LINEAR PROGRAMMING, MODELLING AND SOLUTION

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Report on Case Study: EPower

By Group 20

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7 April 2017

Introduction:

The aim of this project is to develop an optimal electricity generating policy for the company, EPower. It will entail a brief description of the problem and provide the analysis of the results of the "base case" model and other scenarios that we have considered. Firstly, a "base case" model which replicates the current decision-making is built and analysed, then the scenarios which consider average demand, the variability of demand and wind and lastly, the effect of reduction in CO_2 emissions are examined. We will end the report with some recommendations for further investigation that could be taken to further optimise the electricity generating policy in the near future.

Context of the Problem:

The five power generating sources are gas, coal, nuclear, wind and hydro while interconnect is another source of electricity which can be bought from other power system. Each power source has a different maximum power output, running cost (it is assumed that the cost to pump the water up has been taken into account in the running cost of hydropower) and increase cost for increasing the output of the source.

As mentioned earlier, the objective is to maximize the profit by taking into consideration the income from the electricity generated to satisfy demand, less the costs due to electricity generation and the increase in power output.

Solution is constrained by the maximum power output of each generator in each period, the daily emissions (CO_2 and sulphur) limits and the maximum reserve of the reservoir. Besides, the total power output in each period must equal to the demand (which varies throughout the day) plus the demand for pumping water to the hydro reservoir.

Income is made by selling electricity to consumers at a fixed electricity price.

The problem has been formulated as a linear programming problem and modelled using Xpress-IVE software. More details on the model formulation are available in the attached Mosel file.

Different generators work together to deliver optimum operation:

For instance, for wind power, the average maximum output is considered since wind blows at different speed at different periods of the day and different seasons of the year. It is the cheapest source of energy despite its unstable nature. Besides, coal and gas are relatively cheap sources of energy in spite of the fact that they are the only sources responsible for CO_2 and sulphur emissions. Meanwhile, reservoir is installed in higher area to collect natural flow of water. Water is pumped into the reservoir at times of low demand to satisfy "spikes" in demand at the cost of losing 20% of the energy every time we pump the water up to the reservoir. Nuclear power output is best kept stable throughout the day as the increase cost is the highest.

Model: Base Case

The optimal generating policy is that each source should generate the following power output (measured in megawatt (MW)) in each time period:

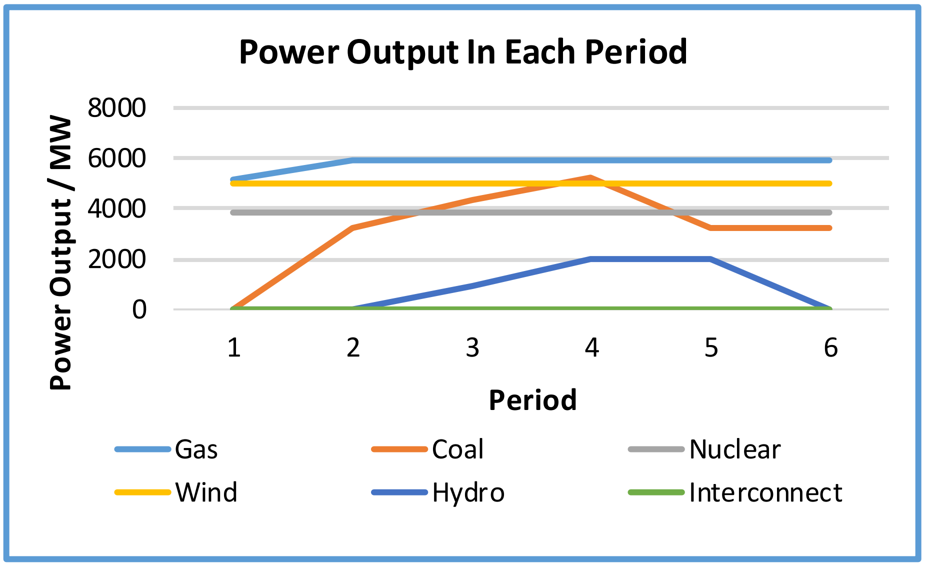

Figure 1: Power output of each source (MW).

Period	1	2	3	4	5	6
Power to pump water (MW)	2000	0	0	0	0	0
Power to release water (MW)	0	0	900	2000	2000	0

Table 1: Power (MW) used to pump and release water in different periods.

Analysis of the data:

In Figure 1, it can be observed that the power output of nuclear is maintained at a constant level throughout the day since its increase cost is the highest while the wind power is fully utilised since its running cost is the lowest. Besides, hydropower is used to satisfy the sudden rise in demand in the middle of the day. Meanwhile, interconnect is not used at all since it has the highest running cost.

In Table 1, it shows that the water is not pumped and released in the same period (since energy is lost due to the imperfect efficiency of the system) for optimal results.

Cost, revenue and profit:

The gross income is £15.12M (Millions) while the total running cost and the total increase cost are £12.70M and £0.39M, respectively, giving a total operational cost of £13.09M, thereby giving a profit of £2.03M per day.

Recommendations:

Emissions of sulphur are at the limit of 30000 units and the value of exceeding this limit is £15.28/unit for availability in between 29585.5 and 35520 units. Meanwhile, CO_2 emissions are at the limit of 200000 units and the value of exceeding this limit is £12.50/unit for availability in between 177840 and 201520 units. Nevertheless, for environmental concerns, it is not advisable to profit by exceeding the emissions limits.

Scenario 1: Using average demand

This scenario is modelled in such a way that the whole day is split into 24 periods with one hour each and the average demand for each period is 18000MW.

Source	Gas	Coal	Nuclear	Wind	Hydro	Interconnect
Power Output (MW)	5729.17	3125.00	3745.83	5000.00	400.00	0.00

Table 2: Power output (MW) of each source in every hour of the day.

Analysis of the data:

Table 2 shows that wind power output reaches its maximum again since it has the lowest running cost. Since the demand remains constant throughout the day, it is unnecessary to pump the water up for later use. Therefore the output from hydropower is only 400MW, which is exactly the natural flow of water in every hour of the day.

Cost, revenue and profit:

The gross income is £15.12M while the total running cost is £12.53M, thereby giving a profit of £2.59M per day. Since the demand is constant throughout the day, there is no increase cost for each source.

Comments:

The model is not realistic.

Demand usually fluctuates throughout the day. The profit obtained is higher than it is supposed to be as it does not need an increase cost. Moreover, the reservoir is only used to collect the natural inflow of water. The amount of natural inflow of water is far below the maximum capacity of the reservoir, which is a waste of resources.

Scenario 2: Increasing maximum wind power output and decreasing demand

A 48-hour model was set up where the first 24 hours replicates the base case while on the second day an increased maximum wind power output of 8000MW and 10% decrease in demand are considered.

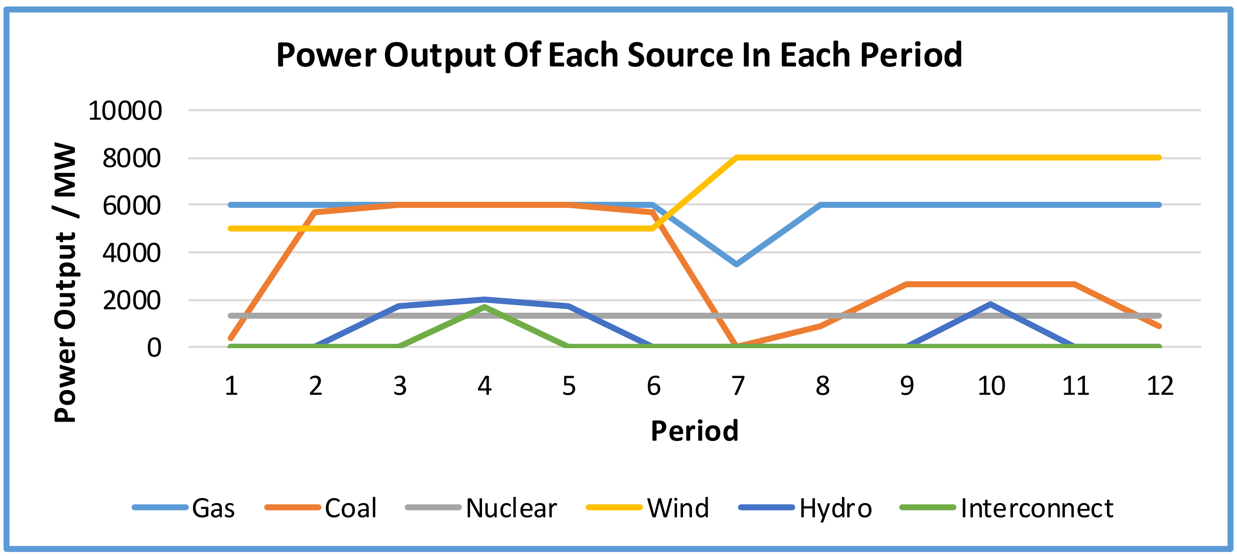

Figure 2: Power output of each source (MW) in 48-hour model.

Analysis of the data:

Figure 2 shows that the cheapest power source, i.e. wind power is fully utilized on both days. Meanwhile, one of the many reasons that the “most expensive” source, interconnect is used to satisfy the “spike” in demand in period 4 is because it is not optimal to manipulate the nuclear power due to its high increase cost.

Cost, revenue and profit:

The average profit is £3.94M per day (which is much higher as compared to the base case) as additional wind power is available to be used to satisfy the demand despite the decrease in demand from period 6 to 12.

Scenario 3: Reducing the limit of CO_2 emissions up to 50%

An additional power of 1000MW from one source will be required if the limit of CO_2 emissions is reduced to half of the current limit. In the case of pumped storage hydro, the maximum reserve and natural inflow are both increased by 50% along with an increase of maximum output from 2000MW to 3000MW. Meanwhile, the average maximum output is increased by 500MW for wind power and 1000MW for other sources.

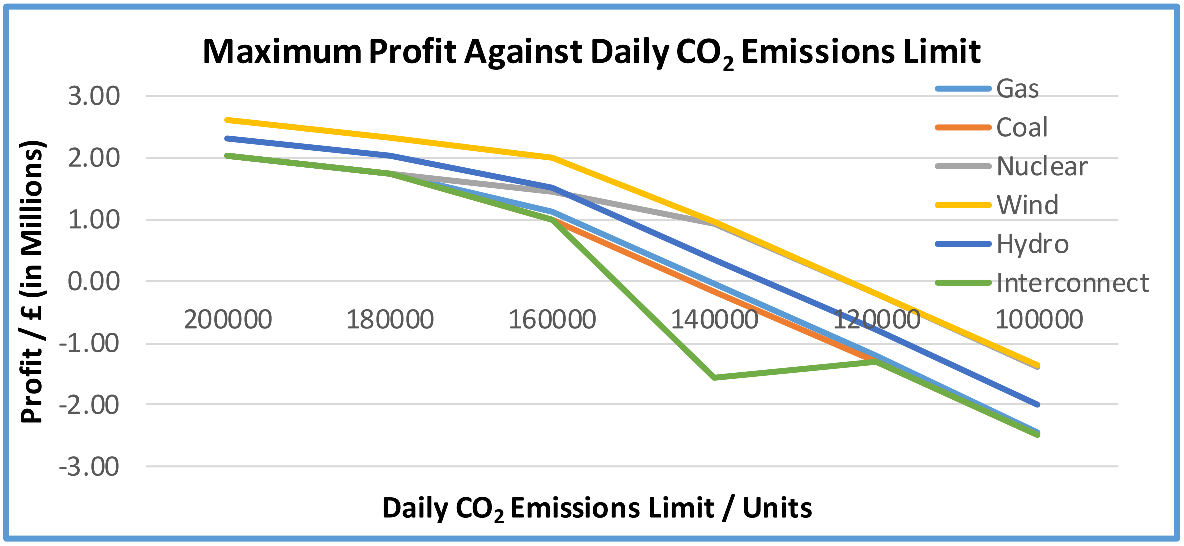

Figure 3: Maximum profit (with the source of interest having additional capacity) when CO_2 emissions limit is reduced up to 50%.

<u>Analysis of the data:</u>

Reduction of CO_2 emissions limit results in the use of more expensive power sources to satisfy the demand as energy allowed to be generated from gas and coal are limited. Hence, a decrease in daily net profit is expected. Therefore, not surprisingly, Figure 3 shows negative net profit for every source when CO_2 emissions limit is reduced by 50%.

<u>Recommendations:</u>

It is not advisable to cut down on the CO_2 emissions limit by more than approximately 25%, as it will turn into a loss beyond that point.

Further Investigation and Conclusion:

Based on the results obtained from different scenarios, wind power is always fully utilised because it is cost-effective. In addition, it is a renewable and environmentally friendly power source. Therefore, it is recommended that EPower should expand its wind power capacity in order to make more profit throughout the year. Air compressors and underground chambers can also be installed in which air is pushed into the chambers to be stored when the wind is strong. If there is no wind on a particular day, compressed air can be released into the generator to generate electricity. On the other hand, the alternative is for EPower to purchase more accurate weather data at the right price. This will reduce the probability of incorrect prediction of wind speed thereby making the daily operation more cost-effective. In reality, wind speed changes from period to period and season to season. Thus, the models could also be improved if the varying wind speed throughout the day and year are taken into account.

Last but not least, the base case model suggests that the operational cost and revenue are around £13M and £15M, respectively, which demonstrates that this is a business with very high running cost (around 87% of the revenue), thereby showing that this optimisation process is crucial for the business to run efficiently and profitably.