An agent-based analysis of main cross-border balancing arrangements for Northern Europe

R. A. C. van der Veen, A. Abbasy, and R. A. Hakvoort

***Abstract*—The topic of electricity balancing market integration is first and foremost concerned with the distinction between different cross-border balancing arrangements. Four main arrangements are ACE netting, BSP-TSO trading, an additional voluntary pool, and a common merit order list. In order to investigate the impact of different cross-border balancing arrangements, an agent-based model has been built, which simulates the operation of the balancing markets of the Netherlands, Germany and the Nordic region, including the surplus and balancing energy exchange resulting from integration. The results show that different arrangements have a different impact on imbalance costs for the market. For the case of Northern Europe, the common merit order list results in the lowest imbalance costs, but ACE netting and the voluntary pool are also beneficial integration steps.**

***Index Terms*—agent-based modelling, ancillary service market, balance responsibility, balancing market, balancing services, cross-border balancing, electricity market, market behaviour, market design, market integration**

I. Nomenclature

ACE = Area Control Error
BRP = Balance Responsible Party
BSP = Balancing Service Provider
PTU = Program Time Unit
TSO = Transmission System Operator

II. Introduction

A. Balancing market

ELECTRICITY balancing markets are institutional arrangements that safeguard the continuous balancing of supply and demand in liberalized electricity markets. A balancing market basically consists of three pillars: balance planning, balancing service provision, and imbalance settlement. Also, it includes three different actors: the Transmission System Operator (TSO), the Balance Responsible Parties (BRPs), and the Balancing Service Providers (BSPs). Balancing service provision concerns the role of the BSPs, who offer balancing energy services to the TSO by submitting balancing energy bids into the balancing energy market before real-time. In real-time, the TSO activates the cheapest upward and/or downward regulation bids in order to restore the system balance. Regulation prices are determined to settle activated bids with. Balance planning and imbalance settlement are related aspects, which concern the role of the BRP. Before real-time, BRPs must submit energy schedules to the TSO, indicating planned electricity production and consumption. After real-time, deviations from those schedules (imbalances) are settled with an imbalance price, which is typically based on the regulation price. The basic time unit in the balancing market is the Program Time Unit (PTU). For each PTU, energy schedules and balancing energy bids are submitted, regulation prices and imbalance prices are determined, and dispatched balancing energy and BRP imbalances are settled.

B. Balancing market integration

In the light of the creation of an Internal Electricity Market for Europe, balancing market harmonization and integration have received the interest of European TSOs, regulators, the European Commission, and the electric power industry. The most concrete element of this is the integration of balancing energy markets for secondary and tertiary control, which entails the exchange of balancing energy between control areas. Such integration is believed to reduce the costs of real-time system balancing due to enhanced competition and higher efficiency of allocation of balancing resources.

Different market arrangements are possible, which realize different degrees and forms of balancing market integration, and have a different impact on balancing market performance. We make a fundamental distinction between four main *cross-border balancing arrangements*, namely Area Control Error (ACE) netting, BSP-TSO trading, an additional voluntary pool, and a common merit order list.

C. Aim

It is the aim of this work to extend our understanding of the varying impact of different cross-border balancing arrangements on balancing market performance, by continuing earlier work on an agent-based analysis of the impact of alternative arrangements in Northern Europe, i.e. the Netherlands, Germany and the Nordic region.

D. Structure

In Section III, a literature review on balancing market integration and cross-border balancing arrangements is

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presented. Then, in Section IV, the general structure of the agent-based model that has been used for the analysis is briefly described. Next, the specific arrangements that have been modelled and studied in the analysis are given in Section V. This is followed by an overview and discussion of the main analysis results in Section VI. Last, the conclusions are presented in section VII.

III. Literature overview

Apart from the technical coordination between the control areas with regard to the reservation of frequency control services [1], balancing markets in Europe are predominantly national. The main exception is the Nordic region, which has a regional regulating power market in operation since 2001. In the light of the general goal of the European Union to create a single Internal Electricity Market in Europe, which manifests itself in the recent and on-going day-ahead and intra-day market coupling projects, balancing market integration appears to be a logical follow-up step.

Balancing market integration has been discussed by former TSO organization ETSO [2], electricity industry organization Eurelectric [3], and by regulator organization ERGEG [4], the last of which presents general integration guidelines, and states that 'a lack of integration of balancing markets is a key impediment to the development of a single European electricity market'. Last but not least, the European Commission has commissioned a report dedicated to balancing market integration, which comes up with a practical road map consisting of three consecutive phases [5].

As stated above, balancing market integration is in essence about the integration of balancing service markets, notably the balancing energy markets for secondary and tertiary control. ETSO was the first to distinguish between cross-border balancing models [6, 7], and in other references on this topic such a distinction has also been made, which indicates its relevance with regard to design, implementation and impact.

Based on the ETSO models, we have defined four main cross-border balancing arrangements: ACE netting, BSP-TSO trading, an additional voluntary pool, and a common merit order list [8]. ACE netting merely involves the prevention of opposing upward and downward regulation in adjacent control areas (balancing markets). BSP-TSO trading enables Balancing Service Providers (BSPs) to bid into the market of another control area. The last two arrangements are forms of TSO-TSO trading, where in an additional voluntary pool TSOs share balancing services with each other on a voluntary basis, whereas the common merit order list concerns the full integration of the different markets into a single multinational (regional) market for real-time system balancing of the entire 'balancing region' [8].

From the aforementioned organizations and corresponding references, ETSO and Eurelectric discuss different arrangements, but they do not explicitly advocate a specific cross-border balancing arrangement. The report for the EC calls TSO-TSO trading preferable above BSP-TSO trading. Also, it states that the exchange of excess services (which would resemble what we call an additional voluntary pool) can be implemented already in an early phase, but that a common merit order list requires harmonization of among others the remuneration scheme. Finally, a short analysis of the impact of a common merit order list, based on Belgian and French bid prices, indicates that a costs reduction in the order of 5% is very well possible, leading to the conclusion that 'the implementation of a cross-border balancing market is a lucrative and achievable goal' [5]. The ERGEG report has adopted the view of this report, by calling the common merit order list the target model for the exchange of manual balancing energy services, and by seeing the voluntary pool as a possible first step, and BSP-TSO trading as an option in case the other two are infeasible (on a short notice) [4].

The literature does not provide with an in-depth systematic analysis of alternative cross-border balancing arrangements; the implicit argument behind the preference for a common merit order list is that this arrangement establishes both the most efficient allocation of available balancing resources and maximizes competition between BSPs, resulting in the lowest total balancing costs. In earlier work, we have engaged in a systematic analysis of arrangements in order to extend the argument and create more insights into the impact of balancing market integration [8-11].

In [8], a qualitative analysis of the main cross-border balancing arrangements confirmed the superiority of the common merit order list, but identified ACE netting has a beneficial first step. Also, it was found that the different arrangements result in varying performance which depends on the detailed arrangement design, the balancing market design and overall power system and market conditions as well.

Furthermore, quantitative analyses have been carried out to produce more concrete results and insights, all of which focussed on the case of Northern Europe. First, from an optimization model study it was concluded that the implementation of a common merit order list potentially reduces the balancing energy costs by 50% under the absence of interconnection capacity constraints [9]. Second, an agent-based analysis dedicated to the impact of BSP-TSO trading for the Netherlands and Norway shows that the balancing energy market price in Norway does not change noticeably thanks to the huge excess of supply and the flat bid ladder of this hydro-based power market, but that the Dutch downward regulation price is negatively affected during peak hours as a result of the export of downward regulation bids to Norway [10]. Third, an agent-based analysis of the impact of ACE netting, fully efficient balancing energy trading (which corresponds with an optimally functioning BSP-TSO trading or voluntary pool arrangement) and a common merit order list caused a balancing energy costs reduction of 40-50% due to the import of the majority of the energy from the Nordic region [11]. This paper continues on the last mentioned analysis by studying and comparing all main cross-border balancing arrangements.

Finally, related research by colleagues included an analysis of the impact of balancing market integration in Northern Europe with a linear optimisation model, which also included a common day-ahead market and both a resource procurement and real-time system balancing phase. Here a balancing energy costs reduction for the common merit order list of 65% was found [12].

IV. Model description

Agent-based simulation, or Agent-Based Modelling (ABM), is a modelling paradigm that focuses on the modelling of individuals who make autonomous decisions, which are however directly or indirectly influenced by the decisions of others. Because balancing market performance is principally determined by behaviour of Balance Responsible Parties (BRPs) and Balancing Service Providers (BSPs), ABM is a suitable methodology for the analysis of balancing markets.

The agent-based model that is used for the analysis of cross-border balancing arrangements is built in MATLAB, and has been used as well in the preceding agent-based analysis. Therefore, a more elaborate version of the below description of the model structure can be found in [11].

A. Model structure

The model represents the interconnected balancing markets of the Netherlands, Germany and the Nordic region. The only physical power system elements included are the interconnectors between the three market areas, which form a constraint for the execution of cross-border balancing. The agents that are modelled are the Balance Responsible Parties (BRPs), which means that analysis takes a BRP perspective, and takes into account the impact of integration on BRP behaviour. The behaviour of BSPs is not included, except for, to a limited extent, the BSP-TSO trading arrangement (see Section V). This limits the value of the analysis, but also simplifies it. The conceptual structure of the balancing market, as applied for all three areas in the model, is shown in Fig. 1.

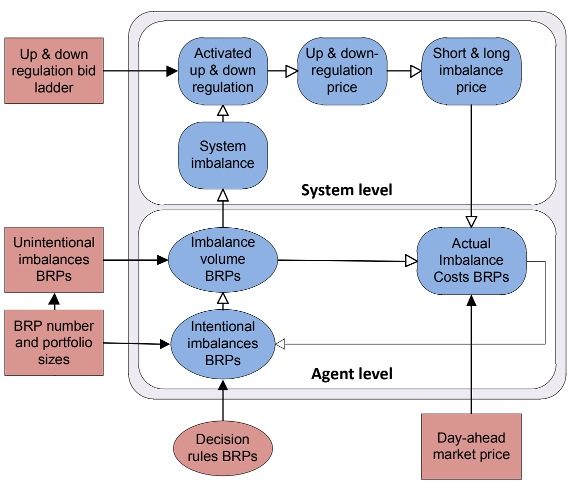

Fig. 1. Conceptual structure of a balancing market within the model

Each balancing market consists of a fixed amount of BRPs who have a certain portfolio size (in MW), i.e. a total sum of production and consumption connections for which a single BRP has balance responsibility. Next to that, each balancing market has an up- and down-regulation bid ladder, consisting of a specific set of upward and downward regulation bids each with a fixed volume (in MW) and a price (in €/MWh). Finally, each balancing market has a fixed day-ahead market price.

The model simulation consists of multiple rounds. Each round equals a Program Time Unit (PTU). In each round, all BRPs decide on a specific intentional imbalance volume out of a fixed set of 'options', using some decision rules (decision-making algorithm), which make the choice of each BRP dependent on the individual 'Actual Imbalance Costs (AIC)' that it ended up with for different options in previous rounds.

At the start of each round, all BRPs decide on an intentional imbalance option. In addition, each BRP is faced with an unintentional imbalance, which arises from a consumption/production forecast error. The sum of the individual intentional and unintentional imbalance is the 'BRP imbalance'. Then, the system imbalance is calculated; it is the sum of all BRP imbalances in the market. Next, amounts of required upward and downward regulation are determined based on the system imbalance. These amounts are then provided by the activation of up- and down-regulation bids from the respective bid ladders. Because the bids are ranked in price order, the cheapest bids are activated. The next step is formed by the determination of the up- and down-regulation price with which dispatched balancing energy of BSPs is settled, and the short and long imbalance price with which individual imbalances of BRPs are settled. This is subject to some specific pricing mechanisms. Next, the Actual Imbalance Costs of each BRP are calculated, which are the product of the difference between the day-ahead price and the relevant imbalance price and the BRP imbalance volume, see Equation (1).

$$\mathrm{AIC}_{n,m} = \begin{cases} (P_{si,m} - P_{da,m}) * IV_{n,m} & \text{if } IV_{n,m} < 0 \\ (P_{da,m} - P_{li,m}) * IV_{n,m} & \text{if } IV_{n,m} > 0 \\ 0 & \text{if } IV_{n,m} = 0 \end{cases} \quad (1)$$

In this equation, $\mathrm{AIC}_{n,m}$ are the Actual Imbalance Costs for BRP n in round m, $P_{si,m}$ is the short imbalance price in round m, $P_{li,m}$ is the long imbalance price in round m, $P_{da,m}$ is the day-ahead market price in round m, and $IV_{n,m}$ is the imbalance volume of BRP n in round m.

Finally, at the end of each round, for each BRP the expected AIC of the selected intentional imbalance option in that round is updated according to equation (2):

$$E(AIC)_{n,X} = (E(AIC)_{n,X} * \mathrm{P}_{\mathrm{recency}} + \mathrm{AIC}_{n,r}) / (\mathrm{P}_{\mathrm{recency}} + 1) \quad (2)$$

In this equation, $E(AIC)_{n,X}$ are the expected AIC for BRP n of option X selected in the active round, $P_{recency}$ is the 'recency parameter', and $AIC_{n,r}$ are the Actual Imbalance Costs for BRP n in active round r.

Now going forward to the start of the next round, the probabilities of choosing specific intentional imbalance options is inversely proportional to the expected AIC of these options. This way, the agents (BRPs) keep on experimenting, while still learning from the results of past rounds and making (partly) rational decisions. The 'recency parameter' has been included to make the results of recent rounds weigh heavier in the decision-making.

B. Model input

The most important model input values are listed in Table I. A more detailed table and description is given in [11].

TABLE I
MODEL INPUT VALUES

Parameters	Areas		
	Nether-lands (NL)	Ger-many (DE)	Nordic region (NO)
Intentional imbalance options (%)	-2.0 / -1.0 / -0.5 / 0.0 / 0.5 / 1.0 / 2.0		
PTU (min.)	15		
Total portfolio size (MW)	25,000	120,000	82,500
Day-ahead market price (€/MWh)	39	38.5	35
Regulation pricing mechanism	marginal	pay-as-bid	marginal
Imbalance pricing mechanism	dual	average	single
Up- and down-regulation bid ladder	fixed set of bids (including bid volume and price)		
Total capacity up (MW)	600	4,000	12,000
Total capacity down (MW)	-700	-4,000	-10,000
Transfer cap. NL-DE (MW)	2,300		
Transfer cap. DE-NO (MW)	1,700		
Transfer cap. NO-NL (MW)	700		
Cross-border flows (MW)	fixed series of flows for three lines		
Number of rounds	1,000		
Recency parameter	0.9		

The BRPs can choose from a set of seven intentional imbalance options, which are represented by percentages of the portfolio size, namely -2%, -1%, -0.5%, 0%, 0.5%, 1% and 2%. The PTU length used in the model is 15 minutes, which is actually applied in the Netherlands and in Germany (the Nordic one is actually 60 minutes, but has been changed to make cross-border balancing possible). The total portfolio size of all BRPs in a market area is in line with the sum of the sum of average production and consumption (two times the average system load) in the three areas, which means that the German and the Nordic market are about five resp. three times bigger than the Dutch market.

The day-ahead market prices are based on the average day-ahead power exchange prices in the areas in 2009. The included pricing mechanisms are based on the actual mechanisms used in the different markets. In the Netherlands and the Nordic region, the price of the last activated bid becomes the regulation price; in Germany each activated bid is awarded its own bid price. Because of the latter, the imbalance price in Germany is the weighted average of activated bid prices. The Netherlands applies dual pricing, which means the long imbalance price is set equal to the marginal down-regulation price and vice versa, except when single-sided regulation occurs, in which case single pricing is applied. Single pricing means here setting both the long and short imbalance price equal to the marginal price in the major regulation direction. For the Nordic region, this is only applied to consumption balances in reality, but we apply this to the entire market for the sake of (relative) simplicity [13].

The up- and down-regulation bid ladders of the different areas are based on regulation (bid) data from 2009 [14-16]. It must be noted that not a lot of detailed bid data could be obtained, which means that the accuracy of the bid ladders is not very high. The first parts of the up- and down-regulation bid ladders for the three areas are shown in Fig. 2. It can be noticed that the Dutch ladder is steepest, whereas the Nordic ladder is the flattest. In addition, the Nordic region has a very large over-supply of bids. Thus, the Nordic region has both the cheapest balancing resources of Northern Europe, and a large abundance of resources, which points to a high economic value of balancing market integration in this region.

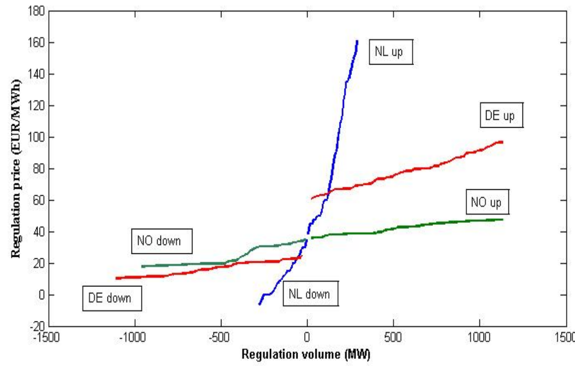

Fig. 2. Fixed up- and down-regulation bid ladders of the three areas. ‘NL’ = Netherlands, ‘DE’ = Germany, ‘NO’ = Nordic region.

Furthermore, there are fixed cross-border capacity and cross-border flow values for the three interconnections between the areas, which are based on ENTSO-E data. The fixed cross-border capacities are derived from D-1 NTC values, whereas the cross-border flow data series are directly taken from a period in 2010 [17].

Finally, one simulation run is 1,000 rounds long, which corresponds with at least ten full days, and the recency parameter is set to 0.9.

V. MODELLED ARRANGEMENTS

In order to analyse the impact of the cross-border balancing arrangements on balancing market performance we have modelled six arrangements, which are illustrated in Fig. 3. They are presented in order of increasing degree of integration. Included are the four main cross-border balancing arrangements introduced in Section III, a model with maximally efficient balancing energy trading called ‘Balancing energy trading’, and the reference case of separate markets. A short explanation of the modelled arrangements is given below.

A. Separate markets

In this reference arrangement, with which the other arrangements will be compared, the three balancing markets of the Netherlands, Germany and the Nordic region are operating independently. The interconnection lines are not used.

B. ACE netting

In this arrangement, Area Control Error (ACE) netting occurs. For this, the system imbalances of the three areas are compared. The occurrence of opposite system imbalances will cause ‘surplus energy flows’ from the surplus area to the deficit area, resulting in reduced activation of upward/downward regulation in the deficit/surplus area.

System imbalances are completely removed when possible, otherwise the netting of ACEs takes place proportionally (cf. [11]). The availability of interconnection capacity is checked.

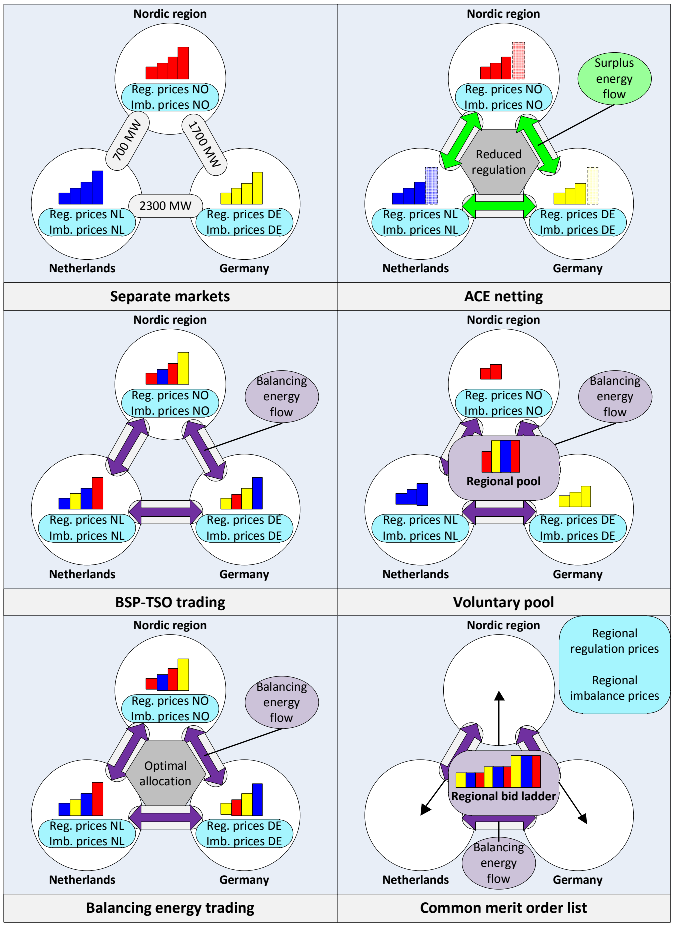

Fig. 3. The six modelled cross-border balancing arrangements

C. BSP-TSO trading

Here, balancing energy bids mays be offered into the balancing energy market of another area instead of the own. Specifically for this arrangement, the BSPs are represented by agents that are responsible for the submission of one specific bid. Each round each BSP has to choose a market/area in which to bid, but the bid price and volume remain fixed. The chance of choosing a specific market is proportional to the average profit that the BSP gained over the previous rounds in which it bid in that market. On top of that, there is a 10% that the BSP will randomly select a market. Like in the remaining arrangements, the availability of cross-border capacity for the exchange of balancing energy is checked before energy (a bid) is imported or exported. If there is capacity, the exchange is put through and the capacity value is reduced accordingly; if there is not, the bid is skipped.

D. Voluntary pool

In the modelled version of the additional voluntary pool each market keeps a certain 'national share' of bids for national use, which is set equal to 2% of the total portfolio size of the areas. These include the cheapest bids of the area. Remaining bids are offered to the other areas. If the bid price of an offered bid is lower than the bid price of the last (most expensive) bid of the national share of the area it is offered to, it will be included in the bid ladder of that area. Otherwise, it will be offered to the third area using the same rules. If it is not included there either, the bid is not included in any bid ladder. The above procedure for the creation of three national bid ladders only takes place at the start of the simulation run.

E. Balancing energy trading

In this arrangement, a regionally optimal allocation of balancing energy services takes place for the real-time system balancing of the three areas. This includes ACE netting. The balancing market rules remain national, and are the same as in separate markets. Actually, this arrangement can be considered to represent a BSP-TSO trading or voluntary pool arrangement in which an optimal allocation of balancing energy services occurs. However, it can also be considered to be a common merit order list where national pricing mechanisms still apply.

F. Common merit order list

The balancing energy markets of the three areas are integrated into one regional bid ladder (separately for upward and downward regulation), and a regionally optimal allocation of balancing energy services takes place, like in the last arrangement. This is modelled in the following way. First, ACE netting is performed. Then, bids are considered for activation in order of increasing bid price. If a bid can be utilized to reduce the system imbalance of the own area, it will be done so. Otherwise it will be utilized in one of the other areas, which is subject to the availability of cross-border capacity.

VI. Analysis Results

Each model version, representing a different cross-border balancing arrangement, has been run ten times, and the averages of the output variable values have been taken to end up with the final analysis results. The description of the analysis results is divided between general and arrangement-specific results.

A. General results

The most striking impact of the introduction of different cross-border balancing arrangements is on the realized surplus energy exchange for ACE netting and the balancing energy exchange for the voluntary pool, balancing energy trading and the common merit order list. The surplus energy exchange in the ACE netting arrangement reduces the dispatched balancing energy in the three areas by less than 25% (see below), and thereby causes a limited reduction of the total real-time balancing costs and imbalance costs. In the last four arrangements however, the vast majority of the balancing energy that is dispatched in the Netherlands and Germany to restore the system balance is imported from the Nordic region. In Fig. 4 is can be seen that for BSP-TSO trading, balancing energy trading and the common merit order list the import percentages for these two areas are higher than 50% and can become as high as 80%. The Nordic region, however, imports nothing in all arrangements except for BSP-TSO trading (see below). These enormous exchange volumes are the result of the cheap and abundant resources in the Nordic region, and the availability of cross-border capacity, which proved to be large enough to enable this level of balancing energy exchange. Moreover, the detailed analysis results show only the interconnector between the Netherlands and the Nordic region was a large constraint for energy exchange: in 60% of the rounds this line was congested in the direction from the Nordic region to the Netherlands.

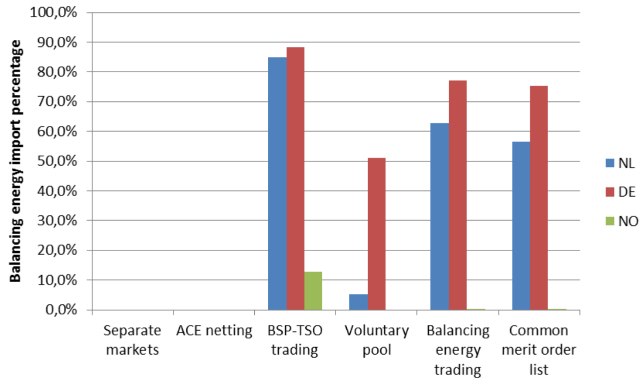

Fig. 4. The percentage of dispatched balancing energy that is imported. 'NL' = Netherlands, 'DE' = Germany, 'NO' = Nordic region.

In Fig. 5, the total imported and exported balancing energy volumes over the entire simulation run are indicated for the three areas, split out for up- and down-regulation. This shows that the energy volumes imported by Germany from the Nordic region are much higher than the volumes imported by the Netherlands, which is caused by the much lower demand and the limited available cross-border capacity. Furthermore, Fig. 5 shows that the level of import of Nordic upward regulation bids is higher than that of downward regulation bids.

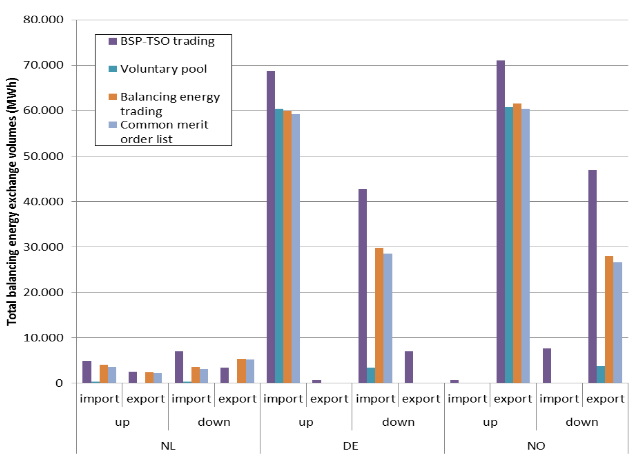

Fig. 5. Total balancing energy import and export volumes

Next, it can be noted that the Netherlands exports a significant amount of balancing energy, which goes to Germany. This is partly caused by a suboptimal activation procedure in the model versions of the last two arrangements. Finally, some peculiar differences between arrangements stand out; these will be discussed below.

In general, balancing energy exchange results in reduced up- and down-regulation prices, which in turn leads to lower imbalance prices. However, the most important indicator from the perspective of the electricity market as a whole is formed by the total Actual Imbalance Costs (AIC), as introduced in Section IV. The AIC reflect the actual costs of real-time balancing for the market, because they can be considered the opportunity costs of trading in the day-ahead or intraday market to prevent imbalances. The 'total AIC' are the sum of all actual imbalance costs incurred by all Balance Responsible Parties in an area over the entire simulation run. Fig. 6 gives the total AIC for the three areas for all modelled cross-border balancing arrangements. It can be observed that the total AIC of the Netherlands and Germany generally decrease immensely, by 50-80%, but that the total AIC of the Nordic region remains on the same level, or even increases significantly (see below). This can be directly explained by the high degree of balancing energy imports of the Netherlands and Germany from the Nordic region: These largely reduce regulation and imbalance prices, and thereby the Actual Imbalance Costs, whereas the costs in the Nordic region cannot reduce much further as it already has the cheapest balancing resources in case of separate markets.

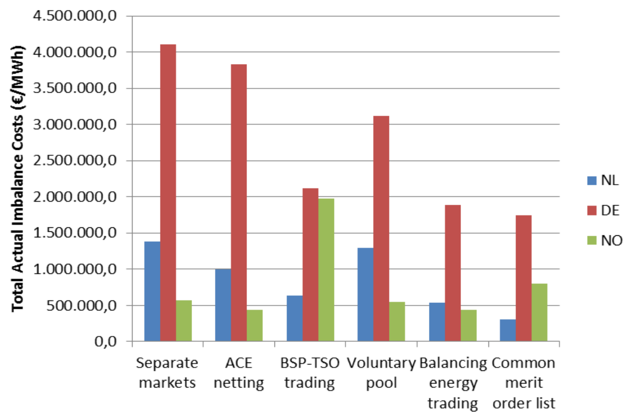

Fig. 6. Impact of arrangements on total Actual Imbalance Costs

The reduction of Actual Imbalance Costs for the BRPs is also reflected by the average penalty (in €/MWh) for BRPs to be 'long' (BRP surplus) and to be 'short' (BRP shortage), which are shown in Fig. 7 and Fig. 8. These penalties are just the day-ahead price minus the long imbalance price resp. the short imbalance price minus the day-ahead price, and are the basis for the calculation for the AIC (see equation (1)). A positive penalty means average costs (which the BRP pays); a negative penalty means an average profit (which the BRP receives).

The first thing that can be noticed is that the penalties generally reduce as well, which is in line with the total AIC reductions. However, it is remarkable that the penalties differ quite unsystematically between arrangements, and that the sign of the penalties often changes. This is caused by changes in the relative shapes of up- and down-regulation bid ladders effectuated by the integration, as a result of which it can suddenly be more favourable for BRPs to opt for a BRP imbalance in the other direction. An important example can be provided by the comparison of separate markets with the common merit order list. In separate markets, there is a general incentive for German BRPs to be long and for Nordic

BRPs to be short as the corresponding average penalties are actually a profit to them. However, in the common merit order list, these incentives are the other way around. Such shifts in incentives bring the BRPs in the model to choose intentional imbalance options in the other direction, which leads to shifts in the dominant system imbalance direction. This could mean a negative effect of integration from a security of supply perspective, because system surpluses pose a lower security threat than system shortages.

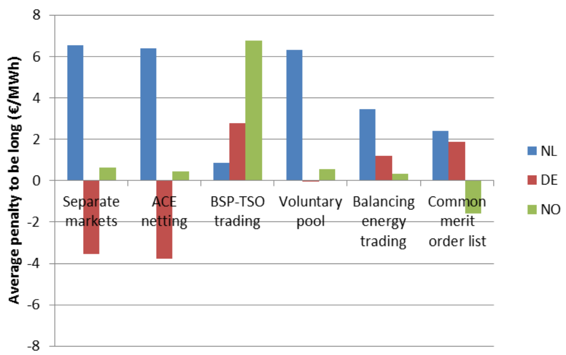

Fig. 7. Impact of arrangements on the BRP penalty to be long

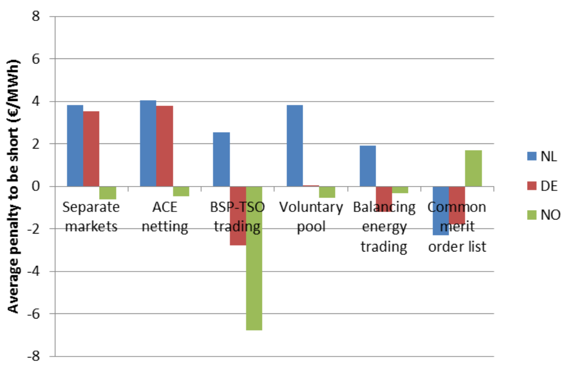

Fig. 8. Impact of arrangements on the BRP penalty to be short

Also, it should be noted that single imbalance pricing is applied in all cases, except for the Netherlands in the first five arrangements. This means for the Dutch BRPs relative high imbalance costs, which are largely reduced in the common merit order list due to introduction of regional single pricing. Single pricing generally leads to an evening out of imbalance costs for BRPs, but on the system level high penalties will still introduce high financial risks, as the total AIC values show.

B. *Arrangement-specific results*

A discussion of the impact of individual cross-border balancing arrangements on balancing market performance in Northern Europe is given below.

1) Separate markets: Most striking is that the total Actual Imbalance Costs (AIC) of the Nordic region are more than 50% lower than those of the Netherlands, whereas the system is three times bigger. This is caused by the presence of a huge oversupply of very cheap hydro-based balancing resources in the Nordic region, and by its use of single pricing.

2) ACE netting: ACE netting reduces the activated up- and down-regulation volumes in all areas, which results in more favourable regulation prices, and therefore lower total AICs for the different areas. However, the AIC reduction is largest for the Netherlands, about 25%, because of its smaller system size and the use of dual pricing [cf. 11].

3) BSP-TSO trading: This arrangement leads to a much lower total AIC for the Netherlands and Germany, but a much higher total AIC for the Nordic region. This is caused by the massive exodus of bids from the Nordic region to Germany and the Netherlands, leaving the Nordic region behind with a relatively small amount of bids. As a result, the Nordic region imports 12% of the dispatched downward regulation, and the imbalance penalties are really high, with BRP shortages being much more favourable then BRP surpluses. The latter has led to a very high system shortage occurrence of 70%.

4) Voluntary pool: Compared with BSP-TSO trading the total AIC reductions from the implementation of the voluntary pool are a lot smaller for Germany, and even more so for the Netherlands. On the other hand, the total AIC of the Nordic region remains about the same. This can be explained by the national share of bids that stays within the own area, which results in a much lower import of balancing energy from the Nordic region. The Dutch import percentage is only 5%, because the cheapest Dutch bids have a more favourable bid price than the cheapest Nordic bids that are shared with the other markets in this arrangement. This situation holds to a much lower extent for Germany.

5) Balancing energy trading: The Dutch and German total AIC reductions are clearly lower than for the former arrangements, but here too the Nordic total AIC remain the same (as the Nordic region has the cheapest bids of the North-European region). The first is caused by the import of 60-80% of the balancing energy from the Nordic region, and the execution of ACE netting.

6) Common merit order list: The total AIC values are even a bit lower for the Netherlands and Germany compared to balancing energy trading, which is probably caused by the change to single imbalance pricing. The Nordic total AIC is much higher than in the balancing energy trading arrangement, however, which is the effect of the regional marginal pricing by which imbalance prices are based on the marginal bid prices of the activated bids in the entire region. As a remark, the results show that the uniform regulation and imbalance prices lie in the middle of the range of prices in separate markets, which means that prices within the region have converged. This will, like holds for market integration in general, benefit some areas more than others, and may also be unfavourable to some, even though the net benefit for the region is clearly positive.

C. *Sensitivity analysis*

A sensitivity analysis has also been conducted. It turns out that the model results are not very sensitive to the reduction of available cross-border capacity for cross-border balancing, even though an increase in congestions has been observed. This is probably caused by the fact that balancing energy can always be exchanged in the direction opposite to the momentary cross-border flow, in combination with a simultaneous demand for both up- and down-regulation within the same areas for most PTUs. Furthermore, the impact of small bid ladder changes do not significantly affect the results, but obviously, large changes do, which is a main reason why the impact of integration is case-dependent.

VII. Conclusions

Based on the agent-based analysis of six different cross-border balancing arrangements for the case of Northern Europe, it is concluded that the choice of a cross-border balancing arrangement as the key decision in the balancing market integration process has a very large impact on balancing market performance. This is clearly shown by the varying impact on the total Actual Imbalance costs (AIC), i.e. the costs of real-time balancing for the market.

The total AIC of the Netherlands and Germany are largely reduced by most arrangements, whereas the Nordic total AIC remain the same or even increase, which is the result of the import of the vast majority of the balancing energy in the Netherlands and Germany from the Nordic region, which has a huge oversupply of balancing energy bids that are also cheapest in the North-European region. Imbalance penalties are also reduced, but the signs are often shifting, resulting in shifts in dominant system imbalance directions.

The analysis shows that, for Northern Europe, the implementation of ACE netting and a voluntary pool have a small positive effect on the total AIC for all three areas, but that balancing energy trading causes a very large AIC costs reduction for all three areas. The common merit order list leads to similar AIC reductions as balancing energy trading for the Netherlands and Germany, but the costs for the Nordic region are higher due to the regional marginal pricing. BSP-TSO trading leads to a huge increase of total Actual Imbalance Costs for the Nordic region, because many of the cheapest Nordic bids submit their bids in another market. This does not occur in the voluntary pool due to the national share that is not exchanged, which however limits the AIC reductions for the Netherlands and Germany as well.

Viewing the impact of arrangements on total imbalance costs in Northern Europe, we can recommend ACE netting and the additional voluntary pool as beneficial balancing market integration steps, and the common merit order list as the most beneficial and final step. This is in line with the recommendations in [5]. The results for the modelled balancing energy trading arrangement indicate that an optimally functioning voluntary pool, or a merit order list in which national pricing mechanisms are still used, might however be preferable in order to prevent an imbalance costs increase in the Nordic region.

Reflecting on the analysis, it must be emphasized that this analysis has only taken a BRP perspective, that is, only the impact of arrangements on BRP behaviour has been taken into account. In reality, BSPs will probably adapt their bidding strategies as a result of integration, as new market opportunities and risks emerge. If, as literature implicitly argues, balancing market integration indeed enhances competition in balancing energy markets, balancing costs and imbalance costs can be expected to further reduce. This will only hold if gaming opportunities or new forms of market power do not emerge, which is something we expect will not happen for Northern Europe given the huge over-supply of cheap Nordic balancing energy bids [cf. 8, 10].

A final reservation regarding the results is that the analysis is based on the power system and (balancing) market conditions of Northern Europe, which makes a generalization on the impact of cross-border balancing arrangements on balancing market performance impossible. Moreover, the arrangements can take many different forms, whereas the modelled arrangements involve specific assumptions and operational rules, which prevent firm conclusions regarding the impact of different arrangements for Northern Europe.

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