Energy Portfolio Management for Sustainable Campus

EEEL 4220 Fall 2024 Project 3

1 Introduction

You are a renewable energy manager of a college campus in upstate New York. You are purchasing daily energy supply contracts for tomorrow and your options are below

1. **At-risk wind contract.** A wind farm nearby offers you at-risk wind generation capacity at $250 per MW capacity for tomorrow, the actual generation depends on the real-time wind power capacity factor (i.e., the actual wind generation is the product of the provided capacity factor with your wind power contract quantity). The maximum capacity this wind farm offers is 20 MW.
2. **Generator contracts.** A natural gas generator nearby offers three services
   - **Baseload contracts.** The first is baseload generation service, the generator provides $15/MWh baseload generation (i.e., the generation will be fixed from 12:00 AM to 11:59 PM) for tomorrow, equivalent to $360 per MW (1MW over 24 hours).
   - **Peak load contracts.** The second is peak load generation service, the generator provides peak demand supply from 8 AM to 6 PM at $20/MWh, equivalent to $200 per MW.
   - **Generator contracts.** The third is load following service, the generator can provide any supply as requested by the campus up to the contracted capacity. This is an option call contract, the option fee for this service is $50 per MW, and the exercise fee is $18/MWh.

   The capacity of this generator is 10 MW, so the total amount of the three service contracts cannot exceed 10 MW.
3. **On-site solar.** The campus has a 1 MW capacity of solar panels installed which will provide free solar energy to the campus depending on the actual solar power capacity factor.
4. **Spot market.** Your local utility will settle all contract imbalances at real-time market price plus an additional $5/MWh service fee. Note that the local utility **does not allow** the campus to sell energy back to the grid, hence if the net generation (contracted supplies minus the net demand) is positive, the surplus supply will not be paid.

You must decide how many wind and generator contracts to purchase before the start of the next day (except for the generator option contract you can decide the exercise capacity in real-time). You do not know what could happen for tomorrow, but your student intern has provided you with five possible scenarios with equal probabilities for tomorrow. Each scenario contains predicted campus demand, real-time price, and the capacity factor for wind and solar. All profiles are generated at a 15-minute resolution.

2 Project Objective

Your boss has requested you to provide the following results so he can make the final trading decision:

- What is the minimum expected cost to serve the campus demand for tomorrow and what is the corresponding contract portfolio?
- How do we minimize the worst-case cost scenario for tomorrow, and what is the corresponding contract portfolio?

Since your boss has taken the energy system optimization and economics class before, he requires you to use **optimization** to get the optimal energy portfolio. Hence simple Excel spreadsheet analysis will not be enough.

In addition, the school board would also like to hear your suggestions about the feasibility to power the campus entirely with renewable energy. Based on what you have observed from these five scenarios and your portfolio management results, summarize possible pathways toward a sustainable campus, and the relative costs associated with these pathways. In this discussion, you don't need to limit your options to the trading options listed above but should focus on the scenario data and the cost numbers of different resource types. You are also encouraged to search for the most up-to-date costs regarding different energy resources.

3 Tips

Here are some tips to get you started

1. The first task is essentially a two-stage stochastic optimization problem, as most of the decisions are made ahead of the operating day. The only decision you need to make during the operating day is to decide how many generations you would like to get from your load following the call option. You can assume this natural gas generator is fast enough so it can produce any amount of power you request.

2. It is easier to think backward when trying to solve stochastic optimization problems. First, think about how to formulate the problem during the operating date for each given scenario, in which you can assume you the contract portfolios are already fixed. For example, you can first formulate an optimization problem for each given scenario that calculates the total cost and decides how much on-option natural gas generation to call. This can be formulated in compact form as

$$\min_{x_s} Q_s^\top x_s \text{ subjects to } A_s x_s \leq B_s y \tag{1}$$

   where x_s are the decision variables over scenario s, y is the contract portfolio that has already been fixed for the operating day. Q_s should include the exercise price and the real-time price, and the constraint limits how much gas generation you can call based on your option capacity.

   Then you can combine all scenarios together by assigning them equal probabilities ω_s (**Pay attention to the subscript s representing whether the variable/parameter depends on the scenario**)

$$\min_{x_s, y} R^\top y + \omega_s \sum_{s=1}^{N} Q_s^\top x_s \text{ subjects to } A_s x_s \leq B_s y \text{ and } Cy \leq D \tag{2}$$

   where N is the number of scenarios, R includes the price of all contracts except option exercise fees and real-time market prices, and y represents the amount of contract (in MW) you want to purchase before the day.

   In operation, you will run (2) before the operating day to decide the contracts to be purchased one day ahead, assuming all possible scenarios of tomorrow. After solving (2) and during the operating day, you take the optimized y as inputs and run (1) to decide the exercise of option contracts and spot trades.

3. The second task is a robust optimization problem in which you are trying to optimize against the worst-case scenario, and be aware, the worst scenario also depends on your generation portfolio. For example, if you weigh more on wind generation capacity, then the scenario with the least wind becomes the worst-case scenario.

   One way to solve this robust optimization problem is to use conditional value-at-risk (CVaR) optimization and set the β to 80%, the same granularity as the scenario possibilities. Therefore, the CVaR optimization will automatically pick the worst-case scenario. The CVaR formulation, followed by the previous stochastic compact form, can be listed as

$$\min_{\alpha, M, x_s, y} \alpha + \frac{1}{N(1-\beta)} \sum_{s=1}^{N} M_s \tag{3}$$

$$M_s \geq R^\top y + Q_s^\top x_s - \alpha \tag{4}$$

$$M_s \geq 0 \tag{5}$$

   followed by the same set of constraints in the earlier formulation. The literature for CVaR optimization can be found in this link. Note that

$$\min_{x \in A} [x]^+ \tag{6}$$

   can be equivalently represented as

$$\min_{x \in A} M \text{ subjects to } M \geq 0 \text{ and } M \geq x \tag{7}$$