Module 2 – Electricity Spot Markets (e.g. day-ahead)

2.3 From prices to settlement

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Settlement process

- After energy schedules and the system price are determined, comes the settlement process...

- Using everyday terms:
  - who should pay what?
  - who should get paid, and what amount?

(Obviously, only those with energy production or consumption scheduled are concerned)

- Any opinion?
Settlement process

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- Using everyday terms:
  - who should pay what?
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(Obviously, only those with energy production or consumption scheduled are concerned)

- Any opinion?

- The two main approaches to settlement rely on
  - pay-as-bid pricing
  - uniform pricing
# Our example auction setup

Supply: (for a total of 1435 MWh)

<table>
<thead>
<tr>
<th>Company</th>
<th>Supply/Demand</th>
<th>id</th>
<th>$P_j^G$ (MWh)</th>
<th>$\lambda_j^G$ (€/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT®</td>
<td>Supply</td>
<td>$G_1$</td>
<td>120</td>
<td>0</td>
</tr>
<tr>
<td>WeTrustInWind</td>
<td>Supply</td>
<td>$G_2$</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>BlueHydro</td>
<td>Supply</td>
<td>$G_3$</td>
<td>200</td>
<td>15</td>
</tr>
<tr>
<td>RT®</td>
<td>Supply</td>
<td>$G_4$</td>
<td>400</td>
<td>30</td>
</tr>
<tr>
<td>KøbenhavnCHP</td>
<td>Supply</td>
<td>$G_5$</td>
<td>60</td>
<td>32.5</td>
</tr>
<tr>
<td>KøbenhavnCHP</td>
<td>Supply</td>
<td>$G_6$</td>
<td>50</td>
<td>34</td>
</tr>
<tr>
<td>KøbenhavnCHP</td>
<td>Supply</td>
<td>$G_7$</td>
<td>60</td>
<td>36</td>
</tr>
<tr>
<td>DirtyPower</td>
<td>Supply</td>
<td>$G_8$</td>
<td>100</td>
<td>37.5</td>
</tr>
<tr>
<td>DirtyPower</td>
<td>Supply</td>
<td>$G_9$</td>
<td>70</td>
<td>39</td>
</tr>
<tr>
<td>DirtyPower</td>
<td>Supply</td>
<td>$G_{10}$</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>RT®</td>
<td>Supply</td>
<td>$G_{11}$</td>
<td>70</td>
<td>60</td>
</tr>
<tr>
<td>RT®</td>
<td>Supply</td>
<td>$G_{12}$</td>
<td>45</td>
<td>70</td>
</tr>
<tr>
<td>SafePeak</td>
<td>Supply</td>
<td>$G_{13}$</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>SafePeak</td>
<td>Supply</td>
<td>$G_{14}$</td>
<td>60</td>
<td>150</td>
</tr>
<tr>
<td>SafePeak</td>
<td>Supply</td>
<td>$G_{15}$</td>
<td>50</td>
<td>200</td>
</tr>
</tbody>
</table>
Our example auction setup

*Demand:* (for a total of 1065 MWh)

<table>
<thead>
<tr>
<th>Company</th>
<th>Supply/Demand</th>
<th>id</th>
<th>$P_i^D$ (MWh)</th>
<th>$\lambda_i^D$ (€/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CleanRetail</td>
<td>Demand</td>
<td>$D_1$</td>
<td>250</td>
<td>200</td>
</tr>
<tr>
<td>El4You</td>
<td>Demand</td>
<td>$D_2$</td>
<td>300</td>
<td>110</td>
</tr>
<tr>
<td>EVcharge</td>
<td>Demand</td>
<td>$D_3$</td>
<td>120</td>
<td>100</td>
</tr>
<tr>
<td>QualiWatt</td>
<td>Demand</td>
<td>$D_4$</td>
<td>80</td>
<td>90</td>
</tr>
<tr>
<td>IntelliWatt</td>
<td>Demand</td>
<td>$D_5$</td>
<td>40</td>
<td>85</td>
</tr>
<tr>
<td>El4You</td>
<td>Demand</td>
<td>$D_6$</td>
<td>70</td>
<td>75</td>
</tr>
<tr>
<td>CleanRetail</td>
<td>Demand</td>
<td>$D_7$</td>
<td>60</td>
<td>65</td>
</tr>
<tr>
<td>IntelliWatt</td>
<td>Demand</td>
<td>$D_8$</td>
<td>45</td>
<td>40</td>
</tr>
<tr>
<td>QualiWatt</td>
<td>Demand</td>
<td>$D_9$</td>
<td>30</td>
<td>38</td>
</tr>
<tr>
<td>IntelliWatt</td>
<td>Demand</td>
<td>$D_{10}$</td>
<td>35</td>
<td>31</td>
</tr>
<tr>
<td>CleanRetail</td>
<td>Demand</td>
<td>$D_{11}$</td>
<td>25</td>
<td>24</td>
</tr>
<tr>
<td>El4You</td>
<td>Demand</td>
<td>$D_{12}$</td>
<td>10</td>
<td>16</td>
</tr>
</tbody>
</table>
Market clearing results

After market clearing, the supply and demand schedules are:

<table>
<thead>
<tr>
<th>Supply id.</th>
<th>Schedule (MWh)</th>
<th>Demand id.</th>
<th>Schedule (MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G_1$</td>
<td>120</td>
<td>$D_1$</td>
<td>250</td>
</tr>
<tr>
<td>$G_2$</td>
<td>50</td>
<td>$D_2$</td>
<td>300</td>
</tr>
<tr>
<td>$G_3$</td>
<td>200</td>
<td>$D_3$</td>
<td>120</td>
</tr>
<tr>
<td>$G_4$</td>
<td>400</td>
<td>$D_4$</td>
<td>80</td>
</tr>
<tr>
<td>$G_5$</td>
<td>60</td>
<td>$D_5$</td>
<td>40</td>
</tr>
<tr>
<td>$G_6$</td>
<td>50</td>
<td>$D_6$</td>
<td>70</td>
</tr>
<tr>
<td>$G_7$</td>
<td>60</td>
<td>$D_7$</td>
<td>60</td>
</tr>
<tr>
<td>$G_8$</td>
<td>55</td>
<td>$D_8$</td>
<td>45</td>
</tr>
<tr>
<td>$G_9$-$G_{15}$</td>
<td>0</td>
<td>$D_9$</td>
<td>30</td>
</tr>
</tbody>
</table>

$D_{10}$-$D_{12}$ | 0

The system price is of 37.5 €/MWh, corresponding to the price offer of $G_8$. 


Settlement with pay-as-bid pricing

- How does that work? For those scheduled,

  - **Consumption side:** $R_{i}^{DA,D} = -\lambda_{i}^{D} y_{i}^{D}$, $R_{i}^{DA,D} \leq 0$, (since being a payment)
  - **Supply side:** $R_{j}^{DA,G} = \lambda_{j}^{G} y_{j}^{G}$, $R_{j}^{DA,G} \geq 0$ (since being a revenue)

### Payment and revenues for our example market clearing

- **Consumption side (payments):**
  - $D_1$ pays $250 \times 200 = 50000$ €, $(R_{1}^{DA,D} = -50000)$
  - $D_2$ pays $300 \times 110 = 33000$ €, $(R_{2}^{DA,D} = -33000)$, etc.
  - $D_9$ pays $30 \times 38 = 1140$ €, $(R_{9}^{DA,D} = -1140)$

- **Supply side (revenues):**
  - $G_1$ receives $120 \times 0 = 0$ €, $(R_{1}^{DA,G} = 0)$
  - $G_2$ receives $50 \times 0 = 0$ €, $(R_{2}^{DA,G} = 0)$, etc.
  - $G_8$ receives $55 \times 37.5 = 2062.5$ €, $(R_{8}^{DA,G} = 2062.5)$
Settlement with pay-as-bid pricing

- How does that work? For those scheduled,
  - Consumption side: \( R_{i}^{DA,D} = -\lambda_{i}^{D} y_{i}^{D} \), \( R_{i}^{DA,D} \leq 0 \), (since being a payment)
  - Supply side: \( R_{j}^{DA,G} = \lambda_{j}^{G} y_{j}^{G} \), \( R_{j}^{DA,G} \geq 0 \) (since being a revenue)

Payment and revenues for our example market clearing

- Consumption side (payments):
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- Supply side (revenues):
  - \( G_{1} \) receives \( 120 \times 0 = 0 \) €, \( R_{1}^{DA,G} = 0 \)
  - \( G_{2} \) receives \( 50 \times 0 = 0 \) €, \( R_{2}^{DA,G} = 0 \), etc.
  - \( G_{8} \) receives \( 55 \times 37.5 = 2062.5 \) €, \( R_{8}^{DA,G} = 2062.5 \)

- Do you foresee the potential consequences of pay-as-bid pricing, e.g., in terms of fixed cost recovery for energy producers and strategic behaviour of market participants?
Settlement with uniform pricing

- How does that work? For those scheduled,
  - Consumption side: $R_{i,D}^{DA} = -\lambda^{S} y_{i}^{D}$, $R_{i,D}^{DA} \leq 0$ (since being a payment)
  - Supply side: $R_{j,G}^{DA} = \lambda^{S} y_{j}^{G}$, $R_{j,G}^{DA} \geq 0$ (since being a revenue)

Payment and revenues for our example market clearing

- Consumption side (payments):
  - $D_{1}$ pays $250 \times 37.5 = 9375 \text{ €}$, $(R_{9,D}^{DA} = -9375)$
  - $D_{2}$ pays $300 \times 37.5 = 11250 \text{ €}$, $(R_{9,D}^{DA} = -11250)$, etc.
  - $D_{9}$ pays $30 \times 37.5 = 1125 \text{ €}$, $(R_{9,D}^{DA} = -1125)$

- Supply side (revenues):
  - $G_{1}$ receives $120 \times 37.5 = 4500 \text{ €}$, $(R_{8,G}^{DA} = 4500)$
  - $G_{2}$ receives $50 \times 37.5 = 1875 \text{ €}$, $(R_{2,G}^{DA} = 1875)$, etc.
  - $G_{8}$ receives $55 \times 37.5 = 2062.5 \text{ €}$, $(R_{8,G}^{DA} = 2062.5)$
Settlement with uniform pricing

- How does that work? For those scheduled,
  - Consumption side: $R_{i}^{DA,D} = -\lambda^S y_i^D$, $R_{i}^{DA,D} \leq 0$, (since being a payment)
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Payment and revenues for our example market clearing

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- It is expected to attenuate some of the potential negative consequences observed with pay-as-bid pricing
Properties induced by these two settlement approaches

- Day-ahead markets with the two settlement approaches guarantee **individual rationality**
  
  In both cases, consumers will pay at most what they were ready to pay, and producers will receive at least what they wanted to be paid for, i.e.,

\[
R_{i}^{DA,D} \leq \lambda_{i}^{D} y_{i}^{D}, \quad \forall i, \quad R_{j}^{DA,G} \geq \lambda_{j}^{G} y_{j}^{G}, \quad \forall j
\]
Properties induced by these two settlement approaches

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  \[ R_{i}^{DA,D} \leq \lambda_{i}^{D} y_{i}^{D}, \quad \forall i, \quad R_{j}^{DA,G} \geq \lambda_{j}^{G} y_{j}^{G}, \quad \forall j \]

- Day-ahead markets with the two settlement approaches guarantee **revenue adequacy**

  In both cases, the sum of revenues is greater than or equal to the sum of payments, i.e.,

  \[ \sum_{j} R_{j}^{DA,G} \geq \sum_{i} R_{i}^{DA,D} \]
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  \[ R_{i}^{DA,D} \leq \lambda_{i}^{D} y_{i}^{D}, \quad \forall i, \quad R_{j}^{DA,G} \geq \lambda_{j}^{G} y_{j}^{G}, \quad \forall j \]

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  In both cases, the sum of revenues is greater than or equal to the sum of payments, i.e.,

  \[ \sum_{j} R_{j}^{DA,G} \geq \sum_{i} R_{i}^{DA,D} \]

- Uniform pricing yields **budget balance**. Pay-as-bid pricing does not
  
  Only for uniform pricing, the sum of revenues is by definition equal to the sum of payments
Use the self-assessment quizz to check your understanding!