

# Energy Markets

*Acknowledgements:* This exercise session is inspired from the exercise sessions given in the class *Renewables in Electricity Markets* given by Pr. Pierre Pinson from DTU. We thank him for sharing its content with us.

## Exercise Session 3: Intra-day and balancing markets

The aim of this exercise session is to appraise and better understand the basic structure of electricity markets, and most particularly its intra-day and balancing mechanisms.

### Problem 1: Setting up our own balancing market

This Problem builds on Exercise sessions 1 and 2 which focused on day-ahead markets. Especially, we assume that the day-ahead market was cleared following Problem 4 (of Exercise session 1), i.e., based on the list of supply and demand offers described in Problems 2 and 3 (of Exercise session 1), respectively.

Before actual operation, a list of market players who can provide balancing services for that time unit is gathered. To simplify things, all of these players already participated in the day-ahead electricity market. Only generators (not demand) are ready to provide balancing. These include:

Supplier Name	Supplier id.	Up. Quant. [MWh]	Up. Price [€]	Down. Quant. [MWh]	Down. Price [€]
Flexigas	$G_1$	15	80	-	-
RoskildeCHP	$G_4$	5	50	15	15
BlueWater	$G_5$	20	35	20	5

1.1 What is the generation schedule for these generators after the market clearing of Problem 4 (in Exercise Session 1)? Please re-calculate their revenues after day-ahead market clearing.

The market equilibrium is at a quantity of 202 MWh and a price of 32€/MWh. The revenues and payments of market participants are illustrated at Table 1 and Table 2.

Supplier Name	Supplier id.	Quantity produced [MWh]	Market price [€/MWh]	Revenue [€]
Nuke22	$G_2$	100	32	3200
ShinyPower	$G_3$	32	32	1024
BlueWater	$G_5$	70	32	2240

Table 1: Producer's production and revenues

Demand Name	Demand id.	Quantity purchased [MWh]	Market price [€/MWh]	Payment [€]
WeLovePower	$D_1$	35	32	1120
CleanChange	$D_2$	23	32	736
ElRetail	$D_4$	38	32	1216
QualiWatt	$D_5$	43	32	1376
IntelliWatt	$D_6$	6	32	192
El-Forbundet	$D_7$	57	32	1824

Table 2: Consumer's consumption and payments

1.2 Draw the supply curve corresponding to these balancing offers.

### Supply vs Demand curve

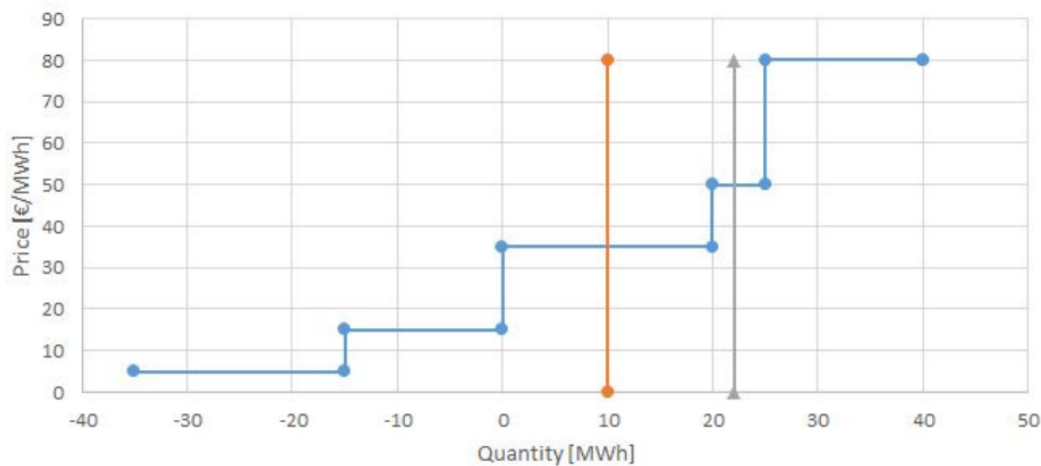


Figure 1: Supply curve of balancing offers

- 1.3 Nuke22 has a problem with its cooling system, yielding a shortage of 22MWh in comparison with the amount contracted through the day-ahead market. What is the resulting demand for our balancing market? Add this demand curve to your previous drawing.

The cooling problem of Nuke22 results to a final production of 78 MWh. The demand in the balancing market is  $\Delta P = 22$  MWh (Demand > Production).

- 1.4 What is the resulting balancing price, and who will provide the balancing service? How many MWh and in which direction?

The resulting balancing price is  $\lambda^B = 50\text{€/MWh}$ , because if the supply will be increased by 1 unit (1 more MWh to be produced), unit  $G_4$  with an offer price of  $50\text{€/MWh}$  will produce. The balancing service will be provided by  $G_5$  (20 MWh) and  $G_4$  (2 MWh).

- 1.5 Calculate the revenues and payments for all participants in this balancing market. Deduce the combined revenues, considering both day-ahead and balancing markets.

In the balancing market, the settlement leads to:

- $G_2$  paying  $22 \text{ MWh} \cdot 50\text{€/MWh} = 1100\text{€}$ .
- $G_5$  receiving  $20 \text{ MWh} \cdot 50\text{€/MWh} = 1000\text{€}$ .
- $G_4$  receiving  $2 \text{ MWh} \cdot 50\text{€/MWh} = 100\text{€}$ .

Considering both day-ahead and balancing stages

- $G_2$  receives  $100 \text{ MWh} \cdot 32\text{€/MWh} = 3200\text{€}$  at the day-ahead market and has to pay  $1100\text{€}$  at the balancing market. So, in total  $G_2$  receives  $2100\text{€}$ .
- $G_5$  receives  $70 \text{ MWh} \cdot 32\text{€/MWh} = 2240\text{€}$  at the day-ahead market and an additional amount of  $1000\text{€}$  at the balancing market. So, in total  $G_5$  receives  $3240\text{€}$ .
- $G_4$  receives  $100\text{€}$  at the balancing market.

- 1.6 Go again through points 1.3-1.5 now considering that it is CleanCharge that needs 10 MWh more than in the original day-ahead contract.

CleanCharge needs 10 MWh more than the original day-ahead contract. The demand in the balancing market is  $\Delta P = 10$  MW (Demand  $\neq$  Production).

The resulting balancing price is  $\lambda^B = 35\text{€/MWh}$ , because if the supply will be increased by 1 unit (1 more MWh to be produced), unit  $G_5$  with an offer price of  $35\text{€/MWh}$  will produce.

The balancing service will be provided by  $G_5$ . In the balancing market,  $D_2$  and  $G_5$  participate.

In the balancing market, the settlement leads to:

- $D_2$  paying  $10 \text{ MWh} \cdot 35\text{€/MWh} = 350\text{€}$ .  $G_5$  receiving  $10 \text{ MWh} \cdot 35\text{€/MWh} = 350\text{€}$ .

Considering both day-ahead and balancing stages

- $D_2$  pays  $23 \text{ MWh} \cdot 32\text{€/MWh} = 736\text{€}$  at the day-ahead market and an additional amount of  $350\text{€}$  at the balancing market. So, in total  $D_2$  pays  $1086\text{€}$ .
- $G_5$  receives  $70 \text{ MWh} \cdot 32\text{€/MWh} = 2240\text{€}$  at the day-ahead market and an additional amount of  $350\text{€}$  at the balancing market. So, in total  $G_5$  receives  $2590\text{€}$ .

## Problem 2: One-price vs. two-price imbalance settlements

This Problem is a follow-up of Problem 1 (hence similarly building on Exercise Session 1). We therefore still assume that the day-ahead market was cleared following Problem 4, i.e., based on the list of supply and demand offers described in Problems 2 and 3, respectively. The list of players who can provide balancing services for that time unit was given in Problem 1.

Quite a few market participants are not able to meet their contracts, and will then induce imbalances. The full list includes:

Participant Name	Participant id.	Deviation [MWh]
ShinyPower	$G_3$	+5
WeLovePower	$D_1$	+8
Nuke22	$G_2$	+10

In the above table, a deviation of +10 MWh means that the market participant (i) generates 10 MWh more than his contract if being a supplier, or (ii) consumes 10 MWh more than his contract if on the demand side. We now aim at performing the imbalance settlement following both one-price and two-price systems.

- 2.1 Assess the overall system imbalance resulting from this individual imbalances. Will the system need upward or downward regulation?

In total, there is +15 MWh of production and +8 MWh of demand, which results to +7 MWh of production (excess production). The system will need down regulation.

- 2.2 Which are the units whose imbalance are putting the system off-balance, and which are (involuntarily) helping the system getting back to balance?

$G_2$  and  $G_3$  are putting the system off-balance as their production is increased and  $D_1$  involuntarily helps the system due to the increase in demand.

- 2.3 Clear the balancing market as in Problem 2. Determine the balancing price and the schedule of the generator(s) involved in balancing.

A unit can provide down regulation at the balancing stage only if it has been already scheduled to produce power at the day-ahead stage. For this reason, down regulation is provided by  $G_5$  and the balancing price is  $\lambda^B = 5\text{€/MWh}$ .

- 2.4 What is the difference between the one-price and two-price imbalance settlements?

The rationale behind one-price balancing markets implies that deviations from the day-ahead schedule are settled at a price that is more favorable than the day-ahead price if the sign of the participant's imbalance is opposite to the sign of the overall system deviation.

Other balancing markets are designed according to the two-price (or dual-price) imbalance settlement principle. In this type of market design, only wanted deviations (i.e., from dispatchable producers) opposite in sign from the system imbalance are rewarded financially with a balancing market price that is more favorable than the day-ahead price.

- 2.5 Calculate revenues and payments for the 3 market participants in imbalance, and for the generator(s) providing balancing under a one-price settlement.

In the balancing market,  $G_3$ ,  $G_2$ ,  $G_5$  and  $D_1$  participate.

- $G_3$  receives  $5 \text{ MWh} \cdot 5\text{€/MWh} = 25\text{€}$ .
- $G_2$  receives  $10 \text{ MWh} \cdot 5\text{€/MWh} = 50\text{€}$ .
- $G_5$  pays  $7 \text{ MWh} \cdot 5\text{€/MWh} = 35\text{€}$ .
- $D_1$  pays  $8 \text{ MWh} \cdot 5\text{€/MWh} = 40\text{€}$ .

Considering both day-ahead and balancing stages

- $G_3$  receives  $32 \text{ MWh} \cdot 32\text{€/MWh} = 1024\text{€}$  at the day-ahead market and an additional amount of  $25\text{€}$  at the balancing market. So, in total  $G_3$  receives  $1049\text{€}$ .
- $G_2$  receives  $100 \text{ MWh} \cdot 32\text{€/MWh} = 3200\text{€}$  at the day-ahead market and an additional amount of  $50\text{€}$  at the balancing market. So, in total  $G_2$  receives  $3250\text{€}$ .
- $G_5$  receives  $70 \text{ MWh} \cdot 32\text{€/MWh} = 2240\text{€}$  at the day-ahead market and has to pay  $35\text{€}$  at the balancing market. So, in total  $G_5$  receives  $2205\text{€}$ .
- $D_1$  pays  $35 \text{ MWh} \cdot 32\text{€/MWh} = 1120\text{€}$  at the day-ahead market and an additional amount of  $40\text{€}$  at the balancing market. So, in total  $D_1$  pays  $1160\text{€}$ .

$G_3$  and  $G_2$  are penalized in the balancing stage as they sell their production surplus at a lower price than it could have received at the day-ahead market.  $G_5$  has to pay the market operator for repurchasing energy at the balancing market. Since this power was initially sold at the day-ahead market at the price  $\lambda^S = 32\text{€/MWh}$ .  $G_5$  realizes a net profit on the energy that is asked not to produce, as the repurchasing price  $\lambda^B = 5\text{€/MWh}$  is lower than the initial selling price. In this case,  $D_1$  is rewarded as the additional consumption is paid a lower rate. This is done because it helps the system to be balanced, even though it is done involuntarily.

- 2.6 Calculate revenues and payments for the 3 market participants in imbalance, and for the generator(s) providing balancing under a two-price settlement. Compare with the outcome of 2.5. In the balancing market,  $G_3$ ,  $G_2$ ,  $G_5$  and  $D_1$  participate.

- $G_3$  receives  $5 \text{ MWh} \cdot 5\text{€/MWh} = 25\text{€}$ .
- $G_2$  receives  $10 \text{ MWh} \cdot 5\text{€/MWh} = 50\text{€}$ .
- $G_5$  pays  $7 \text{ MWh} \cdot 5\text{€/MWh} = 35\text{€}$ .
- $D_1$  pays  $8 \text{ MWh} \cdot 32\text{€/MWh} = 256\text{€}$ .

Considering both day-ahead and balancing stages

- $G_3$  receives  $32 \text{ MWh} \cdot 32\text{€/MWh} = 1024\text{€}$  at the day-ahead market and an additional amount of  $25\text{€}$  at the balancing market. So, in total  $G_3$  receives  $1049\text{€}$ .
- $G_2$  receives  $100 \text{ MWh} \cdot 32\text{€/MWh} = 3200\text{€}$  at the day-ahead market and an additional amount of  $50\text{€}$  at the balancing market. So, in total  $G_2$  receives  $3250\text{€}$ .
- $G_5$  receives  $70 \text{ MWh} \cdot 32\text{€/MWh} = 2240\text{€}$  at the day-ahead market and has to pay  $35\text{€}$  at the balancing market. So, in total  $G_5$  receives  $2205\text{€}$ .
- $D_1$  pays  $35 \text{ MWh} \cdot 32\text{€/MWh} = 1120\text{€}$  at the day-ahead market and an additional amount of  $256\text{€}$  at the balancing market. So, in total  $D_1$  pays  $1376\text{€}$ .

The only difference with the outcome of 3.5 regards the balancing market results for the participants that are involuntarily decreasing the overall system imbalance. In this case,  $D - 1$  is not rewarded and buys energy from the balancing market with the spot price  $\lambda^S = 32\text{€/MWh}$ .

- 2.7 Let us imagine that these 3 market participants in imbalance could have known about their real consumption/supply before the day-ahead market settlement. Adapt the list of offers of Exercise Session 1 and clear the day-ahead market. Deduce the revenues and payments of these 3 market participants. Would they have been better off in that case?

After adapting the list offers in the day-ahead market-clearing, the new supply and demand curves are illustrated in Figure 2. The equilibrium is at a quantity of  $217 \text{ MWh}$  and a price of  $32\text{€/MWh}$ .

Producers  $G_3$ ,  $G_5$  and  $G_2$  will be supplying power at their maximum offers, 37, 70 and 110 MWh, respectively. Consumers  $D_2$ ,  $D_1$ ,  $D_5$ ,  $D_7$ ,  $D_4$  and  $D_6$  will be consuming 23, 43, 43, 57, 38, and 13 MWh, respectively.

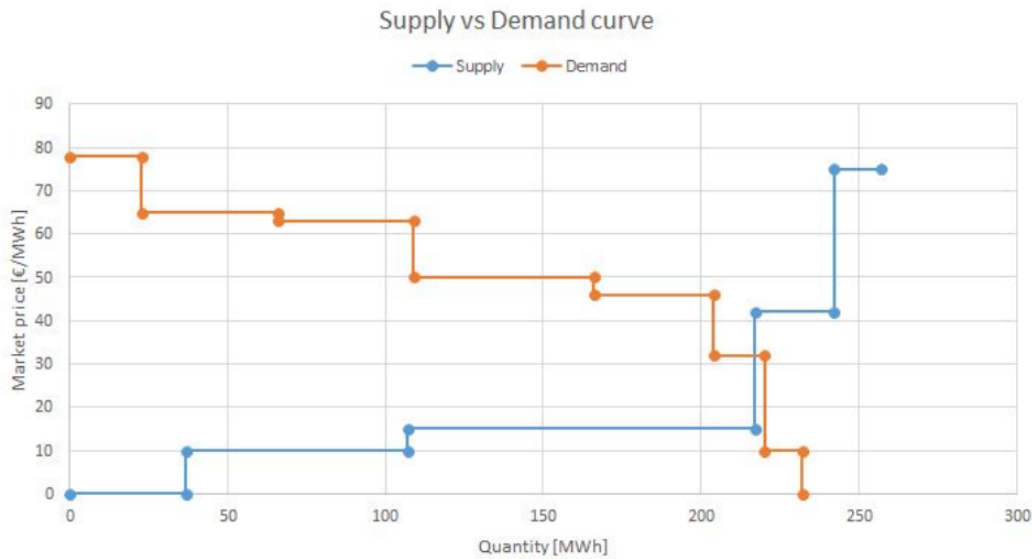


Figure 2: Demand vs Supply Curve

The revenues and payments would be:

- $G_3$  receives 37 MWh · 32€/MWh = 1184€.
- $G_2$  receives 110 MWh · 32€/MWh = 3520€.
- $G_5$  receives 70 MWh · 32€/MWh = 2240€.
- $D_1$  pays 43 MWh · 32€/MWh = 1376€.

It can be noticed that the generators are in all cases better off. As far as the consumption  $D_1$  is concerned, the payment between cases 3.6 and 3.7 is the same. Comparing with 3.5, consumption  $D_1$  pays more in cases 3.6 and 3.7.

### Problem 3: Analysis of the balancing situation for a given day based on data

For this Problem, we aim at understanding the balancing situation for a given day based on the data publicly available on the NordPool website. The webpages of interest are that for [day-ahead prices](#) and that for [regulation prices](#). Let us focus on the market area DK1, for the case of 21 January 2018.

- 3.1 Extract day-ahead and regulation prices (“Price up” and “Price down”) to have them on a piece of paper, or a file to import in Matlab/R/Excel/etc. What do these prices mean?
- 3.2 Are these prices always equal or not?
- 3.3 Find example hours for each of the 3 potential balancing situations (up, down and no-regulation).
- 3.4 Do you expect the price for upregulation to be higher/lower than the day-ahead price? Explain why?
- 3.5 Same questions for the downregulation price.
- 3.6 Have a look at some other days in January to see how often the various balancing situations occur, and how different prices can be.

Corrections are omitted for that part. Results for that exercise may be subject to feedback on an individual or group basis instead.