Renewables in Electricity Markets Course Assignment 2: Stakeholder Perspective

Teacher: Jalal Kazempour (DTU)
Deadline: May 12, 2025

March 31, 2025

This assignment contains tasks 1.1–1.4, based on Lectures 8 and 9, as well as tasks 2.1–2.3, based on Lecture 10.

Introduction to the Tasks Based on Lectures 8 and 9

Consider a price-taking wind farm with an installed capacity of 500 MW. The objective is to formulate and solve an optimization problem to determine its optimal offering strategy in terms of production quantity in the day-ahead market. The offer price is assumed to be zero. The analysis spans a 24-hour period, focusing exclusively on the day-ahead and balancing markets while excluding the reserve and intra-day markets.

Sources of Uncertainty: For each hour of the following day, the analysis considers the following three sources of uncertainty:

1. Wind power production,
2. Day-ahead market price,
3. The real-time power system condition (whether the system experiences a supply deficit or excess),

Scenarios will be generated to model these uncertainties, assuming no correlation among the sources. Historical data can be utilized for scenario generation, where each realization from a past day can be considered as a separate scenario.

Scenario Generation for Wind Power Production Forecast: Possible references include:

- FINGRID website (Finnish TSO)
- ELIA website (Belgian TSO)

- https://sites.google.com/site/datasmopf/wind-scenarios
- https://www.renewables.ninja

Scenario Generation for Day-Ahead Price Forecast: Price scenarios can be generated from the Nord Pool website, assuming the wind farm is located in DK2 and using the corresponding hourly day-ahead prices.

Scenario Generation for the Real-Time Power System Condition: To model the power system condition, 24 random binary (two-state) variables can be generated, each representing whether the system will experience a power supply deficit or excess during a specific hour. This can be done using a Bernoulli distribution for each hour, among other methods.

Final Scenarios: Model the three sources of uncertainty using at least 1,600 scenarios. Assuming no correlation among the three sources of uncertainty, the total number of scenarios is determined by the product of the number of scenarios for each uncertain source. For example, if 20 wind power scenarios, 20 day-ahead price scenarios, and 4 power system condition scenarios are considered, the total number of scenarios will be $20 \times 20 \times 4 = 1,600$.

Out of these 1,600 scenarios, at least 200 scenarios will be selected as in-sample scenarios for decision-making (Steps 1.1, 1.2, and 1.4). The remaining scenarios, known as out-of-sample scenarios, will be used for ex-post analysis (Step 1.3).

Balancing Price Forecasts: For simplicity, balancing price forecasts in a scenario can be generated by multiplying the day-ahead prices in that scenario by a coefficient (either 0.85 or 1.25, depending on the system condition in that scenario). The balancing price will be higher than the day-ahead price (i.e., equal to the day-ahead price multiplied by 1.25) in the case of a power supply deficit. In contrast, it will be the day-ahead price multiplied by 0.85 in the case of a power supply excess.

Recall from Lectures 5b and 8:

1. Under the **one-price** scheme, regardless of whether the imbalance caused by the wind farm is desired (i.e., helps the system) or not, the wind farm will be subject to the balancing price.
2. In contrast, under the **two-price** scheme, the wind farm may be subject to either the balancing price or the day-ahead price, depending on whether the imbalance is desired (i.e., helps the system) or not. If the imbalance caused by the wind farm is desired, the wind farm will be subject to the day-ahead price. Otherwise, if the imbalance is undesired, it will be subject to the balancing price. Whether the imbalance is desired or not cannot be determined *a priori*, so this should be part of the optimization problem to be developed.

Tasks based on Lectures 8 and 9

1.1 **Offering Strategy Under a One-Price Balancing Scheme:** Following Lecture 8, formulate and solve the stochastic offering strategy problem for a one-price balancing scheme using in-sample scenarios. Determine the optimal hourly production quantity offers of the wind farm in the day-ahead market and calculate the expected profit. Additionally, illustrate the cumulative distribution of profit across the in-sample scenarios. Do we observe the wind farm bidding either 0 or full capacity (an all-or-nothing strategy)? If so, why?

1.2 **Offering Strategy Under a Two-Price Balancing Scheme:** Repeat Step 1.1, but now consider a two-price balancing scheme. Analyze any significant differences between the results of Step 1.1 and Step 1.2, particularly in terms of the offering strategy and profit distribution.

1.3 **Ex-post Analysis:** Following Lecture 8, conduct ex-post cross-validation analyses to evaluate the quality of the offering decisions made in both Steps 1.1 and 1.2. With 200 in-sample and 1,400 out-of-sample scenarios, perform an 8-fold cross-validation analysis. For each run (with the given 200 in-sample and 1,400 out-of-sample scenarios), calculate the expected profits for both the in-sample and out-of-sample analyses. After completing all 8 runs, calculate the average expected profits for both the in-sample and out-of-sample analyses. Considering the results from all 8 runs, compare the average expected profits from the in-sample analyses to those from the out-of-sample analyses. Based on this comparison, can we interpret how satisfactory the offering decisions are? While keeping the total number of scenarios at 1,600, discuss whether altering the number of in-sample scenarios from 200 would improve the quality of the offering decisions, and if so, to what extent.

1.4 **Risk-Averse Offering Strategy:** Following Lecture 9, formulate and solve the risk-averse offering strategy problem for the wind farm under both one- and two-price balancing schemes ($\alpha = 0.90$). Gradually increase the value of β from zero and plot a two-dimensional figure showing expected profit versus Conditional Value at Risk (CVaR). Explain how the offering strategy and profit volatility evolve as β increases. Additionally, discuss how the profit distribution across scenarios changes when risk considerations are incorporated. Lastly, analyze whether changing the set and number of in-sample scenarios leads to significant changes in the risk-averse offering decisions. This task does not require any ex-post out-of-sample or cross-validation analyses.

Introduction to the Tasks Based on Lecture 10

In Lecture 10, we explore the offering strategy for stochastic assets in ancillary service markets. Specifically, we consider a price-taking stochastic flexible load, which can either be a large energy consumer or an aggregator of small-scale loads, such as electric vehicles. This flexible load has a range of energy consumption from 0 kW to 600 kW. For simplicity, we focus on the FCR-D UP market in DK2 with hourly bids, where the flexible load seeks to sell its flexibility. The load can offer this service due to its ability to quickly adjust its consumption level. Importantly, we assume there is no minimum bid size requirement. To keep the analysis manageable, we consider a single hour for bidding with minute-level resolution for the flexible load's consumption.

Data Generation for Future Stochastic Load: Randomly generate 300 consumption load profiles, ensuring that for each profile, the load at every minute falls between 220 kW and 600 kW. Additionally, the change in consumption between two consecutive minutes must not exceed 35 kW. These limits are set for the stochastic data generation process and do not represent technical constraints. Out of these 300 profiles, 100 will be used for in-sample decision-making (i.e., reserve capacity bidding to the FCR-D UP market in kW), while the remaining 200 will be designated for out-of-sample analysis. Each in-sample profile will have an equal probability.

Tasks Based on Lecture 10

2.1 **In-sample Decision Making: Offering Strategy Under the P90 Requirement:** Given the P90 requirement of Energinet, determine the optimal reserve capacity bid (in kW) of the stochastic load in the FCR-D UP market for the given hour. Utilize both ALSO-X and CVaR techniques to solve this problem, as these methods may yield different results.

2.2 **Verification of the P90 Requirement Using Out-of-Sample Analysis:** Using the 200 testing profiles, verify whether the P90 requirement is satisfied for both solution techniques used. This step does not require solving any optimization problem. Instead, compare the optimal reserve bid obtained in Step 2.1 with the actual power consumption under each testing profile. For example, if the stochastic load bids 300 kW to the FCR-D UP market for a given hour, and its consumption at a certain minute within that hour is 270 kW, this would indicate a reserve shortfall of 30 kW for that minute.

2.3 **Energinet Perspective:** Take the perspective of Energinet and investigate how varying the P90 requirement (e.g., by adjusting the allowed frequency of reserve shortfall between 80% and 100%) impacts the optimal reserve bid (in-sample analysis using ALSO-X) and the expected reserve shortfall (out-of-sample analysis). Analyze whether there is an observable trade-off between these two factors as the P90 requirement is relaxed or tightened.

Note: Please refer to the introduction slides presented on February 3, 2025, for the report template and page limit. A grade deduction of 1.5% will be applied for each page exceeding the limit, except for the appendix, which should only include input data.