

The MacKay Carbon Calculator

The [MacKay Carbon Calculator](#) is a webtool developed by the Department for Business, Energy & Industrial Strategy (BEIS) to calculate UK carbon emissions and future carbon pathways. The following resource is written by the Royal Geographical Society (with IBG) for secondary school A level teachers and students.

The webtool consists of 30 interactive graphs, maps and flow diagrams which are linked to levers on the left of your screen. Every lever change will instantly alter the shape of the graphs to highlight the impact of decision-making on carbon emissions.

The intended aim is to raise awareness about climate change and to draw attention to the government's 2050 net zero carbon emission target.

It is primarily for teachers delivering A level geography, though it may also be relevant to mathematics, chemistry, biology, and physics.

How to use this tool

When you open the MacKay Carbon Calculator you will see three sections to the layout:

1. The 6 'lever groups' on the left of your screen (Transport, Buildings, Industry etc.), one of which (Buildings) is open to show the eight 'levers' of decarbonisation in that group. There are a total of 45 levers of decarbonisation which dropdown when the lever group name is clicked. Each lever has an information sheet, which you can see by clicking the lever name.
2. The interactive graphs in the middle. There are 30 in total which you can see by clicking the tabs in the blue banner (Overview, Transport etc), most of which have two-page options below.
3. The emissions meter on the right of the screen, showing UK greenhouse gas emissions reduction relative to 1990 emissions, in which the bottom of the meter is 'Net Zero' (-100%).

Turn your attention to the lever groups on the left of the screen. Each lever group and lever has a choice of one of four lever levels of ambition. They look like horizontal Tetris™ building blocks and are all pre-set to level 1.

Hover your cursor over this first column of filled-in squares and you will see the number '1' pop up. Click on other blocks and you will see the numbers '2', '3' and '4'. These are the lever 'levels of ambition' and represent:

1. Minimal effort to reduce emissions by 2050
2. Ambitious effort to reduce emissions
3. Highly ambitious effort to reduce emissions
4. Maximum effort at the limits of what is possible for reducing emissions

Display the transport levers by clicking on the 'Transport' lever group. Lever level 4 is an expert group's opinion as to the limits of plausible effort to decarbonise. For levers that are 'shares', such as the share of 'light vehicles' (such as cars) that are electric, the limit is 100% (ie. all light vehicles are electric). For levers that represent societal behaviour (e.g. UK transport demand), it reflects the limit of what experts thought society might accept. For other levers, the level 4 might represent the maximum plausible build rate (e.g. nuclear power stations) or the maximum available resource (e.g. wind energy), which appear under the Electricity Supply lever group.

Some combinations of level 4 are not possible (e.g. for light vehicles, to be both 100% electric and 100% hydrogen-fuelled). If you make an impossible selection, the calculator decides how much of

each ambition to use based on a priority order shown in the lever information sheets that you can see by clicking the lever name. Electric cars are higher priority than hydrogen-fuelled cars, so only the level 4 ambition for electric cars would be applied.

The aim of the teaching resources should therefore counsel restraint to gain a firm grasp of what might be achieved in reality.

Why not start exploring this webtool by clicking on one of the 45 lever names such as *Light Vehicles* to read an information sheet?

Exam board links

Understanding the cycle of carbon and carbon emissions are a key part of the A level geography specification.

The table below shows the direct links to the four exam boards for A level geography.

AQA	3.1.1.3. Changes in the carbon cycle over time, to include natural and human impact. 3.1.1.4. The role of feedbacks within and between cycles and their link to climate change and implications for life on Earth.
Edexcel	6.3. A balanced carbon cycle is important in sustaining other earth systems but is increasingly altered by human activities. 6.7. Biological carbon cycles and the water cycle are threatened by human activity.
OCR	3.a. Human factors can disturb and enhance the natural processes and stores in the water and carbon cycles. 4.a. The impact of long-term climate change on the water and carbon cycles.
Eduqas	3.4.7. The need for sustainable solutions to meet the demand for energy. 3.5.4. Causes and consequences of recent and cyclic climate change including extreme weather events

Summary of skills and command words

Below is a summary table of the skills and command words that are covered in the following four lessons.

Skills covered in lessons	Exam command words included
1 Column chart	Describe
2 Stacked area chart	Analyse
3 Pie chart	Compare and contrast
4 Clustered bar graph	Suggest

Lesson 1

Title: Getting Started

Aim: to provide an initial introduction to the tool.

Hide the levers so that only the lever group names are visible, by clicking on the lever group name. Click on the drop-down box 'Example Pathways' and change the setting to All Level 2. Encourage students to note that this changes the ambition level for all levers to Level 2 and results in an 88% reduction in UK greenhouse gas emissions in the meter. Changing the dropdown to All Level 3 result in a 104% reduction in emissions. This gives an indication of the average ambition need to meet Net Zero. To help understand which areas we might need to focus most of our efforts, there is also the ESC (Energy System Catapult) Illustrative Net Zero balanced pathway to 2050, which shows a 100% reduction (i.e. Net Zero) – all from 1990 levels.

Below are some 'what if' scenarios for students to engage with.

1. Hover your cursor over the top line of the Greenhouse Gas Emissions graph. Because the graph is interactive, it will show you the numerical value for each individual category. What are the Total Emissions for 2030 using the All level 2 drop-down?
2. Can you see which category on the graph will drop the most between 2020 to 2050 in an All Level 2 scenario? Try to work the answer out just by sight, then hover your cursor over each category on the graph to check. If you find the graph difficult to read click the three-horizontal lined symbol to the top-right of the graph, select Download XLS and use the raw data.
3. Press the 'Reset' button to return all the lever settings to level 1. What is the Total Emissions value in 2030?
4. Now change the level of ambition for specific lever groups on the left. What if the UK achieved level 3 for Transport and level 3 for CO2 Removal and Gases but only achieved 'minimal effort' level 1 for the other 4 categories? What is the reduction in UK emissions in the meter? What would total Greenhouse Gas Emissions be for: 2030, 2040 and 2050? Is net zero achieved by 2050? If not, what else needs to change? Encourage the student to continue modifying the lever group levels of ambition.
5. This is a suggested activity to practise a key geographical skill. Ask students to choose levels of ambition for each of the lever groups to try to reach Net Zero (-100% in the meter), being careful to minimising reliance on extreme levels of ambition (Level 4). Explain to students that they can select fractional levels of ambition by clicking the same block repeatedly, and that they should decide which lever groups we should make most effort to decarbonise, be it Transport, Land Use etc. When finished, create a table showing the breakdown of Greenhouse Gas Emissions for your pathway for 2020, 2030, 2040 and 2050. Now draw 4 stacked column charts to show the breakdown for each of these decadal milestones. In the example table below, the values for 2020 are already filled out to help, since this is the earliest year that ambition can start. When finished, describe which lever groups are responsible for most existing UK emissions, and how their 4 charts show these emissions falling between now and 2050.

If students are struggling to extract the data, you can either zoom in on the graph or click on the three-horizontal lined symbol to the top-right of the graph. Select Download XLS to download the excel data sheet to get the raw data.

Note: there may be small discrepancies between the totals on the graph and the totals in the table, this is due to decimal points and rounding up the data.

	2020	2030	2040	2050
Total Emissions (Mt.CO ₂ e/year)	442			
Dedicated GHG Removal	0			
Electricity Generation	62			
Hydrogen Production	0			
Other Energy Supply	30			
Waste Management	15			
Agriculture & Land Use	25			
Industry	59			
Buildings Residential	67			
Buildings Non-residential	36			
Transport Domestic	102			
Transport International	46			

*Total Emission figures are taken from the XLS file and may differ slightly from rounded values on the graph

6. Extension task: Primary energy is the energy needed to produce the energy that we use and includes losses such as the inefficiency of thermal power stations for electricity generation. Do the same exercise as above for the Primary Energy Consumption graph. Collect the data for 2020, 2030, 2040 and 2050 using whatever combination of lever group levels of ambition you chose earlier. Explain how our fuel use will change between now and 2050 as a result of the pathway the student has selected.
7. You have produced a fantastic piece of work, well done! Now click on the three-horizontal lined symbol to the top-right of the graph. Select Download PDF document, print it off and keep it to accompany your column charts.

Lesson 2

Title: Achieving net zero and the future of transport.

Aim: students will learn about all the levers of decarbonisation, how one lever affects another, and which are most important in achieving net zero.

In 2019, the UK enacted legislation committing us to achieving net zero emissions of greenhouses gases by 2050. On the left-hand side of the calculator are the 'levers' of decarbonisation which students can use to develop a pathway to decarbonisation and net zero. There are a total of 45 levers grouped under the headings Transport, Buildings, Industry, CO₂ Removal & Gases, Electricity Supply, Land use and biofuels. The lever group can be expanded or collapsed to show or hide the levers, by clicking on the lever group name.

For example, clicking the Transport lever group causes 12 levers to appear, which are about travel demand and modes of travel, vehicle groups (light vehicles, heavy vehicles, aviation) and fuel types (electricity, hydrogen, biofuel, or hybrid).

Similarly:

- Building levers are about consumer behaviour, insulation, and types of heating system
- Industry levers are about industry efficiency, fuel types and industrial carbon capture
- CO₂ Removal & Gases levers are about hydrogen, biomethane and greenhouse gas removal
- Electricity Supply levers are about low carbon electricity generation (nuclear, renewables)
- Land Use and Biofuels are about farming efficiency, forestry, and bioenergy

To help students understand how the 45 levers might be used to develop a balanced pathway to net zero, the ESC (Energy System Catapult), who are an independent not-for-profit centre of excellence for energy and clean growth, have developed the ESC Illustrative Net Zero pathway, which can be seen by clicking the 'Example Pathway' dropdown menu, and selecting 'ESC Illustrative Net Zero'. You will notice that when you select this option the emissions meter drops to -100% on the right of the screen (-100% is 'net zero'). This lesson has exercises about the ESC pathway, to help students understand the key choices to be made to achieve net zero.

Below are some suggested activities for students to use in the classroom.

1. Select the example pathway for ESC Illustrative Net Zero. Click the Transport lever group name in order to show the levers in that group. What are the main themes in the transport levers?
2. Click the UK Transport Demand lever name to download and read the information sheet. What factors create transport demand? Since higher levels of ambition reduce greenhouse gas emissions, how can your choices about travel lessen your impact on emissions?
3. Close the information sheet. Look at the ambition levels that the ESC Illustrative Net Zero pathway has chosen. In which two areas have ESC decided we need to be most ambitious? You will see that ESC thinks a priority for high decarbonisation effort is International Aviation demand where they have chosen ambition level 3.7 (fractional levels can be chosen by clicking repeatedly on a level). This is between level 3 (a 12% increase in international aviation) and level 4 (a 3% decrease in international aviation). Level 4 may not sound very ambitious in the light of the impact of Covid-19 on international travel, but in the long term, experts thought it would be very difficult to persuade people to forego international flying to holiday destinations. ESC also chose a very high ambition of 3.7 for Light Vehicles. What does the ESC level of ambition for Light Vehicles represent? Do you think this is achievable? If you had a car, would it be electric?



- 4. Looks at the Heavy Vehicle levers. Which fuels do ESC think heavy vehicles like HGVs, trains, buses, and ships change to? Which fuels don't ESC think will be important for heavy vehicles, and can you think why?
- 5. Turn your attention to the Final Energy Consumption graph. This will require you to click on Cumulative Emissions / Final Energy in the header towards the top of the screen.
- 6. This is a suggested activity to practise a key geographical skill. Look at the Final Energy Consumption graph for the ESC example pathway. The graph you are looking at is a stacked area chart. A stacked area chart can sometimes be hard to extract data from. Estimate by sight the Final Energy Consumption for each of the seven ways energy is consumed (in TWh/yr) for 2050, then go to this date on the graph and see if you were right! (The graph is interactive, hover your cursor over the line.

	2020	2030	2040	2050
Total Emissions	1641			
Dedicated GHG Removal	0			
Agriculture & Land Use	13			
Industry	304			
Buildings Residential	486			
Buildings Non-residential	233			
Transport Domestic	423			
Transport International	182			

*Total Emission figures are taken from the CSV file and may differ slightly from rounded values on the graph

- 7. Analyse the change in the ESC pathway based on the popup descriptions of lever levels. What is the overall pattern? What are the main differences? The high value? The low value? Are there any anomalies? Always use data in your answer!
- 8. Extension task: Have a look at the levers in each lever group in the ESC pathway and note where ESC think we need to be most ambitious. Now reset the levers all to Level 1, and see if you can develop a net zero pathway to hit a 100% reduction in carbon on the carbon meter, just like the ESC Illustrative Net Zero example? Use the popup description of ambition levels to help avoid making impossible selections (like all cars being both electric and hydrogen). Analyse the change in your pathway as you did for the ESC pathway and compare the results.
- 9. You will have produced some thought-provoking comparison work, so well done! As a final task, click on the three-horizontal lined symbol to the top-right of the graph. Select Download XLS, print off the raw data to keep.



Lesson 3

Title: UK housing.

Aim: to emphasise to students the importance of energy efficient housing and the need to decarbonise how homes are heated.

Housing will be a major challenge when trying to make all buildings zero carbon by 2050 as most homes use natural gas (a fossil fuel) for heating, they are often poorly insulated and some lack space for modern solutions, such as a ground source heat pump. Cavity wall insulation can't be provided to older homes that have solid walls, such as are present in many period properties. As a result, some UK houses can't be well insulated and aren't suitable for heat pumps, but will need a different solution, such as a hybrid heat pump (which has a small boiler to boost the heat pump on very cold days) or a hydrogen boiler. Victorian housing is simply not energy efficient, and even whole house retrofits in which every practical insulation measure is applied, only result in a little over 20% improvement in energy efficiency, on average.

In addition, the UK population is set to rise, which will cause demand for housing to increase. From 2018 to 2043, England is projected to have a population increase of 10.3%, Northern Ireland 5.7%, Wales 3.7%, and Scotland 2.5%.

Set the example pathway to ESC Illustrative Net Zero. Click on the tab at the top of the page to change the graph from Overview to Buildings.

1. Look at the levers in the Buildings lever group. For which two levers do ESC think we need to be most ambitious on decarbonisation? What do these ambition levels represent (look at the popup descriptions)?
2. Click the lever names for Buildings Temperature and Hybrid Heat Share and read the information sheet. Does Level 3 Building Temperature mean we will have to get used to homes being colder? What temperature is your home heated to?
3. Describe the Residential change in the Emissions – Buildings graph.
4. For the Energy Consumption – Buildings & Heat Networks graph which four types of energy increase over time? What fuel do they replace?
5. What does this mean for the way we heat our homes?
6. Now click on the three-horizontal lined symbol to the top-right of the graph. Select Download PDF document for both the Emissions – Buildings graph and the Energy Consumption – Buildings & Heat Networks graph. Print the graphs and include them in your work.
7. Consider the Victorian housing problem of energy inefficiency. Modify ESC Illustrative Net Zero by changing the Building category. Change all the Building category levers to level 1 (minimal effort to decarbonise). What has changed in the Residential category in the Emissions – Buildings graph?
8. Describe the changes to the Energy Consumption – Buildings & Heat Networks graph: which forms of energy have been removed from this graph? Which ones have changed in size? Can you think of a reason why?
9. Of the two pathways (ESC Illustrative Net Zero and Buildings levers level 1) which one shows greater levels of Waste Heat? Research what can be done with Waste Heat and make a bullet point list of how to use it.



- 10. If we use a lot more heat pumps, we will need to generate a lot more electricity, and this electricity needs to be low carbon (nuclear or renewables) if we are to get maximum benefit for decarbonisation.
- 11. This is a suggested activity to practise a key geographical skill. Electricity is already in the process of being decarbonised, especially due to renewables like offshore wind farms. Collapse all the lever groups so that none of the levers are shown. Click the Electricity tab at the top of the page and study the Electricity Supply graph. Create a pie chart for how the ESC example pathway sees electricity being generated in 2050, and a second pie chart for how electricity was generated in 2015. If necessary, click on the three-horizontal lined symbol to the top-right of the graph, and select Download XLS to see the raw data.

Electricity Supply Type	ESC pathway, 2050		2015	
	TWh/yr	Degrees°	TWh/yr	Degrees°
Net Imports				
Biomass & Waste CCS				
CHP				
Coal				
Gas				
Gas CCS				
Biomass and Waste				
Tidal, wave and hydro				
Solar				
Wind				
Nuclear				
Total ESC Illustrative Net Zero 2050				

*Total Emission figures are taken from the CSV file and may differ slightly from rounded values on the graph

- 12. Compare and contrast the two pie charts for the ESC Illustrative Net Zero in 2050, and how electricity was generated in 2015. Under the ESC pathway, will the electricity supply increase/decrease? Which types of electricity supply will grow, and which will reduce or disappear?

Lesson 4

Title: Possible futures for land use.

Aim: students will consider what changes need to be made in Land use & biofuels.

A change in land use will be an essential part of the UK achieving net zero by 2050. Changes will need to be made in diet, agriculture and farming yields and efficiency.

Click the 'reset levers' button to set all levers to level 1. Collapse the lever groups to hide the levers, and raise the ambition level to 3 for Transport, Buildings and Industry and ambition level 2 for CO2 Removal and Gases and Electricity Supply. Check that the meter for carbon reduction to the right of the screen is at -96% from 1990 levels of carbon emissions. Answer the following questions.

1. Expand the Land use & biofuels lever group on the left of the screen to show the levers that make up this group. Using only these levers what also needs to change to achieve net zero (-100% in the meter)?
2. The Farming Yield & Efficiency lever is crucial to the success of becoming carbon neutral mid-century. Click on the lever and read the lever information page. In what ways will reducing numbers of cattle and sheep impact on emission levels?
3. Aside from land for grazing why might land use also be swallowed up by the livestock sector?
4. In what ways might consumer choices about diet affect the numbers of cattle and sheep?
5. This is a suggested activity to practise a key geographical skill. Turn your attention to the model lever table in the lever information page for Farming Yield & Efficiency by clicking the lever name. The changes in livestock numbers shown are based on the Climate Change Committee (CCC) speculative scenario which was used as the basis for Level 4. Draw a clustered bar graph for the three different species of livestock with level then the sub-lever heading Number of livestock on the x axis and units in millions on the y axis. In each cluster draw a column for: Poultry, Cattle, and 'Pigs Sheep & Other', for each level of ambition.
6. Analyse your graph by adding comments about the pattern and any specific figures of interest between the different ambition level decisions. Can you provide an interpretation? Always quote data in your comments!
7. Focus on the Key Interaction paragraph. What other subcategories does Farming Yield & Efficiency affect?
8. Do not change your ambition choices from the previous question. If the UK is to achieve an increase in forested land and an increase in land devoted to growing biofuels, then the country must free up land by increasing yields and productivity in farming. Click on the Land Use and Bioenergy tab at the top of the screen.

With the current ambition levels (ambition level to 3 for Transport, Buildings and Industry — and ambition level 2 for CO2 Removal and Gases and Electricity Supply) and the question 1 answer (Farming Yield & Efficiency ambition level 4 and Forestry ambition level 3), what happens to the Total Potential Land line on the second graph? Look at the Forestry information sheet, what does Forestry Level 3 represent?

9. What are the emissions associated with Forestry Level 3 in 2050? Why do you think these are these negative? Why do you think negative emissions are very important?



10. Now reduce Forestry back down to ambition level 1 (the only Land Use lever not at level 1 should be Farming Yield & Efficiency, remaining at ambition level 4). In 2050, what will be the change in:
 - a) Total Emissions — Land Use and Biofuels graph?
 - b) The Land Area Trade Off graph?
11. Try to fill the Remaining Available Land with the other subcategory Land for Biofuels — if you increase this, can all available land be used by 2050, even at the maximum plausible ambition (Level 4)? Look at the information sheet for Land for Bioenergy and explain why this is.
12. Suggest what could be done with any Remaining Available Land that might be available due to livestock reduction? Create a mind map activity of ideas with 'How could we use land differently in the future?' with the following limitations:
 - It must be environmentally friendly, i.e. the land use should not damage or pollute the environment.
 - The land should be used in a manner which is consistent with the goal of achieving being carbon net zero by 2050.
 - Consider the following terms to help: biodiversity, green space, recreation, semi-natural landscapes, multifunctionality, conservation, agritourism, climate change mitigation and sustainable communities.