Encounter Edu

Climate and Energy

Geography | Ages 14 - 16

Teacher Book

BELMONT FORUM

NWO

NERC SCIENCE OF THE ENVIRONMENT

Royal Netherlands Meteorological Institute
Ministry of Infrastructure and Water Management

UNIVERSITY OF EXETER

Contents

Applicable standards

GCSE Geography

AQA GCSE Geography

Element of the curriculum	Lessons 1	2	3	4	5	6	7	8
Locational knowledge								
• 3.1.1.3 Weather hazards – The UK is affected by a number of weather hazards.		✓						
Place: processes and relationships								
• 3.1.1.3 Weather hazards - Global atmospheric circulation helps to determine patterns of weather and climate.	✓							
People and environment: processes and interactions								
• 3.1.1.4 Climate change - Managing climate change involves both mitigation (reducing causes) and adaptation (responding to change).			✓					
• 3.1.1.4 Climate change - Climate change is the result of natural and human factors and has a range of effects.				✓	✓			
• 3.2.3.1 Resource management - The changing demand and provision of resources in the UK creates opportunities and challenges.				✓				
• 3.2.3.1 Resource management - Different strategies can be used to increase energy supply.					✓	✓	✓	✓

OCR GCSE Geography

Element of the curriculum	Lessons 1	2	3	4	5	6	7	8
UK Environmental Challenges								
• How air masses cause extreme weather conditions in the UK, including extremes of wind, temperature and precipitation.	✓							✓
• Identification of renewable and non-renewable energy sources.			✓	✓				✓
• The contribution of renewable and non-renewable sources to energy supply in the UK.			✓	✓				✓
• The extent to which non-renewable energy could and should contribute to the UK's future energy supply.			✓		✓	✓		✓
• Strategies for sustainable use and management of energy at local and UK national scales, including the success of these strategies						✓		✓
• The development of renewable energy in the UK and the impacts on people and the environment						✓		✓
Geographical Skills								
• To use climate graphs		✓						✓
• To use UK weather and climate data		✓						✓

Applicable standards

GCSE Geography

Edexcel GCSE Geography **Element of the curriculum**	**Lessons** **1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Resource management								
• Energy resources can be classified as renewable and non-renewable.			✓	✓				✓
• Advantages and disadvantages of the production and development of one non-renewable energy resource.			✓					✓
• Advantages and disadvantages of the production and development of one renewable energy resource.			✓					✓
• The composition of the UK's energy mix.			✓		✓			✓
• Advantages and disadvantages of the production and development of one non-renewable energy resource.				✓				✓
• Advantages and disadvantages of the production and development of one renewable energy resource.				✓		✓		✓
• How technology can resolve energy resource shortages.						✓		✓
Weather hazards and climate change								
• How human activities (industry, transport, energy, farming) produce greenhouse gases (carbon dioxide, methane) that cause the enhanced greenhouse effect.							✓	✓
Geographical Skills								
• To use weather charts		✓						✓
• To use UK weather and climate data		✓						✓

Applicable standards

National Geography Standards 2nd Edition

Geography Element of the curriculum	Lessons 1	2	3	4	5	6	7	8
The world in spatial terms								
• Standard 2: How to use maps and other geographic representations, geospatial technologies, and spatial thinking to understand and communicate information	✓	✓			✓			
Physical systems								
• Standard 7: The physical processes that shape the patterns of Earth's surface	✓			✓				
Environment and safety								
• Standard 15: How physical systems affect human systems	✓	✓						
Physical systems								
• Standard 18: How to apply geography to interpret the present and plan for the future.			✓		✓	✓	✓	✓

Lesson 1: What is the global atmospheric circulation model?

Overview

In this lesson students will learn about jet streams, the global atmospheric circulation model and how they affect the weather around the world. Students will be able to explain the global circulation atmospheric model through the use of either a drawing, a model or a physical display.

Learning outcomes

- Identify different atmospheric events that will affect weather
- Describe the global atmospheric circulation model
- Explain how global atmospheric circulation affects weather

Resources

Slideshow 1:
What is the global atmospheric circulation model?

Student Sheet 1a:
Air pressure and jet streams

Student Sheet 1b:
Global atmospheric circulation model

Student Sheet 1c:
Jet stream

Thinglink:
How do weather cells affect the global climate?

Subject Update:
Learn more: Global atmospheric circulation

Lesson 2: What impacts the weather in NW Europe?

Overview

In this lesson students will use all their knowledge of weather systems and use a variety of satellite maps of Northwestern Europe to predict the weather for the next day. Students will then go on to use satellite images to describe the weather of Northwestern Europe and explain what has caused this weather and what conditions would be expected as a result of what is shown on the satellite images.

Learning outcomes

- Label the countries in Northwestern Europe
- Describe and explain the climate of different countries in Northwestern Europe
- Explain what could affect variations of weather and climate in Europe

Resources

Slideshow 2:
What impacts the weather in NW Europe?

Student Sheet 2a:
Map of Northwestern Europe

Student Sheet 2b:
Climate data for Europe

Student Sheet 2c:
European climate data exam questions

Lesson 3: How can we predict the weather of the future?

Overview

This lesson for higher ability students extends student knowledge of climate models and how they can be used in policy development. The HIWAVES research team wrote an academic paper investigating the impact of predicted climate on renewable energy production. This lesson looks at how the research team used climate models as part of their work and then focuses on the academic journal article written by the team and supports students to access information from this level of research output.

Learning outcomes

- Examine the need to understand what the future climate may look like
- Name and evaluate the effectiveness of climate models
- Describe the findings from the academic journal article

Resources

Slideshow 3: How can we predict the weather of the future?

External Link: Meteological conditions leading to extreme low variable renewable energy production and extreme high energy shortfall (2019) Van der Wiel et al.

External Link: Carbon brief Q&A: How do climate models work?

Subject Update: Learn more: Climate models

Subject Update: Climate and Energy HIWAVES journal article student summary

Lesson 4: How is energy produced?

Overview

In this lesson students will learn about how different types of energy are generated and stored, focussing on examples of renewable and non-renewable sources. Students will also look at the energy production matrix of the UK, the Netherlands and the European union, comparing and contrasting them.

Learning outcomes

- Describe the different types of energy
- Explain how energy is produced and stored
- Analyse the different energy matrices

Resources

Slideshow 4: How is energy produced?

Student Sheet 4a: Renewable energy

Student Sheet 4b: Non-renewable energy

Lesson 5: What are the issues with renewable energy?

Overview

Renewable energy is currently responsible for approximately 30% of energy production in the UK. This figure has steadily risen since 1990, but is the increase enough? Can we produce enough energy via renewable sources to meet energy needs? What are the issues faced when generating renewable energy? In this lesson students will evaluate the positives and negatives of renewable energy production. They will also consider how renewable energy is affected by the weather.

Learning outcomes

- Map the location of renewable energy production
- Consider the threats to the production of renewable energy
- Explain the effectiveness of renewable energy production

Resources

Slideshow 5: What are the issues with renewable energy?

Student Sheet 5a: Mapping UK renewable energy production

Student Sheet 5b: UK climate data

Lesson 6: What will our future energy needs be?

Overview

In this lesson students will be thinking about what our energy needs may be in the future, and how we will generate enough energy to meet those needs. Students will also study a diagram from an academic journal article to evaluate the reliability of renewable forms of energy.

Learning outcomes

- Outline the generation and storage of renewable energies
- Predict future energy demand
- Evaluate the reliability of renewable energy

Resources

Slideshow 6:
What will our future energy needs be?

Student Sheet 6a:
Electricity consumption

Student Sheet 6a:
How reliable is renewable energy?

Lesson 7: How can governments plan for a low carbon future? Part 1

Overview

This summary lesson sees students work in groups to propose how a low carbon future could be achieved through carefully planned electricity production. Working in small groups students will consider how electricity should be generated in the future as part of a low carbon strategy. Students will need to evaluate different strategies to ensure that their proposals are robust enough to cope with the risks identified in the research. This research will be presented in the next lesson. Students will need access to computers for research, planning and creating a presentation.

Learning outcomes

- Assess the need for low carbon electricity generation
- Propose methods for generating electricity in the future
- Evaluate strategies to manage any risks involved

Resources

Slideshow 7:
How can governments plan for a low carbon future? Part one

Student Sheet 7a:
How can governments plan for a low carbon future?

Mark Scheme 7a:
Assessment Criteria

Lesson 8: How can governments plan for a low carbon future? Part 2

Overview

In their small groups, students will be presenting their ideas for a low carbon future to the class. Each student group will evaluate the other presentations. Once the presentations are finished, students will reflect on the whole experience. They need to consider what they contributed, what they discovered, what sources of information they used, and what they might change.

Learning outcomes

- Present with confidence and clarity, providing evidence for your ideas
- Propose an energy solution for a low carbon future
- Evaluate success for yourself and others using criteria

Resources

Slideshow 8:
How can governments plan for a low carbon future? Part two

Student Sheet 8a:
Group peer assessment

Student Sheet 8b:
Self-assessment evaluation sheet

Teacher guidance

The Teacher Guidance for each lesson uses a set of icons as seen below to provide visual clues to support teachers:

Lesson activities

Explain
teacher exposition using slides or script to support

Demonstration / watch
students watch a demonstration or video

Student activity
activity for students to complete individually such as questions on a Student Sheet

Pair activity
activity for students to complete in pairs

Group work
activity for students to complete in groups

Whole class discussion
teacher conducts a whole class discussion on a topic or as a plenary review

Home learning
home learning exercise for after school or alternatively, a lesson extension

Teacher ideas and guidance

Assessment and feedback
guidance to get the most from AfL (Assessment for Learning)

Guidance
further information on how to run an activity or learning step

Idea
optional idea to extend or differentiate an activity or learning step

Information
background or further information to guide an activity or explanation

Technical
specific ICT or practical hints and tips

Health and safety
health and safety information on a specific activity

What is the global atmospheric circulation model?

Age 14-16

60 minutes

Curriculum links

- Explore causes of weather events through understanding of the atmospheric circulation model

Resources

Slideshow 1:
What is the global atmospheric circulation model?

Student Sheet 1a:
Air pressure and jet streams

Student Sheet 1b:
Global atmospheric circulation model

Student Sheet 1c:
Jet stream

Thinglink:
How do weather cells affect the global climate?

Subject Update:
Learn more: Global atmospheric circulation

Lesson overview

In this lesson students will learn about jet streams, global atmospheric circulation and how they affect the weather around the world. Students will be able to explain the global atmospheric circulation model through the use of either a drawing, a model or a physical display.

Lesson steps	Learning outcomes
1. **Introduction (5 mins)** Set the context of the unit of work and what students will be covering over the eight lessons. Then, share the learning outcomes for this lesson.	• Understand the wider context and learning outcomes
2. **Different weather systems (10 mins)** Students will learn about air pressure and how it affects the weather.	• Identify different atmospheric events that will affect weather
3. **Global atmospheric circulation model (15 mins)** Students will learn about the global atmospheric circulation model. Students will be able to describe how the air moves around the cells, including the reasons for the movement of air.	• Describe the global atmospheric circulation model
4. **Demonstration (10 mins)** Students demonstrate their learning by creating an alternative way to display the global atmospheric model.	• Explain how global atmospheric circulation affects weather
5. **What affects the weather of the UK? (10 mins)** Students apply understanding about the global atmospheric circulation model and predict how the position of the jet stream can impact weather in the UK.	• Identify different atmospheric events that will affect weather
6. **Plenary (10 mins)** Students answer an exam question This should be peer assessed using the mark scheme.	• Reflect on learning

TEACHER GUIDANCE 1 (page 1 of 4)
WHAT IS THE GLOBAL ATMOSPHERIC CIRCULATION MODEL?

Step	Guidance	Resources
1 5 mins	Step 1 introduces students to the unit of work. · Spend some time going through the unit of work. Make it clear what students will achieve by the end of the unit, such as conducting their own independent research and presenting their findings to the class for peer review. · Use slide 3 to review the learning objectives with students. · Use slide 4 to prompt students to describe what the weather is like in three locations at different latitudes. · Ask students to think if are there any observable patterns across latitudes. Students should describe that it is hot and wet at the equator with temperatures cooling with increasing latitudes. Some students may recognise that there an increased variability in weather between 30 and 60 degrees, in the extra tropical storm track regions. · Share slide 5, showing students that some parts of the Earth have a greater net gain in solar radiation. This is consequence of the spherical shape of the Earth resulting in the equator receiving more direct sunlight. This temperature difference shapes global weather patterns.	**Slideshow 1:** Slides 1-5
	Satellites measure the amount of solar radiation absorbed by the climate system and the amount of thermal radiation emitted into space at the top of the atmosphere (outgoing longwave radiation). The difference (net radiation) tells us that the tropical regions are net heated by the sun and the extra-tropical regions are net cooled by the outgoing longwave radiation. The net heat received in the tropical regions is transported towards the poles by atmospheric winds and oceanic currents and balances the net heat loss to space in the extra-tropical regions.	

WHAT IS THE GLOBAL ATMOSPHERIC CIRCULATION MODEL?

Step	Guidance	Resources
2 10 mins	Step 2 sees students building foundational knowledge of air pressure. · Using slide 6, students learn how high pressure often results in calm and sunny weather. · Using slide 7, students learn how low pressure often results in cloudy weather and increased likelihood of precipitation. · Hand out Student Sheet 1a and ask students to use the diagram on slide 8 for support. · Students use Student Sheet 1a to draw diagrams which show how low and high air pressure are different including annotations which describe how the weather may vary depending on the air pressure.	**Slideshow 1:** Slides 6-8 **Student Sheet 1a:** Air pressure and jet streams

This task assumes prior knowledge of air pressure. If students are unable to answer adequately then spend some time going through the key information about air pressure and the impact it has on weather. More information about air pressure is provided below.

Air pressure and weather:

The movement of air around the Earth follows a particular pattern governed by key principles:

- The Earth is unevenly heated by the sun
- Hot air (less dense) rises, cold air (more dense) falls
- Temperature differences results in a pressure difference
- Air pressure is the mass of particles in the air column above
- Particles move from high pressure to low pressure

What causes ‘good’ weather?

Dry cool air falls in the air column. The cooler air compresses near the earth’s surface creating high pressure. The compression heats the air and the clouds dissolve because warm air can contain more water vapour than cold air. As a result, we experience sunny and dry conditions.

In summer the cloudless skies mean the sun is strong and it gets warm. In winter, the sun is less powerful and without the insulation of clouds more heat is lost from the Earth’s surface, as a result temperature drops.

What causes ‘bad’ weather?

Warmer air rises in the air column, creating low pressure near the Earth’s surface. The rising hot air cools forming clouds because cold air can contain less water vapour than hot air. We generally call localised low pressure systems storms, they bring colder, wetter and windier weather.

WHAT IS THE GLOBAL ATMOSPHERIC CIRCULATION MODEL?

Step	Guidance	Resources
3 15 mins	Step 3 focuses on students understanding the global atmospheric circulation model. · Show the diagram on slide 9, ask students to identify what the diagram shows. · Once you have established that the diagram is in fact showing the global atmospheric circulation model, go through the information about the global atmospheric circulation model on slide 10, including what it is and why it happens. For further knowledge about the global atmospheric circulation model, see the Subject Update. · Hand out a copy of Student Sheet 1b to each student. · Use slides 11-13 to go through the model with the students, discussing each of the cells and how the air moves from the equator to the polar regions. · Students annotate the diagram on Student Sheet 1b. Students complete the tasks on slide 17 and include the name of the different cells, the prevailing wind directions, any landforms that may be formed in the cell and why that is important, most common weather conditions at 0 degrees, 30 degrees, 60 degrees and 90 degrees.	**Slideshow 1:** Slides 9-15 **Student Sheet 1b:** Global atmospheric circulation model **Subject Update:** Learn more: Global atmospheric circulation **Thinglink:** How do weather cells affect the global climate?
4 10 mins	Step 4 see the students cement their understanding of the global atmospheric circulation model. · Students use the information they have learnt about the global atmospheric circulation model and create a demonstration, cementing their knowledge and understanding of the model. That demonstration could be anything, a poem or even a physical demonstration. A popular choice is to blow up a balloon and annotate it with a marker pen.	**Slideshow 1:** Slide 15
5 10 mins	Step 5 allows students to apply the ideas they have learned in the lesson to explain weather patterns in the UK. · Using slide 16 as a prompt, ask students to describe what factors might affect weather in the UK. · Once students have had the opportunity to share their ideas, reveal slide 17 which illustrates cold and hot air converging, similar to what happens at the boundary of the Polar and Ferrel cells. · Using slide 18, ask students to describe the image they can see and to try and predict what it might be. · Share slide 19-21 and describe what the jet stream is. · A key point to iterate to students is that air pressure is not a static thing. It constantly changes and one of the reasons for that change is the jet streams.	**Slideshow 1:** Slides 16-22 **Student Sheet 1c:** Jet stream

WHAT IS THE GLOBAL ATMOSPHERIC CIRCULATION MODEL?

Step **Guidance** **Resources**

- Hand out Student Sheet 1c to each student.
- Students draw a diagram indicating how the jet stream can affect the weather of the UK. Remind students to include annotations on their diagram.
- Using slide 22 ask students to consider and explain how the location of the jet stream will affect the weather of the UK.

What is a jet stream?
In the tropics air moves directly from high pressure to low pressure, but away from the equator. Due to the rotation of the Earth, the motion of air is deflected to the right in the Northern hemisphere and to the left in the Southern hemisphere. This is called the Coriolis effect.

The result is that strong westerly winds develop, called the subtropical Jet stream, and the motion is no longer from high to low pressure away from the equator. Instead this forms along lines of constant pressure (isobars). Therefore, in the region of the Jet stream, we find the low pressure and cold air polewards and on the equatorial side we find the high pressure and warm air. The Jet stream is unstable and the creation of storms makes the region of the Jet stream turbulent and a bit messy. The Jet stream can sometimes split into two jets, one north of the other, strengthen, weaken, and recombine. The greater the difference in temperature, and subsequent difference in pressure, the faster the air within the jet stream moves. Thus small meanders in the Jet stream easily cause large changes in temperature at the surface.

How does the jet stream impact weather in the UK?
The position of the jet stream relative to a location can dictate the weather conditions experienced. Let us use the UK as an example. When the jet stream is north of the UK it receives warmer, high pressure air from subtropical regions. This gives rise to decreased cloud cover, and decreased likelihood of precipitation. Due to a change in cloud cover, this means in summer it is warmer and in winter it is colder than normal. When the jet stream is on top of the UK, storms travelling with the jet pass over the country and bring wet, windy, unsettled weather. When the Jet stream is south of the UK, it is cold weather and relatively calm with small showers, and no stormy conditions.

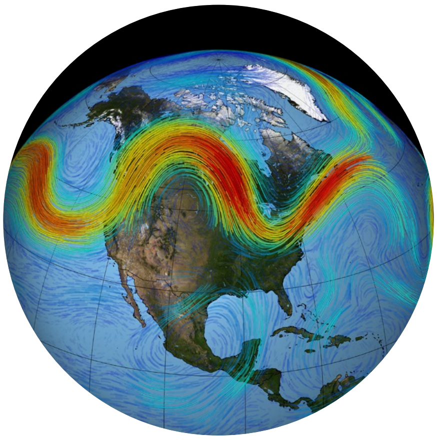
6
10 mins

Step 6 asks students to answer an exam question.

- Students answer a 6 mark exam question on slide 23 and peer asses each other's answers using the mark scheme on slide 24.

Slideshow 1:
Slides 23-25

Air pressure



Draw diagrams that show how high and low air pressure vary. Include annotations of the weather conditions caused by high and low air pressure.

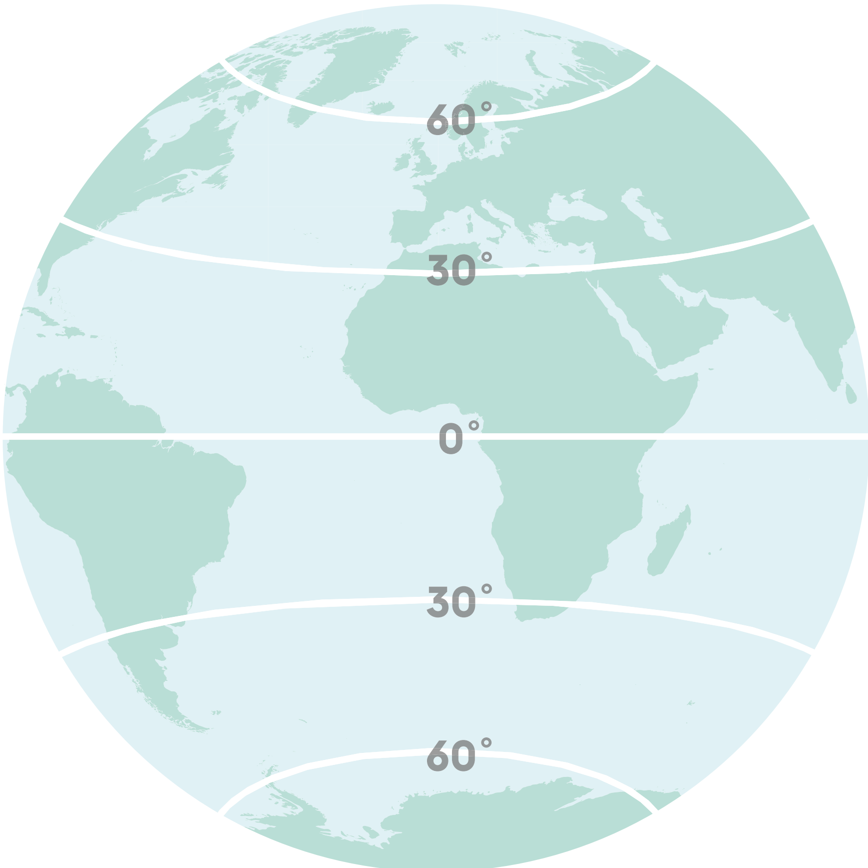
Low pressure	High pressure

Global atmospheric circulation model

Annotate the diagram to show the global atmospheric circulation model.

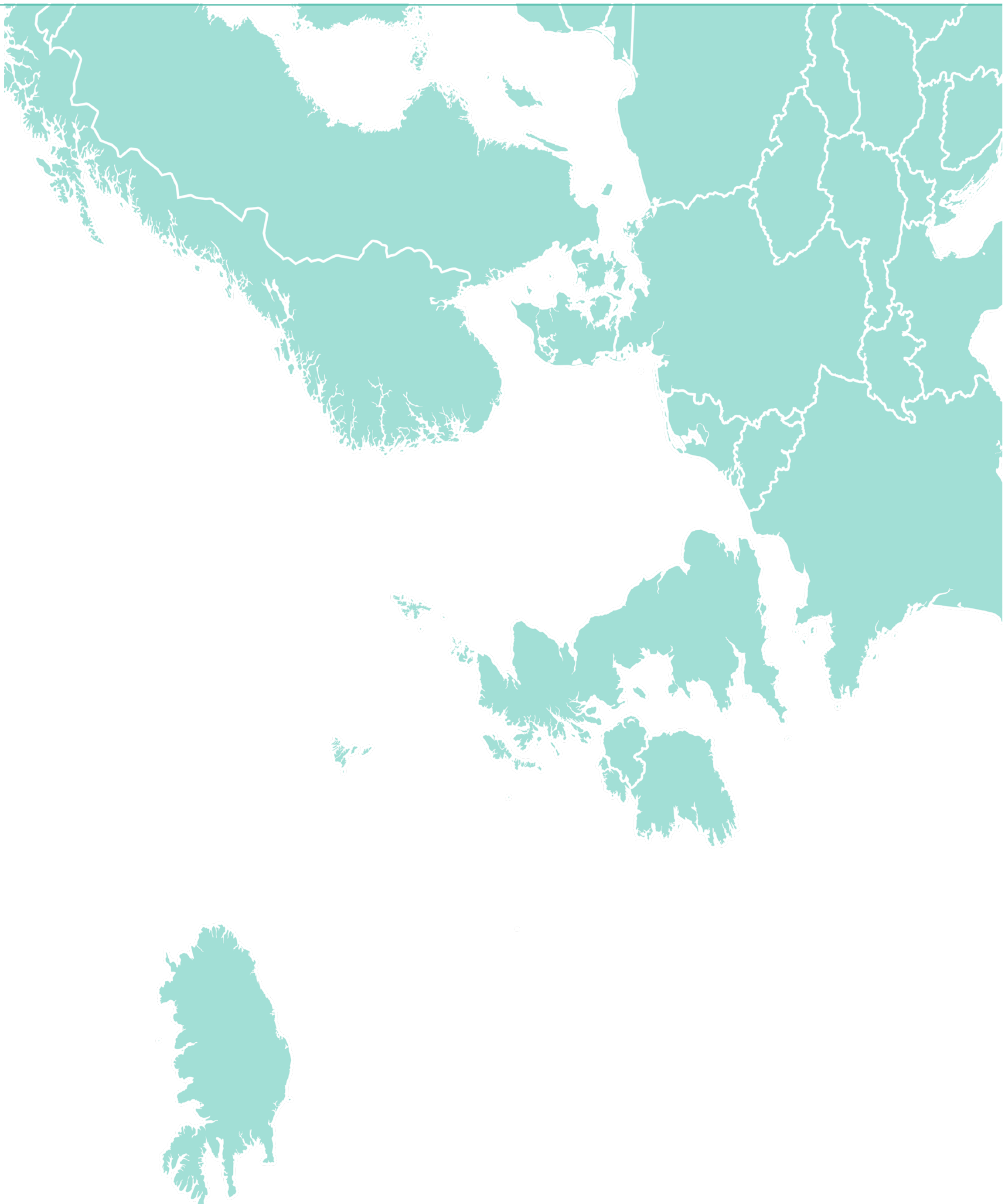
Include:

- The different cells and their names
- The areas of high and low pressure
- The direction of the prevailing wind



STUDENT SHEET 1c

Jet stream



jet streams over Europe

Draw a diagram indicating how the jet stream can affect the weather of the UK. Include annotations.

What impacts the weather in NW Europe?

Age 14-16

60 minutes

Curriculum links

- Predict weather using satellite imagery

Resources

Slideshow 2: What impacts the weather in NW Europe?

Student Sheet 2a: Map of Northwestern Europe

Student Sheet 2b: Climate data for Europe

Student Sheet 2c: European climate data exam questions

Lesson overview

In this lesson students will use all their knowledge of weather systems, and use a variety of satellite maps of Northwestern Europe to predict the weather for the next day. Students will then go on to use satellite images to describe the weather of Northwestern Europe and explain what has caused this weather and what conditions would be expected as a result of what is shown on the satellite images.

Lesson steps	Learning outcomes
1. **Introduction (5 mins)** Share the learning outcomes of the lesson.	• Understand the wider context and learning outcomes
2. **Northwestern Europe (10 mins)** Students will use atlases to label the countries on a map of Northwestern Europe.	• Label the countries in Northwestern Europe
3. **Climate of Northwestern Europe (25 mins)** Students look at the climate data for Northwestern Europe. Students analyse the data, identifying the hottest, wettest, driest countries. Students use isobar maps for Northwestern Europe to predict the weather for the following day.	• Describe and explain the climate of different countries in Northwestern Europe
4. **Factors affecting weather (10 mins)** Students work in pairs and discuss how the location of the jet stream will cause different types of extreme weather in the UK.	• Explain what could affect variations of weather and climate in Europe
5. **Plenary (10 mins)** Students demonstrate their learning by completing an exam question.	• Reflect on learning

TEACHER GUIDANCE 2 (page 1 of 2)
WHAT IMPACTS THE WEATHER IN NW EUROPE?

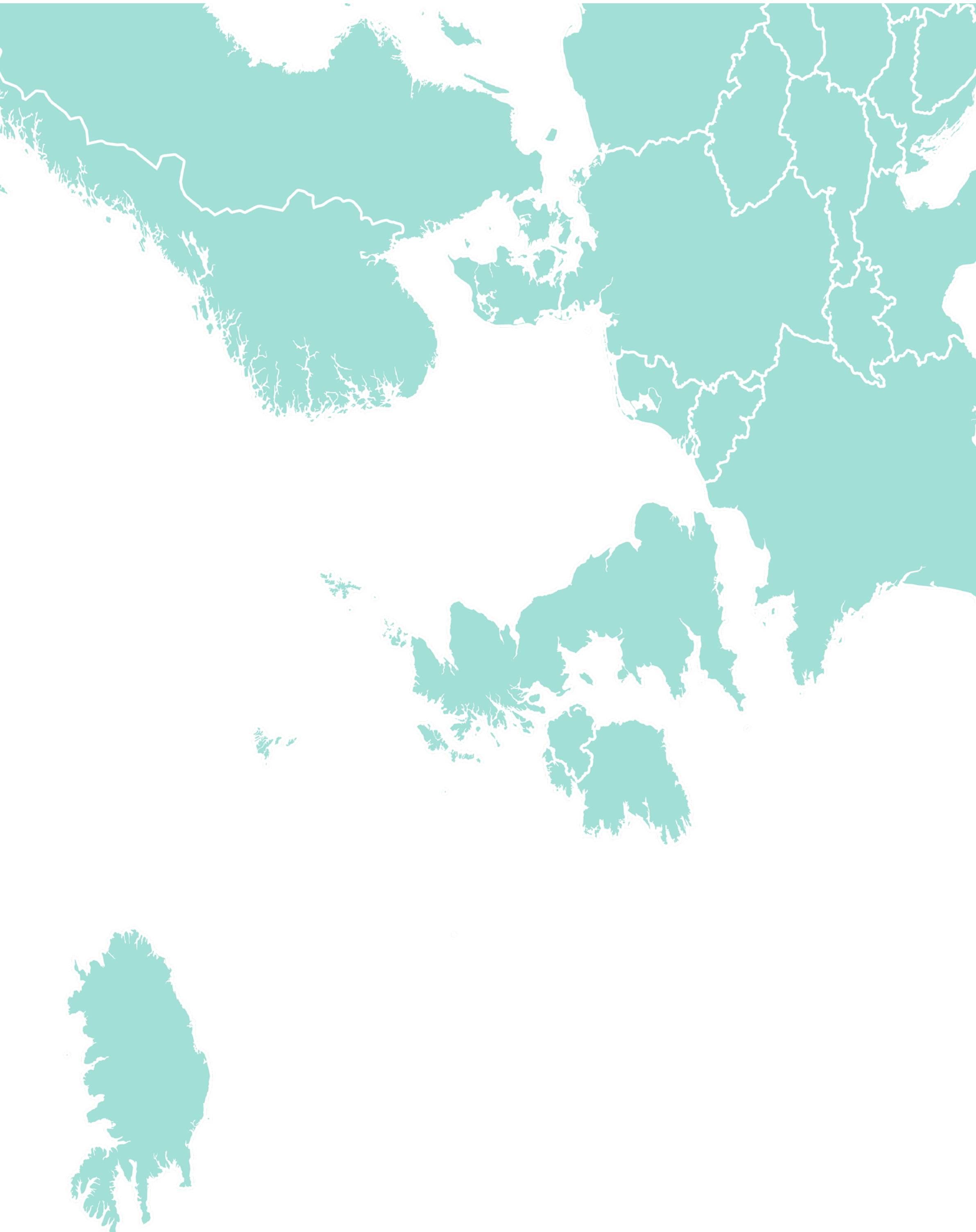
Step	Guidance	Resources
1 5 mins	Step 1 introduces students to the learning objectives of the lesson. · Read through the learning objectives with the class. · Explain to the students that this lesson will be building on what they learnt last lesson. This lesson students will be applying what they learnt about the global atmospheric circulation model and more specifically how it affects countries in Northwestern Europe.	**Slideshow 2:** Slides 1-3
2 10 mins	In step 2 students will map the countries in Northwestern Europe. · Test students on their knowledge of the countries in the Northwestern Europe. · Students use an atlas to label the different countries on the map of Northwestern Europe. · As a challenge task students to predict differences in the climate of the different countries in Europe.	**Slideshow 2:** Slides 4-5 **Student Sheet 2a:** Map of Northwestern Europe
3 25 mins	Step 3 sees students study the climate data for the countries in Northwestern Europe. · Ask students to discuss the difference in climate they have predicted earlier in the lesson. · While students share their predictions hand out Student Sheet 2b. · Students annotate their maps identifying key information from the climate data. Including identifying and labelling the hottest, coldest, wettest, driest and sunniest countries. · Show students the isobar map on slide 7. · Direct students to use the isobar map to guess what the weather would have been like in London, Berlin and Kiev. If students are struggling, remind them that when isobars are close together it indicates low pressure, resulting in unsettled and often very windy weather and big gaps between the isobars indicates high pressure, which means the weather should be calm, and settled with no wind or precipitation. Ask them to use the climate data to also predict what the temperature might be. The date of this isobar image is the 10th June 2019. · Ask students to put their hands up to share their predictions. · Show students the weather for the three different cities on slides 8-10. Were any of the students close?	**Slideshow 2:** Slides 6-10 **Student Sheet 2b:** Climate data for Europe

TEACHER GUIDANCE 2 (page 2 of 2)
WHAT IMPACTS THE WEATHER IN NW EUROPE?

Step	Guidance	Resources
4 10 mins	Step 4 sees students explain how the location of the jet stream can cause extreme weather in the UK. · Have students look at the images on slide 11 and discuss with the people in their group what the weather will be like due to the location of the jet stream over the UK shown on each image. Students make notes in their books whilst they are discussing the images. · Ask students to share their thoughts with the class. Ensure you go through each image. · When the jet stream is located on top of or to the north of the UK then the weather will be warmer and more settled. This is because the warmer air of the Mediterranean is able to move north to the UK. · When the jet stream is located to the south of the UK then the weather will be colder and wetter. This is because the cold air from the Arctic moves south to the UK. · When the jet stream has sharp waves in it the contrast between the hot and cold air results in very unsettled weather. This will be when we receive the most wind and precipitation. · Using the map on slide 12, task students to describe the weather, predict the location of the jet stream, and explain how the location of the jet stream would have affected the weather. · Challenge student to think about what other conditions would have caused the heatwave and how the jet stream may have caused the heatwave the UK experienced in 2018. · Hopefully students will mention that the heatwave was due to the jet stream sitting to the north of the UK,combined with high pressure resulting in the UK experiencing the settled and warm weather usually experienced closer to the Mediterranean.	**Slideshow 2:** Slide 11-12
5 10 mins	Step 5 asks students to answer an exam question. · Students answer the exam questions on slide 13. These are also replicated on Student Sheet 2c. · Ask students to peer assess each other's work before having a class discussion about the answers.	**Slideshow 2:** Slides 13-15 **Student Sheet 2c:** European climate data exam questions

STUDENT SHEET 2a

Map of Northwestern Europe

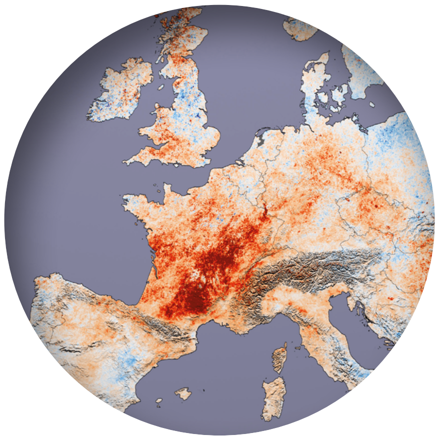


Climate extremes in Europe

Label the countries and, using weather data; locate the hottest, coldest, wettest, driest and sunniest countries.

STUDENT SHEET 2b

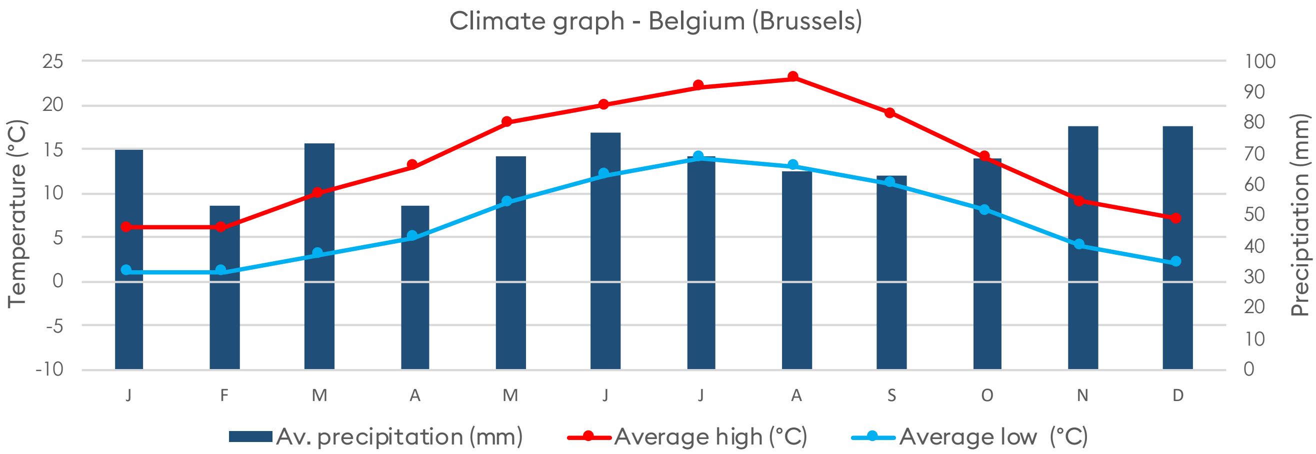
Climate data for Europe



Using the data provided, annotate Student Sheet 2a, a map of Northwestern Europe.

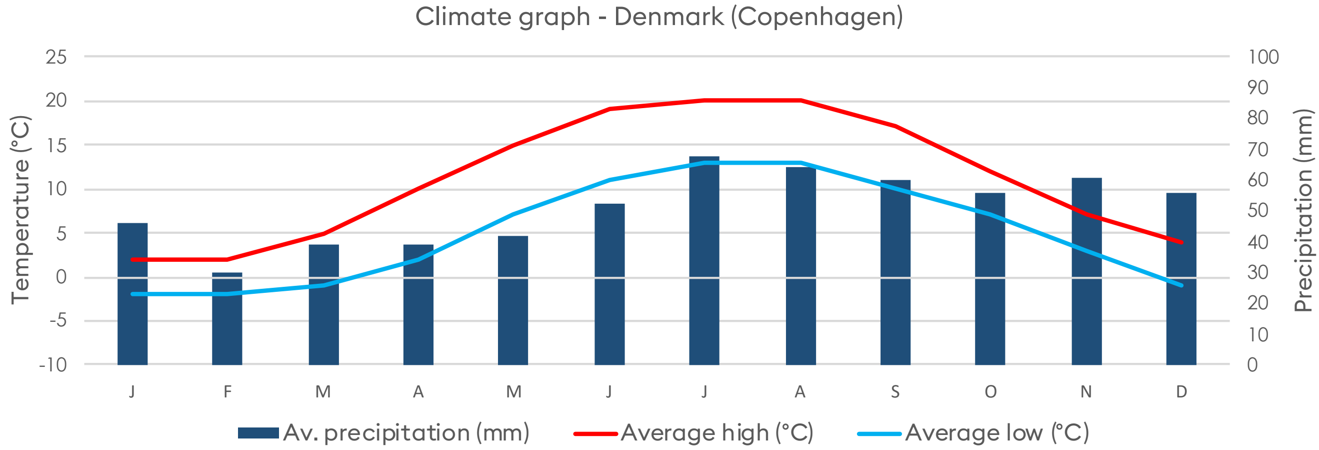
Label the temperature ranges for each country, in addition to identifying the actual hottest, coldest, wettest, driest and sunniest countries.

Belgium (Brussels)	J	F	M	A	M	J	J	A	S	O	N	D
Average high (°C)	6	6	10	13	18	20	22	23	19	14	9	7
Average low (°C)	1	1	3	5	9	12	14	13	11	8	4	2
Av. precipitation (mm)	71	53	73	53	69	77	69	64	63	68	79	79
Days with precipitation	13	10	13	11	11	10	10	10	9	10	13	12
Hours of sunshine	52	76	106	151	193	180	192	196	139	113	65	41

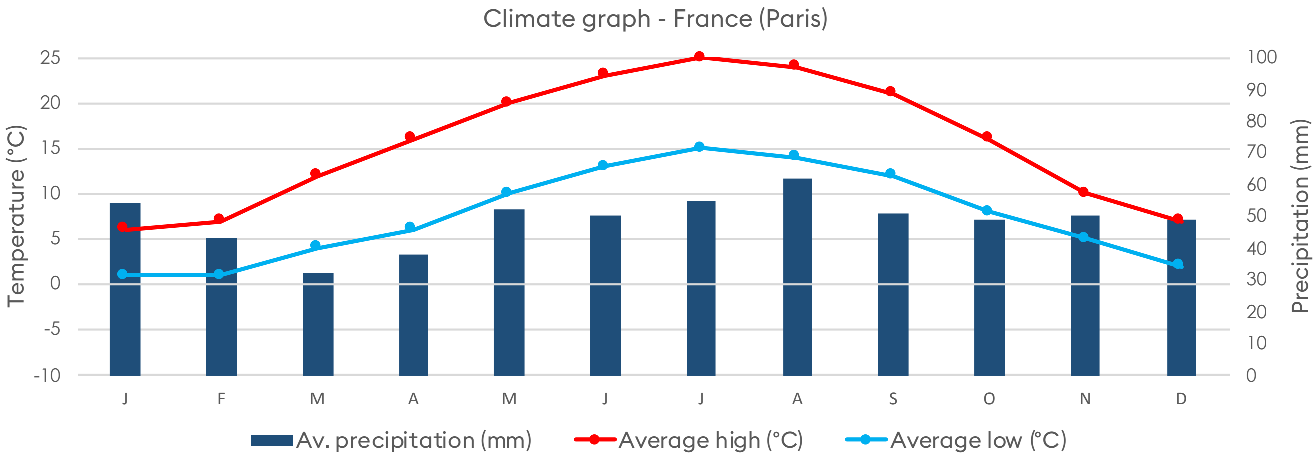


STUDENT SHEET 2b

Denmark (Copenhagen)	J	F	M	A	M	J	J	A	S	O	N	D
Average high (°C)	2	2	5	10	15	19	20	20	17	12	7	4
Average low (°C)	-2	-2	-1	2	7	11	13	13	10	7	3	-1
Av. precipitation (mm)	46	30	39	39	42	52	68	64	60	56	61	56
Days with precipitation	10	8	9	8	8	8	10	10	10	9	12	11
Hours of sunshine	45	67	110	168	217	218	202	193	133	90	55	42

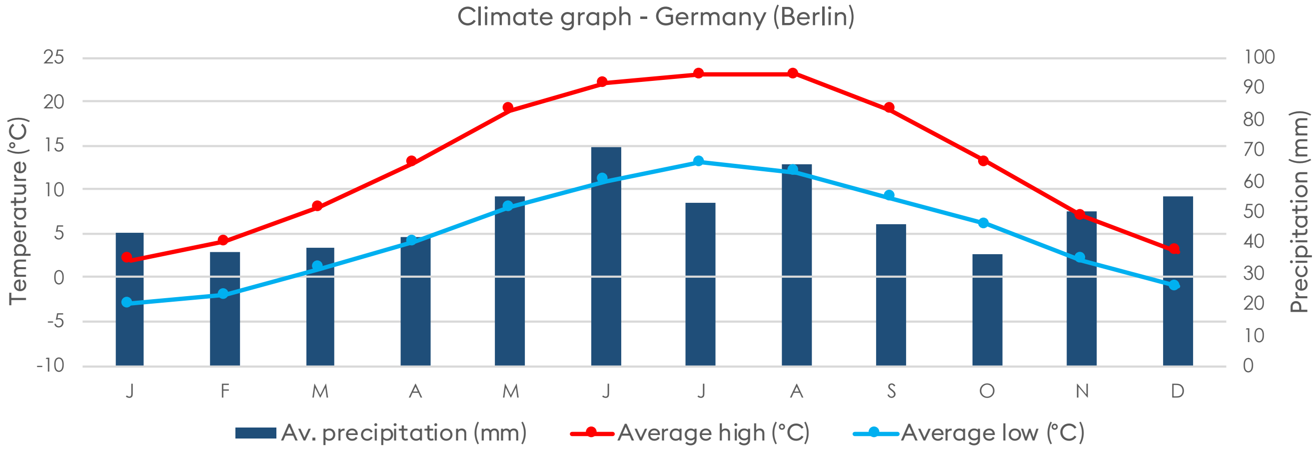


France (Paris)	J	F	M	A	M	J	J	A	S	O	N	D
Average high (°C)	6	7	12	16	20	23	25	24	21	16	10	7
Average low (°C)	1	1	4	6	10	13	15	14	12	8	5	2
Av. precipitation (mm)	54	43	32	38	52	50	55	62	51	49	50	49
Days with precipitation	17	14	12	13	13	12	12	13	13	14	15	16
Hours of sunshine	64	83	152	185	223	233	231	204	166	122	63	53

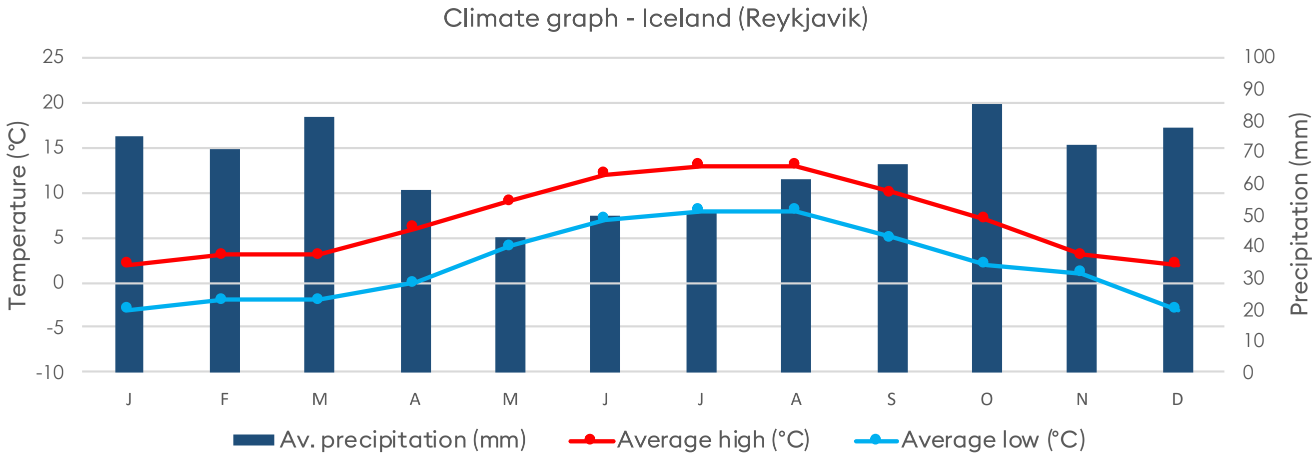


STUDENT SHEET 2b

Germany (Berlin)	J	F	M	A	M	J	J	A	S	O	N	D
Average high (°C)	2	4	8	13	19	22	23	23	19	13	7	3
Average low (°C)	-3	-2	1	4	8	11	13	12	9	6	2	-1
Av. precipitation (mm)	43	37	38	42	55	71	53	65	46	36	50	55
Days with precipitation	10	9	8	9	10	10	9	10	9	8	10	11
Hours of sunshine	47	81	121	161	220	229	217	211	161	112	53	37

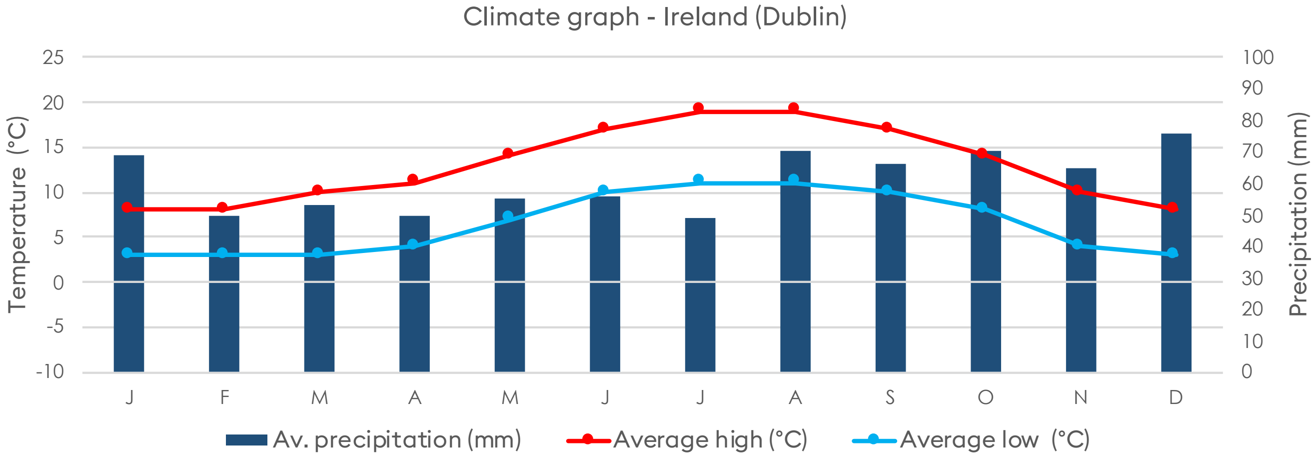


Iceland (Reykjavík)	J	F	M	A	M	J	J	A	S	O	N	D
Average high (°C)	2	3	3	6	9	12	13	13	10	7	3	2
Average low (°C)	-3	-2	-2	0	4	7	8	8	5	2	1	-3
Av. precipitation (mm)	75	71	81	58	43	50	51	61	66	85	72	78
Days with precipitation	13	12	14	14	10	11	10	12	12	14	12	14
Hours of sunshine	27	52	111	140	192	161	171	155	125	83	38	12

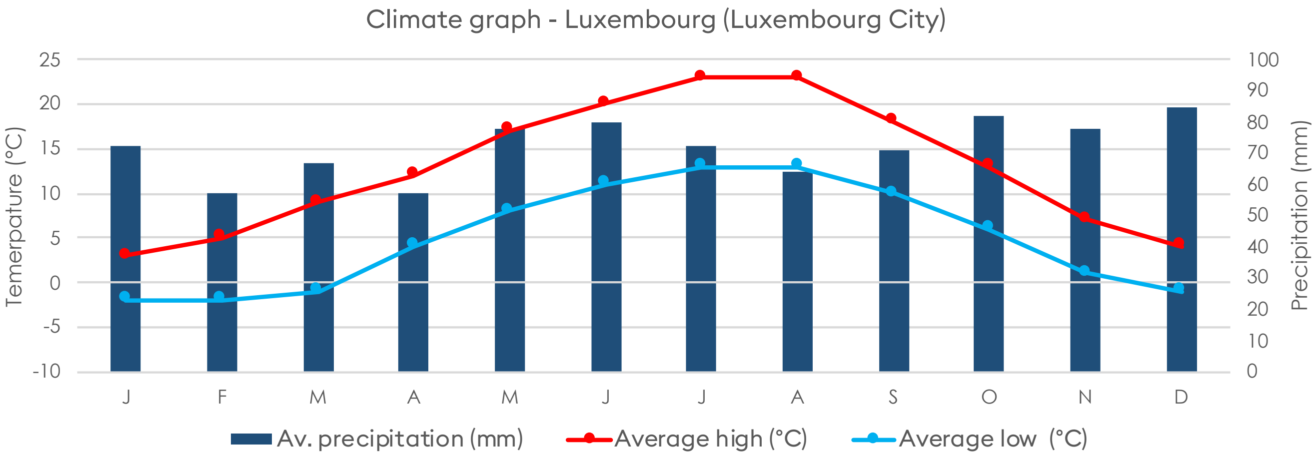


STUDENT SHEET 2b

Ireland (Dublin)	J	F	M	A	M	J	J	A	S	O	N	D
Average high (°C)	8	8	10	11	14	17	19	19	17	14	10	8
Average low (°C)	3	3	3	4	7	10	11	11	10	8	4	3
Av. precipitation (mm)	69	50	53	50	55	56	49	70	66	70	65	76
Days with precipitation	13	10	11	10	11	10	9	11	10	11	11	12
Hours of sunshine	56	71	110	157	188	180	166	157	128	97	71	51

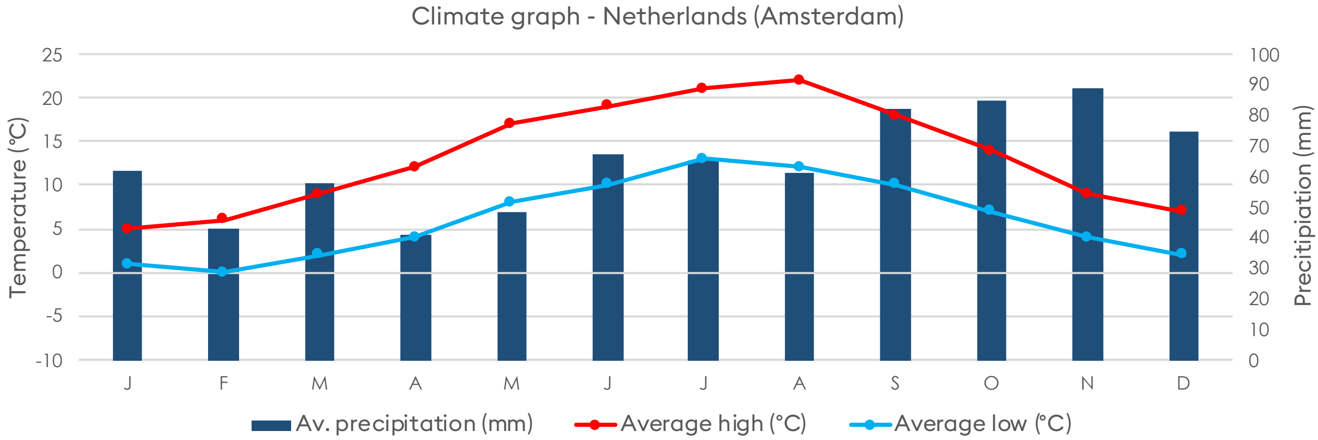


Luxembourg (Luxembourg City)	J	F	M	A	M	J	J	A	S	O	N	D
Average high (°C)	3	5	9	12	17	20	23	23	18	13	7	4
Average low (°C)	-2	-2	-1	4	8	11	13	13	10	6	1	-1
Av. precipitation (mm)	72	57	67	57	78	80	72	64	71	82	78	85
Days with precipitation	12	10	12	10	11	11	9	9	9	11	12	12
Hours of sunshine	46	81	118	171	210	209	234	227	154	103	55	39

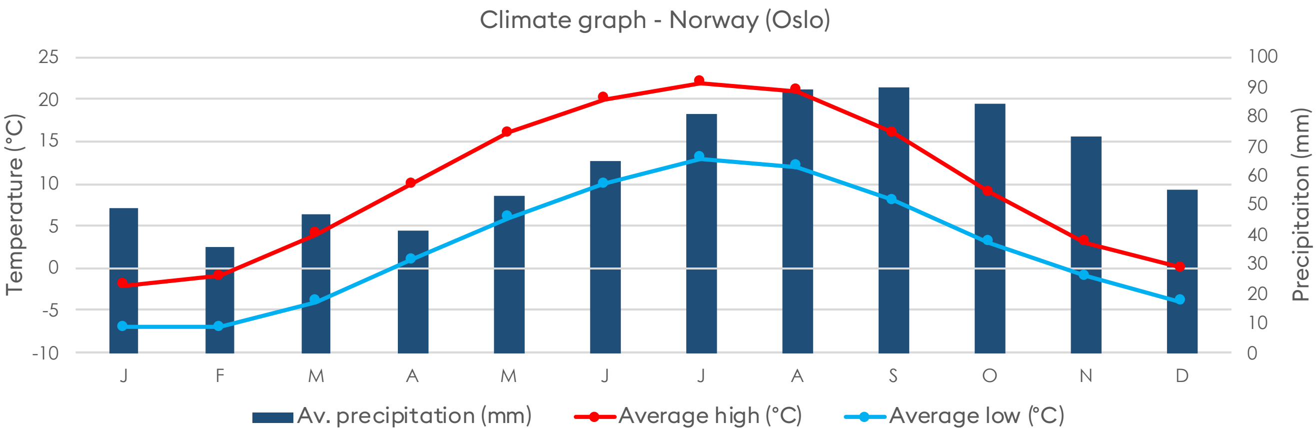


STUDENT SHEET 2b

Netherlands (Amsterdam)	J	F	M	A	M	J	J	A	S	O	N	D
Average high (°C)	5	6	9	12	17	19	21	22	18	14	9	7
Average low (°C)	1	0	2	4	8	10	13	12	10	7	4	2
Av. precipitation (mm)	62	43	58	41	48	67	65	61	82	85	89	75
Days with precipitation	17	13	17	14	14	14	13	13	16	17	19	18
Hours of sunshine	53	80	116	166	217	200	208	201	133	103	58	45

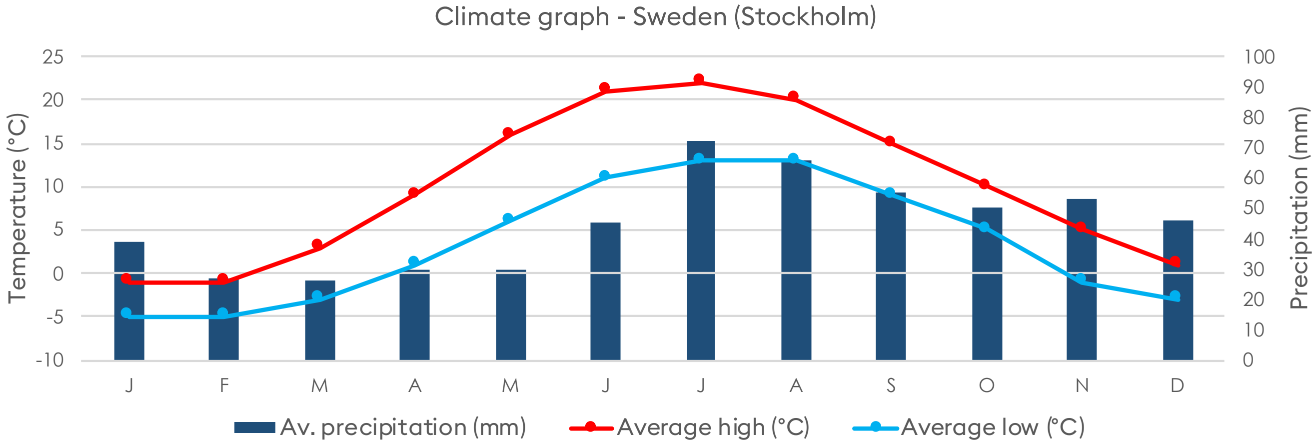


Norway (Oslo)	J	F	M	A	M	J	J	A	S	O	N	D
Average high (°C)	-2	-1	4	10	16	20	22	21	16	9	3	0
Average low (°C)	-7	-7	-4	1	6	10	13	12	8	3	-1	-4
Av. precipitation (mm)	49	36	47	41	53	65	81	89	90	84	73	55
Days with precipitation	9	8	8	7	8	10	11	11	11	11	10	9
Hours of sunshine	40	76	126	178	220	250	246	216	144	86	51	35

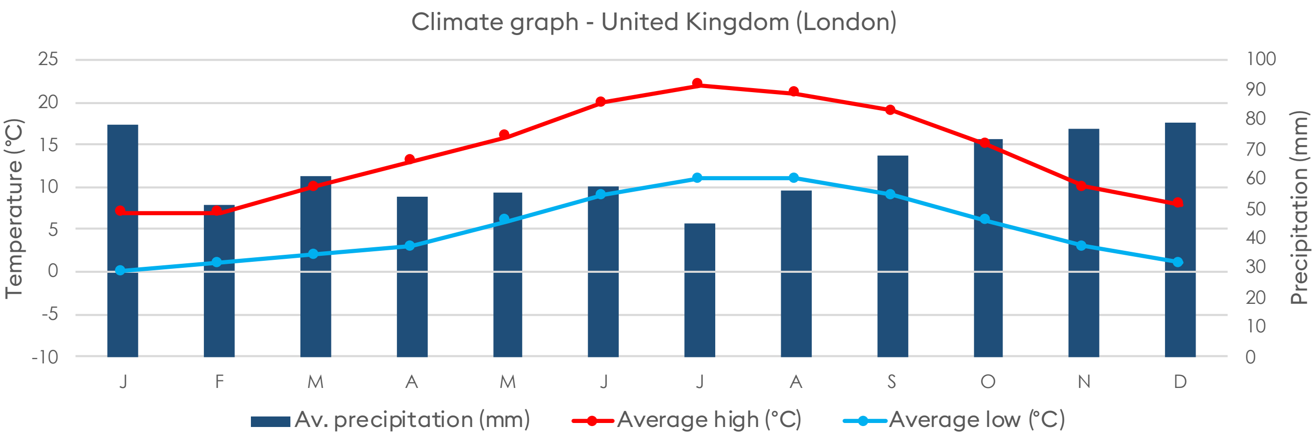


STUDENT SHEET 2b

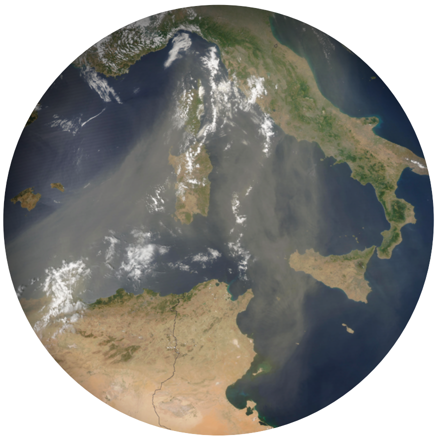
Sweden (Stockholm)	J	F	M	A	M	J	J	A	S	O	N	D
Average high (°C)	-1	-1	3	9	16	21	22	20	15	10	5	1
Average low (°C)	-5	-5	-3	1	6	11	13	13	9	5	-1	-3
Av. precipitation (mm)	39	27	26	30	30	45	72	66	55	50	53	46
Days with precipitation	10	7	7	7	7	7	10	10	10	9	11	10
Hours of sunshine	40	72	135	185	276	292	260	221	154	99	54	33



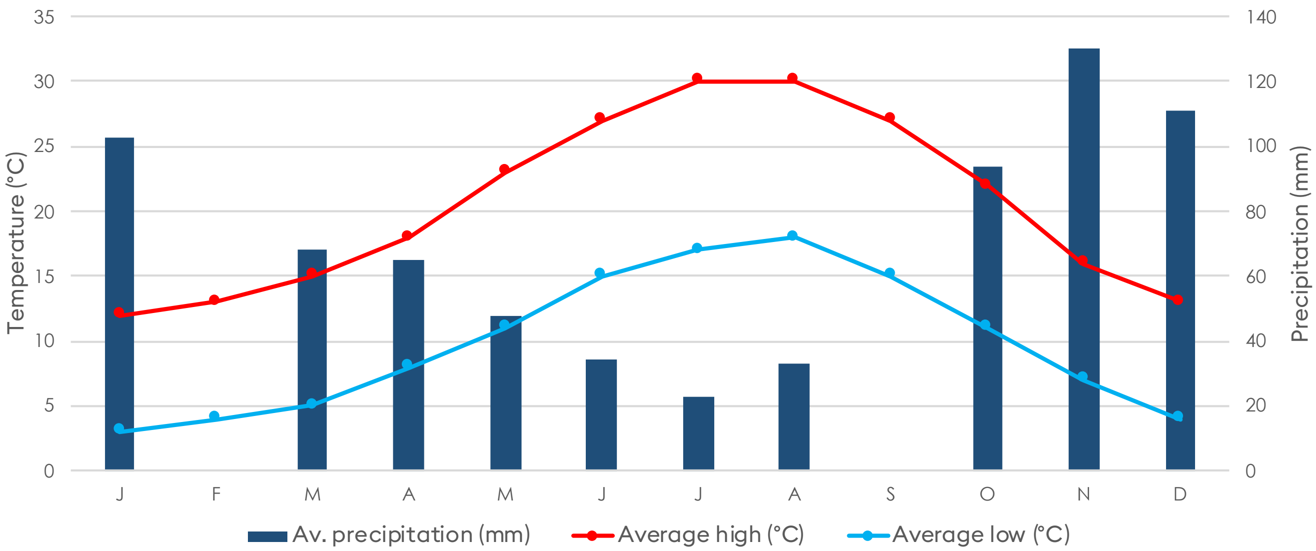
United Kingdom (London)	J	F	M	A	M	J	J	A	S	O	N	D
Average high (°C)	7	7	10	13	16	20	22	21	19	15	10	8
Average low (°C)	0	1	2	3	6	9	11	11	9	6	3	1
Av. precipitation (mm)	78	51	61	54	55	57	45	56	68	73	77	79
Days with precipitation	17	13	11	14	13	11	13	13	13	14	16	16
Hours of sunshine	52	71	113	153	204	204	205	195	148	111	69	48



European climate data exam questions



Italy (Rome)	J	F	M	A	M	J	J	A	S	O	N	D
Average high (°C)	12	13	15	18	23	27		30	27	22	16	13
Average low (°C)	3	4		8	11	15	17	18	15		7	4
Av. precipitation (mm)	103	99	68	65	48	34	23	33	68	94	130	111



Questions

1. Complete the climate graph. (2 marks)
2. Complete the data table. (2 marks)
3. Describe the climate of Rome. (3 marks)

How can we predict the weather of the future?

Age 14-16

60 minutes

Curriculum links

- Develop critical thinking through evaluating climate model research

Resources

Slideshow 3:
How can we predict the weather of the future?

External Link:
Meteological conditions leading to extreme low variable renewable energy production and extreme high energy shortfall (2019) Van der Wiel et al.

External Link:
Carbon brief Q&A: How do climate models work?

Subject Update:
Learn more: Climate models

Subject Update:
Climate and Energy HIWAVES journal article student summary

Lesson overview

This lesson for higher ability students extends student knowledge of climate models and how they can be used in policy development. The HIWAVES research team wrote an academic paper investigating the impact of predicted weather on renewable energy production. This lesson looks at how the research team used climate models as part of their work and then focuses on the academic journal article written by the team and supports students to access information from this level of research output.

Lesson steps	Learning outcomes
1. Introduction (5 mins) Share the learning outcomes of the lesson.	• Understand the wider context and learning outcomes
2. Climate models and their uses (20 mins) Students will read a background briefing on climate models and their application in this research. A series of questions can be used for guiding a shared discussion or for independent learning.	• Examine the need to understand what the future climate may look like • Name and evaluate the effectiveness of using climate models
3. Analysing an academic journal article (20 mins) Using a student summary of the HIWAVES academic journal article, students will learn about the structure of this research output and analyse either a student summary or the full paper. A series of questions can be used for guiding a shared discussion or for independent learning.	• Name and evaluate the effectiveness of using climate models • Describe the findings from the academic paper
4. Exam question (15 mins) Students answer the exam question and peer assess each other's answers.	• Reflect on learning

TEACHER GUIDANCE 3
HOW CAN WE PREDICT THE WEATHER OF THE FUTURE?

Step	Guidance	Resources
1 5 mins	Step 1 introduces students to the learning objectives of the lesson. · Inform students of the lesson's learning objectives · Ask students to predict what they think the climate may be like in the future. Instruct students first to write their predictions into their book independently before sharing as a class.	**Slideshow 3:** Slides 1-3
2 20 mins	In step 2, students will consider the application of climate models, in particular their application to the research focus of the HIWAVES team. · Use the question on slide 4 to develop students' ideas about the use of climate models. · Hand out copies of the Subject Update or access online. · Use the questions on slide 5 to guide either a whole class reading and discussion or for students to work independently. Further information about climate models can found on the Carbon Brief website at: https://www.carbonbrief.org/qa-how-do-climate-models-work	**Slideshow 3:** Slides 4-5 **Subject Update:** Learn more: Climate models
3 20 mins	This lesson step focuses on the academic journal article written as part of the HIWAVES project. · Hand out copies of the article summary or ensure students can access the article online. · Read through the student summary as a class or in groups, pairs or individually. · Use the questions on slide 6 to guide a whole class discussion followed by giving students time to write their answers down independently. The full academic journal article: Meteorological conditions leading to extreme low variable renewable energy production and extreme high energy shortfall, (2019) Van der Wiel et al., Renewable and Sustainable Energy Reviews 111, (2019) 261–275, can be accessed online at: https://doi.org/10.1016/j.rser.2019.04.065	**Slideshow 3:** Slide 6 **Subject Update:** Climate and Energy HIWAVES journal article student summary
4 15 mins	Step 4 sees students answer an exam question and peer assess each other's answers. · Students answer the 6-mark exam question on slide 7 and peer assess each other's answers using the mark scheme on slide 8.	**Slideshow 3:** Slides 7-8

How is energy produced?

Age 14-16

60 minutes

Curriculum links

- Explore the production of energy and their spatial distribution.

Resources

Slideshow 4:
How is energy produced?

Student Sheet 4a:
Renewable energy

Student Sheet 4b:
Non-renewable energy

Lesson overview

In this lesson students will learn about how different types of energy are generated and stored, focussing on examples of renewable and non-renewable sources. Students will also look at the energy production matrix of the UK, the Netherlands and the European Union, comparing and contrasting them.

Lesson steps	Learning outcomes
1. Introduction (5 mins) Share the lesson objectives with the students. Test prior knowledge of different energy types.	• Understand the wider context and learning outcomes
2. Renewable energy (20 mins) Students focus on wind, wave and solar energy production. Students will study how the energy is generated and how and where it is stored.	• Describe the different types of energy • Explain how energy is produced and stored
3. Non-renewable energy (20 mins) Students focus on oil and gas energy production. Students identify where the different types of energy are generated and where they are stored.	• Describe the different types of energy • Explain how energy is produced and stored
4. Energy matrices (15 mins) Students look at tables that show the energy matrix of the UK, the Netherlands and the European union as a whole.	• Analyse the different energy matrices

TEACHER GUIDANCE 4 (page 1 of 2)
HOW IS ENERGY PRODUCED?

Step	Guidance	Resources

1
5 mins
	Step 1 introduces students to the lesson.
	· Read through the learning objectives with the class.
	· Assess students' prior knowledge of energy. Asking questions such as:
	  · What are the different types of energy?
	  · What energy production is included in the different categories?
	  · How do you distinguish between the two types of energy?
	· Use slide 4 to review the whole class discussion and identify any types of energy sources which were not previously mentioned.
		Slideshow 4:
		Slides 1-4

2
20 mins
	Step 2 develops students' knowledge and understanding of renewable energy.
	· Introduce the task to the class. Students will be gathering information today about renewable and non-renewable energy.
	· Ask students to draw a mind map in their books. Half the mind map will be for renewable energy and the other half for non-renewable energy. Use the example on slide 5 to guide students.
	· Stick the information on student sheet 4a around the room.
	· Review the basics of renewable energy using slides 6-9.
	· Students walk around the room and read information about wind, wave and solar energy. Students make notes in their books. The information will focus on the following questions:
	  · How is the energy produced?
	  · How much is produced each year?
	  · Where is it stored?
	· Students use the notes they have collected to annotate the mind map consolidating all the information about renewable energy.
	· Once students have finished, invite them back to their seats to answer the exam question on slide 10.
		Slideshow 4:
		Slides 5-10
		Student Sheet 4a:
		Renewable energy

TEACHER GUIDANCE 4 (page 2 of 2)
HOW IS ENERGY PRODUCED?

Step	Guidance	Resources

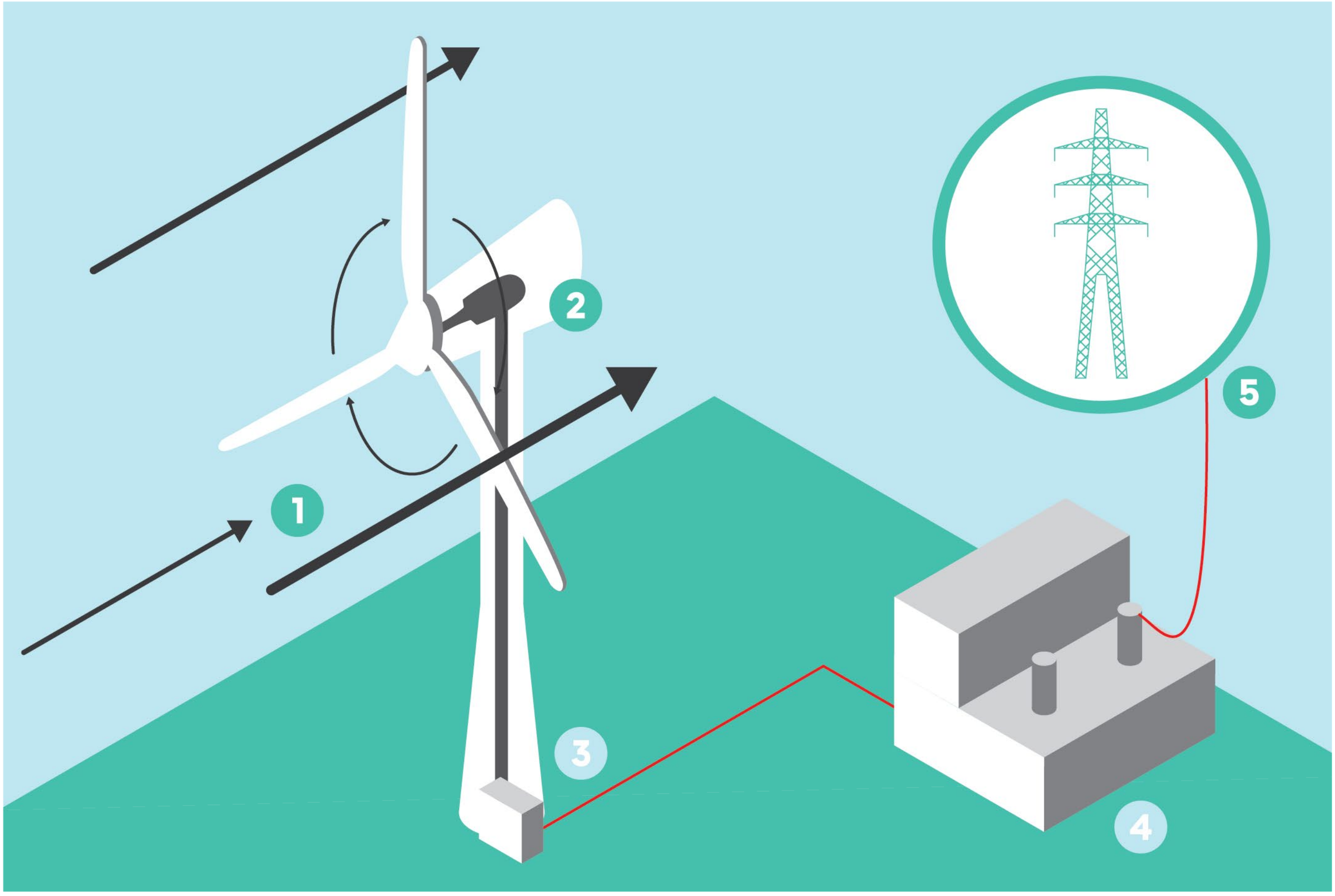
3
20 mins
	Step 3 focuses on non-renewable energy.
	· Ask a student to collect in Student Sheet 4a, the renewable energy information sheets, and distribute Student Sheet 4b, the non-renewable information sheets.
	· Students read the information about oil and gas and make notes in their books.
	· The information will focus on the following questions:
	  · How is the energy formed?
	  · How is the energy produced?
	  · Where does the energy come from?
	  · How is used each year?
	· Students complete the mind map with the notes they have collected.
	· Showing slide 11, review students understanding of non-renewable energy through targeted questioning.
	· As a challenge task, ask students to write their own exam questions, they need to be 1, 2, or 4 mark exam questions and should include a mark scheme. Students then answer each other's questions and peer assess them.
		Slideshow 4:
		Slide 11
		
		Student Sheet 4b:
		Non-renewable energy

4 15 mins	In step 4 students examine the energy production of the UK, Netherlands and Europe as a whole. · Students use the data on slide 12 to draw a pie chart representing the electricity production of the UK, Netherlands and Europe. · Students describe the three pie charts and compare the data. · Students finish the lesson by predicting how the pie charts might change in the future. · Any pie charts not finished during the lesson students can be completed as home learning. Printed copies of slide 12 would be needed to support this.	**Slideshow 4:** Slide 12

STUDENT SHEET 4a

Renewable energy

How is wind energy produced?



1. The wind passes over the blades and makes them turn (kinetic energy).
2. The blades turn a shaft within the top section of the turbine.
3. The shaft turns a generator which turns the kinetic energy into electrical energy.
4. A transformer converts this electrical energy into the correct voltage for the local network.
5. The electricity is then transported via the national grid.

How much wind energy is produced each year in the UK?

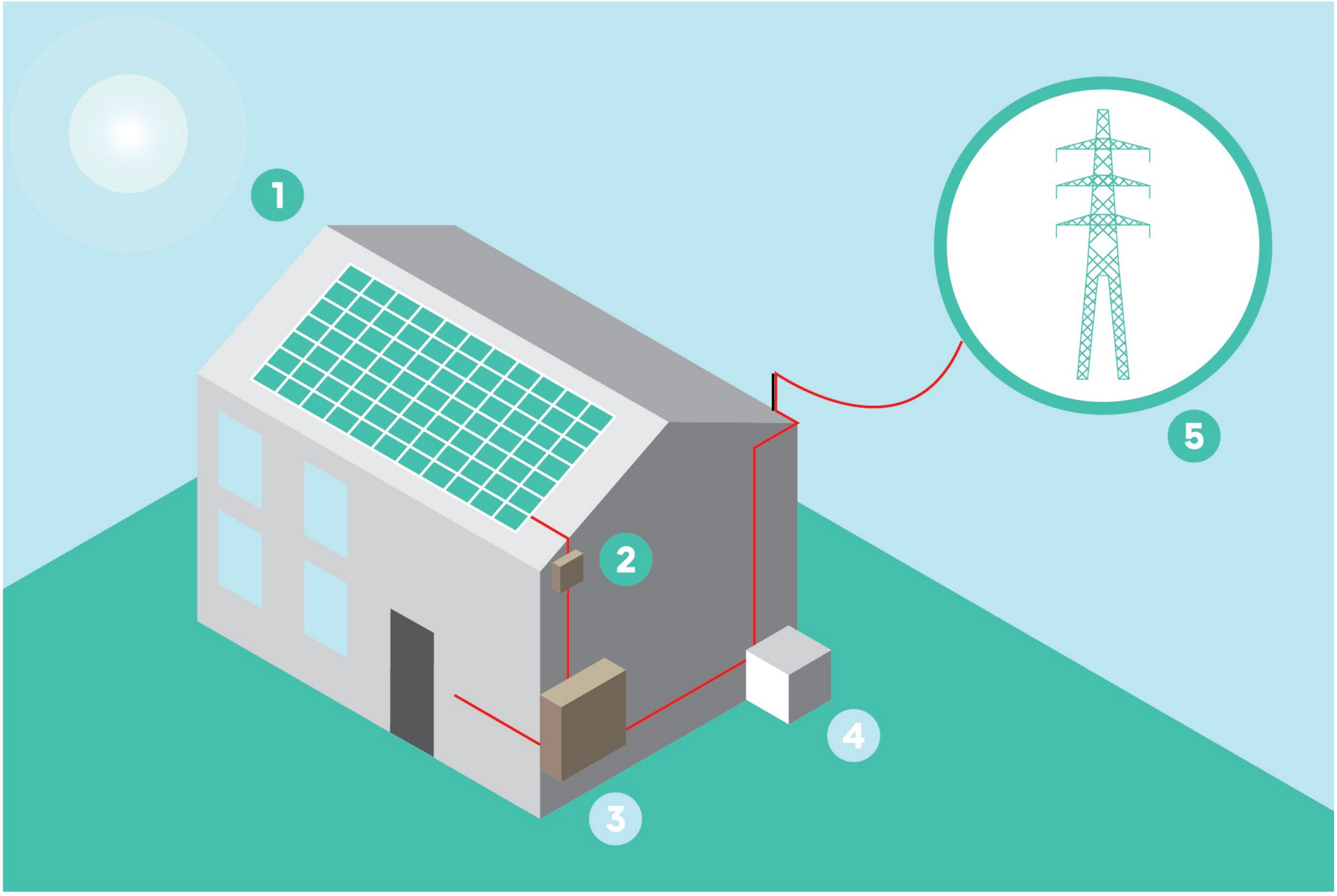
It is estimated there are 7,779 onshore wind turbines and 1,932 offshore turbines in the UK.
In the first quarter of 2018, combined onshore and offshore wind turbines generated 17.72 TWh of energy.

Where is wind energy stored?

Once the energy is generated, it can be stored in a number of ways, the most common is battery storage. Scottish Power has plans to build a mega storage facility, adding 50 megawatts of storage. It has plans for the £20 million pound facility to be operational by 2020. Wind energy an also be stored using compressed air, hydrogen fuel cells and hydroelectric pump stations.

Renewable energy

How is solar energy produced?



1 Solar Photovoltaics (PV), use photovoltaic cells to collect the sun's energy. The cells convert sunlight into electricity. Solar PV panels use daylight, not direct sunlight, so they can be used when it is cloudy.

2 When the sunlight hits the cell, an electric field is produced across the layers of silicon (or any material that can conduct electricity).

3 Electricity generated from domestic installations are used as DC electricity within the home.

4 Spare capacity is converted into AC electricity using an inverter.

5 This excess solar generated electricity is then shared with the national grid.

How much solar energy is produced each year in the UK?

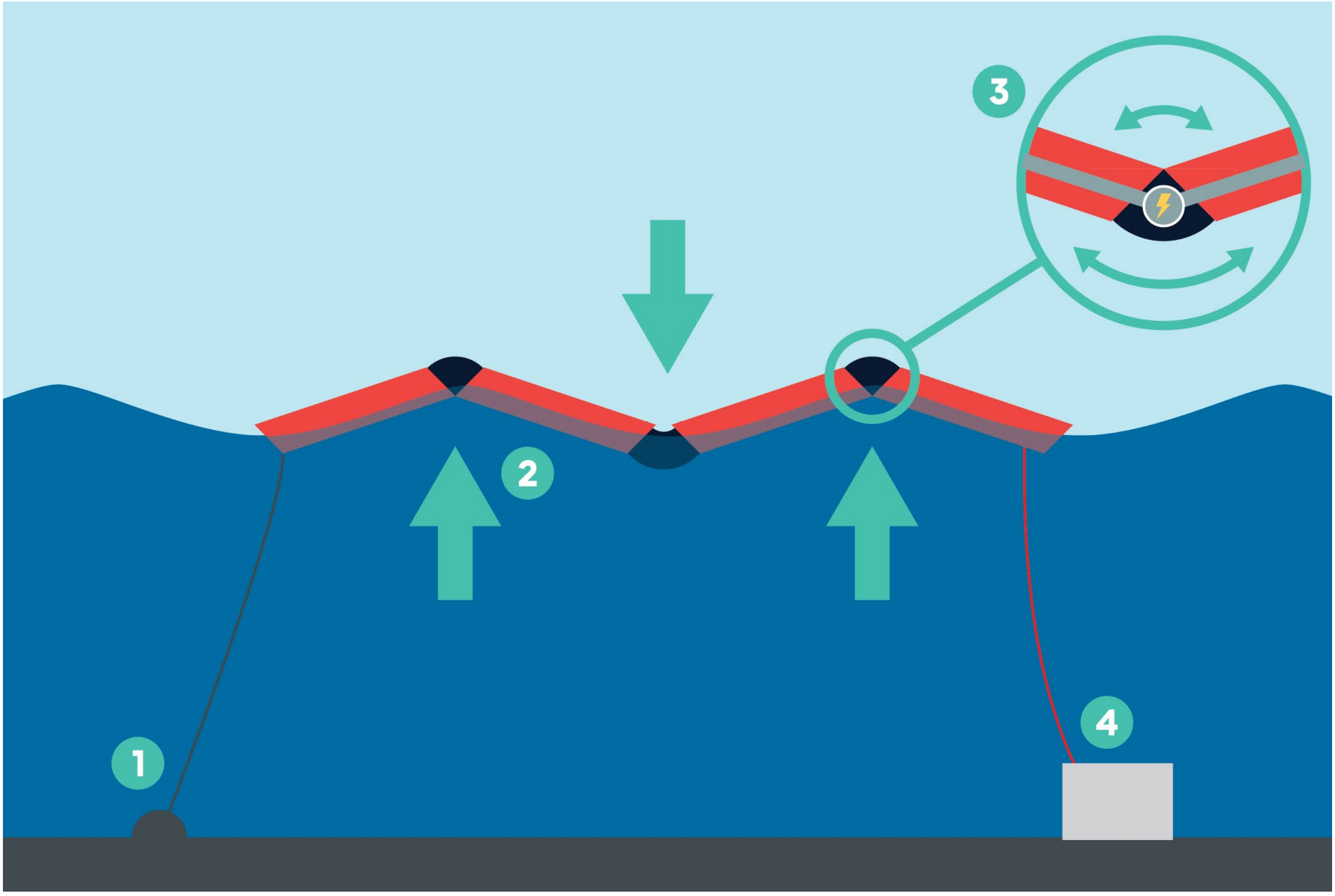
In the first quarter of 2018, 5% of all the renewable energy generated was Solar PV energy, with 4.7TWh of electricity produced. As of 2015, there were 426 solar farms in the UK.

Where is solar energy stored?

Once the energy is generated, it can be stored in a number of ways, the most common is battery storage, though it can also be stored using hydrogen fuel cells.

Renewable energy

How is wave energy produced?



1. The front of the 'snake' is anchored to the sea floor, this means the structure is not an obstacle to the waves, rather it will roll with the motion of the waves.
2. The structure consists of a number of sections linked by hinged joints. To generate energy each section has a hydraulic ram which pumps high pressure fluid through hydraulic motors.
3. As the waves cause the sections to move the hydraulic ram moves, the movement of the hydraulic motors cause the electrical generators to produce electricity.
4. All the generated power from all the sections is then fed down a single cable to a junction on the seabed.

How much wave energy is produced each year in the UK?

The Pelamis wave power generator is just one way that wave energy can be generated. It is estimated that wave and tidal could generate 20% of the UK electricity, but the investment into wave energy is limited. Currently, wave and tidal energy accounts for only 0.004 TWh of electricity production in the UK.

Where is wave energy stored?

Once the energy is generated, it can be stored in a number of ways, the most common is battery storage.

STUDENT SHEET 4b

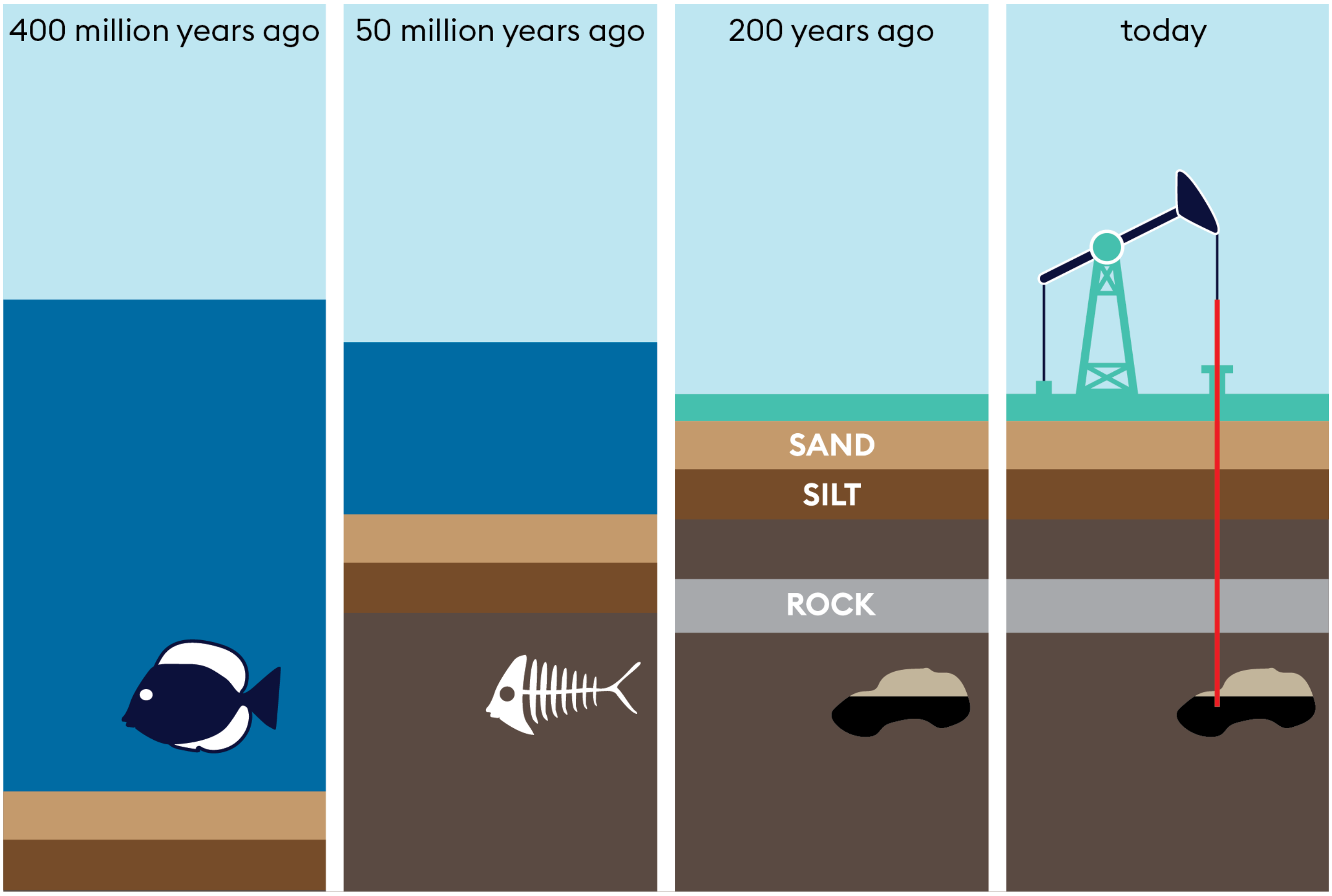
Non-renewable energy

How are oil and gas formed?

Oil and gas are fossil fuels, this means they are finite resources, which will run out, formed over millions of years. 300-400 million years ago plants and animals that died in the sea were buried by sand, silt and other sediment. Due to the extended pressure and heat, the remains of the dead plants and animals turn into oil and natural gas.

How is the energy produced?

When oil and gas are burnt, they generate a lot of heat which is used to generate electricity.



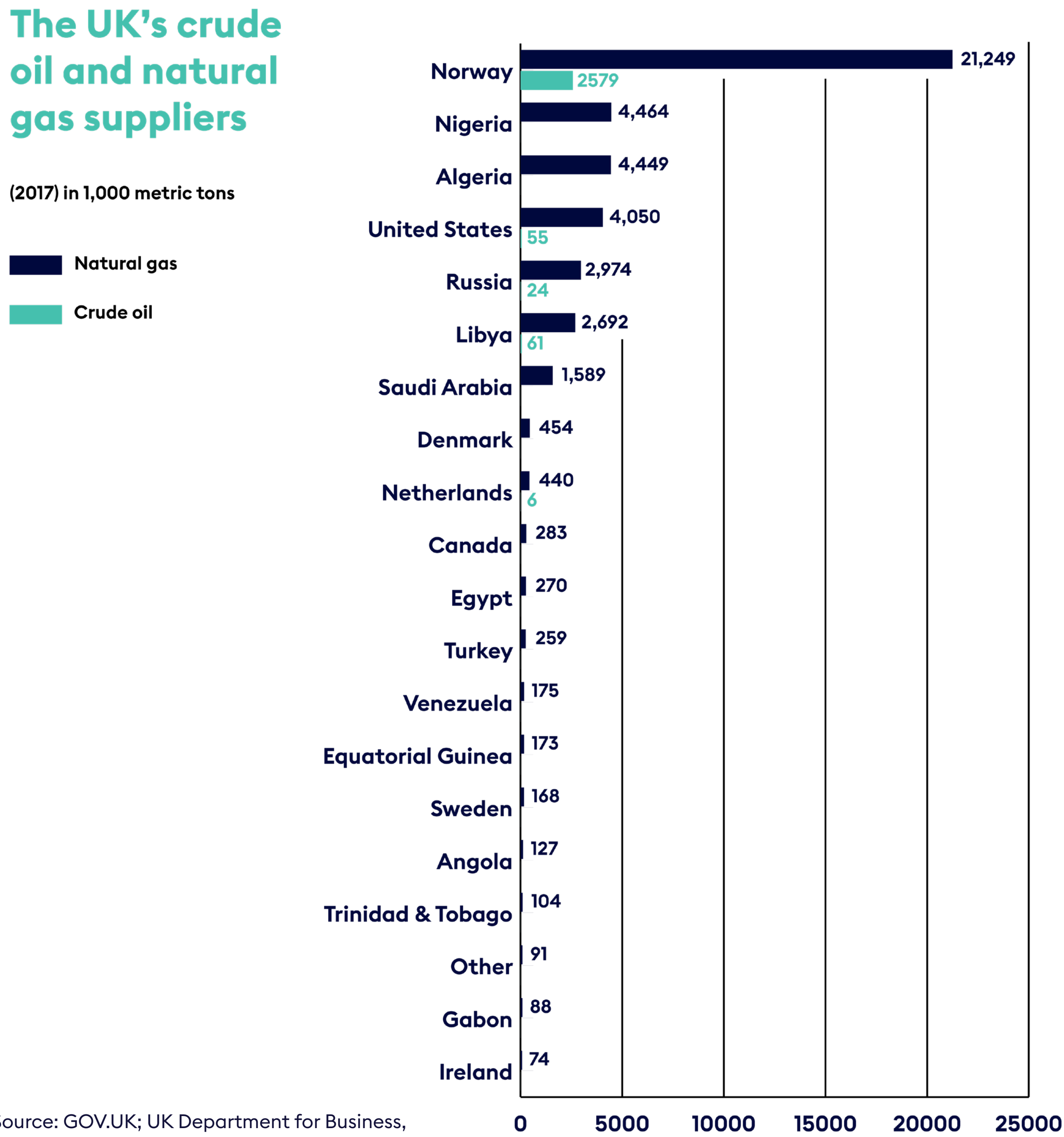
STUDENT SHEET 4b

Where does the UK's oil and gas come from?

In 2017, the majority of crude oil and natural gas that is imported into the UK comes from Norway.

How much oil and gas are used each year in the UK?

In 2017, 42.2 million tonnes of gas and 63.9 million tonnes of oil where used in the UK.
[Source: World Bank]



Source: GOV.UK; UK Department for Business, Energy and Industrial Strategy

UK imports of gas and oil

The UK receives 44% of its gas and oil from the North Sea and the Irish Sea. Another 47% of the gas used in the UK comes via pipelines from Europe. The remaining 9% is transported to the UK by ship.

Where is oil and gas stored in the UK?

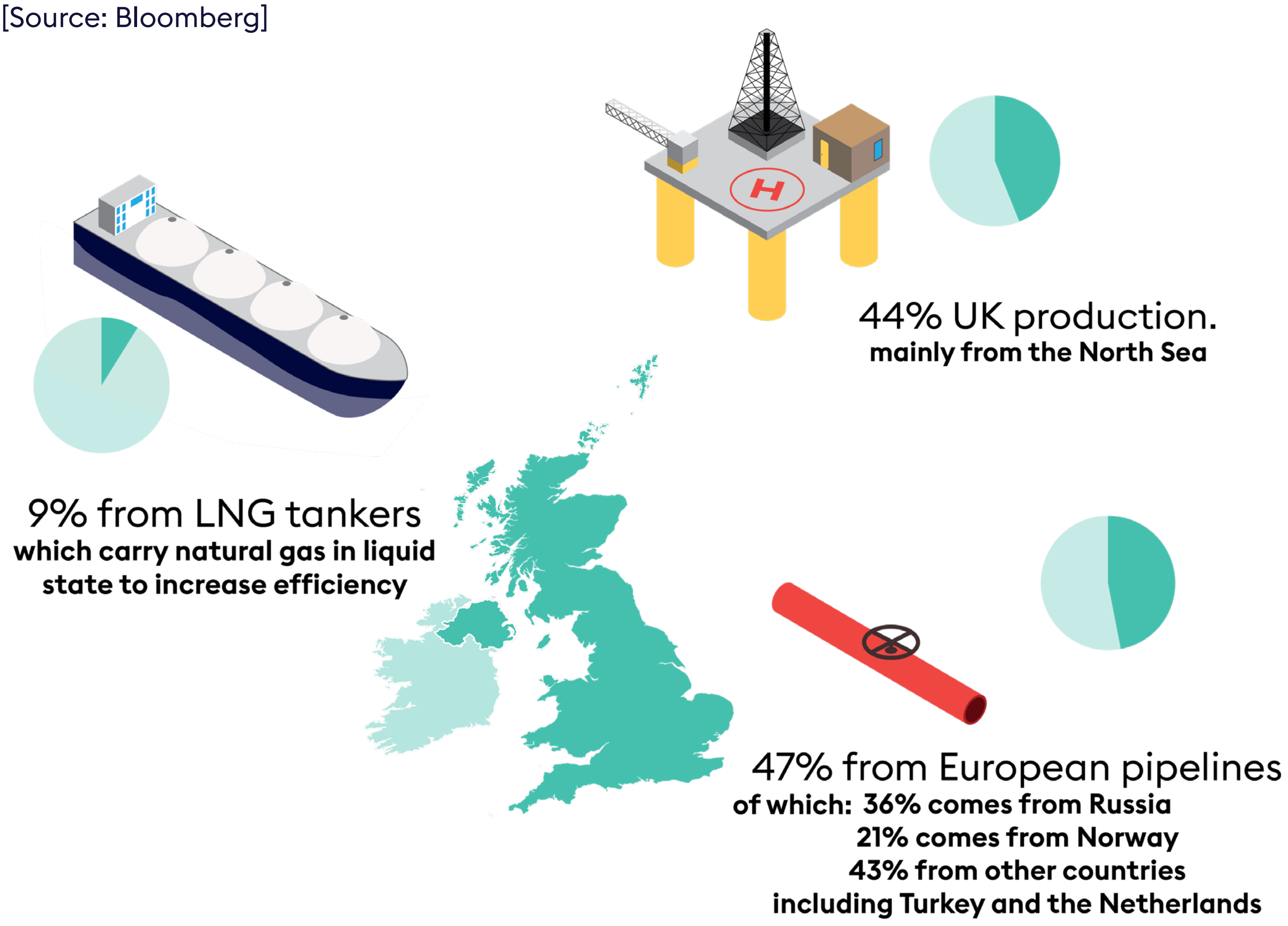
The demand for gas and oil fluctuates throughout the year, so storage facilities are necessary to meet these demands.

Underground gas storage is seen as the better option as it has significantly greater scale potential and is cheaper than carefully constructed and monitored facilities above ground.

One example is Hornsea, located on the East Yorkshire coast. There are nine man-made salt cavities that have the capacity to store 296 million cubic metres of gas. For reference 18 million cubic meters of gas is necessary to meet the needs of approximately 4 million homes.
[Source: Ofgem]

The UK imports crude oil and refines it into petroleum products. There are six oil refineries in the UK that produce 60 million tonnes of product each year.

In 2018, UK oil production rose to 1.09 million barrels per day, and the UK is on the brink of becoming a net oil exporter for the first time since 2004.
[Source: Bloomberg]



Source: British Gas

What are the issues with renewable energy?

Age 14-16

60 minutes

Curriculum links

- Examine how physical resources influence renewable energy potential

Resources

Slideshow 5:
What are the issues with renewable energy?

Student Sheet 5a:
Mapping UK renewable energy production

Student Sheet 5b:
UK climate data

Lesson overview

Renewable energy is currently responsible for approximately 30% of energy production in the UK. This figure has steadily risen since 1990, but is the increase enough? Can we produce enough energy via renewable sources to meet energy needs? What are the issues faced when generating renewable energy? In this lesson students will evaluate the positives and negatives of renewable energy production. They will also consider how renewable energy is affected by the weather.

Lesson steps	Learning outcomes
1. Introduction (5 mins) Students go through the lesson objectives. Use this time to test students' memory of what they have learnt so far.	• Understand the wider context and learning outcomes
2. Renewable energy in the UK (20 mins) Students map where renewable energy is generated in the UK. Students describe the location and distribution of the renewable energy production locations.	• Map the location of renewable energy production
3. Weather in UK regions (20 mins) Students annotate a map of the UK with regional weather and climate data, identifying any distinct differences. Students then consider how the climate variations across the map affect the effectiveness of the renewable energy production.	• Consider the threats to the production of renewable energy
4. Evaluation (10 mins) Students evaluate the effectiveness of renewable energy generation. Students consider whether the UK is able to generate enough energy to meet demand.	• Explain the effectiveness of renewable energy production
5. Exam question (5 mins) Students answer an exam question.	• Reflect on learning

TEACHER GUIDANCE 5 (page 1 of 2)
WHAT ARE THE ISSUES WITH RENEWABLE ENERGY?

Step	Guidance	Resources

1
5 mins
	Step 1 introduces students to the lesson.
	· Read through the learning objectives with the class.
	· Choosing students at random, ask them questions such as:
	  · What is the difference between renewable and non-renewable energy?
	  · Why should we use renewable energy?
	  · How much of the energy generated in the UK is from renewable energy?
		Slideshow 5:
		Slides 1-3

2 20 mins	In step 2, students map the location of renewable energy production in the UK. · Hand out Student Sheet 5a and atlases or devices with access to digital maps. · Students use the information on the second page of the Student Sheet, which has the name and location of a number of different renewable energy sites, to map the different locations of renewable energy production in the UK. · Students should use a key when drawing the different sites on the map. · Once students have finished the map, instruct them to write a description about the locations of the different sites. Ask students to identify a relationship between the location of the site and the type of energy generated.	**Slideshow 5:** Slide 4 **Student Sheet 5a:** Mapping UK renewable energy production
3 20 mins	In step 3 students look at the weather and climate of the UK and how it varies between different regions. · Students use the climate data on Student Sheet 5b. · Students annotate the map of the UK on Student Sheet 5a with key climatic data about the different regions of the UK. · Students assess the information on their map of the UK and identify any correlation between the climate and the prevalent renewable energy source. · As a challenge task ask students to analyse the map and identify if there are any regions not utilising the natural weather in the region effectively to generate more renewable energy.	**Slideshow 5:** Slide 5 **Student Sheet 5b:** UK climate data

TEACHER GUIDANCE 5 (page 2 of 2)
WHAT ARE THE ISSUES WITH RENEWABLE ENERGY?

Step	Guidance	Resources
4 15 mins	In step 4 students examine the energy consumption of the UK, Netherlands and the European Union as a whole. · Show students the information on slides 6 and 7. Given what they might know about popular demands for a swifter move to net zero carbon emissions in the UK, how feasible might this be? · Encourage students to identify potential issues	**Slideshow 5:** Slide 6-7
5 5 mins	Step 5 challenges students to practise an exam style questions. · Students answer the 2-mark exam question on slide 8. · Review answers as a whole class discussion.	**Slideshow 5:** Slide 8

STUDENT SHEET 5a

Mapping UK renewable energy production

STUDENT SHEET 5a

Map the following examples of the highest capacity operational renewable energy production sites in the UK, each site shows their megawatt capacity. Remember to add a key to distinguish the different types.

Site name	Location	Capacity
Offshore wind farms		
Walney 3 wind farm	Nr. Walney Island, Irish Sea	660MW
London array phase 1	Thames estuary	630MW
Beatrice wind farm	Moray firth, North Sea	588MW
Gwynt Y Môr	Liverpool bay, Irish Sea	576MW
Greater Gabbard wind farm	Nr. Suffolk, North Sea	504MW
Onshore wind farms		
Clyde wind farm	South Lanarkshire	350MW
Whitelee wind farm	East Renfrewshire	322MW
Kilgallioch wind farm	South Ayrshire	239MW
Pen Y Cymoedd	Rhondda Cynon Taff	228MW
Greater Gabbard wind farm	Scottish Highlands	228MW
Solar parks / farms		
MOD Lyneham solar park	Wiltshire	69.8MW
Wroughton Airfield solar park	Wiltshire	50MW
West Raynham solar park	Norfolk	49.9MW
Melksham solar farm	Wiltshire	49.6MW
Eveley solar farm	Hampshire	49MW
Wave farms		
Hayle wave hub	Nr. Cornwall, Celtic Sea	23MW
Wello penguin device	Nr. Orkney, North Sea	1MW
Lewis Oyster Wave array	Nr. Hebrides, Atlantic Ocean	50MW†
Billia Croo extension	Nr. Orkney, North Sea	23MW†
Milford Haven Wave Dragon	Nr. Pembrokeshire, Irish Sea	20MW†

Source: UK Department for Business, Energy and Industrial Strategy. September 2019 Renewable Energy Planning Database

† Not operational at time of writing, under construction or in planning

UK climate data

Use the following climate figures from 2018 to annotate your UK renewable energy map.

Why are certain sites where they are?

Are certain areas not using the full energy potential of their climate?

North Scotland	J	F	M	A	M	J	J	A	S	O	N	D
Average wind speed (knots)	10.3	10.5	9.1	8.3	8.3	7.7	7.7	8.6	9.3	9.3	8.9	9
Mean temperature (°C)	1.8	1.6	2.3	6.3	10.3	12.4	14.3	12.4	10.1	7.8	6	4.1
Rainfall (mm)	191	98.4	75.8	79.5	49	64.3	79.1	103.6	228.8	205.7	120	135.6
Hours of sunshine	34.7	92.1	91.2	158.8	226	210.9	157.8	108.7	94.6	75.3	54.9	23.2

West Scotland	J	F	M	A	M	J	J	A	S	O	N	D
Average wind speed (knots)	8.6	9.2	9.4	8	7.2	7	6.7	6.6	7.1	7.5	7.9	7.6
Mean temperature (°C)	3	2.3	3	7.1	11.1	13.8	15.3	13.4	10.9	8.6	6.8	5.1
Rainfall (mm)	248.4	116.7	103.7	109	55.9	91.5	101.9	146.6	176.6	171.6	221.9	171.2
Hours of sunshine	36.4	89.6	94	130.7	237.8	239	202.4	111.4	99.6	85.8	57.9	29.6

East Scotland	J	F	M	A	M	J	J	A	S	O	N	D
Average wind speed (knots)	11.1	10.9	11	9.4	8.8	8.3	8	8.1	9	9.6	9.4	9.6
Mean temperature (°C)	1.8	1.2	2	6.4	10.6	13	15.5	13.2	10.6	8	6.1	3.5
Rainfall (mm)	112.5	57.3	123.2	74.5	34.2	61.7	63.8	75.2	102.1	103.3	154.9	88.4
Hours of sunshine	48.3	89.2	87.2	147.7	230.3	213.4	204.9	136.9	120.3	93.8	52.9	45.7

Northern Ireland	J	F	M	A	M	J	J	A	S	O	N	D
Average wind speed (knots)	11	11	10.8	9.1	7.7	7.7	7.7	7.4	8.1	8.9	9.5	9.3
Mean temperature (°C)	3.9	2.9	3.9	7.9	11.8	14.9	15.8	14.4	11.5	9.2	7.2	6.4
Rainfall (mm)	170.9	74	85.8	80.9	58.3	49.1	80.6	102	57	69.6	146.1	109.5
Hours of sunshine	46.3	91.6	90.4	131	224.7	238.1	173.4	105	98.6	95.5	61.9	22.6

North Wales & North West England	J	F	M	A	M	J	J	A	S	O	N	D
Average wind speed (knots)	12.8	12.1	11.5	9.7	9.5	8.7	8.6	8.9	9.7	11.6	11.9	12.4
Mean temperature (°C)	4.3	2.5	3.8	8.4	12.1	15.1	17	15.2	12.3	9.5	7.4	6.2
Rainfall (mm)	155.4	76.2	92	100.8	48.5	33.8	59.9	94.5	141.2	117	117.2	160.9
Hours of sunshine	43.5	90.7	84.5	121.5	256.6	257.1	250.1	133.9	121.1	99.5	58.1	29.4

South Wales & South West England	J	F	M	A	M	J	J	A	S	O	N	D
Average wind speed (knots)	11.7	11.5	10.6	8.8	8.9	6	7.5	7.7	8.7	10.4	10.3	11.5
Mean temperature (°C)	5.8	3.3	4.9	9.4	12.4	16.1	18.2	16.1	13.5	10.4	8.2	7.7
Rainfall (mm)	163.1	62.6	166.1	104.8	50.4	11.9	48.9	93.3	96.5	108	179.7	180.6
Hours of sunshine	52.8	109	87.8	124.8	233.7	261	264	141.2	140.6	130.8	64.5	22.7

STUDENT SHEET 5b

Midlands	J	F	M	A	M	J	J	A	S	O	N	D
Average wind speed (knots)	8.3	8.9	7.8	8.3	7.9	7.1	7.4	7	6.7	8	8.4	8.9
Mean temperature (°C)	4.9	2.5	4.5	9.4	13.1	16	19.1	16.7	13.5	10.3	7.7	6.5
Rainfall (mm)	84.3	34.6	105.7	82.3	57.3	12	32	55.4	61.7	56.9	62.7	93.4
Hours of sunshine	53.6	94.3	76.4	115.7	254	243.4	274.2	167.8	151.2	123.9	63.7	46.7

East and North East England	J	F	M	A	M	J	J	A	S	O	N	D
Average wind speed (knots)	8.3	7.6	7.2	5.6	5	4.8	4.8	4.8	5.4	5.9	6.3	6.6
Mean temperature (°C)	4.1	2.1	3.8	8.6	12.2	14.6	17.8	16.2	13	10	7.4	5.4
Rainfall (mm)	71.5	46.7	95.3	78.2	35.5	26.6	42.6	57.7	58.6	66.3	71.6	71
Hours of sunshine	56.9	81.8	83.4	126.6	264	228.3	249.5	167.9	147.8	125.3	64.3	55.3

East Anglia	J	F	M	A	M	J	J	A	S	O	N	D
Average wind speed (knots)	12.2	11.8	11.2	10.3	9.8	8.8	8.4	8.5	9.3	10.3	10.6	11
Mean temperature (°C)	5.4	2.7	5.2	0.5	13.4	16.2	19.9	17.9	14.6	11.6	8.3	6.7
Rainfall (mm)	54.1	40.3	70.9	66.7	38.4	6.5	21.1	64.3	30.7	55.7	50.2	62.7
Hours of sunshine	60.2	101.5	77	132.8	268	249.2	292.1	208.1	181.5	162.8	84.5	55.2

South East and South Central England	J	F	M	A	M	J	J	A	S	O	N	D
Average wind speed (knots)	6.5	6.3	6.1	5.6	5	4.5	4.3	4	4.2	4.7	5.1	5.6
Mean temperature (°C)	6	2.9	5.5	10.5	13.7	16.6	20	17.5	14.3	11.3	8.4	7.2
Rainfall (mm)	82	40.9	102.5	80.7	56.4	3	30.9	68.2	40.1	55.2	114.6	101.8
Hours of sunshine	56.8	115.5	78.3	136.8	269.3	265.6	300.6	194.2	188.2	147.1	74.7	46.7

What will our future energy needs be?

Age 14-16

60 minutes

Curriculum links

- Different strategies can be used to maintain or increase energy supply

Resources

Slideshow 6: What will our future energy needs be?

Student Sheet 6a: Electricity consumption

Student Sheet 6b: How reliable is renewable energy?

Lesson overview

In this lesson students will be thinking about what our energy needs may be in the future, and how we will generate enough energy to meet those needs. Students will also study a diagram from an academic journal article to evaluate the reliability of renewable forms of energy.

Lesson steps	Learning outcomes
1. **Introduction (5 mins)** Share the lesson objectives. Recap the unit of work and what has been covered so far.	• Understand the wider context and learning outcomes
2. **Renewable energy recap (10 mins)** Students recap their knowledge and understanding of renewable energy.	• Outline the generation and storage of renewable energies
3. **Future energy needs (15 mins)** Students predict the amount of electricity that will be consumed in the future. They will need to take into account social and economic changes.	• Predict future energy demand
4. **Reliability of renewable energy (20 mins)** Students study one of the diagrams from the journal article written by the research team. They examine the reliability of two different forms of renewable energy that vary output with weather conditions.	• Evaluate the reliability of renewable energy
5. **Exam question (10mins)** Students answer an exam question and peer assess each other's answers.	• Reflect on learning

TEACHER GUIDANCE 6 (page 1 of 2)
WHAT WILL OUR FUTURE ENERGY NEEDS BE?

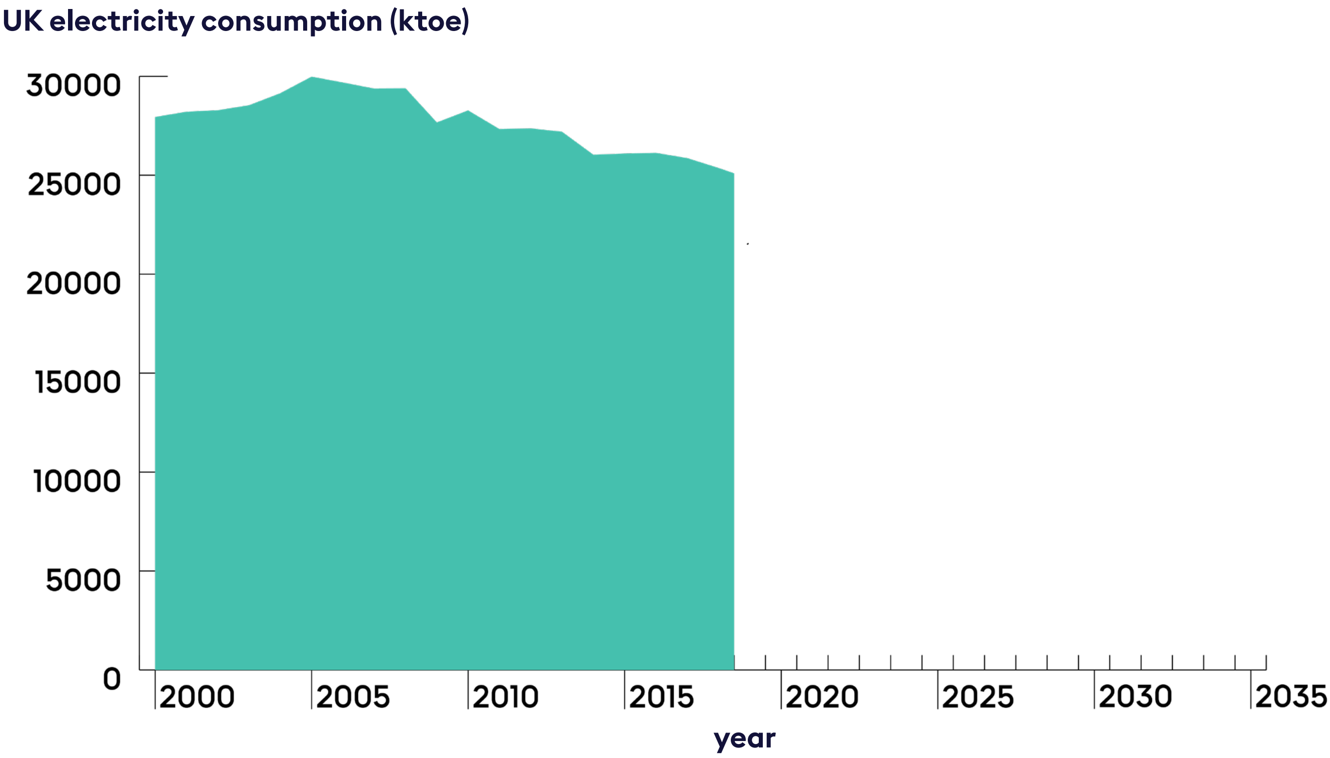
Step	Guidance	Resources
1 5 mins	Step 1 introduces students to the lesson. · Go over the unit of work, recapping what has already been covered. Spend some time going through the learning objectives.	**Slideshow 6:** Slides 1-3
2 10 mins	Step 2 focuses on recapping students' knowledge and understanding of renewable energy. · Students answer the questions on slide 4 in their books in full sentences. · As a group task, student could work together to draw a detailed diagram showing the generation and storage of one type of renewable energy. The diagram that is drawn the quickest and with the most detail will be awarded.	**Slideshow 6:** Slide 4
3 20 mins	Step 3 focuses on electricity energy consumption. · Hand out copies of Student Sheet 6a to student groups. The graph shows electricity consumption in the UK from 2010 to 2018. · In groups, students will need to complete the graph to predict the electricity energy consumption for years 2019-2035. · Student groups should list the four main factors they think will affect electricity consumption in the future. · If you have an interactive white board, ask a member of each student group to come to the front of the classroom and draw their group's predicted UK electricity consumption. As they do this, they should explain the factors that they think will influence this. · After each group has presented show the UK Government predictions on slide 6. Slide 7 gives more detail on electricity consumption on a per sector basis · Students write a description of either graph in their books. · Ask students to give their presumptions as to why electrical energy consumption is expected to rise.	**Slideshow 6:** Slides 5-7 **Student Sheet 6a:** Electricity consumption

WHAT WILL OUR FUTURE ENERGY NEEDS BE?

Step	Guidance	Resources
	Some student groups may need prompt questions: · How do students think the UK population will develop over the coming decade? · How do students think the UK economy will develop over the coming decade? · How do students think the majority of cars will be powered in the future? · How much technology will the average UK resident own in the future? · How will factories be powered in the future? · How have energy saving and energy efficient technologies affect future consumption? · Have students noticed energy ratings on any appliances in their home environment?	
4 15 mins	Step 4 asks students to use a graph from the Van der Wiel journal article to evaluate the reliability of renewable energy. · Go through the diagram and text on Student Sheet 6b as a whole class. · Use slide 8 to show the diagram in more detail. · Go through the questions as a whole class discussion. · The issues faced by renewable energy are important for students to be able to complete their presentations in the following lessons.	**Slideshow 6:** Slide 8 **Student Sheet 6b:** How reliable is renewable energy?
5 10 mins	Step 5 asks students to answer an exam question. · Students answer a 6-mark exam question on slide 9 and peer asses each other's answers using the mark scheme on slide 10.	**Slideshow 6:** Slides 9-10

Electricity consumption

On the graph below, continue the line to predict UK electricity demand.



List four factors that you think will influence this prediction:

1:	
2:	
3:	
4:	

How reliable is renewable energy?

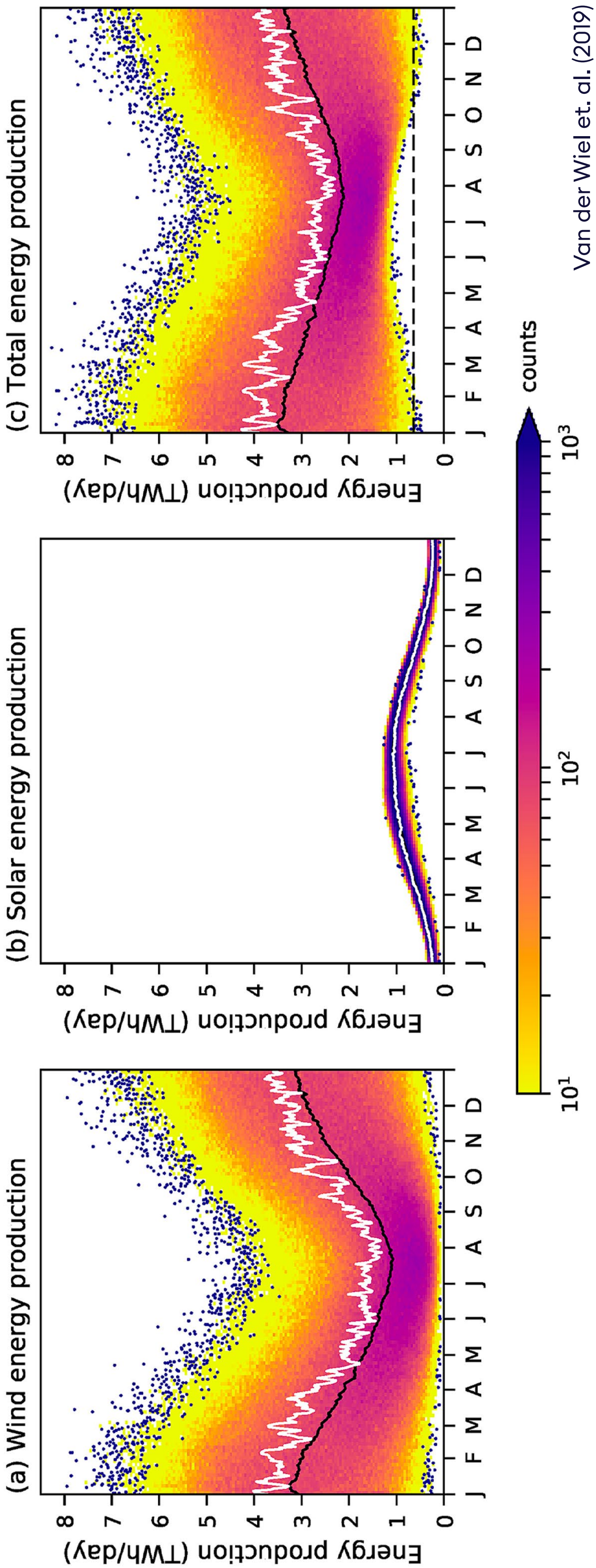
The diagram overleaf is from an academic journal article investigating how weather conditions may lead to an energy shortfall in the future.

The full title of the article is "Meteorological conditions leading to extreme low variable renewable energy production and extreme high energy shortfall", published in 2019 in Renewable and Sustainable Energy Reviews. You can view it online at: https://doi.org/10.1016/j.rser.2019.04.065.

- The diagram shows the amount of energy forecast to be produced by wind and solar, as well as these two sources combined.
- The main variable for wind energy production is wind speed. The main variables for solar energy production are daylight hours and cloud cover.
- The research team ran a climate model to simulate the weather for Europe and to calculate the variability of wind speed and cloud cover over the year. From this the quantity of energy production in Terrawatt hours per day was calculated.
- The key to the diagrams shows the likelihood of a particular level of energy production, with yellow being less likely, the moving to orange, red, magenta and purple as the likelihood increases.
- The black line shows the mean average energy production in the climate model and the white line shows the mean average using real weather data from 1979 to 2017.
- On the far right diagram (c), there is a dashed line along the bottom. This represents the threshold for a 1-in-10 year low energy production extreme event.

Discussion questions

1. How does the predicted level of wind energy production change during the year?
2. How does the predicted level of solar energy production change during the year?
3. Give two reasons why these changes may occur.
4. Would you say that renewable energy is more or less reliable compared to non-renewable forms of energy? Give reasons for your answer.
5. Does combining different forms of renewable energy make it more reliable overall? Give reasons for your answer.
6. Should society be concerned about the potential energy shortfall if relying on renewable energy? Give reasons for your answer.



Van der Wiel et. al. (2019)

How can governments plan for a low carbon future? Part one

Age 14-16

60 minutes

Curriculum links

- Debate how societies can meet future energy demand and the climate context

Resources

Slideshow 7:
How can governments plan for a low carbon future? Part one

Student Sheet 7a:
How can governments plan for a low carbon future?

Mark Scheme 7a:
Assessment Criteria

Lesson overview

This summary lesson sees students work in groups to propose how a low carbon future could be achieved through carefully planned electricity production. Working in small groups students will consider how electricity should be generated in the future as part of a low carbon strategy. Students will need to evaluate different strategies to ensure that their proposals are robust enough to cope with the risks identified in the research. This research will be presented in the next lesson. Students will need access to computers for research, planning and creating a presentation.

Lesson steps	Learning outcomes
1. **Introduction (5 mins)** Students go through the lesson objectives.	• Understand the wider context and learning outcomes
2. **Framing the task (5 mins)** During this lesson, students will be developing their presentations. Take the opportunity to review expectations, assessment criteria and to ensure that students have access to a device for online research.	• Assess the need for low carbon electricity generation
3. **Research (25 mins)** Students use the proposal frame to develop ideas for their proposals.	• Propose methods for generating electricity in the future
4. **Plan and slideshow (20 mins)** Students will work as a group to write a plan for their presentations and start working on their presentations.	• Evaluate strategies to manage any risks involved
5. **Consolidation (5 mins)** Ask each student group to identify the work they need to complete before the presentation lesson.	• Reflect on learning

TEACHER GUIDANCE 7 (page 1 of 2)
HOW CAN GOVERNMENTS PLAN FOR A LOW CARBON FUTURE? PT. 1

Step	Guidance	Resources
1 5 mins	Step 1 introduces students to the final part of the unit of work. · Spend some time going through the learning objectives and what they students should achieve by the end of lesson. · Encourage students to consider all they have learnt in previous lessons in this lesson.	**Slideshow 7:** Slides 1-3
2 5 mins	In step 2, frame the main presentation activity for the lesson. · Use the information on slides 4-7 to frame the presentation activity. This can be used throughout the lesson to emphasise the information on the sheets handed out to students.	**Slideshow 7:** Slide 4-7
3 25 mins	In step 3 the students will complete their internet-based research. · Ask students to get into small groups of three to four. Whilst students are getting themselves sorted, handout Student Sheet 7a and Mark Scheme 7a. · Students work in groups to research their answers to the sections listed on Student Sheet 7a. · Students will need access to devices for online research. It may be worth reminding students that changes in spatial planning of wind and solar electricity generation would be unlikely to mitigate against energy shortfall. As this research tasks relies on information from previous lessons, it may be useful to have resources available to students or point to where these can be found on the Encounter Edu website. Students may also need reminding that not all sources of information online are reliable. How might they assess the reliability or accuracy of the information they find?	**Student Sheet 7a:** How can governments plan for a low carbon future? **Mark Scheme 7a:** Assessment criteria

HOW CAN GOVERNMENTS PLAN FOR A LOW CARBON FUTURE? PT. 1

Step	Guidance	Resources
4 20 mins	In step 4 students start to plan and create their presentation. · At the midpoint for this lesson, review how students are progressing. · Ask students why it is important to look at the assessment criteria. Are they any changes they can easily make to their presentation plans?	**Student Sheet 7a:** How can governments plan for a low carbon future? **Mark Scheme 7a:** Assessment criteria
5 5 mins	Step 5 asks students to evaluate how they have progressed and what further needs doing. · Select a student from each group to share how they have progressed and what they still need to complete before the presentation lesson.	

STUDENT SHEET 7a

How can governments plan for a low carbon future?

Create a new political party to develop an energy policy for the future. To do this you will need to consider the following issues.

In groups, make notes on the following points, before developing your presentation to deliver next lesson.

Your political party (1 slide)

Give your political party a name and remember to list the members. When you give the presentation remember to introduce yourselves and the values you stand for.

Assessing the need for a low or zero carbon electricity supply (2 slides)

You may have seen news about climate change and the advocacy work by young people such as Greta Thunberg. You will need to consider:

- Is moving to a low or zero carbon electricity supply necessary?
- How urgent is the move? Or does society have time to wait for new technologies to emerge?
- What costs are acceptable both economically and socially?

Proposal for how electricity should be produced (2 slides)

Based on your assessment of the need to move to low or zero carbon electricity production, make a selection of different forms of energy.

- Consider the balance that you would like to make between renewable and non-renewable forms of electricity production.
- Are there non-renewable forms of energy that have low or zero carbon emissions?
- Are there different forms of renewable energy production that are being underused? Why do you think this might be the case?

Risks involved in your electricity production proposals (2 slides)

The academic journal article written by the research team identified risks involved in relying solely on wind and solar as choices for renewable energy production.

- Identify any risks involved in your electricity production proposals.
- Use graphics or information from the journal article (Meteorological conditions leading to extreme low variable renewable energy production and extreme high energy shortfall) to support your conclusions.

Propose how you are going to manage these risks (2 slides)

It is unlikely that you will be able to change the climate of Europe to make sure that the wind always blows and that the sun always shines. However, there are some other ideas that you can evaluate.

- Renewable energy can be stored. Research online some of the different storage ideas and decide whether any of these would be an effective solution.
- If you decide that using carbon emitting forms of electricity production are still necessary, are there carbon offset measures that could be used? How effective would these be?
- Are there other forms of renewable energy that are being underused and how could this be changed? Research what some of the barriers may be to using these more.
- If there are occasions that there might not be enough energy, could energy reduction strategies be put in place? Would an energy reduction strategy cover all eventualities?
- One option in the case of an energy shortfall would be to limit electricity to essential use only. This would mean that hospitals could run, but maybe you wouldn't be able to watch TV or heat your house above 15°C. How might this work and would voters be happy?

Summary (1 slide)

Summarise your proposals and why you think they are the best solution. Use information from previous sections to back up your argument.

Assessment Criteria

	Level 1 Limited 1-3 Marks	Level 2 Clear and consistent 4-6 Marks	Level 3 Comprehensive 7-9 Marks
Content	• Points lack development • No data used	• Information is presented well • Some evidence of a structure • Limited used of data used	• Information is complex and detailed • Key points are highlighted • Good use of evidence throughout
Delivery	• Poorly presented, no eye contact with audience, mumbling when presenting • Only one person presenting	• Group effort, with some participation from all members of group • Clearly spoken, some eye contact with the audience	• Body language and voice are suitable and sophisticated • Presentation has a clear structure, with each section fulfilled • Participation from all members of group
Vocabulary	• Informal vocabulary is used	• Key words used sporadically but effectively and appropriately	• Formal language used throughout • Key terminology used regularly and effectively • Language used is suitable for the purpose and audience
Relationship with audience	• No audience participation initiated	• Some audience participation initiated, uses are basic	• Great and varied use of audience participation

How can governments plan for a low carbon future? Part two

Age 14-16

60 minutes

Curriculum links

- Present how to balance energy production as a means of mitigating the effects of climate change

Resources

Slideshow 8:
How can governments plan for a low carbon future? Part two

Student Sheet 8a:
Climate and energy group peer assessment

Student Sheet 8b:
Climate and energy self-assessment and evaluation

Lesson overview

In their small groups, students will be presenting their ideas for a low carbon future to the class. Each student group will evaluate the other presentations. Once the presentations are finished, students will reflect on the whole experience. They need to consider what they contributed, what they discovered, what sources of information they used, and what they might change.

Lesson steps	Learning outcomes
1. **Introduction (5 mins)** Students go through the lesson objectives.	• Understand the wider context and learning outcomes
2. **Prep for slideshow (10 mins)** Students ensure that each student knows exactly what they are doing during the presentation.	• Present with confidence and clarity, providing evidence for your ideas
3. **Slideshows (30 mins)** Students present their slideshows to the rest of the class. As groups are presenting the rest of the class will peer assess each group.	• Evaluate success for yourself and others using criteria • Propose an energy solution for a low carbon future
4. **Self-evaluation (5 mins)** Students evaluate their performance in the slideshow, and contribution to the group work.	• Evaluate success for yourself and others using criteria
5. **Memory game (10 mins)** Students will work in a team to draw a diagram. They will have only a small amount of time to remember what they can about the diagram.	• Reflect on learning

HOW CAN GOVERNMENTS PLAN FOR A LOW CARBON FUTURE? PT. 2

Step	Guidance	Resources
1 5 mins	Step 1 introduces students to the lesson. · Go through the learning objectives. · Ask students to recap what they have learnt during this unit of work.	**Slideshow 8:** Slides 1-3
2 10 mins	In step 2 students will ensure they are ready to present their findings. · Students should use the 10 minutes to ensure they are ready to present, they are confident of the different roles during the presentation and if there is any audience engagement, when it will happen and how will it happen. · Use this time to ensure the slideshows are lined up and ready to be presented. That may mean having students have their presentations on a specific area on your PC. · Once all presentations are ready to go hand out Student Sheet 8a, one to each student group. · Spend some time going through the expectations of the group-peer assessments. · Each group will peer assess just one other group. This could be decided by you prior to the lesson or do it spontaneously during the presentations. · Remind students of the behaviour expectations while students are presenting.	**Slideshow 8:** Slide 4 **Student Sheet 8a:** Climate and Energy group peer assessment
3 30 mins	Step 3 sees the students presenting their proposals. · The groups present their proposals to the class in turn. · The designated groups will peer assess the presenting group using Student Sheet 8a. · Whilst the groups are presenting ask them questions to challenges and develop understanding.	**Slideshow 8:** Slide 4 **Student Sheet 8a:** Climate and Energy group peer assessment

TEACHER GUIDANCE 8 (page 2 of 2)
HOW CAN GOVERNMENTS PLAN FOR A LOW CARBON FUTURE? PT. 2

Step	Guidance	Resources
4 5 mins	Step 4 focuses on students' self-evaluation. · Hand out Student Sheet 8b, one to each student. · Talk though the expectations from the self-evaluation sheet. · Students should take a few minutes of silent contemplation to complete the self-evaluation honestly and to the best of their ability.	**Slideshow 8:** Slide 5 **Student Sheet 8b:** Climate and Energy self-assessment and evaluation
5 10 mins	Step 5 revisits a key diagram and theory. · Students should form groups of 4 or 5. · Each team should be given an A3 piece of paper. · Explain to students that the aim of the activity is cooperation and revision. Students will work together to draw an accurate diagram of the global atmospheric circulation model. · Students need to number themselves 1, 2, 3... · When you call a specific number, say 1 for example, all the students who are designated 1 will come to the front desk where they will look at a completed diagram of the Global Atmospheric circulation model (print off the diagram on slide 7, but do not show this to students yet). · They will have only 10 seconds and then they will have to return to their desks and draw what they can onto the A3 sheets of paper on their desks. In 30 seconds, the next student will come up and look at the diagram. · This process will be repeated till each student has gone up once. · Once completed the group that has the best diagram will come to the front of the classroom and explain the Global Atmospheric Circulation Model to the rest of the class. If there is any information missing, ask the other students to come and annotate the diagram. Show slide 7 at this point.	**Slideshow 8:** Slides 6-7

Group peer assessment

Students:

	Level 1 Limited 1-3 Marks	Level 2 Clear and consistent 4-6 Marks	Level 3 Comprehensive 7-9 Marks
Content	• Points lack development • No data used	• Information is presented well • Some evidence of a structure • Limited used of data used	• Information is complex and detailed • Key points are highlighted • Good use of evidence throughout
Delivery	• Poorly presented, no eye contact with audience, mumbling when presenting • Only one person presenting	• Group effort, with some participation from all members of group • Clearly spoken, some eye contact with the audience	• Body language and voice are suitable and sophisticated • Presentation has a clear structure, with each section fulfilled • Participation from all members of group
Vocabulary	• Informal vocabulary is used	• Key words used sporadically but effectively and appropriately	• Formal language used throughout • Key terminology used regularly and effectively • Language used is suitable for the purpose and audience
Relationship with audience	• No audience participation initiated	• Some audience participation initiated, uses are basic	• Great and varied use of audience participation

Pupil comments:

Mark:

/9

Self-assessment evaluation sheet

Name:

Date:

How much did you contribute to the research and presenting of the presentation?

What aspect did you find most challenging? Why?

What would you change? Consider the process, the people you work with and your presentation.

Which skills have you improved?

Any other comments:

Image credits:

LOCATION:	WITH THANKS:
SS 1a	NASA
SS 1b	Wind turbines: Omheidi
SS 1c	Dzoko Stach via Pixabay
SS 2a,b,c	Annadetejag via Pixabay
SS 4a	Pavlofox via Pixabay
SS 4b	Christine Westerback via Pixabay
SS 5a	Peter Dargatz via Pixabay
SS 6a	Michael4Wien via Pixabay
SS 6b	UK parliament via Wikipedia
SS 7a	

ALL OTHER IMAGES ARE COURTESY OF ENCOUNTER EDU

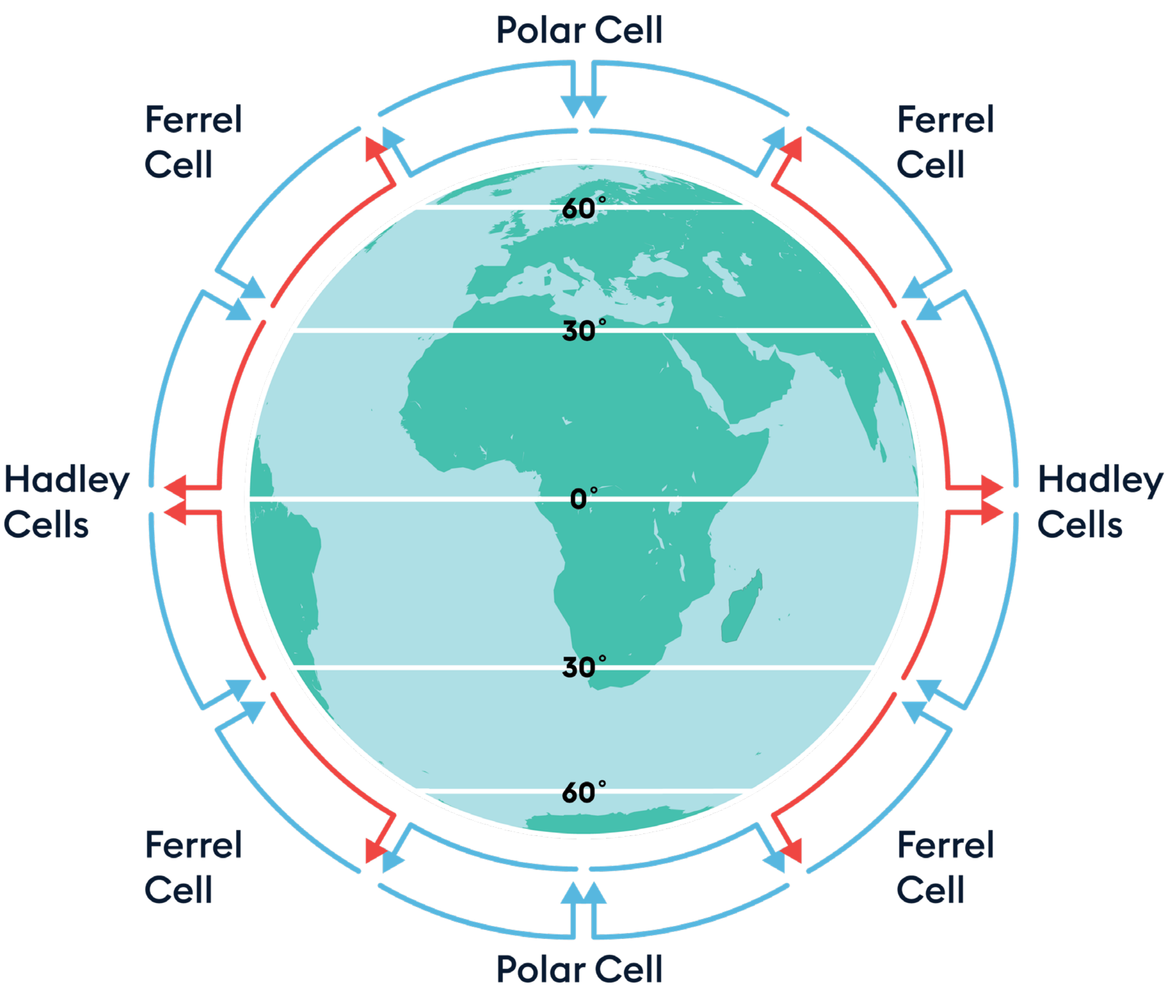
Learn more: Global atmospheric circulation

What is it?

The global atmospheric circulation model is a simplified version of how air currents in the atmosphere move. It is used to help explain weather patterns and climatic regions.

The global atmospheric circulation model is based around cells. These cells are regions where the air moves from low pressure to high pressure. There are three cells in each hemisphere.

Either side of the equator is the Hadley cell, with the Ferrell cell next and then the Polar cell at the top and bottom of the planet.



How does air circulate?

Within each cell, the air moves in a circular fashion. Taking the Hadley cell, warm air at the equator (0° of latitude) rises and then cools in the upper atmosphere, then circles back down towards the tropics (i.e. 30° of latitude).

The air in the Ferrell cell moves in the opposite direction to the air in the Hadley cell with warm air moving toward the polar regions. The warm air that has travelled up from the equator converges with the cold air at 60° of latitude that has travelled down from the polar regions. As the air converges the warm air is forced to rise and move back towards the equator.

The overall effect of the Polar cell is to move cold air towards the equator. At the poles (i.e. 90° of latitude) the cold air sinks. It then moves towards the equator. At 60° the combination of warm and cold air causes the warm air to rise, resulting in low air pressure at 60°. At 60° latitude the polar front is found. This is the result of the warm air that has travelled up from the equator and cold air from the poles being unable to mix well.

The Hadley and Polar cell are controlled by the suns heat (thermally direct) whereas the is Ferrell cell is controlled by the other two cells and how the air is moving in them causing it to be thermally indirect.

What is the global atmospheric system?

The global atmospheric system is a natural system that acts to reduce the extreme heat difference between the equator and the poles. As the air is moved around, it prevents the equator becoming increasingly hotter and the poles becoming increasingly colder.

How does the global atmospheric circulation model affect weather patterns?

Due to the Coriolis affect (the Earth's spin), when the air is moving in the different cells, it is forced to move in different directions, and this has an impact on the prevailing wind direction.

The global atmospheric system impacts jet streams. Due to differences in air temperature and pressure at 30° and 60° latitude a jet stream is formed, the greater the difference between the air temperatures, the stronger the jet stream. The Polar jet stream can have an impact on the weather of mid latitude countries such as the UK. When the jet stream is further north, it allows the more settled warmer conditions found to the south of the jet stream to occur in the UK. Consequently, when the Polar jet stream moves further south the unsettled colder weather located north of the jet stream will occur in the UK.

How does the global atmospheric circulation model affect weather patterns?

There are many conditions that can affect the climate of a location including distance from the sea, ocean currents, relief of the land, distance from the equator and the prevailing wind direction.

There is clearly some correlation between climate and the global atmospheric circulation model and consequently the location of major physical landscapes and ecosystems.

At the equator (i.e. 0° of latitude) there is low air pressure and the air is very warm, this results in tumultuous weather with regular storms. The hot temperatures and high rainfall are the perfect conditions for tropical rainforests.

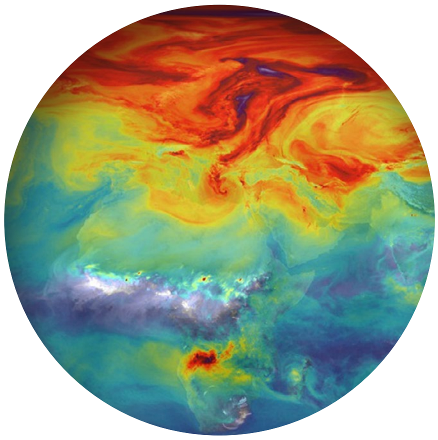
At 30° of latitude there is high air pressure caused by the air from the Hadley and Ferrell cells converging. This results in very settled weather, with a distinct lack of precipitation. At 30° latitude the temperature is hot. These conditions have resulted in the formation of deserts.

At 60° of latitude the temperature is much cooler, but with low air pressure it is unsettled. This results in the weather we experience in the UK, with distinctive wet and cold winters and warm summers.

At the poles (i.e. 90° of latitude) there is high pressure. This results in settled weather, although it is extremely cold in the polar regions the lack of cloud and subsequent rain means there are deserts in the Polar Regions as well.

SUBJECT UPDATE

Learn more: Climate models



What are climate models?

This subject update examines the use of climate models in the context of renewable energy planning as part of the Climate and Energy unit of work.

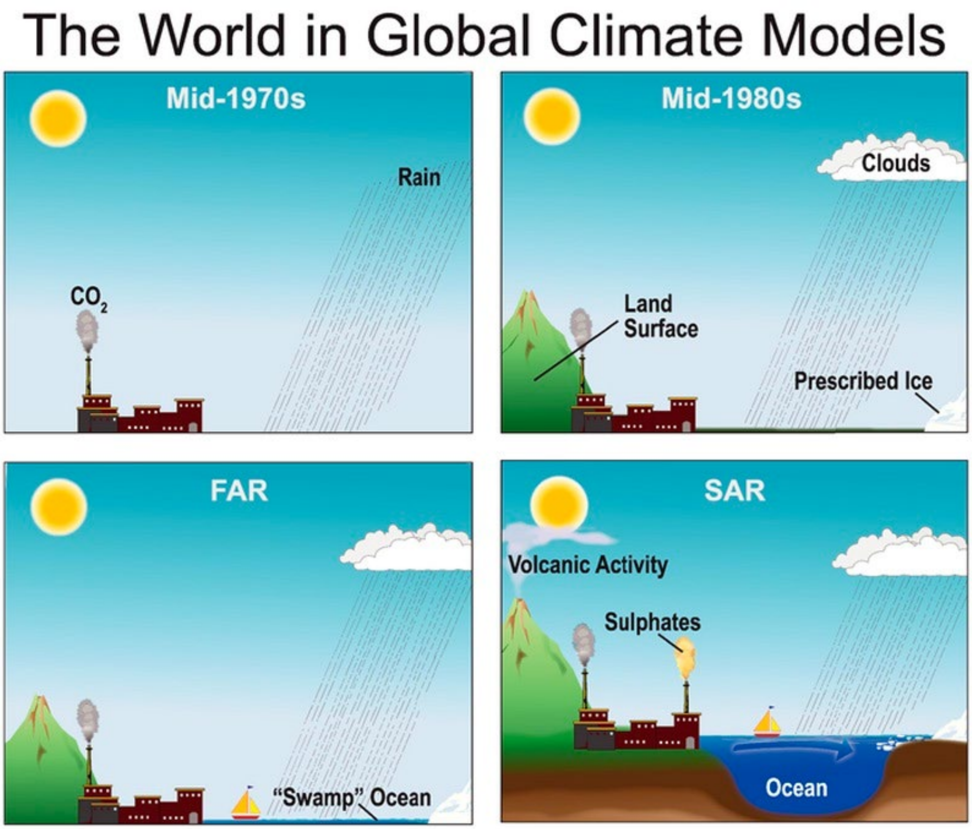
Policy-makers require robust information on which to base decisions. Governments across Europe are exploring how best to reduce carbon emissions, and a part of this effort is to move to an increased reliance on renewable forms of energy production. However, the amount of energy that can be produced using renewable forms (e.g. wind and solar energy) is sensitive to the weather in the future.

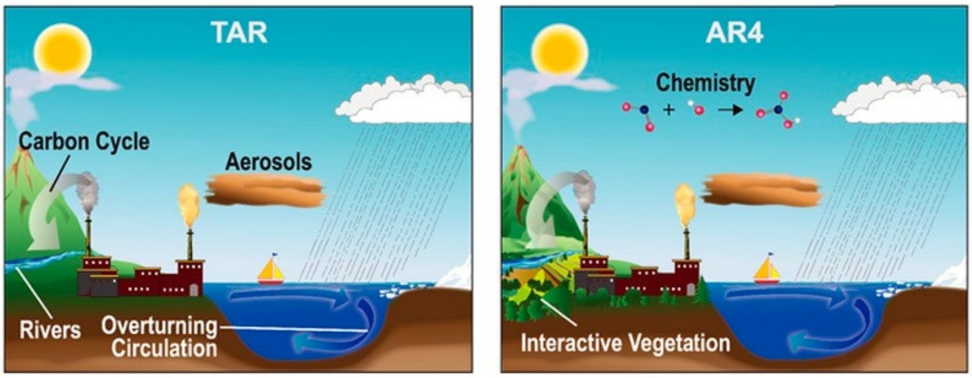
To predict, more accurately, the amount of energy that can be produced by wind and solar energy requires the prediction of future weather. To do this requires the use of computer models that take a selection of inputs that affect weather and climate and utilise equations to predict future climate trends.

Climate models are used to predict the impact of increased levels of atmospheric carbon dioxide, but this is only one factor that they take into account. Climate models are built using equations, including the famous Navier-Stokes equations that governs how fluids (water and air) flow.

These combinations of equations are complex and the computer code describing them contains enough code to fill 18,000 pages of printed text and requires incredibly powerful computers to run.

The models are continually developed. As the diagram below, from the intergovernmental Panel on Climate Change shows, climate models have become more complex over time.





Many different climate models exist that give different weight to different factors in the earth system. Climate models are then validated and tuned to give the best possible predictions. Validation or checking is done by comparing the outputs of the climate model with observed measurements and evidence of past climate using proxies such as tree rings.

Tuning, is the process by which scientists run tests with the model to find the value for a given factor that will give the best representation of the climate.

Dr James Screen, assistant professor in climate science at the University of Exeter, describes how scientists might tune their model for the albedo (reflectivity) of sea ice. He told Carbon Brief:

> **Dr James Screen**
> **Assistant professor in climate science at the University of Exeter**
>
> **In a lot of sea ice models, the albedo of sea ice is a parameter that is set to a particular value. We don't know the 'correct' value of the ice albedo. There is some uncertainty range associated with observations of albedo. So whilst developing their models, modelling centres may experiment with slightly different – but plausible – parameter values in an attempt to model some basic features of the sea ice as closely as possible to our best estimates from observations. For example, they might want to make sure the seasonal cycle looks right or there is roughly the right amount of ice on average. This is tuning.**

If all parameters were 100% certain, then this calibration would not be necessary, Screen notes. But scientists' knowledge of the climate is not perfect, because the evidence they have from observations is incomplete. Therefore, they need to test their parameter values in order to give sensible model output for key variables.

Looking at the methodology used by the HIWAVES team, two climate models were selected: EC-Earth, which is adopted by the ECMWF (European Centre for Medium-Range Weather Forecasts) seasonal forecasting system, and the Hadley Model created by the UK Met Office. The Hadley model is also used for the Met Office to produce seasonal weather forecasts that predict a cold winter or rainy summer.

The models are not perfect. Climate modelling experiments are generally done at lower resolution than weather forecasts, which are higher resolution and use smaller grid boxes. This is in part due to limited computer resources to run climate models. As a result, climate models are often less accurate at predicting weather. This is because some physical processes occur at scales smaller than can be calculated in the models, for example the behaviour of clouds, radiation and turbulence. Although the team were looking at future weather, they relied on the data from climate models, sacrificing increased resolution for the ability to run the model numerous times.

> **Dr Karin van der Wiel**
> **Researcher at Royal Netherlands Meteorological Institute (KNMI)**
>
> **Specifically, in this study, we found that the models had slightly too low wind speeds over land areas. We analysed the potential impact of this specific bias and found that the results were not too badly impacted. Also, we compared the model results to the results based on real weather situations and found that similar patterns came out. We therefore trust the results from the two models. It is also the reason why we considered two models in order to be able to check whether both models agree on the outcomes.**

SUBJECT UPDATE

Learn more: HIWAVES article student summary

This is a summary of the scientific article Meteorological conditions leading to extreme low variable renewable energy production and extreme high energy shortfall, Renewable and Sustainable Energy Reviews (https://doi.org/10.1016/j.rser.2019.04.065) as part of the Climate and Energy unit.

A note on the structure of academic journal articles

Academic journal articles are written according to a set format. Journal articles start with an abstract that gives a general overview of what the paper covers. An introduction covers the issue being investigated and can refer to previous research in this area. The next sections are about methodology. This allows readers to see how the team achieved their results. Following this, the researchers outline their findings and this can be broken into several sections. This paper then includes a section called sensitivity of results. The sensitivity refers to whether any other factors outside those being investigated could have influenced the findings. The paper ends with a discussion looking at how the findings fit with the larger issue under investigation, and then conclusions and outlook that summarises the findings and their implications.

Introduction

One of the ways that Europe will be able to tackle the climate crisis is by moving to zero or low-carbon energy production. Renewable energy is already part of the power mix in Europe and its use is set to grow.

In a future with a higher proportion of renewable energy, there are challenges and risks. The drawbacks of wind and solar energy are that they do not provide a reliable and consistent power supply, as the amount of production depends on the weather conditions.

If the amount of energy needed on a given day were to outstrip the amount of energy being produced by renewables, even if just for a number of days, this would result in an energy shortfall. This means that energy planners will need to consider what back-up plans to put in place.

While this is a known issue in theory, this research is the first time that accurate figures have been put to the nature of the risk and scale of the challenge. This research looks at two risks. First, it examines the natural variability of wind and solar energy production over the year and how this matches demand. Second, it predicts which types of weather event may increase the chance of an energy shortfall.

Data and methods

Predicting the weather and climate is not easy. There are many factors that influence weather and general trends are easier to describe rather than whether it will be a sunny holiday in a few months' time. To work out the predicted wind and solar energy production, the team ran a series of computer models to calculate the wind speed, solar radiation and temperature over a grid of 100 kilometre by 100 kilometre squares across north western Europe. To ensure accuracy, the computer ran the climate simulation many times, resulting in 2,000 years' worth of climate data.

To calculate predicted energy demand, the team considered that the change in energy demand over the year is influenced by temperature, i.e. we use more energy in the winter to stay warm, and potentially a little more in the summer with air-conditioning. This variability was then combined with data on historical energy demand and population data to predict how energy demand may fluctuate over a year in the future.

Weather and energy production

When the research team computed the mean average renewable production, they found that the average wind energy production for the year was 2.1TWh per day and 0.7TWh per day for solar in Western Europe in total[1]. However, these figures varied over the year. With more wind during winter months (December, January and February) energy production was computed at 3.0 TWh per day, but this fell to just 1.2 TWh per day in the calmer summer months (June, July and August). This annual cycle is further complicated by the highly variable pattern of wind speed, with winter wind energy production ranging from 0.2 TWh per day to a high of 7.9 TWh per day.

Solar energy understandably saw peaks in the summer months (June, July and August) with longer daylight hours and less cloud cover, with a mean average for these months of 1.0TWh per day. During the winter (December, January and February) this fell to a mean average of 0.3TWh per day.

The overall picture saw combined mean total renewable energy production in winter exceeding that of the summer (3.3 versus 2.1 TWh per day), but energy production from these sources was also most variable during the winter months.

Energy production from wind and solar is not only affected by this seasonal variation between summer and winter, but also by weather events. The research identified instances of low energy production days. The research identified instances of low energy production days that had a 1-in-10 year chance of occurring. The team worked to see what weather conditions were causing these low energy days, which saw North Sea wind energy production fall by up to 63%. The research showed that high pressure systems over continental Europe reduced wind speeds significantly and the team found that these events had a significant impact on energy production, with lower wind speeds reducing the amount of energy produced by wind turbines.

From the data they learned that longer periods of high pressure, up to 14 days long, also occurred, this would mean that energy production is low for 14 days in a row.

Potential energy shortfall

Any variation in energy production only matters for society if it means production cannot keep up with demand. The modelled European total energy demand peaks early in February due to cold temperatures (December, January and February mean of 8.5 TWh per day) and is lowest mid-summer (June, July and August mean of 7.2 TWh per day)[2].

Average renewable energy shortfall, i.e. the energy demand not met by renewables, is fairly constant throughout the year at 5.1TWh per day. There is, however, large variability over the year. The research focused on events where the energy shortfall exceeded 8TWh per day. All of these occurred during the winter months from November to March, with 81% in December and January. This is because of the effect of low temperature on demand, coupled with low energy production.

Similar to low renewable energy production events, high energy shortfall events happen during periods of high pressure. In this case it is a combination of low wind speeds limiting energy production with colder temperatures driving up demand. During these energy shortfall events, the entirety of the region was colder than normal, in some places 6°C below average.

Discussion and Conclusion

The main objective of this study was to investigate meteorological situations in relation to renewable energy generation.

It was found that there were particular meteorological conditions that cause energy shortfall. Findings showed that periods of high pressure cause atmospheric blocking which resulted in shortages of renewable energy production. It was found that events (7-14 days) tend to occur in the heart of winter.

The results were robust to changes in the spatial distribution of wind turbines and solar panels, the high-pressure weather events cover most of Europe, affecting renewable energy production of the whole region.

It was assumed that wind turbines over land were 80m and the offshore turbines were 120m. With increases in the height of the turbines more wind will be harvested, leading to higher absolute energy production.

Future studies should include interdisciplinary research teams as they provide a new way of analysing climate data. There should also be a focus on discovering the 'true' societal impact, with more studies identifying interactions between climatic drivers, hazards and societal risk. The research from such studies will help us become more resilient and implement more effective systems of energy production and storage.

The basic question for policy-makers and citizens is how to deal with the variability of the weather in a future with a high proportion of energy coming from renewables.

[1] TWh stands for Terrawatt hour. A terawatt is 10^{12} watts, i.e. 1,000,000,000,000 or 1 trillion watts. So, 2.8 TWh per day of energy production is equivalent to 1,022.7 TWh per year. In comparison, the UK currently generates 338.6 TWh of electricity (2017 UK Government figures), and The Netherlands generated 114.9 TWh in 2016 (US Government figures).

[2] To put this into context, the average domestic electricity consumption in the UK in 2018 was 3.4 MWh per year (2018 UK government figures). So, the energy demand looked at in this paper is enough to power 923 million UK homes or 2.36 billion TVs left on for 24 hours a day (NB domestic consumption is only a fraction of overall electricity use).