31761 - Renewables in Electricity Markets (June 2014)
List of Projects & Instructions

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General instructions

The main aim of a 3-week course is to develop specific knoweldge and hands-on experience on a specific topic. Here, the plan is to give you a flavour of problems related to renewables in electricity markets based on a limited set of lectures, games, exercises, and mainly through a project of your choice.

Data analysis, optimization and programming

For all these projects, one will need a minimum background (and/or interest) in data analysis, optimization and programming. Preferred tools for completing the projects include:

- the statistical software **R** - For an introduction manual, see **R** intro
- the mathematical software **Matlab** - For a good introduction (by D.F. Griffiths, University of Dundee, UK), see **Matlab** intro
- the modelling system **GAMS** - - For a good introductory tutorial (by R.E. Rosenthal, Naval Postgraduate School in Monterey, California, US), see **GAMS** tutorial

Project types

Four types of projects may be considered for the course:

1. *What will be future electricity prices with higher renewable energy penetration?*
2. *Simulating and analysing the impact of renewables on both zonal and nodal markets*
3. *Participating in the Global Energy Forecasting Competition (GEFCom) 2012 - Wind track*
4. *Trading renewable energy in electricity markets*

as well as any variations or alternative ideas you may have.

Below, these various types of projects are described in more or less details, giving hints on the various paths that may be chosen. Final objectives are described, and, as long as you can provide proposal answers based on your project work and experimental investigation, **the choice of the right path to follow is yours!** Note that in case you have strong feelings about some other project idea, feel free to suggest and describe, as I am sure it may be a relevant one.

It is group work...

For the project work to be done, you should form groups of 2-3 students, and find ways to optimally share tasks. At the end of the project, the evaluation will be based on a report (max. 15-20 pages) common to all the group members, as well as a short presentation (10-15 minutes) where all group members should contribute. The group should be composed such that the various group members have complementary background, and also to ensure that the right programming skills are there for the work to be done.

The reports and presentation should cover:

1. a description of the problem, and a list of the subproblems to be dealt with,
2. where you found supporting information for doing the work, e.g., documentation on websites, articles, book chapters, etc.
3. what data you collected, and where you found it,
4. the results from you investigation, supported by some key figures and plots,
5. a discussion on potential advantages and weaknesses of your approach, and what other approaches could be tried in the future,

6. the code in appendix (or sent by email, or uploaded at Campusnet)

The files for the reports should be titled “name1-name2-. . ..doc” or “name1-name2-. . ..pdf” (or other formats you may want to use). Presentations may be prepared with Powerpoint, Latex-Beamer or Prezi. If the code is to be sent or uploaded, it should placed into an archive titled “name1-name2-. . ..zip”

A proposal timeline

Here is a proposal timeline for the project work to be performed within the course:

Day 1	Project initiation - The projects are generally presented and discussed, and a reading list is provided to help the students make their choice on a project type
Day 2	No project work
Day 3	Decision on project types, problem formulation, searching for data and tools that will permit to do the work
Days 4-9	Data analysis, programming, etc.
Days 9-10	Possibility to have a “mid-term project review” (a 15-30 minute chat with the instructor) to help fix some issues and define the final steps to completion
Days 10-11	Finalization of the project following the “mid-term” guidelines
Days 13-14	Fine-tuning of the results, while preparing reports and presentations
Day 15	Taking turns giving presentations, while others finalize their report to be handed in that day

It is obviously not a mandatory timeline - The aim is mainly to help you optimally organize your work.

1 Project 1 - What will be future electricity prices with higher renewable energy penetration?

1.1 Context

In the mind of most actors of the energy industry, the large scale integration of renewable energy generation in electricity markets is totally changing the market dynamics, hence bringing uncertainty in their activities. A typical question we hear from these actors is *"what will be future electricity prices with higher renewable energy penetration?"*

Now, imagine you are a consultant or a young academic, and that you have been asked this question... The idea here is to try to find some elements of answers regarding evolution of price characteristics of the day-ahead wholesale electricity market (but also of the regulation market if you are motivated). Note that depending on the results of your project, we may be able to give you a long list of relevant contacts in industry who will be happy to hear from you!

Focus is to be given to Denmark. Other countries/markets could be analysed, though it could become more difficult...

1.2 Expected results

The results should take the form of a characterization of future prices in electricity markets (compared, for instance, to prices over the last 5 years), giving information on:

- Average yearly prices
- Variations in prices, expressed through a number of criteria, e.g., variance/standard deviation, min and max prices, etc., and plots illustrating price time series and price distributions

These results should be presented under various scenarios. For example, if considering 2009-2013 as the base years, consider the situation where the wind power capacity in Denmark increases by 20%, 50%, 100%, 200%.

1.3 Proposal paths to completion

Here are a few hints on how to proceed in order to complete this project:

1. Read relevant literature on basics of electricity markets:
   - supply and demand equilibrium in day-ahead electricity markets,
   - zone splitting and its impact
   - merit-order effect of wind power (and more generally renewable energy)
2. Download and extract relevant data
   - price curves market data for a few samples days at Nord Pool system price curves
   - download the wind power data (forecasts and observed) at Nord Pool data download page
3. Play with the data to see
   - how the market equilibria would change with more wind and with potential additional congestions
   - how the time series of wind power (forecasts and observed) would look like if having more installed wind capacities
4. Set up a program that can download price curve market data for longer periods, and produce new system prices.

If that was too easy, you may want to consider adding some simulated solar power generation in your analysis (to be provided by the instructor). In addition, it could be relevant to set up a simple multi-zonal market clearing algorithm,

1.4 Suggested readings (to start with)

Jónsson T, Pinson P, Madsen H (2010). On the market impact of wind energy forecasts. *Energy Economics* **32**(2): 313–320 (pdf)

Morales JM, Conejo A, Madsen H, Pinson P, Zugno M (2014). Impact of stochastic renewable energy generation on market quantities. Chapter 6 in *Integrating Renewables in Electricity Markets - Operational Problems*, Springer Verlag: New York (pdf) - also the references therein

Munksgaard J, Morthorst PE (2008). Wind power in the Danish liberalised power market - Policy measures, price impact and investor incentives. *Energy Policy* **36**(10):3940–3947 (pdf)

2 Project 2 - Simulating and analysing the impact of renewables on both zonal and nodal markets

2.1 Context

As explained through some of the first lectures, there are two main types of setup for electricity markets, with zonal and nodal pricing. For the former one, the price is to be determined for a whole market zone at once, regardless of the transmission capacity of the network. Only one price exists for the whole market zone. In the latter case, the pricing accounts for the transmission network and for power flows on this network. Consequently, the market prices may be different for the various nodes of the network, depending on potential congestion. Zonal pricing is commonly used in Europe, while nodal pricing is used in the US. It is often argued that nodal pricing is a better approach since better reflecting the network constraint. This is what we will try to analyse here accounting for a large share of wind power in the system.

2.2 Expected results

The results should take the form of simulation results showing the differences between the zonal and nodal version of a day-ahead market, with a substantial penetration of wind energy. The simulations results should cover, for a given day,

- zonal market prices for every market time unit,
- nodal prices for every market time units and every nodes of the system,
- actual operations during that day,
- difference in social welfare at the time of market clearing, as well as actual costs of operating the system (day-ahead market settlement + balancing costs)

These results should be presented under various scenarios, i.e., for various sets of wind power forecasts and observations over a day.

2.3 Proposal paths to completion

Here are a few hints on how to proceed in order to complete this project:

1. Read relevant literature on basics of electricity markets:
   - supply and demand equilibrium in day-ahead electricity markets,
   - market clearing for zonal and nodal pricing
   - merit-order effect of wind power (and more generally renewable energy)
2. Setup your test case:
   - obtain a network model and the characterization of all lines and generators (available here)
   - get some example days of wind power and load data (forecasts and observed) at Nord Pool data download page, to be scaled to a realistic level for your system, and distributed at relevant nodes
3. Write the market clearing algorithms for both
   - zonal market, and
   - nodal market
4. Simulate the actual operations of the system, considering balancing and congestion...
5. Evaluate revenues of the various market participants

6. Look at the problem for your various days of data with wind and load forecasts and observations

If that was too easy, you may want to consider adding additional generators constraints (e.g. ramping), leading a a more complex Mixed Integer Linear Program (MILP).

2.4 Suggested readings (to start with)

Morales JM, Conejo A, Madsen H, Pinson P, Zugno M (2014). Impact of stochastic renewable energy generation on market quantities. Chapter 6 in *Integrating Renewables in Electricity Markets - Operational Problems*, Springer Verlag: New York (pdf) - also the references therein

Zeineldin HH, El-Fouly THM, El-Saadany EF, Salama MMA (2009). Impact of wind farm integration on electricity market prices. *IET Renewable Power Generation* **3**(1): 84–95 (pdf)

3 Project 3 - Participating in the Global Energy Forecasting Competition (GEF-Com) 2012

3.1 Context

There is a lot of interest in proposing, evaluating and comparing methods for short-term (i.e. 0-48 hours ahead) prediction of the power generation from renewable energy sources, to be used in decision-making for market participation, maintenance planning, power system operations, etc. Today, renewable energy forecasts have become a must-have for a lot of decision-makers, while the *MIT Technology Review* placed renewable energy forecasting in their Top 10 Breakthrough Technologies in 2014 (link).

Two years ago, the Global Energy Forecasting Competition (GEFCom) 2012 was launched as an attempt to provide a platform for data scientists, academics, etc. to benchmark their approaches to forecasting. The competition was hosted by kaggle.com, with a prize money of 7500$ for each track (wind power and load forecasting). For comparison, companies likes Facebook regularly recruit through Kaggle: instead of a prize money, your prize is a job as data scientist in Palo Alto...

After the competition was finalized, the data was still left available on the webpage, for people to be able to compare their results with what was done there. For instance, one may be able to access the wind power forecasting track at GEFCom12 Wind Track. The aim of this project is for you to have a try, propose an approach (or several) to wind power forecasting, and then compare your results to those from the CEFCom2012 participants

3.2 Expected results

The results for this type of project will be the score(s) obtained by your forecasting methods, and compared with a sample of 5 entries (to be provided) registered on Kaggle for the GEFCom12 Wind Track. Obviously, the methods for obtaining these results should be explained and motivated...

3.3 Proposal paths to completion

Here are a few hints on how to proceed in order to complete this project:

1. Read relevant literature on basics of wind power forecasting and related to GEFCom2012 (see below)
2. Download and extract relevant data:
   - wind power observations at GEFCom12 Wind Track
   - weather forecasts (wind speed and direction) at GEFCom12 Wind Track
3. Play with the data
   - to assess whether the data needs some "cleaning" (/data quality check) before to be used for developing your models
   - analyse the data characteristics to find out how to build a forecasting model, e.g., for a given wind farm, by looking at the relationship between predicted wind speed and observed power generation
4. Build your own forecasting model and apply it to the datasets
5. Then, additional and independent datasets will be provided to see how your models would perform in the real-world. These datasets will be available at this link
6. Relevant scores (e.g., Root Mean Square Error) can be calculated, reported and compared with those of the entries of GEFCom2012. Sample competitors' results are available for Competitor 1, Competitor 2, Competitor 3, Competitor 4 and Competitor 5.

If that was too easy, I will find some ways to spice it up!

3.4 Suggested readings (to start with)

Foley AM, Leahy PG, Marvugliac A, McKeogh EJ (2012). Current methods and advances in forecasting of wind power generation. *Renewable Energy* **37**: 1–8 (pdf)

Hong T, Pinson P, Fan S (2014). Global Energy Forecasting Competition 2012. *International Journal of Forecasting* **30**(2): 357–363 (pdf)

Hyndman RJ, Athanasopoulos G (2014). *Forecasting: Principles and Practice*. Online and open-access book at otexts.org (link)

Morales JM, Conejo A, Madsen H, Pinson P, Zugno M (2014). Renewable energy sources - Modelling and forecasting. Chapter 2 in *Integrating Renewables in Electricity Markets - Operational Problems*, Springer Verlag: New York (pdf) - also the references therein

4 Project 4 - Trading renewable energy in electricity markets

4.1 Context

Wind power producers have to offer their energy generation through electricity markets, despite the varibaility and uncertainty in their power throughput. This makes that they may consider a number of alternative strategies for participating in electricity markets, which could be more or less successful. The aim of this project is therefore to simulate and analyse the situation where you would operate a wind farm and trade its energy generation through the Nord Pool. Note that all data is real, and so the money figures will be real too!

4.2 Expected results

The results should take the form of simulation results, plots and tables, showing the evolution of revenues day after day over the whole period of market participation. Summary values of the market participation results shoudl also be given (e.g., yearly revenue from day-ahead market, yearly balancing costs, average price per unit produced, etc.).

The various trading strategies employed should also be detailed and supported.

4.3 Proposal paths to completion

Here are a few hints on how to proceed in order to complete this project:

1. Read relevant literature on basics of wind power participating in electricity markets (see below)
2. Download and extract relevant data:
   - wind power forecasts and observations at this link.
   - relevant market data (day-ahead prices, balancing sign and prices) at Nord Pool data download page
   - remember that when simulating participation in markets, no data from the future can be used (!!) For instance, when offering on Nord Pool for the 12 June 2012, you cannot know the day-ahead price, or any balancing market information for that day and any day after that...
3. Propose a set of offering strategies, using wind power forecasts (possibly enhanced to account for uncertainty aspects[1]), and market data
4. Implement the offering strategies, and simulate them for the years 2012 and 2013
5. Analyse the outcome from using these offering strategies, in terms of:
   - revenues from the day-ahead market
   - revenues from the balancing market
   - performance ratio
   - cumulative revenues and variability of returns
6. Then, iterate and try to improve these offering strategies...

If that was too easy, look at the proposal of Zugno et al. (2013) below, and upgrade your strategies along these lines.

[1] if aiming to upgrade the forecasts to probabilistic, some specific guidelines will be given

4.4 Suggested readings (to start with)

Morales JM, Conejo A, Madsen H, Pinson P, Zugno M (2014). Renewable energy sources - Modelling and forecasting. Chapter 2 in *Integrating Renewables in Electricity Markets - Operational Problems*, Springer Verlag: New York (pdf) - also the references therein

Morales JM, Conejo A, Madsen H, Pinson P, Zugno M (2014). Trading stochastic production in electricity pools. Chapter 7 in *Integrating Renewables in Electricity Markets - Operational Problems*, Springer Verlag: New York (pdf) - also the references therein

Pinson P, Chevallier C, Kariniotakis G (2007). Trading wind generation from short-term probabilistic forecasts of wind power. *IEEE Transactions on Power Systems* **22**(3): 1148–1156 (pdf)

Zugno M, Jónsson T, Pinson P (2013). Trading wind energy based on probabilistic forecasts of both wind generation and market quantities. *Wind Energy* **16**(6): 909–926 (pdf)