“Participation of Renewables in Electricity Markets”

Pierre Pinson

Technical University of Denmark

DTU Electrical Engineering - Centre for Electric Power and Energy
mail: ppin@dtu.dk - webpage: www.pierrepinson.com

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Learning objectives

Through this lecture and additional study material, it is aimed for the students to be able to:

1. Explain **how to design a market participation strategy**

2. Calculate **revenues from market participation** (and compare them to optimal potential revenues)

3. Formulate and solve **a newsvendor problem**
Outline

1. Starting with a practical example
   - setup
   - trading renewable energy generation for a given day in 2016
   - various strategies and their performance

2. Decision-making under uncertainty
   - context: the newsvendor problem - revisited
   - formulating the problem, mathematically

3. Optimal offering for renewable energy producers
   - Specifics for renewables and electricity markets
   - formulating the problem, mathematically
   - solving and application
   - potential extensions

4. Leading to some important conclusions
Starting with a practical example
The setup

- Students of the course 31761 ("Renewables in Electricity Markets") got convinced to join forces and start an energy trading company: **Rogue Trading (RT®)**
The setup

- Students of the course 31761 ("Renewables in Electricity Markets") got convinced to join forces and start an energy trading company: Rogue Trading (RT®)

- And, the course responsible suggested you first invest in that new-generation wind farm...

  - **Nominal capacity**: 350 MW
  - Energy production sold through the **Nord Pool** (Western Denmark area)
  - **Balance responsibility**

- From early 2016, you are to trade your energy generation through the Nord Pool
How to proceed

- What should we do before to get into the market?

  1. Understand how the electricity market works! It should be fine... if not, please go back to lectures 0-4
  2. Get all necessary data/info to make informed decisions, for instance:
     - get a good grip of market prices (e.g., how they can be influenced by neighboring zones, or the local generation mix)
     - gain knowledge of price and volume dynamics through historical data analysis
     - find ways to know how much your wind farm is going to produce for every time unit
  3. Design your offering strategy, which can consist of:
     - a totally improvised approach to market participation (you named your company Rogue Trading after all...)
     - a set of expert rules to decide on what to do when,
     - a well-thought optimization model
How to proceed

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Sample trading day

27 March 2016 - 11am

- Your forecast provider gave you this wind power forecast for tomorrow: $\hat{y}_i$, $i = 1, \ldots, 24$

- From power generation estimates, one readily deduces 24 blocks of energy offered to the market

- However, how much will you actually offer?
We call it “Let’s trust the forecast!”: directly take the forecasts and make them our offers ($E_i, i = 1, \ldots, 24$) for the 28th of March.

\[ E_i = \hat{y}_i, \quad i = 1, \ldots, 24 \]

<table>
<thead>
<tr>
<th>hour 1</th>
<th>129 MWh</th>
<th>hour 7</th>
<th>138 MWh</th>
<th>hour 13</th>
<th>159 MWh</th>
<th>hour 19</th>
<th>122 MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>hour 2</td>
<td>110 MWh</td>
<td>hour 8</td>
<td>137 MWh</td>
<td>hour 14</td>
<td>127 MWh</td>
<td>hour 20</td>
<td>108 MWh</td>
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<tr>
<td>hour 3</td>
<td>96 MWh</td>
<td>hour 8</td>
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<td>hour 15</td>
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<td>hour 21</td>
<td>94 MWh</td>
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<tr>
<td>hour 4</td>
<td>117 MWh</td>
<td>hour 10</td>
<td>180 MWh</td>
<td>hour 16</td>
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<td>hour 22</td>
<td>81 MWh</td>
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<tr>
<td>hour 5</td>
<td>132 MWh</td>
<td>hour 11</td>
<td>198 MWh</td>
<td>hour 17</td>
<td>116 MWh</td>
<td>hour 23</td>
<td>67 MWh</td>
</tr>
<tr>
<td>hour 6</td>
<td>136 MWh</td>
<td>hour 12</td>
<td>187 MWh</td>
<td>hour 18</td>
<td>124 MWh</td>
<td>hour 24</td>
<td>68 MWh</td>
</tr>
</tbody>
</table>

Now, we wait for market-clearing, to receive our cash...
Settlement after market clearing

- **28 March 2016** - prices after market clearing

\[ R_{DA} = \sum_{i=1}^{24} \lambda_i^S * E_i \]

In the present case: \( R_{DA} = 88.334,49\text{€} \ldots \) not a bad day!
Actual production from the wind farm

- **28 March 2016** - Comparing forecasts ($\hat{y}_i$, $i = 1, \ldots, 24$) and power measurements ($y_i$, $i = 1, \ldots, 24$)

- Is there a chance our revenue reduces due to balancing costs?
Balancing needs and prices

- 28 March 2016 - Nord Pool & Energinet data:

- Need for downregulation on most of the hours of the day
Rules for settlement after balancing

- Remember the basic rules of the two-price balancing system:
  - If producing more than expected ($y_i > \hat{y}_i$), each extra energy unit is sold at down-regulation price.
  - If producing less than expected ($y_i < \hat{y}_i$), each missing energy unit is bought at up-regulation price.
  - When the system is in balance, one simply buys (if $y_i < \hat{y}_i$) or sell (if $y_i > \hat{y}_i$) at the spot price $\lambda^S$.
  - Only those putting the system off-balance are to be penalized!

- Resulting revenue from the balancing market:

$$ R_B = \sum_{j \in \mathcal{L}_{down}}^{\downarrow} \lambda_j (y_j - \hat{y}_j) - \sum_{i \in \mathcal{L}_{up}}^{\uparrow} \lambda_i (\hat{y}_i - y_i) $$

- From the graph in slide 14:

$$ \mathcal{L}_{up} = \{1, 2, \ldots, 6, 17, 18, \ldots, 24\} $$
$$ \mathcal{L}_{down} = \{7, 8, \ldots, 16\} $$
Balancing settlement

Based on:
- rules described in the previous slide
- differences between hourly contracts and actual delivery
- hourly balancing prices

we can calculate balancing revenues and costs for every market time unit.

<table>
<thead>
<tr>
<th>hour</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-837.93 €</td>
</tr>
<tr>
<td>2</td>
<td>-934.85 €</td>
</tr>
<tr>
<td>3</td>
<td>-787.80 €</td>
</tr>
<tr>
<td>4</td>
<td>-1171.28 €</td>
</tr>
<tr>
<td>5</td>
<td>-931.60 €</td>
</tr>
<tr>
<td>6</td>
<td>-423.00 €</td>
</tr>
<tr>
<td>7</td>
<td>684.11 €</td>
</tr>
<tr>
<td>8</td>
<td>1536.80 €</td>
</tr>
<tr>
<td>9</td>
<td>1262.94 €</td>
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<tr>
<td>10</td>
<td>318.80 €</td>
</tr>
<tr>
<td>11</td>
<td>132.50 €</td>
</tr>
<tr>
<td>12</td>
<td>100.04 €</td>
</tr>
<tr>
<td>13</td>
<td>558.90 €</td>
</tr>
<tr>
<td>14</td>
<td>1020.60 €</td>
</tr>
<tr>
<td>15</td>
<td>997.60 €</td>
</tr>
<tr>
<td>16</td>
<td>321.86 €</td>
</tr>
<tr>
<td>17</td>
<td>-272.80 €</td>
</tr>
<tr>
<td>18</td>
<td>-769.44 €</td>
</tr>
<tr>
<td>19</td>
<td>-789.32 €</td>
</tr>
<tr>
<td>20</td>
<td>-877.61 €</td>
</tr>
<tr>
<td>21</td>
<td>-613.58 €</td>
</tr>
<tr>
<td>22</td>
<td>-468.69 €</td>
</tr>
<tr>
<td>23</td>
<td>-188.58 €</td>
</tr>
<tr>
<td>24</td>
<td>-322.56 €</td>
</tr>
</tbody>
</table>

This gives an overall balancing cost \( R_B = -2.454,89€ \)

And therefore a revenue for that day of \( R_{DA} + R_B = 85.879,60€ \)

Are you satisfied with your revenue?
Understanding and analysing revenues

- The optimal revenue one could get from BOTH
  - day-ahead market, AND
  - balancing market

  is obtained if being able to offer your actual renewable energy generation to the day-ahead market...

\[ R_{DA}^* = R_{DA} + R_B = 86.627,50€, \quad \text{(with } R_B = 0) \]

- Let us then define a performance ratio for our trading strategies:
  \[ \gamma = \frac{(R_{DA} + R_B)}{R_{DA}^*}, \quad 0 < \gamma < 1 \quad \text{(then expressed in percentage)} \]

- The performance ratio for Strategy 1 (“Let’s trust the forecast!”) is \[ \gamma_1 = 99.1\% \]
  (quite good already since forecast error is low...)

- **Having perfect foresight will never happen** - Is there any other way to improve our revenue?
  - your proposal for a strategy no. 2 (hint: increase a bit your offer)
  - your proposal for a strategy no. 3 (hint: let’s be bold)
  - etc.
Strategy 2

- We call it “Let’s tweak a bit the forecast!”: makes a small adjustment to the forecasts, to reflect your gut feeling about potential balancing needs and costs.
- Offers \((E_i, i = 1, \ldots, 24)\) for the 28th of March then become

\[
E_i = \tau \hat{y}_i, \quad i = 1, \ldots, 24
\]

with \(\tau\) close to 1.
- For instance with \(\tau = 1.05\) (increase offers by 5%):

<table>
<thead>
<tr>
<th>hour 1</th>
<th>135 MWh</th>
<th>hour 7</th>
<th>145 MWh</th>
<th>hour 13</th>
<th>167 MWh</th>
<th>hour 19</th>
<th>128 MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>hour 2</td>
<td>117 MWh</td>
<td>hour 8</td>
<td>144 MWh</td>
<td>hour 14</td>
<td>133 MWh</td>
<td>hour 20</td>
<td>113 MWh</td>
</tr>
<tr>
<td>hour 3</td>
<td>101 MWh</td>
<td>hour 8</td>
<td>163 MWh</td>
<td>hour 15</td>
<td>118 MWh</td>
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<td>99 MWh</td>
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<tr>
<td>hour 5</td>
<td>139 MWh</td>
<td>hour 11</td>
<td>208 MWh</td>
<td>hour 17</td>
<td>122 MWh</td>
<td>hour 23</td>
<td>70 MWh</td>
</tr>
<tr>
<td>hour 6</td>
<td>143 MWh</td>
<td>hour 12</td>
<td>197 MWh</td>
<td>hour 18</td>
<td>130 MWh</td>
<td>hour 24</td>
<td>71 MWh</td>
</tr>
</tbody>
</table>

- The results from this trading strategy are:

\[
R_{DA} = 92.751, 21\€ \quad R_B = -6.680, 79\€ \quad R_{DA} + R_B = 86.070, 42\€
\]

\[
\gamma^2 = 99.3\%
\]
Strategy 3

- We call it “Let’s just be bold about it!”: fully trust your gut feeling and push it to the bound...

- Offers \((E_i, i = 1, \ldots, 24)\) for the 28th of March then become

\[
E_i = 350\text{MWh}, \quad i = 1, \ldots, 24
\]

- The results from this trading strategy are:

\[
\begin{align*}
R_{DA} &= 243.449, 50€ \\
R_B &= -156.822€ \\
R_{DA} + R_B &= 86.627, 50€ \\
\gamma_3 &= 100%
\end{align*}
\]

(Isn’t it a nice miracle?)

- This most certainly deserves a little discussion and explanation...

Key assumptions and issues

- In this practical example, we only illustrated the potential (monetary) consequences of our own decisions, all the rest being the same, i.e.,
  - prices (both day-ahead and balancing)
  - energy volumes
  - others’ offering strategies

- Is that realistic? ... this was discussed in a previous lecture (Lecture 7 - link)

- Definition:

  A market participant is a **price taker** if his decisions and resulting offers (buying or selling) do not affect the market

You can then imagine what a **price maker** is...

- Also, **you will never know the balancing prices in advance!!!**
Decision-making under uncertainty
The newsvendor problem

- The newsvendor problem is one of the most classical problem in stochastic optimization (or statistical decision theory)

- It can be traced back to:


even though in this paper the problem is about how much a bank should keep in its reserves to satisfy request for withdrawal (i.e., the bank-cash-flow problem)

- It applies to varied problems as long as:
  - one shot possibility to decide on the quantity of interest
  - outcome is uncertain
  - known marginal profit and loss
  - the aim is to maximize expected profit!
Everybody seems to want to go and see Eminem, right? (could also be Bruno Mars or Gorillaz, for those who don’t like Eminem)

Maybe some could have the idea of making a profit using this as an occasion...

[Note that this type of activity is not legal, as such purchased tickets cannot be re-sold at a price higher than the official retail price] - Do not get any idea here!

1-day tickets for the day Eminem is playing

They are to be sold out fast, while you know that quite a lot of DTU students will not be able to buy the tickets on time...

On 5 March 2018, you have an opportunity to make a good deal:

- buy a batch tickets (up to 30) at an advantageous price!
- sell them out to your fellow DTU students
“Roskilde ticket pusher” problem©: detailed setup

- Sets of prices:
  - 1-day tickets for Eminem: **1050 dkk**
  - retail price to DTU students: **1100 dkk**
  - unsold tickets can be given to your RUC pusher friend at **930 dkk**

- Why is it a newsvendor problem?
  - this is a one-shot opportunity - batch buy on **5 March 2018** (here and now!)
  - actual DTU demand is uncertain
  - the marginal profit and loss are known - a profit of 50 dkk per ticket sold, and a loss of 120 dkk per ticket unsold
  - the aim definitely is to maximize expected profit!!

- If you were that “Roskilde ticket pusher”, how many ticket would you buy?

  **Socrative please...**  https://b.socrative.com/login/student/ - Room number 675366
You need to know your probabilities

Based on an expert assessment, here is the cumulative distribution function $F$ for the number of tickets ($X$) we may be able to sell to our DTU fellow students.

It shows $P[X \leq n]$ as a function of $n$.

Examples:

- $P[X \leq 8] = 0$: we are 100% sure to sell at least 8 tickets.
- $P[X \leq 10] = 0.1$: we are 90% sure to sell more than 10 tickets.
- $P[X \leq 20] = 0.6$: we are 40% sure to sell more than 20 tickets.
- $P[X \leq 28] = 1$: there is no way we sell more than 28 tickets.
In terms of marginal profit and loss

<table>
<thead>
<tr>
<th>$n$</th>
<th>$P[X = n]$</th>
<th>$P_{sell}$</th>
<th>$P_{no-sell}$</th>
<th>$E[\text{profit}]$</th>
<th>$E[\text{loss}]$</th>
<th>$E[\text{net}]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\leq 8$</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>9</td>
<td>0.05</td>
<td>1</td>
<td>0</td>
<td>50</td>
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<td>50</td>
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<td>0.95</td>
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<td>41.5</td>
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where

- $P[X = n]$: probability that demand is **EXACTLY** $n$ tickets
- $P_{sell}$: probability of selling the $n^{th}$ ticket
- $P_{no-sell}$: probability of **NOT** selling the $n^{th}$ ticket
- $E[\text{profit}]$: expected profit from selling the $n^{th}$ ticket
- $E[\text{loss}]$: expected loss from **NOT** selling the $n^{th}$ ticket
- $E[\text{net}]$: expected net profit related to the $n^{th}$ ticket
So, *how many tickets should our “Roskilde ticket pusher” buy?*
Mathematical formulation

If we have

- $\lambda^P$: purchase cost for a ticket (1050 dkk)
- $\lambda^R$: re-sell price of a ticket (1100 dkk)
- $\lambda^T$: transfer price for unsold tickets (930 dkk)

It then defines

- $\pi^+$: unit cost of buying less than needed
  $$\pi^+ = \lambda^R - \lambda^P$$ (50 dkk)
- $\pi^-$: unit cost of buying more than needed
  $$\pi^- = \lambda^P - \lambda^T$$ (120 dkk)

Then the optimal number $n^*$ of tickets to purchase is such that:

$$\Pr[X \leq n^*] = \frac{\pi^+}{\pi^+ + \pi^-}$$ (here, 0.294)

This defines the nominal level $\alpha^*$ of our original cumulative distribution function $F$.

31761 - Renewables in Electricity Markets
The optimal decision of the “Roskilde ticket pusher” is to pick the quantile with nominal level $\alpha^*$ of his original cumulative distribution function $F$.

Graphically:

$$n^* = F^{-1}(\alpha^*) = 14$$
Optimal offering for renewable energy producers
It is a newsvendor problem!

Let us focus on a market time unit $i$ (say, the hour between 13:00 and 14:00)

- Sets of prices:
  - day-ahead price: $\lambda_i^S$
  - downregulation price: $\lambda_i^{\downarrow}$
  - upregulation price: $\lambda_i^{\uparrow}$

- Why is it a newsvendor problem?
  - one decision to be made before gate closure (i.e., offer for various market time units)
  - actual renewable energy generation is uncertain
  - WE ASSUME THAT the marginal profit and loss are known...

\[
\begin{align*}
\pi_i^{\uparrow} &= \lambda_i^S - \lambda_i^{\downarrow} \quad \text{(for any generated MWh above day-ahead schedule)} \\
\pi_i^{\downarrow} &= \lambda_i^{\uparrow} - \lambda_i^S \quad \text{(for any lacking MWh w.r.t. day-ahead schedule)}
\end{align*}
\]

- the aim definitely is to maximize expected profit!!
Obtaining the optimal offer

- As for the “Roskilde ticket pusher” example, the optimal generation offer of the renewable energy producer for the market time unit \( i \) is

\[
E_i^* = F_i^{-1}(\alpha^*)
\]

with

\[
\alpha^* = \frac{\pi^+}{\pi^+ + \pi^-}
\]

- The problem is... that we do not know \( F, \pi^+ \) and \( \pi^- \)

- We definitely need some forecasts (!), so that

\[
E_i^* = \hat{F}_i^{-1}(\hat{\alpha}^*)
\]

with

- \( \hat{F}_i \): a predicted distribution for renewable energy generation at time unit \( i \)
- \( \hat{\alpha}_i^* \): a “predicted” optimal quantile based on forecasts for the marginal profit and loss \( \hat{\pi}^+ \) and \( \hat{\pi}^- \)
We can get probabilistic renewable energy forecasts!

- *To be discussed more specifically in a future lecture...*

In short, one can get a description $\hat{F}$ of the cumulative distribution function of renewable energy generation for every market time unit.
And expert assessments/forecasts on market penalties

- The same forecast provider or your own market expert could give you a best guess on evolution of penalties for up- ($\pi^-$) and down-regulation ($\pi^+$).

- This can be represented as a general loss function, here with:

\[
\begin{align*}
\pi^+_i &= \lambda_i^S - \lambda_i^\downarrow \\
\pi^-_i &= 7, \quad i = 1, \ldots, 24 \\
\pi^+_i &= \lambda_i^\uparrow - \lambda_i^S \\
\pi^-_i &= 2, \quad i = 1, \ldots, 24
\end{align*}
\]

- The optimal quantile to trade is that for which: $\alpha_i = \frac{7}{7 + 2} = 0.78, \quad i = 1, \ldots, 24$
Results for the newsvendor strategy

- The optimal quantile to trade can be extracted for each market time unit, individually.
- Similar to other strategies, it tends to offer more energy than what you expect to produce.

The results from this trading strategy are:

\[
R_{DA} = 122.771,40€ \quad R_B = -36.030,97€ \quad R_{DA} + R_B = 86.627,50€
\]

\[
\gamma_{\text{newsvendor}} = 100\%
\]
Be ready for a bumpy ride...!

- The outcome of a “newvendor-type” offering strategy can highly fluctuate from one market time unit to the next, and from one day to the next.
- Since being the optimal strategy \textit{in expectation}, it is only best in the long run, under \textbf{A LOT of assumptions}...

- In practice, it was observed that this could lead to a bumpy ride.
- Simple ways to control the “agressivity” of trading strategies (or account for risk-aversion) can be beneficial.
Final remarks

- Participation in electricity markets with a portfolio of renewables requires
  - liquidity
  - being keen on going for a bumpy ride!
  - **ANALYTICS** (modelling, forecasting, and optimization...)

- This is why the coming lectures will focus on *renewable energy analytics*
Further readings

For those who want to go into the more mathematical aspects:


A more general book chapter on the newsvendor problem:

Large-scale integration of renewable energy

Books

In an effort to disseminate our work to students, researchers and practitioners, some collaborators and I have been focusing on producing books that would gather knowledge in renewable energy, forecasting, and electricity markets. For a description of those books, press the links “Electricity markets” and “Forecasting” under the header “Books”.

Wind power forecasting

It is not possible to decide on the level of wind energy to be produced in the coming minutes or days – one relies on nature and the weather. Ways have to be found to optimally assimilate this energy generation in the system. Wind power modeling and forecasting is recognized as a cost-effective and necessary solution to that problem. In my research, I have been looking at a few aspects of wind power forecasting, which I rapidly describe here...

A little toy...

If you wonder how future renewable energy forecasting may look, let me invite you to look at this toy forecasting system, which we will make evolve as new features are to become available.