31761 - Renewables in Electricity Markets

Assignment 1: Build and operate a realistic day-ahead electricity market

General considerations

Assignment 1 concentrates on day-ahead electricity markets, following the lectures, exercise sessions, games and reading material from the first 4-5 weeks of the course. The work to undertake involves a bit of mathematical modelling, implementation in your favourite modelling language (R/Python/Matlab/GAMS/etc.), generation and discussion of results, as well as presentation of the work in a short report.

The aim of Assignment 1 is to evaluate

- your understanding of day-ahead electricity markets,
- your ability to model the day-ahead market mechanism,
- your ability to use real-world data as input,
- your critical analysis of the results generated.

The expected outcome of Assignment 1 includes:

- a report of maximum 10 pages (excluding appendices),
- code pasted in the appendix or delivered as supplementary material.

Assignment 1 is to be performed in groups, where a group is to be composed of 2 students. In special cases groups may reach 3 students, or alternatively have 1 student only (e.g., in case of distance learning).

The **evaluation of Assignment 1 will count for 26.7% of the final grade**. Individual contributions to the assigment must be clearly stated in the report. If not, equal contribution will be assumed.

Description of the Assignment

Let us consider the real-world setup for Denmark, which is split into two market areas commonly known as DK1 and DK2. To make things easier, we will simplify the interactions between Denmark and neighboring countries with set values for import and export of electricity. In case of overproduction, supply should be curtailed, while lack of power supply in meeting the electric power load must translate to load shedding. The available transmission capacity between DK1 and DK2 is of 600MW. A flow-based coupling approach is to be employed for ruling the exchanges between these two areas. In addition, it should be assumed that:

- DK1 imports 200MW from Norway, in a continuous manner,
- DK1 exports 100MW to Germany, every day between 7am and 2pm (and 0 for the rest of the time),
- DK2 imports 150MW from Sweden, every day between 1pm and 7pm (and 0 for the rest of the time).

We aim at simulating it over the whole month of January 2019, in order to obtain wholesale electricity prices for each hour of every day of that month, the schedule for the various participants, as well as their revenues/payments over the month.

1. Set-up for the electricity market

Here is the set-up for our day-ahead electricity markets:

- Instead of having demand curves, the consumption is assumed to be one block to be satisfied based on the list of supply offers. The hourly consumption data are available at the following link. The values for DK1 and DK2 should be considered;
- The offers from wind are available at the following link. We assume here we have two wind power producers in each area of this market (so 4 in total). These are called WestWind_1, WestWind_2, EastWind_1 and EastWind_2. Their share of the production and type of support are described in the Table below;

Supplier name	Supplier id.	Quantity [MWh]	Support	Support [€/MWh]
WestWind_1	WW_1	1/4 of predicted production	none	0
WestWind_2	WW_2	3/4 of predicted production	premium	17
EastWind_1	EW_1	1/3 of predicted production	feed-in tariff	20
EastWind_2	EW_2	2/3 of predicted production	premium	12

These wind producers readily offer the predicted quantities to the day-ahead market. They do not try to correct the forecasts or to be more strategic. Their price offers will depend upon their support scheme and support amount though.

- The full list of other power suppliers, location, as well as their characteristics, is summarized in the Table below. Please note that some power suppliers divide their generation portfolio into several parts. Each of those have a unique "supplier id.". For the revenue caculation in the assignment, there is no need to consider removing the marginal cost of power generation for these various participants;

Supplier name	Supplier id.	Area	Quantity [MWh]	Price [€/MWh]	Offering strategy
FlexiGas	G_1	DK1	400	70	Operates/offers for all time units
FlexiGas	G_2	DK1	330	64	Operates/offers for all time units
FlexiGas	G_3	DK1	345	153	Operates/offers for all time units
Peako	G_4	DK1	390	82	Operates/offers for all time units
Peako	G_5	DK1	510	89	Operates/offers for all time units
Nuke22	G_6	DK1	1000	25	Only operates/offers for time units between 5am and 10pm
CoalAtLast	G_7	DK1	900	250	Operates/offers for all time units
Nuke22	G_8	DK2	1200	19	Only operates/offers for time units between 5am and 10pm
RoskildeCHP	G_9	DK2	320	43	Operates/offers for all time units
RoskildeCHP	G_{10}	DK2	360	39	Operates/offers for all time units
Avedøvre	G_{11}	DK2	400	36	Operates/offers for all time units
Avedøvre	G_{12}	DK2	350	31	Operates/offers for all time units
BlueWater	G_{13}	DK2	730	5	Operates/offers for all time units
BlueWater	G_{14}	DK2	630	10	Operates/offers for all time units
CoalAtLast	G_{15}	DK2	800	250	Operates/offers for all time units

- Uniform pricing is used for the settlement.

2. Steps towards completion of the Assignment

2.1 Formulate the market-clearing as a linear program, along the lines of the Problems in Exercise sessions 1 and 2.

2.2 Implement this linear program with your favorite modelling tool (R/Python/Matlab/GAMS/etc.).

2.3 Use the list of offers and data indicated in the above to clear the market for 2 given market time units, representing cases of high and low wind penetration (i.e., share of wind power generation to meet consumption). Obtain the market price, list of scheduled power producers, as well as energy quantities to be produced.

2.4 Deduce revenues of power suppliers for these given market time units.

2.5 Loop over all market time unit in January 2019, to obtain the same results as in 2.3 and 2.4 for this single market time unit.

2.6 Calculate overall revenues for each market participant over January 2019.

2.7 Make a thorough analysis of electricity prices over that period, as well as usage of transmission capacity between DK1 and DK2. Some of the important aspects to cover include:

- what are the minimum, maximum and average electricity prices for each market zone, as a function of the time of the day?
- how often is the transmission cable congested, possibly also as a function of the time of the day?
- how often are the conventional generators scheduled?
- what is the impact of wind power generation on electricity prices in both areas?
- what are the statistics of wind curtailment (if any) and of negative prices (if any)?
- Is there any load shedding? And, if so, in which context?

Advice(!):
First go through the points 2.1 to 2.4 assuming that there is infinite transmission capacity between DK1 and DK2 (as if there was only one market area for the whole Denmark). Then go through these points again by additionally considering the transmission limitation.

Structure and contents of the report to be delivered

The report for the assignment should include:

- The formulation of the market clearing as a linear program, also describing how the exchange between areas is implemented (be rigorous in the way you write this optimization problem);
- An explanation of how revenues of each and every market participant is calculated based on market clearing price and/or eventual support;
- An example of the clearing of the market for a given market time unit, in order to explain how the clearing is done, whether prices are the same or not in both areas, also listing the scheduled quantities for all market participants as well as their revenues;
- An overview of the revenues of power suppliers for the whole month, also commenting on why some receive much less money than others;
- An analysis of the market outcomes over January 2019 (e.g., average electricity price as a function of the hour of the day, minimum and maximum prices observed in January as a function of the hour of day, frequency of observing congestion on the DK1-DK2 connection, frequency of observing negative prices, impact of wind power generation on prices in DK1 and DK2, etc.);
- The code in an Appendix (if not provided separately)

Delivery of the Assignment

Assignment 1 is to be uploaded through campusnet before the **final deadline of 10.3.2019** (all day included). It should take the form of a zip or tar.gz archive with naming convention "31761-Assignment1-Name1-Name2.zip" (or ".tar.gz"), where "Name1" and "Name2" are the names of the students in the group. More or less students in a group obviously means more or less names to be used in the naming convention.