COMPUTATIONAL MANAGEMENT SCIENCE 2012

Optimal sale bid for a wind producer in Spanish electricity market.

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1.1. Wind Energy in Spain: from incentive scheme towards free market

RD 436/2004
- Regulated Tariff
- Fix subsidy + market price

RD 661/2007
- Regulated Tariff adjusted to IPC value
- Market price+ Variable Subsidy with Cap and Floor

New regulation
- No regulated tariff
- Subsidy considerably reduced and minimal profitability not granted

Wind energy producers need to be competitive on the market developing their own sale strategies.

1.2. Iberian Energy Market

Day-ahead market:

Demand and supply matching for the 24 hours of the following day

Intra-day markets:

Six sessions to adjust sales positions handled in the day-ahead market

Management deviation market:

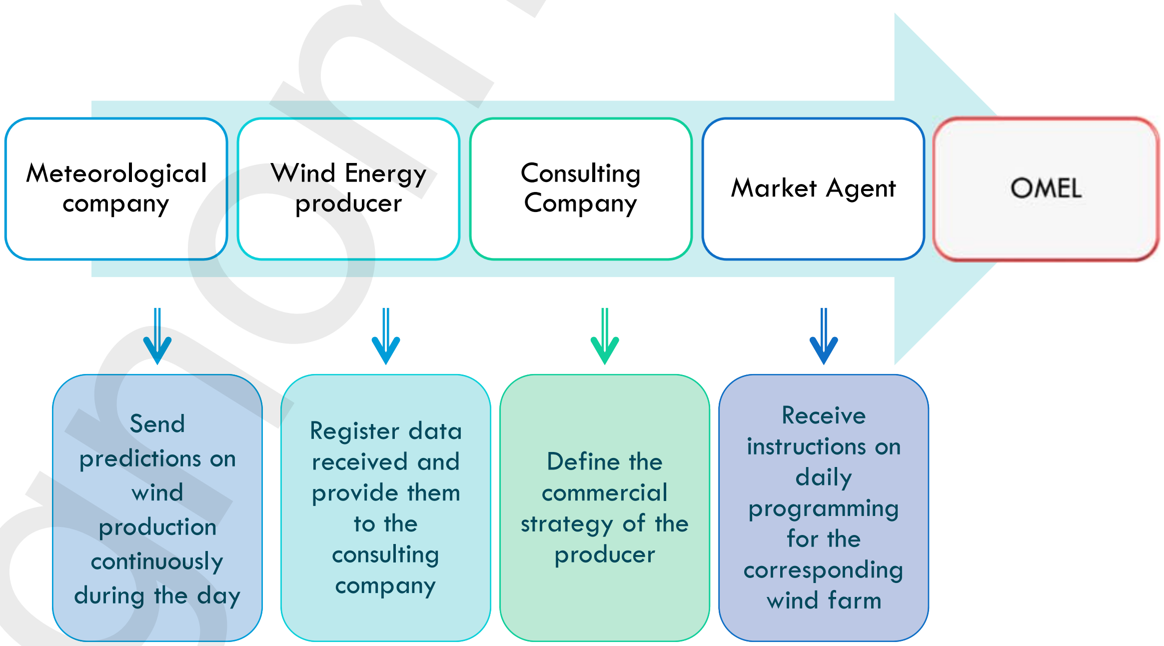
To grant energy demand and supply to match continuously

1.3. Daily and intra-day markets

Markets' windows.

DIA D-1 (hours 1–24)	DIA D (hours 1–24)
Daily Market (close at 10)	(Schedule horizon 24 h)
Intra-day Market session 1 (close at 17.45)	Schedule horizon (28 h)
Intra-day Market session 2 (close at 21.45)	Schedule horizon (24 h)
Intra-day Market session 3 (close at 01.45)	Schedule horizon (20 h)
Intra-day Market session 4 (close at 04.45)	Schedule horizon (17 h)
Intra-day Market session 5 (close at 08.45)	Schedule horizon (13 h)
Intra-day Market session 6 (close at 12.45)	Schedule horizon (9 h)

1.4. The process of sending sale bids to the market



2.1. Previous studying: characteristics of the markets

- The largest number of transactions (approximately 92%) is registered in the day-ahead market;
- Volumes and average prices trends detected annually are respected monthly as well;
- The largest number of transactions in intra-day market is held in the first two sessions that are the “cheapest” ones;
- On average prices of the first three sessions are lower than clearing price of day-ahead markets, while the last three sessions are more expensive.

2.2. Previous studying: commercial strategies currently used.

At 7. 30 a.m. of day D-1 generation estimates for all day D, sent by the meteorological forecasting company are registered on market agent platform

↓

Consulting company manipulate the estimate, inflating it , in order to sale more in the day-ahead market and buy in the cheapest sessions of intra-day market

↓

While receiving continuously generation predictions, it makes adjustments to final programming if a significant difference with the previous data received is detected.

3.1. Mathematical formulation

We implement a two stage linear stochastic model in order to **MAXIMIZE THE DAILY PROFIT** associated to a plant with a capacity of 16.2 MW, with the aim of eliminating consulting costs and better the commercial strategy of the company, **considering as source of randomness**:

- **The error in the prediction registered at 7.30**
- **Fluctuations in intra-day market prices**

These random variables are considered independent.

3.2. Scenario generation

- **Forecasted wind generation:**
  - hourly data have been observed and a homogeneous behaviour has been detected along then day;
  - the empirical function has been drawn, it can be approximate by a N(-0.48, 5.35);
  - a bootstrap method has been used to do re-sampling and create S=64 scenarios for the day-ahead hourly wind generation $\mathbf{g}_i^s$ (hour "i") with probability $\mathbf{p}^s$, s=1,…,S;
- **Intra-day market prices:**
  - all the available historical data of the sequence of market prices has been reduced (Corchero, 2011) in order to obtain a suitable set of R=200 scenarios of the intra-day market prices π_{ij}^r, (session "j", hour "i"), with probability $\mathbf{q}^r$, r=1,…,R.

3.3. Variables

- **First stage variables x_i:**

  it is the hourly quantity of energy to sell in auction "i" of the day-ahead market (initial offer of the wind producer for day D before 10 a.m. of day D-1);

- **Second stage variable y_{ij}^{rs}:**

  hourly energy volumes negotiated in hour "i" of the session "j" of intra-day market for wind generation and price scenarios "s" and "r" respectively (adjustments realizable from 17.45 of day D-1 and up to12.45 of day D that determine final programming of the plant).

3.4. Objective function.

$$\max \underbrace{\sum_{i=1}^{24} \lambda_i * x_i}_{\text{Incomes achieved in day-ahead market}} + \sum_{s=1}^{S} p^s \sum_{r=1}^{R} q^r * \left[\underbrace{\sum_{j=1}^{m} \sum_{i \in A(j)} \pi_{ij}^{r} * y_{ij}^{s,r}}_{\text{Incomes achieved in intra-day market sessions}} - \underbrace{\sum_{i=1}^{24} c_i * \left(x_i + \sum_{\forall j \mid i \in A(j)} y_{ij}^{s,r} - g_i^s \right)}_{\text{Total cost of penalization because of deviations}} \right]$$

3.5. Constraints

$$\alpha * \bar{e}_i \leq x_i \leq b$$

Restrictions on hourly sale bid in day-ahead market

$$y_{i1}^{s,r} \geq -\beta * x_i \quad i = 1, \dots, 24 \quad s = 1, \dots, S \quad r = 1, \dots, R$$

Restrictions on hourly quantities to buy in the first intra-day market

$$g_i^s \leq x_i + \sum_{\forall j \mid i \in A(j)} y_{ij}^{s,r} \leq b \quad i = 1, \dots, 24 \quad s = 1, \dots, S \quad r = 1, \dots, R$$

Restrictions on final programming

3.5. Constraints

$$0 \leq x_i + \sum_{\forall j \leq n \mid i \in A(j)} y_{ij}^{s,r} \leq b \quad i = 1, \dots, 24, n = 1, \dots, 5 \quad s = 1, \dots, S \quad r = 1, \dots, R$$

Restrictions to grant non-negative sale bid

$$-\gamma_j * b \;, \leq y_{ij}^{s,r} \leq \gamma_j * b \quad i \in A(j) \quad j = 1, \dots, m \quad s = 1, \dots, S \; r = 1, \dots, R$$

Restrictions on transactions size

3.6. Computational issues.

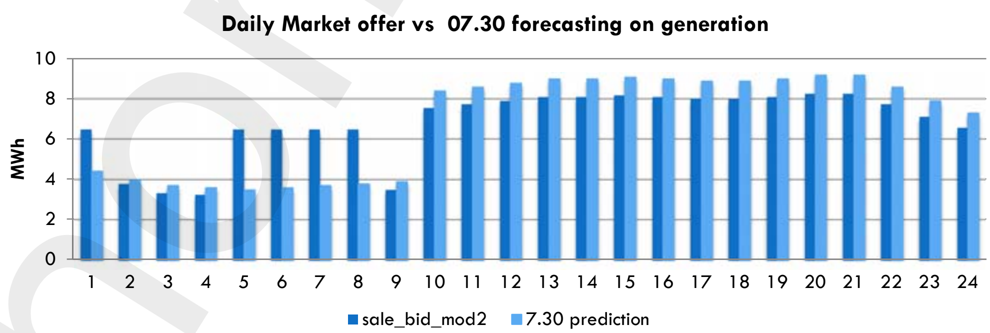
The linear stochastic programming model has been implemented using AMPL/CPLEX.

Model	#x	#y	#restrictions	execution time
with generation scenarios	24	6848	17.624	30 seconds
with generation and price scenarios	24	1.369.600	3.520.024	9 minutes and 45 seconds

* both models implemented with machine Fuji Rx200 56 (2XCPUs Intel Xeon X5680 Six Core/RT 3.33 GH, 64Gb RAM).

4.1. Results

Solution with low day-ahead market prices.

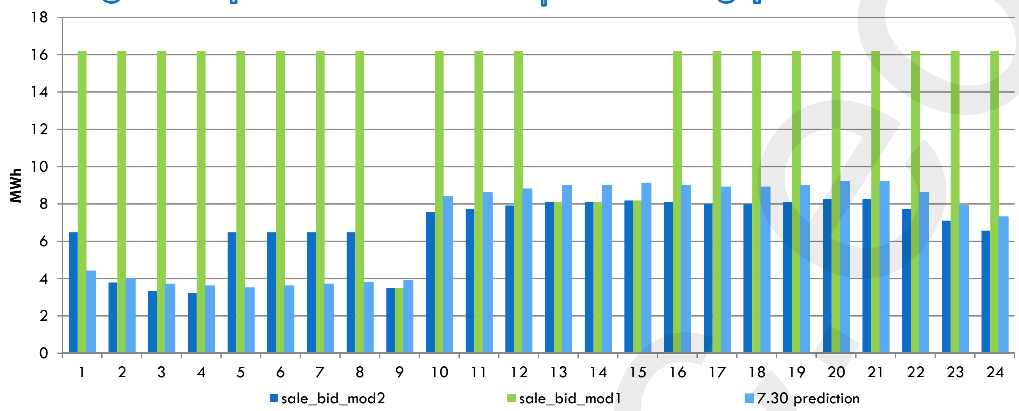


•The solution prescribes to offer the minimum except in hours 1, 5, 6, 7 and 8, when constraints on transaction size and deviation cost are active.

•In any of the other hours of the day it is more profitable to sell energy in intraday markets.

4.2. Results

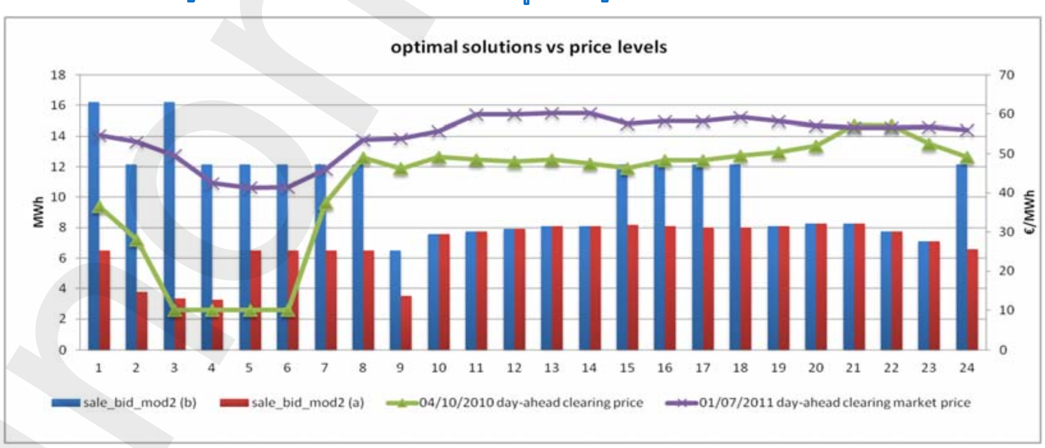
Change in optimal solution x_i^* including price scenarios



The solution of the model including both sources of randomness, the one due to prediction error and the other due to variability in intra-day markets prices (sale_bid_model2), is more prudent because it considers the possibility of both positive and negative differences in price levels compared to day-ahead market.

4.3. Results

Sensitivity of the solution x_i^* to price levels.



Optimal solution does not depend only on differences in price levels between day-ahead and intra-day market sessions but also on deviation costs and technical restrictions due to market rules.

4.4. The Value of the Stochastic Solution

In order to calculate the potential benefit achievable using a stochastic model instead of a deterministic one where random parameters are replaced by expected values, we calculate the VSS:

$$VSS = u^*(x^*, g, \pi) - u^*(\overline{x}, g, \pi)$$

Implementing the model with low price scenario we obtain a VSS of 133 € while using higher prices we reach a value of **2124 €**.

Hence, it is very useful to use a model including scenarios for both error in generation forecasting and intra-day prices.

5. Conclusions

Solving a two stage stochastic problem including scenarios for the error in generation forecasting and intra-day market prices, we found a **new commercial strategy** for a wind energy producer that allows to:

- ✓**Maximize average daily profits**
- ✓**Account for penalization costs** due to deviations in real production
- ✓**Not to incur in anti-competitive practices** introducing technical restrictions due to market rules.

Moreover, we **increase company efficiency** eliminating all costs related to consulting and bettering a practice currently used in the market.

That can be easily done using commercial packages that provides a solution in a reasonably **short time**.


THANK YOU FOR YOUR ATTENTION