Wind Energy: Teacher Worksheet

Level: Advanced

Subject: Physics, Engineering

Duration: 40-60 minutes

Type: Guided Classroom Activity

Learning Goals:

- Understand and apply the physics of energy
- Calculate how much energy a windmill could produce given wind speeds recorded at your local weather station

Materials:

- paper
- glue
- wooden stick
- pin
- scissors
- TA00055 data (downloaded)
- computer with MS Excel and internet

Methods:

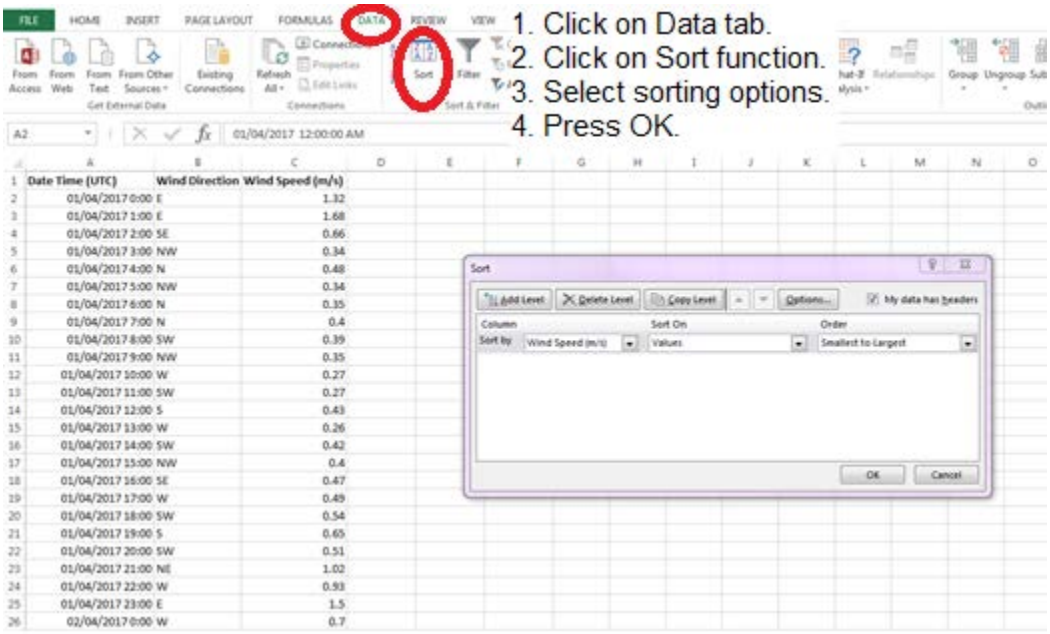
PART I: Fundamental Principles of Wind Energy [20 minutes]

1. Ask the students to make their own windmills. You can certainly skip this activity if you feel it is too young for your class, or you do not have time. It is intended to have a bit of fun and interaction (and think about the physical processes) before the students complete the worksheet. If you need to describe to the students how to create their own windmill, here is a step-by-step guide: www.theguardian.com/lifeandstyle/gallery/2009/jun/23/making-windmill-guide
2. Encourage them to experiment with their windmills. Tell the students to try to make the blades spin by blowing on them. Note how little or how much energy you need. What happens when you just breathe on the blades? What happens when you blow from different directions? Students should try to explain your observations and write down their answers on their student worksheet.

PART II: Wind speed data [10 minutes]

3. Ask the students to download the wind speed data for the past month from your local weather station. Weather data can be found on the School-2-School website at https://school2school.net/teaching-materials/, here you can login information to download weather data from the website or a pre-formatted weather data as an Excel file.
4. Allow the students to format and filter the data. For this exercise, your students will need to use the Data → Sort option to find the windiest and least windy hours, and the AVERAGE function to calculate the average speed for each day. See screenshots below for more information.

Sorting Data:



Date Time (UTC)	Wind Direction	Wind Speed (m/s)
01/04/2017 0:00	E	1.32
01/04/2017 1:00	E	1.68
01/04/2017 2:00	SE	0.66
01/04/2017 3:00	NW	0.34
01/04/2017 4:00	N	0.48
01/04/2017 5:00	NW	0.34
01/04/2017 6:00	N	0.35
01/04/2017 7:00	N	0.4
01/04/2017 8:00	SW	0.39
01/04/2017 9:00	NW	0.35
01/04/2017 10:00	W	0.27
01/04/2017 11:00	SW	0.27
01/04/2017 12:00	S	0.43
01/04/2017 13:00	W	0.26
01/04/2017 14:00	SW	0.42
01/04/2017 15:00	NW	0.4
01/04/2017 16:00	SE	0.47
01/04/2017 17:00	W	0.49
01/04/2017 18:00	SW	0.54
01/04/2017 19:00	S	0.65
01/04/2017 20:00	SW	0.51
01/04/2017 21:00	NE	1.02
01/04/2017 22:00	W	0.93
01/04/2017 23:00	E	1.5
02/04/2017 0:00	W	0.7

SUM function:

02/04/2017 0:00	W	0.7	0.016567568
02/04/2017 1:00	SE	0.58	0.009424289
02/04/2017 2:00	SW	0.34	0.00189846
02/04/2017 3:00	S	0.2	0.000386416
02/04/2017 4:00	N	0.63	0.012077757
02/04/2017 5:00	N	0.5	0.006037743
02/04/2017 6:00	NE	0.65	0.013264922
02/04/2017 7:00	NE	0.73	0.018790278
02/04/2017 8:00	E	0.9	0.035212119
02/04/2017 9:00	E	1.06	0.057528391
02/04/2017 10:00	N	0.55	0.008036236
02/04/2017 11:00	N	0.4	0.003091325
02/04/2017 12:00	N	0.39	0.002865223
02/04/2017 13:00	N	0.5	0.006037743
02/04/2017 14:00	N	0.49	0.005682676
02/04/2017 15:00	NE	0.63	0.012077757
02/04/2017 16:00	NW	1.18	0.079361643
02/04/2017 17:00	W	0.84	0.028628757
02/04/2017 18:00	SW	0.82	0.026632147
02/04/2017 19:00	SE	1.09	0.062552421
02/04/2017 20:00	S	1.19	0.081396459
02/04/2017 21:00	S	1.01	0.049765544
02/04/2017 22:00	S	0.74	0.019573108
02/04/2017 23:00	W	0.5	0.006037743

=sum(D26:D49)

AVERAGE function:

02/04/2017 0:00	W	0.7
02/04/2017 1:00	SE	0.58
02/04/2017 2:00	SW	0.34
02/04/2017 3:00	S	0.2
02/04/2017 4:00	N	0.63
02/04/2017 5:00	N	0.5
02/04/2017 6:00	NE	0.65
02/04/2017 7:00	NE	0.73
02/04/2017 8:00	E	0.9
02/04/2017 9:00	E	1.06
02/04/2017 10:00	N	0.55
02/04/2017 11:00	N	0.4
02/04/2017 12:00	N	0.39
02/04/2017 13:00	N	0.5
02/04/2017 14:00	N	0.49
02/04/2017 15:00	NE	0.63
02/04/2017 16:00	NW	1.18
02/04/2017 17:00	W	0.84
02/04/2017 18:00	SW	0.82
02/04/2017 19:00	SE	1.09
02/04/2017 20:00	S	1.19
02/04/2017 21:00	S	1.01
02/04/2017 22:00	S	0.74
02/04/2017 23:00	W	0.5

=average(C26:C49)

PART III: Calculations [20 minutes]

5. Introduce the formula on the *Student Worksheet*, relating it to kinetic energy and basic principles. It would be best to derive the formula on a blackboard for the students, so they understand where it comes from. If you as a teacher are unfamiliar with the context of the equation, this link could be useful to review as it provides a breakdown of how the equation provided in the student sheet is derived from basic physics principles (Newton's laws, kinetic energy, etc.): http://www.raeng.org.uk/publications/other/23-wind-turbine

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

Where:

P = power output, W

C_p = maximum power coefficient

ρ = air density, kg/m^3

A = rotor swept area = πr^2 (r is the rotor radius in m), m^2

v = wind speed, m/s

Assume that the windmill has a blade length (radius) of 10 m, the windmill captures 25% of the wind's kinetic energy (maximum power coefficient), and air density is 1.23 kg/m^3. Other helpful information on wind turbines can be found at: www.windpowerengineering.com/construction/calculate-wind-power-output/

6. Allow the students to complete the calculations on the Student Worksheet. Ask them to show their calculations. Encourage them to complete the discussion questions as well. Next, calculate the total energy the same windmill could have generated on the two days of the windiest and least windy hours above. Use hourly wind speeds, not a daily average.

7. Compute the average wind speed for the two days (windiest and least windy), and the amount energy that the windmill would have generated had the wind been steady at this speed.

Wind Energy: Answer Key

**NOTE: This answer key uses the TA00055 April 2017 data.

Results:

1. Maximum wind speed (hour): **4.6 m/s** on (date and time): **07/04/2017 3:00**
   Minimum wind speed (hour): **0.2 m/s** on (date and time): **02/04/2017 3:00**
2. Energy for windiest hour: **4.7 kWh**

   $A = \pi r^2 = \pi * 10^2 = 314.159$

   $P = \frac{1}{2} C_p \rho A v^3 = 0.5 * 0.25 * 1.23 * 314.159 * 4.6^3 = 4701.518\ W$

   $E = Pt = 4701.518 * 1 = 4701.518\ Wh = 4.7\ kWh$

3. Energy for least windy hour: **0.0004 kWh**
   See sample calculation above.
4. Total energy for windiest day: **295.9 kWh**
   See spreadsheet in *Supplementary Materials* for calculations.
5. Total energy for least windy day: **13.5 kWh**
   See spreadsheet in *Supplementary Materials* for calculations.
6. Average wind speed on windiest day: **1.7 m/s**
   See spreadsheet in *Supplementary Materials* for calculations.
7. Average wind speed on least windy day: **0.7 m/s**
   See spreadsheet in *Supplementary Materials* for calculations.
8. Total energy for windiest day (average): **5.7 kWh**
   See spreadsheet in *Supplementary Materials* for calculations.
9. Total energy for least windy day (average): **0.4 kWh**
   See spreadsheet in *Supplementary Materials* for calculations.

Discussion:

PART I: Fundamental Principles of Wind Energy
What happens when you just breathe on the blades? What happens when you blow from different directions? Try to explain your observations.

The students should be able to observe the effect of wind speed (their blowing) on windmill motion, and relate it to physics principles.

PART III: Calculations
Why is the energy calculated differently when using hourly versus average daily wind speeds? [Hint: kinetic energy is proportional to the square of velocity.]

The average velocities are lower than the maximum velocities per day, and this difference is amplified by the factor of three applied to velocity in the equation.

Wind Energy: Student Worksheet

Methods:

PART I: Fundamental Principles of Wind Energy

1. Make your own windmill with the paper, glue, stick, pin, and scissors. If you do not know how ask your teacher.
2. Try to make the blades spin by blowing on them. Note how little or much energy you need. What happens when you just breathe on the blades? What happens when you blow from different directions? Try to explain your observations.

PART II: Wind speed data

3. Download the wind speed data for the past month from your local weather station (or use TA00055 data).
4. Open it in MS Excel.
5. Format the data, and filter it to find the maximum and minimum wind speed hours.

PART III: Calculations (use space below and show all calculations)

6. Calculate the amount of energy (in kilowatt-hours, kWh) that a windmill could have generated in the windiest and least windy hours last month. Use the formula:

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

   where
   P = power output, W
   C_p = maximum power coefficient
   ρ = air density, kg/m^3
   A = rotor swept area = πr^2 (r is the rotor radius in m), m^2
   v = wind speed, m/s

7. Assume that
   a. the windmill has a blade length (radius) of 10 m,
   b. the windmill captures 25% of the wind's kinetic energy, and
   c. air density is 1.23 kg/m^3.
8. Now calculate the total energy the same windmill could have generated on the two days of the windiest and least windy hours above. Use hourly wind speeds, not a daily average.
9. Compute the average wind speed for the two days (windiest and least windy), and the amount energy that the windmill would have generated had the wind been steady at this speed.

Results:

1. Maximum wind speed (hour): _____on (date and time): _____
   Minimum wind speed (hour): _____on (date and time): _____
2. Energy for windiest hour: _____

3. Energy for least windy hour: _____

4. Total energy for windiest day: _____

5. Total energy for least windy day: _____

6. Average wind speed on windiest day: _____

7. Average wind speed on least windy day: _____

8. Total energy for windiest day (average): _____

9. Total energy for least windy day (average): _____

Discussion:

PART I: Fundamental Principles of Wind Energy

What happens when you just breathe on the blades? What happens when you blow from different directions? Try to explain your observations.

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PART III: Calculations

Why is the energy calculated different when using hourly versus average daily wind speeds? [Hint: kinetic energy is proportional to the square of velocity.]

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