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Assessment of the Shadow Auction Mechanism as a Fallback Procedure for Single Day-Ahead Coupling

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Abstract

In the event of Single Day-Ahead Coupling being unavailable, fallback procedures are triggered. The main fallback procedure used for the allocation of cross-border-capacity in the day-ahead market timeframe is the explicit allocation in the form of physical transmission rights of electrical energy, also known as Shadow Auction.

According to the European Commission, any Single Day-Ahead Coupling fallback procedure should lead to an "efficient" way of allocating cross border electricity transmission capacity. Yet, the efficiency of the Shadow Auction as the main fallback procedure was questioned in the past considering its historical results. As a possible cause, legislation on remuneration of long-term transmission rights based on market spreads, was discussed within market participants.

ENTSO-E conducted a study with the support of Technische Hochschule Ulm to assess the question whether remuneration of long-term transmission rights based on market spreads reduces incentives to allocate capacity in the Shadow Auction and, thus, reduces its efficiency. To assess economic incentives for market participants to take part in the Shadow Auction mechanism, a Cournot model was developed considering historical bid curves and cross-border transmission capacities. By using fundamental easy-to-access data, this study aims to produce understandable and interpretable results for this complex scenario.

The results show that market participants owning long-term transmission rights currently have at most reduced incentives to participate in Shadow Auctions compared to other market participants. In practice, this leads to a measurable loss of public welfare, suggesting that modifications are necessary. The study concludes by discussing proposals for possible changes.

Keywords Market Coupling · Shadow Auction · Long-Term Transmission Rights · Energy Regulation

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Bewertung des Shadow Auction Mechanismus als Backup-Verfahren für das Single Day-Ahead-Coupling

Zusammenfassung

Für den Ausfall des Single Day-Ahead-Coupling (SDAC) wird als Backup-Verfahren die sogenannte *Shadow Auction* (SA) eingesetzt. Dabei wird zonenübergreifende Kapazität im Day-Ahead-Markt in Form von physischen Übertragungsrechten über explizite Auktionen vergeben.

Gemäß der Regulierung der Europäischen Union muss die Vergabe von zonenübergreifender Kapazität in einem Backup-Verfahren für das SDAC auf „effiziente“ Art erfolgen. In der Vergangenheit wurde jedoch die Effizienz der SA aufgrund historischer Ergebnisse vermehrt in Frage gestellt. Als mögliche Ursache wurde eine Regulierung der EU diskutiert, welche vorgibt, dass langfristige, zonenübergreifende Übertragungsrechte auf der Basis von Marktspreads vergütet werden müssen. Auf Initiative der ENTSO-E hin wurde mit Unterstützung der Technischen Hochschule Ulm eine Studie durchgeführt, die analysieren soll, ob die Vergütung von langfristigen Übertragungsrechten auf Grundlage von Marktspreads die Anreize für die Kapazitätsvergabe in den *Shadow Auction* tatsächlich verringert und somit deren Effizienz mindert. Um die ökonomischen Anreize der Marktteilnehmer zur Teilnahme an der *Shadow Auction* zu bewerten, wurde ein Cournot-Modell unter Verwendung historischer Gebotskurven und zonenübergreifender Übertragungskapazitäten entwickelt. Ziel der umsetzungsorientierten Studie ist es durch die Verwendung grundlegender, leicht zugänglicher Daten, verständliche und interpretierbare Ergebnisse für dieses komplexe Szenario zu präsentieren.

Die Ergebnisse zeigen, dass Marktteilnehmer, die langfristige Übertragungsrechte besitzen, derzeit im Vergleich zu anderen Marktteilnehmern zumindest verringerte Anreize haben an den *Shadow Auctions* teilzunehmen. In der Praxis führt dies zu einem messbaren Verlust an öffentlicher Wohlfahrt sodass regulatorische Änderungen gegeben sind. Verschieden Vorschläge zu entsprechenden Änderungen werden abschließend in der Studie diskutiert.

Abbreviations

ACER European Union Agency for the Cooperation of Energy Regulators

Symbols

bze exporting Bidding zone

1 Introduction

The so-called single day-ahead coupling (SDAC) depicts the auctioning process to match collected orders and simultaneously allocate cross-zonal capacity for different bidding zones in the day-ahead market. In the event of unavailability of the SDAC (i.e., decoupling event[1]), fallback procedures are triggered according to Article 44 in the European Commission (EC) regulation “Establishing a guideline on capacity allocation and congestion management” (EC 2015). The main fallback procedure used for the allocation of cross-border-capacity in the day-ahead market timeframe, is the explicit allocation in the form of Physical Transmission Rights (PTR) of electrical energy, also known as Shadow Auction (SA) (JAO 2018).

Article 44 (EC 2015) “Establishment of fallback procedures” mandates that TSOs “By 16 months after the entry into force of this Regulation [...] shall develop a proposal for robust and timely fallback procedures to ensure efficient, transparent and non-discriminatory capacity allocation in the event that the single day-ahead coupling process is unable to produce results”. With the start of Central Western Europe (CWE) Market Coupling on 9 November 2010 (Weber et al. 2010), as the main predecessor of today’s SDAC, the implementation of the SA-mechanism as the fallback procedure was obvious, as it retained in most parts the widely known former standard procedure for explicit allocation of cross-border-capacity. Since 2010, the SA-mechanism has been standardized and centralized at the Joint Allocation Office (JAO) for different bidding zone borders but not changed substantially.

So far, the SA-mechanism has been executed only few times—last on 13 January 2021 as IT issues at the European Power Exchange (EPEX) caused a partial decoupling event (SDAC JSC 2021). Consequently, ENTSO-E held a workshop on remuneration flaws and mitigation actions in April 2021, conducting multiple surveys about the Shadow Auction. The SA-mechanism was criticized by relevant stakeholders, like market participants or regulators, as it seemed to cause (or did not prevent) an inefficient or even—at some bidding zone borders—incomplete allocation of capacity. Quickly, it was speculated that the complexity of the SA-mechanism excludes *de facto* many small and medium market participants and thereby, reduces liquidity in the explicit auctions of PTRs in a decoupling event. Yet, this may only be part of the explanation as some major market partici-

[1] The decoupling of the individual market areas e.g. due to an error in the bidding process. This results in auctions for the following day being held in each country individually.

pants holding financial or physical Long Term Transmission Rights (LTTRs) might be in fact not economically incentivized to participate in the explicit auction (ENTSOE-E 2021).

To address the question why the SA-mechanism as a fallback procedure failed in efficiently allocating capacity, a study concerning economic motivation or demotivation of different types of market participants to engage in explicit auctions in case of a decoupling was initiated by ENTSO-E and carried with the support of Technische Hochschule Ulm. The implementation-oriented model approach used in the study includes modelling probable profit or loss of different types of market participants taking part in the SA based on historical market data. Specifically, the study assesses how LTTR remuneration on the basis of day-ahead market spreads affects market participants' incentives to take part in the SA.

The paper is organized as follows. Sect. 2 elaborates on the capacity allocation mechanisms briefly mentioned in this introduction. Sect. 3 gives a short overview on existing literature using Cournot based models for energy markets. Furthermore, it introduces the basic model approach used in this paper. In Sect. 4 data used for the model is described. The mathematical formulation for the developed model along with the different considered scenarios is given in Sect. 5. In Sect. 6 results regarding the allocated capacity as well as average welfare effects considering the different scenarios are presented. Sect. 7 concludes by discussing proposals for changes to the SA.

2 Cross Border Capacity Allocation Mechanisms

To better understand mechanisms relevant for this study, this section briefly introduces the most important concepts of cross border capacity allocation.

Cross border capacity allocation differentiates between long term allocation in form of Long-Term Transmission Rights (LTTRs) and short-term allocation via implicit Single Day-Ahead Coupling (SDAC).

Long Term Transmission Rights (LTTRs) are considered to be essential features of the electricity market as they ensure cross-border trade between bidding zones on a long-term basis e.g., for hedging purposes. LTTRs are auctioned via the forward capacity allocation, which is performed on the single allocation platform (SAP) established by all European TSOs through the joint allocation office (JAO) (EC 2016).

The regulatory framework for forward capacity allocation is defined by the harmonised allocation rules (HAR). Particularly they set the rights and obligations for participants as well as requirements for participation in the auction. Among other things, the HAR describe the process of the auction, including determining the marginal price as the auctions result. HAR also defines rules on secondary trading of capacity among traders and the return of LTTRs to the TSOs (ACER 2021).

LTTRs are divided into Physical and Financial Transmission Rights.

Physical Transmission Rights (PTRs) grant the trader exclusive rights to transfer a predefined quantity of energy in between two bidding zones in a specific time period and direction (EC 2016). In the case of Long Term PTRs, returned long-term rights are sold, i.e. the TSO sells them on behalf of the owner (trader). This is done via a nomination to both the TSO of the exporting country and the TSO of the importing country. Nomination is hereby defined as "the notification of the use of long-term cross-zonal capacity by a physical transmission rights holder and its counterparty, or an authorized third party, to the respective TSOs" (EC 2016). The owner of the PTR receives the same compensation as the TSO, i.e., in the regular case of implicit market coupling, the price difference between the two market areas concerned. The situation is different in case of a SA. Here, the owner only receives the result of the SA as compensation—this can be much lower than this price difference (JAO 2018).

Financial Transmission Rights (FTRs) are financial entitlements that grant the holder financial remuneration from the TSO based on the day-ahead market spreads of two relevant bidding zones. The remuneration is regulated in Article 35 of the European Commission regulation "Establishing a guideline on forward capacity allocation" (EC 2016). Opposed to PTRs, FTRs neither give nomination right nor allow the holder to influence the flow of energy between bidding zones (EC 2016).

Single Day-Ahead Coupling aims to efficiently allocate cross border transmission capacity via implicit auctions to maximize social welfare. Market participants in the SDAC only bid for electricity on the exchanges, not reviving individual allocation of capacity. Exchanges then consider available cross-border capacity when calculating prices, aiming to minimize price differences in between market areas (EPEX SPOT 2022). To do so different wholesale electricity markets are coupled, while simultaneously considering cross-border transmission constraints. Here, SDAC relies on a common price coupling algorithm (PCR EUPHEMIA) which considers these constraints as well as network capacities (provided by TSOs) and bids and offers provided by the Nominated Electricity Market Operators (NEMOs). The algorithm returns clearing prices, matched trades, scheduled exchanges, and the net position of each bidding zone (ENTSO-E 2022).

In case implicit allocation is not possible, the Shadow Auction fallback mechanism is deployed, in which explicit day-ahead auctions (allocations) are performed. Thereby only cross zonal capacity is auctioned. Energy must be bought at the respective exchanges (EC 2016). Bids for the SA can be placed at any time. When TSOs and exchanges trigger decoupling, JAO informs participants on the deadline to either place or update their bids. After the deadline, allocation results are computed, and winners will receive the required documents for nomination purposes by JAO (JAO 2018).

3 Model Approach

Two main objectives were pursued developing the model in this study: the use of a straightforward and easy-to-understand modelling approach and the use of public or other easy-to-access data.

The first objective was determined by the broad target group of the study (ENTSO-E and European TSOs, market operators, various types of market participants, regulators, etc.). Hence, the model development was restricted to a simulation framework for selected relevant parts of the SA focusing on assessing economic incentives to allocate cross-bidding-zone-border capacity (cross border capacity) for different types of market participants (electricity traders). This simulation framework intends to enable comparing different scenarios relatively without perfectly modelling reality in all aspects, thus, not necessarily allowing isolated statements on individual scenarios.

The second objective was determined by the transparency and verifiability of the results. Therefore, to integrate information on market coupling and grid capacities into the model, use of publicly accessible data from JAO and ENTSO-E was preferred. Market data was restricted to aggregated bid curves publicly or commercially published by market operators, without using fundamental power plant data or a highly sophisticated network model.

Considering the market situation within a SA, three main types of trading activities can be differentiated:

- Cross-border long-term & day-ahead → Traders that hold LTTR and trade in the day-ahead markets;
- Cross-border only day-ahead → Traders that only use the day-ahead market to cover their positions and are not sensitive to LTTR; and
- Day-ahead only in one or selected bidding zones → Traders that only use the day-ahead market to cover their positions and are not active in cross-border activities.

Previous decoupling events have shown that only a limited number of traders take part in the SA, while many traders are only active within one or more bidding zones (ENTSO-E 2021).

How to economically interpret the market situation of a SA?

First, we may consider a monopoly, where JAO acts as monopolist and the limited number of traders as buyers of cross border capacity. Here, typical characteristics like profit maximization or price discrimination by the monopolist are missing. Yet the empirical findings seem to indicate that the traders engage in strategic behavior in a SA.

This strategic behavior of a limited number of traders in the SA might suggest interpreting the market situation as an oligopoly. But what product is being sold by traders as oligopolists on SA, and who are the buyers of that product? In a somewhat unorthodox interpretation, first a "service of cross border capacity allocation" is defined as a product. This involves the purchase of electricity in one market area and acquisition of cross border capacity and sale of electricity in another market area. Buyers of such a product (mostly indirectly) are all electricity traders who are active in the day-ahead market in one or more market areas (and mostly not active in cross border activities). Such an interpretation implies that trading activities of SA participants are characterized by a strategic interaction, while traders acting exclusively within a bidding zone only submit bids based on marginal costs or marginal utility.

In the past, several theoretical approaches were developed to explain such a market constellation. In recent years, Cournot approaches have been used particularly frequent for modelling energy markets. This is supported by Wolak and Patrick (2001) who are suggesting that Cournot competition appropriately represents the electricity generation market in their paper on the "impact of market rules and market structure on the price determination process in the England and Wales electricity market". The study provides important insights on how to apply their findings on incomplete competition in the energy market to other scenarios outside of the United Kingdom.

Pepermans and Willems (2010) used a Cournot approach in one of their scenarios to numerically derive the social optimal transmission process for cost recovery considering congestions in the grid, while allowing for market power in generation. Furthermore, the paper takes into account the impact of incentives for market participants, i.e., energy producers, in order to improve overall welfare.

Müller et al. (2011) assessed the extent to which cost- and incentive-based regulatory regimes incentivize investment in intelligent grids.

Both Pepermans and Willems and Müller et al. implement a Cournot-based approach towards modeling incomplete competition caused by limited grid transmission capacities.

It is important to mention that Cournot approaches are subject to some theoretical limitations such as complete market transparency. However, they have proven useful in

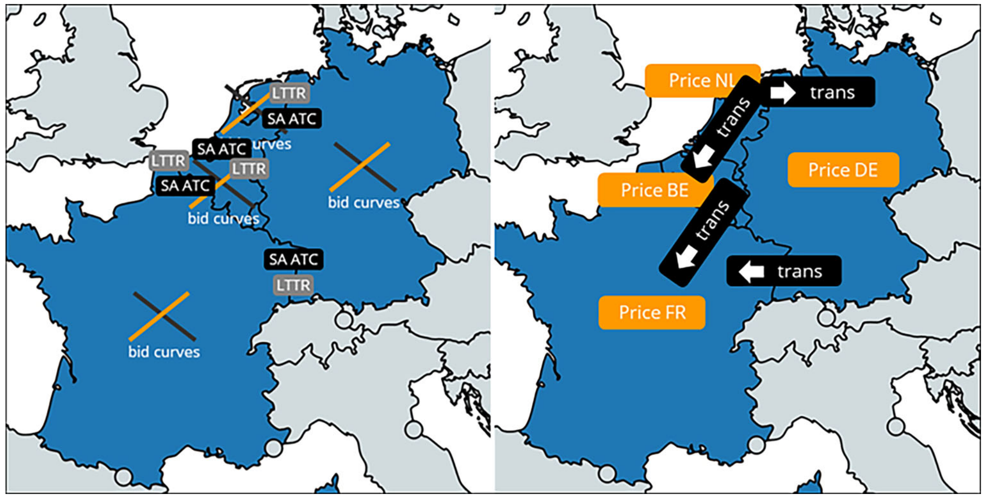

Fig. 1 Input and output variables for the Cournot approach (*Left Side:* LTTRs, ATCs and Aggregated Bid Curves as Input. *Right Side:* Market Prices and Flows as Output)

the past to gain insights into the strategic behavior of traders and to compare different scenarios (Lundin and Tangerås 2017; Willems 2002; Salant 1982)—as utilized in this study. Still, this must be considered, when interpreting absolute numbers of individual scenarios.

A Cournot approach modelling relevant parts of the SA should take into account the input and output variables as shown in Fig. 1. The figure shows only part of the total implemented countries (Fig. 4) to illustrate the basic modelling approach. As input the model considers bid curves for all assessed countries as well as LTTRs and available transmission capacity (ATC) in between countries for the SA. The output displays the corresponding market prices in and transmission flows between countries for each scenario (see Sect. 5.1).

In the approach, a finite number of *n* oligopolistic traders offering the service of cross border capacity allocation (tr) with $tr = TR1, TR2, \ldots TRn$ participate in the SA. Each of these traders holds a certain amount of LTTRs larger or equal to zero. In the following, the term LTTR subsumes PTRs and possible FTRs. For each individual electricity trader an individual LTTR holding can be formally described as $LTTR_{bze,bzi,tr}$ with $tr = 1, \ldots n$ where bze is the exporting and bzi the importing Bidding Zone (BZ) with $bze / bzi = BZ1, \ldots BZn$.

Each trader tr now tries to determine a (non-negative) amount of cross-border trading quantity $xtrans_{bze,bzi,tr}$, maximizing the profit considering the LTTRs. The sum of all $xtrans_{bze,bzi,tr}$ at each bidding zone border has to be less than or equal to the respective available transport capacity $ATC_{bze,bzi}$ of each of the bidding zones.

The profit $PT_{tr,zb}$ of a trader at each zone border is then depending on $xtrans_{bze,bzi,tr}$, the export price P_{bze} and the import price P_{bzi} at a zone border, namely:

$$PT_{tr,zb} = \left(xtrans_{bze,bzi,tr} + LTTR_{bze,bzi,tr}\right) \cdot \left(P_{bzi} - P_{bze}\right) \quad (1)$$

the total profit of a trader is then the result of the sum of the profits at all zone borders:

$$PT_{tr} = \sum PT_{tr,zb} \quad (2)$$

Traders acting exclusively within a bidding zone (buyers), demanding the service of cross border capacity allocation by the oligopolists are implicitly integrated into the model by aggregated bid curves, which contain the electricity demand and supply in a bidding zone of all traders who do not participate in the SA. The prices P_{bze} and P_{bzi} in the bidding zones thus depend on both $xtrans_{bze,bzi,tr}$ and these aggregated bid curves.

An equilibrium is reached in the Cournot model at present, if all $xtrans_{bze,bzi,tr}$ are determined such that no trader tr is able to increase profit by changing these amounts.

As a reference, in addition to the Cournot approach, a perfect market is modelled.

4 Data

The whole assessment is based on historical data from 2020 for European bidding zones and bidding zone borders and essentially uses only the three data types already presented: LTTR and ATC values as well as aggregated bid curves.

Data on LTTR values is publicly available on the website of the Joint Allocation Office (JAO 2021). Monthly and yearly LTTRs from the JAO website have been aggregated to model the Cournot approach. These aggregated LTTRs can be split among different traders (tr) based on scenarios resulting in a dataset $LTTR_{bze,bzi,tr}$ for all Traders $tr = 1, \ldots n$.

ATC values for the Cournot approach are also publicly available on the website of the Joint Allocation Office (JAO 2021). In case of a decoupling event, ATC for SA is published daily by JAO. Essentially, the ATC for SA value corresponds (with minor deviations) to the aggregated monthly and yearly LTTRs. For the year 2020 ATC for SA values are not available for all bidding zone borders, as the SDAC included fewer bidding zones back then. Missing ATC for SA values have been added to the model based on the aggregated monthly and yearly LTTRs, resulting in a dataset $ATC_{bze,bzi}$ for all bidding zone borders.

Historical bid curves are publicly or commercially available at all European Nominated Electricity Market Operators (NEMO 2019). The variety of different formats is challenging in this context: some NEMOs offer aggregated bid curves; some offer bid curves which include every single bid; some use XML-format, some xls- or csv-format; some use local time some do not.

Therefore, aggregated bid curves have been prepared for all bidding zones, using CEST time (like the JAO data) and the same format. As shown in Fig. 2, aggregated bid curves in a bidding zone can be formally described by a finite number of demand segments *(ds)* and supply segments *(ss)* with $ds / ss = DS_1 / SS_1, \ldots DS_{dsno} / SS_{ssno}$ where *dsno* / *ssno* describes the total number of respective segments within a bidding zone. For each *ds* / *ss*, PDS_{ds} / PSS_{ss} describe the constant bid/offer price of the segment and $CDSC_{ds} / CSSC_{ss}$ the cumulated segment capacity.

Bid curves offered by the NEMOs contain all bids that are used for market clearing—including the implicitly (by SDAC) or explicitly allocated cross-border capacities. In order to use the aggregated bid curves in the Cournot approach without underestimating commercial potential for cross-border transactions, they must be adjusted to receive the pure domestic demand and pure domestic supply within a bidding zone. Exemplarily, Fig. 3 shows the adjustment of an aggregated supply curve of a bidding zone where implicit coupling has led to an increased supply. For each *ss* the cumulated segment capacity is reduced by the total

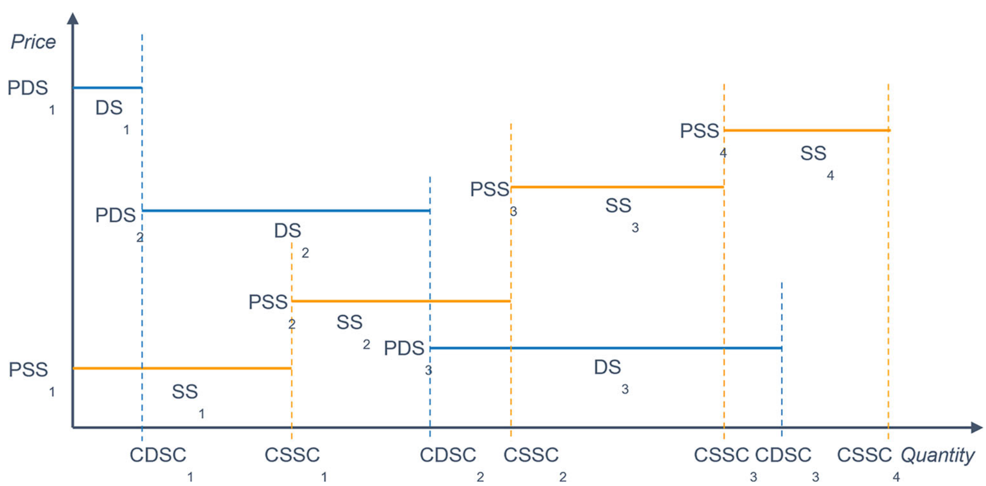

Fig. 2 Aggregated bid curves (*PDS* Constant Bid Price, *DS* Demand Segments, *PSS* Constant Offer Price, *SS* Supply Segment, *CDSC* Cumulated Segment Bid-Capacity, *CSSC* Cumulated Segment Offer-Capacity)

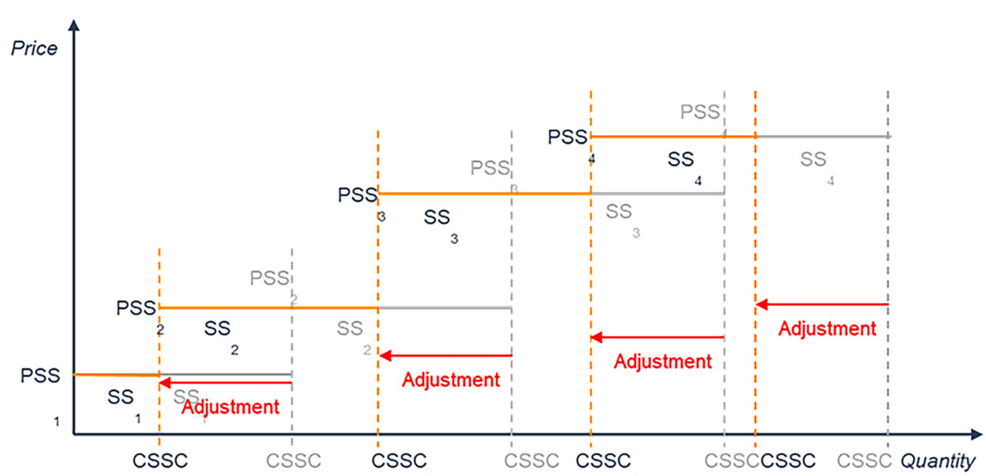

Fig. 3 Adjustment of aggregated bid curves (*PSS* Constant Offer Price, *SS* Supply Segment, *CSSC* Cumulated Segment Offer-Capacity)

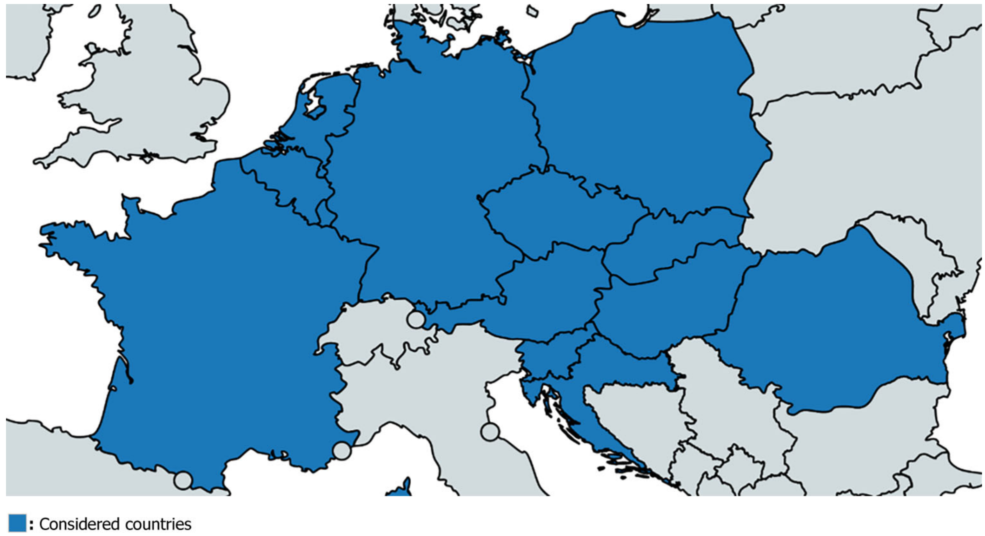

Fig. 4 Geographical scope of the study

allocated import capacity. Likewise, the aggregated supply curve is adjusted based on allocated capacities.

However, with the data available on JAO's website, this adjustment is only possible for bidding zones with implicitly assigned cross-border capacities. Data for zone borders with explicitly assigned cross-border capacities is not available. An adjustment based solely on the bidding zone borders with implicit allocation, however, leads to distortions especially for bidding zones with mixed implicit and explicit allocation of capacities. To reduce these distortions, a pragmatic approach was chosen to limit the adjustments to a maximum value of the ATC for SA value. Although this slightly underestimates the potential for cross-border allocation in the developed Cournot approach, it leads to a more coherent result in the adjustment of bidding zones with a mixed implicit and explicit allocation of capacities. As the resulting slight underestimation of the potential for cross-border allocation is the same for all scenarios, it does not significantly affect the further relative comparison of these scenarios.

5 Methodology

5.1 Scenarios

Different scenarios are compared in the assessment. All scenarios share the same geographical scope and historical data but differ in the number and type of traders active in cross-border trading. The geographical scope of all scenarios includes the bidding zones in 13 countries: France, Belgium, the Netherlands, Luxembourg, Germany, Poland, Czech Republic, Austria, Slovenia, Croatia, Hungary, Slovakia and Romania, as shown in Fig. 4.

The historical data used for all scenarios was retrieved from the relevant exchanges as described in Sect. 4. Before obtaining and reviewing the data, properties were defined in such a way that, among others, different seasons, days of the week and weather conditions should apply. Only limited historical data was available of which the following days were randomly selected, considering above mentioned properties and the 15th hour of the day: 12.4., 22.4., 8.6., 31.7., 9.8., 5.10., 18.11., 24.12. of 2020.

The different numbers and types of traders active in cross-border trading in the five scenarios considered in the assessment are shown below:

- Scenario 1 "Welfare Optimum": An infinite number of traders is assumed so that a welfare optimal allocation of capacity is given, this scenario is modelled as a perfect market and considered as reference for the following scenarios;
- Scenario 2 "Monopoly": A single trader, holding all LTTRs, carries out a profit-optimized allocation of capacity. The monopoly is considered as a special case of an oligopoly with only one supplier. In this as well as the other scenarios the Cournot model is used for calculating the equilibrium;
- Scenario 3 "4 Traders": 4 traders are active on each zone border. Two of them are active on one border only, one does hold LTTRs, one doesn't. The two others are active on all zone borders, again, one holding and one not holding LTTRs. LTTRs are evenly distributed between LTTR-holders;
- Scenario 4 "12 Traders": Each trader in scenario 3 is available three times; and
- Scenario 5 "24 Traders": Each trader in scenario 3 is available six times.

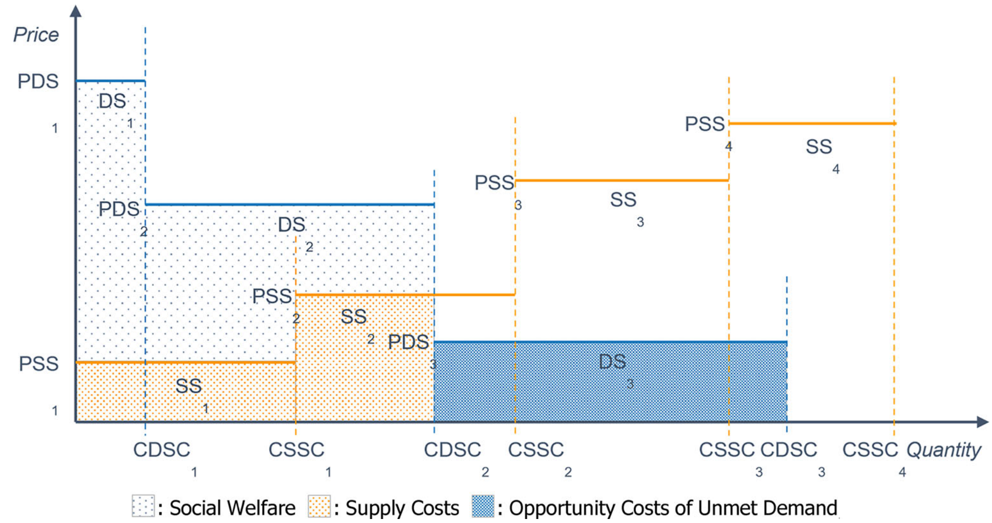

Fig. 5 Social welfare, supply costs and opportunity costs of unmet demand (*PDS* Constant Bid Price, *DS* Demand Segments, *PSS* Constant Offer Price, *SS* Supply Segment, *CDSC* Cumulated Segment Bid-Capacity, *CSSC* Cumulated Segment Offer-Capacity)

5.2 Welfare Optimal Allocation of Capacity

With a welfare optimal allocation of cross-border capacities, an infinite number of traders is assumed in scenario 1. In such a market situation, the welfare optimum within a bidding zone is given when the social welfare (sum of producer and consumer rent) reaches its maximum (see Fig. 5). For aggregated bid curves, as used in this approach, it can be shown that with maximal welfare the sum of supply costs and opportunity costs of unmet demand, as given in Fig. 5, reaches its minimum. This second characteristic is further used to model a welfare optimal allocation of cross-border capacity as a linear optimization program.

To model the supply cost for each bidding zone *bz* and supply segment *ss*, a non-negative variable $xss_{bz,ss}$ and a constant offer price $pss_{bz,ss}$ as well as for each demand segment *ds* a non-negative variable $xds_{bz,ds}$ and a constant bid price $pds_{bz,ds}$ are defined. With $xss_{bz,ss}$ and $xds_{bz,ds}$ we define an objective function with an objective value *Z*—representing the sum of supply costs and opportunity costs of unmet demand (Fig. 5)—to be minimized as shown in Eq. 3. Thereby *xss* is the set that must be found together with *xds* so that the supply cost is minimal

$$Z \geq \sum_{bz,ss} pss_{bz,ss} \cdot xss_{bz,ss} + \sum_{bz,ds} pds_{bz,ds} \cdot xds_{bz,ds} \quad (3)$$

For $xss_{bz,ss}$ and $xds_{bz,ds}$ restrictions apply (cf. Eq. 4):

$$xss_{bz,ss} \leq ssc_{bz,ss}; \quad xds_{bz,ss} \leq dsc_{bz,ss} \quad (4)$$

The restrictions in Eq. 4 reflect the "natural" limits of the possible choice of sets and thus also define the variables capacity of each supply segment $ssc_{bz,ss}$ and capacity of each demand segment $dsc_{bz,ds}$. The values of $ssc_{bz,ss}$ and $dsc_{bz,ds}$ are calculated based on the adjusted cumulated supply/demand segment capacities $cssc_{bz,ss}$ / $cdsc_{bz,ds}$ (cf. Fig. 3 and 5).

In addition to the restrictions on $xss_{bz,ss}$ and $xds_{bz,ds}$ (cf. Eq. 4) an additional market-equilibrium-equation for each bidding zone (*bz*) is needed to ensure that demand including cross-border allocation $xtrans_{bze,bzi}$ is equivalent to supply in each bidding zone (cf. Eq. 5):

$$\sum_{ss} xss_{bz,ss} + \sum_{bzi} xtrans_{bzi,bz} = \sum_{ds} xds_{bz,ds} + \sum_{bze} xtrans_{bze,bz} \quad \forall bz \quad (5)$$

The cross-border trading quantities $xtrans_{bze,bzi,}$ are naturally restricted by the overall capacity $ATC_{bze,bzi}$:

$$xtrans_{bze,bzi} \leq ATC_{bze,bzi} \quad \forall bze, bzi \quad (6)$$

Fig. 6 shows an exemplary presentation of the models outcome for a 4-country framework on 15 October 2020. The welfare optimal allocation and the resulting market price is depicted on the right side based on the available transmission capacity ATC for SA on the left side. From this point onward ATC for SA are omitted in further figures in this article as they remain the same for all scenarios.

5.3 Oligopoly of Traders

The Cournot-model is used to simulate the scenarios 2–5. In this model a market equilibrium for a cross-border allocation, maximizing the profit of each single oligopolistic trader, is calculated in such a way that none of the traders can increase their profit by changing the allocation. Traders account for demand and supply curves within each bidding zone. Demand and supply curves are considered in

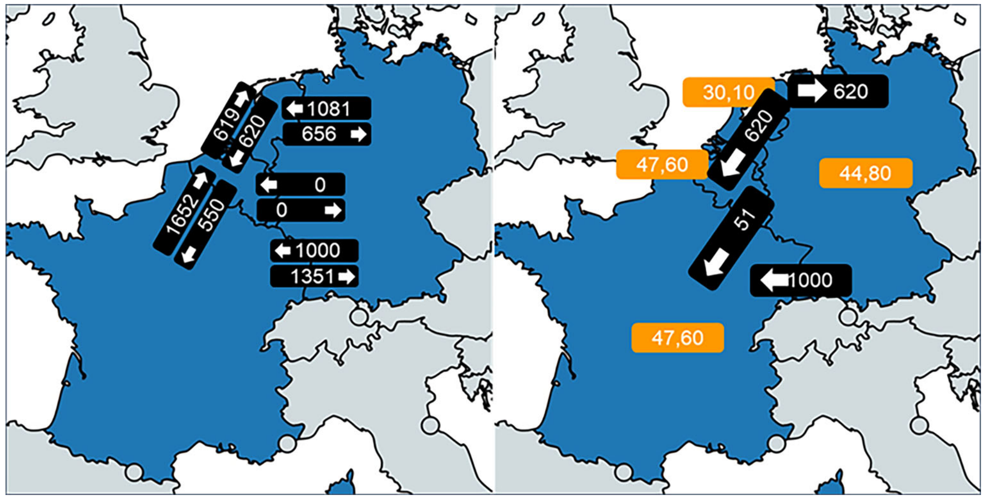

Fig. 6 Exemplary welfare optimal cross-border allocation (*Left Side:* ATC for SA [MW]; *Right Side:* Market Prices [EUR/MWh] and Flows [MW])

form of the residual demand curves, to efficiently model the necessary information. These residual demand curves are calculated for each bidding zone by subtracting the corresponding aggregated supply curve from the aggregated demand curve. As shown in Fig. 7, the residual demand curve in a bidding zone can be formally described by a finite number of residual demand segments *rds* with $rds = RDS_1$, RDS_1, ... For each *rds*, $PRDS_{rds}$ describes the constant price of the segment and $CRDSC_{rds}$ the cumulated residual segment capacity. A residual demand of 0 can be seen at the individual equilibrium price of each bidding zone. High prices correspond to a negative residual demand and low prices to a positive residual demand. For traders, the residual demand curve is a tool for measuring the price effect of buying or selling electricity in a bidding zone.

In a step-by-step development of the model the first step is an approach for the special case of an oligopoly with only one trader (a monopolist) who does not hold any LTTRs. This trader can buy and sell electricity in all bidding zones. Summing up all sales and subtracting the sum of purchases and expected price in the SA equals the profit of the trader. The maximum profit for the trader can be calculated using a mixed integer linear program.

In this program, a binary variable $xb_{bz,rds}$ is used to select a residual demand segment *rds* in each *bz*, thus defining the market price and the possible range of the residual demand of the *bz* by the corresponding *prds* value. Equation 7 is used to select the *rds* with the binary variable:

$$\sum_{RDS} xb_{bz,rds} = 1 \forall bz \tag{7}$$

Purchases and sales by the oligopolistic trader for each *rds* is defined to be $xrds_{bz,rds}$, its sign reflects purchases and sales respectively. In each *bz* only one variable $xrds_{bz,rds}$ can be unequal to 0—this variable is selected with the binary

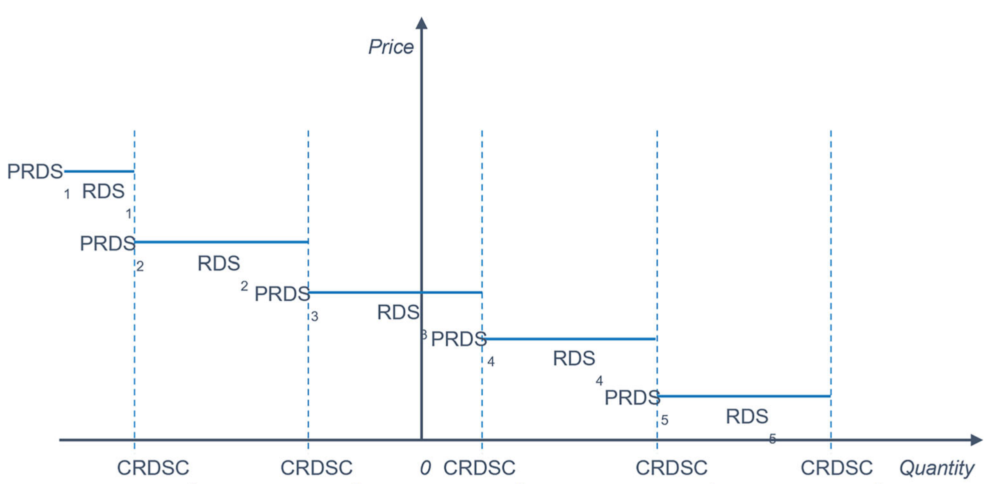

Fig. 7 Residual demand curve (*PRDS* Constant Price of the Segment, *RDS* Constant Bid Price, *CRDSC* Cumulated Residual Segment Capacity)

variable by giving upper and lower limits to the $xrds_{bz,rds}$ variables as shown in the Eq. 8:

$$xrds_{bz,rds} \leq CRDSC_{bz,rds} \cdot xb_{bz,rds}; \quad xrds_{bz,rds} \geq CRDSC_{bz,rds-1} \cdot xb_{bz,rds} \quad \forall bz, rds \tag{8}$$

In Eq. 9 the market equilibrium is defined for each bz:

$$\sum_{bzi} xtrans_{bzi,bz} - \sum_{rds} xrds_{bz,rds} = +\sum_{bze} xtrans_{bze,bz} \quad \forall bz \tag{9}$$

Exports and imports need to be restricted to the ATC values. In addition, net flows from bidding zones with high prices to bidding zones with low prices, which could theoretically occur but are not seen in the real markets, must be prevented. Therefore $xbtrans_{bze,\,bzi}$ is defined to determine whether flows in a certain direction are allowed or not. This binary variable is added to the transport restriction equation (Eq. 6) as shown in Eq. 10:

$$xtrans_{bze,bzi} \leq xbtrans_{bze,bzi} \cdot ATC_{bze,bzi} \quad \forall bze, bzi \tag{10}$$

$xbtrans_{bze,bzi}$ is linked to market spreads using Eq. 11 and only allows flows from low-price to high-price bidding zones, where sln is a sufficiently large number optimizing the time complexity of the model:

$$\sum_{rds} xb_{bze,rds} \cdot prds_{bze,rds} \leq \sum_{rds} xb_{bzi,rds} \cdot prds_{bzi,rds} + \left(1 - xbtrans_{bze,bzi}\right) \cdot sln \quad \forall bze, bzi \tag{11}$$

With this preparatory work, the objective value profit Y as sum of all sales and purchases $xrds_{bz,rds}$ can be maximized by defining the following objective function (Eq. 12):

$$Y \leq \sum_{bz,rds} prds_{bz,rds} \cdot xrds_{bz,rds} \tag{12}$$

Fig. 8 shows an exemplary presentation of the models outcome for a 4-country framework on 15 October 2020. Based on the ATC for SA—previously displayed in Fig. 6—the profit optimal allocation and resulting market prices for the special case of an oligopoly with only one trader (a monopolist) not holding LTTRs, can be seen.

To include LTTRs in the model, the same basic modelling idea can be used for cross-border allocation: LTTRs are modelled as cross-border flows $xlttrtrans_{bze,bzi}$ with LTTR amounts as capacity restrictions, but without influencing the bidding zone prices (cf. Eqs 13, 14 and 15):

$$xlttrtrans_{bze,bzi} \leq LTTR_{bze,bzi} \quad \forall bze, bzi \tag{13}$$

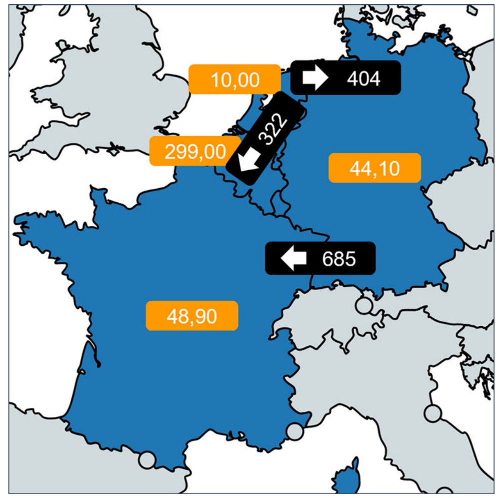

Fig. 8 Exemplary cross-border-allocation in a monopoly without LTTRs (Market Prices [EUR/MWh] and Flows [MW])

$$\sum_{bzi} xlttrtrans_{bzi,bz} - \sum_{rds} xlttrrds_{bz,rds} = + \sum_{bze} xlttrtrans_{bze,bz} \quad \forall bz \tag{14}$$

$$xlttrrds_{bz,rds} \leq sln \cdot xb_{bz,rds}; \quad xlttrrds_{bz,rds} \geq sln \cdot xb_{bz,rds} \quad \forall bz, rds \tag{15}$$

To include LTTRs in the objective function, which optimizes the profit as in Eq. 12, the variable $xlttrrdstrans_{bz,rds}$ is added to $xrds_{bz,rds}$ in Eq. 16. The second term in this equation includes the costs for SA estimated by a trader. This estimation is based on the price spread ($price_{bzi} - price_{bze}$) of a previous run of the model multiplied by a percentage value *transcost*. Thereby *transcost* considers the risk margin for participating in the SA.

$$Y \leq \sum_{bz,rds} prds_{bz,rds} \cdot (xrds_{bz,rds} + xlttrrds_{bz,rds}) - \sum_{bze,bzi} xrds_{bz,rds} \cdot max\left(0, \left(price_{bze} - price_{bzi}\right)\right) \cdot transcost \tag{16}$$

Fig. 9 again shows an illustration of the models' outcome for 15 October 2020. Based on the ATC for SA, the profit optimal allocation and the resulting market prices are depicted. However, in this model setup, the monopolist considers both profit out of cross-border-transactions and LTTRs for his cross-border activities.

To allow multiple oligopolistic traders in the approach, the mathematical model of the SA does not need to be changed. Yet, it is iteratively calculated for each trader in several runs. In the iterative calculation some parameters are changed for each iteration. In the beginning, a starting

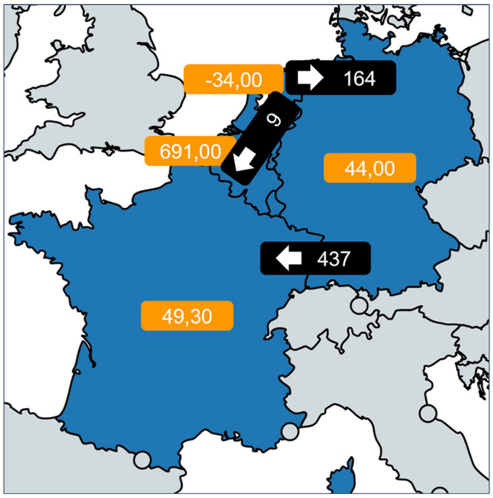

Fig. 9 Exemplary cross-border-allocation in a monopoly with LTTRs (Market Prices [EUR/MWh] and Flows [MW])

solution based on a model solution for a monopoly is used. The cross-border capacity allocated by the monopolist is simply divided by the number of traders at each border and then assigned to each trader.

Several steps have to be completed before a model run for a trader can be started. First, the allocated cross-border capacity of all other traders is determined based on the starting solution, or later on the model runs for each trader. Second, the residual demand curve is changed based on this allocated capacity. Therefore, purchases and sales of all the other traders are integrated into the residual demand curves. Finally, the ATC values are changed by subtracting the allocated capacity of all other traders. After starting a model run, the described parameters are changed. This procedure is repeated until no more changes of allocated capacity occur for any trader and a Nash-equilibrium is reached where no trader can increase its profit by changing trading activities.

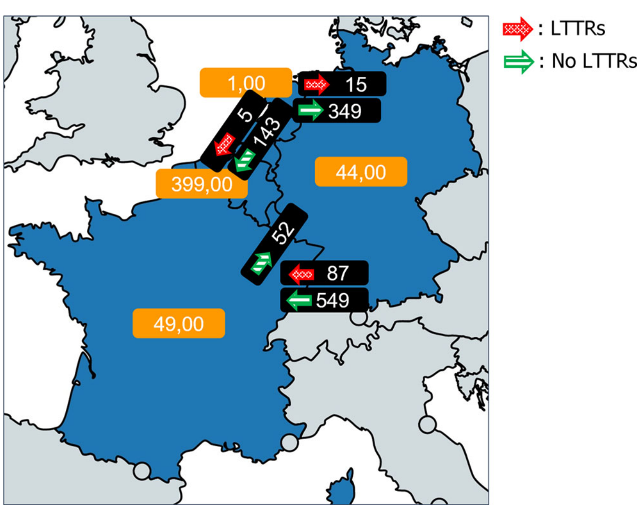

Fig. 10 Exemplary cross-border-allocation in an oligopoly (Market Prices [EUR/MWh] and Flows [MW])

Fig. 10 shows an exemplarily presentation of the models' outcome for 15 October 2020. Based on the ATC for SA the profit optimal allocation and the resulting market prices are depicted. In this model setup, oligopolists considering both profit out of cross-border-transactions and LTTRs as well as oligopolists considering only profit out of cross-border without LTTRs activities are included. It can be seen that the capacity allocated by oligopolists considering LTTRs is much lower than the capacity allocated by oligopolists not considering LTTRs.

6 Results and Discussion

A market equilibrium has been calculated for each of the scenarios described in Sect. 4. As a first step, the amount of allocated capacity in the different scenarios has been analysed. In Fig. 11, the allocated capacity is shown as the sum over all bidding-zone-borders in the scenarios. Allocated SA capacity increases with competition yet stays lower compared to the welfare optimum. Even in the scenario with 24 traders, allocated capacity on each border in the simulation is more than 30% lower on average than for the welfare optimum. These results reaffirm that implicit market coupling is superior to explicit market coupling even in market situations with many traders. However, it can be assumed that a growing number of traders will minimize the gap between the allocated capacities and the welfare optimum.

In a next step, allocated capacity has been further analysed and allocated capacities between traders holding LTTRs and traders not holding LTTRs have been compared. Fig. 12 shows that the percentage of allocated capacity by LTTR holders is 15% on average and less than 30% of total allocated capacity in all simulated scenarios. Fig. 12 also shows that under the model's conditions, the economic incentives to allocate capacity in a SA situation are quite

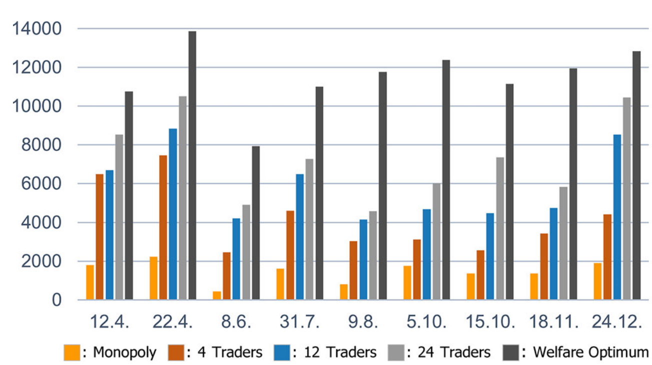

Fig. 11 Allocation of capacity (in MWh) in all considered scenarios

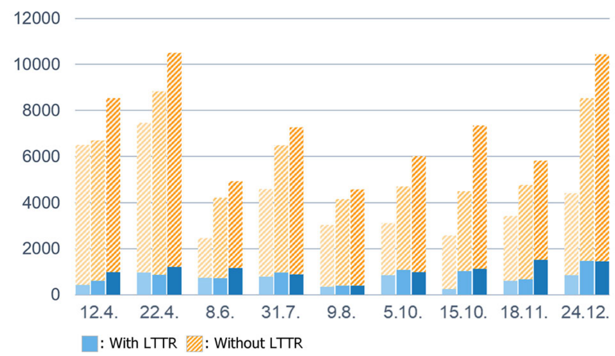

Fig. 12 Allocation of capacity (in MWh) by types of traders (*1st Bar* 4 Trader, *2nd Bar* 12 Trader, *3rd Bar* 24 Trader)

low for LTTR holders. This might explain why traders holding LTTRs were significantly underrepresented in the SA, resulting in inefficiently allocated capacity in historical SA situations.

In addition to allocated capacities, welfare effects for the different scenarios were analysed. These effects are represented in Table 1 as an average relative to scenario 1.

Social welfare (a) is defined thereby as the sum of consumer and producer rent of the observed electricity markets. Total economic surplus (b) is defined as social welfare + congestion rent + traders' profit. Effects on social welfare (d) equals total social welfare – welfare optimum. Effect on total economic surplus (e) is defined as effect on social welfare + congestion rent + traders' profit – congestion rent in the scenario with welfare optimum.

Table 1 also shows that—compared to effects on social welfare in other figures discussed for decoupling events—welfare based on the SA ATC is already significantly lower than with flow-based market coupling (c). This explains the first important finding concerning welfare effects, namely the effect on social welfare decreasing significantly with growing competition. This development is even more evident when assessing the total economic surplus. However, it turns out that even in scenarios with high competition, significant distributional effects remain. Compared to the welfare optimum, the LTTR remuneration still increases by a factor of 50. This finally increases network tariffs as TSOs can ultimately pass on the remuneration costs to tariff payers.

7 Conclusion

Article 44 (EC 2015) mandated a fallback procedure "to ensure efficient, transparent and non-discriminatory capacity allocation" in case of a decoupling event. The simulation shows that the probability of a trader holding Long Term Transmission Rights (LTTRs) to allocate cross-border capacity in SA is significantly reduced compared to those traders not holding LTTRs. On average, the 50% traders holding LTTRs are responsible for only 15% of the allocation. Regarding the model formulation, in particular Eq. 16, it is obvious that in the study framework profit out of allocating cross-border capacities is smaller than the decline in LTTR remuneration due to diminishing market spreads in most cases. Therefore, LTTR remuneration based on market spreads significantly reduces the incentives to take part in the SA for LTTR holders. Allocating capacities for LTTR holders is economically not reasonable in most cases.

Even with high numbers of traders, the design of the SA mechanism reduces social welfare. In a scenario with 24 traders active on each border (based ENTSO-E (2021) we estimate that this figure is not even achieved on borders with high liquidity like for example France and Germany), negative impact on social welfare is still only reduced by about two thirds compared to a monopoly situation and strong distributional effects at the expense of tariff payers remain (see Sect. 6).

In our opinion, based on the modelled Cournot approach we propose the following two points for further discussions

Table 1 Average welfare effects of scenarios 2–5 relative to scenario 1

–	**Total Social Welfare [EUR][a]**	**Congestion Rent [EUR]**	**Traders Profit [EUR]**	**LTTR Remuneration [EUR]**	**Total Economic Surplus [EUR][b]**
Welfare Optimum with SA ATCs[c]	183,379,375	42,416	–	43,169	183,422,544
–	**Effect on Social Welfare[d]**	**Congestion Rent**	**Traders Profit**	**LTTR Remuneration**	**Effect on total Economic Surplus[e]**
Monopoly	–1,542,386	654,443	234,603	8,970,718	–695,756
4 Traders	–1,409,083	802,620	267,540	7,450,912	–381,339
12 Traders	–704,999	422,742	140,914	2,964,685	–183,759
24 Trders	–469,112	343,909	114,636	2,333,125	–52,983

[a]sum of consumer and producer rent of the observed electricity markets
[b]social welfare + congestion rent + traders' profit
[c]the effect of the scenario on social welfare compared to the welfare optimum
[d]total social welfare – welfare optimum
[e]effect on social welfare + congestion rent + traders' profit – congestion rent in the scenario with welfare optimum

to optimize SA as fallback options in case of unavailability of the Single Day-Ahead Coupling (SDAC)—e.g., a decoupling event.

First, as LTTR holders are disincentivised to allocate significant amounts of capacity in the SA, more traders not holding LTTRs, should be motivated to take part in the SA. This will help to allocate more capacities as it has been shown that traders without LTTRs allocate about six times more capacity than traders holding LTTRs.

Second, new ways to remunerate LTTRs in decoupling events, which are not closely linked to market spreads, could be developed to increase incentives to allocate capacities. However, it should be considered that LTTR remuneration is directly linked to day-ahead auction results and new ways to remunerate LTTRs can reduce bid prices in the LTTR-auction.

Beyond the focus of this study the development of alternatives to the whole SA process should be considered. In our opinion, the process is quite complex compared to low incentives to allocate capacities for the traders in a decoupling event. A simple way of implicit coupling as an alternative to today's SA process may be worth considering. Considering the upcoming implementation of Intraday Auctions, they could be an alternative fallback. To further develop the European Intraday electricity markets ACER decided on a methodology for setting a framework for the pricing of capacity among bidding zones in the intraday electricity market. The methodology introduces three pan-European implicit auctions to price cross-zonal capacity, which will complement the already functioning single intraday coupling based on continuous trading (ACER 2019). In view of the upcoming implementation of these cross-zonal capacity auctions, it should be reviewed—e.g., regarding liquidity—whether they could be used as an alternative fallback.

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