Powering the Future: A card exercise for classroom use.

Pam Dugdale, Head of Physics, Cronton Sixth Form Campus, Riverside College, Halton, Cheshire, UK.

Email: pam.dugdale@cronton.ac.uk

Introduction

This paper introduces a card exercise which allows students to make decisions about how best to provide electrical power to their country. The work presented emphasises the use in the classroom of real data to solve real problems, in this case balancing electrical power supply and demand in the UK. With some additional research the task may be easily adapted for use in other countries. Whilst completing the activity, the students are required to make important choices between renewable and non-renewable electricity generation. It is a highly differentiated task ranging from simple addition to quite challenging calculations taking into account the availability and variability of natural resources. This means that it can be used with classes from Year 9 through to Year 13.

The card exercise

The exercise sets a fixed target for national electrical power demand, say 50,000 MW, and the students are required to use the information provided on the pack of information cards to find a combination of power generators that would meet this demand. Each card provides data or equations relating to a particular type of power generator, e.g. coal-fired power station, wind turbine or hydroelectric.

The information cards are organised into difficulty levels. Level 1 cards are the simplest, and provide typical power output. For example, the Level 1 card for an onshore wind turbine is shown below:

Wind Turbines

Level 1

Wind turbines convert the kinetic energy of the wind into kinetic energy of the turbine blades. A generator converts the kinetic energy of the turbine blades into electrical energy.

Typical power output = 2 MW

www.bwea.com
http://www.bbc.co.uk/news/uk-wales-10883774

Cenmaes Windfarm, Wales

Higher-level cards add increasing degrees of complexity, such as geographical and natural resource limitations. Level 2 cards give information about less traditional types of power generator, such as wave power and tidal power. They also require a higher level of mathematical ability. For example the data given for photovoltaics is power per unit area and students must make judgements and estimates about suitable panel sizes.

An example of a Level 2 card for a tidal barrage is shown below:

Tidal Barrage

Level 2

A tidal barrage power station converts the gravitational potential energy of water which has been trapped behind the barrage at high tide into electrical energy. The water flows back to the sea at low tide. Water turbines convert the kinetic energy from moving water into kinetic energy of the turbine blades. A generator converts the kinetic energy of the turbine blades into electrical energy.

Real data for proposed UK barrage sites:

	Capacity / MW
Severn – outer line	12000
Severn – inner line	7200
Solway Firth	5580
Morecambe Bay	3040
Wash	2760
Mersey	620

www.merseytidalpower.co.uk

Potential site of Mersey Barrage

Level 3 cards are significantly more challenging. For example, the Level 3 wind turbine card requires the students to use the equation for power of the wind hitting a wind turbine with real wind speed data from across the UK. At this level, the students are also expected to consider the problems of the generator switch-on time and the problems associated with storing energy to meet fluctuating demand.

An example is shown below:

What happens if the wind doesn't blow?

Level 3

A wind turbine rated at 2 MW will only produce this much power when the wind is blowing at 13 ms^{-1}.

The equation which allows us to calculate the power from the wind is:

$$P = \frac{1}{2}\rho A v^3$$

where P is the power in Watts, ρ is the density of air in kg m^{-3}, A is the swept area of the turbine blades in m^3, and v is the wind speed in ms^{-1}. In addition, wind turbines have an efficiency of about 30% (similar to most other types of power station).

Typical wind speeds for locations across the UK:

Location	Sheltered terrain / ms^{-1}	Sea coast/ ms^{-1}	Open sea/ ms^{-1}	Hills and ridges/ ms^{-1}
SE England and Midlands	4.5	6.0	7.0	9.0
Wales and N England	5.0	7.0	8.0	10.5
Scotland	6.0	8.5	9.0	11.5

Note: These values give the wind resource at 50m above sea level.

AQA AS Physics Breithaupt

Cenmaes wind farm Wales

Progression to higher levels increases the amount and complexity of the information provided. Students are also asked to consider mechanical and thermal efficiencies and fundamental limits such as the Betz limit for wind power.

Finally, the problems associated with public opinion are tackled. These include the opinions of anti-nuclear and anti-windfarm as well as anti-pylon protest groups. Challenges associated with the relative locations of power supply sources and high-demand areas, such as cities, and the impacts these have on the expansion of the national grid distribution network are also considered.

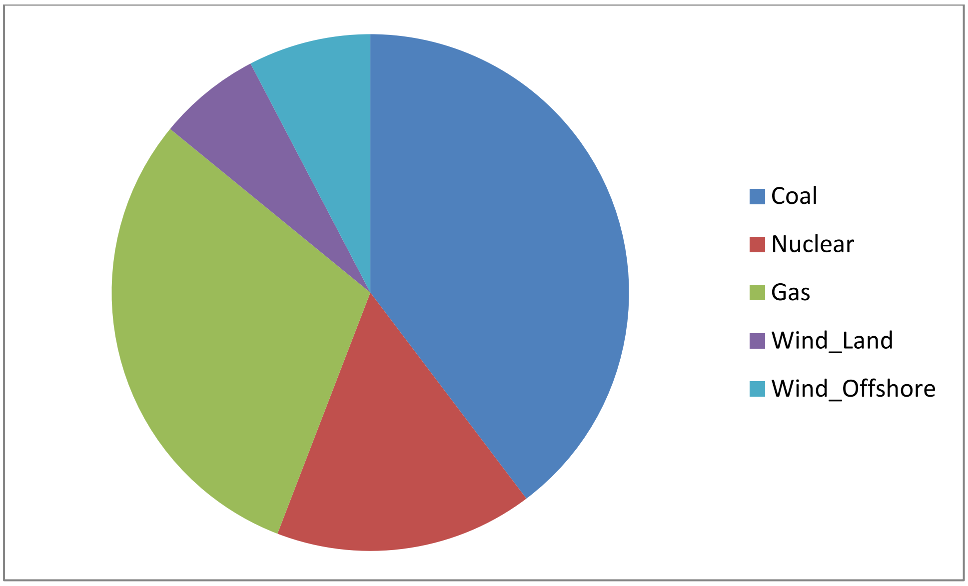
Running the exercise

During the lesson, the students work in groups of between 2 and 4. They are given a power demand target. This could be a typical value, say 50,000 MW, or a real-time live value taken from the national grid website. Their first task is to use the Level 1 cards to suggest a combination of power stations to meet the demand. This is their 'proposal' which must be submitted to the teacher in an appropriate format, for example a completed proposal form or poster. The students then move on to Level 2 cards and use the additional information to modify their power production plan.

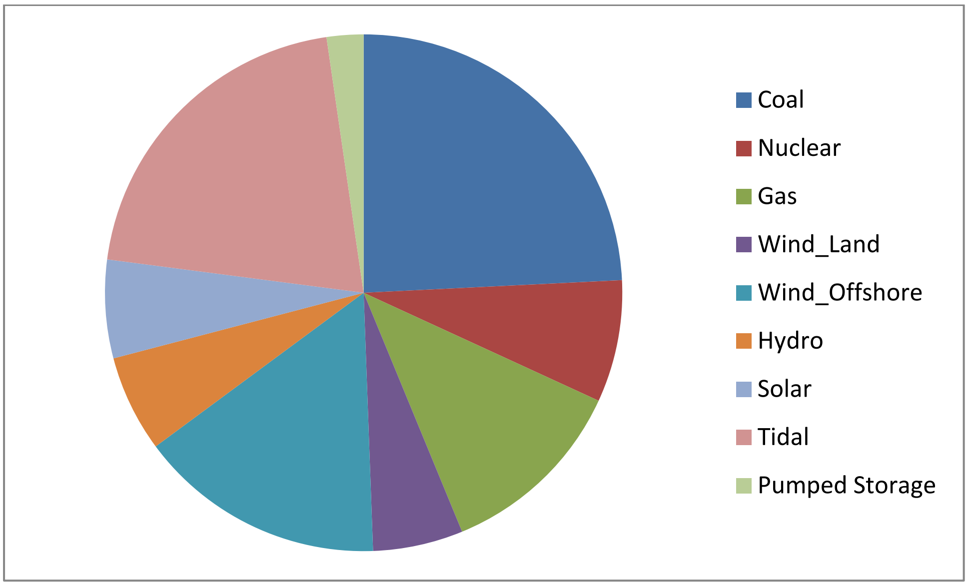
This process is repeated, making use of higher level cards, until the students are happy with their proposal or can progress no further as the task requires use of skills and knowledge above their current academic level. The teacher can control this by not handing out cards above Level 2 for younger learners. Throughout the lesson the teacher acts as a facilitator and guides students through the problem solving, estimation and calculation process.

At end of the lesson, the teacher reviews outcomes with each group, and the class. The final results can be presented as a report or poster and may involve statistical analysis of the group and class data, presented as pie or bar charts. Examples of results from a group of 30 Year 12 students are given below. These show a clear shift towards tidal and offshore wind, and away from fossil and nuclear fuels:

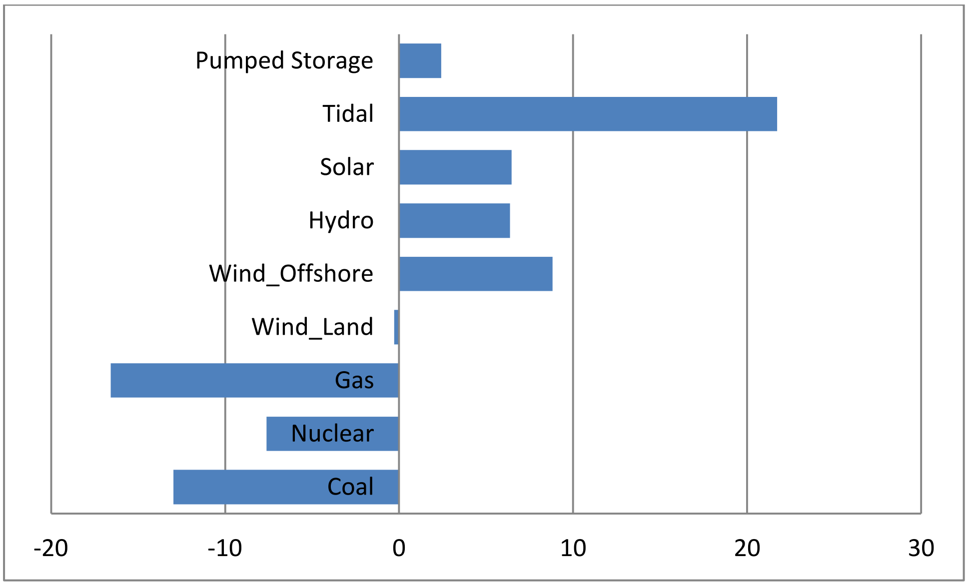
Year 12: Results from initial proposal (Level 1 cards)



Year 12: Results from final proposal (Level 4 cards)



Year 12: Percentage change between initial and final proposal



Reflection

One of the main challenges in preparing this task is sourcing all of the data. In many cases the best source is the manufacturer or power company. For example, wind turbine data is freely available on manufacturers' websites and most power companies list the capacity of their power stations on their corporate websites. Geographical information for tides and wind speeds is also available on the internet and from a range of published material. For further details see [1].

This task has been trialled with four different student groups. The youngest students were in Year 9 and the oldest students were in Year 13. The Year 9 students were provided with only the Level 1 and Level 2 cards. The Year 13 students were provided with all of the cards and had previously studied many aspects of electrical power production.

All students who completed the exercise benefited from practising manipulating data with different prefixes e.g. kilo, mega, giga and handling large numbers. At the higher levels the students made use of the equations for kinetic energy and gravitational potential energy, and the derivations of equations for the power of the moving air hitting a wind turbine and the power from a tidal barrage. They also used density calculations and worked with new concepts such as mass flow rates and volume flow rates.

The feedback from all students was good. The students tended to be pro-wind power but quickly realised the very large numbers of wind turbines required to meet demand and were able to quantify the power loss that occurs when the wind doesn't blow. To resolve this, the younger students tended to take the mathematically easier route of adding several large coal-fired or nuclear power stations to their proposal. It was observed that many of the students taking part in the trial lived in the vicinity of a large coal-fired power station, which may have influenced their attitudes towards this potential solution. Some lower-ability students made few changes to their original plans as they struggled to manipulate the data and equations required to develop alternative strategies. In many cases students of all ages and abilities identified the need for 'redundancy', and proposed solutions that would supply more power than was nominally required, in case a power station failed.

The Year 12 and 13 students were able to make reasoned estimates to support their proposal. For example, they calculated the total roof space available for photovoltaic solar panels by making reasonable approximations of national population and the number of domestic houses, the probability of a house having a south-facing roof, and the approximate size of a roof. The Year 13 students were able to include additional knowledge learned from their course and enrichment activities, such as an interest in Thorium nuclear power sparked by attending a Christmas Lecture at a local university and discussions with the education outreach officer from the local STFC Daresbury Laboratory.

The most able students suggested that the information card exercise might be further refined with the consideration of financial data, such as the building, maintenance and running costs for each type of power generator data.

In conclusion, the task has now been successfully trialled with around 80 students of varying academic abilities and backgrounds ranging from Year 9 to Year 13. It has worked well in all cases, and kept students actively engaged for between 60 and 90 minutes.

Reference

[1] “Students to solve the world’s energy problems, An analytical approach to teaching alternatives to carbon” Dugdale. P. Accessed online:
http://www.iop.org/activity/groups/subject/env/prize/file_52517.pdf

[last accessed 18th May 2012]