Key Stage Four:
Learning about the impact and uses of Solar Photovoltaics in Africa and the UK

Teachers notes and student work sheets

Key Stage Four: Learning about the impact and uses of Solar Photovoltaics in Africa and the UK

Overview

Solar photovoltaics can make a difference to lives in Africa and in the UK. This three lesson resource pack draws out those ideas while teaching about air quality, sustainable energy, and working scientifically, for GCSE Sciences 2016 (students aged 14-16). The pack is the result of a collaboration between Solarcentury, SolarAid and the University of York Science Education Group (UYSEG).

About Solarcentury

Solarcentury is in business for a purpose: to make a meaningful difference in the fight against climate change. All our customers benefit from our experience in terms of engineering quality, sheer breadth of deployment and absolute commitment to solar.

One of the world's most trusted, respected and long-standing solar panel companies founded in 1998, we've been around since the early days of the solar industry and have been part of the evolution that has made solar PV the attractive investment it is today. We've put solar on more types of sites than any other company in the industry, and have won multiple awards for product innovation.

This isn't just our business, it's our mission. Our commitment to making solar accessible is deep-rooted and long-term, and our solidly-established business is growing steadily worldwide.

About SolarAid

SolarAid is an international charity that combats poverty and climate change. We are providing access to solar lights in some of the most remote regions of the world and building a movement to eradicate the kerosene lamp.

The problem

598 million people in Africa alone have no access to electricity. Without electricity families have no clean source of light, leaving millions to rely on expensive and dangerous alternatives. Many use homemade kerosene lamps which are a poor source of light; they emit toxic black smoke, eat up to 15% of a family's income and are extremely hazardous. Children can't study at night, the working day ends prematurely and indoor air pollution presents a serious health hazard.

The solution

With a solar light, everything changes. Solar light customers tell us that investing in a solar light saves money, improves health, makes their homes safer and helps children study at night. Each solar light shining also means one less kerosene lamp, saving around 200kg of carbon dioxide per year.

About UYSEG

UYSEG is a research and curriculum development group based in the Department of Education at the University of York. It aims to make a sustained positive impact on the outcomes of science education through the development and evaluation of research-informed curricula that illustrate the importance of science for society. http://www.york.ac.uk/education/research/uyseg/

Contents of this pack

This pack contains three lesson outlines, with supporting presentations and activity sheets for students. Each lesson outline provides an opportunity to teach to some of the assessable learning outcomes for GCSE Science 2016 in the context of using solar energy.

Lesson 1: How can solar energy make a difference in Africa?

This lesson uses the context of SolarAid's mission to replace all kerosene lamps in Africa with solar lamps by 2020 to consider ideas about renewable and non-renewable resources, and to consider the benefits and risks of different technologies. The lesson provides opportunities to draw on ideas from physics, chemistry and biology, showing that often all the sciences are needed to describe and solve problems.

Lesson 2: Is solar energy part of the solution in the UK?

This lesson uses the context of exploiting solar energy in the UK to consider ideas about renewable and non-renewable resources, and to consider the benefits and risks of different technologies. The lesson provides opportunities to practice mathematical skills as well as showing how ideas from physics, chemistry and biology are needed to address the some of the issues that face UK society.

Lesson 3: Investigating solar panels

This lesson uses the context of siting photovoltaic panels to develop understanding of practical investigations and the use of models in developing scientific explanations.

Health and safety

Whilst safety guidance is given for the practical activities described in these notes, it is the responsibility of the teacher check that the activity they are proposing is compatible with their employer's risk assessments.

Lesson 1: How can solar energy make a difference in Africa?

Overview:

This lesson uses the context of SolarAid's mission to replace all kerosene lamps in Africa with solar lamps by 2020 to consider ideas about renewable and non-renewable resources, and to consider the benefits and risks of different technologies. The lesson provides opportunities to draw on ideas from physics, chemistry and biology, showing that often all the sciences are needed to describe and solve problems.

Links to GCSE Sciences 2016:

Physics:

- describe the main energy resources available for use on Earth (including fossil fuels, …. and the Sun), compare the ways in which they are used and distinguish between renewable and non-renewable sources
- recall that electromagnetic waves ….. are transmitted through space …… and explain, with examples, that they transfer energy from source to absorber

Chemistry:

- explain how modern life is crucially dependent upon hydrocarbons and recognise that crude oil is a finite resource.
- describe the major sources of carbon monoxide, …….. particulates in the atmosphere and explain the problems caused by increased amounts of these substances.

Biology:

- explain the effect of lifestyle factors, on the incidence of non-communicable diseases

Working scientifically:

- explain everyday and technological applications of science; evaluate associated personal, social, economic and environmental implications;
- evaluate risks both in practical science and the wider societal context

Intended learning outcomes

- describe the chemical reaction that takes place when kerosene (paraffin) burns
- describe and explain the risks of using a kerosene lamp in the home
- explain why solar energy is a renewable energy resource but kerosene is not
- explain the meaning of sustainability using the example of a swap from using a kerosene lamp to a solar cell and LED lamp
- •explain the personal, social and environmental benefits of a swap from using a kerosene lamp to a solar cell and LED lamp to a solar cell and LED lamp

Resources:

SolarAid resources:

Presentation PPT Lesson 1 how can solar make a difference

Burning kerosene demonstration

paraffin (kerosene type: HARMFUL)
mineral wool
wooden splint
crucible
heat-resistant mat
250 cm^3 Pyrex beaker
tongs

Other resources

Candle and matches
Solar lamp – a lamp which includes a solar cell for charging and an LED lamp
Torch with rechargeable batteries
solar panel with plug leads
white LED with connections

Lesson outline:

Introduction

Slide 2 Show an image of the Earth from space at night.

What can information can we infer from this image?

- It must be a composite image not a single photograph – the Earth is never all in darkness
- •It shows that some parts of the world have much more light at night which suggests:
  - they may be much more densely populated (although not always the case, North Korea has plenty of people but not much light emitted, compared with South Korea)
  - some places have more access to electricity
- other information could be gathered if a series of such images were taken over a number of years, showing city growth for instance).

Slide 3 Look at the next map showing population density and compare the two maps; what does this tell us?

- Parts of Africa have population densities comparable to part of Europe, but not the same amount of night-time light.

Slide 4 Large areas of Africa do not have access to mains electricity – what would that mean for life opportunities?

Group discussion: ask students to spend short time thinking about an average day for them and how it would be different if they didn't have mains electricity.

You could show this clip:

Life without electricity in rural Tanzania http://bit.ly/OVZ5tM

Or show the **Slide 5** of a boy doing his homework by the light of a small kerosene lamp.

Kerosene (paraffin) is a mixture of hydrocarbons produced during the fractional distillation of oil; it is a non-renewable resource. The simple kerosene lamps are made from recycled tin cans and have a rope wick. **Slide 6** More expensive lamps may have a glass chimney.

Main activities

Demonstration: Burning kerosene

Use this demonstration to show that Kerosene (paraffin) burns with a smoky flame.

Tell students that kerosene is a hydrocarbon. Ask them to predict what will happen when the fuel is ignited, with reasons for their prediction. **Slide 7**

Procedure:

1. Put a small clump of mineral wool in a clean crucible on a heat-resistant mat.
2. Add two or three drops of kerosene to the mineral wool.
3. Close the fuel bottle and move away from the experiment.
4. Light the fuel with a burning splint.
5. Use a pair of tongs to hold a Pyrex beaker above the flame, so that the base is in the flame.
6. Observe the black soot on the base of the beaker.

Safety guidance: Keep the fuel container closed as much as possible. Wear eye protection. Make explicit the safety precautions you used when carrying out the demonstration.

Discussion:

Discuss the chemical reaction that takes place when hydrocarbons burn, including ideas about incomplete combustion and the production of carbon monoxide and particulates.

Ask students to write balanced equations to show:

- complete combustion of heptane – how much oxygen is required? **Slides 7 & 8**
- incomplete combustion of heptane when only 6 molecules of oxygen are available. Hydrogen is more reactive so water is formed but there is insufficient oxygen to react with all the carbon so carbon monoxide and carbon particulates are formed. **Slides 9 & 10**

The demonstration shows that kerosene lamps produce a smoky flame, giving poor light, and harmful pollutants, including particulates .

Activity: Risk assessment

Students use the Risk Assessment (Page 8) activity sheet to write a risk assessment for using small kerosene fuelled lamps in the home. **Slide 11**

Discussion: What's the alternative?

Show some alternatives:

- Candles
- Conventional battery torches – both filament and LED
- Solar powered lamps

Show that in Africa, where the map showed there was little light at night, there is plenty of Sun. **Slide 12**

A solar panel on the roof can charge a battery during the day to provide energy at night. **Slide 13**

Demonstrate the principles behind the solar powered lamp with a simple solar cell powering a single LED.

Plenary activity

Show the video clip Meet John http://bit.ly/1GHO9fb

Evidence of learning:
What other benefits would solar lights bring? Students should be able to suggest benefits linked to each of the following slides:

- Education **Slide14**
- Health **Slide 15 & 16**
- Safety **Slide 17**
- Financial **Slide18**
- Environmental **Slide19**
- Sustainability **Slide 20**

Introduce SolarAid – a charity that aims to eradicate the kerosene lamp from Africa by 2020.
Slide 21

Follow up homework

Write a script or record a 2-minute presentation to persuade the school charity committee to adopt SolarAid for its next fundraising activity.

Useful weblinks:

http://www.solaraid.org/jointhemovement/

http://www.sunnymoney.org/index.php/about/impact/

http://www.sunnymoney.org/index.php/about/kerosene-vs-solar/

More information about energy resources from Practical Action

http://practicalaction.org/solar-power

http://practicalaction.org/technical-briefs-schools-energy

Risk Assessment – using kerosene lamps to light the home

A risk assessment analyses a practical activity to identify any hazards and to describe steps taken to reduce the risk of harm.

What are the hazards of using a kerosene lamp in a small home without windows? How could the risks be reduced?

To do:

Complete the risk assessment by identifying all the hazards associated with using a kerosene lamp and suggest ways of reducing the risks.

You should think about the hazards of using the lamp and also the hazards of storing the kerosene.

Chemical or Procedure	Hazard	Precautions to reduce risk
Burning kerosene		
Storing kerosene		

To answer:

Although the hazards of using kerosene lamps can be reduced, there will always be accidents. Suggest a safer alternative to using kerosene lamps.

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Lesson 2: Is solar energy part of the solution in the UK?

Overview:

This lesson uses the context of exploiting solar energy in the UK to consider ideas about renewable and non-renewable resources, and to consider the benefits and risks of different technologies. The lesson provides opportunities to practice mathematical skills as well as showing how ideas from physics, chemistry and biology are needed to address the some of the issues that face UK society.

Links to GCSE Sciences 2016:

Physics:

- describe the main energy resources available for use on Earth (including fossil fuels, …. and the Sun), compare the ways in which they are used and distinguish between renewable and non-renewable sources

Chemistry:

- explain how modern life is crucially dependent upon hydrocarbons and recognise that crude oil is a finite resource.
- describe the potential effects of increased levels of carbon dioxide and methane on the Earth's climate and how these effects may be mitigated, including consideration of scale, risk and environmental implications.

Biology:

- explain some of the benefits and challenges of maintaining local and global biodiversity

Working scientifically:

- explain everyday and technological applications of science; evaluate associated personal, social, economic and environmental implications;
- translate data from one form to another

Use of mathematics:

- Recognise expressions in standard form;
- Use percentages;
- Translate information between graphical and numeric form;
- Calculate areas of triangles and rectangles

Intended learning outcomes

- identify the renewable and non-renewable sources of electricity generation used in the UK
- describe some advantages of reducing dependence on fossil fuels for electricity generation
- describe the arguments for and against the use of the potential sources of renewable energy
- explain how solar energy can make a contribution to the UK's commitment to reducing carbon emissions

Resources:

SolarAid resources:

Presentation PPT Lesson 2 Is solar power part of the energy solution in the UK

Lesson outline:

Introduction

Behind the headlines: Show **slide 2** and ask students to make links between the headlines. You could print out the headlines and ask students to make a 'mind-map' to visualise the links between the ideas. There are hyperlinks from each of the headlines to the original articles.

Ideas might include:

- there is a changing balance of energy resources in the UK
- less coal produced and more gas imported makes UK more dependent on other countries
- winter power cuts occur when power stations cannot supply enough electricity – due to fuel shortages, or when power lines come down in bad weather
- climate change is due to increased CO_2 emissions so we need to use less fossil fuels
- nuclear power does not cause carbon emissions so a delay in building new power stations may mean more carbon emissions
- solar energy is renewable and does not produce CO_2 emissions
- the claim for solar is a quote – is it reasonable?

Hyperlinks:

UK Coal confirms Thoresby pit closure date
http://www.itv.com/news/calendar/update/2015-06-19/latest-update-on-kellingley-and-thoresby-from-uk-coal/

Gas imports from Russia's Gazprom giant to soar after new Centrica deal
http://www.independent.co.uk/news/business/news/gas-imports-from-russias-gazprom-giant-to-soar-after-new-centrica-deal-10248692.html

Millions of Britons face winter power cuts
http://www.express.co.uk/news/uk/435107/Millions-of-Britons-face-winter-power-cuts

Solar energy 'could provide 4% of UK electricity by 2020'
http://www.bbc.co.uk/news/science-environment-32028809

Climate-smart cities could save the world $22tn, says economists
http://www.theguardian.com/environment/2015/sep/08/climate-smart-cities-could-save-the-world-22tn-say-economists

Hinkley Point nuclear delayed, says EDF
http://www.bbc.co.uk/news/business-34149392

Travel chaos as power cut hits London
http://www.dailymail.co.uk/news/article-194118/Travel-chaos-power-cut-hits-London.html

UK's coal plants to be phased out within 10 years
http://www.bbc.co.uk/news/business-34851718

Main activities

How is electricity generated in the UK currently?

Slide 3 shows the twitter feed from @ElectricMixUK on 9th September 2015. Use this slide or project the live feed.

Check students' knowledge about each of the categories

- Which are fossil fuels? (coal, gas)
- Which are renewable? (wind, hydroelectric)
- What other renewables might be included in 'Other' apart from hydroelectric? (Other renewable sources include solar, tidal and wave, of which solar is much the largest contributor.)

Ask students to use the data to calculate the total electricity generated at the time shown. (36 GW at 11.00 am (top set of data).

Slide 4 Shows the energy flow chart for electricity generation in 2014, a form of Sankey diagram. (https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes) Some questions for students :

- In what way is this a more useful way of presenting the data than the twitter feed? (Gives the total energy input from each source over the year – rather than a snapshot, shows relative amounts of each type.)
- Why are wind, wave and solar all bundled together (all renewable, and solar and wave would be too narrow to be visible on this scale).
- The total input to the diagram = 820.7 Twh. What percentage of that is solar? (about 0.5%)
  - (The total input and output are not identical, probably due to rounding errors in the figures on the diagram.)
- What proportion of the energy input is lost in the generation and distribution process? (490 TWh/820 TWh) . What happens to that energy? (It mostly warms the surroundings – thermal power stations always lose more energy to the surroundings than they transfer electrically. There is also energy loss in transmission cables.)

Estimating the potential contribution solar energy could make to the UK electricity supply

How much energy can be generated by the solar panels on a house roof?

Slide 5 illustrates the principles behind domestic solar energy. Or use https://youtu.be/UIoZ29cKpgE

Slide 6 provides data about the amount of solar radiation in the UK. Some questions that you could ask:

- where in the UK gets the most sunlight over a year and where the least? The map shows the south coast of England and Wales get the most sunlight.
- how does the amount of radiation vary over a day?
- how does the sunlight vary over the year and why? (less sunlight in winter because days are shorter and the sun is lower in the sky so at a shallower angle, the energy is spread over a wider area).

Slides 7 & 8 and the Activity sheet *How much electricity could be generated using solar energy?* (Page 16) take students through calculations to estimate the energy that could be contributed by solar panel on a typical house roof.

Slide 7 Q 1 on the activity sheet – answers include:

1 Output measures the rate at which a square metre of solar panel transfers energy from the Sun to other energy stores. Manufacturers use the peak output to make it possible to compare different panels.

The average power is much less than the peak output because

- the output will vary during the day:
  - o peak will be when the Sun is brightest and shining most directly on the panel
  - o position of the Sun in the sky changes during the day
  - o Sun lower in the sky in winter
  - o output will be lower on a cloudy day
  - o day lengths vary during the year
- the output will depend on the direction and angle of the roof
- output will be lower further north in the UK

Slide 8 Calculates the output from panels on the roof of a house

Q2a power = 16 W/m2 x 14 m2 = 210 W

Q2b energy = 0.22 kW x 12 h/day x 365 days = 950 kWh (2sf)

(Reference: http://www.withouthotair.com/)

Slide 9 Is about how much energy a family uses in a year.

The activity sheet (Page 17) Question 2 includes a table for students to use to estimate their family use of energy.

The graph shows the average energy consumption per electrified household across a range of countries.

A number of points can be discussed from this data:

- linking back to the calculation in slide 7, a UK household might be able to generate half their electricity from solar panels – saving significantly on their energy bills.
- why are there such differences in energy consumption?
- how might this graph have looked for data from ten years ago?
- some of the countries with low energy consumption are also countries with plenty of Sun, so they may be able to benefit even more (this links back to lesson 1 *How can solar energy make a difference in Africa?*)

Slide 10 suggests some questions a family might ask before installing solar panels. Ask students to explain why each of these questions is important to ask, and where they would find the information to answer the questions.

Some of the answers can be found from Solarcentury's website:

Video showing solar tiles being installed:
https://youtu.be/ckdvgIDcSMY

Solarcentury's latest solar installation for housing
http://www.gosunstation.com/howsolarpanelswork/

Calculator to estimate potential costs and savings
http://www.solarcentury.com/uk/solar-calculator/?postcode=
(This links forward to lesson 3 Investigating solar cells)

Slide 11 Solar panels on houses will only provide about half a family's needs, so there will need to be a lot more solar panels installed to get to 4% of all UK electricity generated this way. Slide 11 shows some other places that solar panels are being placed:

- roofs of industrial buildings
- roof of car show room
- Roof of Vauxhall bus station
- roof of Blackfriars station on Blackfriars Bridge – a time-lapse video of this installation is here https://youtu.be/qleBLGJqvmc More about the installation here: http://www.blackfriarssolarbridge.com/
- solar farms

Slide 12 Solar farms raises some questions about solar farms. Show the video clip Solar Farms – the right place https://youtu.be/Qz5vJIR_n2g about solar farms. You might show the video clip twice – before they watch the clip for the second time ask students to think about the following issues and how they are answered:

- What are the effects of solar farms on habitat and biodiversity?
- What is the effect of a solar farm on the landscape?
- Is a solar farm the best use of agricultural land?
- What are the benefits of using land for solar farms?
- Should solar farms be subsidised by government?

On the second showing give the students paper to make notes to answer the questions.

This video is made by Solarcentury, a solar energy company. You might want to present other points of view, perhaps this report from BBC News http://www.bbc.co.uk/news/uk-29679312

Slide 13 How much energy could solar farms provide?

A 16 ha farm in Norfolk has the potential to supply 7400 MWh . (1 ha is approximately the area of the grass inside a 400 m running track.)

On slide 4 we saw that there is currently about 300 TWh of useful electricity generated in the UK.

On slide 2 there was a headline that solar energy could provide 4% of UK electricity. How many solar farms would that need?

$$\frac{4}{100} \times 300 \text{ TWh} = 12 \text{ TWh} = 1.2 \times 10^7 \text{MWh}$$

$$\frac{1.2 \times 10^7 \text{ MWh}}{7400 \text{ MWh}} = 1600 \text{ solar farms}$$

Slide 14 What could an energy mix deliver?

Reference: http://www.solar-trade.org.uk/wp-content/uploads/2015/08/STA-Solar-Facts-and-Statistics-August-2015.pdf

Plenary activity

Evidence of learning:

Slide 15 poses 4 questions that students should be able to answer if they can:

- identify the renewable and non-renewable sources of electricity generation used in the UK
- describe some advantages of reducing dependence on fossil fuels for electricity generation
- describe the arguments for and against the use of the potential sources of renewable energy
- explain how solar energy can make a contribution to the UK's commitment to reducing carbon emissions

Follow up homework

Write a proposal to install solar panels on the school roof.

Useful weblinks:

http://www.solarcentury.com/uk/about-solar/

http://www.solarschools.org.uk/

How much electricity could be generated using solar energy?

Solar panels are appearing on the roofs of houses. In this activity you will use data to find out if it is realistic to say that solar energy could make a useful contribution to the electricity requirements for the UK.

How much energy can be generated from the solar panels on a house roof?

1. Solar panel companies quote the **peak** output from solar panels. This is about 140 W/m^2. But the **average** output of a solar panel in the UK is about 16 W/m^2 over a year.
   Write down two factors that help explain why the **average** output of a solar panel on the roof of a house is so much less than the peak output.

....

....

In the photograph the panels on the roof of one house cover an area of about 14 m^2 .

(a) Calculate the average output power from the roof in watts. ....

(b) Calculate the energy the panels could provide over a year. Give your answer in kWh. ....

How much energy does a family use in a year?

2. Here is some data in a table to help you estimate the energy used by your family. To make it simpler this calculator estimates the energy supplied by electricity and assumes the house is heated using gas.

appliance	power rating (kW)	time used (minutes)	number of times in a week	total time used (minutes)	total time (h)	total energy (kWh) = power (kW) x time (h)
kettle	2.0					
hair dryer	0.70					
laptop computer	0.25					
washing machine	2.00					
iron clothes	2.20					
television	0.30					
lights	0.60					
cooker hot plate	2.40					
microwave oven	0.70					
toaster /grill	1.50					
fan heater	1.50					
electric shower	8.50					
Total energy in a week						
Total energy in a year = total energy in a week x 52						

3. Use your answers to 1(b) and 2 to calculate the percentage of the energy a family uses that could be generated using solar panels on their roof. ....

4. What issues should a family consider if they are thinking about installing solar panels on their roof? Suggest and explain three questions they might ask the installer.

....

....

....

Lesson 3: Investigating solar panels

Overview:

This lesson uses the context of siting photovoltaic panels to develop understanding of practical investigations and the use of models in developing scientific explanations.

Links to GCSE Sciences 2016:

Physics:

- explain how the power transfer in any circuit device is related to the p.d. across it and the current, and to the energy changes over a given time
- recall that electromagnetic waves ….. are transmitted through space …… and explain, with examples, that they transfer energy from source to absorber

Working scientifically:

- use a variety of models to solve problems, make predictions and to develop scientific explanations;
- plan experiments make observation to test a hypothesis;
- make and record observations and measurements using a range of apparatus and methods
- interpret observations including identifying patterns and trends and drawing conclusions
- evaluate methods and suggest possible improvements and further investigations
- present reasoned explanations including relating data to hypotheses
- communicate the scientific rationale for investigations, methods used, findings and reasoned conclusions.

Practical work:

- Use of appropriate apparatus to measure current, potential difference (voltage) and resistance, and to explore the characteristics of a variety of circuit elements

Intended learning outcomes

- identify factors that may affect the outcome of a solar cell investigation
- describe how to measure the output from a solar cell
- evaluate the data collected, explaining the extent to which data increases or decreases confidence in the hypothesis
- explain how their laboratory experiment relates to the circumstances in which photovoltaic
- cells are used, either on a small scale or large scale situation
- suggest criteria for positioning of photovoltaic cells on a domestic roof, in an industrial context, or in a small scale context for lighting

Resources:

SolarAid resources:

Investigating solar panels – teacher and technician guidance SAKS4Act3TG_Prac.docx

Investigating solar panels Student activity sheet SAKS4Act3_ Prac.docx

Investigating factors that affect output from solar panels Presentation SAKS4PP3_Prac.pptx

Additional resources needed:

Available per group

- solar panel with plug leads
- multimeter, set to read potential difference, in V
- repositionable lamp
- ruler and metre rule
- tracing paper and scissors (optional: black or coloured tissue paper as a comparison)
- protractor and a way of propping up the panel like on a roof or lamp
- tape or drywipe marker to mark positions of panel and lamp on the bench

Lesson outline:

Introduction

Slide 2 To engage the students in the reasons for investigating the output of photovoltaic panels show some images of solar panels in a variety of contexts.

Slide 3 Ask students to suggest the factors that might affect output, and how they might be modelled and investigated in the laboratory.

Factors that affect the energy transferred to the panel:

- angle of panel and direction of panel relative to the Sun – some sites, such as roofs, the angle is fixed by the angle of the roof but on flat sites, such as fields, the angle can be fixed by the installer. More able students might be challenged to suggest why the angle and direction might be different in different parts of the world.
- cloud cover – some of the photographs show panels under a cloudy sky – will there still be an output?
- area – compare the small panel on the African house and the large array in some of the other photographs. This seems to be a fairly obvious factor that a bright student might not think worth investigating, but they could be challenged to suggest the mathematical relationship between area and output.
- time of year – this is related to the angle of the Sun – in winter the Sun is lower in the sky and the energy arriving per unit area is less – hence the seasons.
- location in the country – the position of the Sun at midday is overhead at the equator, as you go further north (or south) the sun is lower in the sky at midday, so less energy per square metre.

Focus on a few of these factors to investigate in class. The factors you select will depend on the resources available.

Main activities

The main activity of this lesson is, planning and carrying out the practical investigation. Detailed teacher guidance is given in *Investigating Solar Panels Teacher and technician guidance*. There is also a student sheet *Investigating solar panels.*

Plenary activity

Plenty of time should be allowed for the plenary activity to discuss the outcomes of the investigation. (This might make a further lesson.)

Give each group an opportunity to present their results to the class.

Points to bring out include:

- ideas about quality of data
    - if the spread between values (the range) for a particular condition is low then there can be more confidence in the data – showing repeatability
    - if different groups carrying out the same experiment get similar outcomes that also increases confidence – showing reproducibility
- linking outcomes to predictions – if the outcome matched the prediction it leads to more confidence in the hypothesis, but doesn't necessarily should that the reasoning was correct, if some other effect could have given the same outcome (this can be quite a challenging idea)

Follow up homework

Students could be asked to use the information collected by all the class to write advice for users of the small solar lamps, suggesting how they can ensure that the panel collects maximum energy for charging the battery.

Investigating solar panels – teacher and technician guidance

Aims

This item supports the teaching of scientific enquiry in the context of generating electricity using solar panels. It involves using a practical investigation to model and investigate the factors that affect solar output.

The Thinking about Your Procedure section scaffolds the formation of a hypothesis and features the use of a model to investigate a phenomenon. The Evaluation section asks students to evaluate their prediction and also asks students about validity of their model.

The investigation provides an opportunity for practice in using a voltmeter and reading from a digital scale.

Teaching notes

- Give clear instructions about connecting wires to the multimeter ports. School voltmeters should cope with the p.d. but if the experiment is built-up on to measure power output, the current may require mA precision and measurement of R will be possible with a multimeter, so students could be introduced to the multimeter at this point.
- As with all circuit practicals, be swift to check that each group has working equipment, and be ready with spare multimeters and lamps to swap in so that time is spent on the important aspects.

Requirements

Available per group

- solar panel with plug leads
- multimeter, set to read potential difference, in V
- repositionable lamp
- ruler and metre rule
- tracing paper and scissors (optional: black or coloured tissue paper as a comparison)
- protractor and a way of propping up the panel like on a roof or lamp
- tape or drywipe marker to mark positions of panel and lamp on the bench

Technician notes

- Solar panels can be protected by making polystyrene moulds to sit them in to minimise shock or impact whilst students use them (eg DT technicians might do this).
- Inform the teacher of the maximum operational voltage of the solar panels, if relevant, so that they can instruct students – to prolong the life of the equipment.

Health and Safety

- The lamps may get hot, depending on the type of lamp used.

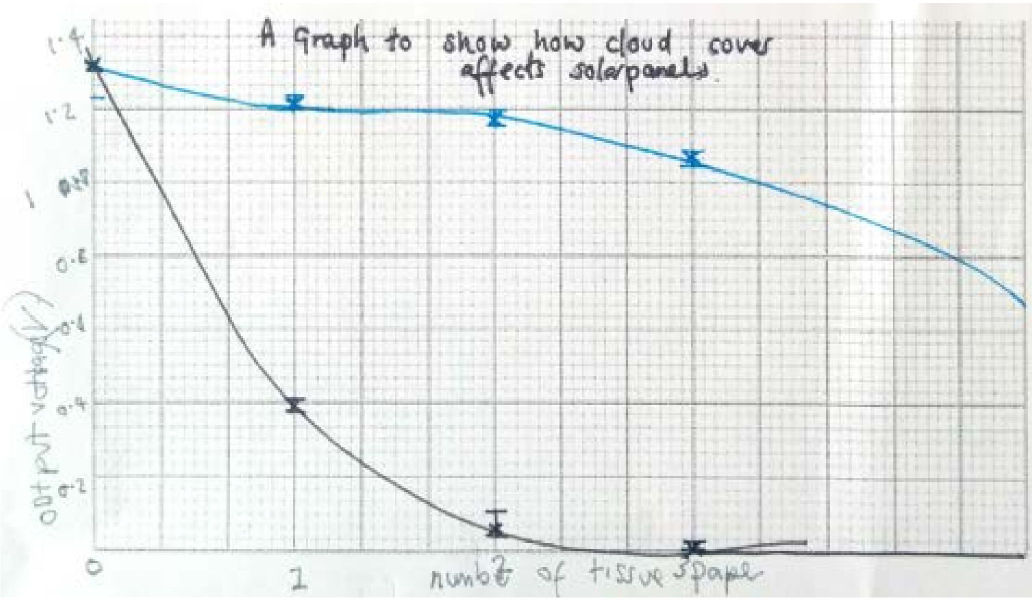
To extend: Teachers may also wish to ask some students to connect an LED and record current. Then power may be calculated and compared to the operating powers of real devices.

A further variation of the experiment could be to investigate what happens to the output as the 'Sun' moves across the sky. This could be offered as an extension challenge.

To support: simple adjustments such as having the tissue paper already cut to size (for layers or for fractions or percentage of coverage) will enable Foundation-level students to progress through the activity with focus on the key objectives.

Example data for the 'cloud cover' investigation

Coverage (number of sheets)	Output voltage (V)			Mean voltage (V)
	1st test	2^{nd} test	3^{rd} test	
0	1.33	-	-	1.33
1 white tissue paper	1.23	1.22	1.22	1.22
2	1.16	1.15	1.16	1.16
3	1.09	1.08	1.06	1.08
1 black tissue paper	0.39	0.40	0.38	0.39
2	0.04	0.12	0.05	0.07
3	0.03	0.02	0.01	0.02



Top White tissue paper

Bottom Black tissue paper

Suggested marking points for the activity

Planning

1. Factor identified
2. Description should explain how the change they will make relates to the 'real life' factor. For example:
   - o increasing layers of tissue paper to model increasing cloud cover
   - o changing the angle between the panel and the bench to model changing angle of panel
   - o covering part of the panel with opaque material to model changing area of panel
3. Prediction should describe the change and its predicted effect – as I ….. the output will ……
4. The explanation should relate to amount of energy reaching the panel.

Evaluation

5. Look at the line of best fit on your graph
   a) What trend is shown by your data? – Look for an "As the…the.." "er-er" statement. Higher level answers should state whether the relationship is linear or describe the increasing or decreasing gradient.
   b) How well does the data match your prediction? – Answers depend on outcome
   c) Answers should relate confidence to the spread in values across the sets of readings and perhaps also to comparing their results with those of others in the class who did a similar experiment.
6. How well do you think your model matches the conditions where solar lamps are used? – real cloud cover is patchier and not all the same thickness across an area. But the paper model still represents a variation in light intensity which would be experienced by a solar panel as a result of any combination of cloud coverage and thickness.

For the direction experiment: One of the Solar Aid products has a display to show when the solar panel is in the best orientation for charging – this would correspond to the highest potential difference reading in this experiment. So, orientation is important for lamps as well as rooftops – and easier to adjust.

Further information

If you wanted to construct power comparison questions or make the link to combustion chemistry via the kerosene (paraffin) lamps that solar lamps are replacing, or even to extend to a taster of concepts such as the Planck Law to explain why kerosene lamps give off lots of infrared but are dim to the human eye, here are two useful links for teacher back-up reading:

What is 1 Lux of difference colours of light?
http://www.physlink.com/Education/AskExperts/ae409.cfm

Luminous efficacy of kerosene vs solar lights:
http://large.stanford.edu/courses/2011/ph240/machala1/

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Investigating solar panels

This practical activity models the real-world daily use of solar panels. You will use the scientific approach to enquiry to investigate the output of solar panels in different conditions. You will then decide how relevant your findings are to outdoor use of solar-powered devices.

To read

Solar Aid is a charity that provides simple and reliable solar-powered lamps to households in the developing world, on affordable and sustainable terms. These lamps charge up a battery inside them when light is absorbed by a solar panel during the day. For the basic model, a day's charge provides 4 hours of light in the evening. These lamps are replacing kerosene lanterns, which are hazardous, dim and use a non-renewable fuel.

Users place their solar lamps outdoors or on a window sill during the day. In the UK, south-facing rooftops absorb the most sunlight and solar panels on those roofs generate the most electricity.

Safety

- Sensible laboratory behaviour with the hot lamps, battery-powered multimeter and scissors is required.
- Your teacher will tell you the maximum potential difference (voltage, in V) that your solar panel can withstand. e.g. if the maximum is 1.5V, start with the lamp quite far away from the panel, with a low reading in V, and move the lamp closer until it reads around 1.45 V and no more.

Apparatus

Available per group:

- solar panel with plug leads
- multimeter, set to read potential difference, in V
- repositionable lamp
- ruler and metre rule
- tracing paper and scissors (optional: black or coloured tissue paper as a comparison)
- protractor and a way of propping up the panel like on a roof or solar lamp
- tape or drywipe marker to mark positions of panel and lamp on the bench

Thinking about your procedure

Choose whether to model:

- the effect of cloud cover
- the effect of the angle of the panel
- the effect of the direction the light source is coming from
- the effect of area of panel.

You have the materials above available to you. Use the next sheet to describe your plans and to record your results.

Investigating the effect of .... on solar panel output

1. Which factor are you changing? ....

2. How will you model that change with the apparatus you have available?

....

....

3. What do you think will happen? (prediction):

....

4. Give a scientific reason for your prediction (hypothesis):

....

Results

Factor	Output voltage (V)			Mean voltage (V)
	1st test	2^{nd} test	3^{rd} test	

Now plot your data on graph paper.

Evaluation

Answer these questions

5. Look at the line of best fit on your graph
   a. What trend is shown by your data?

....

   b. How well does the data match your prediction?

....

   c. How confident are you in your results?

....

6. How well do you think your model matches the conditions where solar lamps are used?

....

....