Case study: EPower

Introduction

`EPower` is provides electricity for a small country from five power sources: gas, coal, nuclear, wind and an interconnect. The company needs your advice on how to reduce its environmental impact. The objective is to maximize profit.

Terminology

Power output is measured in Megawatts (MW). Electricity (energy) generated is power output over a period of time: it is equal to "power" × "time" and is measured in Megawatt hours (MWh). So, for example, a power station operating at 5000 MW for four hours generates 20000 MWh of energy.

Power source parameters

The model of each power source has three parameters

- The maximum power output (MW)

  This is an upper bound on the power output

- The running cost (£/MWh)

  This is the cost of energy per MWh. For example, if a particular power source costs £30/MWh and operates at 5000 MW for four hours then the energy it generates [20000 MWh] costs £600000 = £30/MWh×20000 MWh

- The increase cost (£/MW)

  There is a cost for increasing the output of a power source. When fuel is used to produce heat, power cannot just be "switched on": extra fuel must be used before the output can be increased. When power is bought from another country, there is a penalty for increasing the amount bought. For renewable energy sources such as wind, there is a low cost of increasing power output. Although wind power output increases immediately if the wind blows harder, this clearly cannot be controlled!

  The cost of increasing power output cannot be modelled by multiplying the difference in power outputs by the cost in £/MW. If the difference is negative, this would allow money to be made by reducing power output! Thus the increase is modelled as a non-negative decision which must be at least the difference in power output.

Electricity is bought from EPower at a cost of £35/MWh

Emissions

Burning fossil fuels creates emissions which damage the environment, the principal ones being carbon dioxide (CO_2) and sulphur (as oxides SO_2 and SO_3). Sulphur is associated with burning coal and causes "acid rain" which has harmful effects on plants and aquatic animals. Carbon dioxide is the principal cause of global warming. `EPower` must not exceed daily limits of these two pollutants, whose emissions are linear functions of the amount of electricity generated from coal and gas fired power stations.

Demand

Power demand varies through the day and the total (net) output from the power sources must equal demand. Assuming that the demand pattern each day is the same, the power outputs in the final period of the day should be set with a view to demand "rolling over" at the end of the period to the level of the first period of the day.

Wind power

Generating electricity from the power of the wind is the most popular form of "renewable" energy. A power system will have particular installed generating capacity, but its theoretical maximum output is only reached when wind conditions are ideal. On a given day, the wind will only blow with a particular power and variations can be hard to predict. `EPower` has a theoretical maximum output of 22000 MW.

Interconnect

Another source of electricity is to buy it from another power system. For example, there is a cable connecting the British and French systems, allowing power to be transmitted between them. For `EPower` it is convenient to view this as a (relatively expensive) power source.

The consultancy process

As presented by a senior colleague of LPMS consulting.

Overview

- Develop a "**base case**" model which replicates current decision-making. This builds confidence with the client, demonstrating understanding of status quo and generating faith in future recommendations.
- Use the model to investigate what `EPower` has asked (see below for details). Gives the client what was asked for
- Identify a few further specific ideas for the client to consider. This shows we do more than the minimum
- Suggest what further consulting might consider. Hopefully this will lead to us getting a further fee!

Base case

Stage 1 of the case study is to develop a base case model and run it in the two extreme wind conditions

- The best case scenario: when the full wind power output is available for a sustained period
- The worst case scenario: when the no wind power output is available for a sustained period

"Sustained period" is taken to mean that the daily energy generation schedule for all sources is in "steady state".

Data The file `EPower0.dat` contains all the data required to model the company's system for planning purposes.

Decision variables: in each time period

- Power output for each source
- Increase in power output for each source (which is not simply the difference in output levels)

Identify the **Objective:**

- The income from the electricity produced to satisfy demand, less the costs due to electricity generation and increase in power output.

Identify the **Constraints:**

- Generator power output in each period must not exceed the maximum available
- Total power output in each period must equal the demand to be supplied
- Emissions limits must not be exceeded

Note that a simplified (interim) model which can be used for development is one with data for `Times: [1]` corresponding to average demand over the day.

Note that in order to develop the model and carry out investigations, it will be necessary to set up "special case" constraints etc for specific power sources. In particular, a power source can be limited (or removed) by working with a useable maximum power output value that is the maximum power output value multiplied by a positive (zero) constant.
The aim of developing wholly generic models driven which are blind to the content of index sets is an ideal which cannot always be achieved.

Investigation

Planning for the two extremes is too crude, but the average wind power output is uncertain. EPower wants advice on how to plan for a range of average wind power output scenarios and the effect of the following

- A political decision to stop using nuclear power
- An economic decision to build a pump storage system

You will consider these decisions for a particular average wind power output. The data for the model with a pump storage system are in `EPower.dat` This file contains a value for `AverageWindOutputMultiplier` that should be over-written with the particular value given to you.

Pumped-storage hydro

Natural flow of water due to rain falling in higher areas flowing to the sea via water systems is a source of energy used in many countries with high mountains. The potential energy of water falling as rain in mountains is converted into kinetic energy of flowing water which can be used to driver generating turbines. This is usually achieved by collecting water in a reservoir and releasing it when power is required. For `EPower`, the average natural flow into its planned reservoir corresponds to a power output of 400 MW. If this is collected over 24 hours, the reservoir contains 9600 MWh of energy which can be released at a maximum output of 2000 MW. This is a cheap energy source [once the expensive reservoir has been built] and can be switched on almost instantaneously. As such, it is ideal for satisfying spikes in demand. However, with the exception of countries like Norway, the nature of the geography is such that relatively little total power demand can be satisfied from pure hydro systems.
In countries whose upland areas are relatively small, reservoirs can be used to store significantly more potential energy than would accumulate naturally by using power generated at times of low demand to pumping water up to them. [Examples in the UK are Ffestiniog (360 MW) and Dinorwig (1700 MW) in Wales and Cruachan (440 MW) in Scotland.] At times of high demand, the water is released and the pumps operate as turbines to generate electricity. Not all the energy used to pump water up is recovered: the efficiency is about 80%. The store of energy in the reservoir is a natural inventory problem: in each period there is a flow in and out, and the amount stored must lie between zero and the maximum reserve. This store of energy must be the same at the end of a day as it was at the beginning

of the day: the standard inventory “wrap-around”. [The energy loss due to the imperfect efficiency of the system means that it should never be optimal to pump and release in the same period.]

Decision variables: In each time period EPower must (in addition to the base case decision variables) decide on the following:

- The power demand for pumping water
- The reserve in the reservoir. The latter is implied by the flows in/out but, like manufacturing inventory, it is easier to model with excess variables related by equations.

Objective: The cost of building the reservoir is modelled by adding £1 million to EPower’s daily costs

Constraints/bounds: In each time period

- Inventory constraint for the water stored in the reservoir
- Upper bound on the water stored in the reservoir at the end of the time period
- The power demand for pumping water must be added to consumer demand to ensure that enough power is generated in the rest of the system

Note:

- Results for the Stage 1 power system (without the pump storage reservoir) are obtained by setting the useable maximum hydro power output and natural inflow to zero, and then redefining the hydro-power model.
- The effect of not using nuclear power is observed by setting the useable maximum nuclear power output to zero.

Deliverables

You will deliver your findings as Mosel model and written report. Your report whould have a cover page and no more than 4 sides of A4. Your model consistes of one MOSEL file and data file for its scenario. The breakdown of marks to be assigned is as follows

Marks	For
25	Results
25	Mosel skills
25	Report content
15	Report-writing skills
10	Bonus

The bonus is for observations/conclusions/recommendations and unprompted investigations

Report

The report should be written for a manager who understands the electricity supply industry and business, but not linear programming. The report should introduce the aspect of the company to be investigated, placing the investigation in context. It should not include large tables of data (refer to an appendix if necessary) or “equations”. It must state the “base case” results clearly, using tables and charts (sparingly), showing the client that you are starting from a point well-understood. Consider the points to be investigated systematically, using tables and charts (sparingly), and don’t just give results, but also

interpretation and analysis. Think what else you could investigate with your model and offer general observations, conclusions and recommendations.
Aim to produce a neat and tidy document with right-left justified text, reported values quoted to a sensible number of significant figures and with tables and charts a sensible size. Don't spend **hours** beautifying your document since this can raise suspicions that the content might be weak. Something of **you** should come across!

Model

Write the model to be readable by a Mosel user, ensuring that the base cases and (at least) your average maximum wind power scenario can be solved using your (modified) `EPower.dat`. Submit the file `EPower.dat` corresponding to your scenario. Use good Mosel style.
Note that you will be solving multiple models corresponding to different scenarios. If you make use of the Mosel's ability to use a `procedure` to report results after each LP has been solved, then it will simplify your model by avoiding duplicated code.