TradeWind

Further Developing Europe's Power Market for Large Scale Integration of Wind Power

WP7 – Analysis of Market Rules
D7.6 – Conclusions

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1 INTRODUCTION

In practice, electricity from wind energy faces national frontiers. These are based on national market rules and rules for allocation of interconnector capacity, both of which are badly adapted to wind energy, and on incompatibility of market rules between countries. The objective of the analysis of wind energy in power markets was the identification and mitigation of these barriers.

In particular we may expect that:

- with high wind power penetration, some market designs will be more beneficial than others in terms of socio-economic cost, price volatility and required ancillary services for system operation;
- the effect of different market rules can be determined by sensitivity analysis; some measures, e.g., efficient cross-border allocation or short gate closure times, may have a much stronger effect on wind power trade than others;
- the value of European market integration in different stages can be quantified for different cases.

The analysis of market rules within TradeWind covers a descriptive part, an analysis of the current situation and a market simulation part in order to quantify the effects of market integration.

The present summarizes the results from WP7 and formulates conclusions for the different aspects.

2 SIGNIFICANT INTERCONNECTORS

Significant interconnectors have been defined as those interconnections whose availability to wind power (allocated day ahead or intra day) determines the transcontinental exchange of wind power. A set of significant interconnectors for different regional wind power markets was established.

For the cross-border trade of electricity from wind energy the concept of regional wind power markets has been introduced. The definition of regional wind power markets has been based on the regional markets as pursued by the European Regulators' Group for Electricity and Gas (ERGEG) [1]. The ERGEG's regional markets have been matched with the objective of wide market access for wind power as pursued by TradeWind. The result are regional wind power markets based on the ERGEG's regional electricity markets but not fully identical (Table 1). In addition, TradeWind introduces a North Sea power markets with the lines of an offshore grid as significant interconnectors. The concept of a North Sea offshore grid integrating a common energy market around the North Sea, and possibly the Baltic Sea, has now become part of the European Commissions Second Strategic Energy Review [2].

Table 1: Wind power market regions as defined for the TradeWind project

Wind Power Market Region	Countries
Central-West	Austria, Belgium, France, Germany, Luxembourg, Netherlands, Switzerland
Northern	Denmark, Finland, Germany, Norway, Poland, Sweden
UK and Ireland	France, Great Britain, Republic of Ireland, Northern Ireland, Netherlands
Central-South	Austria, France, Germany, Greece, Italy, Slovenia, Switzerland
Southwest	France, Portugal, Spain
Central-East	Austria, Czech Republic, Germany, Hungary, Poland, Slovakia, Slovenia
North Sea	Belgium, Denmark, Germany, Great Britain, Netherlands, Norway

Significant interconnectors have then been determined, on the one hand, based on the European Commission's Priority Interconnection Plan and, on the other hand, based on the lack of interconnector capacity for a functioning day-ahead or intra-day spot market.

Sets of significant interconnectors have been identified for the seven wind power market regions. They have been further considered for the identification of critical transmission corridors in the parallel work packages WP5: Continental power flows and WP6 Grid scenarios.

3 MARKET BARRIERS AT SELECTED INTERCONNECTORS

3.1 Selection of Study Cases

In many of the potential wind power market regions as defined above, the significant interconnectors often are allocated inefficiently. This is often due to the current market rules as they exist on the different sides of national borders and the procedures for spot market access and allocation of these interconnectors.

The market and regulatory situation for significant interconnectors with current rules has been analysed in detail. For this purpose, the market and allocation rules between countries as of today have been checked on their compatibility in order to identify specific market and regulatory barriers. The analysis has been focussed on interconnectors that can be considered essential regarding wind power trade and of which empirical data are available today.

The analysis is focussed on the interconnection between Germany and Western Denmark. The reasons why this interconnector/border has been chosen are threefold:

- The border connects two different market regions as of today, namely, EEX and NordPool. The integration of EEX with the Nordic market (EEX–NordPool coupling) and with the Central West market (Pentalateral market coupling, PLC) was envisaged for 2008/2009 [3,4]. Hence, an analysis of market functioning before this integration is very timely.
- In both markets, Denmark-West and Germany, a large capacity of wind power is available. This is essential in order to analyse the interaction of wind power with international market organization.
- For both countries good historical data are available including wind power generation, load, interconnector capacity allocation data and prices.

Other interconnectors that may be worth a closer look are the Moyle Interconnector between Ireland and Great Britain and the interconnectors between France and Spain. This is, first of all, because in some of these countries there is already a high share of wind power available and, secondly, because their interconnectors can be considered significant bottlenecks for trans-continental trade. On the other hand, in France and Great Britain, wind power does not yet affect the power market prices and power flows as in Western Denmark or Germany. Therefore, the authors decided to focus on the Danish-German border as mentioned above.

In a first step, the influence of wind power on market prices was determined for both sides of the German-Danish border. In a second step, the allocation of interconnector capacity was evaluated with regard to the price difference between both markets.

3.2 Results and Discussion

Influence of Wind Power on Market Prices

The influence of wind power generation on the spot market prices has been examined for the different market zones. For Eastern Denmark, the price elasticity is twice as high than in Western Denmark, namely, 1.67 €/MWh as compared to 0.73 €/MWh for an additional 100 MWh/h of wind power in the system. For Germany, the elasticity is 0.21 €/MWh.

All these values can be considered moderate with regard to the influence of wind power on the price. In contrast the availability of interconnector capacity to the market has a relatively more significant influence on the market prices than wind power alone.

Extreme Prices

Unlike in Eastern Denmark or Germany, zero prices occur regularly in Western Denmark, usually at moments of high wind power generation and low load. When at these periods the interconnectors to Sweden and Norway are fully loaded, no more power can be exported.

Notably, although these situations do not occur so often in Eastern Denmark and Germany, zero-prices are not at all insignificant. However, in Eastern Denmark and Germany, they cannot be associated as clearly to the abundance of wind power as in the system of Western Denmark. Especially in Germany, zero prices regularly occur also at relatively low wind power injection and may be due to other generation plants with low marginal cost.

One can conclude that in the small system of Western Denmark, wind power immobilizes the market at moments of insufficient interconnector capacity. In this sense, the Great Belt interconnector scheduled for 2010 will increase the interconnection capacity with Nordel. Moreover, an increased transfer capacity with Germany is of utmost importance in order to allow for trade and stable prices in Western Denmark. These findings as derived from the 2006 data are well in line with the European Commission's Priority Interconnection plan [5] and the TradeWind findings from deliverable D7.1 about significant interconnectors as enablers for regional wind power markets [6].

Efficiency of Interconnector Allocation

In a perfect regional power market consisting of different zones with limited interconnector capacity, market prices among the zones would differ only when no interconnector capacity is available. Moreover, interconnectors would only be used for trade from the area with the lower price to the one with the higher price. This is not the case for the German-Danish (W) border. The available transfer capacity on this interconnector is auctioned the day ahead, before gate closure of the spot markets in Germany and Western Denmark. Auctions in both directions are carried out. Typically, market parties buy capacity for both directions and use only one, depending on their day-ahead price estimate. Arbitrage is obviously relatively limited as compared to an implicit auction of the interconnector.

Figure 1 illustrates the efficiency of interconnector allocation for the year 2006. Capacity auctions have been taken hourly for each direction separately, yielding 17518 prices. Hence, virtually always a price was fixed for each of the two directions. The available capacity is efficiently used in a situation of positive price difference with positive capacity and in a situation with negative price difference and negative capacity. In total this makes 49% of all capacity auctions. For 33% of all capacity auctions, capacity was auctioned for inefficient use, namely, for bringing power from the high-price to the low-price area. For 18% of the auctions, capacity was not utilized, notably sometimes with a significant price difference between both markets.

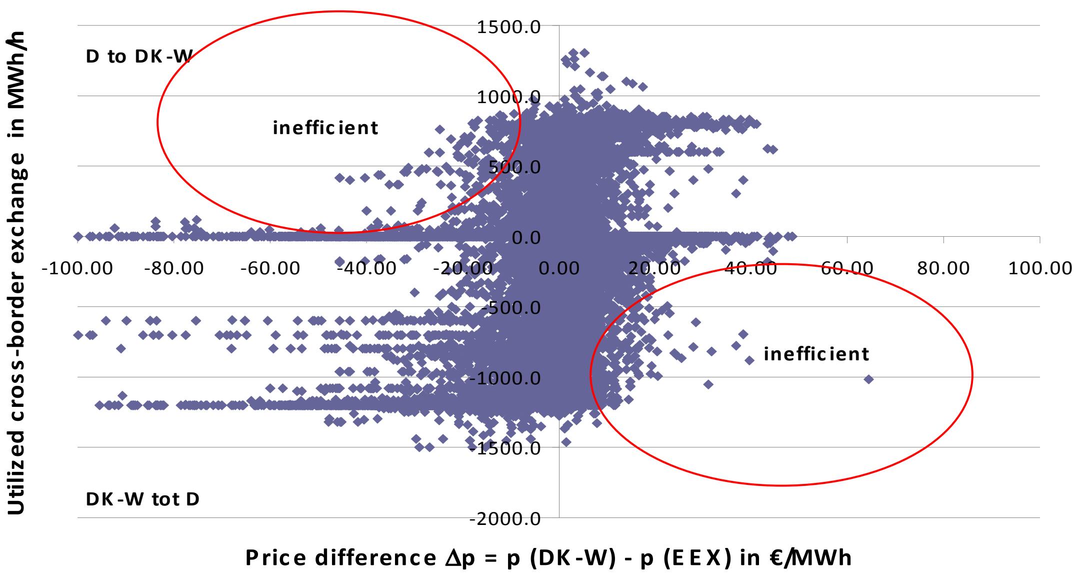

Figure 1: Utilized transfer capacity at the German Danish border and price difference between EEX and Elspot (Denmark West); market data for 2006 [7].

Obviously, arbitrage can hardly be optimized via such an interconnector that is allocated by a separate auction preceding the clearance of different spot markets. From weighting the prices with the transferred volumes the earnings from arbitrage can be estimated to be about 111 million Euros while the losses for trade in the *wrong* direction amount to approximately 13 million Euros. This makes about 10% of the earnings from arbitrage being lost again due to inefficient capacity allocation.

From these results we can conclude that efficient regional market integration requires implicit auctioning for an efficient allocation of interconnectors. This is essential for regional market integration as a whole. Moreover, since wind power needs to utilize spatial variation over large distances to a maximal extent, for the European market integration of wind power, efficient allocation methods are required.

Conclusion

We can conclude that

- in general terms the influence of wind power on wholesale day-ahead prices is moderate,
- in situations of high wind power generation with limited interconnectivity, prices can become zero or negative, indicating an abundant availability of wind power in a market,
- the allocation of interconnectors to the market is often inefficient.

In conclusion, higher interconnector capacity is necessary for a trans-continental market integration of wind power but not sufficient. In addition, efficient allocation mechanisms are required allowing for the optimal utilization of available transfer capacity.

The need for efficient allocation of interconnectors reflects a market imperfection originating from a lack of information about the prices at the capacity auction and the different day-ahead markets. Therefore, it can not be taken into account in a straight-forward way. For the trade of wind power over long distances, efficient, that means implicit, capacity allocation mechanisms are essential.

4 MARKET RULES FOR SIMULATION

4.1 Characteristics and Parameters

A set of market rules for facilitating an efficient market integration of wind power needs to take into account the characteristic properties of wind energy, namely:

- Wind power is not perfectly predictable. The quality of wind power forecasts increases with decreasing forecast horizon and with increasing size of the area for which the forecast is calculated. Along with each forecast, confidence margins can be supplied in order to schedule reserves for compensation of the forecast error.

- Wind power is variable with characteristic variations in the range of several hours to a few days. Large intra-hourly variations occur rarely. Wind speed is correlated for short distances but not for long distances in the order of a thousand kilometres and more.

- Wind energy requires no fuel. Therefore, its marginal cost is very low and electricity is produced without GHG emissions. Consequently, wind power should be used whenever wind is available. At times of low demand wind power will have to compete with power from bulk load plant, which often cannot adapt their output to fast changing set points.

Answering to these properties, we assume that the main parameters that influence the market integration of wind power are:

- the flexibility of rescheduling of dispatch decisions (time dimension),

- the flexibility of the cross-border exchange (time + spatial dimension) and

- the available interconnector capacity (constraints).

The first two parameters are market design parameters. A high flexibility of rescheduling of dispatch decisions will be required when demand and generation are subject to frequent and significant unexpected changes during the day. Flexibility is introduced by generation units with short activation times, e.g., combined cycle gas turbine units or reservoir hydro units. Regarding the second parameter, high flexibility of cross-border exchange is beneficial for market harmonisation. With increasing share of variable generation, flexible cross-border exchange mechanisms contribute to optimising the dispatch on international instead of on national level. As illustrated before, the efficiency of cross-border exchange also depends strongly on the mechanism for capacity allocation. Ideally, capacity is allocated in an implicit way via market coupling mechanisms rather than by an explicit auction. However, since the available market models assume perfect markets, a market simulation including the imperfections of explicit auctioning is not possible.

The third parameter, the available interconnector capacity, is purely technical. It reflects the degree to which the countries are interconnected. Today the interconnector capacity for some important borders is constrained which leads to a limitation of possible exchanges. In the future, grid upgrades and improved congestion management may lead to higher available capacities for cross border exchange. We can, for example, assume the ideal unconstrained case of Europe as a copper plate, or another case where all reinforcements proposed by the Trans-European Networks action will have been realized. This parameter is not a market parameter but rather a boundary condition or constraint for the market simulation work.

In a given energy economic context we can define a multitude of cases within these coordinates, defined by flexibility of rescheduling, flexibility of cross-border exchange and the available interconnector capacity (Figure 2). Parametric studies with the different cases show in how far the markets benefit from a better market framework in terms of these three dimensions. The energy economic context is defined by the electricity demand, the generation mix including the overall wind power share and the prices of fossil fuel and CO_2 emission allowances. The market simulations have largely been based on the European Commissions PRIMES scenario from 2007 [8].

Calculations for the different cases return socio-economic quantities like the operational costs of power generation, that reflect the value of different cases for society, and techno-economic quantities that reflect the potential value from the viewpoint of a market participant.

Notably, focussing on the three parameters listed above very much reduces the complexity of the system. For a discussion on market parameters and the influence of the size of the regional power markets in practice and a ways to include explicit auctioning of interconnectors, see [9].

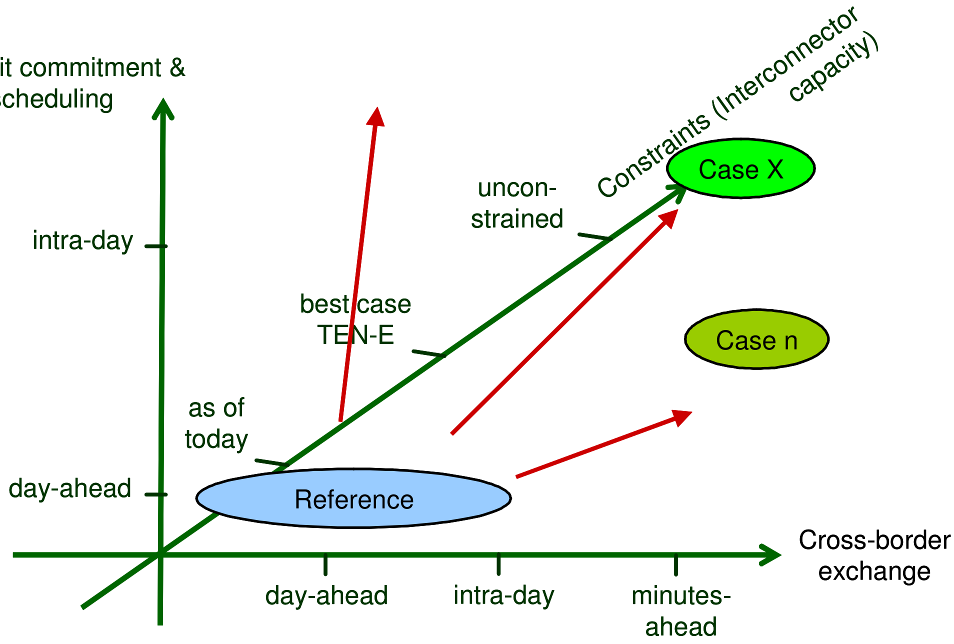

Figure 2: Cases for market simulation as a function of two criteria and the constraints of interconnector capacity [10]

5 MARKET MODELING BY SIMULATION

5.1 Method and Approach

Starting Point

The functioning of the European electricity markets with a high share of wind energy has been analyzed. The objective is to allow for market efficiency evaluation for different market designs and stages of integration. The analysis is based on the outcomes of market simulation with different levels of market integration and for different lead times for trade (i.e., different types of generation plant being available for rescheduling and different reserve requirements for wind power balancing). The results are quantified by means of selected indicators (see [10] for detailes).

In particular we may expect that:

- with high wind power penetration, some market designs will be more beneficial than others in terms of socio-economic cost, price volatility and required ancillary services for system operation;
- the effect of different market rules can be determined by sensitivity analysis; some measures, e.g., efficient cross-border allocation or short gate closure times, may have a much stronger effect on wind power trade than others;
- the value of European market integration in different stages can be quantified for different cases.

Modeling Tools

The two models used for the simulation of power markets in WP7 in order to study the efficiency of the power market, are the Wilmar planning tool and the Prosym tool. Both models are sophisticated simulation tools for modelling realistic dispatch decisions in a market environment characterised by variable and stochastic resources. However, the models have different approaches to uncertainty. While in Prosym, uncertainty is represented by the demand for spinning reserves, in Wilmar it is introduced via a stochastic scenario tree. Therefore, results from both tools cover different cases and parameters. Similar cases from both tools can not be compared directly, but they partly complement each other [10,11].

Models and Scenarios

The calculations range throughout a space of market rule combinations. For Wilmar, the different cases range from nationally contained spot markets with low flexibility for rescheduling to an integrated European market with possibilities for transferring even reserve power over borders. Four scenarios have been investigated for each of the scenario years 2020 and 2030. For Prosym the calculations cover four cases for the target year 2020, characterized by different degrees of connectivity between countries and by differences in gate closure from day-ahead to intra-day. The gate-closure is reflected by assumptions on the wind power forecast error and the associated requirements for spinning reserves. In addition, the sensitivities have been checked with Prosym for the following three parameters: namely, installed wind power capacity, oil and gas prices, and wind power curtailment strategy.

For the two modelling tools, the wind power scenarios, electricity demand, fuel prices, CO_2 costs and transfer capacity values between countries are the same. The assumptions can differ slightly depending on the level of detail with which the generation portfolio is modelled, but also the treatment of reserves and possibilities for rescheduling. The calculations with Prosym cover 18 European countries with a detailed dataset. Sweden, Finland, Luxemburg, the island of Ireland, the Baltic countries and the countries of East and South-East Europe are not included The calculations with Wilmar cover 25 countries excluding the Baltic countries, Malta and Cyprus. The results from both tools are quantified by a consistent set of indicators. All cases are summarized in Table 2.

Table 2: Cases for simulation

Case	Unit commitment / reserve req.	Cross-border exchange	NTC constraints	Energy economic context
Wilmar AllDay2020	day ahead rescheduling	day ahead rescheduling	base 2020	scenario 2020, medium wind
Wilmar ExDay2020	intra-day rescheduling	day ahead rescheduling	base 2020	scenario 2020, medium wind
Wilmar AllInt2020	intra-day rescheduling	intra-day rescheduling	base 2020	scenario 2020, medium wind
Wilmar AllIntExRes 2020	intra-day rescheduling	intra-day rescheduling & exchange of reserves	base 2020	scenario 2020, medium wind
Wilmar AllDay2030	day ahead rescheduling	day ahead rescheduling	best 2030	scenario 2030, medium wind
Wilmar ExDay2030	intra-day rescheduling	day ahead rescheduling	best 2030	scenario 2030, medium wind
Wilmar AllInt2030	intra-day rescheduling	intra-day rescheduling	best 2030	scenario 2030, medium wind
Wilmar AllIntExRes 2030	intra-day rescheduling	intra-day rescheduling & exchange of reserves	best 2030	scenario 2030, medium wind
Prosym d-1 base NTC	Hourly rescheduling	Implicit exchange	base 2020	scenario 2020, medium wind
Prosym t-3 base NTC	Hourly rescheduling	Implicit exchange	base 2020	scenario 2020, medium wind
Prosym d-1 best NTC	Hourly rescheduling	Implicit exchange	best 2030	scenario 2020, medium wind
Prosym t-1 best NTC	Hourly rescheduling	Implicit exchange	best 2030	scenario 2020, medium wind
Prosym Wind 2008	Hourly rescheduling	Implicit exchange	base 2020	scenario 2020, but wind 2008
Prosym 200% Fuel Prices	Hourly rescheduling	Implicit exchange	base 2020	scenario 2020 but with doubled oil & gas prices, medium wind
Prosym Wind must run	Hourly rescheduling	Implicit exchange	base 2020	scenario 2020, medium wind, must-run status for wind power

5.2 Results

Energy-economic Context

The operational costs of power generation are calculated as the sum of fuel costs including start-up fuel consumption, start-up costs, costs of consuming CO_2 emission allowances, and operation and maintenance costs. Energy not served and reserve deficiencies are not included but reported separately. Fuel prices and prices of CO_2 mission allowances, electricity demand and the share of wind power in the system have a direct effect on the operational costs.

According to the market simulations carried out with the tools Wilmar and Prosym, the main effects of the energy economic context are as follows:

- Wind power as a fuel-free source of power contributes significantly to reducing the operational costs (excluding investments and maintenance) of power generation: Assuming the same wind power penetration as of 2008, the operational cost of power generation in 2020 for the 18 countries modelled with Prosym would be 119.2 billion €. An additional 128 GW of wind power to be installed between 2008 and 2020 yields a reduction of almost 10% or 10.8 billion € per year in 2020. The macro-economic cost savings of wind power replacing conventional sources are then 42 €/MWh. This estimate does not take account of investments nor of specific additional costs related to wind power integration such as additional balancing cost and additional incentive costs. Therefore, these savings may be interpreted as being the admissible surplus cost of wind power generation when replacing conventional generation. In other words, from the public support that wind energy receives via quota systems or feed-in tariffs, 42 €/MWh is returned to the public via the consecutive reduction in operational costs of generation. Along with this cost reduction, wind power also contributes to a significant reduction of wholesale power prices in the different countries. The actual reduction in average power price due to wind depends strongly on the country.

- Although wind power capacity between 2020 and 2030 was assumed to increase by 70 GW, CO_2 emissions increase with 3.6%. This increase in CO_2 is mainly due to the structure of the power generation mix and the increasing electricity demand in the cases modelled. Notably, the applied increase in electricity demand according to Europrog (see Appendix 1) is relatively high in comparison to other data sources for the years beyond 2020. In particular, Europrog considers only little improvements in energy efficiency on the long term. These results emphasize the importance of energy efficiency and high CO_2 prices in reducing CO_2 emissions.

- With doubled oil and gas prices in 2020 as compared to the European Commission's 2007 baseline scenario (46 $05/boe), the operational costs of power generation will be about 23% or €25 billion higher. In most countries, 2020 power prices would increase by €20-30/MWh if the fuel prices doubled. Accordingly, the macro-economic value of fuel-free generation in this case would be higher.

Interconnector Capacity

As not much additional cross-border capacity is considered in the best NTC case compared to the base NTC case (Appendix 2) and since this is only done for a few countries, there are no significant changes in the import-export balance of most countries. France and Germany will remain net exporters while Italy will remain net importers of electricity. A significant increase of power exchange can be observed for those countries that today are connected only to a limited extent and for which large increases in interconnection capacity have been assessed in Chapter 5. The difference is especially significant with regard to imports into Italy and into Great Britain.

In conclusion, simulation results show savings with increasing NTC. It is recommended to further investigate the effect of major transmission upgrades as suggested in WP5 in follow-up studies.

Flexibility of Re-scheduling of Dispatch Decisions

The following conclusions can be made regarding the organisation of cross-border exchange, unit commitment and scheduling in international electricity markets:

- In general terms, allowing unit commitment to be re-scheduled as close as possible to real time leads to savings in operational costs of power generation and stable power prices. Not allowing intra-day rescheduling would cause volatile and regularly spiking prices, especially in smaller countries.

- Reducing the demand for reserves by accepting wind power forecasts up to three hours before delivery would yield a reduction in operational costs of power generation of €260 million per year. This cost reduction assumes a perfect market and would be much larger under current market conditions.

The impact of different market designs on CO_2 emissions is very small, namely 0.1 up to 0.3% of emissions as calculated for the ExDay case for each target year. This is because the model, for a given target year, has to satisfy the same load. Moreover, the generation from wind power and hydropower remains the same, as do the installed capacities of biomass and nuclear power with their very high capacity factors. In total, they have to cover the same amount of load in each market design case because all carbon free production forms are utilised nearly to the maximum amount. Consequently, overall CO_2 emissions mainly depend on whether the merit order gives priority to coal or gas fired units.

Flexibility of the Cross-border Exchange

The advantage of flexible markets becomes much more prominent when flexible unit commitment and rescheduling are not only applicable to national markets but also to cross-border exchange.

- Allowing for intra-day rescheduling of cross border exchange will lead to savings in operational costs of power generation of approximately 1%, or in the order of €1-2 billion per year compared to day-ahead cross-border exchange.

- The cross-border exchange of reserves has a positive but relatively low effect on the operational costs of power generation. In an unbundled market, deviations from the programme are balanced first of all from the portfolios of the parties responsible for balancing. Only afterwards they put demand on the reserve power markets. Nevertheless, cross-border exchange of reserves may lead to a decrease in investment costs for reserve capacity by making existing capacity available across borders.

In conclusion, the establishment of intra-day markets for cross-border trade is key for market efficiency in Europe. In order to ensure efficient allocation of the interconnectors, they should be allocated directly to the market via implicit auction.

For the assumed development of demand and generation mix, wind power curtailment and load shedding hardly ever occur when the market is well designed. An international exchange of reserves is not the first priority for a good market design. It is better to keep the need for reserve power low by intra-day rescheduling of power exchange and by intra-day rescheduling of unit commitment and dispatch of units. The main benefit of exchanging reserve power could consist of possible savings from investments in flexible power plants due to reserves being shared across borders.

6 CONCLUSIONS

Specific conclusions from the market analysis in TradeWind are:

- The establishment of intra-day markets for cross-border trade is of key importance for market efficiency in Europe. Allowing for intra-day rescheduling of cross-border exchange will lead to savings in system costs in the order of €1-2 billion per year as compared to a situation where cross-border exchange must be scheduled day-ahead. In order to ensure efficient interconnector allocation, they should be allocated directly to the market via implicit auction.

- Intra-day rescheduling the portfolio, taking into account wind power forecasts up to three hours before delivery, results in a reduction in system costs of 260 Million Euros per year (compared to day-ahead scheduling) thanks to decrease in demand for additional system reserves. This cost reduction assumes a perfect market and would be higher under the current distorted market conditions.

In particular, the European electricity market needs the following major design characteristics in order to enable effective and efficient wind power integration:

- features for intra-day rescheduling of generators and trade on an international level for low system costs and stable prices ,

- wide-spread application of implicit auctioning to allocate cross-border capacity (i.e. market coupling, market splitting etc.),

- The availability of sufficient interconnection capacity, especially after 2015.

The cross-border exchange of reserves has a positive but relatively low effect on the operational costs of power generation. In an unbundled market, deviations from the programme are balanced first of all from the portfolios of the parties responsible for balancing. Only afterwards they put demand on the reserve power markets. Nevertheless, cross-border exchange of reserves may lead to a decrease in investment costs for reserve capacity by making existing capacity available across borders.

Finally, several important market barriers to wind energy are due to imperfections of the power markets as they are today. In particular these are the limited size of market regions and economically inefficient use of interconnector capacity. Therefore, congestion management schemes should pursue market coupling with implicit auctioning.

For the future, especially the introduction of flexibility and the occurrence of negative prices as a market signal for oversupply deserve further attention. Demand side management is the most interesting measure to make the electricity demand more price elastic. The potential of demand side management should be quantified in terms of energy to be shifted and in terms of price elasticity that may be achieved.

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