ISYE6501 - Course Project

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1 Pre-amble

The course project description requires the following:

- What are the models used to create the solution (at least 3)?
- How would the models be combined?
- What data might be needed?
- How might the data be collected?
- How might the data need to be refreshed, and models re-run?

2 Introduction

The subject of this report is an application of analytics by the European power supplier Vattenfall. The source article can be found here: `https://www.sas.com/en_us/customers/vatenfall-analytics.html`. I originally decided to look at the article in the SAS library as I had visited a Vattenfall power station while on exchange in Germany. I ended up selecting the topic as I was interested in the application of analytics to managing electricity grids, especially in countries like Germany where renewable energy sources are becoming more prevalent.

This report is structured around answering the questions above for the selected case study.

3 Background

The article describes the ”energy balancing” system. Essentially this involves a electricity Transmission Network Operators issuing bids to electricity power plant operators to provide ad hoc electricity generation to ensure the system meets consumer demand. This acts as a ”buffer” to the base load, to cover either higher than expected demand or problems with the base supply. Power plant operators bid their excess generation capacity at a price to cover demand in the short term. In the case study, Vattenfall used analytics to help determine their bid strategy for the energy balancing market.

4 Problem statement & challenges

The article references several different objectives from the analytics model, listed below:

- Optimal bid offer strategy
- Optimal use of available power stations
- A ”decision corridor” for bids based on market data
- Maintain transparency and auditability of bid process
- Meet demand at optimal efficiency and cost
- Make a quick decision using data available
- Limit auction related risk while maximizing surcharge success

I would summarize the objective as: Vattenfall want to maximize their risked profit margin when bidding for energy balancing. They want to use simulation to identify all different profit scenarios and their likelihood of occurrence, so they can bid accordingly. I am defining profit very simply here as:

$$\text{Profit} = (\text{Bid Price - Cost to produce}) \text{ per MWh}$$

The following sections discuss data and modelling relevant for each term in this equation. The production cost is slightly simpler so is addressed first.

5 Cost of Production

A simplified estimate for cost of production would require the models for the following:

5.1 Fuel cost (Model 1)

Factor type	External, uncontrollable
Model type	Exponential smoothing, GARCH
Data required	History of fuel costs over time, industry trend forecasts, fuel contract information, planned production information
Data collection	Previous fuel contracts, current plant operating strategy / business model would be available from the company's commercial / business development team. Industry forecasts may be generated by consulting companies and would likely already be accessible to a company like Vattenfall.
Statement	**Given** historical fuel cost, industry forecast, contract information, planned production, **Use** GARCH **To** Estimate variance in future fuel cost

Fuel cost is critical as it directly influences cost of production. The first step would be to establish whether any fuel already purchased as part of a long term contract (eg fixed) was available to contribute to the ”energy balancing” production. If, for example, the base load usage was lower than forecast when the contract was executed, there may be fuel available at a fixed, known cost. In the case where additional fuel was required, exponential smoothing could be used to capture the seasonal variation throughout the year, and trends over time.

Given that fuel cost could be heavily influenced by single ”unpredictable” events (OPEC decisions, oil markets, geopolitical events), and given that the fuel cost is an input to a stochastic simulation, a GARCH model would be more important. This would be used to estimate the variance in commodity price, and therefore define the range of fuel costs input to the simulation. The ”single value” for fuel price predicted for any point in time by exponential smoothing is probably meaningless given the number of potential predictors not considered.

A separate fuel cost could be modelled for each plant in Vattenfall’s portfolio (eg natural gas, coal). The methodology would be the same for each.

5.2 CO2 Emissions Certificate (Model 1.1)

CO2 emissions cost would fall into the same category as the fuel cost model. They are both based on an external market, both would be influenced by seasonality and the base load power requirement, and both are directly proportional to the cost of production. Using GARCH in this case to estimate the variance over the period of the ”energy balancing” contract would be the critical input to the simulation.

5.3 Power Station Efficiency (Model 2)

Factor type	Internal, controllable
Model type	Regression
Data required	Historical plant efficiency, plant output (as a percentage of nameplate), ambient climate data, plant age
Data collection	This is all collected as part of routine plant monitoring (historical ”real-time” data computed from sensor outputs)
Statement	**Given** Plant efficiency plant output, plant nameplate, ambient temperature data **Use** Regression **To** Quantify efficiency as a function of output

The amount of energy produced per unit fuel would differ based on the total plant output as a fraction of nameplate capacity; this would have a direct impact on cost of production. A regression model could be used to identify efficiency as a function of power output. A key external variable to consider would be ambient temperature, which would need to be added as a predictor, because of its significant effect on plant efficiency for both coal and gas power plants.

This effect on efficiency is important to capture as it affects Vattenfall's overall strategy. In order to participate in the "energy balancing" market, they need to be providing their baseload power at less than nameplate capacity, to allow them to produce extra power if awarded the "energy balancing" bid. If this comes at the expense of reduced plant efficiency, it may offset the premium on bid power price.

This regression model would be used in the final simulation to compute the efficiency of each power plant based on the climate and the plant baseload power required to achieve the "energy balancing" commitment.

6 Bid price

The second and more complicated term in the "profit" equation is the bid price. A higher bid price will obviously result in more profit, but reduce the likelihood of being awarded the "energy balancing" contract. One of Vattenfall's objectives was to incorporate publicly available historical auction data into their simulation model.

6.1 Initial considerations

The bid price model is complicated because of the number of inputs:

- As part of the International Grid Control Cooperation, "energy balancing" can occur between Germany, Denmark, the Netherlands, Switzerland and others. This increases competition and makes demand forecasting complicated (reference `https://www.50hertz.com/en/Market/Balancingenergy/`).
- European energy sources are a fairly even mix between nuclear, renewables, hydrocarbon and solid fuels (reference `https://ec.europa.eu/eurostat/cache/infographs/energy/bloc-2b.html`. Suppliers of each source would likely have a different bid strategy. Renewables may be quite volatile throughout the year; at times they may have spare capacity, at other times they may see production shortfalls due to climate. Solid fuel power stations may be providing base load but may not be flexible enough to provide additional output at short notice. The nuances of each source would have a significant impact on the auction process. This is the main reason that I have included climate / time of year in many of the models.

There are two key models that might have been used by Vattenfall: predicting competitor bid prices, and predicting amount of energy balancing required.

6.2 Competitor pricing (Model 3)

Factor type	External, uncontrollable
Model type	k-Nearest neighbours
Data required	Historical auction data, including: • Time of year • Climate at auction time • Number of unsuccessful bids placed • Time since previous auction • Amount of ”energy balancing” tendered • Winning bid price • Energy source of winning bid (eg renewable, natural gas)
Data collection	According to the source article, auctions are managed by the Federal Network Agency who make the historical data publicly available.
Statement	**Given** Historical auction data **Use** k Nearest neighbours **To** Predict the supply side - market price, energy source of winning bids and total number of bids placed (a measure of competition)

I selected k-Nearest neighbours given the volume of data available. With the international grid connectivity, it is likely that bids for ”energy balancing” are frequent. K-nearest neighbours would allow a model that computes the market price and source type for the closest match bid in the data set.

I think you could also try a regression model for this application as well. It is possible any impact of the ”time of year” predictor would be explained by the ”climate at auction time” variable/s, which would eliminate the seasonal effect (eg auction price would be expressed as a function of temperature, average wind speed etc rather than a particular part of the year). It might be worth testing out both of these models.

Unfortunately I’m not a game theory expert but, based on a cursory web search, suggest there may be a way to model the auction process using game theory. This could be considered as an alternative but I don’t know enough to explain the final model.

6.3 Demand (Model 4)

Factor type	External, uncontrollable
Model type	Exponential smoothing
Data required	Historical auction data, including: • Time of year • Climate at auction time • Time since previous auction • Type of energy sources bid (corollary is important - which ones **did not** bid) • Amount of "energy balancing" tendered
Data collection	As per previous.
Statement	**Given** Historical auction data **Use** Exponential smoothing **To** Predict demand for "energy balancing" - monthly "energy balancing" demand

Energy demand could be modelled using an exponential smoothing models. There is a significant cyclical effect(critical for this model), plus likely a consistently increasing trend (corresponding to "economic growth"), both of which could be captured by an exponential smoothing model. The amount and frequency of "energy balancing" tenders could be used as a proxy for demand.

Modelling energy demand with exponential smoothing is suitable given the demand is short term inelastic so less susceptible to shocks than eg the price of fuel.

Correlating this to the energy source types that bid and did not bid each month would help build a picture of the excess capacity available through the year. This would help Vattenfall build their strategy. At times when renewables clearly have excess capacity, it is likely Vattenfall would need to bid very low (with associated higher risk) to win the bid. In Winter months, however, without as much competition from renewables, Vattenfall might feel more comfortable making a higher bid with less risk of being underbid.

GARCH could be used to augment this analysis and provide better detail on the expected variance as an input to the simulation model.

7 Bringing it together: Simulation (Model 5)

The "climax" of the Vattenfall article is the Simulation model for modelling different auction scenarios.

Model type	Simulation for stochastic optimization
Data required	• Modelled fuel cost and CO2 emissions certificate cost ranges (model 1) • Plant efficiency under known conditions (model 2) • Plant availability (as a % uptime - known) for each plant • Predicted market bid price (model 3) • Time and climate of current bid • Geographical location of required ”energy balancing” vs power plant location • Current demand ranges (model 4)
Data Collection	As per previous models. Information on the current ”energy balancing” requirements - for which the model is being built - would be issued with the bid (eg where is it required, what time of year is it required)
Statement	**Given** Data listed above **Use** Simulation **To** Calculate profit distributions for different bid price and power supply combinations

The simulation would take ranges for the inputs listed to model multiple different bid scenarios. For each bid, the model would compute a value for profit. The profit would either be zero (bid price less than predicted market bid) or equal to bid price minus cost to produce. By varying the input parameters and bid prices, the model would build up a distribution for profit for each bid price.

For each bid price, you could perform a further stochastic optimization to establish the optimum composition for power supply - which power plant should you use to meet the ”energy balancing”. This would use the data already discussed (namely, fuel cost, CO2 cost, plant efficiencies) to calculate production costs. It would be a sub-section of the simulation.

Objective function	Minimize cost of production $C = \Sigma_i(P_i C_i + T_i)$
Variables	• Fraction of total power P provided by plant i, Φ_i, where $P_i = \Phi_i P$ • Cost per unit of power at plant i c_i • Cost to transmit power from plant i to location of demand, T_i
Constraints	• Sum of fractions must equal 1, $\Sigma\Phi_i = 1$

Matching this answer to the objective, Vattenfall would want to maximize their risked profit. They would do this by choosing the bid price and power supply combination from the stochastic simulation which gave the most favourable profit probability distribution - the best expected value for profit. A high bid might result in a low probability of high profit, but a high probability of zero profit (lower likelihood of outbidding the market). A lower bid might result in higher probability of a medium profit, but a lower probability of a potential loss, if the contract was awarded at the same time as adverse changes to fuel / CO2 costs. Visibility over these distributions would help Vattenfall understand the risks associated when placing their "energy balancing" bid.

It is likely that these bid price vs profit curves would be reviewed by a commercial team who would make a decision on the bid strategy. There may be a simple optimization calculation to select the bid price - of the bid prices simulated, selecting the profit distribution with the highest expected value. Simplifying the distribution to a single number may not correctly capture the risk profile, so Vattenfall might be better of with the commercial team making the decision.

8 Updating models and data

For this problem, the upkeep of model and data relevance would not be difficult. Each time the model is run (that is, each time a tender for "energy balancing" is received), the most up to date data could be collected.

- Historical bid data - available through the Federal Network Agency; update frequency dictated by agency but readily accessible
- Fuel costs - updated with most recent contracts / market spot prices
- CO2 emissions certificates - updated with most recent market data
- Industry trend forecasts - provided by consultants, could be purchased by Vattenfall if and when required
- Plant data - continuously collected in real-time

Models would be re-run with an updated data set for each bid. The Vattenfall commercial team could then make a decision on the bid based on the model output and the company risk profile at time of bid.