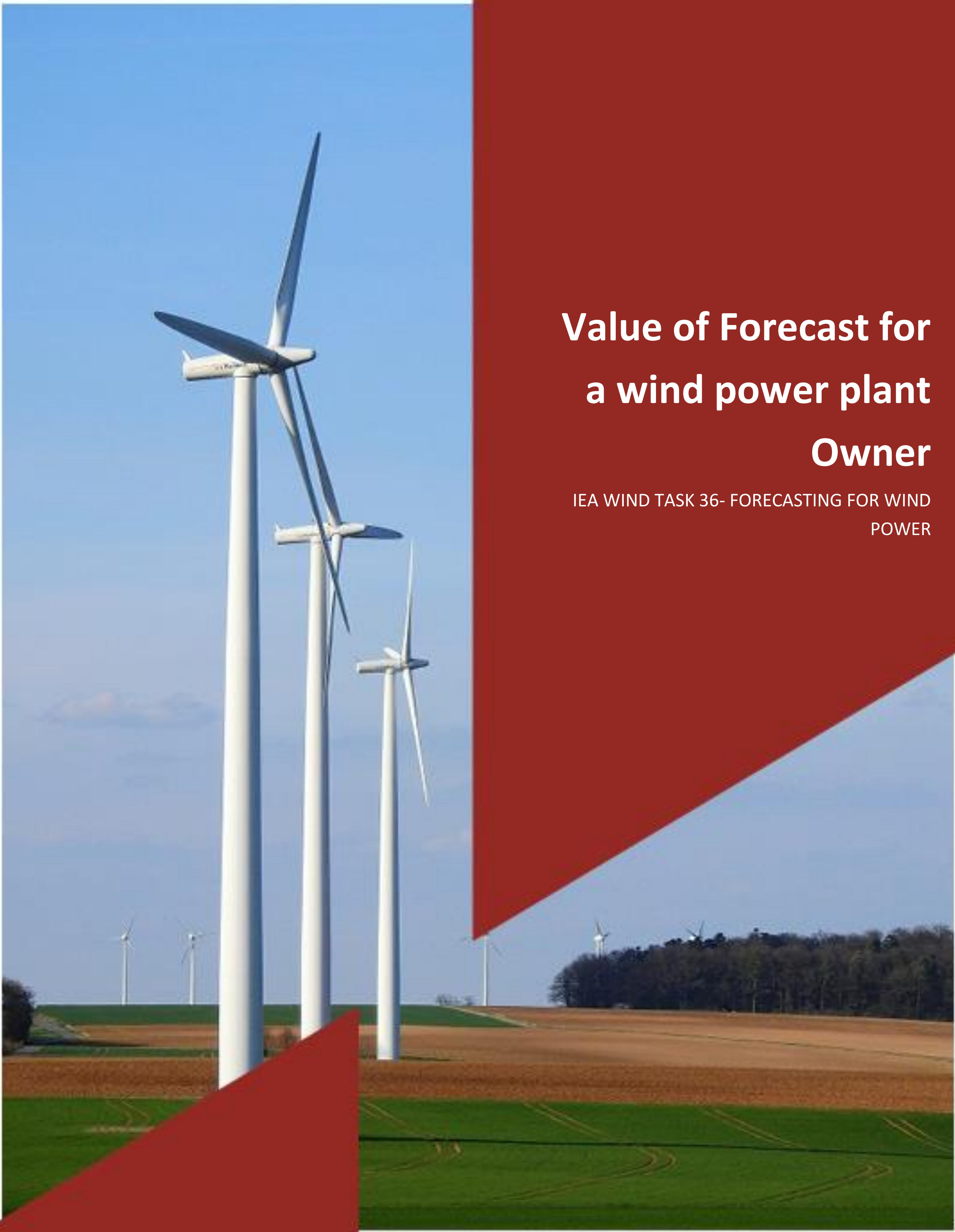

Value of Forecast for a wind power plant Owner

IEA WIND TASK 36- FORECASTING FOR WIND POWER

December 2021

Ea Energy Analyses

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Contents

Executive Summary

The report is part of Ea Energy Analyses' contribution to IEA Wind Task 36 Forecasting (Phase 2). It describes the value of good wind power forecasts. In this study a sufficiently precise, qualitative definition of a "good" wind power forecast is a forecast which matches the generation well and results in small imbalances in the market.

Importance of good wind power forecast

Good Wind power forecasts are of great importance for several actors of the power system. For example, they are important for the TSO being responsible for the balance of the power system. Here, the quality of forecasts is important for the security of supply and the amount of necessary reserves to be procured. As reserves are expensive a good forecast can save significant costs of operating the system. Other actors are BRPs (Balance Responsible parties) in the market, generator companies with a portfolio of different types of power generation, aggregators, met-services and commercial forecasters.

Report focus and scope

This report focuses on the value of wind power forecasts for a wind power plant owner. The value is assessed for different bidding strategies in the day-ahead and balancing market.

The analysis does not consider trading in the intraday market. This choice has been made in order to keep the analysis simple. Trading in intraday is continuous and bilateral and the historical price available for a specific actor at a specific point in time is hard to estimate unless portfolio-level data is available. In general, we have had problems with finding available and applicable data for the intraday market.

The study is a partial analysis limited to assess the possibilities of a wind power plant owner to gain from bidding strategically in the day-ahead market and exploiting the regulatory setup of the balancing market. The revenue of bidding strategically is compared with the revenue of a non-strategic "bidding as forecasted".

The analysis studies imbalance settlement according to "one-price" model in day-ahead and balancing markets, as this will be the future default model to prevail in Europe.

On 1st November 2021, the Nordic countries went live with the application of the single price, single position harmonization model, after the four Nordic transmission system operators adopted a decision in this respect on October 2019. Until then production imbalances were settled according to a two-price model.

Conceptual models for bidding are described and earnings/profits in markets are qualitatively estimated.

Earnings in market

With a one-price balance model a wind power plant earns more in the spot and balancing market than bidding in the spot market alone according to a "perfect" wind power forecast, when the wind power plant's imbalance is "helping" the system balance. The opposite is the case when the wind power plant imbalance "worsens" the system balance.

Strategic bidding

In theory, If the wind power plant knows the system imbalances the next day, then the optimal strategy will be to bid the wind plant capacity in the spot market, when the system is in down-regulation and bid 0 MW when the system is in up regulation. In this case a forecast of wind generation has no value.

Mixed strategy

Normally, the wind power owner does not know whether next day's system imbalances will be positive or negative, but he may have a forecast of some quality. In that situation, the wind power owner could choose a mixed bidding strategy with the bid being the forecasted wind power value plus or minus an adjustment dependent on which sign of the system-imbalance is assumed most probable. In this case a good wind power forecast is valuable. And a good forecast of the sign of the system-imbalance would also be valuable.

Price maker

Bidding strategically, the wind power owner could turn out to be a price maker in the balancing market due to his potential large, imposed imbalances on the system. This could change the balancing price unfavourably for him. In that situation the optimal bidding strategy for the wind plant owner will change in the direction of reducing his buying/selling in the balancing market compared to the price-taker situation. (Examples are shown in chapter 5). In this case a wind power forecast that matches the generation well, has value.

In general, bidding strategically is legal, except for the case, when the bidder exploits his possible dominating position in the market.

Case study

The present study includes a case study based on real market data (2019-2020) from Germany. All data has been extracted through ENTSO-E's transparency platform. Market outcomes for a "fictive" 100 MW offshore wind park subject to the German time series of market data have been estimated for different trading strategies of the wind farm. The analysis is limited to the day-ahead market and balancing market.

Bidding as forecasted-case study

As expected, the case study shows that when bidding into the spot market with the forecasted generation in the data set, then a better forecast will provide additional benefits (in spot plus balancing market). In the case study there is a potential for an additional gain of 5 % with a perfect forecast compared to the case with the forecast quality in the data set.

Strategic bidding- case study

On the other hand, if the wind power plant owner chooses to give in strategic market bids, either minimum or maximum generation based on some forecast of the signs of next day's system-imbalances then a wind forecast has no value, no matter its quality. Instead, a forecast with the signs of next day's system-imbalances can be very valuable.

Extreme strategic bidding - case study

In the German case-study, a perfect forecast of the sign of next day's system imbalances and bidding extremes (0 MW or 100 MW) can improve the gain with up to 142% compared to the reference case (with non-strategic bidding according to forecast with current quality).

Strategic bidding based on forecast of imbalance - case study

Similarly, in the case-study the tested forecast of next day's system-imbalances was able to provide 11 % higher gain than the reference case by bidding either minimum (0 MW) or maximum generation (100 MW). Also, for this case, the quality of the wind power forecast had no value.

In this case we arbitrarily assumed the sign of the system imbalance to be the same as the day before. This is of course a very primitive assumption. It should be thought of as a proxy. A better forecast of next day's system imbalance would have achieved gains larger than 11 % compare to the reference case.

Mixed strategy-case study

In the German case-study, the wind power plant can also choose a mixed strategy with the bid being the forecasted value plus or minus an adjustment dependent on which sign of the system-imbalance is assumed most probable. In this case the quality of the wind power forecast has value.

Price-maker in case-study

The all cases described above we have assumed a price-taker situation. The effect of a price-maker situation has been evaluated based on simple assumptions of the relation between balancing price and system-balancing volume.

The results of the price-maker cases should be seen as an illustration of the cannibalisation effect of aggressive strategic bidding.

In the price-maker cases the profit reduces compared to the comparable price taker cases. In one case the reduction is from 39 million Euro (price taker) to 37 million Euro (price maker). In the other case the reduction is from 18 million Euro (price taker) to 15 million Euro (price maker).

Takeaways

If the wind power plant owner can be assumed to be a **price taker**, then the results show than he can profit by bidding in strategically if his forecast for next day's sign of imbalances is credible. The case-study shows that even a very primitive forecast of sign of system balance provides additional profit compared to the reference (bid as forecasted). So, if the assumption of being a **price taker** is credible, then development towards accurate forecasting of sign of imbalance would be most valuable for the wind power plant

However, when studying the German market data in the case-study it is interesting to note that the net-balancing volume for the system is quite limited. The average absolute value of balancing volume for the whole of Germany is about 100 MWh (15 minute value). It is therefore very plausible that a wind power plant often can be a **price-maker** in the balancing market. In that case he may easily cannibalise his revenue or even lose compared to "bid as forecasted" if his impact on the balancing volume is large and maybe even changes the sign of the system-imbalance. Therefore, the wind power plant should be very cautious about speculation involving large imbalances. This has been illustrated by comparing a price-maker case with a price-taker case in the German case-study.

As shown (chapter 5) the wind power plant in the price maker case could benefit most from using a mixed strategy.
In this case development towards accurate forecasting of wind power generation, improved forecasting of sign of imbalance and size of balance volume would be most valuable for the wind power plant.

It is notified that the volume in the German balancing market is small compared to the generation. The reason for the low balancing volume could be attributed to an efficient intraday-market. With such low imbalance volumes then the **price-maker** situation in the balancing market is probable for a wind power plant.

1 Overview

The report is part of Ea Energy Analyses' contribution to IEA Wind Task 36 Forecasting (Phase 2). It describes the value of wind power forecasts for trading in markets with focus on spot and balancing markets. This is done for different bidding strategies of a wind power plant owner.

The analysis does not consider trading in the intraday market. This choice has been made due to keeping the analysis simple. With this this approach the wind plant owner can save money for additional short term forecasts during the day and for keeping 24/7 personnel for intraday trading.

The study is a partial analysis limited to assess the possibilities of a wind power plant owner to gain from bidding strategically in the day-ahead market and exploiting the regulatory setup for the balancing market. The revenue of bidding strategically is compared with the revenue of a non-strategic "bidding as forecasted".

Chapter 2 gives an overview of regulatory framework for power trading in markets. Focus is on balancing markets and imbalance settlement in Europe including the Nordic countries. An important change for the Nordic countries is that generation imbalance volumes from 1 November 2021 will be settled by a so-called "one-price" model.

Chapter 3 goes through the different cases of market outcome for a wind power plant in spot and balancing markets when bidding into spot according to forecasted generation. It is demonstrated that with a one-price imbalance settlement, the economic outcome for the wind power plant depends on the sign of the system imbalance compared to the sign of imbalance of the wind power plant.

Chapter 4 describes strategic bidding for a wind power plant as price taker. and builds on chapter 3.

Chapter 5 outlines the concept of strategic bidding in case the wind power plant is a price-maker in the balancing market.

Chapter 6 describes a case-study for a 100 MW offshore wind park in Germany. The calculations build on historic data for the German bidding zone in the period 1/1-2019 until 31/7-2020. All data is extracted through ENTSO-E's transparency platform.

Chapter 7 summarises the analysis and the case study, it concludes the work and includes discussion.

2 Regulatory framework

The entry into force of the Electricity Balance Guideline (EB GL) in 2017 established, among other things, a harmonization process for imbalance settlement in EU electricity markets.[1] After the proposal of European TSOs on the matter, the Agency for the Cooperation of Energy Regulators (ACER) approved in July 2020 (Decision 18-2020) a method comprising the following main elements for harmonization:

- *Calculation of a single imbalance position:* Balance Responsible Parties (BRPs) shall have one single final position, which is the sum of its external and internal commercial schedules. Previously, depending on the specific rules applied in each Member State, BRPs could have separate production, consumption and trade imbalance volumes.

- *Single imbalance pricing:* BRPs shall pay for their imbalances or be compensated for their contribution to restore the balance with a single price. It is up to the TSO to decide on the specific rules on how to achieve this result, as long as the conditions outlined in the following table are fulfilled:

BRP's position	Imbalance price is positive	Imbalance price is negative
Positive imbalance	Payment from TSO to BRP	Payment from BRP to TSO
Negative imbalance	Payment from BRP to TSO	Payment from TSO to BRP

Table 2.1: Payment of imbalance in accordance with article 55 of the EB GL (EU Regulation 2017/2195)

Under specific conditions, the TSO may propose to the relevant National Regulatory Authority to apply dual imbalance pricing. However, this is not the default option under the method for imbalance settlement harmonization.

2.1 The existing German model

The German imbalance settlement model, where the imbalance settlement period is set to 15 minutes, is based on a calculated single price calculated uniformly for the four German control zones. The calculated price, called the reBAP, is a function of the ratio of total expenditure (EUR) in balancing energy to net balancing energy (MWh) and several incentive components. A stylized representation is as follows:

[1] The imbalance settlement harmonization (ISH) process is outlined in article 52(2) of the EU Regulation 2017/2195

$$reBAP = f\left(\frac{TotalExpenditure \in BalancingEnergy(EUR)}{NetamountofBalancingEnergy(MWh)}, Incentivecomponents\right)$$

, where the Incentive components include price caps, an adjustment factor relative to the German Intraday Price Index (ID AEP) and a scarcity component:

- The adjustment factor ensures a distance of at least 25% (but at least 10 EUR/MWh) between the imbalance price and the ID AEP
- The scarcity component increases the imbalance price by 50% (but at least 100 EUR/MWh) in case of a deficit

By comparison to the Nordic model, the German model is administratively set rather than determined by market participants.

2.2 The existing Nordic model

On 1 November 2021, the Nordic countries went live with the application of the single price, single position harmonization model, after the four Nordic transmission system operators (Svenska Kraftnät, Energinet, Fingrid and Statnett) adopted a decision in this respect on October 2019.

The TSO provides balance in real-time by activating bids in the regulating power market: up-regulation is activated when imbalance in negative and down-regulation when imbalance is positive. The resulting up-regulation price is (equal to or) higher than the spot price, and the resulting down-regulation price is (equal to or) less than the spot price.

One important characteristic of the Nordic model is that it is market based, meaning that the bids in the Nordic regulating power market ultimately determine the price for a given market balancing area (= marginal price for upregulation or down-regulation). Another important element of the newly implemented model is that it is part of a broader process of changes, including the transition to a 15-minute imbalance settlement period.

The basis for the calculation of the imbalance **settlement** (the imbalance position) of BRPs (Balance responsible parties) in a market balancing area is calculated as the deviation between consumption, metered production, trades, metered grid area (MGA) imbalance and imbalance adjustment.[2] This is outlined in *Figure 2.1* below:

Figure 2.1: Calculation of imbalance position. Source: Nordic Imbalance Settlement Handbook: https://www.esett.com/handbook/

If the BRP consumes and sells more electricity than it produced and purchased, there is a deficit in the imbalance, and the BRP is required to purchase the imbalance energy to cover the deficit. Correspondingly, if the BRP produces and purchases more electricity than it consumed and sold, there is a surplus in the imbalance, and the balance responsible party sells imbalance energy to take care of the surplus. If the balancing area was in surplus the BRP is settled with the down-regulation price; If the balancing area was in deficit the BRP is settled with the up-regulation price.

The earlier Nordic balancing settlement model

To explain how the existing Nordic model relates to the previously existing model (valid since 2009, but now phased out), the following table summarizes its main characteristics:

[2] A Metering Grid Area (MGA) is a physical area where consumption and/or production and exchange can be metered.

	Up-regulation	Down-regulation	With no direction
Two-price model for production imbalances (2009 – 2021):			
Negative production imbalance	Up-regulation price	Spot price	Spot price
Positive production imbalance	Spot price	Down-regulation price	Spot price
One-price model for consumption imbalances (since November 2021):			
Negative consumption imbalance	Up-regulation price	Down-regulation price	Spot price
Positive consumption imbalance	Up-regulation price	Down-regulation price	Spot price

Table 2.2: Earlier balancing settlement model in the Nordics between 2009 and 2021 (now phased out). Source: Nordic Imbalance Settlement Handbook: https://www.esett.com/handbook/

2.3 The Spanish model

The Spanish wholesale electricity market is part of the Iberian Power Market (Mercado Ibérico de Electricidad – MIBEL) where both Spain and Portugal participate, and where each country constitutes one bidding zone. The market operators are the Spanish OMIE, which manages the day-ahead and intra-day markets, and the OMIP, which manages the futures market. In Spain, the system operator is the Red Eléctrica de España (REE), which manages balancing reserve markets and is responsible for system balancing.

In line with the imbalance harmonization process in the EU internal market for electricity, Spain will transition on 1 January 2022 (at the latest) towards a single position, single price model. However, there have been allowed two positions (one for consumption and one for production) and a dual pricing system in place.

The following table summarizes the dual pricing system currently applied in Spain from the perspective of a generator:

BRP position	System in up-regulation	System in down-regulation
Positive (actual generation exceeds forecast)	Generator sells excess production at spot price	Generator sells excess production is sold at imbalance price (which is lower than the spot market price) and generator is therefore penalized.
Negative (actual generation is below forecast)	Generator buys deficit production at imbalance price (which is higher than the spot market price) and generator is therefore penalized.	Generator buys deficit production at spot price

Table 2.3: Dual price system applied in Spain from the perspective of a generator. Source: https://www.esios.ree.es/es/mercados-y-precios

2.4 Ireland

Two TSOs operate Ireland's electricity system in the single electricity market. These are EirGrid (for the Republic of Ireland) and SONI (for Northern Ireland), which operate Ireland's single electricity market (SEM), which has been in operation since 2007. Prior to Ireland's market reform (referred to as the Integrated SEM or I-SEM), there was no balancing market, but a settlement of imbalances carried out by the Single Electricity Market Operator (SEMO).

After the I-SEM market rules went live in October 2018, full integration with European markets was achieved, and the wholesale market came to consist of five marketplaces: forward, day-ahead, intra-day, balancing and capacity markets.

Since the inception of the Irish balancing market, a single position and single pricing approach was implemented, thus living up to the requirements of imbalance settlement harmonization established by the EB GL and by ACER.

The high-level design of the SEM Balancing market are as follows:

- Participants are financially responsible for differences between their trade volumes and actual consumption or generation, i.e., a single position forms the basis of the imbalance calculation

- There is a single price for imbalances in both directions and the energy balancing actions (actions taken to ensure that the energy system is in balance). This price is set marginally, i.e., it is based on the cost of generating one additional unit (MWh) of balancing energy

- Non-Energy Balancing actions (actions necessary to maintain the system, e.g., reacting to local grid constraints, managing voltage control on the network, and maintaining system inertia) are settled on a pay-as-bid basis.

3 Wind power plant market bidding strategy: “bid as forecasted”

3.1 Conceptual setup

In this chapter we assume that a wind power generator bids into the spot market according to a provided forecast of expected average at the time of analysis: “bid as forecasted”.
We assume the time resolution in the spot and balancing market is one hour. For simplicity reasons, we do not include possible transactions in the intra-day market.

Besides it is assumed that the balancing market applies one-price imbalance settlement. This design will be in default use in the future in all EU countries (in the Nordics by 1 November 2021).

Figure 3.1 illustrates the concepts of spot price and regulation price. If the power system needs up-regulation, the up-regulation balance price will be the price of the highest bid necessary (marginal bid) in the regulation market to create balance. On the other hand, if the system must down-regulate the balancing price will be the price of lowest bid necessary (marginal bid) for obtaining balance.

As shown in figure 3.1 the up-regulation price is ≥ spot price and the down regulation price ≤ spot price.

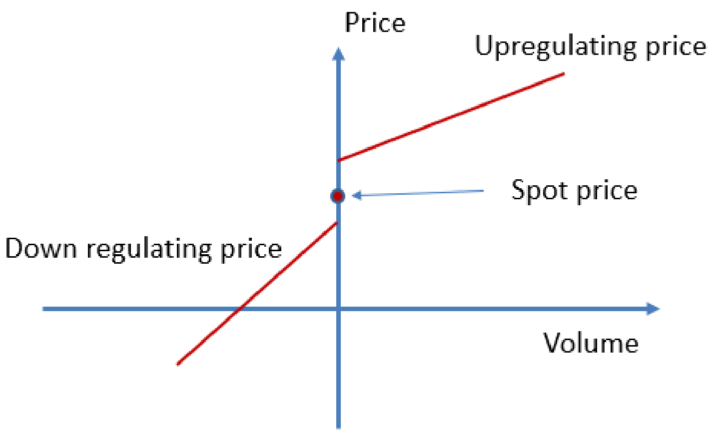

Figure 3.1: Illustration of up and down regulation prices and spot price

3.2 Cases of market outcome

In a given hour in principle there exist different cases of outcome for a wind power plant bidding into the market with the forecasted generation:

1) The forecast is "perfect" meaning that bid in spot is exactly equal to the generation
2) The forecast and bid in spot is higher than the resulting generation
    a. The system is in up-regulation: The wind power plant (or its BRP,) pays the up-regulation price for the missing generation
    b. The system is in down-regulation. The wind power plant pays the down-regulation price for the missing generation.
3) The forecast and bid in spot is lower than the resulting generation
    a. The system is in up-regulation: The wind power plant (or its BRP) is paid the up-regulation price for the surplus generation
    b. The system is in down-regulation. The wind power plant is paid the down-regulation price for the surplus generation.

The four cases in 2) and 3) are illustrated in figure 3.2, table 3.1 and figure 3.3 and table3.2.

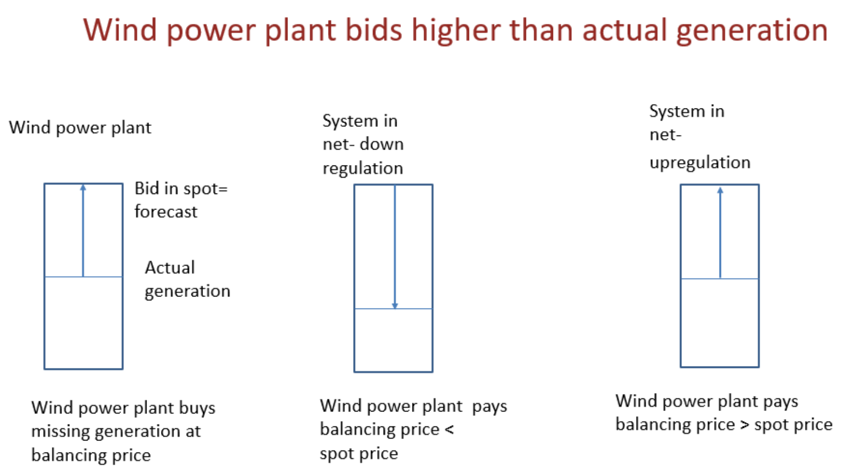

Figure 3.2 Forecast and bid is higher than actual generation

Wind farm: spot bid (= 100 MW) is higher than generation (= 50 MW)
Spot price = 30; up-regulation price = 40; down-regulation price = 20
Perfect forecast profit= 50*30= 1500

- System net down-regulating with 100 MW
- Transactions in balancing market
  - **Wind farm buys 50 MW**
  - Other actors sell 150 MW
  - Net for system is 100 MW down regulation
  - Balance providers pay back 100 MW *balance price (=20)=2000

  This is distributed as:
  - **Wind farm pays 50*20 = 1000**
  - Other actors are paid 150*20 = 3000
- Total wind farm profit in markets :
  - **100*30 - 50*20= 2000**

- System net up-regulating with 200 MW
- Transactions in balancing market
  - **Wind farm buys 50 MW**
  - Other actors buy 150 MW
  - Net for system is 200 MW up regulation
  - Balance providers are paid 200 MW *balance price (=40)= 8000

  This is distributed as:
  - **Wind farm pays 50*40 = 2000**
  - Other actors pay 150*40 = 6000
- Total wind farm profit in markets :
  - **100*30 - 50*40= 1000**

Table 3.1 Example with wind farm giving higher spot bid than generation.

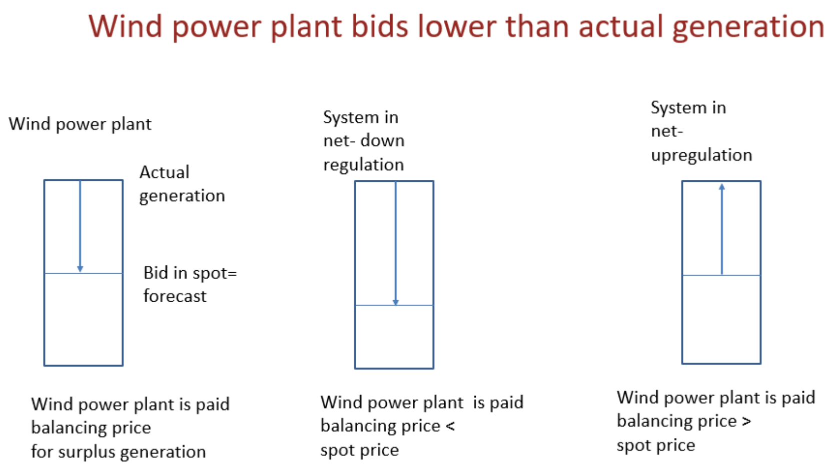

Figure 3.3 Forecast and bid is lower than actual generation

Wind farm: spot bid (=50 MW) is lower than generation (=100 MW)
Spot price = 30; up-regulation price = 40; down-regulation price = 20
Perfect forecast profit= 100*30= 3000

- System net up-regulating with 100 MW
- Transactions in balancing market
  - **Wind farm sells 50 MW**
  - Other actors buy 150 MW
  - Net for system is 100 MW up regulation
  - Balance providers are paid 100 MW *balance price (=40)=4000

  This is distributed as:
  - **Wind farm is paid 50 *40=2000**
  - Other actors pay 150*40=6000
- Total wind farm profit in markets :
  - **50*30+ 50*40= 3500**

- System net down-regulating with 200 MW
- Transactions in balancing market
  - **Wind farm sells 50 MW**
  - Other actors sell 150 MW
  - Net for system is 200 MW down regulation
  - Balance providers pay back 200 MW *balance price (=20)= 4000

  This is distributed as:
  - **100 MW farm is paid 50 *20= 1000**
  - Other actors are paid 150*20= 3000
- Total wind farm profit in markets :
  - **50*30+ 50*20= 2500**

Table 3.2 Example with wind farm giving lower spot bid than generation

It follows directly from figure 3.2 and 3.3 and from the examples in table 3.1 and 3.2 that the wind power plant gains in profit (marginal cost of wind is assumed to be zero) compared to a “perfect” wind forecast when the wind power plant balance has opposite sign of total system balance:

- Wind power plant gains when generation is less than forecast (= bid in spot) and the system is in down-regulation
- Wind power plant gains when generation is larger than forecast (= bid in spot) and the system is in up-regulation.

Similarly, the wind power plant loses (compared to “perfect” forecast) when the wind power plant’s imbalance has same sign as the system imbalance.

The outcomes of the market engagement for the wind farm is showed in figure 3.4.

Loss and gain in spot plus balancing market for wind power plant

	System up-regulating	System down-regulating
Wind power generates less than forecast=submitted in spot	Wind power plant loses*	Wind power plant wins*
Wind power plant generates more than forecast= submitted in spot	Wind power plant wins*	Wind power plant loses*

*) “Loses” and “wins” is total income in spot plus balancing market compared to bidding in spot market with a **“perfect”** forecast (no balancing needed)

Figure 3.4 Loss and gain for wind power plant in spot plus balancing markets

4 Strategies for wind power plant bidding: price-taker in balancing market

In this chapter we assume the wind power plant to be a price taker in the balancing market, which means that the plant cannot influence the balancing price by its bidding.

The discussion and results in chapter 3 show that the market design gives incentives to help the system into balance. The wind power plant can profit from strategic bidding in case the system balance for the next day could be forecasted.

In the extreme case a 100 MW wind farm would gain maximum profit by bidding 100 MW into the spot market when the system is in down-regulation and 0 MW into the spot market when the system is in up-regulation. The situation is illustrated in figure 4.1. The challenge for the wind power plant owner is to know the signs of next day's system-imbalances. This is indicated by the red arrows in figure 4.1. In the case of bidding the extremes even a perfect wind power forecast has no value. However, a correct forecast of next day's imbalances would be of high value.

Instead of going full in with an extreme bid we could assume that the wind power plant owner has some idea of the sign of next day's imbalance (in a specific hour). For example, we could assume that the wind power owner has found that a general good estimate (in average) of next day's imbalance in a specific hour when assuming the sign to be the same as 24 hours before.

Wind power plant strategic bidding-price taker

	System up-regulating	System down-regulating
Wind power plant is short (generates less than submitted in spot)	Wind power plant loses*	Wind power plant wins*
Wind power plant is long (generates more than submitted in spot)	Wind power plant wins*	Wind power plant loses*

*) "Loses" and "wins" is total income in spot plus balancing market compared to bidding in spot market with a perfect forecast (no balancing needed)

Risk of moving from "wins" to "loses" if sign of system net-imbalance is guessed wrongly

Figure 4.1 Wind power plant strategic bidding- incentives

Such an evaluation could end up in a mixed bidding strategy where the risk of "guessing" the imbalance sign correctly is assessed. In this mixed bidding strategy, a wind power forecast will have value, see figure 4.2.

An example is shown in figure 4.2.
In this example the bid in spot is the forecasted value plus an adjustment, if system down-regulation is assumed most probable and minus an adjustment, if system is most probably assumed to be in up-regulation. The choice of selecting 10 % in the adjustment formulas in figure 4.2 reflects the result of the wind power plant owner's risk assessment and risk profile.

Assuming system down-regulation :
Wind farm capacity = 100 MW
Forecasted value = 50 MW
Bid in spot = forecasted value + (Wind farm capacity – forecasted value) x 10%
Bid in spot = 50 MW + (100 MW – 50 MW) x 10% = 55 MW

Assuming system up-regulation:
Wind farm capacity = 100 MW
Forecasted value = 50 MW
Bid in spot = forecasted value - (forecasted value- 0 MW) x 10%
Bid in spot = 50 MW - (50 MW- 0 MW) x 10%= 45 MW

Figure 4.2 Example of hybrid bidding strategy. Limited risk.

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5 Strategies for wind power plant bidding: price maker in balancing market

In this chapter we assume that the wind power plant (or a group of wind power plants) can influence the balancing price with their bidding into the market.

As in chapter 4, the incentive for the wind power plant is to bid into the spot market in a way to create an imbalance opposite to the system net-imbalance.

Figure 5.1 shows the qualitative assessment of a wind power plant having influence on balancing price by increasing or decreasing the net-balancing volume for the system. The loss and gain in the figure are measured compared to the price taker situation (figure 4.1).

It follows that the wind power plant's imbalance in all four cases in figure 5.1 lead to losses compared to the price-taker situation (figure 4.1).

Loss and gain for wind power plant in market-
price maker in balancing market compared to price taker

	System up-regulating	System down-regulating
Wind power plant short (generates less than submitted in spot)	1) Wind power plant loses*	2) Wind power plant loses*
Wind power plant long (generates more than submitted in spot)	3) Wind power plant loses*	4) Wind power plant loses*

*) "Loses" is compared to results where wind power plant imbalance does not impact balancing price

Ad 1: wind power generates larger net system imbalance => larger price for up-regulation => wind power plant pays more
Ad 2: wind power generates less net system imbalance => larger price for down-regulation => wind power plant pays more
Ad 3: wind power generates less net imbalance => less price for up-regulation => wind power plant is paid less
Ad 4: wind power generates larger net imbalance => less price for down-regulation => wind power plant is paid less

Figure 5.1 Loss and gain in market when wind power plant's bid impacts the balancing price

The explanation is given in the figure in the comment ad 1) to ad 4) and indicated in figure 5.2, where the numbers 1-4 show the direction of balancing prices in the 4 cases in figure 5.1.

This means that a strategy based on creating large profits by selling or buying large imbalances in the balancing market has its limitations. Cases 2) and 3) which are profitable compared to "bidding according to perfect wind forecast" will have reduced profits, the more the net-volume of system balancing decreases in either down-regulation (case 2: higher down-regulation price) or up-regulation (case 3: lower up-regulation price).

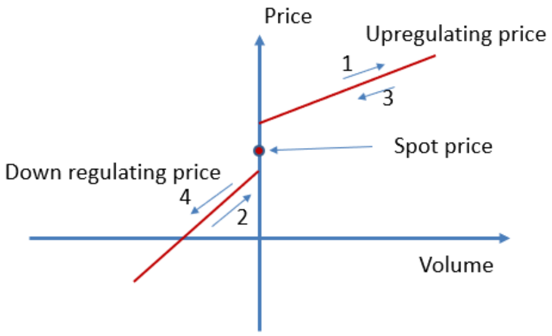
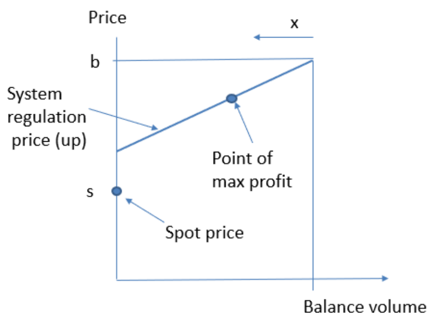


Figure 5.2 Impact on balancing prices according to the wind power plant's bidding into spot (price -maker situation)

This cannibalisation effect can modify the price-maker's strategy of bidding: Instead of bidding extremes (case 2: "capacity of wind farm" or case 3: "0 MW") it may be optimal to bid with a less aggressive strategy. The less aggressive strategies will among others depend on the slopes of the regulation prices with regulating volume, the regulating price without the market maker bid and the spot price. Besides that, a wind power forecast has value as described below.

Figure 5.3 and table 5.1 present an example of price maker's strategy in case 3.



Profit= (g-x)*s + x*(b-a*x)

g= forecast of wind generation of price maker

a= slope of "regulation price"

b= regulation price without market maker bid

x = change of balancing volume due to bid from price maker

Max profit for price maker when :

x = ½ * (b-s)/a; and x is feasible

Optimal bid in spot equals forecast of wind generation "g" minus "x": g-x

Figure 5.3 Example. Max. profit for wind power plant, price maker, case 3.

Example:
b = 90 Euro/MWh
s = 30 Euro/MWh
a = 1 Euro/MWh/MWh
⇒ x = 30 MWh
Forecast for generation = 50 MWh
Optimal bid in spot= 50-30 = 20 MWh

Table 5.1 Example from figure 5.3.

It follows that instead of bidding 0 MW in the spot as in the price-taker case, the optimum in the example is to bid in 20 MW in the spot market.

In analogy figure 5.4 and table 5.2 present an example of price maker's strategy in case 2, capacity of wind farm is assumed to be 100 MW.

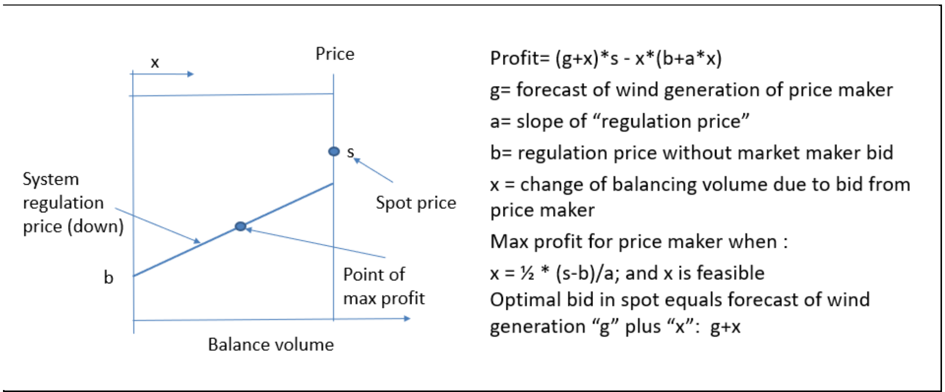


Figure 5.4 Example. Max. profit for wind power plant, price maker, case 2.

Example:
b = 10 Euro/MWh
s = 70 Euro/MWh
a = 1 Euro/MWh/MWh
⇒ x = 30 MWh
Forecast for generation = 50 MWh
Optimal bid in spot= 50+30 = 80 MWh

Table 5.2 Example from figure 5.4.

It follows that instead of bidding capacity of wind farm (100 MW) in the spot as in the price--taker case, the optimum in the example is to bid in 80 MW in the spot market.

The wind power plant must avoid the change of sign of imbalance in case 2) and 3) in figure 5.1 and figure 5.2. If this happens then the wind power plant will lose profit not only compared to the price-taker situation (figure 4.1) but also compared to ”bid as forecasted” (figure 3.4) into spot-market including bidding a “perfect” forecast.

It follows directly from the above discussion that the optimal outcome for the wind power plant owner in case 1 and 4 is to “bid as forecasted” of the wind power and thereby minimise his imbalances.

6 Case study: German offshore wind- 2019-20

6.1 Introduction

This chapter describes a case-study based on market data from Germany in 2019-2020. The objective of the chapter is to illustrate the conceptual descriptions of wind power bidding presented in chapters 3 to 5 with actual data.

6.2 Data

The analysis is performed for the German bidding zone in the period 1/1-2019 until 31/7-2020. All data is extracted through ENTSO-E's transparency platform[3]. This data source was chosen due to its open and transparent nature.

The German bidding zone (Germany is one big price zone) was chosen due to its one price imbalance settlement approach, which is going to be used in general for the whole of Europe, see chapter 2. The analysis has been based on data (generation and forecast) for German offshore wind power (approx. 7000 MW) which forms part of the bidding zone.

The analysis is limited to the day-ahead market and resulting balancing market.. The analysis does not consider trading in the intraday market. This choice has been made due to keep the analysis simple and because of limited availability and applicability of data for intraday market.

The day-ahead price is in the bidding zone set on an hourly basis, while the balancing market is settled with 15 minutes time resolution. In the calculations the hourly day-ahead price (spot price) is assumed constant throughout all four quarters of the hour.

The marginal generation cost of wind generation is assumed to be zero.

6.3 Bidding strategies for 100 MW offshore wind power plant

In our case we will look at the performance of different bidding strategies for a 100 MW offshore wind park. Data for generation and forecast through the time period 1/1-2019 until 31/7-2020 is obtained by proportional scaling the time series for the whole of German offshore wind of 7000 MW down to 100 MW[4]. Prices in spot and balancing market are directly adopted from the raw data series on ENTSO-E's transparency platform. The 100 MW offshore wind farm is assumed to be price-taker.

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[3] ENTSO-E : https://transparency.entsoe.eu/

[4] This simple approach will underestimate the variation in output of the 100 MW windfarm. Nevertheless, the outcome of the analysis regarding market earnings is assumed to give indicative correct results.

The following bidding strategies are compared:

6.3.1 Reference strategy “bid as forecasted”

The reference bidding strategy *is bidding as forecasted* in the period 1/1-2019 until 31/7-2020 .

As an illustration figure 6.1 shows data and results for the reference strategy for the first 2 days in 2019.

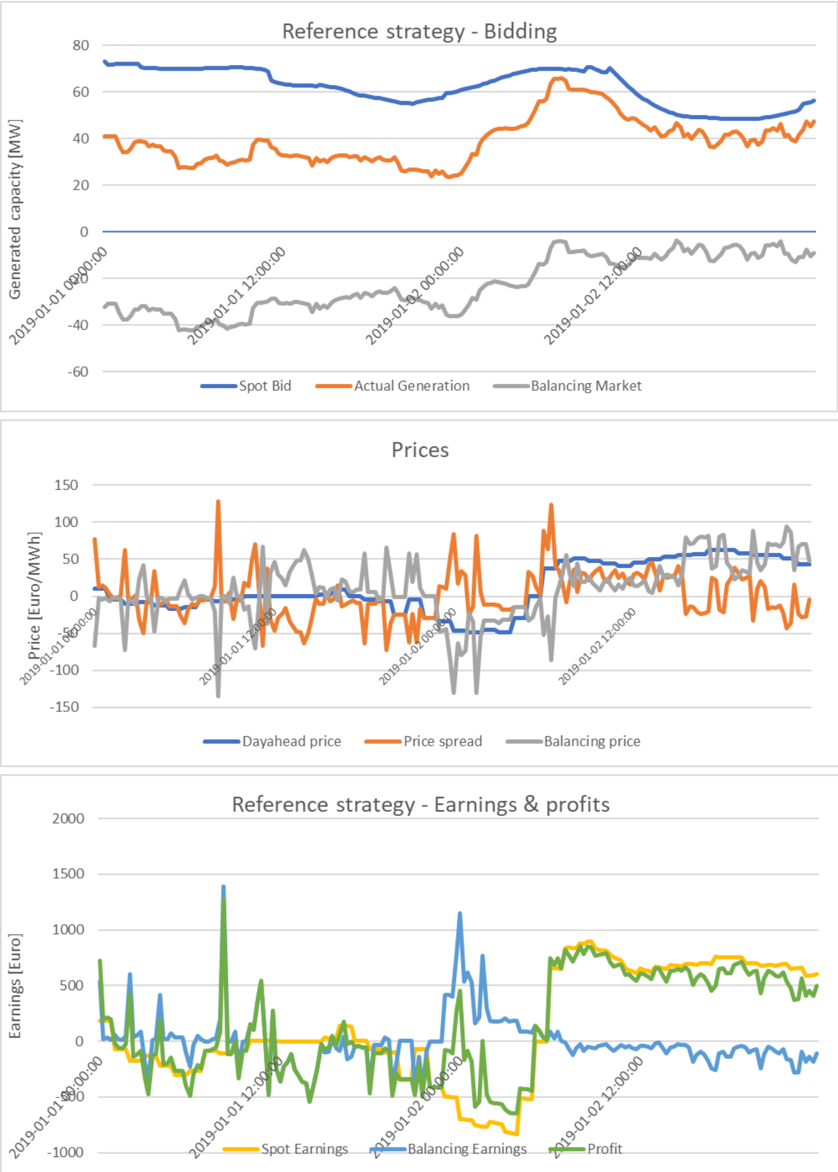

Figure 6.1. Data and results (quarter hourly) for the two first days in 2019 for a 100 MW wind farm. Upper illustration is bidding, actual generation and imbalance. Mid-illustration shows the prices and lower illustration shows profits in

the respective markets: spot, balancing and total (Euro in each 15 minute time interval)

6.3.2 Extreme bidding (price-taker: perfect foresight of sign of system imbalance)

In the extreme case the 100 MW wind farm would gain maximum profit by bidding 100 MW into the spot market when the system is in down-regulation and 0 MW into the spot market when the system is in up-regulation.

This strategy presumes that the wind park owner knows the sign of system imbalance the next day. In the real world the imbalance is not known a day in advance, i.e., it can only be forecasted. The strategy has been included because it will set an upper limit for market outcomes in the spot plus balancing market.

It should be noted that in this extreme case, even a perfect wind power forecast has no extra value.

It should also be noted that the assumption of being a price-taker is questionable. The average numerical value of the balancing volume is approximate 124 MWh/15min in the first two days of 2019. The imbalance of the 100 MW wind plant is up to 40 MWh/15 min (see figure 6.1). For the whole time series from 1/1-2019 until 31/7-2020 the average absolute balancing volume is about 100 MWh/15 min.

6.3.3 Extreme bidding (price -taker) based on forecasting the sign of system imbalance

The non-perfect version of the "Extreme bidding", (6.3.2), draws on the same principle as the "perfect foresight" version. Now we presume a simple forecasting method of the sign of the system imbalance. In our example the forecast of the system imbalance in a given point in time (15 minutes time-interval) is assumed to have the same sign as 24 hours before. The bids are either 100 MW or 0 MW depending on the forecasted sign of system imbalance.

It should be noted that in this extreme case, even a perfect wind forecast has no extra value.
It should also be noted that the assumption of being a price-taker is questionable, see text in section 6.3.2.

6.3.4 Risk-aware bidding strategy (price-taker)

This bidding strategy is a mixture of the reference strategy 6.3.1 and strategy 6.3.3.

The bid in spot is the forecasted value plus an adjustment if system down-regulation is assumed most probable and minus an adjustment if system is most probably assumed to be in up-regulation. The assessment of sign of imbalance could e.g., be based on the sign of the system imbalance 24 hours before.

In the example the adjustment is chosen as outlined in figure 4.2. In this case the quality of the wind power forecast can add value.

6.3.5 Perfect wind forecast

Bidding according to *Perfect wind forecast* assumes that the wind forecast is perfect at estimating next day's realized generation of the wind farm. This strategy will be a variant of the reference strategy (6.3.1). This strategy will thus never lead to taking part in the balancing market and is only illustrative to also show the result of this extreme.

6.3.6 Extreme bidding (price-maker: perfect foresight of sign of system imbalance). Like 6.3.2 but now assuming that wind power plant bid has impact on balancing price.

In this case the balancing price is adjusted following the principles in chapter 5. The wind power plant buys balancing power at down regulation price and sells balancing power at upregulation price. The balancing prices are estimated assuming a linear correlation between balancing volume and balancing price (slope: 0.25 Euro/MWh/MWh) . The slope of the linear correlation is estimated from the data set.

6.3.7 Extreme bidding (price-maker: simple forecast of sign of system imbalance). Like 6.3.3 but now assuming that wind power plant bid has impact on balancing price.

In this case the balancing price is adjusted following the principles in chapter 5. The wind power plant buys balancing power at down regulation price and sells balancing power at upregulation price. The balancing prices are estimated assuming a linear correlation between balancing volume and balancing price (slope: 0.25 Euro/MWh/MWh) . The slope of the linear correlation is estimated from the data set.

6.4 Results

The results of the five different strategies for bidding are shown in table 6.1. As generation cost of wind is assumed to be zero the income in the markets equals the profit achieved.

Numbers in million Euro	Spot market-profit	Balancing market-profit	Total profit	Relative total profit- %
Reference strategy- 6.3.1	17.0	-0.9	16.1	100
Extreme bidding (perfect)-6.3.2	20.5	18.5	39.0	242
Extreme bidding-6.3.3	20.0	-2.2	17.8	111
Risk aware bidding- 6.3.4	17.3	-1.1	16.2	101
Perfect wind forecast- 6.3.5	16.9	0.0	16.9	105
Price maker 6.3.6 – and as 6.3.2	20.5	16.0	36.5	227
Price maker 6.3.7 – and as 6.3.3	20.0	-4.8	15.2	94

Table 6.1. Profits in spot and balancing markets for 100 MW German offshore wind farm with different bidding strategies. Period 1/1-2019 until 31/7-2020. Numbers in million Euro, except last column is in % compared to reference strategy.

Figures 6.2 and 6.3 show the results of table 6.1 in graphical layout.

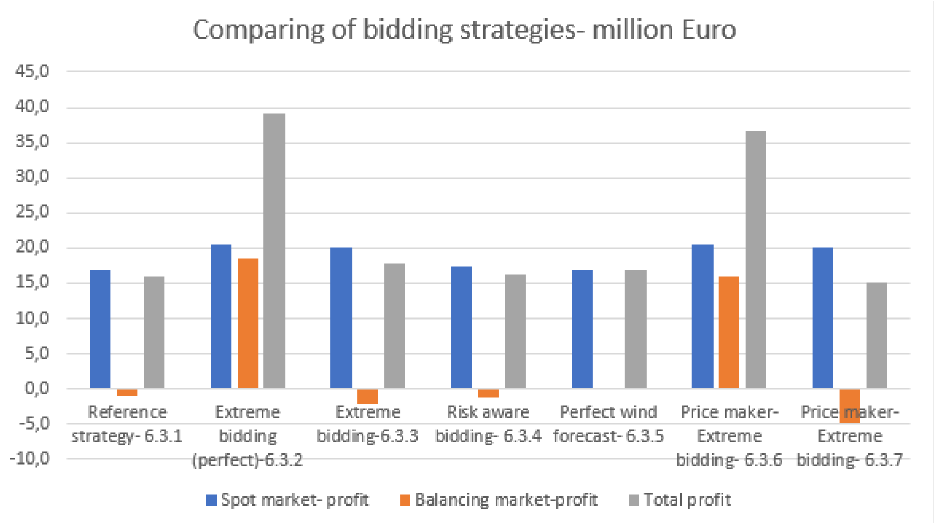

Figure 6.2 . Profits (million Euro) in spot and balancing markets and total for 100 MW German offshore wind farm with different bidding strategies. Period 1/1-2019 until 31/7-2020.

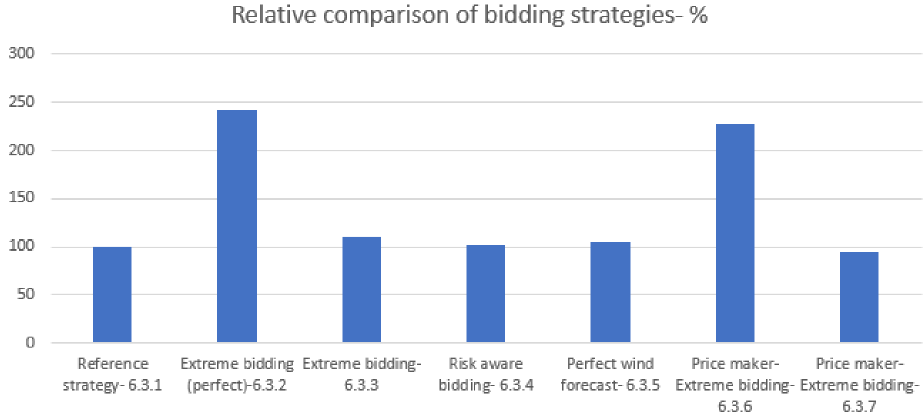

Figure 6.3 . Relative total profits in percent for 100 MW German offshore wind farm with different bidding strategies. Reference strategy = 100 %. Period 1/1-2019 until 31/7-2020

In the price taker situation, the results show the highest profits in the extreme bidding cases: 6.3.2 and 6.3.3.

Case 6.3.6 (price maker) is also an extreme case but compared to 6.3.2 it is assumed that the bidding of the wind power plant changes the balancing prices because the system-imbalance is reduced. The profit thereby reduces from 39 million Euro to 37 million Euro by going from price taker to price maker. The uncertainty on price-volume relation in the balancing market is high and the approach of a linear correlation should be seen as a proxy for evaluating the price maker case. (To illustrate the uncertainty a slope of 0.50 Euro/MWh/MWh instead of 0.25 Euro/MWh/MWh would reduce the profit in case 6.3.6 from 37 million Euro to 34 million Euro).

Case 6.3.7 (price maker) has the same assumptions as case 6.3.3, except that the wind power plant is assumed to be price maker. It follows that the profit (15.2 million Euro) is less that in the reference case (16.1 million Euro).

Case 6.3.6 and 6.3.7 (price-maker) illustrate the point from chapter 5 about cannibalisation effect when bidding with an aggressive strategy in the market.

Strategy 6.3.2. represents an upper limit for profit (142 % more than in reference): the bidder always "guesses" the right sign of the system imbalance in every time interval for the next day. Thus, the bidder always obtains the lowest price for buying and the highest price for selling in the balancing market. The high profit achieved in this market is to be expected.

Strategy 6.3.3 has also a high total profit: 11 % higher than the reference. In this strategy is earned more in spot and earned less (paid more) in balancing market compared to reference.

It should be noted that both strategy 6.3.2 and 6.3.3. are based on bidding in the extremes (100 MW or 0 MW) in the spot market. *In these two strategies even a perfect wind power forecast has no extra value.*

Case 6.3.5 is bid as forecasted with the best possible wind forecast. This strategy represents the best outcome possible in case the wind farm owner does not involve in any kind of speculation. The total profit in this case is 5 % higher than the reference. (The reference is bidding as forecasted with the current forecast quality for 2019-20).

The risk aware strategy (6.3.4) is equal to the reference except that the bid size is adjusted with a certain amount depending on the wind plant owner's risk assessment and risk profile. In the present case the adjustment of the bid size is chosen to be plus or minus 10% of an adjustment parameter, see section 6.3.4. This strategy results in total profit being 1 % higher than the reference case.

It should be noted that strategy 6.3.4 and 6.3.5 both benefit from a wind power forecast and perform better than the reference (6.3.1).

7 Conclusion and discussion

The analysis does not consider trading in the intraday market. This choice has been made due to keeping the analysis simple. With this assumption the wind plant owner can save money for additional short-term forecasts during the day and for keeping 24/7 personnel for intraday trading.

The study is a partial analysis limited to assess the possibilities of a wind power plant owner to gain from bidding strategically in the day-ahead market and exploiting the regulatory setup for the balancing market. The revenue of bidding strategically is compared with the revenue of a non-strategic “bidding as forecasted”.

The report describes the value of wind power forecasts for trading in markets with focus on spot and balancing markets. This is done for different bidding strategies of a wind power plant owner.

Focus is on day-ahead and balancing markets. The analysis is confined to study imbalance settlement according to the “one-price” model as this will be the future model to prevail in Europe.

7.1 Results from conceptual models

Conceptual models for bidding are described and earnings/profits in markets are qualitatively estimated.

With a “one-price” balance model, a wind power plant earns more in the spot market and the balancing market than bidding in the spot market alone according to a “perfect” wind power forecast, when the wind power plant’s imbalance is “helping” the system balance. The opposite is the case when the wind power plant imbalance worsens the system balance.

If the wind power plant knows the system imbalances the next day, then the optimal strategy will be to bid the wind plant capacity when the system is in down-regulation and bid 0 MW when the system is in up regulation. In this case a forecast of wind generation has no extra value.

Normally, the wind power owner does not know the sign of next day’s system imbalances, but he may have a forecast of some quality. In that case the wind power owner could choose a mixed bidding strategy with the bid being the forecasted value plus or minus an adjustment dependent on which sign of the system-imbalance is assumed most probable. In this case a wind power forecast of average quality has value. And a good forecast of the sign of system-imbalance might be of even greater value.

Bidding strategically the wind power owner could turn out to be a price-maker in the balancing market due to his potential large, imposed imbalances on the system. This could change the balancing price unfavourably for him. In that case the optimal bidding strategy for the wind plant owner will change in direction of reducing his transaction in balancing market. In this case a wind power forecast of average quality also has value.

7.2 Results from case-study

We presented a case study based on real market data (2019-2020) from Germany and market outcomes for a 100 MW offshore wind park subject to the German time series of market data have been estimated for different trading strategies of the wind farm.

As expected, the case study shows that when bidding into the spot market with the forecasted generation then a wind power generation forecast of high quality will provide additional benefits (in spot plus balancing market). In the case study there is a potential for additional profit of 5 % compared to the case with the current “average” forecast quality.

On the other hand, if the wind power plant owner chooses to give in strategic market bids, either minimum or maximum generation, based on a forecast of the signs of next day’s system-imbalances then the quality of a wind forecast has no value. Instead, a correct forecast of the signs of next day’s system-imbalances can be very valuable.

In the German case-study a perfect forecast of the signs of next day’s system imbalances can improve the profit with up to 142% compared to the reference case (with non-strategic bidding according to forecast with current average quality).

Similarly, a simple forecast of next day’s system-imbalances (sign of system-imbalance assumed the same as the day before) could provide 11 % higher profit than the reference case by bidding either minimum or maximum generation depending on forecast of system imbalance. Here a wind power forecast has no extra value.

In the German case-study the wind power plant can also choose a mixed strategy with the bid being the forecasted value plus or minus an adjustment dependent on which sign of the system-imbalance is assumed most probable. In this case the quality of the wind power forecast can add value.

The cases described above all assume a price-taker situation. The effect of a price-maker situation has been evaluated based on simple assumptions of the relation between balancing price and system-balancing volume. The results of the price-maker cases should be seen as an illustration of the cannibalisation effect of aggressive strategic bidding.

In the price-maker cases the profit reduces compared to the comparable price taker cases. In one case the reduction is from 39 million Euro (price taker) to 37 million Euro (price maker). In the other case the reduction is from 18 million Euro (price taker) to 15 million Euro (price maker).

7.3 Discussion

If the wind power plant owner can be assumed to be a **price taker**, then the results show than he can profit by bidding in strategically if his forecast for next day's sign of imbalances is credible. The case-study shows that even a very primitive forecast of sign of system balance provides additional profit compared to the reference (bid as forecasted). So, if the assumption of being a **price taker** is credible, then development towards accurate forecasting of sign of imbalance would be most valuable for the wind power plant

However, when studying the German market data in the case-study it is interesting to note that the net-balancing volume for the system is quite limited. The average absolute value of balancing volume for the whole of Germany is about 100 MWh (15-minute value). It is therefore very plausible that a wind power plant often can be a **price-maker** in the balancing market. In that case he may easily cannibalise his revenue or even lose compared to "bid as forecasted" if his impact on the balancing volume changes the sign of the system-imbalance. Therefore, the wind power plant should be very cautious about speculation involving large imbalances. This has been illustrated by comparing price-maker cases with price-taker cases in the German case-study.

As shown (chapter 5) the wind power plant in the price maker case would benefit from using a mixed strategy.

In this case development towards accurate forecasting of wind power generation, improved forecasting of sign of imbalance and size of balance volume would be most valuable for the wind power plant.

It is notified that the volume in German balancing market is small compared to the generation. The reason for the low balancing volume can be attributed to an efficient intraday-market. With such low imbalance volumes then the **price-maker** situation in the balancing market is most probable for a wind power plant.