Analysis of the Impact of Cross-Border Balancing Arrangements for Northern Europe

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***Abstract*—This paper presents an agent-based analysis of the impact of different cross-border balancing arrangements on balancing market performance for the case of Northern Europe, i.e. the Netherlands, Germany and the Nordic region, taking into account the change in behaviour of Balance Responsible Parties (BRPs). The four compared arrangements are separate markets, Area Control Error (ACE) netting, balancing energy trading, and a common merit order list. It is found that ACE netting reduces the total Dutch imbalance costs by 25%, but that the more advanced arrangements have the potential to reduce those costs for the Netherlands and Germany by as much as 50%. However, in case of the common merit order list the imbalance risks for Nordic BRPs increase largely because of the regional marginal pricing, and the system balance states of Germany and the Nordic region are largely affected due to changes in BRP behaviour. The large imbalance costs reductions in Germany and the Netherlands are the result of the import of more than half of the balancing energy from the Nordic region, which is possible because of the high availability of cross-border capacity between the areas.**

I. Introduction

Balance management is a power system operation service that includes the continuous balancing of power supply and demand in order to stabilize system frequency and thereby safeguard operational security of supply. The authors define a *balancing market* to be an institutional arrangement that establishes market-based balance management in a liberalized electricity market, and that consists of three 'design pillars': balance planning, balancing service provision, and balance settlement. So-called *Balance Responsible Parties (BRPs),* market parties who are responsible for balancing a portfolio of production or consumption connections, submit energy schedules to the *System Operator (SO)*, indicating the planned net energy injection into or withdrawal from the grid within each *Schedule Time Unit (STU)*, often on the day before delivery. Schedule deviations are settled with an *imbalance price*. Next to that, *Balancing Service Providers (BSPs)* provide balancing services to the SO, which are procured and dispatched by the SO to safeguard and restore the system balance. Dispatched balancing energy is settled with a *regulation price*. For each STU, the regulation prices are determined based on the dispatched balancing energy, and the imbalance prices are directly based on the regulation prices or costs. In short, the balancing market is structured in such a way that the BRPs who cause imbalances pay indirectly to the BSPs who resolve the imbalances. See Fig. 1.

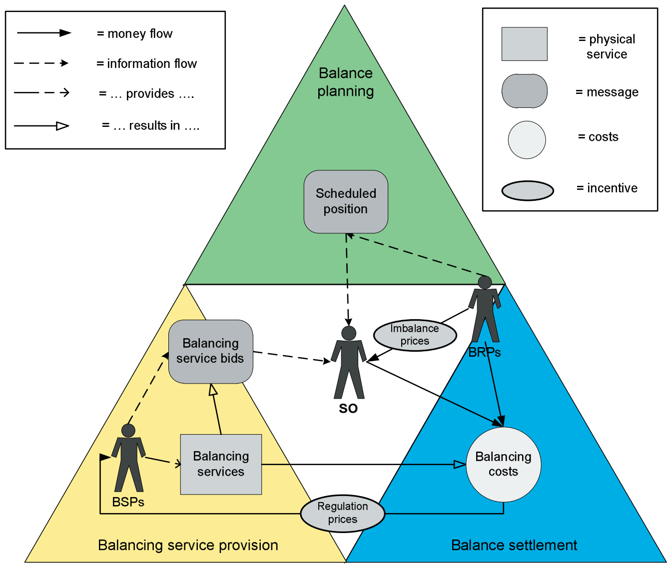

Fig. 1. Structure and concepts of the balancing market

In Europe, each country generally has its own balancing market design, which applies to the own control area, and to the BRPs and BSPs that operate in this area. However, the current trend of day-ahead and intra-day market coupling in Europe puts forward the possibility of balancing market integration, and this is being considered by SOs [1], regulators [2], and the European Commission [3]. In earlier work, a distinction has been made between four different basic *cross-border balancing arrangements*, namely Area Control Error (ACE) netting, BSP-SO trading, an additional voluntary pool, and a common merit order list. From a qualitative analysis it was concluded that these arrangements have a different impact on a range of balancing market performance criteria, and that this impact also depends on the specific power system and market conditions and on the detailed balancing market design [4]. The aim of this paper is to study this topic quantitatively, and to uncover the impact of balancing market integration for Northern Europe, i.e. the Netherlands, Germany and the

Nordic region. This is achieved by means of an agent-based simulation of the North-European balancing markets before and after integration.

The structure of the paper is as follows. In Section II, a short explanation is given of the agent-based research methodology. Next, the agent-based model is described in Section III. In Section IV the analysis results are presented and discussed. Last, some conclusions are drawn in Section V.

II. Methodology

Agent-Based Modelling (ABM) is a relatively new modelling paradigm that focuses on the modelling of individuals who can make decisions. In an agent-based model, these individuals are represented as agents, and individual behaviour is formalised using algorithms [5]. Reference [6] states that "Agent-based Computational Economics researches the two-way feedback between regularities on the macro level and interaction of actors on the micro level". A balancing market has an agent (BRP/BSP) level and a system (SO) level, and includes a feedback between individual decisions and system-level observables, which makes ABM a very suitable methodology for the analysis of balancing markets.

Earlier research of the authors included the development of an agent-based model to analyse the impact of different imbalance pricing mechanisms, in which Balance Responsible Parties are the agents that decide on an over-/under-contracting (balancing) strategy and aim to minimize their imbalance costs [7]. This model has been extended for this paper to analyse the impact of balancing market integration, allowing us to take into account the effect of integration on BRP behaviour.

III. Model Description

The agent-based model, which has been built in MATLAB, basically consists of the balancing markets of the Netherlands, Germany and the Nordic region. The only physical power system elements included are the cross-border capacities between the three areas, which need to be available for cross-border balancing.

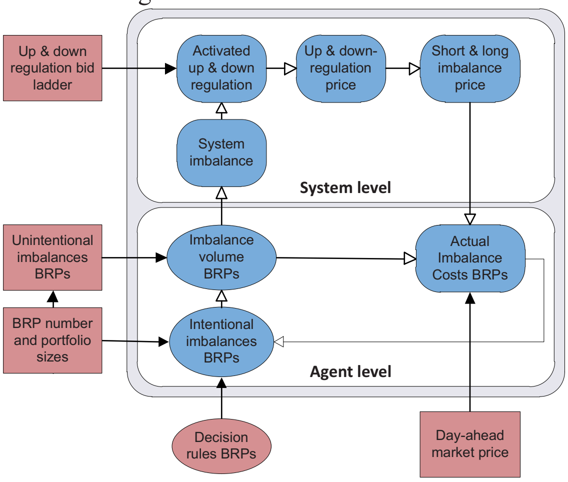

Fig. 2. Conceptual structure of the balancing market model

In Fig. 2 the fundamental structure and functioning of the balancing market, as embedded in the model, is shown. This structure is used for all three areas / markets. On the agent level, there is a set of BRPs with different portfolio sizes, each of which have to decide on an *intentional imbalance*, i.e. deliberate over/under-contracting of electrical energy by means of day-ahead or intra-day trading, for each STU or round. The sum of a BRPs' intentional imbalance and *unintentional imbalance*, i.e. the imbalance that arises from a consumption/production forecast error, is his *BRP imbalance*. The sum of all BRP imbalances forms the *system imbalance*, based on which upward and downward regulation bids are activated from a bid ladder. In turn, based on this activation, two imbalance prices are determined, a *long imbalance price* and a *short imbalance price*. The first is paid *to* BRPs with a positive BRP imbalance (BRP surplus), and the second is paid *by* BRPs with a negative BRP imbalance (BRP shortage). Based on the relevant imbalance price, the day-ahead market price and the BRP imbalance volume, the *Actual Imbalance Costs* are calculated for each BRP, which are fed back to the BRP for consideration in the decision-making on an intentional imbalance in future STUs/rounds. See [7] for more information on the above structure and concepts. Below, the model structure is described in more detail, followed by a description of the decision-making algorithm, input parameter values and the modelled cross-border balancing arrangements.

A. *Model structure*

Consecutively, model assumptions, model input, model steps and model output will be covered, all of which hold for all three areas.

1) Model assumptions: BRPs make a choice out of a fixed set of intentional imbalance options at the start of each round, which is equal to the STU. The resulting Actual Imbalance Costs are immediately processed as new information, which implies that BRPs are assumed to trade on an intra-day basis up to real-time. Moreover, these costs are calculated using a fixed day-ahead market price. Furthermore, there is a fixed upward and downward regulation bid ladder, with the up/down-regulation bid prices being higher/lower than a fixed day-ahead market price. The implication of the fixed bids is that BSPs are assumed to not alter their bidding behaviour over the rounds, or due to the integration, which is a large simplification within this model. Finally, BRPs in the model are not able to internally (passively) balance their portfolio in real-time by adjusting generation/consumption output. Their only balancing strategy consists of over-/under-contracting in the intra-day period, at the fixed day-ahead price.

2) Model input: The model input for each area consists of three main data sets. First, there is a list of BRPs that contains two properties: The portfolio size (in MW) and a standard deviation of the forecast error, which is used to determine unintentional imbalances. Second, the upward and downward bid ladder consist of a fixed set of bids, each with a specific bid volume (in MW) and a bid price (in euro/MWh). Third, there is the fixed day-ahead market price (in €/MWh). Furthermore, there is a fourth type of input that concerns the cross-border capacity: The transfer capacity values for the three interconnections between the areas, and the physical cross-border flows (both in MW).

3) Model steps: The model steps are already described in the beginning of this Section, and are illustrated in Fig. 2. At the start of each round, all BRPs choose a specific intentional imbalance option, 'option' in short. Then, unintentional imbalances are determined based on a draw from a normal distribution function, followed by the calculation of BRP imbalances and the system imbalance. Based on these, the amount of activated up- and down-regulation are calculated. Next, the regulation prices are set equal to the marginally activated bid prices in both directions. Then, depending on the imbalance pricing mechanism of the area, a long and short imbalance price are determined, followed by the calculation of the Actual Imbalance Costs. Based on these, the BRPs update the expected costs of different options, which are used in the decision rules.

4) Model output: The main output of the model consists of the system imbalances, activated regulation volumes, regulation and imbalance prices, and the total Actual Imbalance Costs.

B. Decision-making algorithm

The Actual Imbalance Costs (AIC) are calculated for the active round, for each BRP, according to Equation (1).

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

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.

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):

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

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

The final choice of a BRP for a specific option occurs through a draw from a continuous uniform distribution, with probabilities of choosing different intentional imbalance options being 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 (cf. [8]) has been included to make the results of recent rounds weigh heavier in the decision-making.

C. Input parameter values

The input parameter values that are used in the simulation model are presented in Table I. First of all, there are seven intentional imbalance options, represented by percentages of the portfolio size, namely -2%, -1%, -0.5%, 0%, 0.5%, 1%, and 2%. Furthermore, each round equals a STU of 15 minutes, as is the case in the Netherlands and Germany. The Nordic region actually has a STU of 60 minutes, but an identical STU is at least required for a common merit order list, which is why this input value has been chosen. The STU is not a model input that has any effect on the model parameters, whereas in reality it affects the BRP strategies. Another general input value is the delivery rate of 2, which means that each 2 MW of activated regulation power yields only 1 MWh of balancing energy per hour, because of the limited ramping rate.

The first area-specific input parameter is the standard deviation of the forecast error, which is set to a value that matches the area imbalance volume relative to system size, which is larger for Germany (cf. [9]). Next, the activated up- and down-regulation volumes in the model are proportional to resp. the market shortage (sum of BRP shortages) and the market surplus (sum of BRP surpluses), which enables the modelling of two-sided regulation, i.e. both upward and downward regulation within the same STU. This is determined by the regulation rate. The day-ahead market prices are based on the average exchange prices in 2009.

TABLE I
MODEL INPUT VALUES

	Areas		
Parameters	**Nether-lands**	**Ger-many**	**Nordic region**
Intentional imbalance options (%)	-2.0 / -1.0 / -0.5 / 0.0 / 0.5 / 1.0 / 2.0		
STU (min.)	15		
Delivery rate	2		
Total portfolio size (MW)	25,000	120,000	82,500
$\sigma_{\text{forecast error}}$	0.015	0.0175	0.015
Regulation rate	0.15	0.25	0.2
Day-ahead market price (€/MWh)	39	38.5	35
Regulation pricing mechanism	marginal	pay-as-bid	marginal
Imbalance pricing mechanism	dual	average	single
Initial expected AIC (€)	close to zero (draw from uniform distribution with range [0,1])		
Number of rounds	1,000		
Recency parameter	0.9		
Up- and down-regulation bid ladder	fixed set of bids (including bid volume and price)		
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		

The areas have different pricing mechanisms, which are applied in the model (except for the common merit order list, see below). 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 basically the weighted average of activated bid prices. The Netherlands applies dual pricing, which means that the long imbalance price is set equal to the marginal downward regulation price and the short imbalance price is the upward regulation price. However, if single-sided regulation occurs, single pricing is applied, which means that both the long and short imbalance price are the marginal price in the major regulation direction [7], [9].

Next, there are some general model-related input values. The initial expected Actual Imbalance Costs for different options are set close to zero. They are drawn from a continuous uniform distribution between 0 and 1, so that BRPs will not all choose the same option at the start of the model run. One model run is 1,000 rounds long, which comes down to at least ten full days.

Furthermore, the fixed bid ladders are based on regulation (bid) data from 2009. 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. 3. 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.

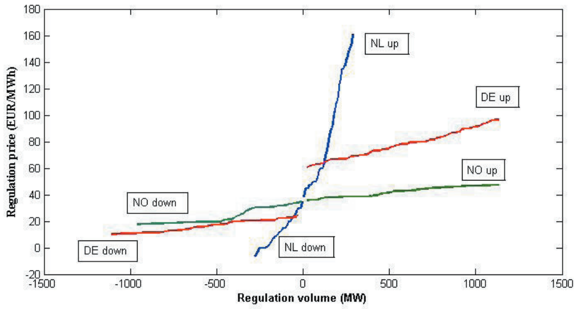

Fig. 3. Fixed up- and down-regulation bid ladders of the three areas

Finally, 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 [10].

D. Cross-border balancing arrangements

In the analysis, four alternative cross-border balancing arrangements, 'arrangements' in short, are compared. They are visualized in Fig. 4. The first arrangement is that of '**separate markets**'. The balancing markets of the Netherlands, Germany and the Nordic region do not interact, but function independently.

In the second arrangement called '**ACE netting**' 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. An important assumption is that, if the system surplus in one area is not large enough to cover the system shortages in the two other areas, or if the sum of the system surpluses in two of the areas is not as large as the system shortage in the third area, proportional surplus energy flows will materialize. Apart from this, system imbalances are completely removed when possible.

The third arrangement included is called '**balancing energy trading**', which can be considered the most advanced and efficient version possible of both the BSP-SO trading and the additional voluntary pool (SO-SO) arrangements described in [4]. Here, the system imbalances of the three areas are removed by activation of the cheapest regulation bids within the region. If the cheapest bids can be utilized in the own area, this will be done; otherwise, they will be exported to another area in case there is cross-border capacity available for the resulting 'balancing energy flows'. Regulation and imbalance pricing is still based on the national rules.

The fourth arrangement is the '**common merit order list**', which is a fully integrated balancing energy market with one aggregate bid ladder for up- and down-regulation. The activation procedure is the same as for the third arrangement, as it is assumed that ACE netting does not take place, but here there are regional pricing mechanisms. A uniform regional upward and downward regulation price is determined for each STU / round using marginal pricing. Likewise, there is a uniform regional long and short imbalance price based on the single pricing principle. This means that the long and short imbalance price are identical, and equal to the regulation price in the dominant regulation direction.

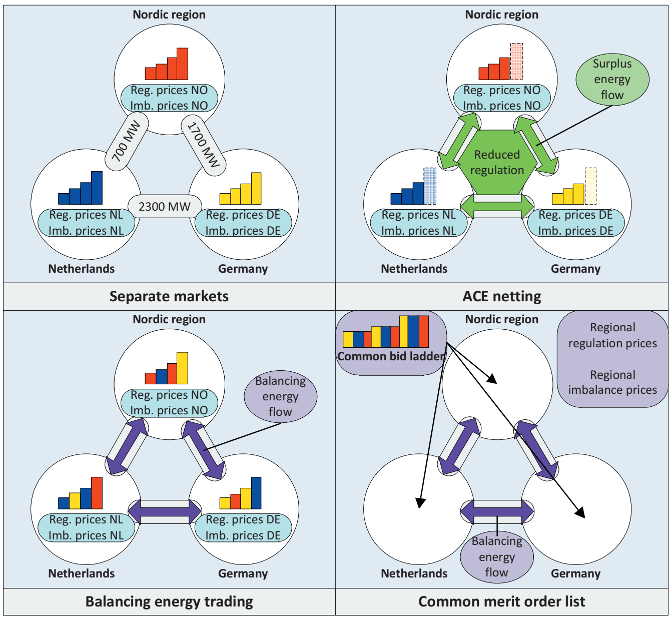

Fig. 4. The four cross-border balancing arrangements in the analysis

IV. Analysis Results

Running the model for each of the four defined arrangements five times and taking the average of the output variable values has led to the main analysis results that are presented in Table II. First, the validity of the model is investigated. After that, the main results are discussed per arrangement.

A. *Validation*

The average activated up- and down-regulation volumes given in Table II are similar to the actual balancing market results in 2010: For up/down regulation, those were +38/-54 MW for the Netherlands, +541 MW/-638 MW for Germany, and +223/-284 MW for the Nordic region. The same is true for the imbalance prices, which is reason to conclude that the analysis results lie close enough to actual North-European balancing market results to be able to draw conclusions from this simulation study on the impact of balancing market integration in Northern Europe.

B. *Impact of arrangements*

ACE netting results in a 25% reduction of the total Actual Imbalance Costs in the Netherlands, and thus creates a large costs reduction for BRPs. In Germany, this reduction is only 5%, and in the Nordic region, the total AIC were very small to begin with thanks to the large supply of cheap hydro-bids. The reason for this is that the Netherlands, being the smallest power system, can much more often 'net' a much larger part of its system imbalance. Moreover, the netting results in a 56% increase of STUs with one-side regulation, increasing the usage of single imbalance pricing, which is cheaper for BRPs.

Balancing energy trading causes a huge total AIC reduction for the Netherlands and Germany of resp. 47% and 38%, which is caused by high import levels of cheap Nordic bids by both countries: 55% of the balancing energy dispatched by the Netherlands is imported, and this is 75% for Germany, made possible by the large oversupply of cheap Nordic bids, and the presence of ample cross-border capacity. Regulation costs reductions have comparable proportions, which is in line with the results of an analysis of the impact of balancing market integration in Northern Europe with a linear optimisation model [11]. The largest effect on imbalance prices is observed in Germany: the single price diminishes by 3.76 €/MWh to an average value that is about 1 €/MWh below the day-ahead market price. This has caused a system balance state in which system surpluses occur in 54.7% of the STUs, as it has become more costly for BRPs to be 'long'. For the Nordic region, nothing really changes.

TABLE II
ANALYSIS RESULTS

	Separate markets			***ACE netting***			***Balancing energy trading***			***Common merit order list***		
Output variables / Country	**NL**	**DE**	**NO**	**NL**	**DE**	**NO**	**NL**	**DE**	**NO**	**NL**	**DE**	**NO**
Average system surplus (MWh)	41	145	79	27	109	62	43	126	80	42	128	98
Average system shortage (MWh)	-42	-122	-97	-28	-99	-68	-43	-140	-97	-45	-142	-80
Occurrence system surplus (%)	49.8	57.2	41.2	41.4	53.7	37.2	47.7	45.3	41.2	47.1	45.9	57.3
Occurrence system shortage (%)	50.2	42.8	58.8	42.7	39.9	50.2	52.3	54.7	58.8	52.9	54.1	42.7
Average upward regulation (MW)	50	460	220	41	424	201	57	542	234	59	543	166
Average downward regulation (MW)	-48	-522	-261	-42	-483	-232	-58	-468	-273	-53	-462	-350
Average upward regulation price (€/MWh)	49.27	66.62	38.59	47.71	66.51	38.32	44.94	50.69	38.59	51.34	51.34	51.34
Average downward regulation price (€/MWh)	26.46	20.99	30.00	27.25	21.21	30.44	32.05	21.94	29.98	21.25	21.25	21.25
Average short imbalance price (€/MWh)	42.96	41.31	34.39	43.13	41.40	34.53	41.69	37.55	34.39	37.13	37.13	37.13
Average long imbalance price (€/MWh)	32.50	41.31	34.39	32.33	41.40	34.53	35.35	37.55	34.39	36.96	36.96	36.96
Average penalty for BRP shortage (€/MWh)	3.96	2.81	-0.61	4.13	2.90	-0.47	2.69	-0.95	-0.61	-1.87	-1.37	2.13
Average penalty for BRP surplus (€/MWh)	6.50	-2.81	0.61	6.67	-2.90	0.47	3.65	0.95	0.61	2.04	1.54	-1.96
Total Actual Imbalance Costs (M€)	1,399	3,317	561	1,028	3,166	439	740	2,065	569	323	2,043	761

The common merit order list results in balancing costs reductions similar to balancing energy trading, because the same economically optimal allocation of balancing energy services is realized in this arrangement. However, the uniform marginal pricing has a very large effect on prices: the regulation prices are set equal to the most expensive activated bid in the entire region, which results in an average upward price of 51.34 €/MWh and an average downward price of 21.25 €/MWh, which are much higher/lower than the highest/lowest day-ahead market price in the region. Furthermore, it can be observed that regulation and imbalance prices have 'merged' toward each other, compared to separate markets. For the Netherlands and Germany, these prices have become much more favourable from a systems' and BRPs' point of view (although BSPs receive less money for dispatched balancing energy). In the Nordic region, however, the penalties for BRP imbalances have increased a lot, which means higher financial risks for BRPs. In all three areas, the large changes in imbalance prices and the resulting changes in penalties have caused a shift of the system balance state, i.e. the relative occurrence of system surpluses and shortages. However, the sums of all BRP imbalance volumes (system imbalance volumes) are about the same, which indicates that the balancing energy exchange and the regional pricing mechanisms do not damage the appropriateness of the incentives for BRPs to balance their portfolio (cf. [7]).

C. *Sensitivity and reflection*

The results are the same for a larger number of rounds, and not sensitive to the recency parameter. Obviously, the choice for larger intentional imbalance options and standard deviations for the forecast error lead to higher Actual Imbalance Costs. The change in the day-ahead price has a large impact, because it changes the imbalance penalties, unless the bid prices are changed at the same time (in which case the effect of the day-ahead price is much smaller). The effect of changes in available cross-border capacity is low, perhaps because of the possibility to exchange balancing energy in the direction opposite to the power flow. Finally, the impact of bid ladders is, as expected, very large: Smaller differences between national ladders means less balancing energy exchanges and imbalance costs reductions.

Reflecting on the above, the results appear to be rigorous. However, the main assumption of the fixed bid ladders limits the value of the results, because in reality Balancing Service Providers will adapt their bidding strategies as a result of balancing market integration. Also, day-ahead prices are fixed in the analysis, which underestimates the fluctuations in prices and resulting balancing energy exchanges. Finally, the results for the different cross-border balancing arrangements are subject to specific assumptions and designs; the relative effects of these arrangements may change for different ones.

V. Conclusions

The balancing markets in Northern Europe (the Netherlands, Germany and the Nordic region) have a quite different design and performance, with the cheap and abundant regulation resources in the Nordic region as the most significant feature. The analysis shows that the impact of different cross-border balancing arrangements in this region is clearly different. ACE netting only causes a 25% imbalance costs reduction for the Netherlands, because of its smaller system size and the reduced activity of dual imbalance pricing. Balancing energy trading reduces the total imbalance costs for the Dutch and German markets by 40-50%, thanks to the import of the majority of the dispatched balancing energy from the Nordic region, made possible by the availability of cross-border capacity. The common merit order list results in similar exchanges and costs reductions, but here the regulation prices are much higher. Although the total Actual Imbalance Costs for the three areas together are lower than for balancing energy trading, the imbalance risks (penalty sizes) are larger for German and Nordic BRPs, which is the result of the marginal regulation pricing on a regional level. Also, the Nordic imbalance costs increase largely. Finally, the analysis results show that BRP behaviour can be largely affected by integration, but that the system imbalance directions are affected much more than the imbalance volumes.

In the agent-based analysis, balancing energy trading and the common merit order list come out as the best arrangement. However, this outcome is subject to the detailed design of the included arrangements. With regard to balancing market integration in general, the analysis results indicate that such integration has a large net positive effect on performance, i.e. more favourable prices and lower imbalance costs. However, the increased dependency on balancing services from other areas and large price and costs increases in some areas may reduce the net benefit of integration, and a lower availability of cross-border capacity will obviously reduce this net benefit as well.

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