31761 - Renewables in Electricity Markets

Exercise session 1: Day-ahead electricity markets

The aim of this exercise session is to appraise and better understand the basic structure of electricity markets, and most particularly its day-ahead mechanism. The session relies on Lectures 0 and 1 available at "Lecture notes for 31761 - Renewables in Electricity Markets".

Problem 1: General description of a day-ahead market and the example of the Nord Pool

This Problem is based on the Nord Pool website, and more particularly its sets of webpages titled "The power market". The most recent status report for Nord Pool is available at: Nord Pool Annual Report 2016. Some hints and answers are also in the lecture slides, and on the wikipedia page for the Nord Pool

1.1 What is the common name of the day-ahead market in Nord Pool?
1.2 How many participants are they in the day-ahead market? And how many power producers in the whole area covered by the Nord Pool? Can you explain why all power producers do not trade through the Nord Pool, and how they then proceed?
1.3 What is the overall volume (on average) of energy generated over the Nordic and Baltic countries?
1.4 What was the overall amount of energy exchanged through the Nord Pool (Nordic and Baltic) day-ahead market in 2016? What about the UK?
1.5 What are the various types of power production technologies in the Nordic and Baltic countries? Rank them in terms of marginal production costs (in increasing order). What are the most important ones?
1.6 Who are the various participants in the day-ahead market? What is their role?
1.7 Who owns Nord Pool? (see webpage "About us")
1.8 What is the market time unit (i.e, a few minutes, a whole day, or...?), and what are the bidding areas?
1.9 What are the assumptions for the definition of bidding areas?

Problem 2: Consideration and ordering of supply offers in a pool

For this and some of the following Problems, we set up our own day-ahead electricity market, with characteristics similar to that of the Nord Pool and analysed in Problem 1. An example of such a day-ahead electricity market was given in Lecture 2.

The market has 5 players on the supply side. For a given time unit (say, between 2pm and 3pm the following day), the market operator has received a set of single-hourly supply offers (i.e., blocks of energy for a single market time unit) from these 5 participants. These offers are defined as:

Supplier name	Supplier id.	Quantity [MWh]	Price [€/MWh]
FlexiGas	G_1	15	75
Nuke22	G_2	100	15
ShinyPower	G_3	32	0
RoskildeCHP	G_4	25	42
BlueWater	G_5	70	10

2.1 What do we call the "supply curve" in the day-ahead market?
2.2 How is it defined based on a set of offers?
2.3 Draw (paper, or plot based on Matlab/R/Excel/etc.) the supply curve for this market time unit.
2.4 What is the total amount of energy offered through the market?
2.5 By the way... Can they be other types of offers than single-hourly offers?

Problem 3: Consideration and ordering of demand offers in a pool

We continue here based on the previous Problem and our day-ahead electricity market setup.

The market has 7 players on the demand side. For the same time unit as in Problem 2 (say, between 2pm and 3pm the following day) the market operator has received a set of single-hourly consumption offers defined as:

Demand name	Demand id.	Quantity [MWh]	Price [€/MWh]
WeLovePower	D_1	35	65
CleanCharge	D_2	23	78
JyskeEl	D_3	12	10
ElRetail	D_4	38	46
QualiWatt	D_5	43	63
IntelliWatt	D_6	16	32
El-Forbundet	D_7	57	50

3.1 What do we call the "demand curve" in the day-ahead market?
3.2 How is it defined based on a set of offers?
3.3 Draw (paper, or plot based on Matlab/R/Excel/etc.) the demand curve for this market time unit.
3.4 What is the total amount of energy asked for through the market? Compare it to the total amount of energy supply offers. Is there a problem there?

Problem 4: Equilibrium and market-clearing

We continue here based on Problems 2 and 3, and our day-ahead electricity market setup.

4.1 Have your supply and demand curve on the same drawing/plot.
4.2 Identify the "equilibrium point". What does it mean in the present case?
4.3 What is the equilibrium price and quantity?
4.4 Who will be effectively supplying power (and how much)? And, who will be effectively consuming (and how much)? Why does that make natural sense?
4.5 Calculate social welfare.

Problem 5: Formulating the market clearing more mathematically

Consider the market setup and list of supply offers of Problem 2, while assuming that the electric power demand to be met is fixed to 180MWh.

5.1 What is the most simple way to find the equilibrium point? Intuitevely, what is the clearing price, who will produce and how much?
5.2 Since demand is fixed, what is the objective of the market clearing with the supply side? Write it as an objective function. Is it a maximization or minimization problem?
5.3 What is the balance condition for the market (between supply and demand)? Write it as a balance constraint.
5.4 Deduce the complete linear program to be used for clearing the market.

As an extension, we now consider that the list of demand offers that is given in Problem 3.

5.5 What should be the objective function of the market-clearing (since having to consider both supply and demand sides)? Write it as an objective function. Is it a miximization or minimization problem?
5.6 What is the balance condition for the market (between supply and demand)? Write it as a balance constraint.
5.7 Deduce the complete linear program to be used for clearing the market.

Feel free to implement those linear programs in R/Matlab/GAMS/etc. in order to verify that you obtain the same solution as in Problem 4. It can only help you for the further work to be done for the first

assignment.

Problem 6: Settlement and revenues

The market has been cleared for this time unit (between 2pm and 3pm the following day) based on the list of suppy and demand offers given in Problems 2 and 3. It is now time to figure out how much the various participants will be paid, or will have to pay...

6.1 Look through the lecture slides, and define the difference between "pay-as-bid" and "uniform pricing".
6.2 Determine the revenues of various market participants on the supply side under uniform pricing settlement. What if using pay-as-bid instead?
6.3 Determine the payments for various market participants on the demand side under uniform pricing settlement. What if using pay-as-bid instead?

Problem 7: Day-ahead market with 2 zones

Let us now complexify a bit the market set-up and make it more realistic. Our market is now split into two zones (West and East). The various suppliers and demands are associated to these zones as follows:

Supplier name	Zone	Supplier id.	Quantity [MWh]	Price [€/MWh]
FlexiGas	East	G_1	15	75
Nuke22	West	G_2	100	15
ShinyPower	East	G_3	32	0
RoskildeCHP	East	G_4	25	42
BlueWater	West	G_5	70	10

Demand name	Zone	Demand id.	Quantity [MWh]	Price [€/MWh]
WeLovePower	East	D_1	35	65
CleanCharge	East	D_2	23	78
JyskeEl	East	D_3	12	10
ElRetail	East	D_4	38	46
QualiWatt	West	D_5	43	63
IntelliWatt	East	D_6	16	32
El-Forbundet	West	D_7	57	50

The available transmission capacity between these 2 zones is of 30MW. In the following we will assess how this may affect the previous market clearing and revenues that were obtained when not having such transmission constraints.

7.1 Make a schematic representation of the system layout (i.e., the two zones with its players, as well as the transmission constraints between these two).
7.2 Assess whether the previous market clearing (from Problem 5) is feasible or not.
7.3 Obtain the supply and demand curves for both zones.
7.4 Add extra virtual offers representing transfer of power from one zone to the next. From which and to which zone should the power flow?
7.5 Determine equilibrium price in both zones. Deduce revenues and payments.
7.6 Compare with the case where there was not transmission constraint.
7.7 What would be the minimum transmission capacity needed here for the price to be the same in the 2 zones?

Problem 8: Extract and analyse data for a day-ahead market

Besides some of the basic modelling and market concepts dealt with through the previous problems, a key aspect of working with electricity markets (including the day-ahead stage) is to develop an ability to find and analyse relevant data. In the present problem, emphasis is then placed on extracting data

from the Nord Pool website in order to appraise what is going on there.

8.1 Pay a visit to the market data page of the Nord Pool website and have a look at prices in tables in chart for the last cleared day. How similar are prices for the 2 market areas of Denmark? What are the daily variations, and can you explain them?

8.2 One may also download more extensive datasets from the historical market data webpage of the Nord Pool website. There you may for instance get some of the data for 2018 so far:

- Hourly consumption data used at the time of clearing the market,
- Hourly wind power forecasts used at the time of clearing the market,
- hourly market prices as the result of the market-clearing process.

Download these data and choose your favorite data analysis environment (R/Matlab/Excel/etc,).

8.3 Find a typical day with high wind power production in DK1, and look at the corresponding prices. Do the same with a typical day with very low wind power production. Is there something to learn here?

8.4 What is the average day-ahead, also called spot prices, for DK1 (Western Denmark) as a function of the time of the day? Its maximum and minimum? Are they defined limits for these minimum and maximum values (i.e., as set by the market rules)?

8.5 What is the average consumption for DK1 and DK2 (Eastern Denmark) as a function of the time of the day?