# ADVANCED CONNECTIONS | CYSYLLTIADAU PELLACH

PHYSICS MENTORING PROJECT | PROSIECT MENTORA FFISEG

# PRE-TUTORIAL MATERIALS

## SESSION 7: WE'RE ALL PHYSICISTS

For this tutorial, you will plan a wind farm in Wales using the knowledge provided, and your own skills as a physicist. You will then present your plans in the tutorial session.

# TASK 1: WIND TURBINE ENERGY YIELD

**15 MINS**

## THE PHYSICS

The power available from a flowing fluid (e.g. air) is:

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

$E =$ power available (W)
$A =$ area
$\rho =$ density of air = 1.2 kg $m^{-3}$
$v =$ velocity of fluid

You can use this equation to work out how much energy is produced by a wind turbine (also known as the **energy yield**)

All of the example projects in this task are based on **real project plans** for wind farms in Wales!!

$$A = \pi r^2$$

area of a circle

## WORKED EXAMPLE

Let's have a go with a real-life example:

*NOTE: the blade diameters and wind speeds given in these examples are estimated/arbitrary values for the purpose of this worksheet.*

**Nant Mithil Energy Park**

This proposed wind farm will have up to **31 turbines.** Each turbine has a blade diameter of **162 m.** The wind speed at the site is **12.40 m/s.**

**1** First, extract the information you need:

$A =$ 20,612 $m^2$
$\rho =$ 1.2 kg $m^{-3}$
$v =$ 12.40 m $s^{-1}$

**2** Now input this into the equation:

$$E = \frac{1}{2} \times 20,612 \times 1.2 \times 12.4^3$$

$$E = 23,579,600 \text{ W} = 23.6 \text{ MW}$$

**3** What's the energy output for the whole wind farm?

$$E = 23.6 \times 31$$

$$E = 731.6 \text{ MW}$$

## NOW YOU TRY!

**Twyn Hywel Energy Park**

This proposed wind farm will have up to **14 turbines.** Each turbine has a blade diameter of **159 m.** The wind speed at the site is **11.13 m/s.**

**Aberedw Energy Park**

This proposed wind farm will have up to **18 turbines.** Each turbine has a blade diameter of **163 m.** The wind speed at the site is **12.12 m/s.**

**Lan Fawr Energy Park**

This proposed wind farm will have up to **40 turbines.** Each turbine has a blade diameter of **161 m.** The wind speed at the site is **12.29 m/s.**

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## HOMES POWERED EQUIVALENT

The annual average domestic household consumption is 3,239 kWh (Jan 2024, DESNZ).

The "homes powered equivalent" is a way of putting the amount of energy generated from renewable sources into perspective. You can calculate it using:

The load factor is the **actual** output of a turbine benchmarked against its theoretical minimum output in a year. For onshore wind power over 5 MW, it's 44.8% = 0.448.

**Homes powered equivalent =** $\dfrac{\textbf{wind farm output (MW) x load factor x number of hours in a year}}{\textbf{average annual domestic household consumption (MWh)}}$

## WORKED EXAMPLE

We're going to use the same wind farms again to calculate their homes powered equivalent:

**Nant Mithil Energy Park**

$$E = 731.6 \text{ MW}$$

**Homes powered equivalent =** $\dfrac{\textbf{731.6 MW x 0.448 x 8,760 hours}}{\textbf{3.239 MWh}}$ **= 886,430 homes**

## YOUR TURN!

**Calculate the homes powered equivalent for the 3 other wind farms.**

## COMPARISONS

On the websites for each wind farm (each button has the link), the MW produced and homes powered equivalent is **much lower** than the values we've just calculated.

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# TASK 2: DESIGN A WIND FARM!

## 30 MINS

Now you're going to have a go at designing your own wind farm in Wales! You will choose the location and type of turbines for your farm. You will be expected to **present your design** in the tutorial session. If you want to make a PPT you can do so, but it's not essential.

### THE LOCATION

There are lots of things to consider when choosing the location of your wind farm:

### WIND SPEED

Wind turbines don't work well at **very low or very high** wind speeds. The minimum/maximum wind speeds are called **cut in/cut out** speeds. Outside of this range, turbines will not rotate:

- **Low Speeds:** the wind isn't strong enough to generate electricity, so the turbine is shut off to avoid unnecessary wear and tear.
- **High Speeds:** protects the machinery and maintains the longest possible lifespan of the blades/machinery. The turbine is shut off, and the blades are rotated to minimise friction depending on the wind direction.
- **Optimal Wind Speed:** typically 12-15 m/s, depending on the turbine.
  - Below this speed, the turbine power output decreases according to the equation given on the last page.
  - At speeds above this, the turbine power output remains constant until the cut-out wind speed as machinery within the turbines prevents overloading.

### ENVIRONMENTAL CONSIDERATIONS

When building turbines, some areas have **planning constraints**:

- Sites of Special Scientific Interest **(SSSI)**
  - A national designation (UK only) which protects a variety of features
- Special Protection Areas **(SPAs)**
  - European designation for protection of birds
- **Peatland**
  - Peatland is a carbon dioxide store, and the ground is too wet to build turbines on
- **Ancient Forestry**
- Proximity to **residential dwellings**

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## TASK 2: DESIGN A WIND FARM!

### 30 MINS

### THE LOCATION CONT.

You can use the following data maps to find a good location for your wind farm based on wind speed and planning constraints:

[Global Wind Atlas]

[Planning Constraints Map]

### TOP TIPS

- It's got to be in Wales
- Can you transport turbines safely to the top of a mountain?
- Would you have to pay to build roads to the site?

### THE TURBINES

You will need to choose your turbine. Different turbines have different specifications and prices:
*NOTE: the prices given in these examples are arbitrary values for the purpose of this worksheet.*

**OPTION 1:** Vestas V162-6.2 MW
Price: £5.2 million
Rotor Diameter: 162 m
Wind Speed Range: 3 - 25 m/s

**OPTION 2:** Nordex N163/6.X
Price: £5.7 million
Rotor Diameter: 163 m
Wind Speed Range: 3 - 26 m/s

**OPTION 3:** Cypress 6.0-164
Price: £5 million
Rotor Diameter: 164 m
Wind Speed Range: 3 - 25 m/s

### DON'T FORGET TO CONSIDER

- Balance the cost of the turbines against their energy yield - are they worth the money?
  - Hint: use the equation on Page 1!

### THE PRESENTATION

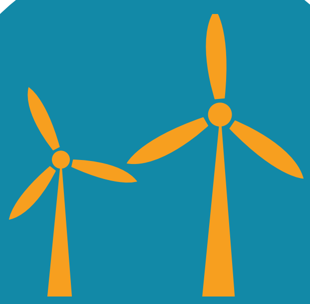
Get creative! Presenting ideas is an important skill to learn for your future education and career.

You could present your wind farm using:

- A PowerPoint
- A leaflet/poster
- A verbal essay
- A website (if you know how to do that!)

**Nervous about presenting?**

- Take some time to practice
- Make notes of what you're going to say
- Take a deep breath - you've got this!



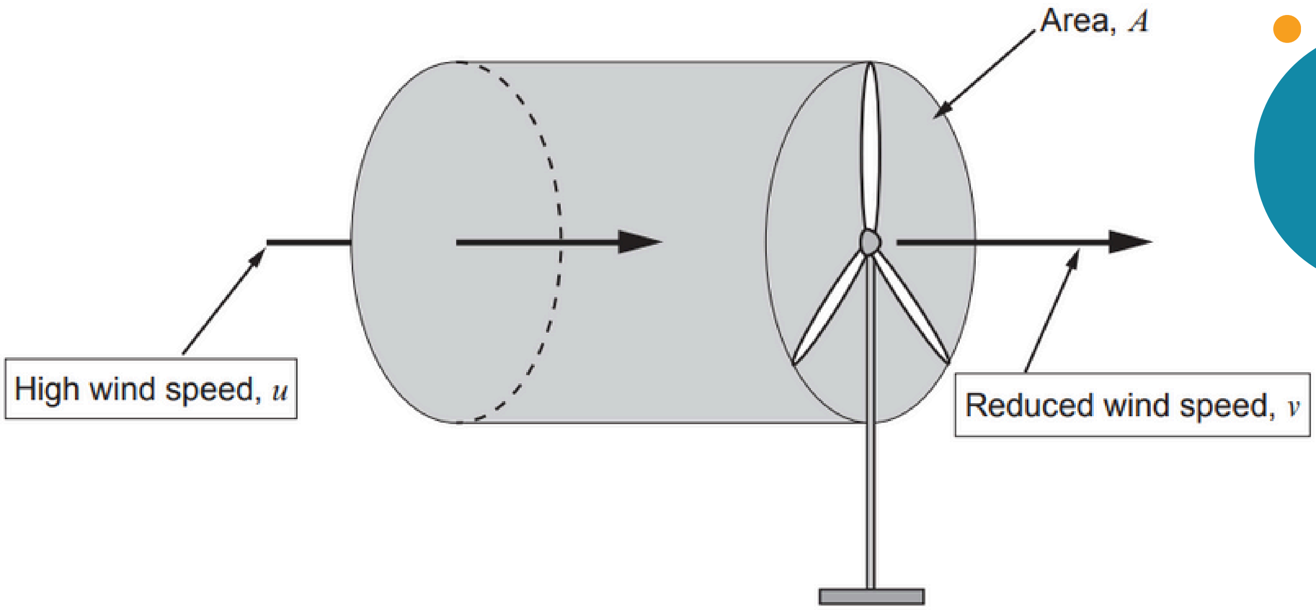
## SESSION 7: WE'RE ALL PHYSICISTS

# OPTIONAL EXTRAS

## EXAM PRACTICE

Try these exam questions:

Wind turbines are used to generate electrical energy. They work by converting as much as possible of the kinetic energy of the air that moves through the area swept out by the blades into electrical energy.




*(a)* (i) The volume of air arriving on the blades per second is $Au$. Show that the kinetic energy per second (the power, $P$) arriving is given by:

$$P = \tfrac{1}{2} A \rho u^3$$

where $\rho$ is the density of the air. [2]

(ii) Use the above equation to complete the following sentences: [2]

(I) The power arriving is proportional to the *square of the radius*. So doubling the length of the turbine blades will increase the power arriving by a factor of

..............................................................

(II) Doubling the wind speed will increase the power arriving by a factor of

..............................................................

(iii) The blades cannot remove all the energy arriving from the wind. Having passed through the blades, the moving air has a reduced speed, $v$, as shown in the diagram. The following equation can be used to approximate the power possessed by this moving air:

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

Use this equation and the one in *(a)*(i) to write an expression for the power **lost** by the air as it passes through the moving blades. [1]

## SESSION 7: WE'RE ALL PHYSICISTS

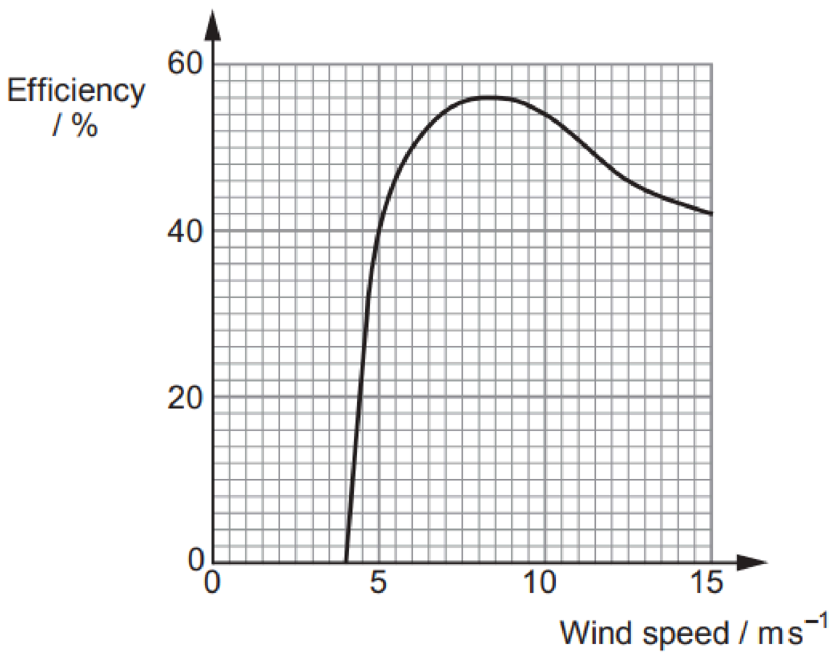
# OPTIONAL EXTRAS

## EXAM PRACTICE CONT.

(iv) Suggest why it is not a good idea to erect wind turbines short distances behind each other. [1]

(v) A wind turbine has blades of length 2.0 m. Wind of speed 7.0 m s$^{-1}$ arrives on the blades, which is reduced to 5.0 m s$^{-1}$ after passing through the blades. Calculate the net power input to the wind turbine. [Assume $\rho_{air}$ = 1.2 kg m$^{-3}$.] [2]

*(b)* The calculation in *(a)*(v) assumes that all the kinetic energy lost from the wind is converted into electrical energy. This is not the case as electrical generators in the wind turbines are not 100% efficient. A significant amount of energy is lost due to friction between the moving parts of the turbine for example. Below is a typical graph of efficiency against the speed of the wind arriving on the blades.




(i) Suggest why no power is generated for wind speeds up to 4.0 m s$^{-1}$. [1]

(ii) Use the graph to determine the actual power generated by the turbine in *(a)*(v) in a wind of speed 7.0 m s$^{-1}$. [2]

*(c)* State why an undersea turbine of the same size as the wind turbine in *(a)*(v), when placed in a water current of speed 7.0 m s$^{-1}$, would provide significantly greater power output than the wind turbine. [1]