	-	-	-	-
GASPOOL	L	8,736	16,470	231	462	1.00	1.22	1.21	0.05	0.04	1.05	150,177	-	142,825	7,352
The Netherlands	L	17,141	24,580	496	992	1.00	1.16	1.00	0.01	0.01	1.00	17,797,001	19,218	17,797,001	19,218
Sum		153,267	257,505	1,157	2,633						1.00	35,413,289	27,199	35,384,255	56,231

Table 19
Inefficiency results for exit connections from NCG based on PRISMA auction data for 2016 considering German definition of firm capacity

Entry	Gas quality	Unconditional		Conditional		Efficiency ratio IER						Actual costs [€]	Auction surcharge [€]	Optimal costs [€]	Inefficiency [€]
		Homogeneous groups	Auctions	Homogeneous groups	Auctions	Min.	Max.	$\bar{x}$	σ	$\frac{\sigma}{\bar{x}}$	Weighted				
Switzerland	H	9,019	26,311	35	87	1.00	1.00	1.00	-	-	1.00	1,149,916	-	1,149,916	-
Czech Republic	H	13,123	13,123	0	0	-	-	-	-	-	-	-	-	-	-
GASPOOL	H	32,722	54,086	76	252	1.00	1.31	1.18	0.10	0.08	1.06	16,232	-	15,272	961
France	H	13,595	19,690	42	84	1.00	1.13	1.01	0.03	0.03	1.02	459,213	-	455,023	4,190
Austria	H	3,718	3,842	8	16	1.00	1.42	1.06	0.14	0.13	1.13	71,271	9,332	71,159	9,443
The Netherlands	H	35,082	39,510	121	242	1.00	13.23	1.16	1.12	0.97	1.21	206,377	47,345	206,133	47,589
Belgium / Luxembourg	H	17,610	17,610	0	0	-	-	-	-	-	-	-	-	-	-
The Netherlands	L	8,183	17,297	51	135	1.00	1.21	1.03	0.07	0.07	1.02	176,781	16	174,162	2,635
Sum		133,052	191,469	333	816						1.03	2,079,790	56,693	2,071,665	64,818

Table 20
Inefficiency results for entry and exit connections to and from Germany and adjacent EU countries based on PRISMA auction data for 2016 considering German definition of firm capacity

Capacity product	Gas quality	Unconditional Homogeneous groups	Unconditional Auctions	Conditional Homogeneous groups	Conditional Auctions	Efficiency ratio IER Min.	Max.	$\bar{x}$	σ	$\frac{\sigma}{\bar{x}}$	Weighted	Actual costs [€]	Auction surcharge [€]	Optimal costs [€]	Inefficiency [€]
Within-day	H	298,392	418,522	327	830	1.00	13.23	1.08	0.69	0.64	1.06	1,540,315	49,998	1,523,800	66,514
Within-day	L	64,205	87,401	431	893	1.00	1.22	1.01	0.04	0.04	1.01	4,467,039	19,235	4,458,426	27,847
Day-ahead	H	13,256	18,671	206	625	1.00	1.42	1.08	0.12	0.11	1.04	652,867	14,659	644,352	23,173
Day-ahead	L	2,923	3,984	335	672	1.00	1.22	1.14	0.11	0.10	1.00	2,126,153	-	2,124,797	1,356
Month	H	285	420	35	100	1.00	1.69	1.16	0.21	0.18	1.01	1,688,423	-	1,673,491	14,932
Month	L	57	75	10	20	1.00	1.00	1.00	-	-	1.00	3,993,695	-	3,993,695	-
Quarter	H	106	156	1	2	1.00	1.00	1.00	-	-	1.00	3,405	-	3,405	-
Quarter	L	20	28	-	-	-	-	-	-	-	-	-	-	-	-
Year	H	258	315	7	16	1.00	1.58	1.19	0.20	0.17	1.02	291,557	-	286,435	5,122
Year	L	42	46	2	4	1.00	1.11	1.06	0.06	0.06	1.00	7,537,072	-	7,537,070	3
Sum		379,544	529,618	1,354	3,162						1.01	22,300,526	83,892	22,245,471	138,947

Table 21
Inefficiency results for entry and exit connections to and from Germany and adjacent non-EU countries based on PRISMA auction data for 2016 considering German definition of firm capacity

Capacity product	Gas quality	Unconditional Homogeneous groups	Unconditional Auctions	Conditional Homogeneous groups	Conditional Auctions	Efficiency ratio IER Min.	Max.	$\bar{x}$	σ	$\frac{\sigma}{\bar{x}}$	Weighted	Actual costs [€]	Auction surcharge [€]	Optimal costs [€]	Inefficiency [€]
Within-day	H	66,315	111,177	158	376	1.00	1.10	1.02	0.04	0.04	1.02	642,121	-	631,058	11,063
Day-ahead	H	2,847	4,771	187	442	1.00	1.10	1.03	0.04	0.04	1.04	593,511	-	574,018	19,493
Month	H	67	95	16	36	1.00	1.10	1.06	0.05	0.05	1.00	884,382	-	884,382	-
Quarter	H	23	30	5	10	1.00	1.10	1.06	0.05	0.05	1.09	872,822	-	805,254	67,568
Year	H	26	38	7	18	1.00	1.10	1.01	0.03	0.03	1.00	15,240,979	-	15,183,491	57,488
Sum		69,278	116,111	373	882						1.01	18,233,815	-	18,078,203	155,612

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