# Engineering and Project Management: Developing a Wind Farm

## Introduction

Mathematics is an important aspect of any construction project, whether it be a small garden shed or a large scale wind farm. Construction workers use a variety of different areas in mathematics whilst practicing their trade. For example, trigonometry is useful for calculating the pitch of a roof or the height of a windmill whilst financial maths ensures that all the project expenses are being accounted for. In fact, mathematicians and engineers regularly collaborate with one another on various construction projects and this requires a variety of skills including communication, teamwork and problem solving.

## Aim of Workshop

The aim of this workshop is to engage students in the type of maths that is involved in the construction of a wind farm, whilst also developing their communication and team working skills. There are two proposed sites to host the wind farm and our engineering firm have to decide which site is most appropriate. The students will therefore be divided into two groups: Site 1 and Site 2. There will be six subgroups in each of the site groups and they will each have their own goals and tasks to work on. At the end of the workshop, the findings from each site will be accumulated and presented at "the final pitch" in a bid to win an investment.

## Learning Outcomes

By the end of this workshop students will be able to:

- Recognise the importance of teamwork and communication
- Work effectively in groups on a common task
- Apply their mathematical knowledge to a real world problem.

## Materials and Resources

**Group 2:**
Protractors, scissors, rulers, coloured paper

**Group 4:**
Rulers

## Engineering & Project Management: Workshop Outline

| SUGGESTED TIME (TOTAL MINS) | ACTIVITY | DESCRIPTION |
|---|---|---|
| 10 mins (00:10) | **Introduction to the task and the structure of groups** | – Depending on the numbers of students, divide students into groups "Site 1" and "Site 2". (There needs to be at least 12 students in each site).<br>– Ensure that there are 6 subgroups in each of the two site groups.<br>– Inform students that each of the two sites must select a project manager to deliver the final pitch. This student needs to know what each subgroup is doing and be a good presenter in order to win the clients' bid. The project manager should also be a member of or join subgroup 3).<br>– Explain to students that each subgroup must work on their own activity sheet and communicate their answers to the other specific groups (noted on their activity sheet) using a reporting sheet (included in Appendix). (It might be useful to discuss with students why such a reporting mechanism might be useful).<br>– Additionally, each subgroup must also appoint a coordinator for their group who is responsible for delivering the report sheet to the relevant subgroup.<br>***Note:*** *Some of the activity sheets have different values for Site 1 and Site 2 hence they are all arranged according to the Site* |
| 40 mins (00:50) | **Activity Sheets** | – Distribute the activity sheets so that each subgroup has a different worksheet (1 to 6).<br>– Students work together to complete the activities on their designated worksheet.<br>– The coordinators of the subgroups deliver the relevant figures and information to the group indicated on their activity sheet.<br>– The project manager gathers all of the information and collaborates with his site teams on the final pitch. |
| 10 mins (01:00) | **Pitches** | – Ask the project managers of both "Site 1" and "Site 2" to make their final pitch.<br>– It may be useful to bring in external parties (teachers, parents, university lecturers etc.) to determine the winning site.<br>– The group with the most ideal proposal wins the contract. |

# Report Sheet Site ___

**To Group:**

**From Group:**

**Report:**

# Site 1

## Engineer Group 1

### Windmill Technicians

Engineers your brief is as follows: we need you to figure out the height and orientation of the windmills that are going to be in our energy farm. Some of the information you will need has already been collected by our scientists, but we need you to make sense of that data and make the best decisions you can to maximise energy output from the windmill.

You will need to work with other groups for this exercise. Assign one person to coordinate with other groups and to coordinate with the project manager.

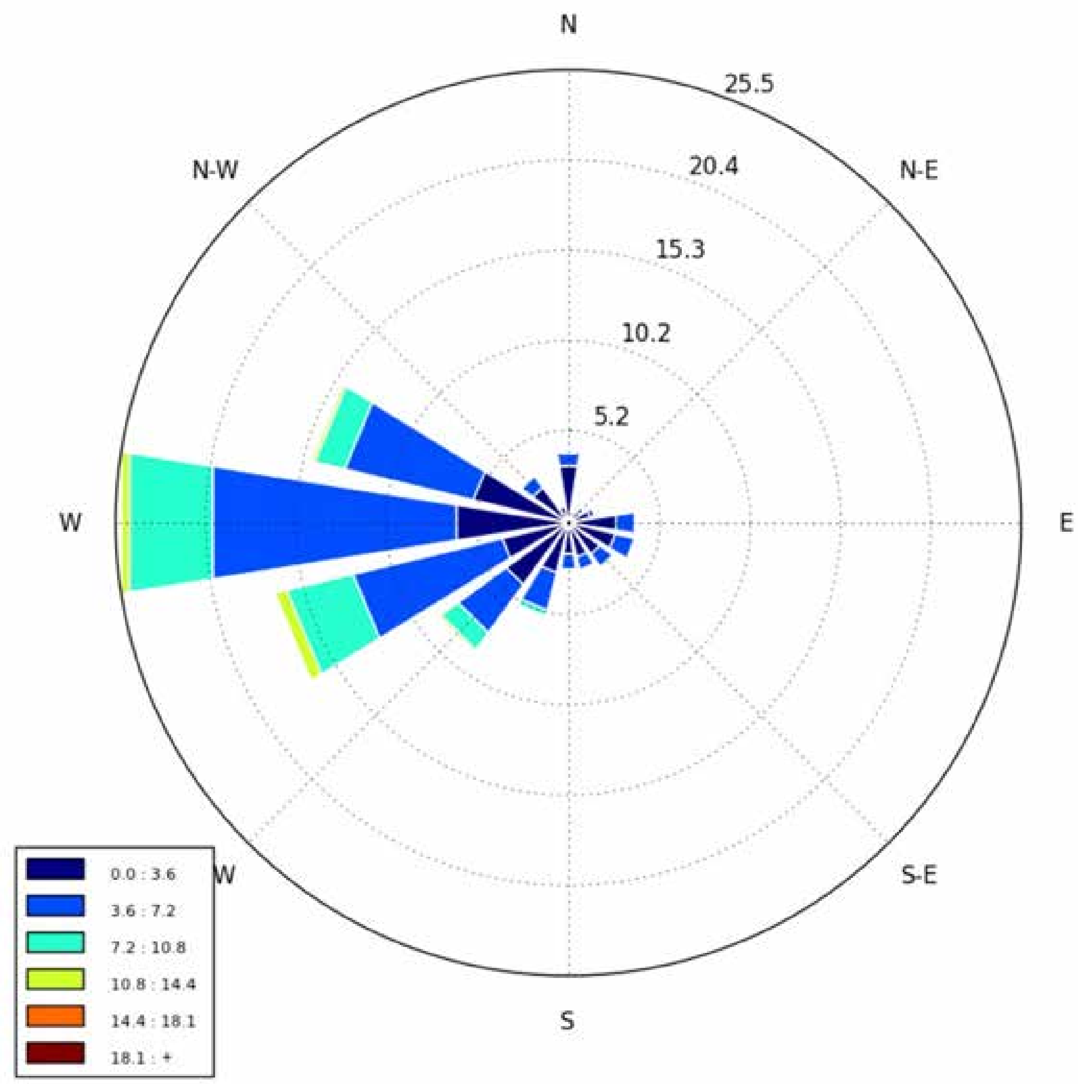
You have **three** tasks

### Task 1: Your first task is to decide on the best orientation for the windmills.

To do this we will be looking at **rose plots** (graphs that measure wind speed (**in knots**) and direction). These graphs give you two different pieces of information:

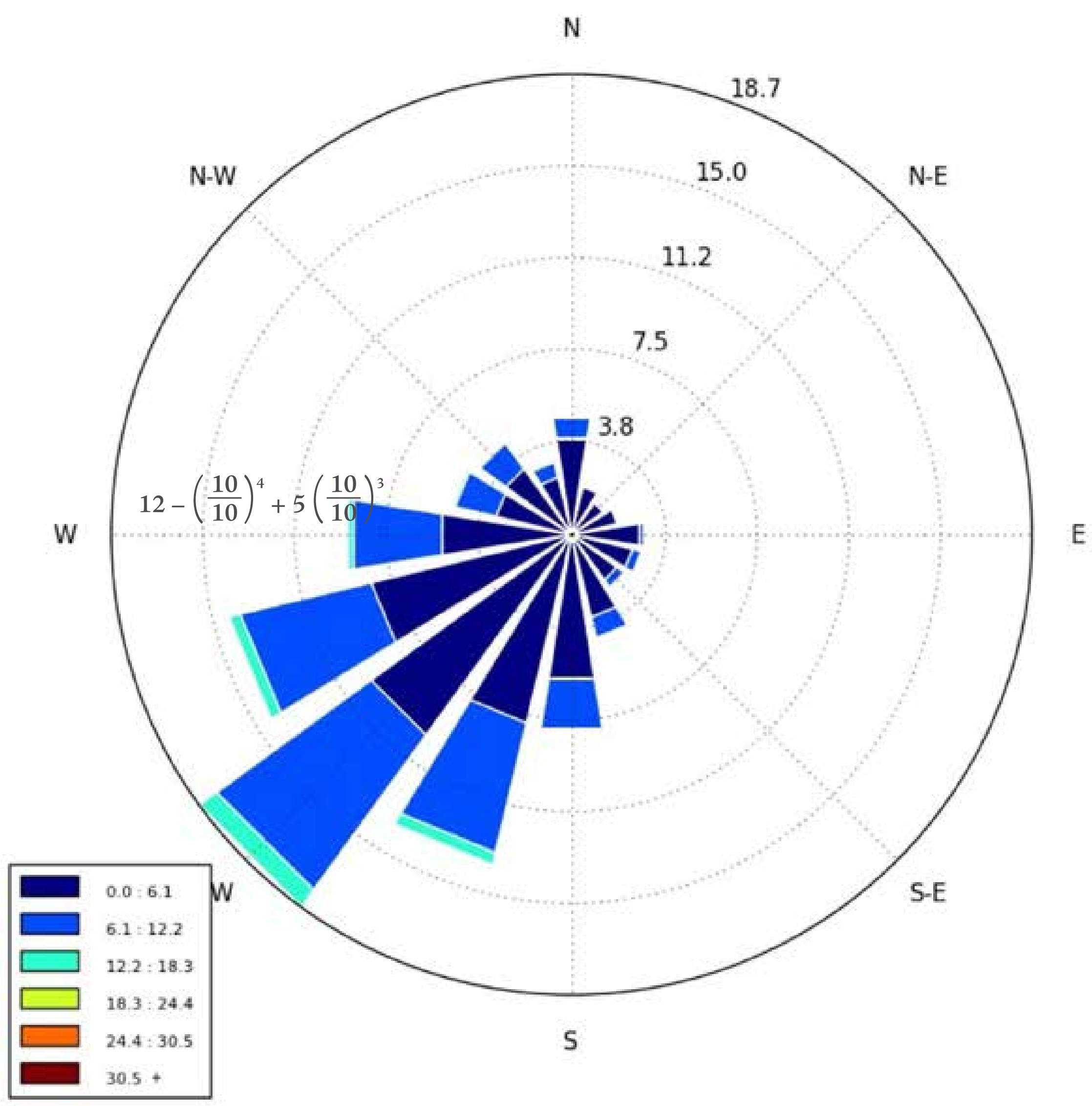
1. The **length** of the bar tells you **how much wind** came *from* that specific direction during the year. The longer the bar, the more wind came from that direction.
2. The colours in the bar tell you **how strong** the wind that came from that direction was. If a bar has lots of light blue or yellow that means the wind from that direction is very strong, if it has mostly dark blue, the wind from that direction was mostly weak (Remember, the lighter colours give the strongest wind!)

Here are two rose plots for the site, collected by Met Éireann, the first is average for the summer months, and the second is average for the winter months.




Credit http://www.niallmcmahon.com/swc_2015_notes.html

**Summer Wind Data (in Knots)**




Credit http://www.niallmcmahon.com/swc_2015_notes.html

### Winter Wind Data (in Knots)

Given these graphs, decide what direction the windmills should face in order to maximise the amount of wind they will receive.

When you have this done please report, using the report card, to **Group 2** with your findings before moving on to the next activity.

## Task 2: Find the most suitable height for the windmill

Our scientists have found that the relationship between wind speed and height from the ground is

$$Wind\ Speed = 12 - \left(\frac{Height}{10}\right)^4 + 5\left(\frac{Height}{10}\right)^3$$

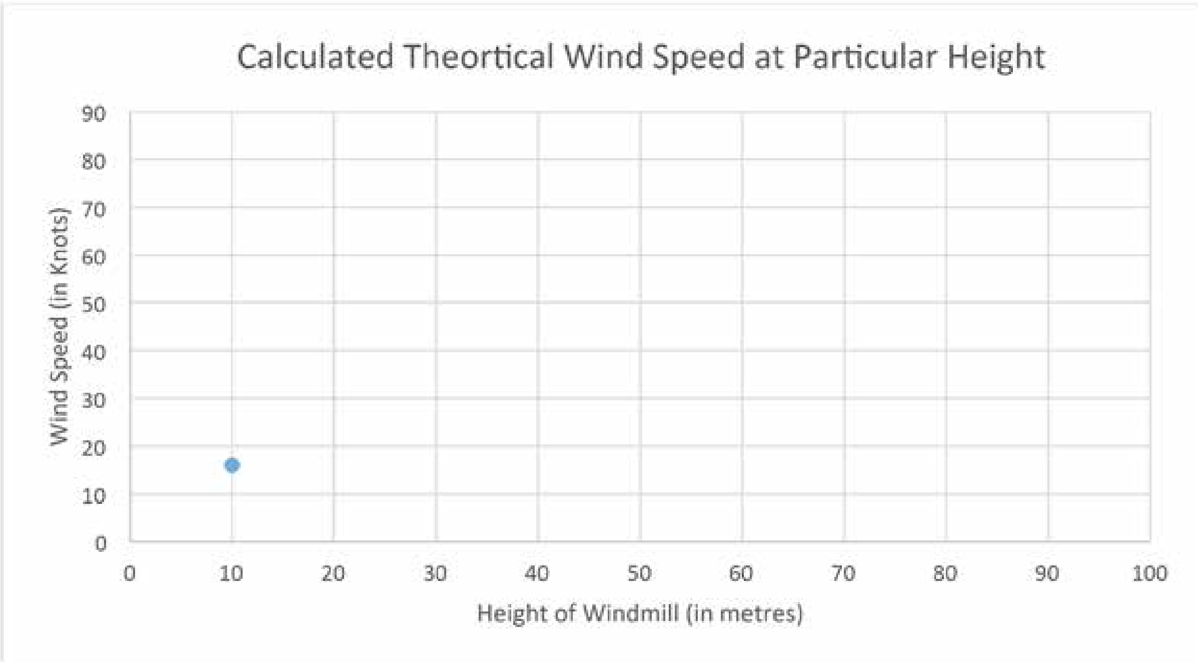
To get a sense of what windmill height will capture the best wind speed we need you to check different values for height and find the wind speed at that particular height. The first is done already:

| HEIGHT (M) | WIND SPEED EQUATION | (WORK OUT FRACTIONS) | (WORK OUT POWERS) | (SIMPLIFY) | VALUES (HEIGHT, WIND SPEED) |
|---|---|---|---|---|---|
| 10 | | $12 - 1^4 + 5(1^3)$ | $12 - 1 + 5(1)$ | 16 | (10,16) |
| 20 | | | | | |
| 30 | | | | | |
| 40 | | | | | |
| 50 | | | | | |

**What's our best estimate for the height of the windmill?**

**Plot your findings to try and find a better answer.**

For each of the values we found, record a point on the graph that corresponds with the x and y axis. The first one is done as an example:




**What's our best choice for the height of the windmill now?**

(Is this different to our previous estimate?)

## Task 3. Find out the maximum height that we can safely make the windmills.

For this you need to go to the Safety Engineers (**Group 6**) and ask for their findings.

Given all of the information you have gathered please choose at what height and orientation you have decided the windmills should be. Record your findings on a separate sheet and give to your project manager.

**Congratulations, engineers!** You have successfully completed this exercise. If you're done, see if you can assist other teams on your site

# Site 1

## Engineer Group 2

### Spatial Engineers

Engineers, your goal is to find the maximum number of windmills that can be safely installed into the site.

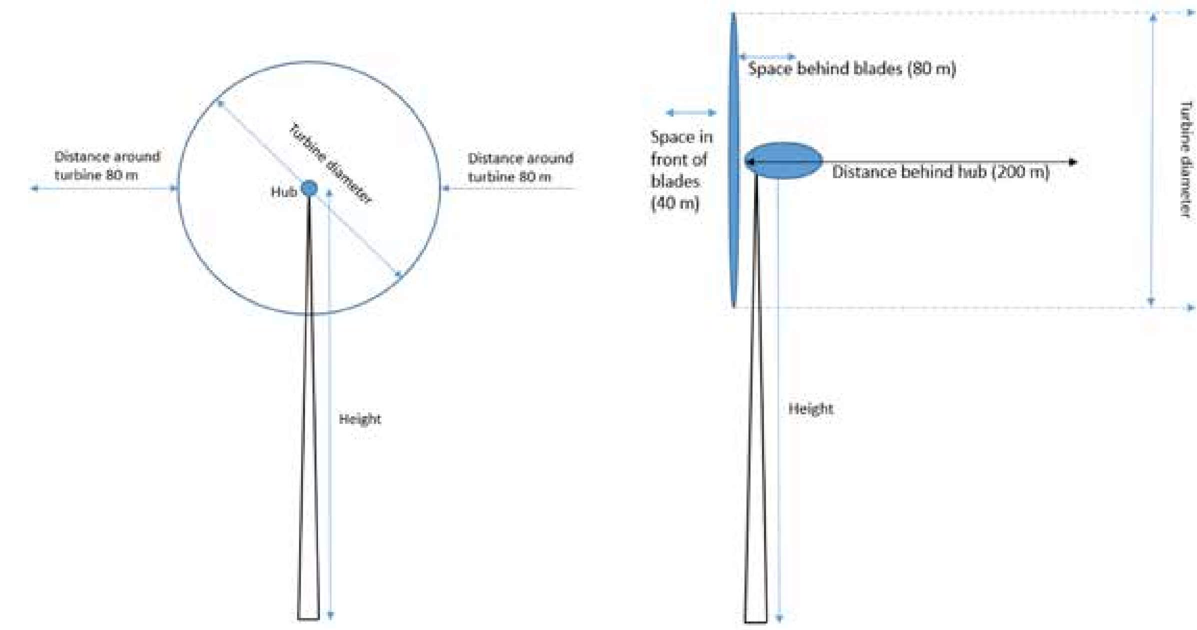
You will need to work with other groups for this exercise. Assign one person to coordinate with other groups and to coordinate with the project manager.

This exercise is split in two parts. In the first part you will calculate the **space** that is required to be left clear around each turbine. Then, using information provided by **Group 1**, you will decide the maximum number of turbines that we can safely have on the wind farm.

## Task 1: Assess the space needed for each turbine.

For safety reasons, there are regulations about how close each turbine can be to another. However, the space that is needed around a turbine is determined by its size. The size of the turbine is its turbine diameter. Windmills with large turbine diameter are built to be taller. There are two graphs below:

- **Graph 1 shows:**
  - The typical height of a windmill given the turbine diameter.
- **Graph 2 shows:**
  - The amount of space that should be left clear in front of turbine's blades,
  - The space that should be left clear behind the turbine's blades.
  - The space that should be left clear directly behind the hub centre. The hub centre is at the centre of where the turbine blades meet




To calculate the clear area needed around each turbine:

1. Consider the two schematics shown above. It shows that:
   a. 80 m must be left clear at every point behind the blades
   b. 40 m must be left clear at every point in front of the blades.
   c. 200 m must be left clear behind the centre of the hub.
   d. 80 m must be left clear around the turbine blades.

2. Consult with each other to design a shape that represents the area required around each turbine. You are welcome to come up with more than one design if you like as long as they satisfy the safety regulations above. There is no one right answer. Be creative!

## Task 2: Find the maximum number of turbines possible to place onto the site

Now that you know the dimensions of the shapes, you'll need to figure out how many of each shape you can fit onto the site.

**Here's how to proceed. For each shape you have designed:**

1. Make lots of cut–outs of that shape. Make sure that they are the dimensions that you decided in the last part.
2. The scaling is 1 cm to 100 m.
3. Consult with the engineers in **Group 1** to find out the direction in which the turbine should be pointing.
4. Use this direction to orient the shape on the site (picture given below).
5. Fit as many of the shapes as possible. (Be careful though to keep the wind mill pointed in the correct way).
6. Report your final answer to the engineers in **Group 5** so they can complete their exercise.


Fill out one project card and hand it in to your project manager.

**Congratulations, engineers!** You have successfully completed this exercise. If you're done, see if you can assist other teams on your site.

# Site 1

## Engineer Group 3

### Financial Analysts

Engineers, your goal is to analyse the cost and profit from the site. You will need to work with other groups so appoint somebody from your group to be the coordinator.

The project manager, who is also a member of your group, will have this task of representing the whole site. Ensure that your project manager is involved and updated at every stage so that they can make the best case for this windfarm.

### Task 1: Find the costs of building a wind farm

There are a lot of costs when it comes to building a wind farm. In fact, we will not be able to consider all of them but we will consider the most important or obvious ones.
We can think of the costs under the following headings:

1. The Site
2. The Components
3. Maintenance
4. The Engineer

## 1. The Site:

**It costs money to purchase the site. Consult with the Land Surveyors from Group 2 to get the cost of purchasing the land:**

It also costs money to prepare the land. This means that you will have to make clear large rocks, big bushes and shrubs and level the land. This will cost a flat rate of €5,000.

**What is the total cost of the site including site preparation?**

## 2. The Components:

It will cost to build the windmills for the site. Each windmill has

a. 1 tower
b. 1 hub
c. 3 blades

The following quotes for the windmill components have been given from 3 different companies Irish Wind, Storm Chasers and Propellers. We are new customers but would hope to become regular customers.

**Irish Wind** is located in Dublin, roughly 120 km from the wind farm. It has been established and trading in energy systems since 1980.

| ITEM | QUOTE FOR NEW CUSTOMERS (€) | QUOTE FOR REGULAR CUSTOMER (€) | EXPECTED LIFETIME (YEARS) |
|---|---|---|---|
| Turbine blade | 1,400 | 1,300 | 3 |
| Hub | 15,000 | 15,000 | 6 |
| Tower | 20,000 | 18,000 | 12 |

**Storm Chasers** is located in London, roughly 250 km from the site. It was established in 1995. It is reputed to have supplied many units to several American and British wind energy projects.

| ITEM | QUOTE FOR NEW CUSTOMERS (€) | QUOTE FOR REGULAR CUSTOMER (€) | EXPECTED LIFETIME (YEARS) |
|---|---|---|---|
| Turbine blade | 1,200 | 1,000 | 3 |
| Hub | 20,000 | 18,000 | 8 |
| Tower | 18,000 | 15,000 | 12 |

**Propellers Inc.** is located in Galway, roughly 50 km from the site. It was established in 2002 and is completely Irish owned.

| ITEM | QUOTE FOR NEW CUSTOMERS (€) | QUOTE FOR REGULAR CUSTOMER (€) | EXPECTED LIFETIME (YEARS) |
|---|---|---|---|
| Turbine blade | 2,000 | 1,500 | 5 |
| Hub | 22,000 | 18,000 | 10 |
| Tower | 21,000 | 17,000 | 15 |

**Consider the quotes you have been given for the components. Which company would be most beneficial (either in the short term or in the long term or both) and would maximise the profits? Be prepared to explain your reasoning and communicate your findings with the Project Manager. There are no wrong answers, but there are optimum situations.**

**How much will the components cost in total (from your chosen supplier)?**

## 3. Maintenance:

There are many things that need to be maintained on a wind farm.

- The windmill itself needs to be cleaned regularly to ensure that it is working efficiently.
- If any of the parts fails, it will need to be replaced.
- Even if it does not fail, there will be a recommended lifetime for each component of the windmill. When it has been operating for as long as its recommended lifetime, then it will need to be replaced even if it is still functional.

To calculate the replacement of parts. Consider the lifetime of the components that you decided on and split the cost evenly over the years. For example, if the lifetime of a component is 5 years and costs €5,000 you will assign €1,000 for it a year.

**Can you calculate the replacement costs for each of the components from your chosen supplier?**

**3 Blades:**

**1 Tower:**

**1 Hub:**

## 4. The Engineer:

An engineer will be contracted to make regular visits to the wind farm to ensure that all windmills are running as expected. The income they generate from this will be considered their regular salary.

Below there are three candidates. You are provided with some information about their qualifications, their work experience (if they have any) and the salary the candidate would get if they are hired. Discuss among each other and decide who you would hire.

**Michael O'Brien**

1. Finished his PhD in UCD last year in Wind Energy Systems
2. 5 years working experience in off–shore wind off the coast of Denmark
3. Expected salary: €50,000 per year

**Linda McNally**

1. Degree in Electrical Engineering with Management
2. Worked as project manager with the Sustainable Energy Authority Ireland on several wind energy projects and has experience in research over the last 10 years
3. Expected salary: €60,000 per year

**Jordan Hoffmann**

1. Graduated with a Master's degree in alternative energy systems this year
2. No work experience
3. Expected salary: €34,000 per year

**Based on the above information, which candidate would you hire and why?**

## Task 2: Calculate the net profit and prepare your presentation

**Consult with the engineers from Group 5 to get the income generated from the wind farm.**

**Table 1:** This table will help you put together all the costs (for one year) that you found from your first task.

| ITEM / SERVICE | COSTS |
|---|---|
| **Purchase of site** | |
| **Preparation of site** | |
| **Cost of components from chosen supplier** | |
| **Replacement of parts** | |
| **Engineer's salary** | |
| **Total costs:** | |

Comparing the total income generated from the wind farm with the total costs to build the wind farm, can we operate effectively as a business? Explain your reasoning

**Congratulations, engineers!** You have successfully completed this exercise. If you're done, see if you can assist other teams on your site.

## Site 1

## Engineer Group 4

### Land Surveyors

Surveyors, your task is to calculate the cost of purchasing the site for the wind farm.
Choose one person who will coordinate with other groups and the project manager. You will need to calculate how big the site is. Then using this information and with the help of the other engineers, you will be able to calculate the total cost of the land. Let's get started!

### Task 1: Calculate the surface area of the site.

The shape of the site is given below. The scaling is 1cm = 100 m. This means that every centimetre that your ruler measures, is the same as 0.1 km in the real world.

1. Using a straight edge or ruler, split the above shape into rectangles and triangles.
2. Use Tables 1 and 2 on the next page to calculate the area of each of the shapes, remembering to convert each of your measurements to kilometres.

**Table 1:** This table will help you to calculate the area of all the triangles.

| TRIANGLE | MEASURE THE LENGTH OF THE BASE, B (in km) | MEASURE PERPENDICULAR WIDTH, W (in km) | AREA: CALCULATE 0.5 x B x w (in $km^2$) |
|---|---|---|---|
| 1. | | | |
| 2. | | | |
| 3. | | | |
| 4. | | | |
| 5. | | | |
| 6. | | | |
| 7 | | | |
| 8. | | | |
| 9. | | | |
| 10. | | | |
| 11. | | | |
| 12. | | | |
| CALCULATE THE TOTAL AREA OF THE TRIANGLES: | | | |

**Table 2:** This table will help to calculate the area of the all the rectangles.

| RECTANGLE | MEASURE LENGTH, L (in km) | MEASURE WIDTH, W (in km) | AREA: CALCULATE l x W (in km2) |
|---|---|---|---|
| 1. | | | |
| 2. | | | |
| 3. | | | |
| 4. | | | |
| 5. | | | |
| 6. | | | |
| 7 | | | |
| 8. | | | |
| 9. | | | |
| 10. | | | |
| 11. | | | |
| 12. | | | |
| 13. | | | |
| 14. | | | |
| 15. | | | |
| 16. | | | |
| 17. | | | |
| 18. | | | |
| 19. | | | |
| 20. | | | |
| 21. | | | |
| 22. | | | |
| 23. | | | |
| 24. | | | |
| 25. | | | |
| 26. | | | |
| 27. | | | |
| 28. | | | |
| 29. | | | |
| 30. | | | |
| 31. | | | |
| 32. | | | |
| 33. | | | |
| 34. | | | |
| | | CALCULATE THE TOTAL AREA OF THE RECTANGLES: | |

## Task 2: Calculate the price of the land:

**Now that you know how large the area of the land is, you can proceed to calculate the price of the land:**

1. The unit price is €27,000 per km2.
2. Fill in Table 4 to find your final answer.
3. Give your final answers to the engineers in Group 3 so they can complete their challenge.

**Table 4:** This table will help you to find the total cost of purchasing this piece of land.

| SHAPE | PUT IN TOTAL AREAS FROM TABLES 1 AND 2 | MULTIPLY BY THE UNIT PRICE |
|---|---|---|
| **Triangle** | | |
| **Rectangle** | | |
| **Totals** | **Total area=** | **Total price=** |

Prepare to report to your Project Manager using the report card.

**Congratulations, engineers!** You have successfully completed this exercise. If you're done, see if you can assist other teams on your site.

# Site 1

## Engineer Group 5

### Electrical Engineers

Engineers, your brief is as follows, we need you to work out the maximum wattage the windmills can output and then work with the Financial Analysts (group 3) to calculate our possible profits from the windfarm's energy output.

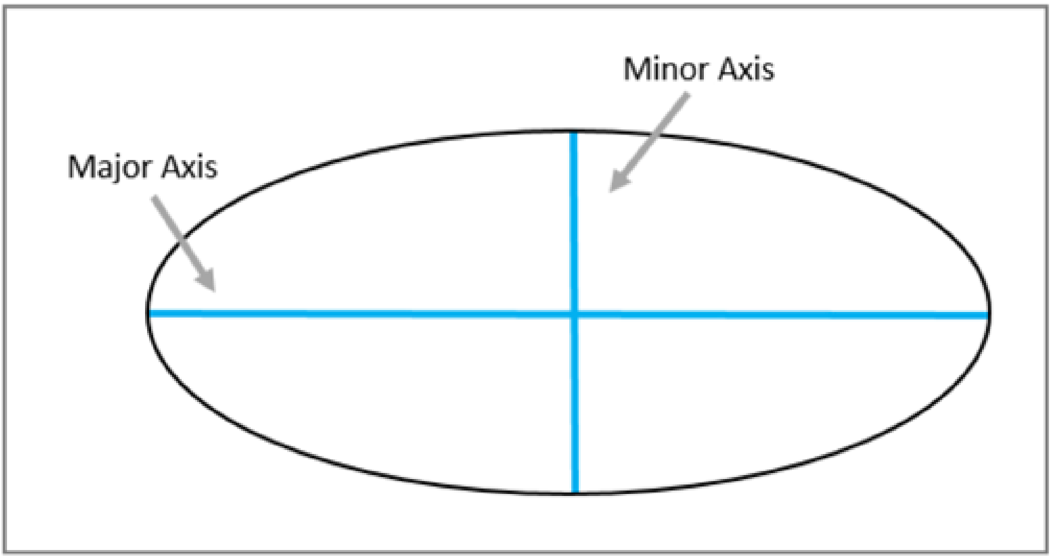
Your first task is to figure out the maximum wattage the windmills can create in order to tell the Safety Engineers (**Group 6**).

The way we'll do this is by finding out first how fast the blades will spin when the wind is at its highest. Then find out how many watts this speed will give us.

## Task 1: Find the speed of the blades at maximum wind speed

To find the speed of the blades we first need to find the area of the blades and use what we know about the relationship between the area and the speed of the blades to find their maximum speed.

Our first step is to find the area of the blades. The blades of a windmill are essentially shaped like an ellipse (which is the term for a squashed circle or an oval). The information we need to know about an ellipse are the lengths of its minor axes and major axes (which you can see in the diagram below).




The formula for the area of an ellipse is:

$$A = \pi ab$$

Where

| A | AREA OF ELLIPSE |
|---|---|
| a | The length of the semi–minor axis (half the length of the minor axis) |
| b | The length of the semi–major axis (half the length of the major axis) |

Our windmill blades are **4.2m** wide at their widest part and they are **18.8m** long.

**Using this can you find out how much area one blade has? How about all three blades?**

Now we need to find out how fast the blades go at the maximum wind speed. Because the blades aren't moving in a straight line (they are rotating around the hub), this speed is given in revolutions per hour.

Our mathematicians have found that relationship of:

$$\omega = \frac{A * v * \sin(\theta)}{8.0498}$$

Where

| | |
|---|---|
| $\omega$ | **The angular velocity (speed the blade is turning) of the blades (in revolutions per hour)** |
| $A$ | **The area of all three blades (in metres squared)** |
| $v$ | **The speed of the wind (in knots)** |
| $\theta$ | **The angle of the blades (in degrees)** |

We've already found A and we know that the blades will be at an angle of 15 degrees, but we still need to know the max speed of the wind which you can get from **Group 1**, the Windmill Technicians.

**Calculate the angular velocity of the blades:**

Once you have the maximum angular velocity, all we need is to convert this to a maximum wattage. We know that one revolution per hour will create 0.24 MW (megawatts) of power with these turbines.

**Use the figure you found above for angular velocity ( $\omega$) to work out the maximum wattage output.**

## Task 2: Calculating the income generated by the wind farm

For this task, you will be working with the Financial Analysts, **Group 3**, to work out how much money the windfarm will make on average over the course of the year.

Firstly, you will need to figure out how much money one windmill makes per year. Then ask **Group 2** how many windmills we will have in order to calculate the windfarm's income per year.
In order to find the amount of money the windmill makes, we need to find out how much energy it will produce.

We know how much power the windmills produce in megawatts from Task 1. We need to convert this to megawatt hours (a unit of energy) by multiplying the power by the amount of time the windmill is producing energy each year.

The windmills will be turned on 12 hours per day, every day of the year, except for Christmas Day, and for one day every 13 weeks for maintenance work.

**This is enough information to calculate how many hours the windmill will be on for in a year.**

**Hours:**

Now we just need to find the value, in euro, of that energy. We know that the suppliers of electricity in Ireland buy energy as described in **table 1.**

We will sell energy to each supplier equally (i.e. **25%** of the energy we produce will go to each supplier)

This is enough information to find our annual income, please report to **Group 3** with your findings once you have finished. **Note:** 1 megawatt hour = 1000 kilowatt hour

**Table 1:** Showing the rate of energy purchased by various suppliers

| COMPANY | RATE PURCHASED | PROJECTED AMOUNT FROM EACH COMPANY |
|---|---|---|
| Electric Ireland | 0.032c per kilowatt hour | |
| Pinergy | 33c per megawatt hour | |
| Airtricity | 0.034c per kilowatt hour | |
| Energia | €1.5 per 5 megawatt hours | |
| **Annual income total:** | | |

# Site 1

## Engineer Group 6

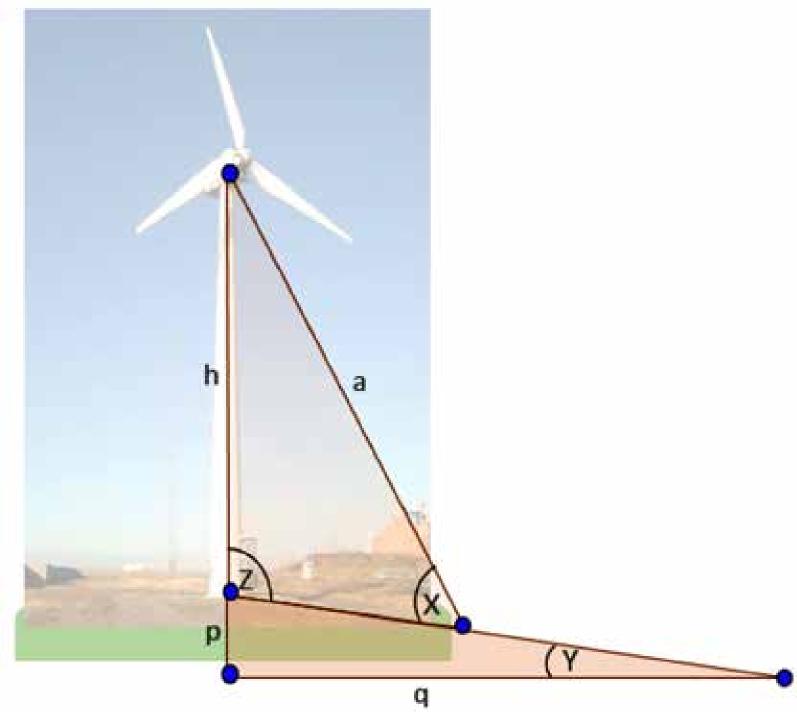
### Safety Technicians

Engineers, your brief is as follows: we need you to figure out the maximum safe height of the windmills that are going to be in our energy farm. Given some guidelines about how the windmill has to be anchored to the ground, you will then need to design a safe electric grid to provide energy to the local community.

Your first job is to find the maximum allowable height for the windmills. Under E.U. regulations, the maximum angle **relative to the ground** our anchors are allowed be placed is **65°**. Also, the anchors must be attached to the top of the windmill. Lastly, the anchors are limited to being **55m** long.

This is enough information to find the maximum height we can build the windmills on flat ground. However, the windmills will all be placed on the top of artificial hills, where the height drops by **1m** for every **10m** you go out.

What you'll have to do is it put all of this information onto the diagram below:




Where,

| | |
|---|---|
| h | **Height of windmill** |
| a | **Length of anchor** |
| p | **Height of hill** |
| q | **Width of hill** |
| x | **Angle of anchor relative to the ground** |
| y | **Angle of elevation of hill** |
| z | **Angle between windmill and ground** |

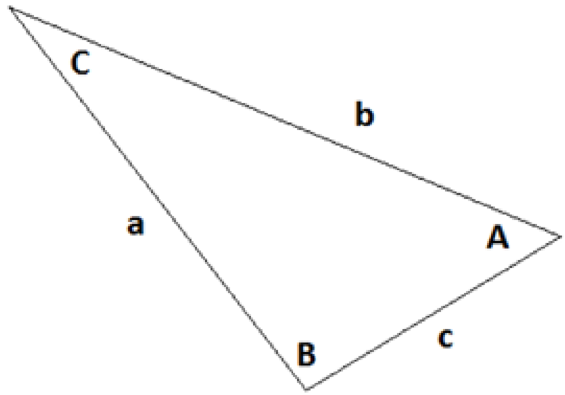
We're looking to find h, but we do this in a number of steps:

1. **Find the slope of the base triangle by finding the rise over the run,** $\frac{p}{q}$ **.**

2. **The slope (m) = tan(Y). Find Y.**

3. **Find the size of the angle z.**

Next we're going to need to use the sine rule, which states that if you have a triangle like the one below:




Then:

$$\frac{a}{\sin(A)} = \frac{b}{\sin(B)} = \frac{c}{\sin(C)}$$

That means that if you knew, say, what a, b and $\sin(B)$ were, you could find $\sin(A)$ using algebra, i.e.

$$\sin(A) = \frac{a * \sin(B)}{\mathrm{b}}$$

So we can now go on to our last steps:

4. **Use the sine rule to find the height of the windmill, h.**

Once you have found this, report to engineer **Group 1** with your findings.

## Task 2: Design the local electric grid

In any electrical system, engineers must be careful of overloads (where an excessive amount of current in the wire causes heat and possible damage to equipment).

For your next task, you are going to have to design the local electric grid to ensure that the likelihood of overloads in the grid is acceptably low, to do this you will first have to find out how many houses you can connect successively for different wattages.

The local council have decided that the probability of an overload during the course of a connections lifetime must be below 0.05 for it to be safe. Our scientists have found that the probability of an overload for n connected houses, with appropriate wattage w is:

$$P\ (overload) = \frac{n}{n + 100 - w}$$

Where,

| | |
|---|---|
| **N** | **Number of houses connected** |
| **W** | **Wattage (in MW or megawatts)** |
| **p** | **Probability of an overload in the connection's lifetime** |

Given this, how many houses could we safely connect for these wattages? We've done the first one to get you started.

The first calculation for n = 1 is:

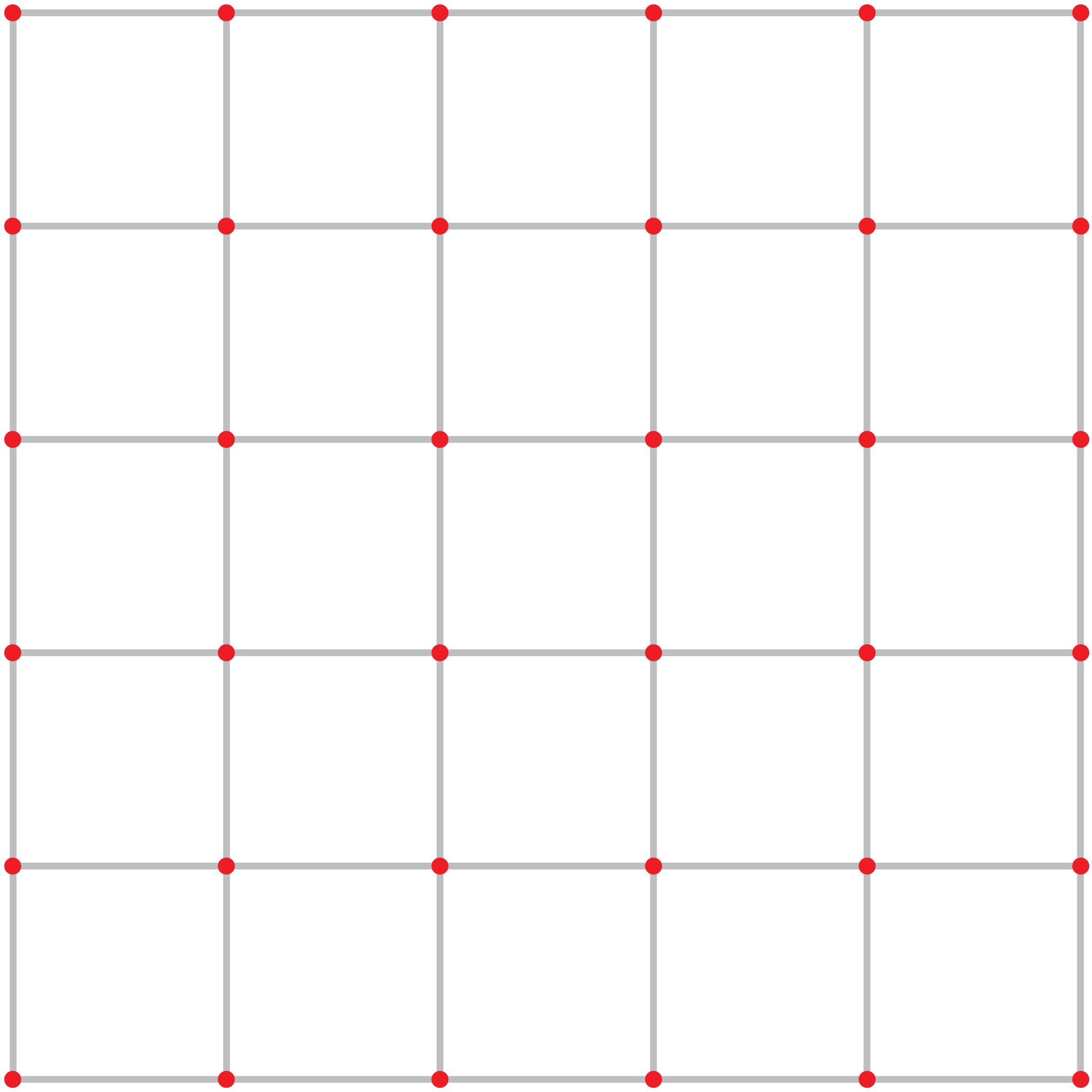
$$\frac{1}{1 + 100 - 10} = 0.011$$

| Wattage | Prob. For N=1 | Prob. For N=2 | Prob. For N=3 | Prob. For N=4 | Prob. For N=5 |
|---|---|---|---|---|---|
| 10MW | 0.011 | 0.022 | 0.032 | 0.043 | 0.053 (too big) |
| 20MW | | | | | |
| 30MW | | | | | |
| 40MW | | | | | |
| 50MW | | | | | |

Now ask the Electrical Engineers **(Group 5)** what the maximum wattage the windmills can output and find the corresponding maximum number of houses we can connect.

Then you need to place the smallest number of transformers on this grid so that you can provide energy to all the houses.

Each red dot on the grid represents a house and you can place a transformer on any of the red dots, this provides energy to that house but doesn't use up one of the connections.



**Congratulations, engineers!** You have successfully completed this exercise. If you're done, see if you can assist other teams on your site.

# Site 2

## Engineer Group 1

### Windmill Technicians

Engineers, your brief is as follows: we need you to decide on the height and orientation of the windmills that are going to be in our energy farm, some of the information you will need has already been collected by our scientists but we need you to make sense of that data, and make the best decisions you can to maximise energy output from the windmill.

You will need to work with other groups for this exercise. Assign one person to coordinate with other groups and the project manager.

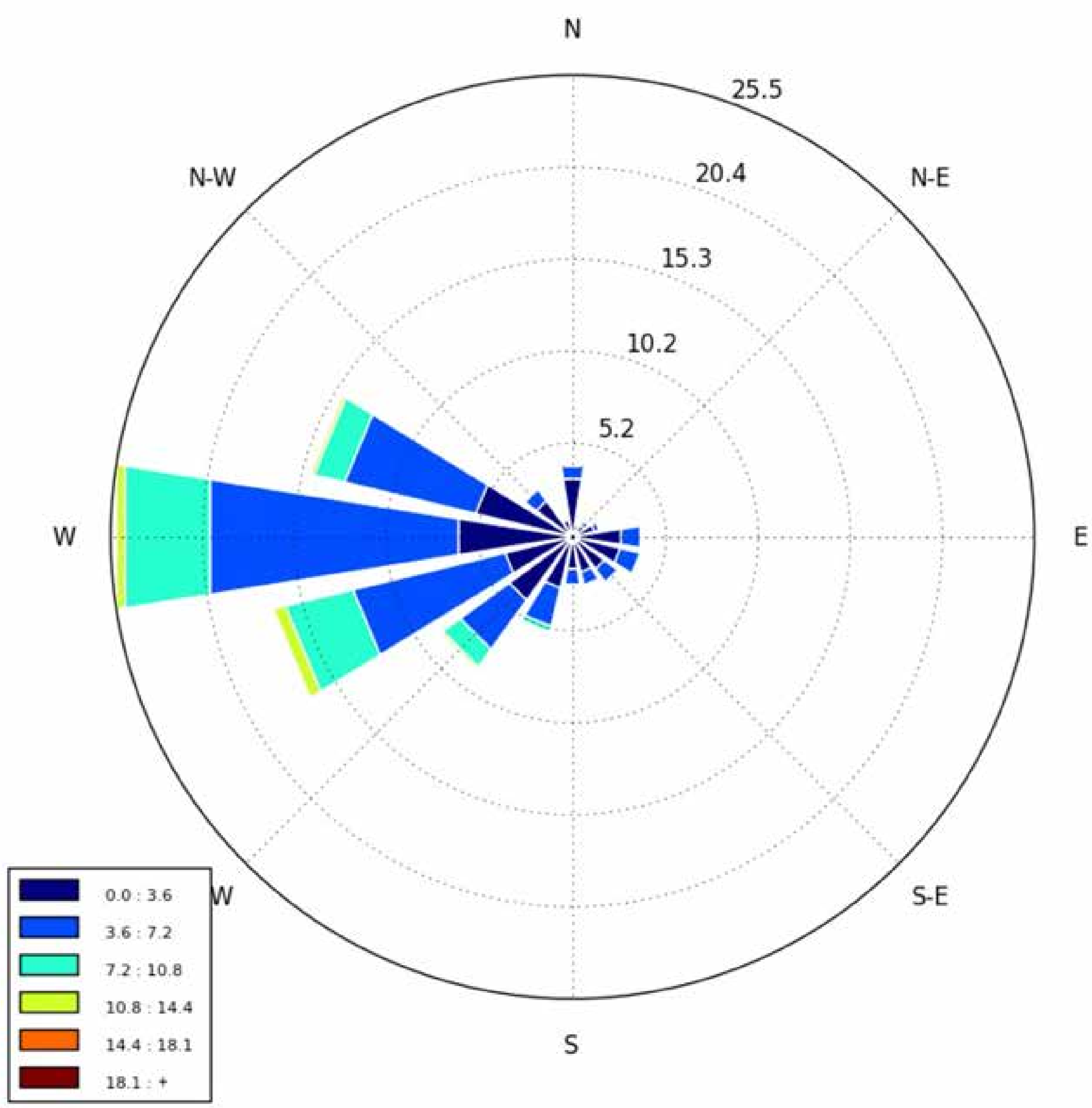
You have <u>**three**</u> tasks.

### Task 1: Your first task is to figure out which orientation is best for the windmills.

To do this we will be looking at rose plots (graphs that measure wind speed (in knots) and direction). These graphs give you two different pieces of information:

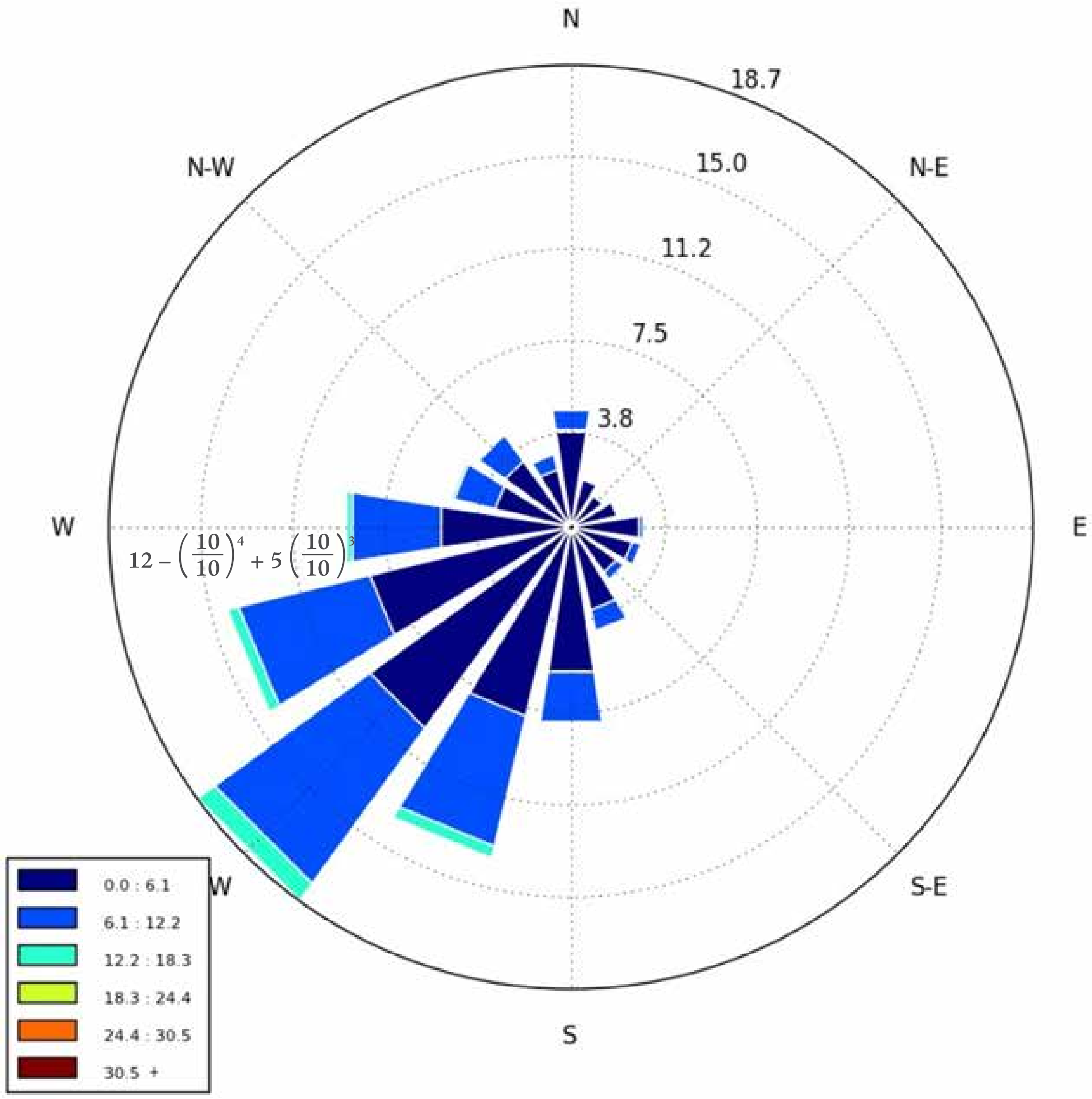
1. The **length** of the bar tells you **how much wind** came *from* that specific direction during the year. The longer the bar, the more wind came from that direction.
2. The **colours** in the bar tell you **how strong** the wind that came from that direction was. If a bar has lots of light blue or yellow, that means the wind from that direction is very strong. If it has mostly dark blue, the wind from that direction was mostly weak (Remember, the lighter colours give the strongest wind!)

Here are two rose plots for the site, collected by Met Éireann, the first is average for the summer months, and the second is average for the winter months.




Credit http://www.niallmcmahon.com/swc_2015_notes.html

**Summer Wind Data (in Knots)**




Credit http://www.niallmcmahon.com/swc_2015_notes.html

**Summer Wind Data (in Knots)**

Given these graphs, we need you to decide what direction the windmills should face in order to maximise the amount of wind they will receive.

When you have this done, please report, using the report card, to Group 2 with your findings before moving on to the next activity.

## Task 2: Find the most suitable height for the windmill

Our scientists have found that the relationship between wind speed and height from the ground is

$$Wind\ Speed = 12 - \left(\frac{Height}{10}\right)^4 + 5\left(\frac{Height}{10}\right)^3$$

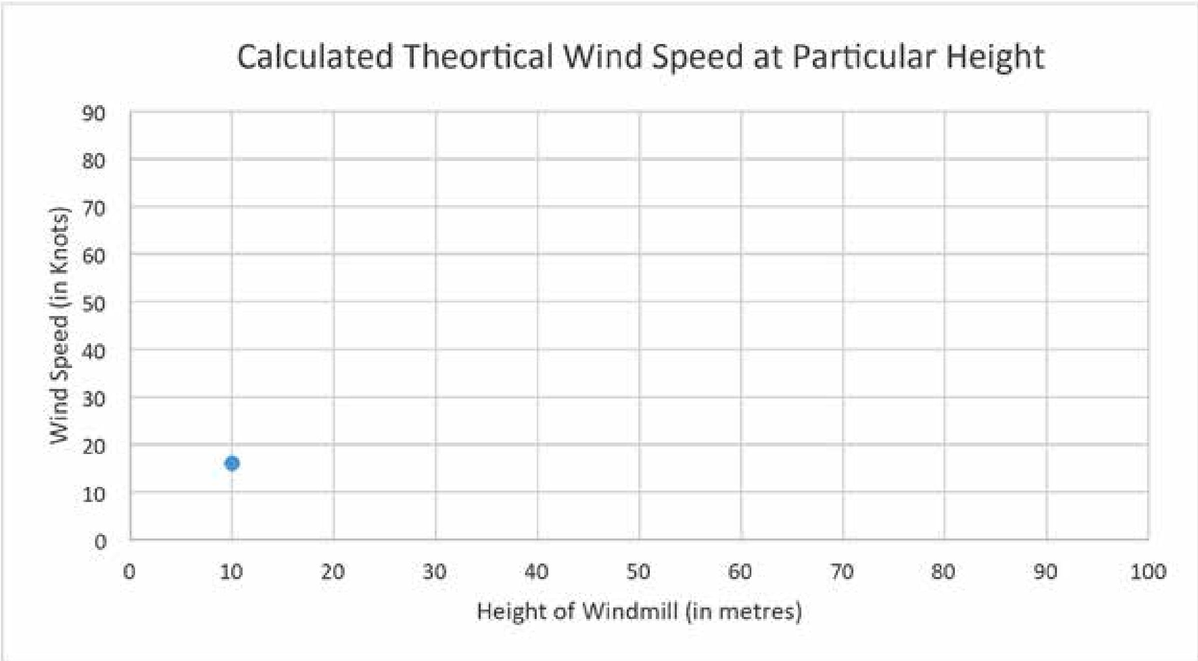
To get a sense of what height will produce the best wind speed we need you to check different values for height and to find the wind speed at that particular height. The first is done already: we've done one of them for you already:

| HEIGHT (M) | WIND SPEED EQUATION | (WORK OUT FRACTIONS) | (WORK OUT POWERS) | (SIMPLIFY) | VALUES (HEIGHT, WIND SPEED) |
|---|---|---|---|---|---|
| 10 | | $12-1^4+5(1^3)$ | $12-1+5(1)$ | 16 | (10,16) |
| 20 | | | | | |
| 30 | | | | | |
| 40 | | | | | |
| 50 | | | | | |

**What's our best estimate for the height of the windmill?**

Let's plot our findings to try and find a better answer.

For each of the values we found, we will plot a point on the graph that corresponds with the x and y axis. The first one is done as an example:




**What's our best choice for the height of the windmill now?**

(Is this different to our previous estimate?)

## Task 3. Find out the maximum height that we can safely make the windmills.

For this you need to go to the Safety Engineers **(Group 6)** and ask for their findings.
Given all of the information you have gathered please choose at what height and orientation you have decided the windmills should be.

**Record your findings on a separate sheet and give to your project manager.**

**Congratulations, engineers!** You have successfully completed this exercise. If you're done, see if you can assist other teams on your site.

# Site 2

## Engineer Group 2

### Spatial Engineers

Engineers, your goal is to find the maximum number of windmills that can be safely installed into the site.

You will need to work with other groups for this exercise. Assign one person to coordinate with other groups and the project manager.

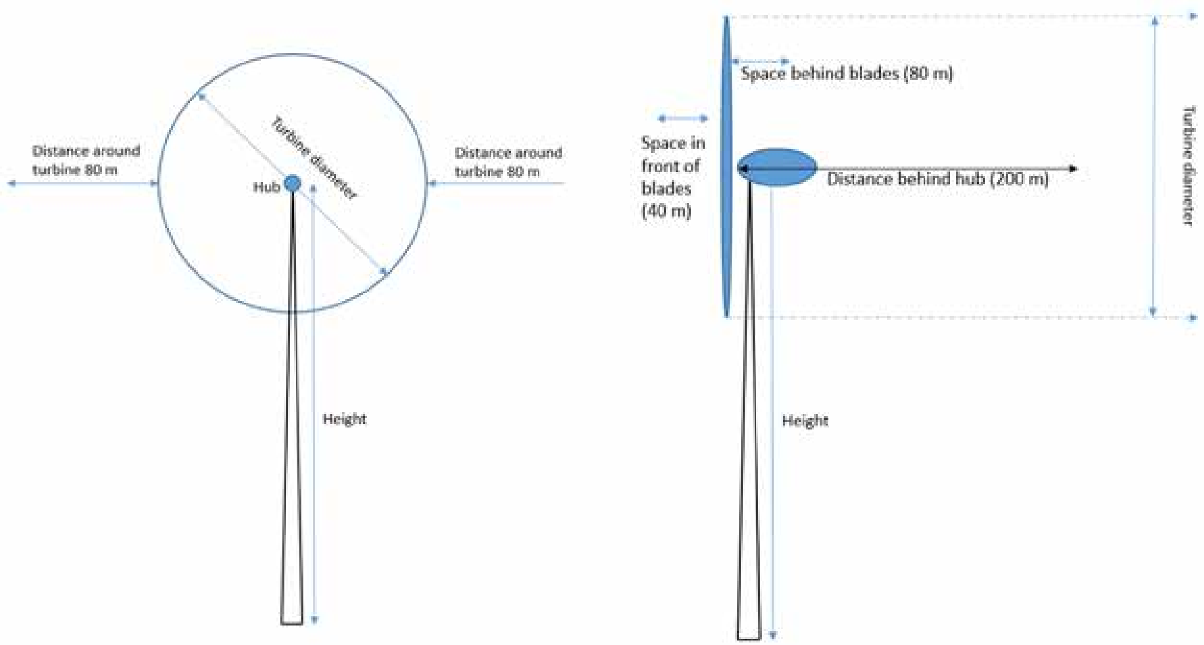
This exercise is split in two parts. In the first part you will calculate the **space** that is required to be left clear around each turbine. Then, using information provided by **Group 1**, you will decide the maximum number of turbines that we can safely have on the wind farm.

## Task 1: Assess the space needed for each turbine.

For safety reasons, there are regulations about how close each turbine can be to another. However, the space that is needed around a turbine is determined by its size. The size of the turbine is its turbine diameter. Windmills with large turbine diameter are built to be taller. There are two graphs below:

- **Graph 1 shows:**
  - The typical height of a windmill given the turbine diameter.
- **Graph 2 shows:**
  - The amount of space that should be left clear in front of turbine's blades.
  - The space that should be left clear behind the turbine's blades.

The space that should be left clear directly behind the hub centre. The hub centre is at the centre of where the turbine blades meet.



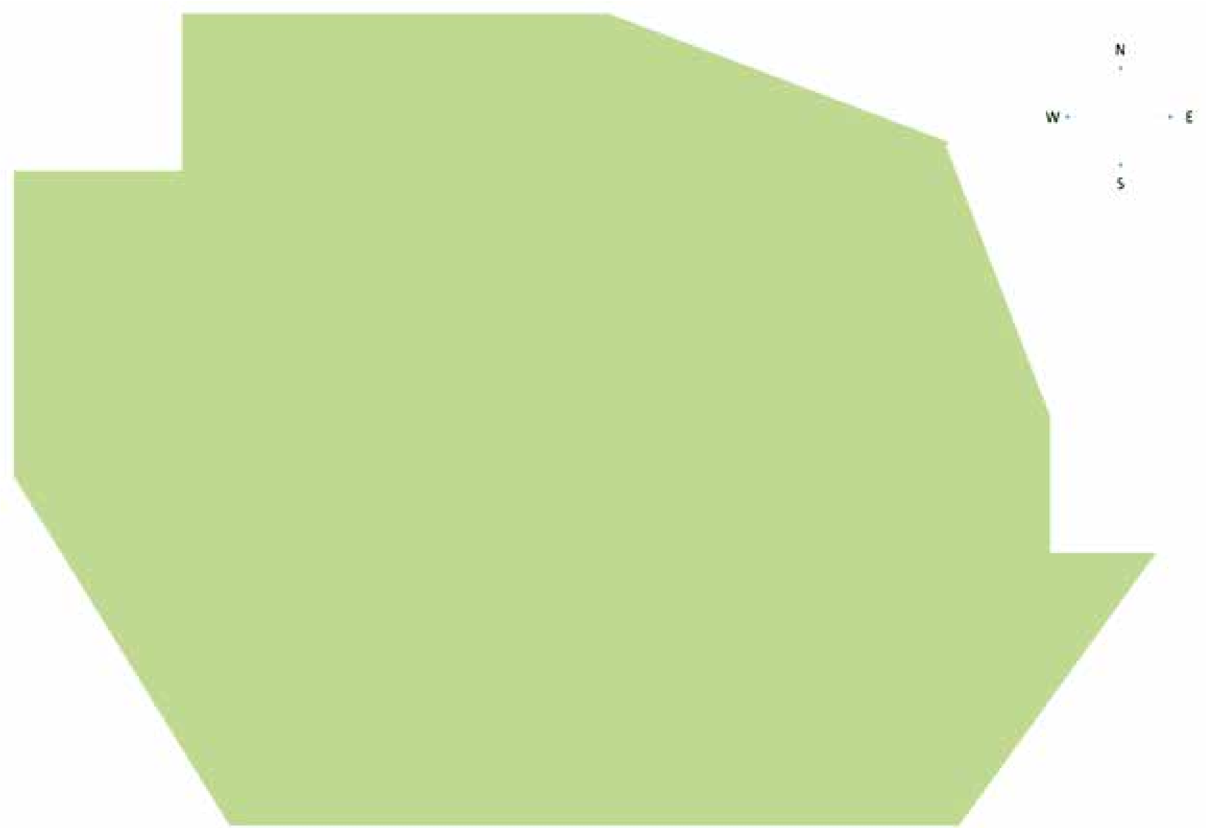

**To calculate the clear area needed around each turbine:**

1. Consider the two schematics shown above. It shows that:
   a. 80 m must be left clear at every point behind the blades
   b. 40 m must be left clear at every point in front of the blades.
   c. 200 m must be left clear behind the centre of the hub.
   d. 80 m must be left clear around the turbine blades.
2. Consult with each other to design a shape that represents the area required around each turbine. You are welcome to come up with more than one design if you like as long as they satisfy the safety regulations above. There is no one right answer. Be creative!

## Task 2: Find the maximum number of turbines possible to place onto the site

Now that you know the dimensions of the shapes, you'll need to figure out how many of each shape you can fit onto the site. Here's how to proceed. For each shape you have designed:

1. Make lots of cut–outs of that shape. Make sure that they are the dimensions that you decided in the last part.
2. The scaling is 1 cm to 100 m.
3. Consult with the engineers in **Group 1** to find out the direction in which the turbine should be pointing.
4. Use this direction to orient the shape on the site (picture given below).
5. Fit as many of the shapes as possible (Be careful though to keep the windmill pointed in the correct way).
6. Report your final answer to the engineers in **Group 5** so they can complete their exercise.




Fill out one project card and hand it in to your project manager.

**Congratulations, engineers!** You have successfully completed this exercise. If you're done, see if you can assist other teams on your site.

# Site 2

## Engineer Group 3

### Financial Analysts

Engineers, your goal is to analyse the cost and profit from the site. You will need to work with other groups so appoint somebody from your group to be the coordinator.

The project manager, who is also a member of your group, will have the task of representing the whole site. Ensure that your project manager is involved and updated at every stage so that they can make the best case for this wind farm.

### Task 1: Cost Find the costs of building a wind farm

There are a lot of costs when it comes to building a wind farm. In fact, we won't even be able to consider all of them but we will consider the most important or obvious ones.

We can think of the costs under the following headings:

1. The Site
2. The Components
3. Maintenance
4. The Engineer

## 1. The Site:

**It costs money to purchase the site. Consult with the land surveyors from Group 2 to get the cost of purchasing the land**

It also costs money to prepare the land. This means that you will have to make clear large rocks, big bushes and shrubs and level the land. This will cost a flat rate of €5,000.

**What is the total cost of the site including site preparation?**

## 2. The Components:

It will cost to build the wind mills for the site. Each windmill has

a. 1 tower

b. 1 hub

c. 3 blades

The following quotes for the windmill components have been given from 3 different companies Irish Wind, Storm Chasers and Propellers Inc. We are new customers but would hope to become regular customers.

**Irish Wind** is located in Dublin, roughly 120 km from the wind farm. It has been established and trading in energy systems since 1980.

| ITEM | QUOTE FOR NEW CUSTOMERS (€) | QUOTE FOR REGULAR CUSTOMER (€) | EXPECTED LIFETIME (YEARS) |
|---|---|---|---|
| Turbine blade | 1,400 | 1,300 | 3 |
| Hub | 15,000 | 15,000 | 6 |
| Tower | 20,000 | 18,000 | 12 |

**Storm Chasers** is located in London, roughly 250 km from the site. It was established in 1995. It is reputed to have supplied many units to several American and British wind energy projects.

| ITEM | QUOTE FOR NEW CUSTOMERS (€) | QUOTE FOR REGULAR CUSTOMER (€) | EXPECTED LIFETIME (YEARS) |
|---|---|---|---|
| Turbine blade | 1,200 | 1,000 | 3 |
| Hub | 20,000 | 18,000 | 6 |
| Tower | 18,000 | 15,000 | 12 |

**Propellers Inc.** is located in Galway, roughly 50 km from the site. It was established in 2002 and is completely Irish owned.

| ITEM | QUOTE FOR NEW CUSTOMERS (€) | QUOTE FOR REGULAR CUSTOMER (€) | EXPECTED LIFETIME (YEARS) |
|---|---|---|---|
| Turbine blade | 2,000 | 1,500 | 5 |
| Hub | 22,000 | 18,000 | 10 |
| Tower | 21,000 | 17,000 | 15 |

**Consider the quotes you have been given for the components. Which company would be most beneficial (either in the short term or in the long term or both) and would maximise the profits? Be prepared to explain your reasoning and communicate your findings with the Project Manager. There are no wrong answers, but there are optimum situations.**

**How much will the components cost in total?**

## 3. Maintenance:

There are many things that need to be maintained on a wind farm:

- The windmill itself needs to be cleaned regularly to ensure that it is working efficiently.
- If any of the parts fails, it will need to be replaced.
- Even if it does not fail, there will be a recommended lifetime for each component of the windmill. When it has been operating for as long as its recommended lifetime, then it will need to be replaced even if it is still functional.

To calculate the replacement of parts. Consider the lifetime of the components that you decided on and split the cost evenly over the years. For example, if the lifetime of a component is 5 years and costs €5,000 you will assign €1,000 for it a year.

**Can you calculate the replacement costs for each of the components from your chosen supplier?**

**3 Blades:**

**1 Tower:**

**1 Hub:**

## 4. The Engineer:

An engineer will be contracted to make regular visits to the wind farm to ensure that all windmills are running as expected. The income they generate from this will be considered their regular salary.

Below there are three candidates. You are provided with some information about their qualifications, their work experience (if they have any) and the salary the candidate would get if they are hired. Discuss among each other and decide who you would hire.

### Michael O'Brien

1. Finished his PhD in UCD last year in Wind Energy Systems
2. 5 years working experience in off–shore wind off the coast of Denmark
3. Expected salary: €50,000 per year

### Linda McNally

1. Degree in Electrical Engineering with Management
2. Worked as project manager with the Sustainable Energy Authority Ireland on several wind energy projects and has experience in research over the last 10 years
3. Expected salary: €60,000 per year

### Jordan Hoffmann

1. Graduated with a Master's degree in alternative energy systems this year
2. No work experience
3. Expected salary: €34,000 per year

**Based on the above information, which candidate would you hire and why?**

## Task 2: Calculate the net profit and prepare your presentation

**Consult with the engineers from Group 5 to get the income generated from the wind farm.**

**Table 1:** This table will help you put together all the costs (for one year) that you found from your first task.

| ITEM / SERVICE | COSTS |
|---|---|
| Purchase of site | |
| Preparation of site | |
| Cost of components from chosen supplier | |
| Replacement of parts | |
| Engineer's salary | |
| **Total costs:** | |

Comparing the total income generated from the wind farm with the total costs to build the wind farm, can we operate effectively as a business? Explain your reasoning

**Congratulations, engineers!** You have successfully completed this exercise. If you're done, see if you can assist other teams on your site.

# Site 2

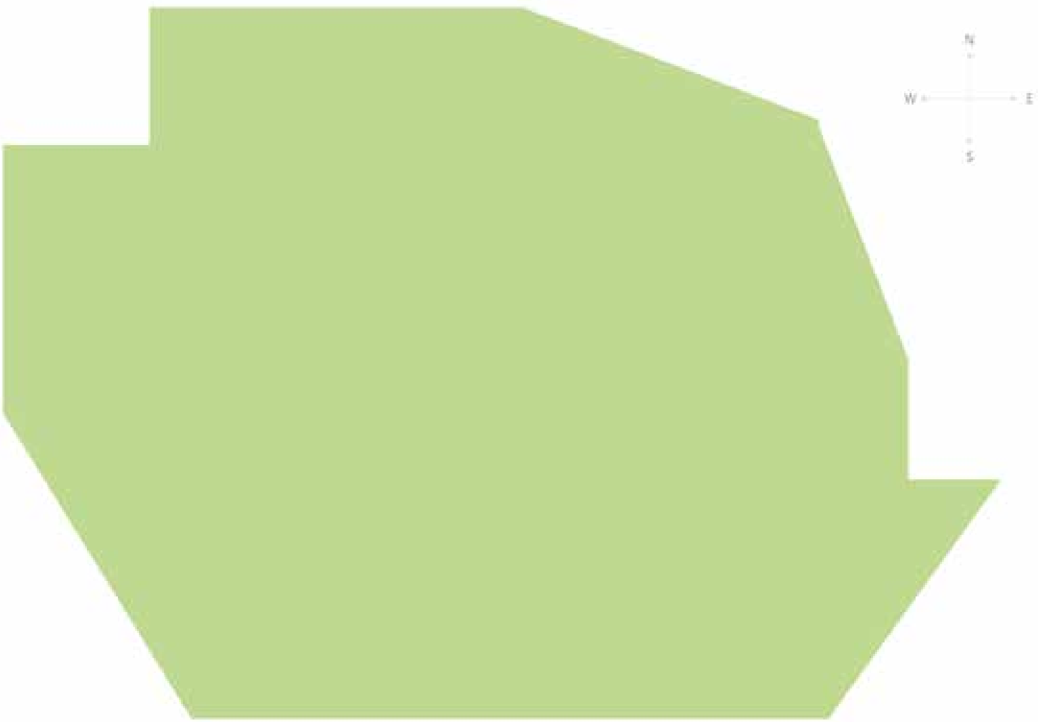
## Engineer Group 4

### Land Surveyors

Surveyors, your task is to calculate the cost of purchasing the site for the wind farm. Choose one person who will coordinate with other groups and the project manager. You will need to calculate how big the site is. Then using this information and with the help of the other engineers, you will be able to calculate the total cost of the land. Let's get started!

### Task 1: Calculate the surface area of the site.

The shape of the site is given below. The scaling is 1cm = 100 m. This means that every centimetre that your ruler measures, is the same as 0.1 km in the real world.



1. Using a straight edge or ruler, split the above shape into rectangles and triangles.
2. Use Tables 1 and 2 on the next page to calculate the area of each of the shapes, remembering to convert each of your measurement to kilometres.

**Table 1:** This table will help to calculate the area of the all the rectangles.

| RECTANGLE | MEASURE LENGTH, L (in km) | MEASURE WIDTH, W (in km) | AREA: CALCULATE L X W (in $km^2$) |
|---|---|---|---|
| 1. | | | |
| 2. | | | |
| 3. | | | |
| 4. | | | |
| 5. | | | |
| 6. | | | |
| 7 | | | |
| 8. | | | |
| 9. | | | |
| 10. | | | |
| 11. | | | |
| 12. | | | |
| 13. | | | |
| 14. | | | |
| 15. | | | |
| CALCULATE THE TOTAL AREA OF EACH OF THE RECTANGLES: | | | |

**Table 2:** This table will help you to calculate the area of all the triangles.

| TRIANGLE | MEASURE THE LENGTH OF THE BASE, B(in km) | MEASURE PERPENDICULAR WIDTH, W (in km) | AREA: CALCULATE 0.5 X B X W (in km$^2$) |
|---|---|---|---|
| 1. | | | |
| 2. | | | |
| 3. | | | |
| 4. | | | |
| 5. | | | |
| 6. | | | |
| CALCULATE THE TOTAL AREA OF ALL OF THE TRIANGLES: | | | |

## Task 2: Calculate the price of the land

Now that you know how large the area of the land is, you can proceed to calculate the price of the land:

1. The unit price is €30,000 per km$^2$.
2. Fill in Table 4 to find your final answer.
3. Give your final answers to the engineers in Group 3 so they can complete their challenge.

**Table 4:** This table will help you to find the total cost of purchasing this piece of land.

| SHAPE | PUT IN TOTAL AREAS FROM TABLES 1 AND 2 | MULTIPLY BY THE UNIT PRICE |
|---|---|---|
| Rectangle | | |
| Triangle | | |
| Totals | Total area = | Total price = |

**Prepare to report to your Project Manager using the report card**

**Congratulations, engineers!** You have successfully completed this exercise. If you're done, see if you can assist other teams on your site.

# Site 2

## Engineer Group 5

### Electrical Engineers

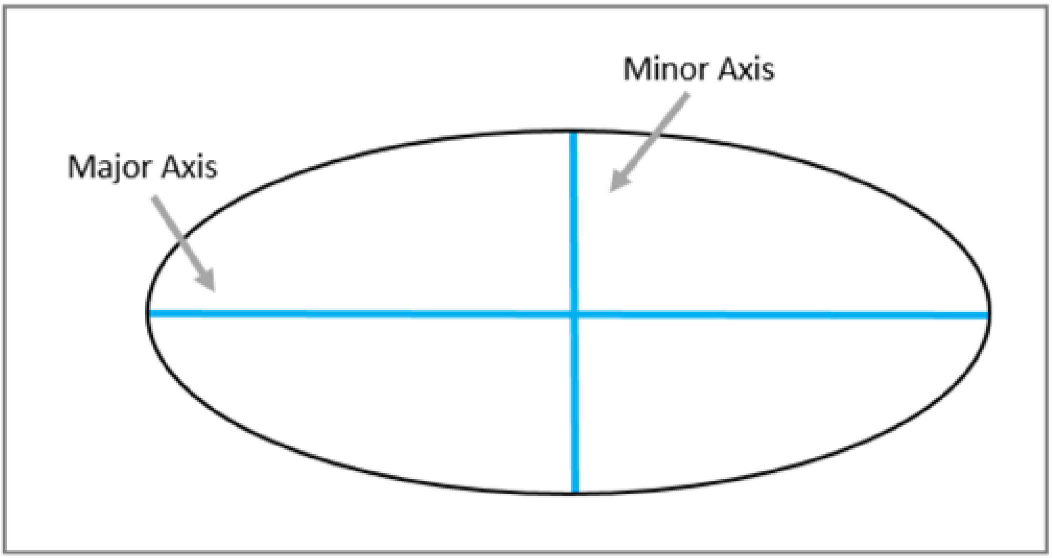
Engineers, your brief is as follows, we need you to work out the maximum wattage the windmills can output and then work with the Financial Analysts (**Group 3**) to calculate our possible profits from the windfarm's energy output.

Your first task is to figure out the maximum wattage the windmills can create in order to tell the safety engineers (**Group 6**).

The way we'll do this is by finding out first how fast the blades will spin when the wind is at its highest. Then find out how many watts this speed will give us.

## Task 1: Find the speed of the blades at maximum wind speed

To find the speed of the blades, we first need to find the area of the blades and use what we know about the relationship between the area and the speed of the blades to find their maximum speed. Our first step is to find the area of the blades. The blades of a windmill are essentially shaped like an ellipse (which is the term for a squashed circle or an oval). The information we need to know about an ellipse are the lengths of its minor axes and major axes (which you can see in the diagram below).




The formula for the area of an ellipse is:

$$A = \pi ab$$

Where

| | |
|---|---|
| **A** | **AREA OF ELLIPSE** |
| **a** | **The length of the semi–minor axis (half the length of the minor axis)** |
| **b** | **The length of the semi–major axis (half the length of the major axis)** |

Our windmill blades are **4.2m** wide at their widest part and they are **18.8m** long.

**Using this can you find out how much area one blade has? How about all three blades?**

Now we need to find out how fast the blades go at the maximum wind speed. Because the blades aren't moving in a straight line (they are rotating around the hub), this speed is given in revolutions per hour.

Our mathematicians have found that relationship of:

$$\omega = \frac{A * v * \sin(\theta)}{8.0498}$$

Where

| | |
|---|---|
| $\omega$ | **The angular velocity (speed the blade is turning) of the blades (in revolutions per hour)** |
| $A$ | **The area of all three blades (in metres squared)** |
| $v$ | **The speed of the wind (in knots)** |
| $\theta$ | **The angle of the blades (in degrees)** |

We've already found A and we know that the blades will be at an angle of 15 degrees, but we still need to know the max speed of the wind which you can get from Group 1, the Windmill Technicians.

**Calculate the angular velocity of the blades:**

Once you have the maximum angular velocity, all we need is to convert this to a maximum wattage. We know that one revolution per hour will create 0.24 MW (megawatts) of power with these turbines.

**Use the figure you found above for angular velocity ( $\omega$) to work out the maximum wattage output.**

Report your findings to Group 6, the Safety Technicians

## Task 2: Calculating the income generated by the wind farm

For this task, you will be working with the Financial Analysts, **Group 3**, to work out how much money the windfarm will make on average over the course of the year.

Firstly, you will need to figure out how much money one windmill makes per year. Then ask **Group 2** how many windmills we will have in order to calculate the windfarm's income per year.

In order to find the amount of money the windmill makes, we need to find out how much energy it will produce.

We know how much power the windmills produce in megawatts from Task 1. We need to convert this to megawatt hours (a unit of energy) by multiplying the power by the amount of time the windmill is producing energy each year.

The windmills will be turned on 12 hours per day, every day of the year, except for Christmas Day, and for one day every 13 weeks for maintenance work.

**This is enough information to calculate how many hours the windmill will be on for in a year.**

**Hours:**

| |
|---|
| |

Now we just need to find the value, in euro, of that energy. We know that the suppliers of electricity in Ireland buy energy as described in **table 1.**

We will sell energy to each supplier equally (i.e. **25%** of the energy we produce will go to each supplier)

This is enough information to find our annual income, please report to **Group 3** with your findings once you have finished. **Note:** 1 megawatt hour = 1000 kilowatt hour

**Table 1:** Showing the rate of energy purchased by various suppliers

| COMPANY | RATE PURCHASED | PROJECTED AMOUNT FROM EACH COMPANY |
|---|---|---|
| Electric Ireland | 0.032c per kilowatt hour | |
| Pinergy | 33c per megawatt hour | |
| Airtricity | 0.034c per kilowatt hour | |
| Energia | €1.5 per 5 megawatt hours | |
| Annual income total: | | |

# Site 1

## Engineer Group 6

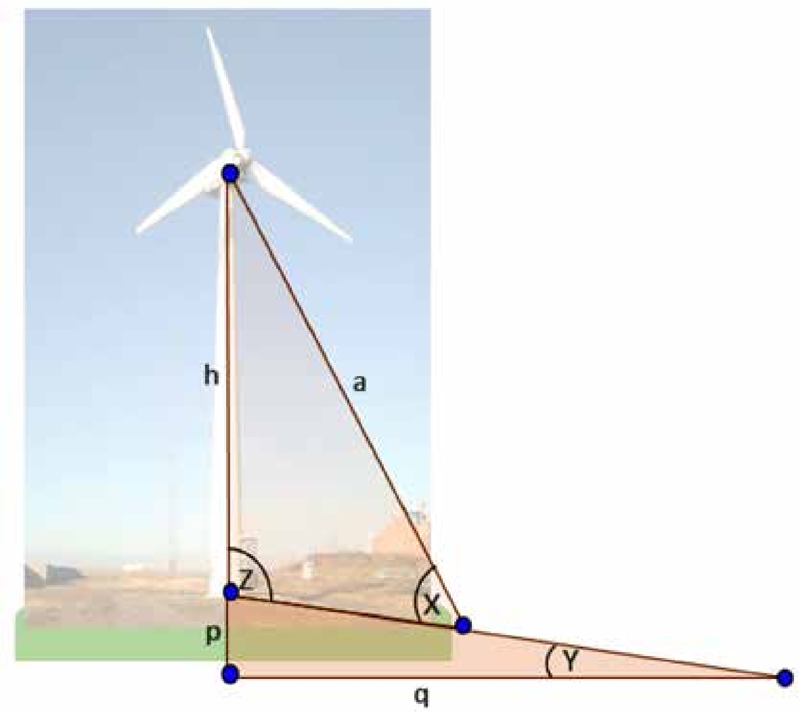
### Safety Technicians

Engineers, your brief is as follows, we need you to figure out the maximum safe height of the windmills that are going to be in our energy farm. Given some guidelines about how the windmill has to be anchored to the ground, you will then need to design a safe electric grid to provide energy to the local community.

Your first job is to find the maximum allowable height for the windmills. Under E.U. regulations, the maximum angle **relative to the ground** our anchors are allowed be placed is 65°. Also, the anchors must be attached to the top of the windmill. Lastly, the anchors are limited to being **55m** long.

This is enough information to find the maximum height we can build the windmills on flat ground. However, the windmills will all be placed on the top of artificial hills, where the height drops by **1m** for every **10m** you go out.

What you'll have to do is it put all of this information onto the diagram below:




Where,

| | |
|---|---|
| h | **Height of windmill** |
| a | **Length of anchor** |
| p | **Height of hill** |
| q | **Width of hill** |
| x | **Angle of anchor relative to the ground** |
| y | **Angle of elevation of hill** |
| z | **Angle between windmill and ground** |

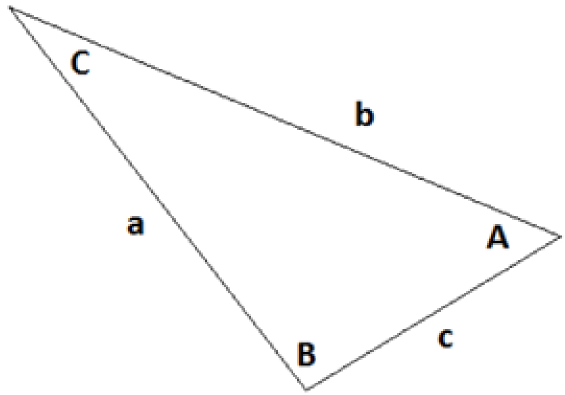
We're looking to find h, but we do this in a number of steps:

1. **Find the slope of the base triangle by finding the rise over the run,** $\frac{p}{q}$ .

2. **The slope (m) = tan(Y). Find Y.**

3. **Find the size of the angle z.**

Next we're going to need to use the sine rule, which states that if you have a triangle like the one below:




Then:

$$\frac{a}{\sin(A)} = \frac{b}{\sin(B)} = \frac{c}{\sin(C)}$$

That means that if you knew, say, what a, b and $\sin(B)$ were, you could find $\sin(A)$ using algebra, i.e.

$$\sin(A) = \frac{a * \sin(B)}{\mathrm{b}}$$

So we can now go on to our last steps:

**4. Use the sine rule to find the height of the windmill, h.**

Once you have found this, report to engineer **Group 1** with your findings.

## Task 2: Design the local electric grid

In any electrical system, engineers must be careful of overloads (where an excessive amount of current in the wire causes heat and possible damage to equipment).

For your next task, you are going to have to design the local electric grid to ensure that the likelihood of overloads in the grid is acceptably low, to do this you will first have to find out how many houses you can connect successively for different wattages.

The local council have decided that the probability of an overload during the course of a connections lifetime must be below 0.05 for it to be safe. Our scientists have found that the probability of an overload for n connected houses, with appropriate wattage w is:

$$P\ (overload) = \frac{n}{n + 100 - w}$$

Where,

| | |
|---|---|
| **N** | **Number of houses connected** |
| **W** | **Wattage (in MW or megawatts)** |
| **p** | **Probability of an overload in the connection's lifetime** |

Given this, how many houses could we safely connect for these wattages? We've done the first one to get you started.

The first calculation for n = 1 is:

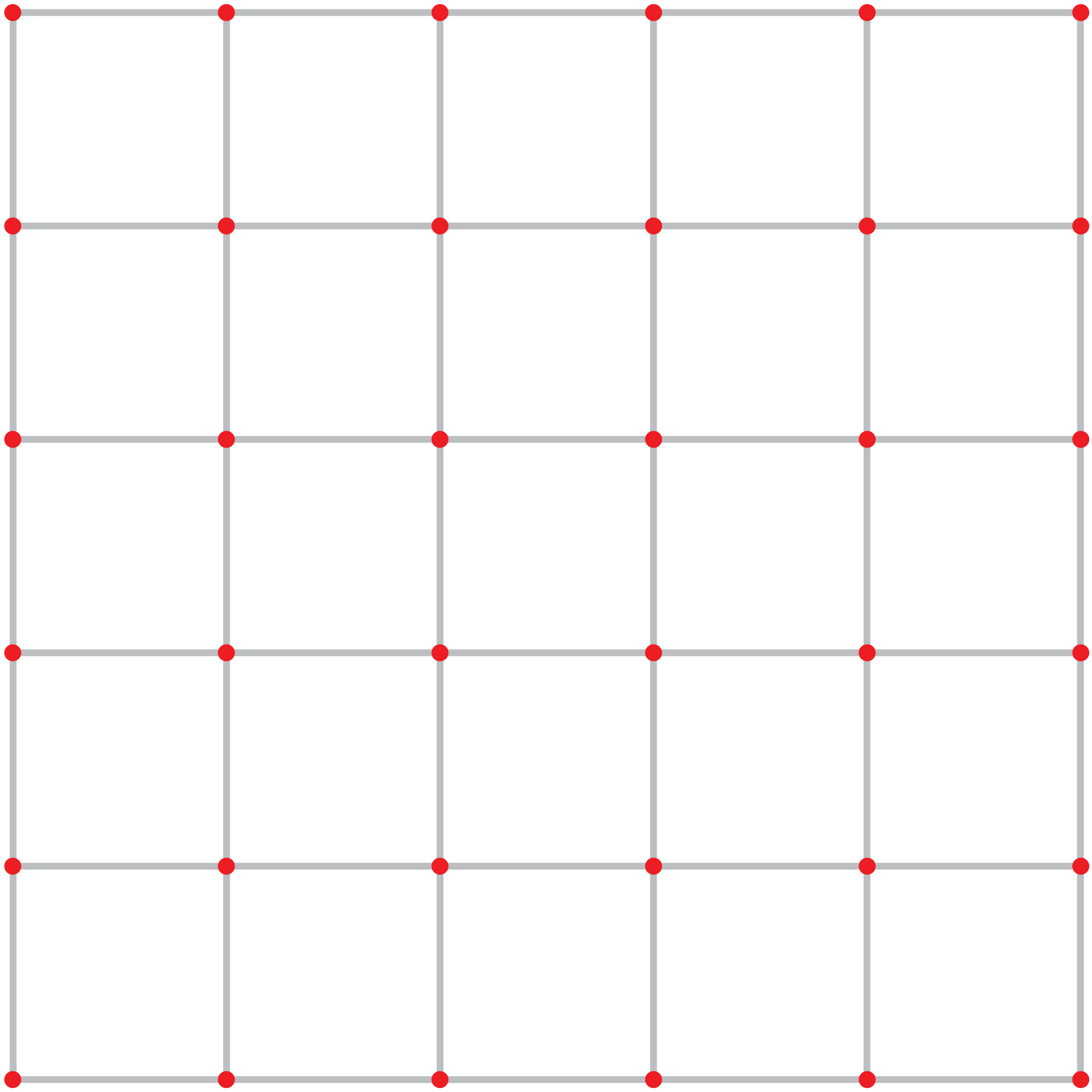
$$\frac{1}{1 + 100 - 10} = 0.011$$

| Wattage | Prob. For N=1 | Prob. For N=2 | Prob. For N=3 | Prob. For N=4 | Prob. For N=5 |
|---|---|---|---|---|---|
| 10MW | 0.011 | 0.022 | 0.032 | 0.043 | 0.053 (too big) |
| 20MW | | | | | |
| 30MW | | | | | |
| 40MW | | | | | |
| 50MW | | | | | |

Now ask the Electrical Engineers **(Group 5)** what the maximum wattage the windmills can output and find the corresponding maximum number of houses we can connect.

Then you need to place the smallest number of transformers on this grid so that you can provide energy to all the houses.

Each red dot on the grid represents a house and you can place a transformer on any of the red dots, this provides energy to that house but doesn't use up one of the connections.



**Congratulations, engineers!** You have successfully completed this exercise. If you're done, see if you can assist other teams on your site.