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DETERMINATION OF ECONOMIC AND ENVIRONMENTAL BENEFITS OF VPP-BASED DEMAND SIDE BIDDING IN A COMMON CROSS-BORDER BALANCING MARKET FOR AUSTRIA, SLOVENIA AND ITALY[1]

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ABSTRACT

This paper studies the economic and environmental benefits of a common cross-border balancing market area in Austria, Slovenia and Italy. As a benchmark the national clearing results of the currently implemented market set-up in these three national balancing markets are used. The chosen market architecture of a common cross-border balancing market is a bilateral/multilateral market-based TSO-TSO model with common merit-order and unshared bids. Build upon the status quo, special attention is put to the insertion of new Balancing Services Providers (BSPs) offering demand response bidding. The results derived from a tailor made balancing market simulation model indicate clear benefits of a common cross-border balancing market in terms of reduced clearing prices/dispatch cost, reduced fossil fuel consumption/costs, reduced CO_2 emissions/costs, reduced network losses, increased competition among market participants, and as a consequence increased liquidity in the balancing markets in general.

[1] The results presented in this paper are derived from the FP7 project ‘eBadge’. The project ‘eBadge’ (http://www.ebadge-fp7.eu/) received funding from the European Community’s Seventh Framework Programme (FP7/2007-2013) under grant agreement n. 318050.

1 INTRODUCTION

At present, the European balancing markets are still characterized by very heterogeneous patterns manifold, e.g. in terms of market structures, market rules, operational procedures and also prequalification criteria for Balancing Service Providers (BSPs) being interested to participant in a particular balancing market. In recent years, however, there have been clear signals and activities to open the European balancing markets in many dimensions, e.g.

- The current development of ENTSO-E's network codes,2 notably NC EB (Network Code Electricity Balancing [1]), clearly outlines the cornerstones for a future cross-border balancing market in Europe.3 The ultimate long-term goal is to head towards the so-called 'target model', envisaging among many other functionalities unlimited cross-border bidding of several BSPs and clearing in a common European balancing market.
- In the daily business, some of the European Transmission System Operators (TSOs) already implemented novel elements like the so-called 'Imbalance Netting'. Imbalance netting directly uses cross-border (i.e. inter-TSO) synergies4 in the balancing market segment. Moreover, counteracting activations of balancing capacities of neighbouring TSOs are avoided in the case of imbalance netting (a precondition therefore is that cross-border transmission between TSOs is not congested). Naturally, this reduces the potential for imbalances and, subsequently, also the market potential for BSPs in general.

In order to implement trans-national European balancing markets as efficient, effective and fast as possible, harmonization of terms, market structures, procedures and prequalification criteria in the different national balancing markets across Europe is the order of the day. Because then only several existing and new BSPs (e.g. also Virtual Power Plants (VPPs) offering demand response; the focus of analyses in the eBadge project) can participant in a non-discriminatory way in transnational balancing markets.

However, when having in mind the currently existing particularities of the national balancing markets in Austria, Slovenia and Italy - the geographical focus of analyses in the eBadge project - it is difficult to anticipate a common, fully competitive balancing market in these three countries already in the next years perfectly according to the expectations in the so-called 'target model'. Therefore, the eBadge pro-

[2] ENTSO-E: European Network of Transmission System Operators for Electricity (www.entsoe.eu)

[3] Moreover, there are also further network codes addressing and affecting cross-border electricity balancing itself and/or cross-border trading in general. For details it is referred directly to the corresponding ENTSO-E website: networkcodes.entsoe.eu

[4] With the exception of Germany, where there are 4 TSOs within the country, the boundary of a TSO also coincides with the political border of the country. In recent years, imbalance netting has been developed and commercially implemented among the 4 German TSOs first. Subsequently, neighboring Central European countries increasingly adopted this approach.

ject recommends intermediate steps between the currently existing national balancing markets and the fully competitive international 'target model' approach:

- A first intermediate model can be a "bilateral/multilateral market-based TSO-TSO balancing model with surplus balancing energy exchange", where different approaches for the implementation of the surplus balancing energy bid exchange and reallocation to the corresponding national merit-order lists are presented.
- A second intermediate model can be a "bilateral/multilateral market-based TSO-TSO balancing model with common merit-order and unshared bids". There exist also different possibilities in terms of withholding and sharing bids among the national balancing markets involved in a common international balancing market.

In [2] several pros and cons of these two different market architectures representing intermediate steps between a purely national and a common international balancing market are systematically discussed and compared. As a result of this comprehensive investigation of these two intermediate models it has been decided to implement the second approach in the eBadge balancing market simulator (see chapter 2 below in detail) and the subsequent economic and market analyses tool. The reasons for this decision are manifold. A selection of some of them is as follows:

- *Avoidance of sharing the most expensive bids only:* Whereas in the "surplus-bid" approach only the most expensive bids would be shared in a common cross-border balancing market (i.e. those not used after sequential clearing of a national balancing market), the chosen "common merit-order and unshared-bid" approach leads to the opposite effect. This means that the most expensive bids only can be withheld, whereas the cheapest ones need to be forwarded and shared in a common cross-border merit-order (see [2] in detail).
- *Simultaneous clearing possible:* Another significant disadvantage of the "surplus-bid" approach is that no simultaneous clearing is possible in the three countries; it rather is a sequential clearing, starting with the country achieving the lowest clearing price. Moreover, ex-ante the number of iterations needed for clearing several of the three balancing markets is also not determined. Therefore, this approach is to some extent obscure. All these reasons finally favour the implementation of the alternative intermediate balancing market model.
- *Non-discriminatory treatment of several balancing bids:* Having in mind the average activation rate of balancing bids in the three balancing markets Austria, Italy and Slovenia (AIS) the "surplus-bid" approach clearly would put some tension to the attempt to foster the activation of bids in a common cross-border balancing market. Moreover, in a surplus-bid approach the least attractive balancing bids of each country are shared only; and they are rarely activated. This aspect is even more important in case of imbalance netting'. This is also a strong argument to opt for the "bilateral/multilateral

market-based TSO-TSO balancing model with common merit-order and unshared bids” approach.

Against this background, the paper is organized as follows: section 2 describes the methodological approach of the analyses. Section 3 presents the different balancing market clearing results (separate national versus common AIS market) based on the currently existing BSP structure in these three markets (see also [4]). In section 4 it is assumed that additional BSPs, notably VPPs offering demand response bids, enter the balancing market and context market shares. The corresponding results are discussed and compared with the initial ones. Concluding remarks finally finish the paper.

2 METHODOLOGY

The above mentioned market architecture implemented in the eBadge balancing market simulator builds upon simultaneous nation-wide submission of both balancing capacity and balancing energy bids. Therefore, it is very flexible to filter out the net effects of individual bids not only in the three separate national balancing market clearings, but also in case of a common cross-border AIS market clearing where some bids are shared among the three balancing zones. And this is exactly what’s needed in the quantitative analyses in this paper.

Firstly, the functionalities of the eBadge balancing market simulator (see [3] in detail) delivering the raw balancing market clearing results for both cases (separate national clearing as well as common AIS market clearing) can be summarized (also in terms of inputs) as follows:

- the balancing energy market is modelled as a real-time power dispatch;
- the imbalance values in each of the modelled zones are known before aFRR (automatic Frequency Restoration Reserve) and mFRR (manual Frequency Restoration Reserve) energy bids are called in both directions (based on defined rules) on the basis of a price merit order to eliminate the system imbalance;
- the amount of cross-border transmission capacity still not allocated after the intraday trading is assumed as available for the exchange of balancing energy;
- historical, real balancing bids and imbalance figures are used as an input for the eBadge simulator (in total, a period of 12 weeks (week 48/2014 until week 7/2015) has been simulated on a ¼ hour basis in the AIS market area);
- Italy is split in six different zones (same clustering as for the Italian day-ahead market), but is considered to be a single node in further analysis, while Slovenia and Austria are represented by one node per country.

The major output/result portfolio of the eBadge simulator - subsequently feeding into the Matlab economic and market analyses tool - can be briefly summarized as follows:

- Imbalance per balancing zone/country;
- All submitted bids (price, quantity) per balancing zone/country for both separate and common clearing in the AIS balancing market area;
- accepted bids (price, quantity) per balancing zone/country for both separate and common clearing in the AIS balancing market area;
- in case of common clearing also cross-border energy flows;
- total balancing cost per country for both separate and common clearing in the AIS balancing market area;
- remaining imbalance per balancing zone/country after both separate and common clearing in the AIS balancing market area;

Secondly, the further economic analysis based on a tailor made Matlab tool builds upon these raw balancing market clearing results. Moreover, in order to be able to filter out different influences of individual bids, each of the bids needs to be described more comprehensively beyond the two parameters price and quantity. Therefore, in a first step, each bid is characterized further by the following additional properties, in order to be able to initialize a default setting for the economic analyses:

- identity (market participant’s ID)
- primary fuel type/mix
- specific fuel cost
- specific CO2 emissions

This characterization is based on the following approaches and is underlying the following assumptions, observations and partly monitored data by TSOs in the respective AIS balancing market area:

- *Bottom-up approach:* In each of the three balancing zones/countries the number of prequalified market participants as well as their power plant portfolio in the aFRR and mFRR balancing market is determined. The number of market participants in the corresponding market segments is countable and the analyses of historical data of balancing market clearings rather give clear indications which type of power plant (and, subsequently, which market participant) have set the clearing price. This information is matched with the inputs of the following bullet point.
- *Top-down approach:* The TSOs from Austria (APG) and Slovenia (ELES) - both also eBadge consortium members - provided the number of market participants, their market shares and the shares of prequalified power plant types in their balancing zones/countries in both balancing market seg-

ments. For Italy the same empirical data has been gathered, except the market share per market participant had to be estimated.5

Finally, the initialization based on the inputs described above enables the economic analyses (default case) for both separate and common clearing in a coupled AIS market area. In particular, the following results - besides price and quantity already derived from the eBadge balancing market simulator - are of interest in a first step:

- overall dispatch cost (separate versus common clearing) and corresponding social welfare gains;
- fossil fuel cost (separate versus common clearing) and corresponding fossil fuel savings;
- CO2 emissions (separate versus common clearing) and corresponding CO2 savings;
- competition index (called HHI)6 among market participants (separate versus common clearing) and corresponding market liquidity increase;
- (avoided) network losses (separate versus common clearing).

Eventually, in a second step, some of the balancing market bids - and finally corresponding activations - are assumed to be demand response bids from new BSPs (notably VPPs aggregating dispersed flexible load potentials) suppressing some of the default bids/market participants. Then, again, the same analysis is conducted as described in first step. The differences of both kinds of results (without (step 1) and with (step 2) demand response bids) are quantified in order to provide a basis for further evaluation and discussion.

3 RESULTS - ECONOMIC AND ENVIRONMENTAL BENEFITS OF A COMMON AIS BALANCING MARKET WITH CURRENTLY EXISTING MARKET PARTICIPANTS

Based on the methodology described above, in this section selected results of the economic and market analyses are presented using the currently existing BSP structure and corresponding empirical data in these three balancing markets. Notably, the following results are presented:

- Available bids on country and common AIS balancing market level for a single ¼ hour as well as for the whole observation period;
- Accepted bids on country and common AIS balancing market level for a single ¼ hour as well as for the whole observation period;

[5] Personal interview with an expert from the Italian TSO: Terna (www.terna.it).

[6] 'Herfindahl-Hirschman Index (HHI) is a commonly accepted measure of market concentration. It is calculated by squaring the market share of each firm competing in a market, and then summing the resulting numbers. The HHI number can range from close to zero to 10,000 (or 1 if normalized). The closer a market is to being a monopoly, the higher the market's concentration (and the lower its competition).

- Clearing cost, fossil fuel consumption (cost) and CO2 emissions (cost) aggregated for one full calendar year for the provision of positive and negative balancing energy for separate national versus common AIS market clearing.

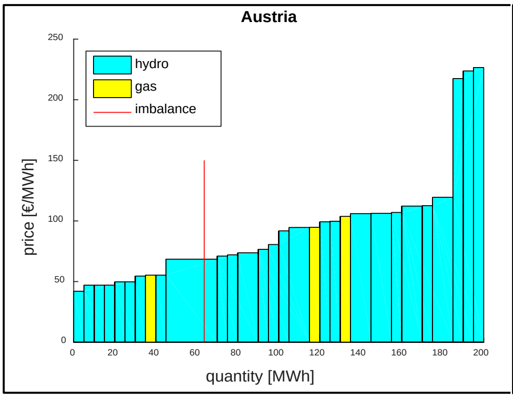
In addition, further results are derived on country and common AIS balancing market level as there are e.g. market concentration (competition index) among market participants, imbalances as well as cross-border flows between the different countries for the following time segments: ¼ hour, whole observation period (12 weeks) and on annual basis. Some of these results are presented in the context of different sensitivity analyses in section 4.

3.1 Evaluation of a Single ¼ Hour

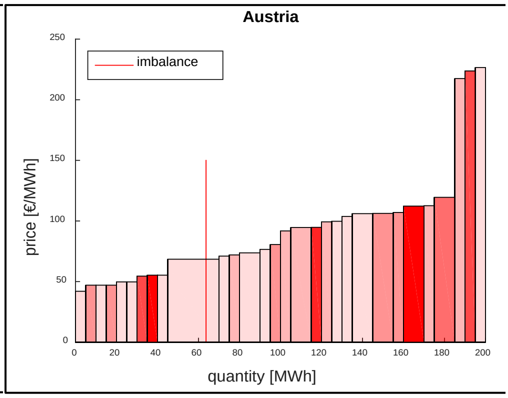
3.1.1 Merit Order per Country

The following Figure 1 presents for the countries Austria, Slovenia and Italy the available bids (both per power plant technology/primary fuel (left) and per market participant (right)) as well as the corresponding imbalance in a single ¼ hour in the whole observation period (12 weeks in total). For this particular ¼ hour, it can be seen that the dominant Austrian primary fuel type in the balancing market segment (both aFRR and mFRR) is hydro power. Minor shares are covered by gas.

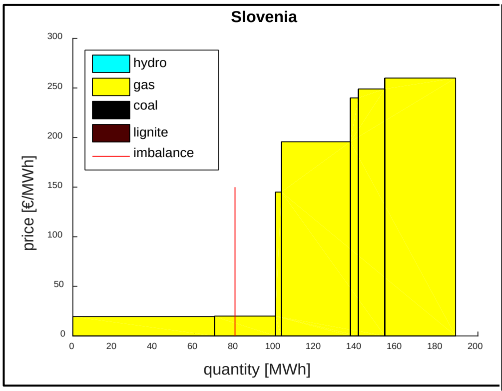
There is also a critical mass of Austrian market participants bidding into the balancing market in this ¼ hour (in total there are 10 companies prequalified in the aFRR and mFRR segment in Austria). In Slovenia for this particular ¼ hour only one company with a gas-fired CCGT is needed to meet the corresponding imbalance. However, in total there are 4 companies prequalified being also successful and/or needed to manage the imbalance in the whole observation period. Last but not least there is Italy with 16 prequalified companies; some of them are successful to meet the imbalance in the particular ¼ hour. The corresponding primary fuel of the Italian companies is gas, coal and oil.



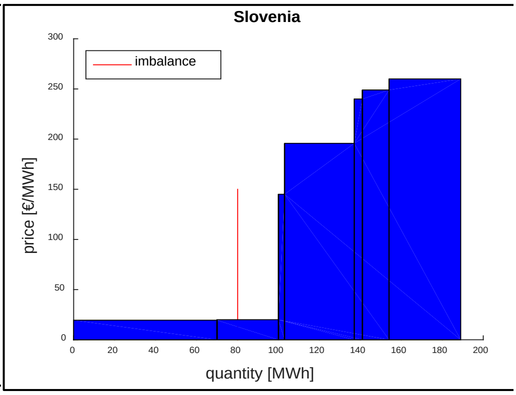
(a) Per Power Plant Technology



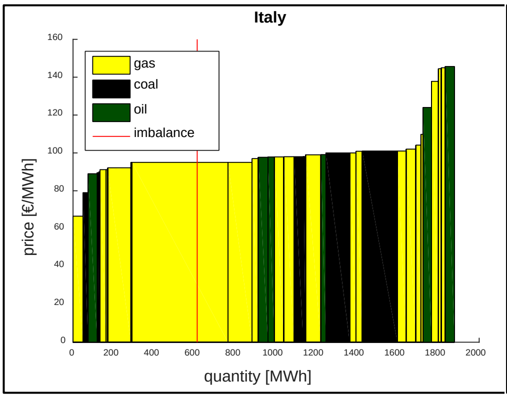
(b) Per Market Participant



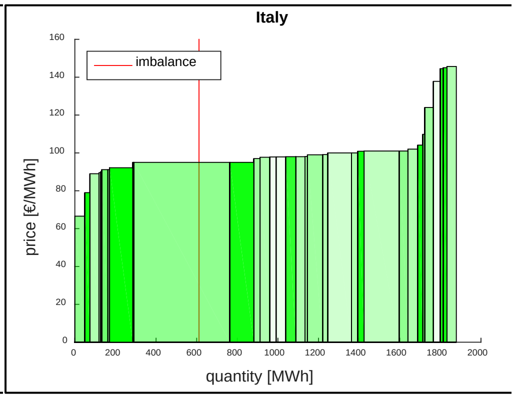
(a) Per Power Plant Technology



(b) Per Market Participant



(a) Per Power Plant Technology



(b) Per Market Participant

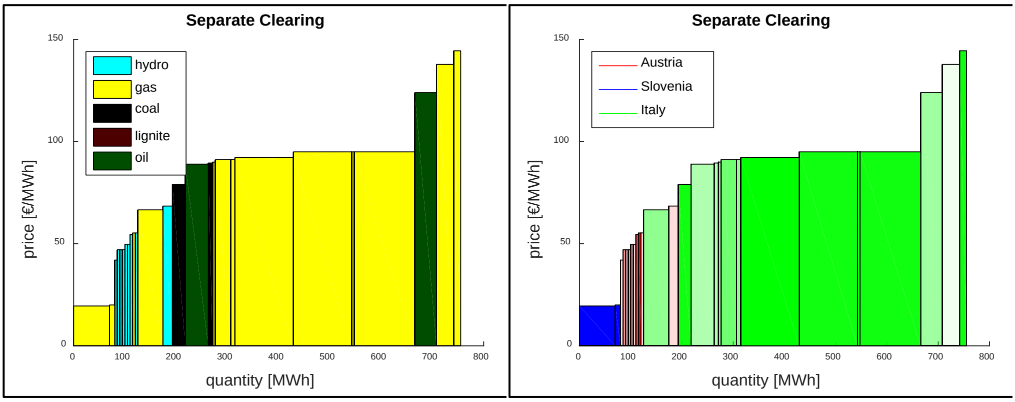
Figure 1: *Available bids in Austria, Slovenia and Italy in the observed ¼ hour: (a) depicts different power plant technologies, (b) depicts different companies offering balancing reserves (different shades indicate different companies).*

3.1.2 Accepted Bids Meeting the Imbalance

All accepted bids in the observed ¼ hour are presented in the following Figures 2 and 3 for both separate and common AIS balancing market clearing. Again, the left figures present the accepted bids per power plant technology/primary fuel whereas the right figures indicate the different market participants.

At first sight, Figures 2 and 3 look quite similar. However, there are slight differences:

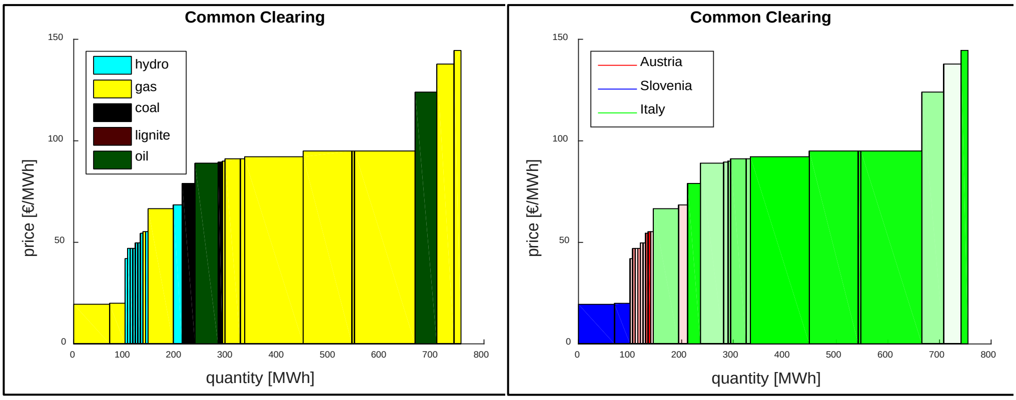
- In case of separate clearing only a fraction of the second Slovenian bid is needed to meet the national imbalance for this ¼ hour (Figure 2 (right)).
- In case of common clearing, however, the entire amount of the second Slovenian bid (gas-fired technology) is selected to meet the total imbalance in several of the three countries (Figure 3 (right)).



(a) Per Power Plant Technology *(b) Per Market Participant*

Figure 2: *Accepted bids of all three countries in the observed ¼ hour in case of separate clearing: (a) depicts different power plant technologies, (b) depicts different companies offering balancing reserves (different shades of a colour indicate different companies within the same country).*

In general, it can be observed that the merit order curves, regardless whether accepted bids of separate or common balancing market clearing is addressed, are characterized in this particular ¼ hour as follows: In Slovenia the cheapest bids are offered, followed by the cluster of Austrian bids and, finally, Italian bids. This means that in this particular ¼ hour the most expensive bid still being needed to meet corresponding imbalance is an Italian bid.



(a) Per Power Plant Technology *(b) Per Market Participant*

Figure 3: *Accepted bids of all three countries in the observed ¼ hour in case of common AIS balancing market clearing: (a) depicts different power plant technologies, (b) depicts different companies offering balancing reserves (different shades of a colour indicate different companies within the same country).*

3.2 Upscaling of the Results of the Whole Observation Period to Annual Results

3.2.1 Clearing Cost: Separate versus common AIS Balancing Market Area Clearing

In the following Figure 4, the net cost of balancing energy in the common AIS balancing market area are presented on annual basis (i.e. up-scaled from ¼ hour values in the observation period). In this context, net costs are composed of positive values (i.e. cost for the TSOs for purchasing positive balancing energy) and negative values (revenues for TSO for purchasing negative balancing energy).7

The results presented in Figure 4 show not only the monetary results of common AIS balancing market clearing, but also the separate clearing results on country level as well as the corresponding differences between both options. Summarizing, it can be stated that common AIS balancing market clearing leads to net balancing cost savings for Austria (-15,5%) and Slovenia (-47,1%). On the contrary, Italy has to accept higher cost (+8,4%). In total, across several of the three countries involved, net balancing cost savings of common AIS balancing market clearing result in -4%.

[7] This means that in liquid balancing markets BSPs are also willing to pay for the provision of corresponding services as long as there is an opportunity for price arbitrage between different market segments. In many balancing markets, however, at present (characterized by limited liquidity) the BSPs expect to be paid by the TSO for the provision of several balancing services.

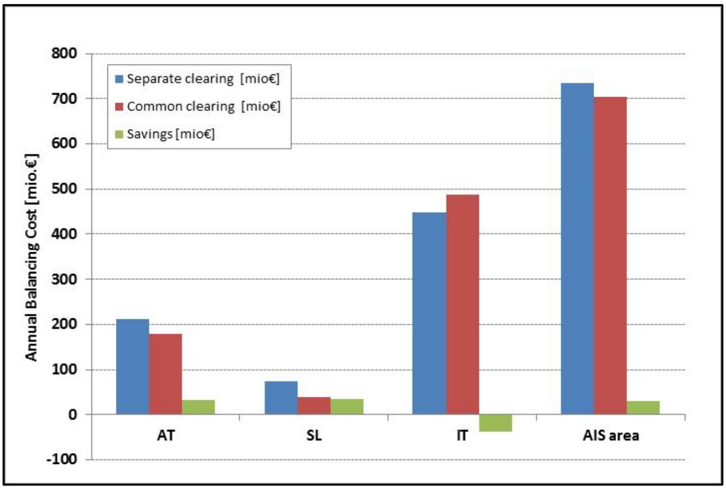


Figure 4: *Net cost of balancing energy for a year (2014) per country as well as in the common AIS balancing market area.*

3.2.2 Fossil Fuel Consumption and CO2 Emissions

In Figure 5 below - based on the results of balancing energy cost on annual basis in Figure 4 and also matched with the corresponding bids per power plant technology and country presented earlier in this section - the corresponding absolute numbers are shown in terms of fossil fuel consumption for the provision of positive balancing energy again for both cases, separate and common AIS balancing market clearing. Also the corresponding fossil fuel savings are drawn in each case. Austria and Slovenia slightly benefit from common AIS balancing market clearing (i.e. reduce fossil fuel consumption) on the expense of Italy. In total, across several of the three countries involved, fossil fuel savings of common AIS balancing market clearing result for the provision of positive balancing energy in 3%.

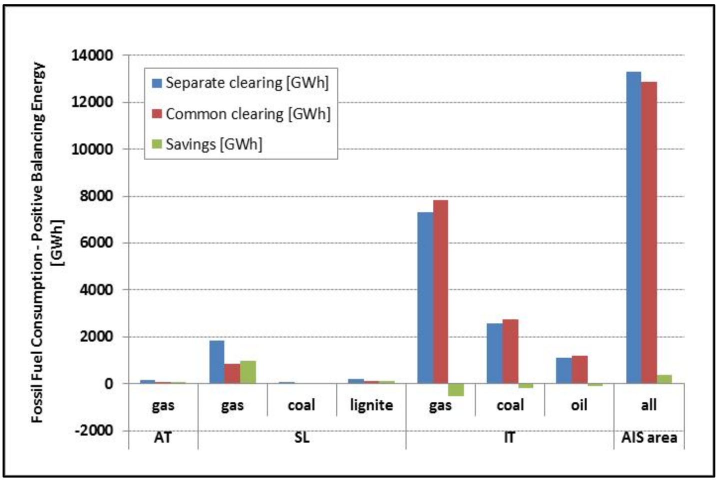


Figure 5: *Fossil fuel consumption for the provision of positive balancing energy for a year (2014) per country as well as in the common AIS balancing market area.*

Derived from the numbers in terms of fossil fuel consumption and savings above, in the following Figure 6 the corresponding CO_2 emissions are presented. Again both separate and common AIS balancing market clearing are shown for the provision of positive balancing energy on an annual basis. Austria and Slovenia benefit in case of common AIS balancing market clearing, whereas Italy has to accept higher CO_2 emissions. This means that Italy does not necessarily benefit from high shares of Austrian hydro power plants available in the balancing market segment. This is mainly due to limited cross-border transmission capacities on the direct interconnector between Austria and Italy.

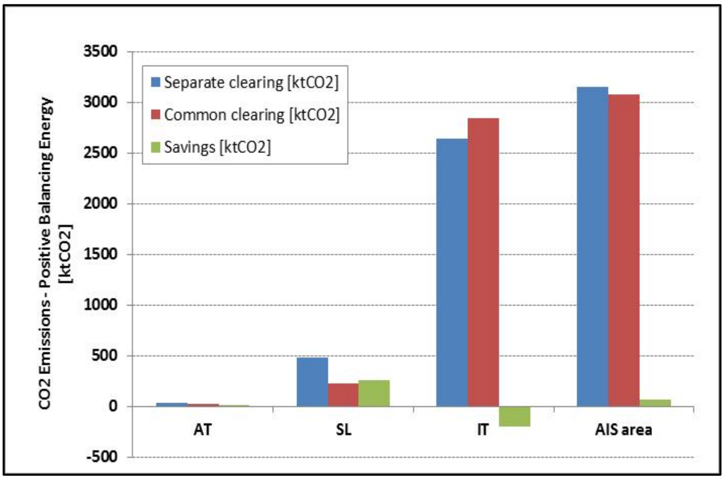


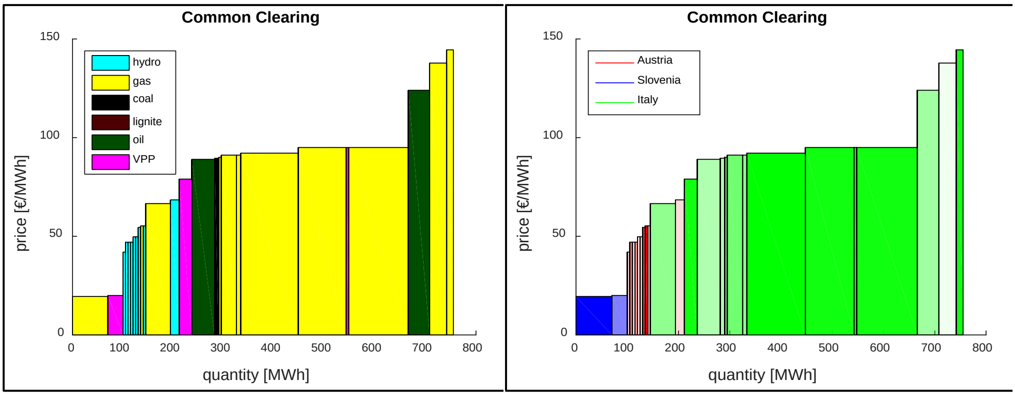
Figure 6: *CO_2 emissions for the provision of positive balancing energy for a year (2014) per country as well as in the common AIS balancing market area.*

4 SENSITIVITY ANALYSES: ADDITIONAL BSPS OFFERING DEMAND RESPONSE BIDS

Build upon the analyses in section 3, where selected results of the economic and environmental analyses of the default settings (in terms of market participants and observed market data) are presented, in the following sensitivity analyses additional BSPs (notably VPPs) offering demand response bids in each of the three countries are assumed. More precisely, the following settings are studied:

- 10% of prequalified BSPs in each country are VPPs; i.e. number of companies offering demand response bids: AT = 2; SL = 1; IT = 3
- 25% of prequalified BSPs in each country are VPPs; i.e. number of companies offering demand response bids: AT = 3; SL = 1; IT = 6

The following Figure 7 presents the corresponding amended price/quantity version of the previous merit-order pendant (Figure 3) for the 10% VPP case. It shows several accepted bids for the case of common AIS balancing market clearing for a particular ¼ hour both in terms of power plant types and VPPs (left) and market participants (right). The corresponding figures for the 25% VPPs case are not presented here; they simply further increase the corresponding VPP shares in both figures.



(a) Per Power Plant Technology *(b) Per Market Participant*

Figure 7: *Accepted bids of all three countries in the observed ¼ hour in case of common AIS balancing market clearing: (a) depicts different power plant technologies and VPPs, (b) depicts different companies and VPPs offering balancing reserves (different shades of a colour indicate different companies within the same country).*

In the following, for the common AIS balancing market clearing case selected results are presented demonstrating the influence of different demand response bids. In detail, the following aspects are highlighted in the analyses:

- Changes in terms of fossil fuel consumption;
- Changes in terms of CO2 emissions;
- Changes in terms of market concentration (competition index HHI).

4.1 Changes in terms of Fossil Fuel Consumption

The following Figure 8 presents the changes in terms of fossil fuel consumption for the provision of positive (left) and negative (right) balancing energy for the following cases: (i) no VPPs (i.e. default case; results are already shown in section 3 for the positive balancing energy case), (ii) 10% VPP penetration and (iii) 25% VPP penetration among the accepted bids in the common AIS balancing market area.

Quantitative numbers shown represent up-scaled annual modelling results.

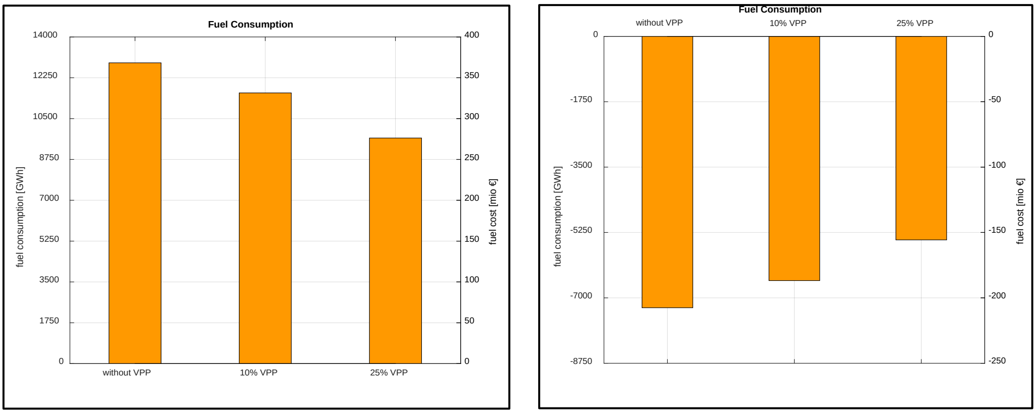


Figure 8: *Fossil fuel consumption for the provision of positive (left) and negative (right)*[8] *balancing energy in case of common AIS balancing market clearing and different shares of VPP penetration.*

Both cases in Figure 8, i.e. provision of positive (left) and negative (right) balancing energy, clearly indicate that an increasing penetration of VPP-based demand response bids in the common AIS balancing market area results in decreasing fossil fuel consumption:

- In case of the provision of positive balancing energy, a 10% VPP penetration results in 11.602 GWh of fossil fuel consumption, 25% VPP penetration in 9.668 GWh (intitially, without VPPs: 12.891 GWh). The corresponding fossil fuel costs are 331 mio€ (10% VPPs) and 276 mio€ (25% VPPs); initially, without VPPs: 368 mio€.
- In case of the provision of negative balancing energy, a 10% VPP penetration results in 6.538 GWh (absolute value) on fossil fuel consumption, 25% VPP penetration in 5.448 GWh (absolute value). The corresponding absolute values for fossil fuel costs are 187 mio€ (10% VPPs) and 156 mio€ (25% VPPs). The initial numbers (without any VPPs) are 7.264 GWh and 208 mio€ respectively.

4.2 Changes in terms of CO2 Emissions

Derived from Figure 8, the following Figure 9 presents the corresponding CO2 emissions and CO2 savings for the three above mentioned cases (no VPPs, 10% VPP, 25% VPP). Figure 9 confirms that VPPs, where underlying demand response bids are assumed, lead to significant reductions in terms of CO2 emissions with increasing VPP penetration in both cases, for the provision of positive and negative

[8] At first sight the negative signs seem to be surprising. However, if (monetary) fossil fuel savings are considered for the provision of negative balancing energy, per se they can't be positive because a precondition for a fossil fueled power plant to provide this service is to operate and, in case of activation, to reduce power output. Therefore, the non-operation mode needs to be the reference point (i.e. no cost) to determine the corresponding (monetary) savings or losses. Against this background the following results need to be interpreted.

balancing energy. For the different quantitative numbers it is referred directly to Figure 9.

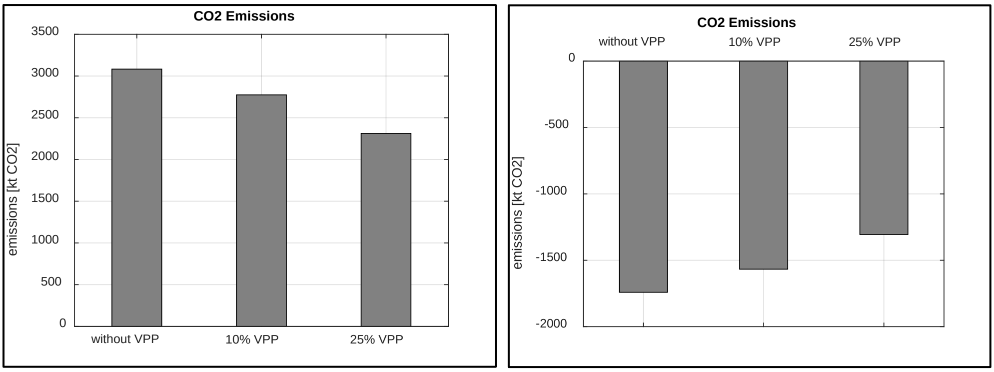


Figure 9: *CO2 emissions for the provision of positive (left) and negative (right) balancing energy in case of common AIS balancing market clearing and different shares of VPP penetration.*

4.3 Changes in terms of Market Concentration (Competition Index HHI)

Eventually, also the changes in terms of market concentration are quantified for the 10% and 25% VPP penetration case in the common AIS balancing market area. For both cases the number of additional VPPs in each of the three countries is already listed at the beginning of this section.

As a performance indicator for competition among market participants in the balancing market the relative frequency of activations of different market participants (on ¼ hour basis) can be used. HHI (already introduced in section 2) is the corresponding indicator identifying the intensity of competition:

- the nearer the mean value in terms of relative frequency of activations (HHI) is towards 0, the higher competition among market participants in the balancing market segment;
- the nearer the mean value in terms of relative frequency of activations (HHI) is towards 1, the lower competition among market participants in the balancing market segment.

Exemplarily, Figure 10 below presents the results in terms of market concentration for 25% VPP penetration both on separate national as well as common AIS balancing market level.

Several of the four results presented in Figure 10 clearly indicate that the mean value in terms of relative frequency of activations moves further towards 0 on the HHI axes with the inclusion of 25% VPP companies bidding demand response into the corresponding balancing market segment. Straightforward, this means that competition among market participants significantly increases not only on separate national, but also on common AIS balancing market level (see lower right diagram in Figure 10). Moreover, VPPs also successfully contest the monopoly situation in some particular ¼ hour time lots in Slovenia and Italy (see Figure 10 for HHI=1).

This clearly indicates the benefits of additional VPPs bidding as new BSPs into the corresponding balancing market segment.

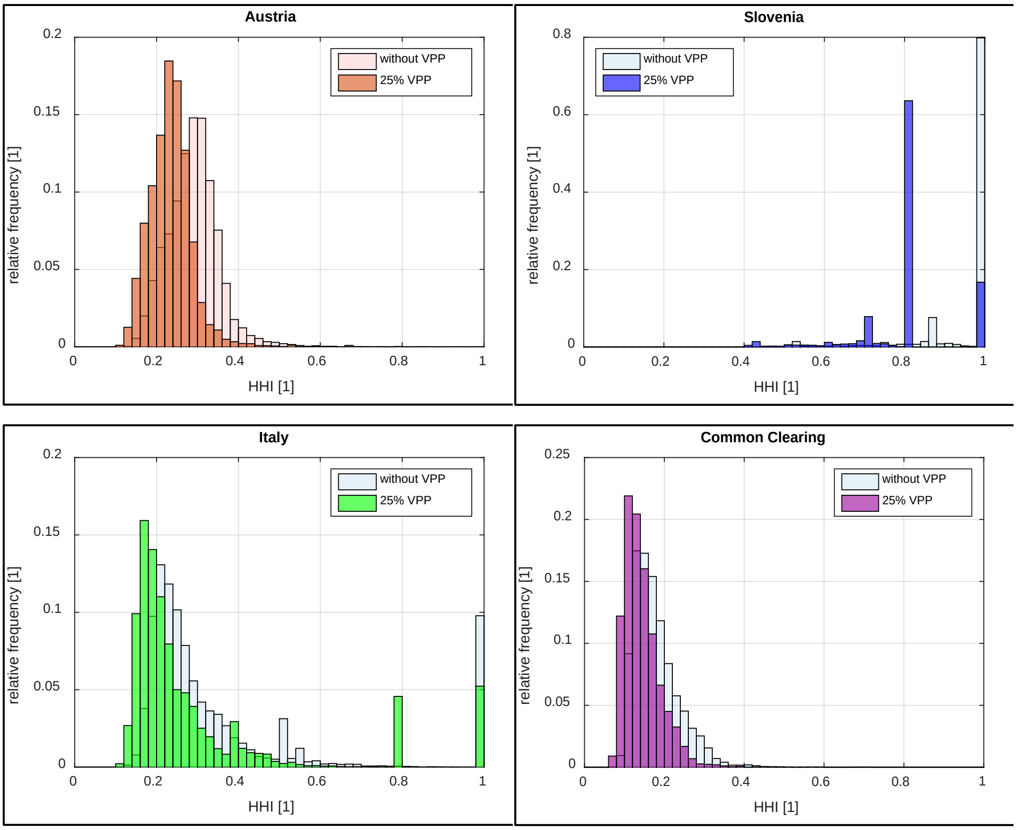


Figure 10: *Comparison of competition index (HHI) in balancing markets without VPPs and 25% VPP penetration in separate national as well as common AIS balancing markets. The number of companies offering VPPs in the different countries is as follows: AT = 3, SL = 1, IT = 6.*

5 DISCUSSION OF RESULTS AND CONCLUSIONS

The analyses in the previous sections clearly indicate that cross-border balancing markets are characterized – compared to separate clearing in each of the national balancing markets –by both economic and environmental benefits. When having in mind the common AIS balancing market structures and currently existing market participants, this means in particular:

- overall dispatch cost and thus clearing prices can be reduced;
- fossil fuel fired power plants can be replaced;
- consequently, CO2 emissions can be reduced;
- competition among market participants can be increased;

- consequently, market liquidity also can be increased.

The further inclusion of new BSPs (e.g. VPPs) offering demand response bids in the balancing markets – regardless whether or not separate national or common cross-border balancing market clearing is implemented – is beneficial manifold. Among others, there are e.g. reduced network losses on the transmission and distribution networks. On average, around 7% of electric energy losses occur due to transmission and distribution of electricity (both, within the footprint of a TSO and also in case of cross-border balancing markets between TSOs). Besides reduced network losses, being quantifiable, also further direct benefits of VPP-based demand response bidding in balancing markets can be listed. Selected candidates are e.g.

- The inclusion of the demand side significantly increases flexibility in electricity systems. Moreover, so far in almost all cases demand has been assumed to be "exogenous" in the electricity system and flexibility has been entirely provided on the generation side. However, the demand side, notably demand response bidding in balancing markets, enables an addition degree of freedom to balancing the electricity system in real time.
- As an immediate consequence, reliability of the electricity system increases if demand response is used as an additional option to maintain real time operation of the electricity system at 50 Hz.

In practice, so far in balancing markets demand response bids are predominantly offered by (big) industrial customers. However, the approach presented in this paper rather refers to the aggregation of small customers (via VPPs) offering demand response potentials. Moreover, the approach shall demonstrate that VPP-based demand side bidding works for both separate national and common cross-border balancing markets.

6 REFERENCES

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