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How to Build a 2050 Calculator

A Guide

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Purpose of this guide

This guide will walk you through the process of building a 2050 Calculator, step by step, based on the experiences of teams around the world who have already built their own Calculators. Compared to most energy models, a 2050 Calculator is relatively simple to build, use, and understand; however, each city, region, or country will have its own specific challenges.

This guide is aimed primarily at people thinking of building a 2050 Calculator, but it's also for anyone wanting to explore whether a 2050 Calculator may be of use to them, or for those who are just interested in the approach, including policy makers and analysts working in government, but equally those working in industry or academia.

This guide builds on an earlier draft developed by the first UK Calculator team (made available in draft form in 2014), with updates to reflect the current UK Calculator (MacKay Carbon Calculator) and the experiences of the 2050 Calculator programme team.

As this guide may not be able to answer every question, an online international community has also grown to allow users to share their experiences and expertise.

This guide contains a chapter on each step of the process to build and launch a 2050 Calculator:

Chapter	Content
1 Introduction	What is a 2050 Calculator? How to use one and the purpose of this guide
2 Getting started	Building support, building a team, and planning your project
3 Defining the scope	Mapping sectors, drawing logic trees, choosing levers and outputs, and searching for data
4 Setting ambition levels	Setting ambition levels 1 to 4, engaging stakeholders to review them, and writing one-pagers
5 Building the Calculator spreadsheet	Building the model in Excel
6 Sector specific guidance	Sector specific guidance on energy, buildings, transport, industry, land use, bioenergy and waste, farming and forestry, and bioenergy and waste transformation
7 Adding other outputs	Adding in costs, air quality, and energy access
8 Quality management	Running quality assurance on the Calculator
9 Putting the Calculator online	Why put the Calculator online and how to do it
10 Launching your Calculator	Being open and transparent, example pathways, launching and re-launching the Calculator
11 Influencing policy	Testing existing policies, developing new ones, and reporting data
12 Engagement and education	Influencing the influential and the My2050 tool
13 Keeping the Calculator alive	Institutionalising the Calculator and the international community

Note that this version of the guide does not cover the development of the My2050 tool.

1. Introduction

1.1 What is a 2050 Calculator?

The 2050 Calculator is a uniquely open source, transparent, and interactive energy and emissions model that can be used to identify a range of physically possible scenarios for the future. This could be with the aim of reducing emissions to tackle climate change, improving air quality, or reducing dependence on fuel imports.

The first 2050 Calculator was developed in 2010 by the UK's Department of Energy and Climate Change (DECC), now the Department for Energy Security and Net-Zero (DESNEZ), to help the UK Government to plan the country's low-carbon transition in an evidence-based way.

The 2050 Calculator allows experts and non-experts alike to model various combinations of technologies in different sectors of the economy to explore energy and emissions scenarios up to 2050 and beyond. The technical energy balancing model at the heart of the 2050 Calculator has been extensively peer reviewed by experts. The model brings together sectoral trajectories in various ways to construct possible pathways to 2050 and beyond. The 2050 Calculator helps everyone to engage in the debate around net zero energy pathways and allows governments to confirm planning is consistent with long-term aims.

The 2050 Calculator takes a systems approach and covers all parts of the economy and greenhouse gas emissions. It's rooted in scientific and engineering realities and looks at what is thought to be physically and technically possible in each sector in the future. It allows the user to consider the choices and trade-offs that are likely to be faced in a particular country.

Crucially, the 2050 Calculator can outline in minutes what would take months of work from experts. It allows you to answer the fundamental question of 'how far can we reduce emissions and meet energy needs?' The model can be used to:

- Engage scientists, engineers, policy makers, and the public on how a country's emissions could change over time
- Bring energy and emissions data alive
- Show the benefits and trade-offs of different versions of the future
- Openly challenge long-held beliefs on what is possible
- Help create realistic policies, Nationally Determined Contributions (NDCs), etc

- A 2050 Calculator can be built in 6 to 12 months.
- A 2050 Calculator can be built by a core team of between 5 to 10 people.
- Institutionalising and regularly updating the model is key to keeping it relevant.

1.2 How to use a 2050 Calculator

Users choose various combinations of technologies in different sectors of the economy to explore energy and emissions scenarios. They do this by moving a number of 'levers' – usually around 40 levers. The levers change either the supply or demand of energy in a particular sector; for example, building nuclear power stations or reducing the distance people travel by car. Users can also change the energy infrastructure, like adding electricity storage or technologies such as geo-sequestration which do not quite fit under supply or demand. The combination of choices create a 'pathway', and the 2050 Calculator then displays the implications of the pathway over time (for example, in terms of energy demand, greenhouse gas emissions, land use, and/or air quality).

For each lever, there are a variety of options to choose from. Most will have four possible 'levels of ambition' labelled 1, 2, 3, and 4. These relate to the amount of effort being used, ranging from doing nothing (level 1) to putting in the maximum amount of effort or going to the limit of technical feasibility (level 4). The levels of ambition allow the user to see the range of opinion from experts as to what's possible in the future. See chapter 4 for more details on levels of ambition. If there's a choice between different options with similar levels of effort or where the concept of 'effort' doesn't really apply, then the levels are labelled A, B, C, and D rather than 1, 2, 3, and 4 (for example, the choice between plug-in electric or hydrogen vehicles or different economic growth scenarios for a country).

The UK's current **MacKay Carbon Calculator** is available in three different versions aimed at various audiences. Other countries have tended to adopt a similar approach:

- **The full model** – built in Excel, and contains all calculations and assumptions. This allows expert users to examine pathways in detail and/or to change assumptions or data to suit their needs (see Figure 1.1).
- **The web tool** – an interactive and user-friendly web interface that allows users to explore all options in an easy way. The web tool is aimed at policy makers and stakeholders but is also suitable for members of the public who are very interested in the subject (see Figure 1.2).
- **My2050** – a simplified, game-style version that is aimed at the general public. Users make fewer choices, but it provides an overview of the main issues and trade-offs (see Figure 1.3).

Figure 1.1: Extract from the full Excel model

Source: Click here

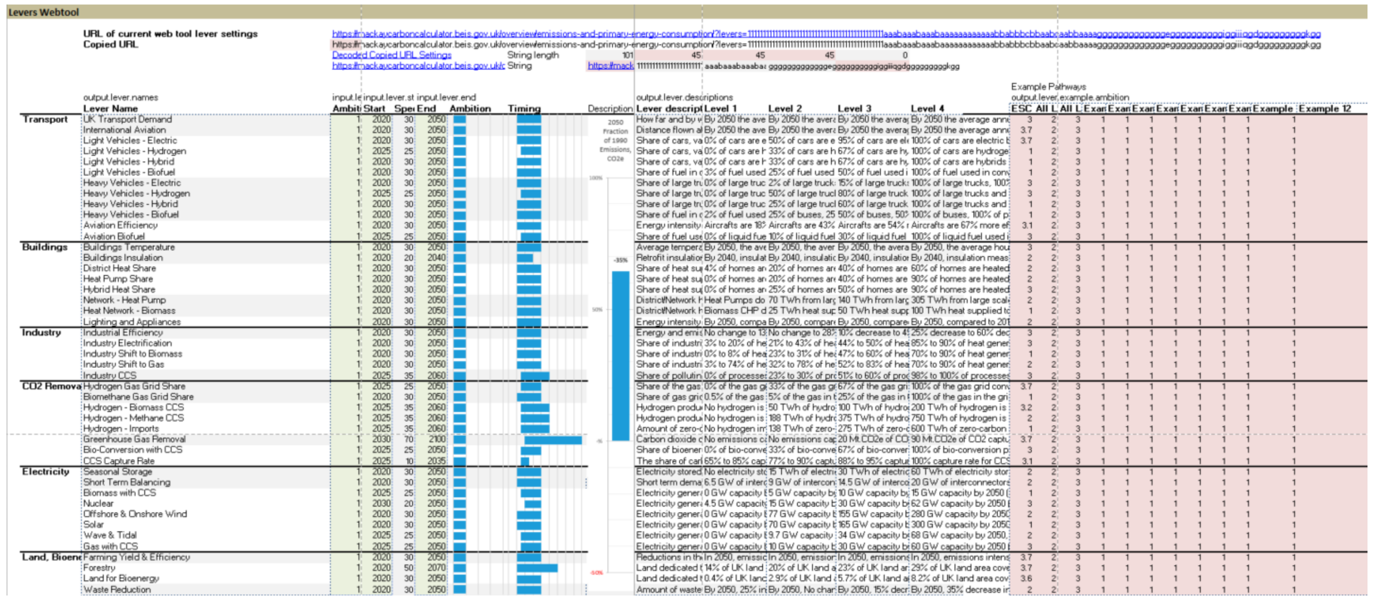

Figure 1.2: The web tool

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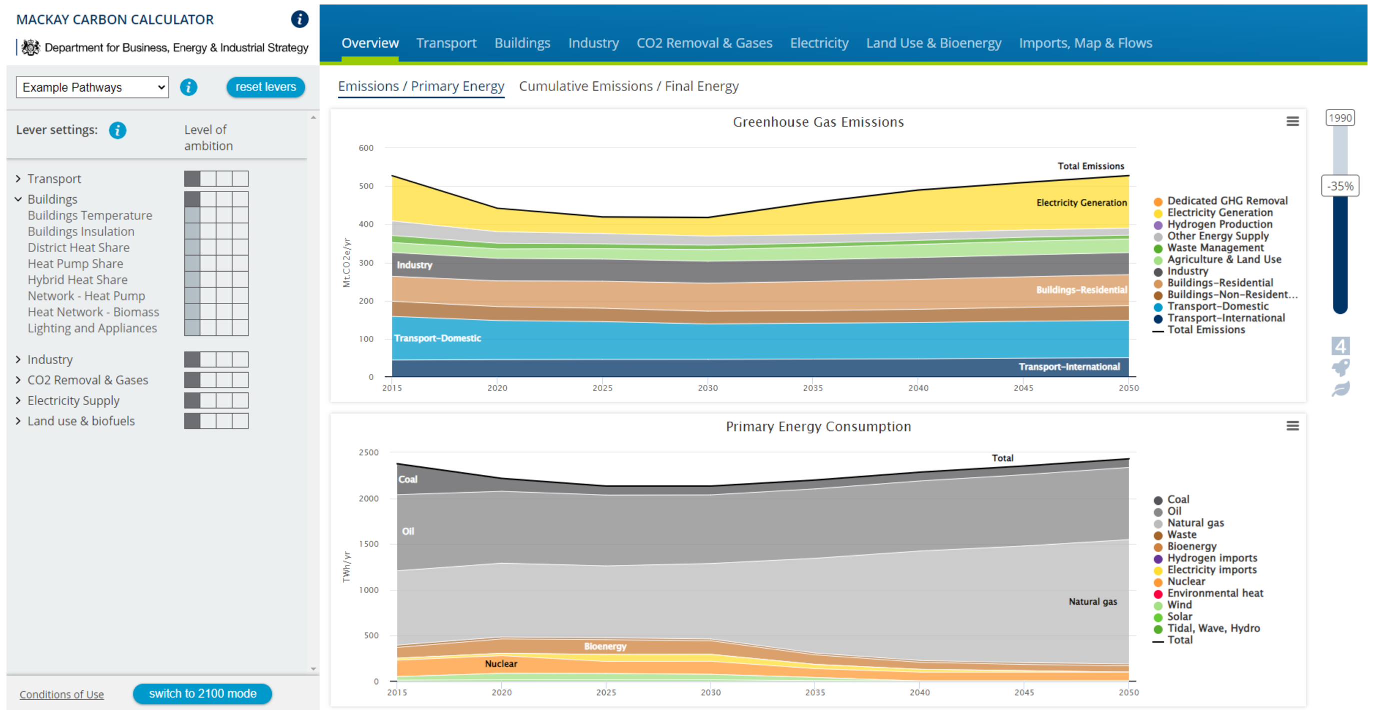
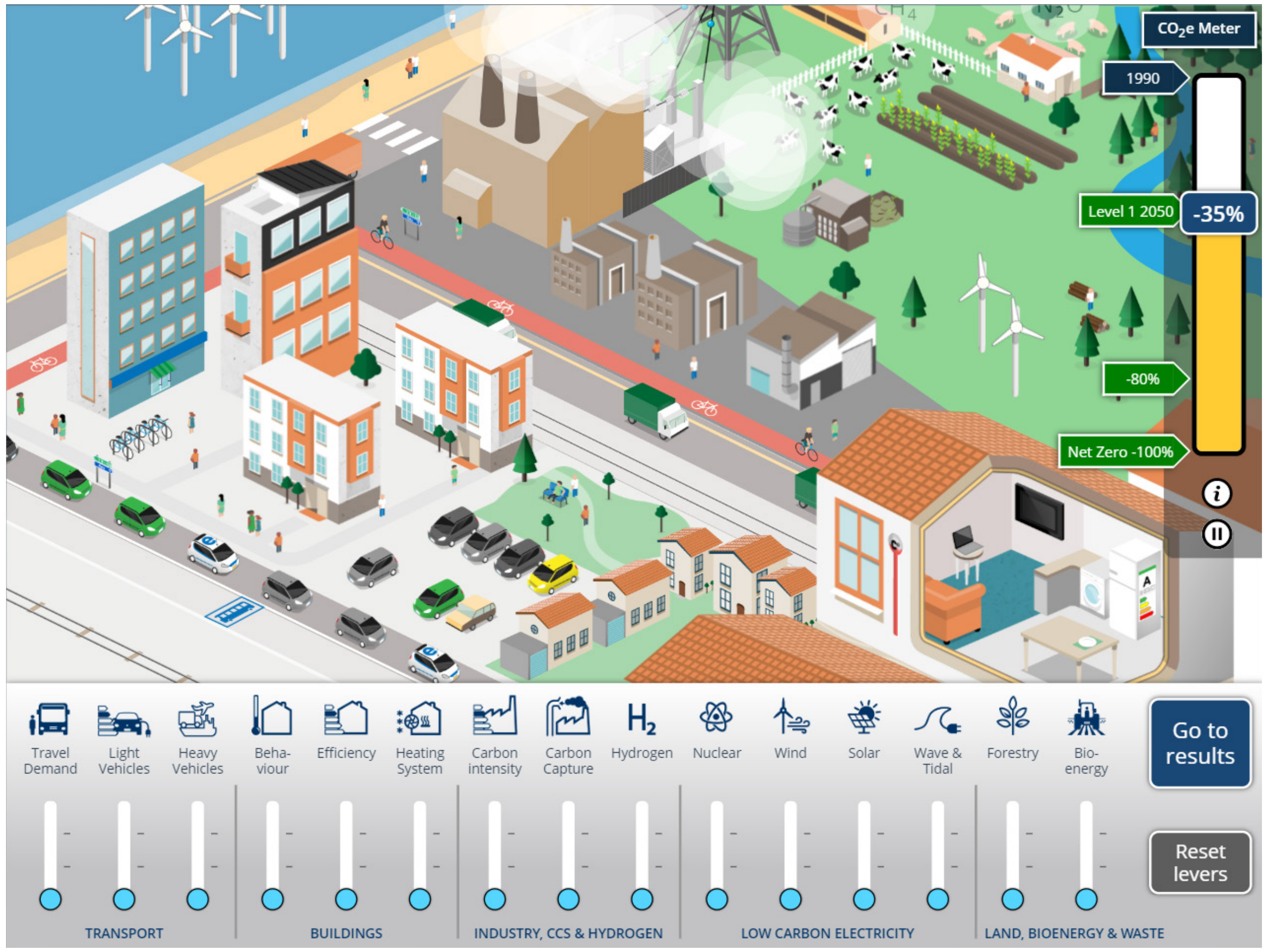


Figure 1.3: My2050

Source: Click here



1.3 Calculators around the world

As a methodology, the 2050 Calculator has been widely adopted. 67 countries, regions and territories have adopted a similar approach and have built their own 2050 Calculators to help inform policy and increase public understanding of energy issues.

Since 2012, the UK Government has funded the 2050 Calculator programme through its International Climate Finance commitment. The programme has supported over 10 countries by providing tailored technical assistance to create bespoke 2050 Calculators.

The UK Government also worked in collaboration with a variety of organisations to build a Global Calculator . The Global Calculator enables users to explore the options for reducing global emissions and the associated impact of climate change.

1.4 What makes the Calculator approach different?

It's easy to use – The 2050 Calculator can be used by policy makers, ministers, academics, non-governmental organisations (NGOs), and the general public. It provides a common language and instant answers to questions for both experts and non-experts.

It's accessible, open, and transparent – The model is built in Excel and is published online with all assumptions documented. Expert stakeholders have been consulted during the build process.

It includes all energy and emissions – The model brings all your options into one place and can include implications for land use, air quality, energy access, and energy security.

It's engineering-based, not economics-based – The model shows what is possible, not what is probable.

Some other models only include the power sector or do not include process emissions from industry or from land use. The 2050 Calculator covers all energy forms (oil, coal, gas, biomass, electricity, etc), and all emissions (from fossil fuel combustion but also from industrial processes and land use, etc); this makes it a more powerful tool, as all options, and their impacts, can be seen.

Many energy models are based on economics, looking at what effect changing prices, demand or supply could have on the market, and in turn, what the optimal energy system would be under these circumstances. Such models use complex equations and assumptions about the behaviour of individuals and firms. They're sometimes called 'black box' models because inputs go 'in' and outputs come 'out', but it's not clear what's happening in the middle because they're so complicated. Typically, this means that only a few experts can properly use such models, and consequently public trust in them can be low.

The 2050 Calculator is different in that it's based more on engineering than on economic forces. Users choose from a range of options for the future without needing to consider the set of circumstances that would cause them to come about. It avoids any assumptions about what motivates behaviour and instead allows the user to see what the impact of changing behaviours directly would be. It's about what's possible, not what's probable.

The 2050 Calculator also differs from most models in that it's not a 'black box'. It's as simple as possible, so as many people as possible can use it. It is also as transparent as possible, so the inner workings are not a mystery. The model is built in Excel so people with no specialist training can open it up and see the calculations. It also produces answers instantly, rather than taking hours or days to run.

A marginal abatement cost (MAC) curve is another tool that's often used by economies to look at the mitigation options available. It gives a good overview as to which options are cheapest, but because it looks at each technology separately, it doesn't consider the co-benefits of combining different actions together; for example, shifting to electric transport can increase emissions if it's not combined with decarbonising the electricity supply. The 2050 Calculator shows how demand, supply, and emissions interact dynamically across sectors, and how entire pathways can be built.

The 2050 Calculator can help answer fundamental questions such as:

- How far could renewables satisfy energy demand in the future?
- What could be the impact of individual behavioural change?
- How much fossil fuel will need to be imported in the future?
- What's the impact of eating more meat on land use?
- What's the impact of improved forest management on emissions?
- Which pathways could achieve an x% emissions reduction target?
- What's the impact of delaying action?
- Could we reduce emissions with high levels of economic growth?
- How much would this cost?
- How diverse will my energy supply be in 2050?
- Will supply meet demand?

1.5 A brief classification of energy models and where the 2050 Calculators fits in

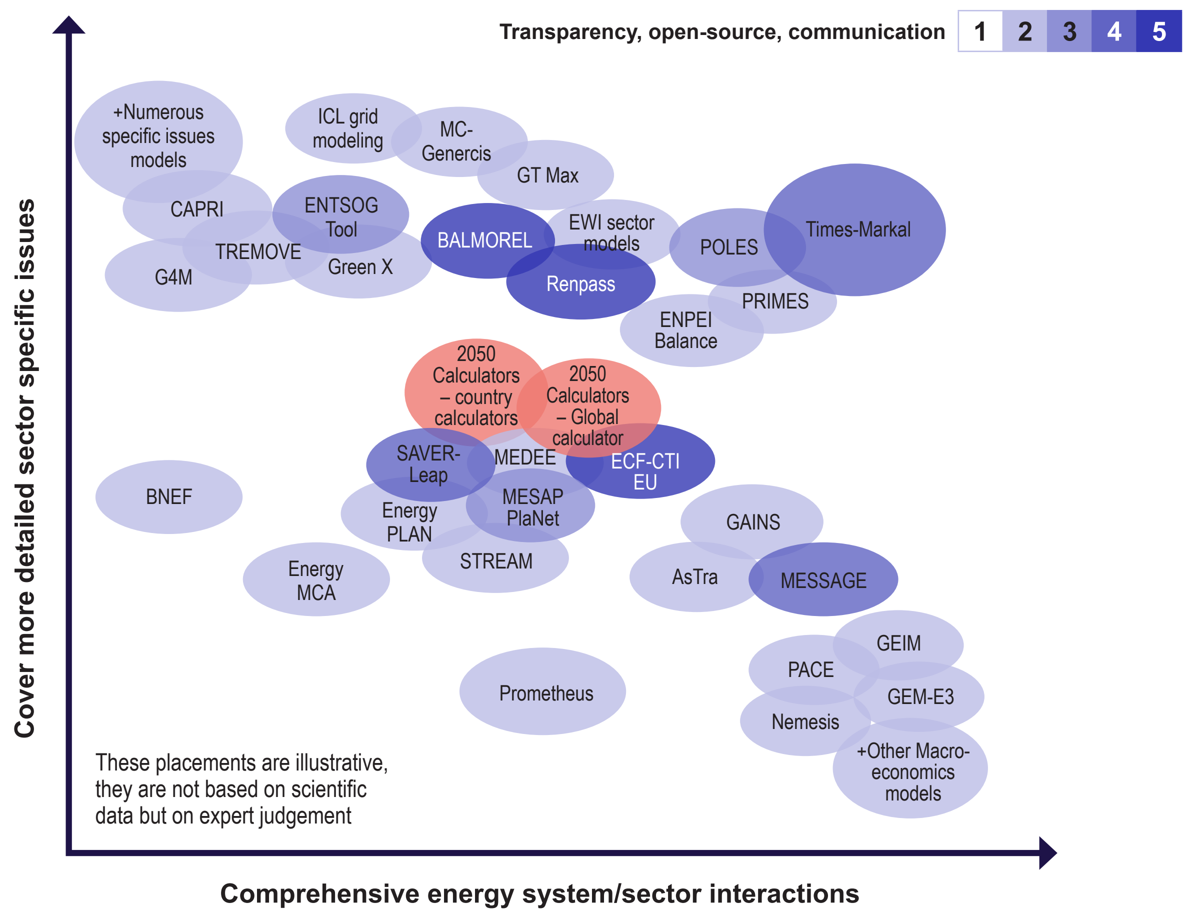
There are more than 100 credible energy models. It's important to use a model that matches stakeholder needs.

The 2050 Calculator provides an intermediary depth of analysis and an intermediary depth of interaction between the different sectors covered by the model.

It's less detailed than the frequently used optimisation models (e.g., PRIMES, TimesMarkal). While these models enhance the relationships between the different sectors, the 2050 Calculator deconstructs relationships with levers and some links between different levers, enabling the 2050 Calculator to provide real time results.

A common pitfall is to start with optimisation modelling prior to having a sufficient understanding of the potential solutions. We recommend using the 2050 Calculator to complement optimisation models and sector specific models to refine the pathway specifications.

Figure 1.4: Energy model use and Calculators



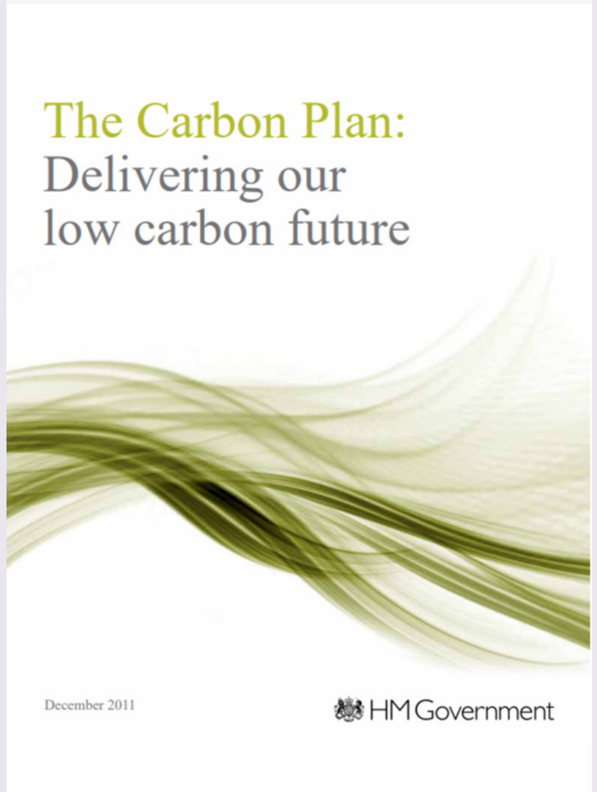
Source: Climact

1.6 Case Study: The UK's Carbon Plan (2011)

The 2050 analysis for the UK's Carbon Plan (2011) is an example of 'joint model working'.

1. The UK used MARKAL to produce a lowest cost pathway to 2050.
2. The team put this MARKAL pathway into the Calculator. From this, the team produced three other pathways. The user-friendliness of the tool made it easy to agree these across government. The team explored the air quality and land use implications.
3. The team estimated the costs of these pathways using MARKAL, the Calculator and ESME models. The team compared the results to get a full picture on the costs.

The 2050 approach is a useful starting point if you are at an early stage of modelling or a useful complement to existing models.



1.7 Project phases

Developing and launching your own 2050 Calculator can be done by following four main phases:

- Initiation
- Scoping
- Model development
- Launch

The **initiation phase** involves getting support from government and other key stakeholders, setting up a team, and securing the resources and funding needed to proceed. The duration of this phase can vary widely depending on how long each of these steps take, and particularly the appetite of key individuals within government. See chapter 2 for more details.

The **scoping phase** involves defining the 2050 Calculator scope, starting to investigate the availability of data, and building the capacity of the team. See chapter 3 for more details.

Model development is expected to take around 6 to 9 months. While a fairly quick first version of the 2050 Calculator can be developed in a couple of months based on the UK's MacKay Carbon Calculator, changes to the model design to reflect a country's national circumstances, and the need to engage with stakeholders on the data, will require some time, making this the longest part of the project. See chapters 4 to 9 for more details.

The **launch phase** is about ensuring that the results of the 2050 Calculator are communicated to an influential audience in an effective way. This will be the time to interrogate results to pick out the key messages that the 2050 Calculator has highlighted about different pathways to 2050. See chapters 10 to 13 for more details.

Possible tasks within each of these phases are shown in the table below.

Task list	Duration	Where to look in this guide
Scoping phase 1. Obtaining support from government and other key stakeholders 2. Determining the aims and objectives of the project 3. Identifying a team 4. Preparing a project proposal and securing funding and resources	3+ months	Chapter 2 (Let's get started)
Initiation 1. Define the project governance: a. Establish the core team b. Map other key stakeholders c. Describe roles and responsibilities d. Define execution and deliverable format of the project 2. Identify stakeholders 3. Define the Calculator scope: a. Inception workshop to introduce the project to stakeholders and gather feedback on: i. The scope of project within the different sectors ii. Availability of good quality data (or lack of it) iii. The uses of the project end products in the context of the country and in relation with other models used b. Building on the inception workshop feedback, clarify the sectors to be included/excluded and define their respective target level of detail (i.e., decide which sectors should be modelled in a detailed way, and which could be modelled at a higher level) 4. Build the capacity of the project team: a. Assess training needs b. Build capacity related to sector modelling c. Training on advanced Excel skills to enhance the capability of the core working team if needed	Around 3 months	Section 2.3 (Build a team) Section 2.4 (Engage with stakeholders) Chapter 3 (Define the scope)

Model development 1. Model each sector: a. Development of lever map and logic trees for each sector b. Data collection, analysis, and validation c. Development of draft version of the Excel spreadsheet d. Hold various technical consultation workshops with key relevant stakeholders for each sector to solicit feedback 2. Develop scenarios: a. Draft scenarios b. Stakeholder consultation to collect feedback c. Integrate stakeholder feedback 3. Develop the web tool: a. Develop the public online web tool to share with wider audience b. Stakeholder consultation based on the online platform (call for evidence) c. Integration of any stakeholder feedback 4. Quality checking of work 5. Gain internal sign-off	Around 6 to 9 months	Chapter 4 (Set ambition levels) Chapters 5 (Build the Calculator spreadsheet) and 6 (Sector specific guidance) Chapter 8 (Putting the Calculator online) Chapter 9 (Quality control and quality assurance)
Launch 1. Prepare communications material – including website 2. Final model launch: a. Launch of endorsed model in an event attended by ministers and high-level representatives to make an opening statement on the various uses of this model, and demonstrate its use so far 3. Outreach activities are important in ensuring that the 2050 Calculator is used by a wide range of stakeholders. Outreach activities could include the following: a. Workshop(s) for other government departments, NGOs, academics, industry bodies, and other stakeholders to demonstrate how to use the 2050 Calculator and also how to develop pathways b. Workshop(s) or events for general public to raise awareness of the tool c. Outreach in schools and universities d. Leaflets, online articles, or other promotional activities	Around 3 months	Chapter 10 (Calculator launch) Chapter 11 (Influence policy) Chapter 12 (Engagement and education)

The timescales shown above are meant as a guideline only. In practice, it may be necessary to spend more or less time on any of the phases.

When drawing up a project plan, it's important to consider other events that may impact the timeline. Perhaps there's an existing conference that would be perfect to launch the 2050 Calculator, or perhaps there is a busy period coming up that's best avoided. Adapt your timetable to fit in with these events.

1.8 The 2050 Calculator international community

With so many teams around the world building their own Calculators, there's a great opportunity to share experiences and expertise to help spread the message of the tool as a transparent model to support evidence-based policy making.

A UK Government-funded programme is currently supporting countries to move to a more sustainable development pathway and to reduce their emissions at a faster rate by creating and using 2050 Calculators. The programme is led by the Department for Energy Security and Net Zero with support from a consortium led by Mott MacDonald and including Climact, Imperial College London, and Ricardo AEA.

One objective of the programme is to grow the 2050 Calculator international community to promote learning between countries, including:

- A LinkedIn group for members of the international 2050 Calculator community to interact and collaborate with one another. It's a good place to ask specific questions you may have about building a 2050 Calculator, with first-hand engagement from community stakeholders around the world
- Annual international workshops up to 2023
- A website which hosts information about the 2050 Calculator and the programme, its history, links to completed Calculators, a resource library with training material, and news and information on events
- Quarterly newsletters are issued to the international 2050 Calculator community by email to provide updates on applications, methodology developments, project news, interesting new pathways, insights, articles/papers, challenges, and opportunities for collaboration, as well as updates on conferences and meetings. Past newsletters can be found on the website (under 'News').

The community is available, not only to ask questions and seek support, but also to support others. Every team building a Calculator has unique challenges and their own skills and ideas which may be useful for new Calculator teams or teams facing similar issues.

Let's get started

2.1 Plan your project

At the outset, it's important to consider the context of your project, for example:

- What are the existing energy sector plans and policies in your country?
- What's your country's NDC and long-term strategy under the Paris Agreement?
- Are there any ongoing complementary projects?
- What existing energy models are already used in country, and how do these currently inform plans and policies? How will your project complement existing energy models?

Similarly, think about what the main aims and objectives of your project will be. Countries with successful 2050 Calculators had a good idea of what the Calculator would ultimately be used for. Examples from other countries include one or more of the following:

- Contributing to NDCs
- Preparing energy sector plans
- Informing energy and climate policy and strategy
- Engaging government, industry, academics, and the public
- Strengthening capacity.

What are the main risks to successful completion of the project and to the project meeting its aims? Describe how you will mitigate each risk. You might consider:

- Lack of political support
- Lack of capacity
- Lack of stakeholder support
- Poor quality and/or unavailable data
- Delays to the timeline
- The completed 2050 Calculator not being used for the project aims.

Having a clear answer to the above questions will help guide you throughout the rest of the planning phase.

2.2 Case Study: The case for a new 2050 Calculator in Nigeria

In 2020, the Nigerian team began developing a new national 2050 Calculator. At the time, about 50% of the population did not have access to electricity, about 80% of grid electricity supply was from gas power, and the energy sector and Agriculture, Forestry and Other Land Use (AFOLU) accounted for 60% and 25% of total GHG emissions respectively. The last approved executive National Energy Policy was in 2005.

The team recognised that there need to have a comprehensive all-inclusive energy policy which captured the importance of reducing the effects of climate change and capture Nigeria's commitments to emissions reduction as party to Paris Agreement and stated in NDCs.

The Calculator project was designed with all of this in mind:

- To give insight when it came to drafting the next energy policy
- To make it easier for stakeholders to chart pathways of renewable and clean energy technologies to deliver energy needs
- To guide the development of energy transition masterplans
- To support increasing NDC commitments.

An updated energy policy would aid in attracting financial investments in the energy sector, support the development and scaling of new, clean energy technologies and show Nigeria's commitment towards emission reduction and fighting the effects of climate change.

2.3 Build support

A 2050 Calculator is a powerful tool if it's built with support from government from the outset. This focuses the project on the questions that those with influence really want answers to, as well as creating a ready-made audience keen to take on board the key messages once it's finished.

Finding a government body to sponsor the project and take eventual ownership of the model is extremely important at this early stage as it can provide political leadership and resources, link the 2050 Calculator to government plans and policies, and help communicate the results of the project to stakeholders.

This is also the time to kick start engagement with policymakers. This should continue throughout the development of the 2050 Calculator eventually allowing them to use the finished Calculator to evaluate existing policies and help inform new plans and policies (see chapter 11 on influencing policy). Countries with successful 2050 Calculators engaged at the policy level early in the process.

Which government body would the 2050 Calculator sit with? Answering this can be a challenge, as every country or region has its own system. In the UK, responsibility for energy and climate change resides in one single department in government, making it a natural home for such a project. In other countries, the situation might not be so clear, but there may be one organisation that has responsibility for energy or environmental policies, or one department that has responsibility for long-term planning in general.

Table 2.1: Where do existing Calculators sit?

Calculator	Sponsor/Owner
Colombia 2050 Calculator	Minambiente (the Ministry of Environment and Sustainable Development)
India Energy Security Scenarios 2047	NITI Aayog, the Indian Government's Planning Commission.
Kenya Carbon Emission Reduction Tool (KCERT)	Ministry of Energy
MacKay Carbon Calculator (UK)	Department for Energy Security and Net Zero (formerly Department for Business, Energy and Industrial Strategy)
Nigeria Energy Calculator (NECAL2050)	Energy Commission of Nigeria (ECN) and the Federal Ministry of Environment
Thailand 2050 Calculator	Energy Policy and Planning Office (EPPO) of the Ministry of Energy
2050 Energy Calculator (US)	Department of Energy Office of Nuclear Energy (DOE-NE)
VN2050Calculator4NDC (Vietnam)	Ministry of Industry and Trade (MOIT)

Nevertheless, other organisations across government will still need to be consulted, since the 2050 Calculator covers everything from building regulations to public transport policy. It's important to involve as many people as possible as early as possible, so that they feel part of the project. If consultation only begins once the 2050 Calculator is built, it's likely that opportunities to learn from expertise will be missed. Using stakeholder knowledge to build the 2050 Calculator is the preferred approach, as it's much more difficult to correct mistakes once a Calculator is completed.

It's likely that a lot of knowledge about the energy system and modelling expertise is held not just at government level, but also in universities, institutions, consultancies, and NGOs. Talking to researchers from all backgrounds can be very helpful. It may be more effective for a government to commission a university or other organisation to do the modelling work for a Calculator, particularly if individuals within that organisation have the capacity, appetite, and capability to undertake the project, or have already worked with government in similar projects; for example, the University of Cape Town built the South Africa Calculator in partnership with the country's Department of Environmental Affairs.

2.4 Build a team

A 2050 Calculator can be built by a core team of between 5 to10 people. The team does not necessarily have to work on the project full time. Many teams have developed a 2050 Calculator while continuing to work on other things.

Each team will need a project leader who will be responsible for the strategic aspects of the work and ensuring that the project has political support. The project leader will

- Provide political and stakeholder leadership
- Be convinced that the 2050 Calculator is a priority worth pursuing
- Be responsible for getting ministers and high-level officials to support the work
- Have good contacts in climate and energy sectors
- Ensure the team has the resources and time to complete the project
- Link the 2050 Calculator to other government priorities
- Be involved in communicating the results to stakeholders.

A project manager or coordinator will be needed and will be responsible for:

- Day to day management of the project
- Reporting to sector leads
- Managing the budget and schedule of the project

The team will also need a capable modeller to oversee the model development. The modeller will:

- Have expertise in Excel
- Collate the work of the sector leads into one tool
- Be numerate but doesn't necessarily need to have a background in energy or climate change.

The team will need somebody to lead communications with external stakeholders (see section 2.5 below on engaging with stakeholders and section 10.4 on communications strategies when launching your Calculator). This could be done the project manager if they have the right skills and experience, or could be carried out by somebody else in a specific role.

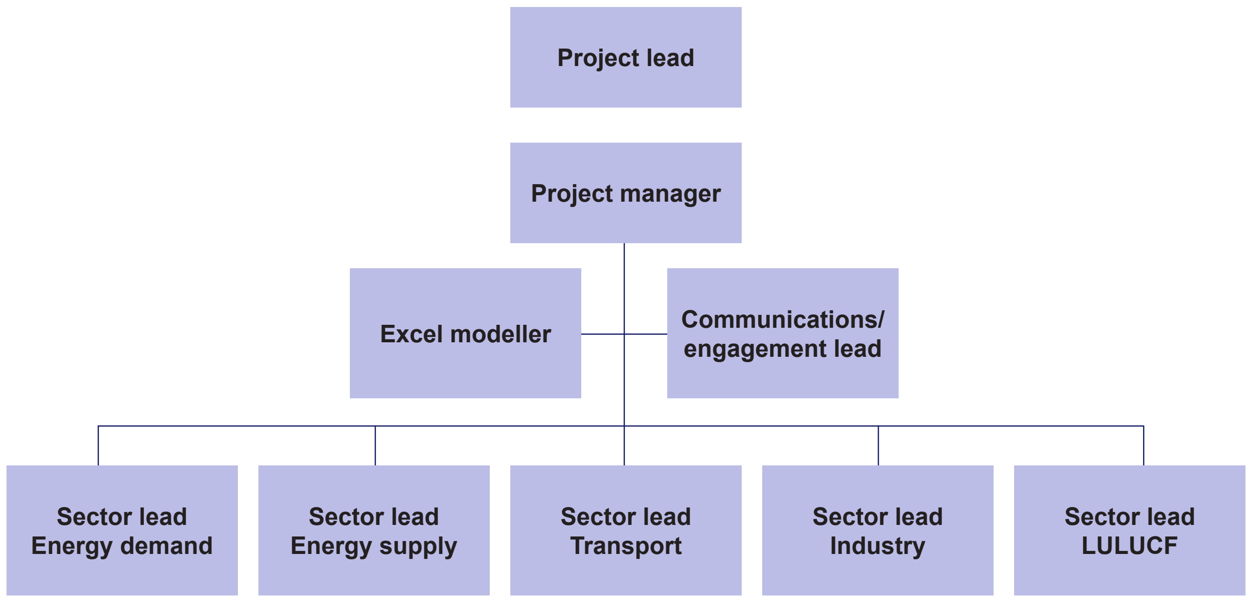
The sectoral pieces of work can be achieved by 3-5 sector leaders, who will be responsible for developing four trajectories for each sector. The sector leaders don't necessarily have to be experts in their field, but they need to be comfortable conducting literature reviews and coordinating opinions from stakeholders, and they need to have confidence interpreting competing views. A good sector leader will:

- Have good research skills
- Be willing to take on a subject and quickly identify pieces of relevant evidence
- Have knowledge of energy and climate (an advantage but not always essential)
- Be able to bring together experts and summarise views
- Have clear writing skills to present findings.

The size and configuration of the implementing team will depend on what resources are available and will therefore look different for each country.

The organogram below shows one way that a team might be organised – but this is flexible.

Figure 1.1: Indicative team structure



Note: This structure is indicative only and could be organised in different ways according to country needs. LULUCF = land use, land use change, and forestry

2.5 Engage with stakeholders

Stakeholders are individuals, groups, or organisations that are directly involved with, or indirectly affected by, the 2050 Calculator. Engaging with stakeholders during the development of the model and involving them in its co-design helps to ensure that the Calculator is robust and will be used when complete (see chapter 11 on influencing policy and chapter 12 on using the Calculator for public engagement and education).

Ensure that there is a clear method for mapping, identifying, and engaging with stakeholders.

This will increase the robustness of the process, will reduce the risk of stakeholder groups being omitted or under-represented, and will provide a record of actions taken and why.

Identifying stakeholders is a good opportunity to use the Theory of Change (Figure 2.1), a specific methodology for planning and participation. By using the theory, you can define long-term goals, then trace or map backwards to identify the steps, and people needed, to achieve the long-term goals.

Figure 2.1: Theory of change infographic, demonstrating the iterative nature of the co-design process

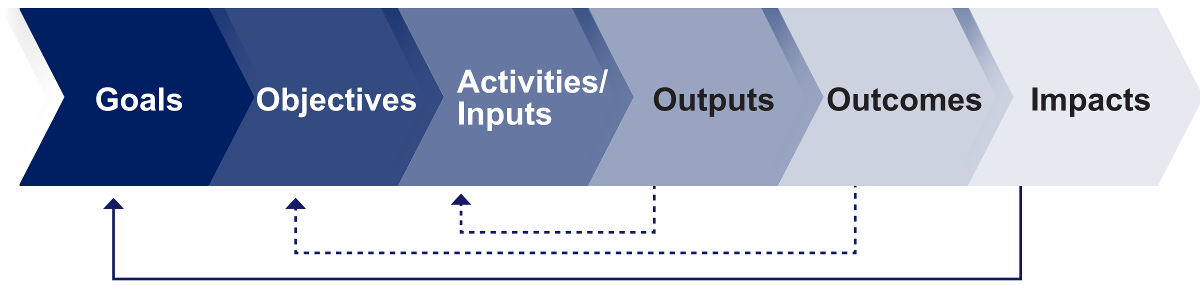
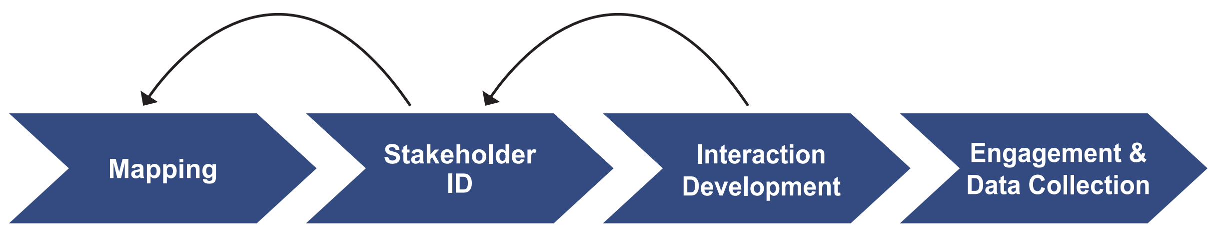


Figure 2.2: The application of 'theory of change' within stakeholder engagement, demonstrating the iterative nature of the methodology



2.5.1 Map stakeholders

Stakeholder mapping is the visual process of laying out all the different types and areas of stakeholders of a project on one map. The main benefit of a stakeholder map is to get a visual representation of all the people who can influence, or be influenced by, your project, and see how they're connected. What sectors do your stakeholders work in? (E.g. land, energy, transport, renewables.) What are their specialisms? (E.g., analyst, policy maker, academic.) Are they on the development or user side of the 2050 Calculator?

Keep in mind what the main aims and objectives of your project are (see section 2.1 above on planning your project). What types of stakeholders will help meet these? What are the main risks to successful completion of the project are. Who should you engage to help mitigate these?

There are generally two types of stakeholders involved in a 2050 Calculator project: those involved in the design/build of the Calculator (including analysts and engineers) and those targeted as users of the completed Calculator (such as policy makers and the public, for example). Both types of stakeholders should be engaged during development but different approaches may be taken for each type.

- Typical stakeholders involved in the design/build:
  - Policy makers
  - Analysts
  - Academics
  - Sector specialists
  - Engineers
  - Representatives from industry
  - NGOs
- Typical stakeholders targeted as users:
  - Policy makers
  - Analysts
  - Academics
  - NGOs
  - Interested members of the public
  - Students
  - Schoolchildren

2.5.2 Identify stakeholders

Once a stakeholder map has been produced outlining the anticipated areas that stakeholders will represent, stakeholder identification can commence. Common methods of stakeholder identification include:

- **Known experts** – identify leading experts in the field from collective knowledge within the team. This may also include a review of government department organograms, news articles, LinkedIn and other online resources.
- **Focus groups** – within your team or with known experts, use focus groups to identify other groups of stakeholders
- **Semi-structured interviews** – with known stakeholders (experts or 2050 Calculator users) present a pre-determined set of questions to explore who else could be a stakeholder
- **Snowballing** – the most commonly used technique, it's often combined with the above. Each time you talk to a known stakeholder, ask who they would recommend as other stakeholders. The list is exhausted when no new stakeholders are being suggested.

The whole process is iterative. Your map will evolve as you develop your list of stakeholders, which, in turn, will feedback into your identification process, and help identify if there's an under- or over-representation of a particular set of stakeholders.

2.5.3 Develop stakeholder engagement plans

Once you have your list of stakeholders, there are various ways to interact with them. Understanding the number of stakeholders and their relevancy to each sector at each stage of the 2050 Calculator development (e.g., developer versus user) helps to inform appropriate methods.

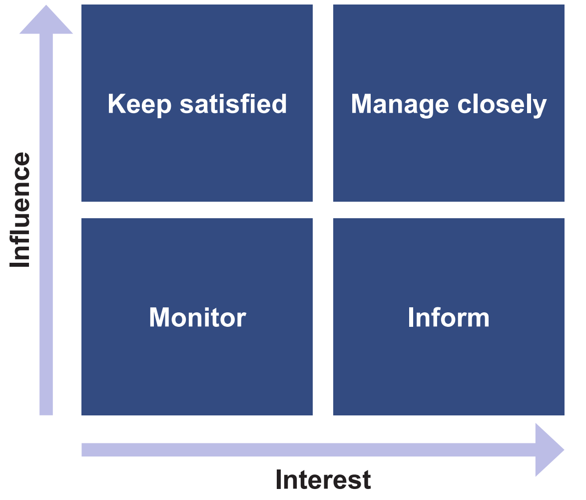
Stakeholder mapping can also help inform the development of stakeholder interaction; for example, mapping stakeholders on an influence versus interest matrix can help identify important stakeholders that must be included in all co-design stages (high interest, high influence), or stakeholders that should be kept informed about progress and invited to later stages of engagement during the call for evidence only (high interest, low influence or vice versa).

This stakeholder planning, mapping, and identification phase can be run in parallel to early 2050 Calculator development. It will help ensure that, when it's time to start including stakeholders in engagement and data collection (section 4.6), there's a comprehensive, representative, and relevant list of stakeholders available, and the best method of interacting with them has been established.

Countries where the calculator process has worked well had a better idea of what the calculator would ultimately be used for - and engaged at the policy level earlier on in the process.

Because of the iterative process, it's important to keep clear records of actions and reasoning, as it helps reduce confusion or repetition when feeding new information back into previous steps.

Figure 1.1: Influence versus interest matrix



2.6 Case Study: Nigeria: Engage early and often

During the development of the first Nigerian Calculator, what little stakeholder engagement took place was mainly after it had been launched. As a result, government agencies and other organisations had limited awareness and understanding of what they could do with the Calculator.

In 2020, the Nigerian team began afresh by developing a new national 2050 Calculator. To drive greater use second time round, the team created a steering committee made up of government stakeholders. Having this committee participate in the development process increased both their awareness of the Calculator and sense of investment of it, making it truly useful for guiding energy policy. The team also carried out an extended period of outreach once the project finished.

Early stakeholder engagement also benefited the project team. To create the new Calculator, the team needed access to data on the region or country. This can be challenging for varied reasons, from poor record-keeping to bureaucratic roadblocks, which early government buy-in helped overcome. Early engagement widened and strengthened the network of stakeholders, and gave the team better understanding of their viewpoints and needs. And it encouraged sharing of insights the Calculator yields.

Define the scope

3.1 Map sectors

The 2050 Calculator works by splitting the energy and emissions system of a country or region into various sectors, modelling the energy demand, supply, and emissions in each sector up to 2050 , and then adding them all together to show the total figures.

The first step is to decide how to divide the energy and emissions system. This will depend on each economy, and on what you want to find out; for example, ‘residential heating’ is a major source of energy demand in the UK due to the climate. In a country like Thailand, where it’s warmer, air conditioning will be a more important area to focus on, so ‘cooling’ is a more appropriate choice. If a sector is not relevant (for example, ‘wave power’ in a land-locked country), do not include it.

In the first UK Calculator, ‘industry’ was modelled as one sector, but the Calculator of the Belgian region of Wallonia splits industry into a variety of sectors so it could be modelled more accurately. The first Indian Calculator splits ‘electricity supply’ into low-carbon technologies and conventional technologies, which the team decided was a very useful distinction for reporting results.

In general, aim to:

- Have as few sectors as possible so that it’s a quick to use tool
- Cover the whole economy and all emissions (it’s best not to ignore land use or industrial process emissions)
- Include all the sectors that people expect, even if they’re small (for example, if most people think that ‘rooftop wind turbines’ are an important potential energy source, then it should be included even if this is factually incorrect).

As a rule of thumb, 40 sectors are about right. It’s recommended to start ‘top down’, rather than working ‘bottom up’, i.e., start by thinking about the transport sector and the fewest sub-divisions possible, rather than thinking of all the possible types of vehicles and how they might be modelled.

The various sectors in the energy economy obviously overlap and interact with each other to produce overall supply, demand, and emission figures. It’s crucial to understand this interplay and to take it into account when designing the model, but not to get overwhelmed by it. Everything should be covered once, but once only to avoid double counting.

The mutually exclusive and collectively exhaustive (MECE) principle should become a mantra for the project, so that the same energy or emissions inputs don’t appear multiple times in the model and make results inaccurate. For figures that are relevant to multiple sectors, exactly where they go in the model will be a matter of personal preference. In such cases, as long as everything is properly documented, there’s no right or wrong answer.

It may be helpful to consider linked technologies together, as this will minimise interaction between sectors; for example, it’s recommended to include one sector for ‘heating and insulation’ since they interact so much.

3.2 Create logic trees

The abiding principle when building a 2050 Calculator is that the model should be ‘as simple as possible, but no simpler’ – you must strike a balance between making sure it’s easy to understand, yet still analytically robust.

Model each sector as simply as possible without compromising accuracy too much. The overall figures, and the major driving forces in supply and demand behind them, are what needs to be correct. Modelling the intricacies of each sector can end up making it more difficult for non-experts to understand what’s going on. Understandably, some experts may not like this approach initially, but this has been key to the 2050 Calculator’s success.

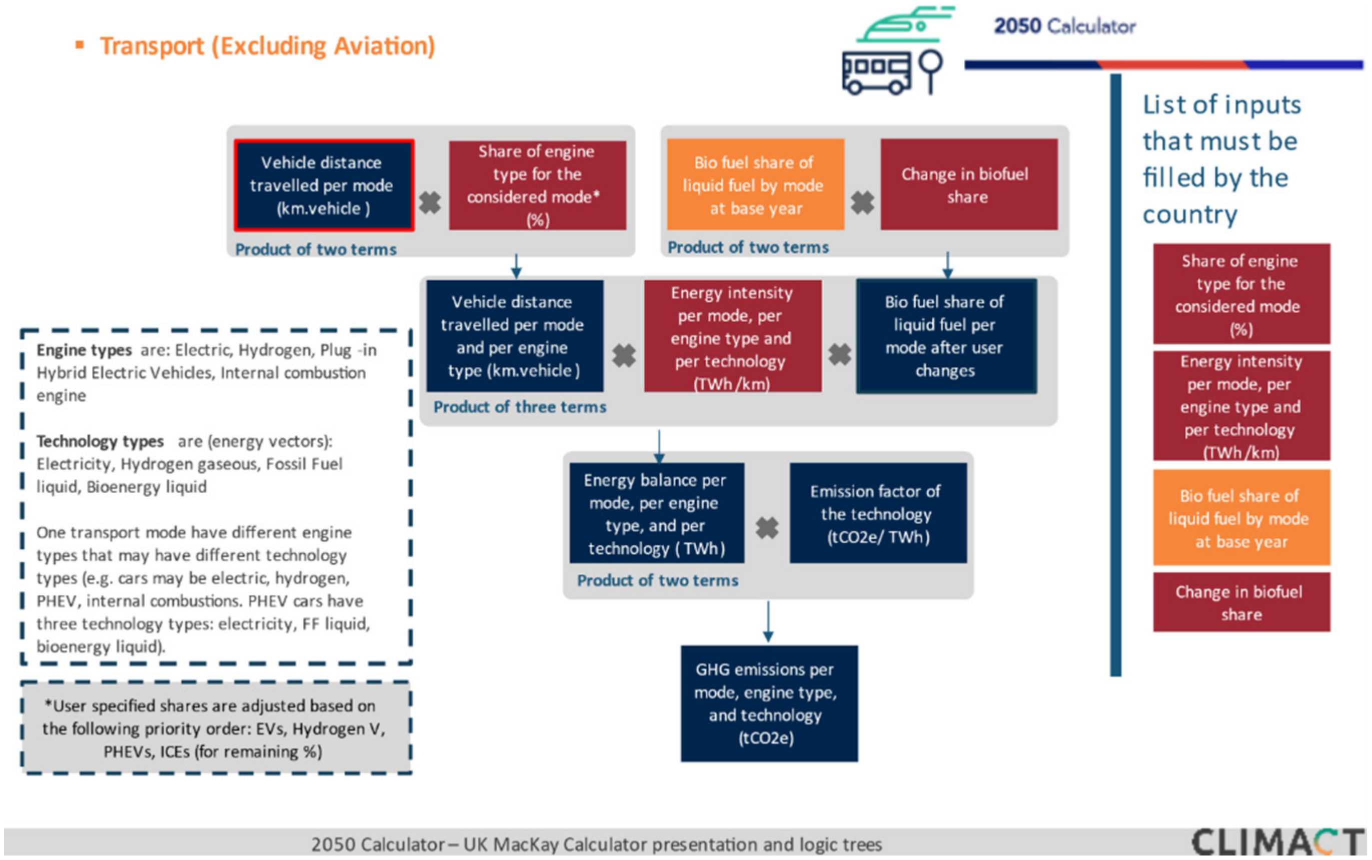
Once you have divided the energy system into sectors, it’s time to look at each sector in more detail and identify the major drivers behind them. This process will help identify what levers (inputs) you can pull to change demand and supply (see section 3.3 below for more on this). You do this by drawing logic trees, which are simple diagrams that show the way in which energy supply and demand relate to produce outputs. At the top of a driver tree is the output the 2050 Calculator is focusing on, like emissions or fuel use. Logic trees are another way of displaying the data and calculations present in the model. If they’re accurate, building your model will be a lot easier.

Developing logic trees early on will simplify the development of a 2050 Calculator. Logic trees allow a visualisation of the major elements of the calculations needed in the model. The visualisation will help you think through the calculations necessary, while the

diagram can also be used to increase stakeholder insight and understanding. If you get the logic trees right, building your model will be a lot easier.

A logic tree diagram will help stakeholders to understand the inner workings of sectoral elements of the Calculator, and how different sector policies controlling emissions could act. This insight and understanding will help stakeholder engagement.

Figure 3.1: Example logic tree for transport sector



3.2.1 Defining the main assumptions

The development of logic trees is the first modelling step in building a Calculator once the model scope is mapped and defined. Modellers decide what the historical data input will be; sketch which levers will be used (this will be formalised in a later step); and how the assumptions, historical data, and levers will influence energy consumption and related emissions.

The tree structure can be a function of the data availability. The choice of the data sources will impact the tree structure. Depending on the objective and type of Calculator being built, it’s important to choose appropriate historical data input; for example, if the model is built to be used for different countries, the input data needs to be easily available for all countries and not too specific. When adapting a generic model to your country, access to different data sources can justify a modification of the calculation tree.

Modellers will need to define the main assumptions to estimate the emissions of the various sectors as efficiently as possible at this stage. Consultation with strategic stakeholders is key to validate the various decisions and assumptions (see section 2.5 on engaging with stakeholders).

3.2.2 Logic tree development

Logic trees are an important step and should not be neglected. Trees developed in other countries are generally used to start the exercise. There are no rules on the time it takes to develop a logic tree; rather it depends on the type of Calculator being built – are all sectors of the economy being modelled? Is it country, regional, or continental scale?

"Logic trees simplify the complicated structure of modelling which helps the developer of the carbon Calculator to easily understand the calculations involved across the sectors and sub-sectors and the data needed for the model." Team member, Malaysia Climate Action Simulator (MCAS).

3.2.3 Logic tree example – transport system

The diagram in Figure 3.1 above shows what a logic tree could look like for a transport system.

Understanding the logic of the calculations used allows identification of the input data a country will need to provide (orange cells in Figure 3.1) as well as the lever values it'll need to define (red cells in Figure 3.1).

To start, you'll need to compile a list of the technology types that are likely to be used in each sector in your country, both now and in the future. Don't be afraid to use expert judgement to begin with – you can always consult with peers or stakeholders to refine your list later. In the transport sector example above, the specific list of inputs that need to be compiled are on the right side of the diagram:

- Share of engine type according to mode (%)
- Engine intensity of use per mode, per engine type, and per technology (TWh/km)
- Biofuel share of liquid fuel by mode in the base year (% of total fuel used)
- Change in biofuel share over time.

For non-transport sectors, the same general principle applies. Consider what the current and future technologies or options are, and what data you'll need to access to, and make a list.

Next, start to build the logic tree diagram – normally from the top, downwards. You don't have to construct the diagram in this way, but it's important to provide a clear narrative, so the reader can understand how the logic tree was developed. This will ensure that your communications are transparent.

Turning back to the transport sector example above, the last box at the bottom of the diagram shows the end point of the calculations – the greenhouse gas emissions per mode, engine type, and technology in units of tonnes CO_2 equivalent. To reach this calculation, the logic tree begins on the first line of the diagram with two groups of calculations: 1) the product of vehicle distance and share of engine type per mode; and 2) biofuel share for the base year and change in biofuel mode.

For the transport sector, it's important to consider biofuel separately (note biofuel may be a blend of fossil fuel and biocarbon fuel) as the CO2 emissions from the use of biocarbon can be estimated and reported but must not be included in national greenhouse gas total emissions. The non-CO2 emissions from biofuel use should be included in national total emissions.

The second line of the logic tree shows the next step in the calculation. Here, the calculation is the product of three things: 1) vehicle distance travelled per mode and per engine type; 2) energy intensity per mode, per engine type, and per technology; and 3) biofuel share of liquid fuel per mode.

The third line of the calculations is the product of two terms: 1) energy balance per mode, per engine, and per technology; and 2) emission factors applicable for the technology. If you don't have access to the country-specific emission factors, you can use default Intergovernmental Panel on Climate Change (IPCC) factors. For a key category in your greenhouse gas inventory, you may wish to consider developing country-specific emission factors in the future.

The product of the two terms leads to the greenhouse gas emissions per mode, engine type, and technology in units of tonnes CO2 equivalent. This is what we need to know. It provides the information needed to start to understand the key sources of emissions in the transport sector and allows planning of mitigation to tackle the sources. The lever values applicable to mitigation that could be built into the Calculator in this example are:

- Share of engine type according to mode (%)
- Change in biofuel share
- Engine intensity of use per mode, per engine type, and per technology (TWh/km).

Understanding these calculations in logic trees is one of the first steps required to integrate the Calculator into a country.

3.3 Choose levers

Once the logic trees are selected for each sector, choose which factors are the major drivers of change in the sector, and therefore which levers should be present in the model. We recommend colour mapping the logic trees to illustrate this step. The levers specify the inputs you will modify. Each lever will allow users to make a choice about what happens in the future.

It's important to understand how levers and logic/driver trees interact. Once you have a logic tree for each of your sectors, you can quickly see how changes in supply and demand affect your outputs.

There can be any number of levers in total in the Calculator, and they can also be grouped together. Experience suggests it's most effective to start focusing on between 25 to 40 expanded levers for a first iteration, and a maximum of 10 groupings. You can expand the lever list to around 100 in future iterations if necessary. The exact number will depend on the target end users, and how much time they need to spend (or how much time they're willing to spend) using the tool. It's unlikely that a decision-maker will be able to spend a lot of time on the model. Generally, the more levers you have, the higher the credibility of the model, but the fewer people will be able to engage with it.

To choose your levers, ask:

- What has changed in the past?
- What is likely to change over time if we do nothing?
- What changes would have the biggest impact?
- What affect could policy or innovation have?
- Could we change people's behaviours?

Generally, each sector should have between 1-5 levers. If there are a few sectors that need to be focused on, then there could be more levers; however, remember the Calculator's audience. If an obscure variable is chosen to change, will a policy maker or an interested member of the public be knowledgeable enough to understand what they're changing and what the different options are? Choosing variables that are relevant to people's lives is much more effective; for example, looking at international aviation, consider the following questions:

- Will people fly more in the future?
- Will planes become more efficient?

When choosing levers, it might be better to use 'number of flights per year' rather than 'average distance flown per flight', as people know how often they fly, but are rarely aware of how far they fly.

Sometimes it's best to combine related technologies or behaviours together into one lever to make the model easier to use; for example, use one lever for the deployment of all small-scale micro-generation, rather than separate levers for micro wind, solar, and hydro. Another example is to combine demand for lighting and appliances into one lever, as they are usually covered by similar policies.

Once you deepen the modeling depth, the lever selection will correspond to the inputs you want to modify directly when specifying your scenarios. They'll break a link in the modelling logic. Therefore, any variable which can be deducted from others should not become a lever.

In the most advanced versions of 2050 Calculators, the calculation of certain variables is either endogenous or exogenous (e.g., industrial material production, energy costs). In these cases, a lever specifies if the variable is specified endogenously or exogenously. If it's endogenous, then the variable is specified by the model. If it's exogenous, then the variable is specified by a lever.

One of the reasons why the Calculator can generate instant results is that many model inputs are specified by levers. Optimisation models typically need to generate endogenously a lot of intermediary results, which increases calculation time.

3.4 Choose outputs

The Calculator can show various impacts of the energy choices that are available. The outputs to include or exclude will depend on what's most important. All the Calculators built so far have looked at greenhouse gas emissions, and some have considered costs, energy security (imports and exports, energy mix, energy balancing), and air quality. Water and biodiversity are also options which are being considered.

3.5 Source the data

Once logic trees are present for all the sectors, it should be clear what data will be required to populate the model. When building an open model like the Calculator, the data used must be either publicly available already, or have permission obtained to make it publicly available. The model won't be able to be published if any confidential data is used, so always keep this in mind when deciding what figures to use.

Data sources will vary from country to country, and region to region. Government statistical departments are a great place to start, but it could be that universities or other research organisations may also have useful data. The government may already have some models containing data, which could be used. Where official data is not routinely collected or easily available, international bodies like the International Energy Agency (IEA) may be able to help.

Not all the data needed will be country-specific. Many of the same assumptions and figures in previously completed Calculators can be used; for example, the efficiencies of solar PV panels will be similar around the world so the assumption can be used from an existing Calculator; however, solar irradiance levels will vary depending on the geographical location.

Sometimes it can be very difficult to get the data needed – perhaps sectors have been split up differently from the data sources so the data cannot match, or the information is just not collected in country. In these cases, it's very important that the logic of the model is not compromised to fit the data. Instead, try to adapt the data to suit the model. Use proxies, estimates, and international precedents. Just make sure all these assumptions are documented, so users can see what has been done and are able to assess its suitability.

Set ambition levels

4.1 Level options

Each lever in the Calculator will have four different options available to users – level 1, level 2, level 3, and level 4. The options represent trajectories for increasing levels of 'effort' from now to 2050. What this effort means will depend on the aims of the individual Calculator; for example, in the UK MacKay Carbon Calculator, effort was always directed towards reducing greenhouse gas emissions. For demand levers, high effort means that energy demand was reduced; for supply levers, high effort means increasing the supply of low-carbon energy. In the first Indian Calculator, effort on the supply side was targeted at increasing energy security rather than reducing emissions per se, as that version of the Calculator was focused on energy independence.

Whatever the aim of the Calculator, levels 1 to 4 are defined in the following way:

- Level 1 – No effort
- Level 2 – Effort described by most stakeholders as achievable
- Level 3 – Effort needing significant change – hard but deliverable
- Level 4 – The maximum possible due to physical/ engineering/behavioural constraints only.

Defining the four levels for each of the levers is a challenge, but one that is made a lot easier if experts from government, academia, industry, and NGOs are consulted. By considering opinions from a wide range of stakeholders, the conclusions will be a lot more reliable and confidence in the Calculator will grow.

4.2 Sector forces

Generally, there are three types of forces constraining how much effort is possible in a sector:

- Geographic constraint – for example, the number of houses that could have solar panels installed; the amount of land available to grow biocrops; the number of rivers that could be used for hydroelectricity.
- Behavioural constraint – for example, how much people would be willing to reduce the amount they travel; change their mode of transport; use their air conditioning less.
- Engineering constraint – for example, the number of nuclear power stations that could be completed if we built at the highest rate ever seen in the past from now until 2050.

While some levers will be affected by more than one of these constraints, usually there is one overriding constraint that can be used to guide the thinking when setting each level.

4.3 Level 1

At first glance, level 1 seems to be the easiest of the four to define; however, in reality, it can be quite complicated. The idea of 'no effort' is not the same as 'business as usual' for many sectors. If nothing is done, that doesn't mean that things will stay the same for 30 or 40 years. Depending on the lever, the following definitions of level 1 could be helpful:

- Tomorrow the government announced that X technology would no longer be supported, and it was clear that the private sector wouldn't proceed alone. In this case, the technology would be quickly phased out, or never deployed in the first place if it's a new technology.
- No action is taken to change X behaviour, so current trends continue into the future.
- Public opinion was so strongly against X technology that government prohibited its use. All existing examples of the technology will be allowed to run until the end of their useful life or aggressively phased out.
- Government goals are not being achieved in sector X.

It's tempting to make level 1 a 'business as usual' scenario that reflects current policy; however, defining it as 'no effort' instead shows what would happen without these policies, therefore, showing where these policies add value. It also acts as a baseline to give people more choice, enabling those with strong views to reflect their opinions (for example, people who are against nuclear power).

4.4 Level 4

Defining level 4 for each sector is an exercise in extreme optimism. Level 4 is not what is likely or easily achievable, or perhaps even desirable for many people. It's the maximum that could possibly be achieved for technical or practical reasons. Depending on the lever, the following definitions of level 4 could be helpful:

- Imagine an effort from government similar to the US Apollo space programme for the behaviour or technology in question. What could be achieved?
- The opinion of the most ambitious credible expert (perhaps an 'evangelist' for a particular technology), backed up by evidence either from their own calculations or published work.

- Draw on an example of something achieved in another country. If another country achieved it, why can't we? For example, how much nuclear capacity could you build if you used the same high build rate seen in France during the 1970s and 1980s?

Level 4 should be difficult to achieve, and this should be made clear to the user. The current UK Calculator helpfully flags how many levers the user has set at level 4. Setting many levers at level 4 means that maximum effort needs to be expended across many sectors and in many different directions, which may not be realistic.

The advantage of including these difficult options is that the model is able to span the full range of opinions, so it can be supported by a larger number of organisations. If the full range of options is not included, the Calculator will no longer be a tool exploring the question 'what if?'

4.5 Levels 2 and 3

Levels 2 and 3 will obviously fall somewhere between levels 1 and 4 in terms of effort, and are designed to show different levels of realistic government intervention for a technology or behaviour:

- Level 2 could be used to show existing policies for a sector, i.e., action is already being taken here, and this is the impact it will have.
- Level 3 is more than what is currently being done. It should be ambitious, but the majority of experts should view it as achievable.

4.6 Engagement workshops

Once you have formulated draft levels 1 to 4 of all the levers, it's time to ask the experts what they think. This can be done by holding a half-day or whole-day workshop for each sector to gather stakeholders together and get the debate going.

Section 2.4 discusses how to identify and engage with different stakeholders. So, which stakeholders should be invited to the workshops? It's important to get a range of opinions from the more conservative to the more extreme end – there will be people who believe passionately in a particular technology, or the potential for behavioural change. These voices should be welcomed, as long as they have good evidence to back up their claims. You should already have a good idea of the stakeholders who should be invited to these workshops, and as such have a list of stakeholders that include:

- Representatives of major companies
- Representatives of professional or trade bodies
- Academics
- Representatives of environmental NGOs or action groups
- Representatives of women's groups, community groups, and other marginalised groups
- Those working in government.

Prior to engagement, it should be made clear to the stakeholders what the underlying methodology of the Calculator is, as well as any basic questions about the day. It's important to have a clear understanding of the structure of the workshop, what you're hoping to gain from the stakeholders, and how you'll be using the information gathered from the day. Having a clear outline of these factors helps ensure that the workshop runs as smoothly as possible and you can make informed decisions if the structure of the day changes, or if priorities need to be reorganised last minute.

The focus of the workshop should be on setting the levels, and perhaps some of the assumptions used.

At the start of the workshop, introduce the Calculator project and its aims. The main messages to get across are:

- The 2050 Calculator is designed to simulate different possible futures
- It needs to consider a wide range of possible scenarios to do this; levels 1, 2, 3, and 4 enable this
- We want your evidence to inform the levels
- You don't have to all agree, and a range of views is good.
- There are many different ways you could get the discussion going, for example:
- Show the draft trajectories for each lever in turn. Do the participants agree with level 1? Is level 4 too ambitious, or does it not go far enough? Do they have any extra evidence that has not been considered?
- Specify what assumptions are being explored, and then ask the participants to write down their viewpoint of what the number should be for each of the four levels on separate post-it notes. You can then gather all the post-it notes together, grouped by level, and discuss areas of agreement and disagreement
- Use an example from one of the existing Calculator countries.

A series of smaller or one-to-one meetings with experts can also be held instead of large workshops. This is a decision that can be best informed by following the iterative, systematic approach to co-design and co-development set out in Section 2.4 of this guide. Understanding your time constraints and list of stakeholders early in the project means that you can plan the best form of stakeholder engagement for your team and your. If you realise too late that smaller or one-to-one meetings would be more productive for your team, it will be significantly harder to accomplish than if established early on in the project. For example, the Calculator team in Mexico have used the approach of smaller meetings – it takes longer, but you may get more honest and/or focused feedback.

4.7 Write one-pagers

Every lever in the Calculator has a 'one-pager' which explains the background to the lever and what each level means. One-pagers are usually available for reference in pdf format and are embedded into the Calculator's web tool or can be downloaded as a pack for use with the full Excel model. When writing one-pagers, it's extremely important to be clear and concise – remember the audience may not be experts in energy, and so any technical terms or jargon should always be explained. A great one-page note:

- Briefly summarises the sector and the situation today
- Briefly sets out the meaning of levels 1-4, and the key implications of each level of deployment. It should include all the main figures involved (being consistent with units so that they can be compared), but not so much detail as to bore or confuse the reader
- Briefly discusses factors that the user should consider when making a choice; for example, the effect on other levers, amount of land used, or impact on air quality. Any likely social impacts, particularly those that differentially impact different sectors of the population, should be included
- Illustrates the levels, ideally by comparing the deployment to historical levels or deployment in other countries, to give an indication of how difficult or easy it would be to achieve. It can be helpful to include some information about how the levels were set
- Illustrates the levels with a bar chart showing the amount of energy that sector produces or uses. The bar chart should have the same scale across every one-page note, so that one-page notes can be compared with each other. Other graphs, images, and diagrams can be included as well. It's a good idea to test one-pagers early on, with colleagues who're aren't working on the project, to make sure they're easy to understand.

Appendix A has some examples of one-pagers from the UK Calculator.

Build the Calculator spreadsheet

5.1 Overview

The 2050 Calculator model is developed entirely within a single, stand-alone Excel workbook. The workbook contains its own user interface and all the assumptions and modelling methodologies required to calculate the implications of a selected pathway for energy, emissions, and all other implemented outputs.

The 2050 Calculator model has a flexible structure that can be modified to account for structural differences between various country economies. The Excel base of the model means that it's easy to substitute data and/or add sectors and technologies, if deemed necessary, to accurately map the structure of a country's economy.

There are two broad approaches to adapting the 2050 Calculator:

- **Replace UK (or other completed 2050 Calculator) data** – The simplest way to create your own version of the 2050 Calculator is to replace the data in the UK version of the model with your country's own numbers. This approach works well with countries who have a similarly structured economy to the UK. It's easy to do and doesn't require additional model design. This was the approach used by teams in South Korea and Belgium.
- **Replace UK data and restructure** – In countries where the economy is significantly different to the UK, some restructuring of the model will be needed to present an accurate picture. China has restructured its model to account for variations in energy and transport demand between rural and urban areas, as well as significant temperature differences between the north and south of the country. China has also added additional industry sectors that more accurately reflect its economy.

Building the Excel model is a sizeable task which requires knowledge of a variety of specific concepts that are unique to the Calculator. The concepts are perhaps best learned in turn. To reflect this, the explanation of each concept is presented separately in the following sections.

Some more recent Calculators have been built using alternative platforms from Excel; for example, the EUCalc and Pathways Explorer mainly rely on KNIME, which visualises data flows and can embed programming (e.g., Python). The upside of using other platforms is that they enable deeper, more rigorous models and better readability. The downside is that developers need to master further skills, and users are less likely to be able to interrogate the model.

5.1 Complex Excel formulae

5.1.1 Original 2050 Calculator

The original 2050 Calculator relied mainly on simple formulas. Their structures were less constrained. The upside was a flexible approach. The downside was that it was harder to follow the flow of calculations. Array formulae were used in some versions which potentially reduces accessibility to some stakeholders.

5.1.2 The Global Calculator

The Global Calculator relies mainly on named tables. The operations between tables are performed either using index() and match() or sumifs() formulae. The downside of using tables is that the formulas are very long and difficult to read. To shorten the formula length, tables are limited to a single column where possible, requiring only one match() formula. To select the right column, the formula indirect() is used.

5.1.3 MacKay Carbon Calculator

The current UK Calculator (the MacKay Carbon Calculator) relies mainly on named ranges. The ranges are specific to one line. The symbol '@' is used to shorten formulas inside named tables referencing cells; for example if variable A specifies the population (in inhabitants), and variable B specifies the average distance travelled per person each year (in 'km/person/year'), then the distance travelled each year (C) would be obtained through: **°=@A.*@B**

In all cases, the formulae choice is limited by the processing ability of the converter tool that translates the Excel model into a web app (see section 8.2).

5.2 Excel model structure

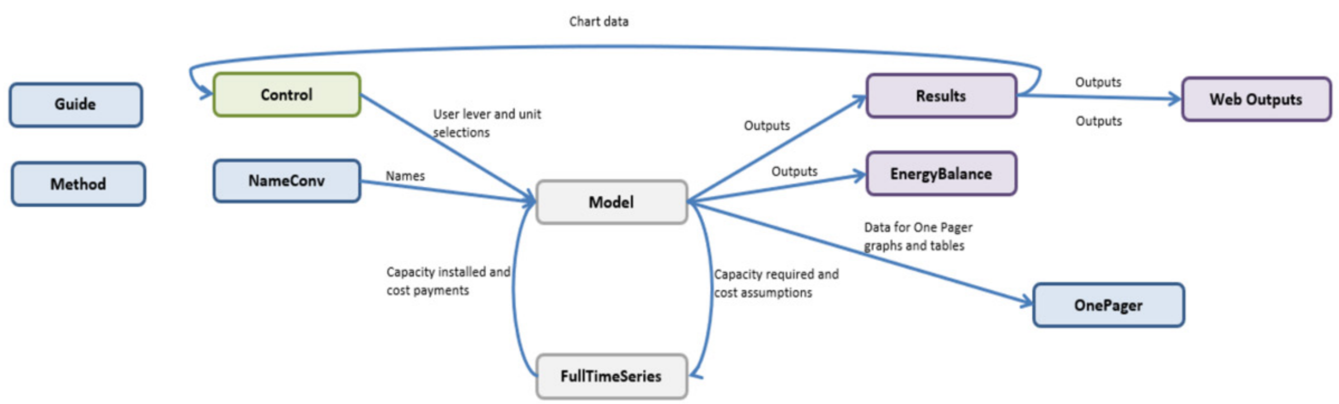
The current UK Calculator (MacKay Carbon Calculator V198.0) has 11 separate worksheets.

Table 5.1: Worksheets in the MacKay Carbon Calculator V198.0

Sheet	Category	Sponsor/Owner
Guide	Documentation	User and developer guidance
Control	User control	User lever and unit selections. Basic chart outputs
One-pager	Documentation	This sheet contains equivalent graphs, tables, and priority flow diagrams to those presented in the model one-pagers
Web outputs	Outputs	Outputs to populate the graphs displayed on the web tool
Results	Outputs	Model output extraction, processing, and visualisation
Energy Balance	Outputs	Full energy and emissions balance for a single year
Model	Transformations and assumptions	Model inputs and transformations including full assumptions log
FullTimeSeries	Transformations and assumptions	Capacity and cost calculations performed at single year time intervals
Method	Documentation	Model documentation
NameConv	Documentation	Model naming convention
SourceLog	Documentation	Log of primary input sources for the UK Energy Pathways Calculator

The worksheets interact with one another as per Figure 5.1 below.

Figure 5.1: Sheet structure



Source: Click here

5.3 Units

The Calculator allows easy adaptation of units in which certain key values are displayed. This enables quantities to be adapted, even if they don't match the unit of the consulted source. Some sources typically use petajoules (PJ), while others might prefer terawatt-hours (TWh).

In the 'model' worksheet (from line 1006), the 'unit conversion factors' section provides a list of factors for the following types of values:

0. Scaling
1. Time
2. Energy
3. Power
4. Power to energy
5. Distance
6. Area
7. Mass
8. Cost

When you input data into the model, you must check the unit which is used and compare it to the unit used in the consulted source. You can then provide the data found and multiply it by the conversion factor in the model. Each conversion factor is associated to a named cell; for example, if a source provides energy consumption in [toe] while the unit used in the model is [GJ], you can enter "= value found in toe *"toe_to_GJ". "toe_to_GJ"* being the named cell to convert toe into GJ.

5.4 Energy balance principle

Think about a 2050 Calculator as an accounting system for energy. Energy is converted from one form to another by sectors. The rest of the Calculator is meant to keep track of where the energy comes from and where it goes. It's straightforward to check whether all flows have been captured because it's a physical principle that energy cannot come from nowhere or disappear into nothing. The net balance of all energy entering and leaving a sector must be zero: energy is 'conserved'. We sometimes refer to this idea as the 'energy balance principle'.

As an example, the UK Calculator (MacKay Calculator) assumes that electricity supply and demand is balanced. If seasonal storage is deployed by the user, electricity can be stored between seasons to help balance demand and supply across the year. User selected capacity that is not required to satisfy electricity demand is assumed not to be built.

Electricity supply and capacity is calculated through the following steps:

- User lever inputs are translated into capacity profiles and combined with the fixed capacity assumed in the model (e.g., for hydro, there is no lever in the MacKay Calculator as it's assumed that there will be no further significant capacity deployment for hydro in the UK).
- The maximum possible generation per season is calculated based on each technology's average load factor for the season.
- The generation priority order assumed in the model is used to define what's used in each season. Each technology is used to its maximum output before deploying the next item in the priority order. If demand is still not satisfied by the user inputs or fixed technologies, then unabated combined cycle gas turbine (CCGT) is deployed (i.e., back-up technology).
- The capacity required to meet generation in each season is calculated from the actual generation in the period and the load factor.
- 'Capacity required calculated' is the maximum capacity required in each season.

5.5 Stress test

The stress test is an important assessment of the 2050 Calculator model development. Simply put, it means balancing energy demand and supply. To avoid power outages, electricity demand needs to be balanced with supply at all times. This can be challenging given the fluctuating nature of both demand and supply of energy. Some forms of electricity generation fluctuate more than others, such as many forms of renewables; therefore, it's essential to identify a means of balancing the electricity network, such as storage, demand shifting, and interconnection. The UK, for example, uses interconnectors to allow for import and export of electricity from Europe.

5.5.1 Peak capacity test in the UK Calculator

The UK 2050 Calculator takes a broad view of the energy system, modelling five-year intervals to allow for some high-level conclusions. There are instances, however, where a more additional detail would yield some useful results; for example, a detailed minute-by-minute assessment of the balancing requirements within the electricity sector, taking all variables into consideration, would be a useful exercise to assess the required back-up generation (or capacity margin) required at any given time. However, it's not possible to do this with the 2050 Calculator. Rather, the model attempts to make this type of assessment under the worst-case scenario, thus providing an estimate of maximum requirement for stand-by generation capacity.

The ‘peak capacity test’ compares peak electricity demand to electricity generation and storage capacity available at peak times. Peak demand is assumed to be the coldest day in winter, when space heating, appliances, and lighting are at their highest demand (for hot countries, this equates to widespread air conditioning in the height of summer). If sufficient flexibility is available to meet the peak period, then it’s expected that there will be sufficient capability to manage more routine, shorter-term fluctuations from day-to-day and hour-to-hour.

The electricity generation and storage capacity assumed to be available at the peak period is calculated as follows:

- Each generation and storage technology has an associate peak contribution of capacity share or derating factor (peak contribution of capacity share = share of total capacity installed that can be relied on in a period of peak demand)
- The total capacity that can be relied on to meet the peak power demand is calculated by multiplying the capacity installed by the derating factor for each technology.

If availability is less than the peak power demand, then unabated gas peaking plans are installed to meet the capacity shortfall.

This is described in detail in the ‘method’ worksheet from row 1504 in the MacKay Calculator.

5.5.2 Power cuts and unserved demand

Some countries have a shortfall in power. This is when people want to use electricity, oil or gas, but it’s not available (i.e., unmet or unserved demand). Some countries are in a situation where they export fuels despite not having enough to meet domestic needs.

There are two ways this could be modelled:

- On the demand side (preferred approach)
- On the supply side.

5.5.2.1 Demand side modelling

To model power cuts on the demand side for the present day, model the actual demand for energy that’s actually supplied. Don’t try to indicate or model what the demand for energy would have been if only the supply had been higher.

For the future, either:

- Assume that demand for energy grows in all scenarios because, gradually, the supply will fall short of demand less often. This might reflect a national target of when there will be universal access to energy; or
- Give the user a choice about how fast demand grows. The choice should reflect different options for how fast there might be good access to energy; for instance, you might add a road transport choice that reflects what proportion of time oil is available when it’s needed (ranging between, for example, 100% at level 1, and 60% at level 4). This would then be used on the demand worksheets to shrink the distance travelled by car to reflect the lack of fuel, which will then feed into lower demand for fuel from that sector.

5.5.2.2 Supply side modelling

To model power cuts on the supply side, model all the demand sectors as if demand could always be met by supply. This means making an estimate of the demand that is not met because people can’t get the energy they need. It will be important to provide a warning on the Excel control page and on the web interface that points out to users when their choices mean there will be power cuts.

The disadvantages of this approach are:

- It’s a more complicated approach
- It will result in demand totals that may not match national statistics
- It could allow the end user to create seemingly impossible pathways (if they don’t spot that their emissions are low or energy security is high because of un-met demand).

5.6 Emissions calculation

Within the UK Calculator, most emissions are from the combustion of fuels. The general approach to calculate combustion emissions is to multiply quantities of fuels used by a relevant emissions factor. The list of emissions factors can be found in the ‘model’ worksheet from line 1327 in the MacKay Calculator. For each fuel, there are three emissions factors – one for CO_2 emissions, one for CH_4 emissions, and one for N_2O emissions.

Other emissions in the MacKay Calculator include process emissions from industry, feedstock emissions, and emissions from different land use and agricultural processes. These are explained in detail in the ‘method’ worksheet.

5.7 Adding a lever

Adding levers to your Calculator, when using the Mackay Carbon Calculator workbook as the template, allows users to explore different scenarios relevant to your county which can enhance the flexibility and usefulness of your Calculator. For example, in Kenya, domestic cooking is done using various technologies in addition to gas and electricity such as biomass, biogas and bioethanol. You might want to add a lever to adjust the share or penetration of a cooking technology based on reduction or increase of use of different technologies, different from those already in the Mackay Carbon Calculator.

To add a lever or a variable that can be adjusted in the Excel and web tool versions of the Calculator, you need to keep in mind the interconnection between the spreadsheets as illustrated in Figure 5.1.

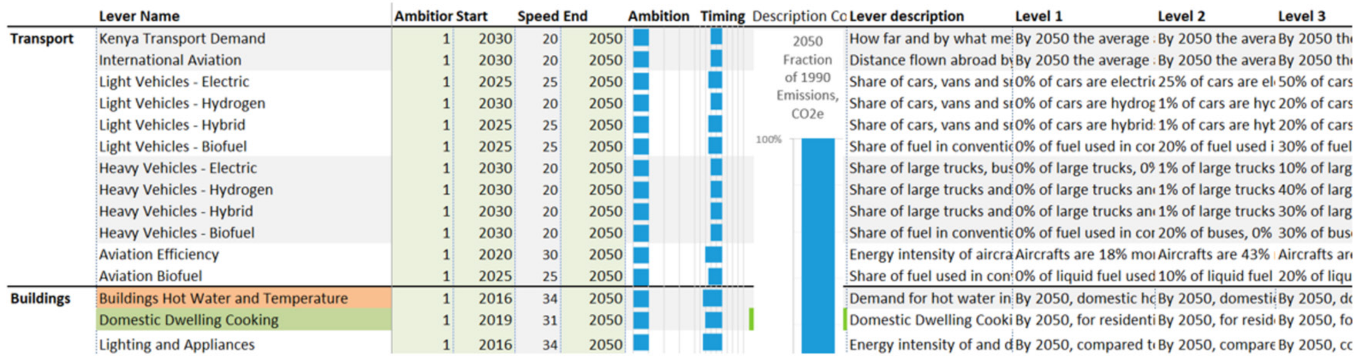
5.7.1 Step 1: Add the levers to the Control sheet

Step 1.1 Create a lever in the Levers Webtool section of the Control sheet

To begin, add the main lever to the Levers Webtool section of the Control sheet. This will control the ambition levels setting for subsequent sub-levers under it. The Levers Webtool section of the Control Sheet controls the levers that appear on the webtool. Enter the Lever Name, Ambition Level (default is set to 1 and users can adjust it), Start, Speed, Lever description and Level descriptions (see Figure 5.2 below). In this example, a domestic dwelling cooking lever was added that control levers for the share penetration of cooking technologies currently used in Kenya.

The Lever Webtool section also allows one to add details to the example pathway for this lever.

Figure 5.2: The Lever Webtool section of the Control sheet demonstrating the addition of a new lever coloured in green

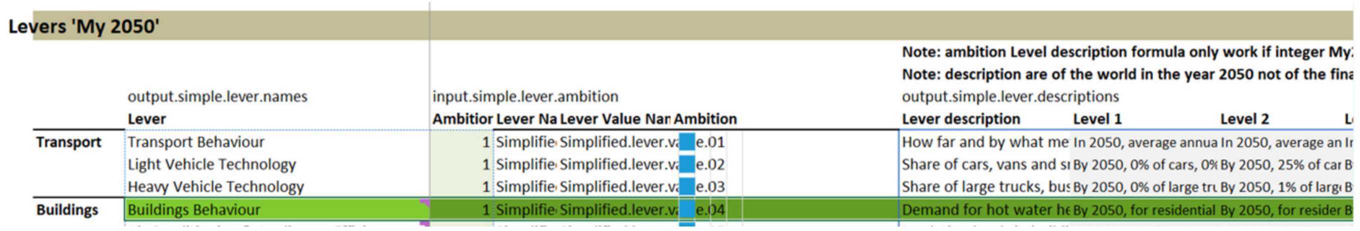


	Lever Name	Ambitior	Start	Speed	End	Ambition	Timing	Description Co	Lever description	Level 1	Level 2	Level 3
Transport	Kenya Transport Demand	1	2030	20	2050			2050 Fraction of 1990 Emissions, CO2e	How far and by what me	By 2050 the average	By 2050 the avera	By 2050 th
	International Aviation	1	2030	20	2050				Distance flown abroad by	By 2050 the average	By 2050 the avera	By 2050 th
	Light Vehicles - Electric	1	2025	25	2050				Share of cars, vans and s	0% of cars are electri	25% of cars are el	50% of cars
	Light Vehicles - Hydrogen	1	2030	20	2050				Share of cars, vans and s	0% of cars are hydrog	1% of cars are hyc	20% of cars
	Light Vehicles - Hybrid	1	2025	25	2050				Share of cars, vans and s	0% of cars are hybrid	1% of cars are hyb	20% of cars
	Light Vehicles - Biofuel	1	2025	25	2050			100%	Share of fuel in conventi	0% of fuel used in co	20% of fuel used i	30% of fuel
	Heavy Vehicles - Electric	1	2030	20	2050				Share of large trucks, bus	0% of large trucks, 0%	1% of large trucks	10% of larg
	Heavy Vehicles - Hydrogen	1	2030	20	2050				Share of large trucks and	0% of large trucks an	1% of large trucks	40% of larg
	Heavy Vehicles - Hybrid	1	2030	20	2050				Share of large trucks and	0% of large trucks an	1% of large trucks	30% of larg
	Heavy Vehicles - Biofuel	1	2030	20	2050				Share of fuel in conventi	0% of fuel used in co	20% of buses, 0%	30% of bus
	Aviation Efficiency	1	2020	30	2050				Energy intensity of aircra	Aircrafts are 18% mo	Aircrafts are 43%	Aircrafts ar
	Aviation Biofuel	1	2025	25	2050				Share of fuel used in con	0% of liquid fuel used	10% of liquid fuel	20% of liqu
Buildings	Buildings Hot Water and Temperature	1	2016	34	2050				Demand for hot water in	By 2050, domestic hc	By 2050, domesti	By 2050, dc
	Domestic Dwelling Cooking	1	2019	31	2050				Domestic Dwelling Cooki	By 2050, for residenti	By 2050, for resid	By 2050, fo
	Lighting and Appliances	1	2016	34	2050				Energy intensity of and d	By 2050, compared t	By 2050, compare	By 2050, cc

Step 1.2 Create a Lever in the Levers ‘My 2050’ Section

Next, create a lever in the Levers ‘My 2050’ section of the Control sheet. This is the simplified version of the lever for the My2050 tool.

Figure 5.3: The Levers ‘My 2050’ section of the Control sheet with a simplified version of the lever added



Levers 'My 2050'

Note: ambition Level description formula only work if integer My:
Note: description are of the world in the year 2050 not of the fina

	output.simple.lever.names	input.simple.lever.ambition				output.simple.lever.descriptions			
	Lever	Ambitior	Lever Na	Lever Value Nar	Ambition	Lever description	Level 1	Level 2	L
Transport	Transport Behaviour	1	Simplifie	Simplified.lever.va	e.01	How far and by what me	In 2050, average annua	In 2050, average an	Ir
	Light Vehicle Technology	1	Simplifie	Simplified.lever.va	e.02	Share of cars, vans and s	By 2050, 0% of cars, 0%	By 2050, 25% of car	B
	Heavy Vehicle Technology	1	Simplifie	Simplified.lever.va	e.03	Share of large trucks, bus	By 2050, 0% of large tru	By 2050, 1% of large	B
Buildings	Buildings Behaviour	1	Simplifie	Simplified.lever.va	e.04	Demand for hot water he	By 2050, for residential	By 2050, for resider	B

Link the new lever back to the webtool controls which is on the right of the Levers Webtool section as well as the corresponding My2050 ambition levels as displayed in Figure 5.4

Figure 5.4: Shows the My2050 levers columns in the Lever Webtool section of the Control sheet

output.leve	output.lever.default.end				Webtool ambition corresponding to My20				
Default Sta	**Default En**	**Defa**	**My20**	**My2050 Lever**	**1**	**2**	**3**	**4**	**My2050 A**
2020	2050	30	1	Buildings Behaviour	1	2	3	4	1
2020	2050	30	1	Buildings Behaviour	1	2	3	4	1
2020	2050	30	1	Air Conditioning & Appliances Effic	1	2	3	4	1

Step 1.3 Create a lever and ambition levels in the Manual Lever Selection and Model Lever Values Applied section of the Control sheet

Next, scroll down to the Manual Lever Selection and Model Lever Values Applied section of the Control Sheet. This is where you add the new sub-levers or levers. In this section, input:

a. The name of the lever keeping in line with the naming convention and its description
b. The Manual Choices: Share/Penetration, Start, Speed and Units

Figure 5.5: Adding new levers to the Manual Lever Selection and Model Lever Values Applied section of the Control Sheet

AmbShrPen.dDwl.dStvG.	Domestic dwelling cooking gas share	1	2020	30		...
AmbShrPen.dDwl.dStvBioGs.	Domestic dwelling biogas share	1	2020	30		...
AmbShrPen.dDwl.dStvE.	Domestic dwelling electricity share	1	2020	30		...
AmbShrPen.dDwl.dStvWd.	Domestic dwelling wood share	1	2020	30		...
AmbShrPen.dDwl.dStvChar.	Domestic dwelling charcoal share	1	2020	30		...
AmbShrPen.dDwl.dStvKero.	Domestic dwelling kerosene share	1	2020	30		...
AmbShrPen.dDwl.dStvBioeth.	Domestic dwelling bioethanol share	1	2020	30		...
AmbShrPen.dDwl.dStvBiometh.	Domestic dwelling biomethane share	1	2020	30		...

c. Scroll to the right of the Manual Lever Selection and Model Lever Values Applied section. Link to the ambition level units and ambition levels that will be input in the Model sheet (see step 2.2 below) by entering the cell reference as the name given to the corresponding cell in the Model sheet.

Note:

- Ambition level units are obtained using the Excel formula = OFFSET ([level [No]_name],0, -1) to obtain data entered in the Units column of the Model sheet
- Ambition levels 1-4 are referenced using the formula – = [level [No]_name]
- The selected ambition level is reference using the formula – = [level_name] (not captured in Figure 5.6 below)

Figure 5.6: How to reference to the ambition level values input in the Model Sheet

=OFFSET(lv1.AmbShrPen.dDwl.dStvG.,0,-1)	=lv1.AmbShrPen.dDwl.dStvG.	=lv2.AmbShrPen.dDwl.dStvG.	=lv3.AmbShrPen.dDwl.dStvG.
=OFFSET(lv1.AmbShrPen.dDwl.dStvBioGs.,0,-1)	=lv1.AmbShrPen.dDwl.dStvBioGs.	=lv2.AmbShrPen.dDwl.dStvBioGs.	=lv3.AmbShrPen.dDwl.dStvBioGs.
=OFFSET(lv1.AmbShrPen.dDwl.dStvE.,0,-1)	=lv1.AmbShrPen.dDwl.dStvE.	=lv2.AmbShrPen.dDwl.dStvE.	=lv3.AmbShrPen.dDwl.dStvE.
=OFFSET(lv1.AmbShrPen.dDwl.dStvWd.,0,-1)	=lv1.AmbShrPen.dDwl.dStvWd.	=lv2.AmbShrPen.dDwl.dStvWd.	=lv3.AmbShrPen.dDwl.dStvWd.
=OFFSET(lv1.AmbShrPen.dDwl.dStvChar.,0,-1)	=lv1.AmbShrPen.dDwl.dStvChar.	=lv2.AmbShrPen.dDwl.dStvChar.	=lv3.AmbShrPen.dDwl.dStvChar.
=OFFSET(lv1.AmbShrPen.dDwl.dStvKero.,0,-1)	=lv1.AmbShrPen.dDwl.dStvKero.	=lv2.AmbShrPen.dDwl.dStvKero.	=lv3.AmbShrPen.dDwl.dStvKero.
=OFFSET(lv1.AmbShrPen.dDwl.dStvBioeth.,0,-1)	=lv1.AmbShrPen.dDwl.dStvBioeth.	=lv2.AmbShrPen.dDwl.dStvBioeth.	=lv3.AmbShrPen.dDwl.dStvBioeth.
=OFFSET(lv1.AmbShrPen.dDwl.dStvBioeth.,0,-1)	=lv1.AmbShrPen.dDwl.dStvBiometh.	=lv2.AmbShrPen.dDwl.dStvBiometh.	=lv3.AmbShrPen.dDwl.dStvBiometh.

d. In step 1.1 a new lever was added that will appear in the web tool. In this step the sub-levers are linked to this main lever to capture the ambition level selected by a user under the main lever in the web tool.

Figure 5.7: The data required in the Web Tool Lever columns in the Manual Lever Selection and Model Lever Values Applied section of the Control sheet

Web tool_Lever	Web tool_Share/Penetra	Web tool_	Web tool_	My2050_Lever	My2050_S	My2050_S	My205
Web Tool Lever	**Share/Penetration**	**Start**	**Speed**	**My2050 Lever**	**Share/Pen**	**Start**	**Speed**
Domestic Dwelling Cooking	1	2019	31	Buildings Behaviour	1	2020	30
Domestic Dwelling Cooking	1	2019	31	Buildings Behaviour	1	2020	30
Domestic Dwelling Cooking	1	2019	31	Buildings Behaviour	1	2020	30
Domestic Dwelling Cooking	1	2019	31	Buildings Behaviour	1	2020	30
Domestic Dwelling Cooking	1	2019	31	Buildings Behaviour	1	2020	30
Domestic Dwelling Cooking	1	2019	31	Buildings Behaviour	1	2020	30
Domestic Dwelling Cooking	1	2019	31	Buildings Behaviour	1	2020	30
Domestic Dwelling Cooking	1	2019	31	Buildings Behaviour	1	2020	30

Note:

- The values above are equal to the cell reference of the lever entry created in step 1.1. An example is illustrated in Figure 5.8 below.

Figure 5.8: How the lever Ambition Level, Speed, Start, and End are linked to the Lever Web tool section

Domestic dwelling cooking gas share	=Control!$C$83	=Control!$D$83
Domestic dwelling biogas share	=Control!$C$83	=Control!$D$83
Domestic dwelling electricity share	=Control!$C$83	=Control!$D$83
Domestic dwelling wood share	=Control!$C$83	=Control!$D$83
Domestic dwelling charcoal share	=Control!$C$83	=Control!$D$83
Domestic dwelling kerosene share	=Control!$C$83	=Control!$D$83
Domestic dwelling bioethanol share	=Control!$C$83	=Control!$D$83
Domestic dwelling biomethane share	=Control!$C$83	=Control!$D$83

e. Next, you will set the user selected ambition level, start year and speed based on user inputs. This is done using an Excel lookup function that obtains the ambition level selected by the user.

=@INDEX ([Manual choices: webtool choices array],, MATCH("Webtool",[Manual Lever Selection header array],0))

f. The next sets of inputs are the Speed Test check, which shows if an action takes place faster than level 4 under default timing. If the check is true, it will return 1. Use the Excel formula below:

=IF(OR(AND(Lever 1 Value <= Lever 2 Value, Lever 2 Value <= Lever 3 Value, Lever 3 Value <= Lever 4 Value), AND(Lever 1 Value >= Lever 2 Value, Lever 2 Value >= Lever 3 Value, Lever 3 Value >= Lever 4 Value)), IF((ABS(User selected level value - Lever 1 Value) / technology speed) -10^-12 > (ABS(Lever 4 Value-Lever 1 Value) / technology speed), 1, 0), 0)

In the same section, link to the business-as-usual values for the lever looked up from the Model sheet.

5.7.2 Step 2: Add the lever to the Model Sheet

The Model sheet serves as the backbone of the Calculator and contains the main calculations and formulas that estimate CO_2 emissions based on the user's inputs.

Step 2.1 Add cells to fetch the user inputs from the Control sheet

In the Model sheet, identify the area where you want to introduce the lever. Create input cells that will take as values the user selected ambition level set in the Control sheet. The value of the user selected ambition level is looked up from the Control sheet using the named range set in Step 1.3 (e). Notice the values are in grey to indicate that user input is not required in this section; rather a formula is applied to obtain the value.

Figure 5.9: How to capture user selected level of ambition for a given lever

Cookin BNH.						
	Deplc BNH.					
ıst	BNH.	Ambition for Deployment Share/Penetration-Domestic Dwelling-Cooking Gas	AmbShrPen.dDwl.dStvG.	...	1	...
ıst	BNH.	Ambition for Deployment Share/Penetration-Domestic Dwelling-Bio Gas	AmbShrPen.dDwl.dStvBioGs.	...	1	...
ıst	BNH.	Ambition for Deployment Share/Penetration-Domestic Dwelling-Electricity	AmbShrPen.dDwl.dStvE.	...	1	...
ıst	BNH.	Ambition for Deployment Share/Penetration-Domestic Dwelling-Wood	AmbShrPen.dDwl.dStvWd.	...	1	...
ıst	BNH.	Ambition for Deployment Share/Penetration-Domestic Dwelling-Charcoal	AmbShrPen.dDwl.dStvChar.	...	1	...
ıst	BNH.	Ambition for Deployment Share/Penetration-Domestic Dwelling-Kerosene	AmbShrPen.dDwl.dStvKero.	...	1	...
ıst	BNH.	Ambition for Deployment Share/Penetration-Domestic Dwelling-Bio-Ethanol	AmbShrPen.dDwl.dStvBioeth.	...	1	...
ıst	BNH.	Ambition for Deployment Share/Penetration-Domestic Dwelling-Bio-Methanol	AmbShrPen.dDwl.dStvBiometh.	...	1	...

Step 2.2 Add cells to enter ambition level values

Create cells where users can input the desired value for the ambition levels and use a named range to refer to the lever value throughout the model as shown in Figure 5.10. Notice the value cells are coloured pink indicating that user input was required for these set of rows.

Figure 5.10: How to create a lever and its ambition level values

BNH.	lv1.Ambition for Deployment Share/Penetration-Domestic Dwelling -Cooking Gas	lv1.AmbShrPen.dDwl.dStvG.	...	0.3	..
BNH.	lv2.Ambition for Deployment Share/Penetration-Domestic Dwelling -Cooking Gas	lv2.AmbShrPen.dDwl.dStvG.	...	0.2	..
BNH.	lv3.Ambition for Deployment Share/Penetration-Domestic Dwelling -Cooking Gas	lv3.AmbShrPen.dDwl.dStvG.	...	0.1	..
BNH.	lv4.Ambition for Deployment Share/Penetration-Domestic Dwelling -Cooking Gas	lv4.AmbShrPen.dDwl.dStvG.	...	0	..
BNH.	lv1.Ambition for Deployment Share/Penetration-Domestic Dwelling -Bio Gas	lv1.AmbShrPen.dDwl.dStvBioGs.	...	0.01	..
BNH.	lv2.Ambition for Deployment Share/Penetration-Domestic Dwelling -Bio Gas	lv2.AmbShrPen.dDwl.dStvBioGs.	...	0.03	..
BNH.	lv3.Ambition for Deployment Share/Penetration-Domestic Dwelling -Bio Gas	lv3.AmbShrPen.dDwl.dStvBioGs.	...	0	..
BNH.	lv4.Ambition for Deployment Share/Penetration-Domestic Dwelling -Bio Gas	lv4.AmbShrPen.dDwl.dStvBioGs.	...	0	..
BNH.	lv1.Ambition for Deployment Share/Penetration-Domestic Dwelling -Electricity	lv1.AmbShrPen.dDwl.dStvE.	...	0.01	..
BNH.	lv2.Ambition for Deployment Share/Penetration-Domestic Dwelling -Electricity	lv2.AmbShrPen.dDwl.dStvE.	...	0.3	..
BNH.	lv3.Ambition for Deployment Share/Penetration-Domestic Dwelling -Electricity	lv3.AmbShrPen.dDwl.dStvE.	...	0.7	..
BNH.	lv4.Ambition for Deployment Share/Penetration-Domestic Dwelling -Electricity	lv4.AmbShrPen.dDwl.dStvE.	...	1	..

Step 2.3 Add cells to select the user selected lever, start, speed and end

Create cells that take user selected ambition level value as the input. This is achieved using an IF statement to obtain the ambition level value depending on the level of ambition set by the user (step 2.1).

= IF([user selected level] < 2, +([level 1 ambition value]* (2 -[user selected level])) +(level 2 ambition value * ([user selected level] -1)), IF([user selected level] < 3, +(level 2 ambition value * (3 -[user selected level])) +(level 3 ambition value * ([user selected level] -2)), +(level 3 ambition value * (4 -[user selected level])) +([level 4 ambition value] * ([user selected level] -3))))

Figure 5.11: How to obtain the level of ambition values based on the lever selection

BNH.	lever selection Deployment Share/Penetration-Domestic Dwelling -Cooking Gas	LvrShrPen.dDwl.dStvG.	...	0.3	.
BNH.	lever selection Deployment Share/Penetration-Domestic Dwelling -Biogas	LvrShrPen.dDwl.dStvBioGs.	...	0.01	.
BNH.	lever selection Deployment Share/Penetration-Domestic Dwelling -Electricity	LvrShrPen.dDwl.dStvE.	...	0.01	.
BNH.	lever selection Deployment Share/Penetration-Domestic Dwelling -Wood	LvrShrPen.dDwl.dStvWd.	...	0.45	.
BNH.	lever selection Deployment Share/Penetration-Domestic Dwelling -Charcoal	LvrShrPen.dDwl.dStvChar.	...	0.12	.
BNH.	lever selection Deployment Share/Penetration-Domestic Dwelling -Kerosene	LvrShrPen.dDwl.dStvKero.	...	0.08	.
BNH.	lever selection Deployment Share/Penetration-Domestic Dwelling -Bio-Ethanol	LvrShrPen.dDwl.dStvBioeth.	...	0.03	.
BNH.	lever selection Deployment Share/Penetration-Domestic Dwelling -Biomethanol	LvrShrPen.dDwl.dStvBiometh.	...	-	.

Create cells that take as input the start, speed and end set in Step 1.3 (e).

Figure 5.12: How to obtain for the start year, speed and end for each lever

BNH.	lever selection Action Start-Domestic Dwelling -Cooking Gas	LvrStart.dDwl.dStvG.	...	2019	..
BNH.	lever selection Action Start-Domestic Dwelling -Biogas	LvrStart.dDwl.dStvBioGs.	...	2019	..
BNH.	lever selection Action Start-Domestic Dwelling -Electricity	LvrStart.dDwl.dStvE.	...	2019	..
BNH.	lever selection Action Start-Domestic Dwelling -Wood	LvrStart.dDwl.dStvWd.	...	2019	..
BNH.	lever selection Action Start-Domestic Dwelling -Charcoal	LvrStart.dDwl.dStvChar.	...	2019	..
BNH.	lever selection Action Start-Domestic Dwelling -Kerosene	LvrStart.dDwl.dStvKero.	...	2019	..
BNH.	lever selection Action Start-Domestic Dwelling -Bio-Ethanol	LvrStart.dDwl.dStvBioeth.	...	2019	..
BNH.	lever selection Action Start-Domestic Dwelling -Biomethanol	LvrStart.dDwl.dStvBiometh.	...	2016	..
BNH.	lever selection Action Speed-Domestic Dwelling -Cooking Gas	LvrSpeed.dDwl.dStvG.	years	31	..
BNH.	lever selection Action Speed-Domestic Dwelling -Biogas	LvrSpeed.dDwl.dStvBioGs.	years	31	..
BNH.	lever selection Action Speed-Domestic Dwelling -Electricity	LvrSpeed.dDwl.dStvE.	years	31	..
BNH.	lever selection Action Speed-Domestic Dwelling -Wood	LvrSpeed.dDwl.dStvWd.	years	31	..
BNH.	lever selection Action Speed-Domestic Dwelling -Charcoal	LvrSpeed.dDwl.dStvChar.	years	31	..
BNH.	lever selection Action Speed-Domestic Dwelling -Kerosene	LvrSpeed.dDwl.dStvKero.	years	31	..
BNH.	lever selection Action Speed-Domestic Dwelling -Bio-Ethanol	LvrSpeed.dDwl.dStvBioeth.	years	31	..
BNH.	lever selection Action Speed-Domestic Dwelling -Biomethane	LvrSpeed.dDwl.dStvBiometh.	years	34	..
BNH.	lever selection Action End -Domestic Dwelling -Cooking Gas	LvrEnd.dDwl.dStvG.	...	2050	..
BNH.	lever selection Action End -Domestic Dwelling -Biogas	LvrEnd.dDwl.dStvBioGs.	...	2050	..
BNH.	lever selection Action End -Domestic Dwelling -Electricity	LvrEnd.dDwl.dStvE.	...	2050	..
BNH.	lever selection Action End -Domestic Dwelling -Wood	LvrEnd.dDwl.dStvWd.	...	2050	..
BNH.	lever selection Action End -Domestic Dwelling -Charcoal	LvrEnd.dDwl.dStvChar.	...	2050	..
BNH.	lever selection Action End -Domestic Dwelling -Kerosene	LvrEnd.dDwl.dStvKero.	...	2050	..
BNH.	lever selection Action End -Domestic Dwelling -Bio-Ethanol	LvrEnd.dDwl.dStvBioeth.	...	2050	..
BNH.	lever selection Action End -Domestic Dwelling -Biomethane	LvrEnd.dDwl.dStvBiometh.	...	2050	..

Step 2.4 Modify the relevant formulas or calculations to incorporate the lever

Identify the cells or ranges that depend on the lever and adjust the formulas accordingly. For example, if the lever represents the share/penetration of a given cooking technology, you will need to update the formulas that calculate the carbon emissions based on the share/penetration of the technology.

Test the model by adjusting the lever and observing the impact on the calculations and results. Verify that the model updates correctly and reflects the changes made through the lever.

5.8 Removing a lever

To remove a lever from the Calculator in Excel, when using the Mackay Carbon Calculator workbook as the template, you can follow these steps.

5.8.1 Step 1: Remove the levers from the Model sheet

a. Identify the lever that you want to remove. Locate the named ranges that represent the lever or variable that takes input from the Control sheet, the variables that take input from the ambition level values and the variables on lever selection, and clear the input in the Value column. Mark the rows with a different colour to indicated that these rows are inactive. Optionally, you can delete or clear the cell or named range that represents the lever to remove any lingering references or user inputs associated with it.

Figure 5.13: Removing a lever and its values from the Model sheet

Dom :	BHT.				
	BHT.	Ambition for Temperature Internal Mean -Domestic Dwelling	AmbTmpIn.dDwl.	...	0
	BHT.				
	BHT.	lv1.Ambition for Temperature Internal Mean -Domestic Dwelling	lv1.AmbTmpIn.dDwl.	°C	0
	BHT.	lv2.Ambition for Temperature Internal Mean -Domestic Dwelling	lv2.AmbTmpIn.dDwl.	°C	0
	BHT.	lv3.Ambition for Temperature Internal Mean -Domestic Dwelling	lv3.AmbTmpIn.dDwl.	°C	0
	BHT.	lv4.Ambition for Temperature Internal Mean -Domestic Dwelling	lv4.AmbTmpIn.dDwl.	°C	0
	BHT.				
	BHT.	lever selection Temperature Internal Mean -Domestic Dwelling -Space Heat	LvrTmpIn.dDwl.dSH.	°C	0
	BHT.	lever selection Action Start-Domestic Dwelling -Space Heat	LvrStart.dDwl.dSH.	...	0
	BHT.	lever selection Action Speed-Domestic Dwelling -Space Heat	LvrSpeed.dDwl.dSH.	years	0
	BHT.	lever selection Action End -Domestic Dwelling -Space Heat	LvrEnd.dDwl.dSH.	...	0

b. Locate the formulas or calculations that depend on the lever. These formulas would reference the cell or named range associated with the lever. In the formulas or calculations that depend on the lever, replace the reference to the lever with a fixed value or remove the reference altogether. If you want to replace the reference with a fixed value, determine the desired value and enter it directly into the formula or calculation. If you want to remove the reference, delete the part of the formula that refers to the lever. Ensure that you maintain the integrity of the remaining formula.

c. Once you have modified all the formulas or calculations that depend on the lever, review the rest of the workbook to ensure there are no other references or calculations related to the lever. Test the Calculator to verify that the lever has been effectively removed and that the calculations and results are not affected by its absence.

5.8.2 Step 2. Remove the levers from the Control sheet

a. In the Levers Webtool section of the Control sheet, delete the row that contains the lever that you would like to remove to ensure that it does not appear on the web tool. The same step should be taken in the Levers 'My 2050' section.

b. In the Manual Lever Selection and Model Lever Values Applied section, you can delete the values corresponding to the rows for the lever to be removed. Mark the rows with a different colour to indicated that these rows are inactive. Optionally, you can delete or clear the cell or named range that represents the lever to remove any lingering references or user inputs associated with it.

Figure 5.14: Removing a lever and its values from the Control sheet

AmbTmpIn.dDwl.	Dwelling internal temperature				
AmbShrPen.dCnsv.	Domestic insulation/conservation measure deployments				
AmbHtLsRt.dDwlNwl.	Dwelling new build standards				
AmbDemUnitIndx.dDwl.dHW.	Domestic hot water demand index	1.2	1.1	1	1.29835101
AmbShrPen.dHWSlr.	Domestic hot water solar heater share	0.1	0.2	0.3	0.00695995
AmbShrPen.dHWE.	Domestic hot water electricity share	0.7	0.7	0.7	0.69803298
AmbShrPen.dHWwd.	Domestic hot water wood share	0.2	0.1	0	0.29500707
AmbDemUnitIndx.nFlr.dSH.	Non-domestic space heat demand index				
AmbShrPen.nCnsv.	Non-Domestic insulation/conservation measure deployments				
AmbDemUnitIndx.nFlrNwl.dSH.	Non-Domestic new build standards				
AmbDemUnitIndx.nFlr.dHW.	Non-Domestic hot water demand index	1.1	1	0.9	1.19835101
AmbShrPen.dDHN.	Domestic District heat share				
AmbShrPen.dHPALL.	Domestic Heat Pump share				
AmbShrPen.dHyb.	Domestic Hybrid Heat Pump share				
AmbShrPen.nDHN.	Non-Domestic District heat share				
AmbShrPen.nHPALL.	Non-Domestic Heat Pump share				
AmbShrPen.nHyb.	Non-Domestic Hybrid Heat Pump share				

5.9 Error debugging

When working with Excel, there are several common errors that one should watch out for. These errors can occur due to various reasons, such as incorrect formulas, invalid data types, circular references, or inconsistencies in cell references. Here are some of the most common Excel errors:

1. **#VALUE!:** This error typically occurs when a formula refers to cells with incompatible data types or when a function is expecting a different type of data than what is provided.
2. **#DIV/0!:** This error is displayed when a formula attempts to divide a value by zero or an empty cell. It indicates an invalid mathematical operation.
3. **#REF!:** This error occurs when a formula refers to a cell or range that no longer exists or has been deleted. It can also occur if the formula references another worksheet that has been renamed or deleted.
4. **#N/A:** This error stands for "Not Available" and is displayed when a value or result cannot be found. It can occur when using lookup functions like VLOOKUP or when performing calculations that involve missing or unavailable data.
5. **#NAME?:** This error is shown when Excel does not recognize a name used in a formula. It can occur if a referenced named range or named function is misspelled or not defined.
6. **#NUM!:** This error occurs when a calculation results in an invalid numeric value or an overflow/underflow condition. It can happen when performing complex mathematical operations or using functions that require specific input conditions.
7. **#NULL!:** This error arises when a formula contains an intersection of two ranges that do not overlap. It can occur when using the intersection operator (a space) between non-intersecting ranges.
8. **Circular References:** Circular references occur when a formula refers back to its own cell or depends on itself indirectly through a chain of references. Excel displays a warning when circular references are detected as they can cause incorrect or infinite calculations.

To prevent these errors, it's important to double-check formulas, ensure consistent data types, validate cell references, and handle any potential division by zero scenarios. Additionally, using error-handling techniques like IFERROR, ISERROR, or validating data inputs can help mitigate errors and provide appropriate feedback or alternative results when errors occur.

Sector specific guidance

This section presents the modelling logic that is used in the UK MacKay Carbon Calculator to show an example of how specific sectors can be modelled. It's only one of many examples, used here to understand the type of logic that can be deployed to model various sectors of the economy and show the interrelationships that exist between sectors. There are many other ways of modelling the sectors of the economy.

You can find more detailed descriptions of the modelling behind the MacKay Carbon Calculator in the 'method' worksheet included in the Calculator itself.

6.1 Electricity generation

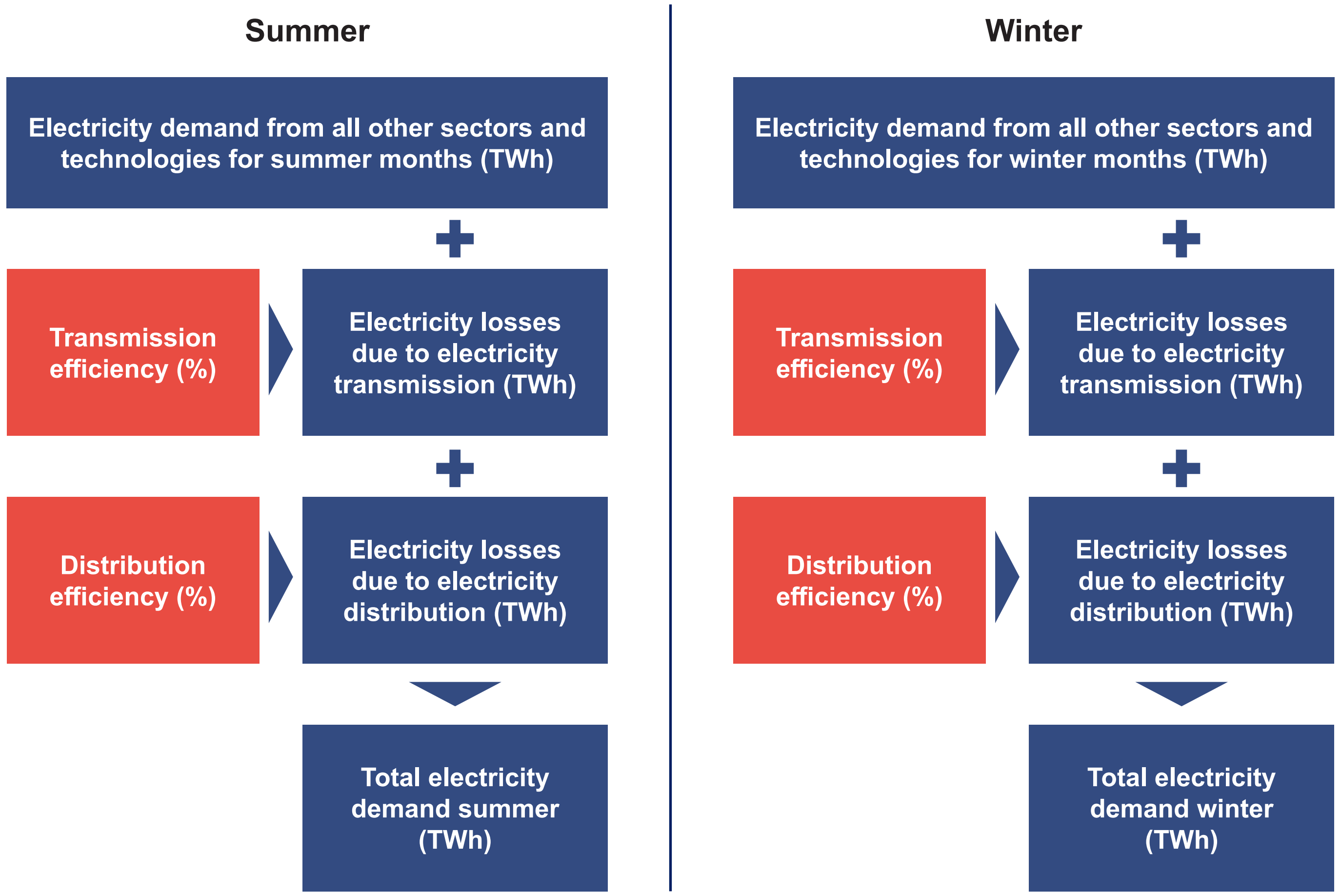
The electricity generation module is used to:

- Calculate the total electricity production required after transmission, distribution, and seasonal storage losses
- Calculate peak demand
- Defines which technologies are used to supply electricity
- Calculate the energy requirements and emission associated with electricity supply.

6.1.1 Electricity demand

The electricity generation module first calculates the **total electricity production which is required**. In the MacKay Carbon Calculator, the year is divided into two periods of six months – 'winter' and 'summer' months. The demand in electricity is calculated separately for each period. The total demand is calculated by adding electricity losses (due to transmission and distribution networks) to the demand coming from all other sectors (Figure 6.1).

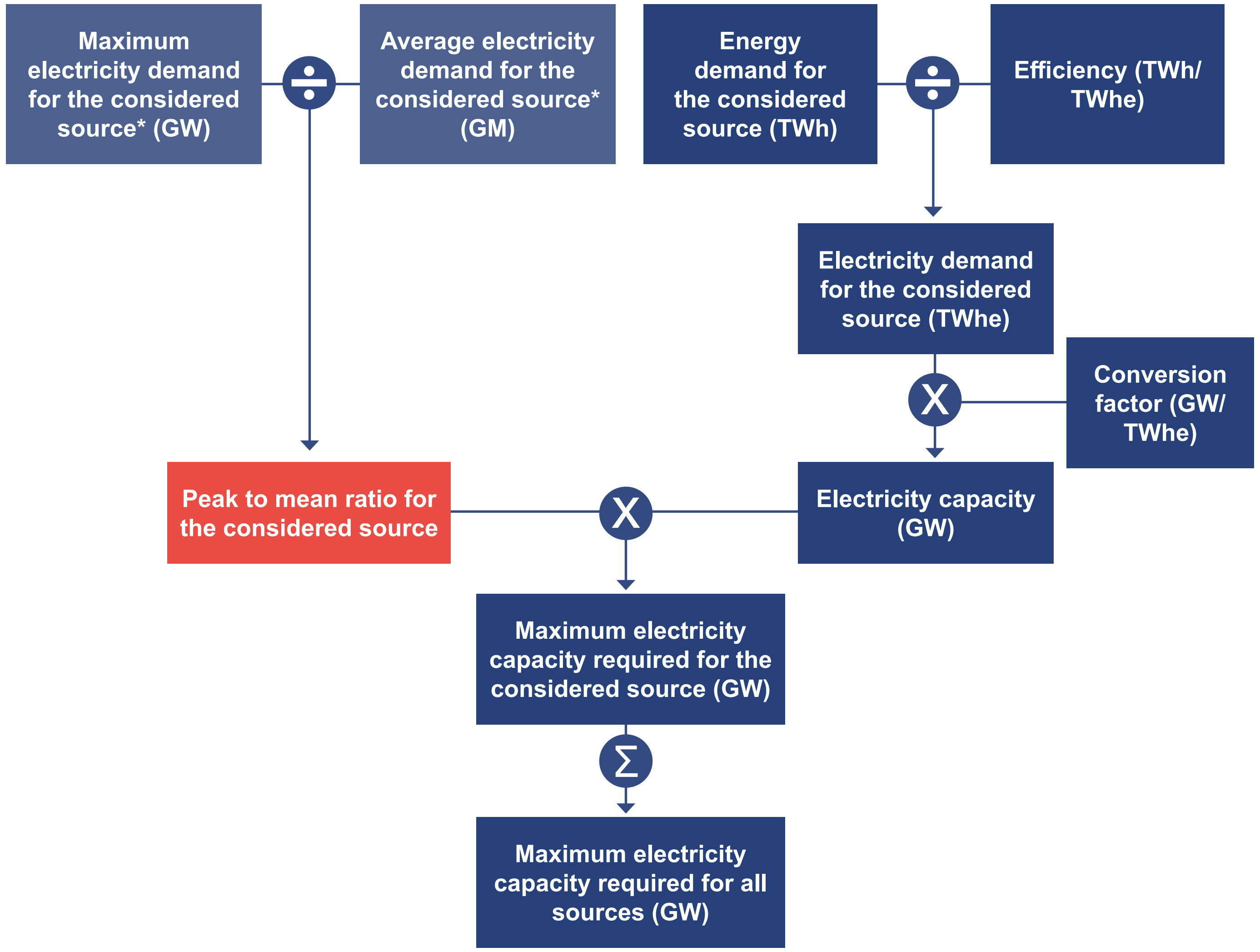
Figure 6.1: Calculation of the total electricity demand



In parallel, **the total capacity required to meet demand is defined** by summing the maximum required capacity of all electricity demand sources defined in the model. The maximum capacity required by one source of electricity demand is calculated by multiplying the average required capacity by the peak-to-mean ratio (Figure 6.2).

As an example, air conditioners are a source of electricity demand. On average, air conditioners consume 10TWh of electricity which requires an average capacity of 1.1GW (indicative numbers). We know that during heat waves, air conditioners can require four times more electricity, which defines the peak-to-mean ratio. The maximum capacity required for air conditioners is therefore 4.4GW.

Figure 6.2: Peak demand calculation



*Example of electricity demand source = air conditioners

6.1.2 Electricity supply

The following electricity production technologies are considered in the MacKay Carbon Calculator – biomass with carbon capture and storage (CCS), nuclear, wind onshore, wind offshore, solar photovoltaics (PV), tidal stream, tidal range, wave, gas CCS, hydro, biomass, and coal unabated.

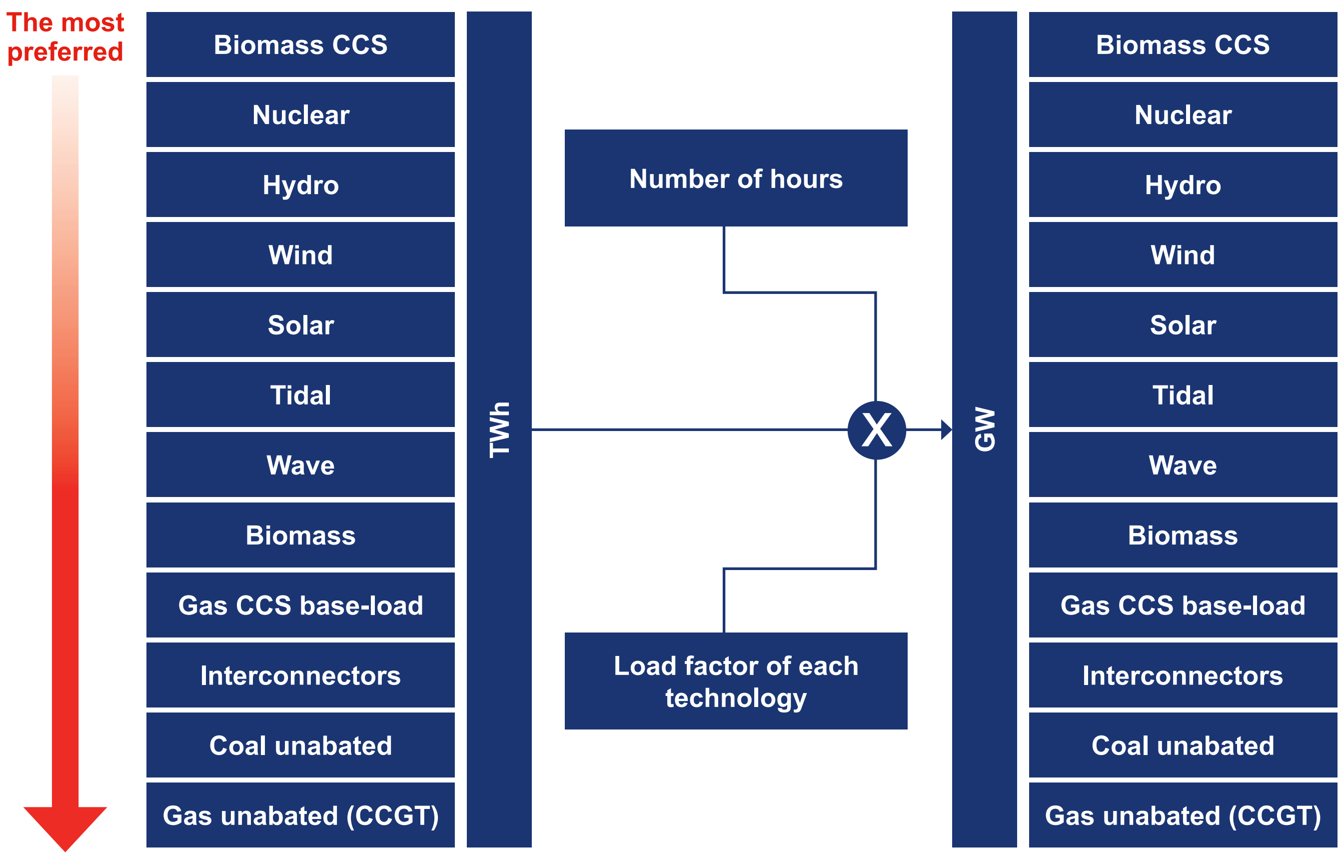
The evolution of the capacity deployed by each technology is defined by a lever for some technologies (biomass with CCS, nuclear, wind, solar PV, tidal stream, tidal range, wave, gas CCS) and by a single baseline evolution for other technologies (hydro, biomass, and coal unabated).

Once the capacity is defined, the total possible electricity production is calculated for each technology by multiplying it by its respective load factor and the number of hours in a year. In the MacKay Carbon Calculator, specific load factors are defined for 'summer' months and 'winter' months.

When the maximum electricity production per technology is calculated, the electricity demand (calculated in section 6.1.1) is met by one technology at a time, from the technology considered the best to the technology considered the least desirable. See the order of preference in Figure 6.3 below. At the end of this calculation, the quantity of electricity produced by each technology is defined and then transformed into capacity required.

The capacity deployed is then compared to the peak demand capacity requirement, considering the share of capacity deployed that can be relied on during the peak demand period. If there's a gap between the relied on capacity deployed during peak demand and the required capacity to avoid a black out, interconnectors and short-term balancing technologies are considered. The considered short-term balancing technologies are demand side response, vehicle to grid, and battery storage. A lever controls the evolution of the deployment of these technologies.

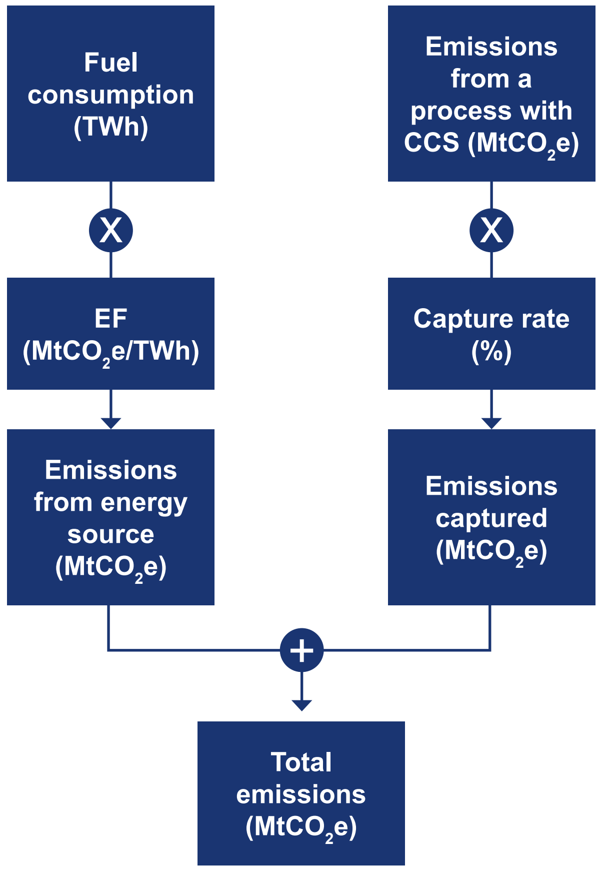
Figure 6.3: From electricity production to capacity generation



6.1.3 Energy, emissions, and electricity generation

For each technology, the quantity of electricity produced is transformed into fuel demand by considering the efficiency defined as the units of useful output (electricity + waste heat) produced from one unit of input fuel. The emissions are then calculated by multiplying the fuel consumption by the respective emission factor. If CCS is used with the considered technology (e.g., biomass CCS), negative emissions are considered (Figure 6.4).

Figure 6.4: Calculation of emissions related to electricity generation



6.2 Buildings

The buildings sector is divided into two separate modules. The first module is the Buildings-Heat module and the second is the Buildings-Non-Heat module. The Buildings-Heat module calculates the greenhouse emissions due to space and water heating. The Buildings-Non-Heat module calculates the greenhouse gas emissions due to cooking, lighting and appliances, and cooling. The model also differentiates between domestic and non-domestic buildings.

For the Buildings-Heat module, the first step calculates the demand in energy for space heating. For domestic buildings, this is calculated by considering heat loss performances of: (i) existing buildings which are not renovated; (ii) renovated existing buildings; and (iii) new buildings. The difference between desired inside temperature and outside temperature is also considered on a monthly basis. For non-domestic buildings, the energy demand per square meter of existing building is defined for the base year and is then influenced by an index for future years. The index will depend on the rate at which we consider renovation will take place. For newly constructed non-domestic buildings, the energy consumption per square meter is calculated by multiplying the energy demand per square meter of existing buildings by an index (because it's considered that newly constructed buildings perform better than existing ones), and then by a second index (because these newly constructed buildings could perform even better in the future). The demand in hot water is calculated by multiplying the demand per person by the population (for domestic buildings) or the demand per square meter by the area of non-domestic buildings (for non-domestic buildings). An index lever allows the user to control the relative evolution of the demand per person or per square meter.

Once the total energy demand is defined for space heating and hot water, the demand is multiplied by technology share (see Figure 6.5 for the list of considered technologies), fuel consumption for each technology (see Figure 6.5 for the list of considered fuels), energy efficiency index per technology, and per fuel. This allows calculation of the energy consumption per fuel. Emissions are then calculated by multiplying fuel consumptions by the respective emissions factors.

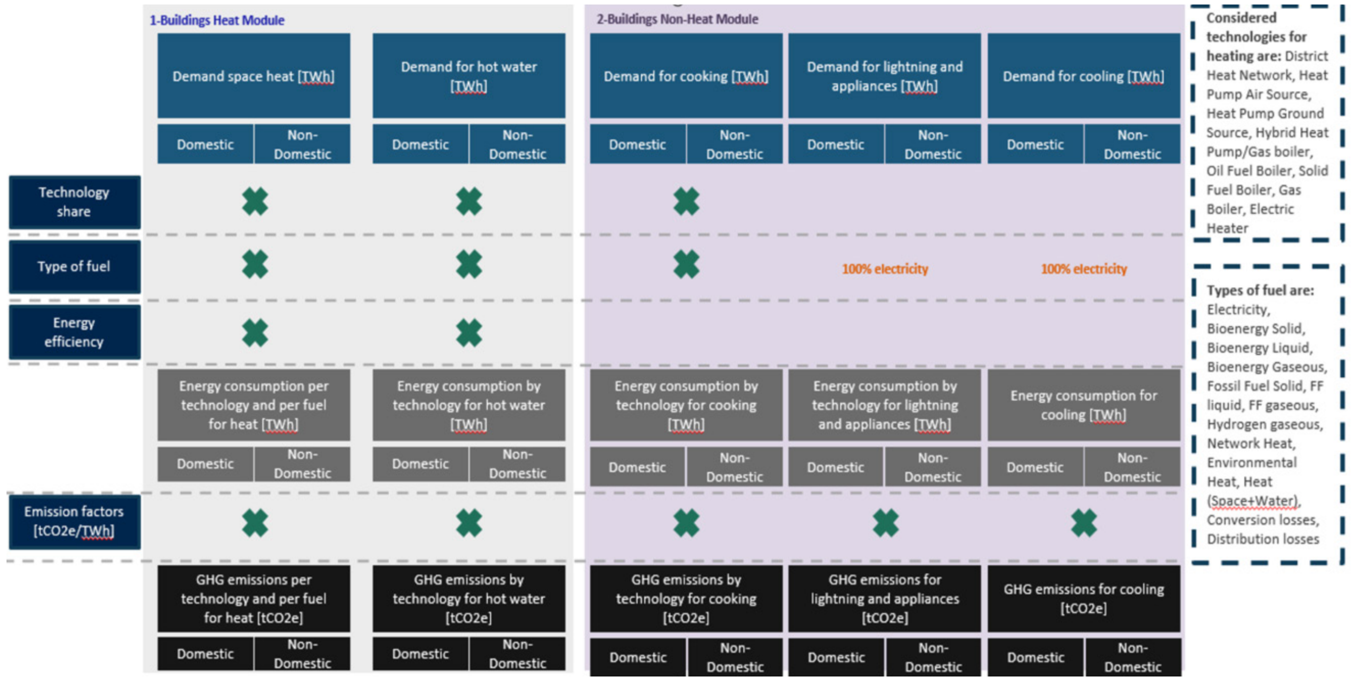
For the Buildings-Non-Heat module, energy consumption from cooking is calculated by multiplying the energy consumption per person at the base year by the population.

Energy consumption from lighting and appliances are calculated by multiplying the energy demand per person by the population (for domestic buildings) or per square meter by the area (for non-domestic buildings). The energy demand per person or per square meter is multiplied by a behavioural index to represent behaviour changes that could happen in the future. The energy demand per person or square meter is also multiplied by an energy efficiency index to represent technology improvements that could happen in the future.

Energy consumption for cooling in domestic buildings is calculated by multiplying the base year cooling demand per dwelling by the number of dwellings, and by the share of dwellings that have air conditioning. The user can control the evolution of the share of dwellings with air conditioning using a lever. For non-domestic buildings, the energy demand for cooling is calculated by multiplying the demand per square meter by the area of non-domestic buildings. The user can control the evolution of the demand per square meter.

Once total energy demand is calculated for cooking, lighting and appliances, and cooling, the fuel consumption is calculated by multiplying the technology share and the share of fuels per technology. The latter is only applicable to cooking as it's considered that lighting and appliances, and cooling use electricity only. Emissions are then calculated by multiplying the fuel consumption by the respective emissions factors.

Figure 6.5: Buildings – high level logic



Source: Climact

6.3 Transport

The modelling of the transport sector is divided into three distinct modules (Figure 6.6). The first module is the Transport Demand module and calculates the vehicle distance travelled per mode of transport. The second module, Transport (Excluding Aviation) module is the calculation of energy consumption for each fuel and greenhouse gas emissions for all transport modes, excluding aviation. The third module, Transport Aviation module calculates energy consumption per engine type and greenhouse gas emissions relative to aviation.

In the Transport Demand module, the passenger distance travelled (psg.km) is calculated for each mode by multiplying the total transport demand per person by the population, and then by the share of the total distance travelled met by each mode. The user of the model can control the evolution of the transport demand per person. Then, the passenger distance travelled is converted to vehicle distance travelled by dividing the occupancy rate (passengers/vehicle) of the mode. A user lever controls the evolution of the occupancy rate.

For international aviation, the total international aviation demand is calculated by multiplying the passenger distance travelled per person by the population. A lever controls the evolution of the demand per person. The passenger distance travelled is transformed into vehicle distance travelled by dividing by the occupancy rate (passengers/vehicle).

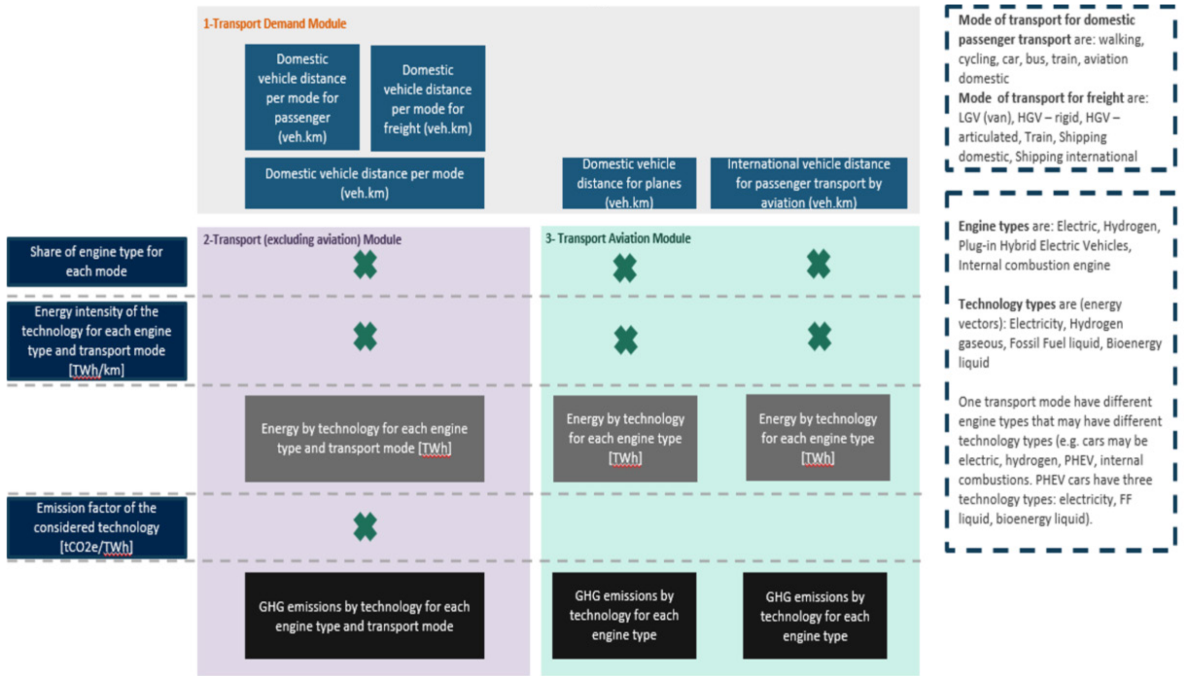
For freight, the level of demand from each freight mode is set to a fixed profile. The weight distance travelled is transformed into vehicle distance travelled by dividing it by the freight occupancy rate (kg/vehicle) of each mode.

The Transport (Excluding Aviation) module calculates: (i) the share of the demand which is met by each powertrain (vehicle type); (ii) the energy consumption; (iii) the emissions; (iv) capacity and cost of all transport modes (other than aviation); and (v) road transport refuelling infrastructure.

The energy consumptions are calculated by multiplying the distance vehicles travelled by each mode by the share of each engine type that can be considered for each mode (see Figure 6.6 for the list of considered modes and engine types), and by the energy intensity of the considered technology for each engine type/ transport mode (see Figure 6.6). The emissions are then calculated by multiplying the energy consumption per technology by the associated emission factor. Decarbonisation can be achieved using biofuels, hydrogen, electrification, and/or hybridisation.

The calculation of energy consumption and emissions for the **Transport Aviation module** follows the same logic as the Transport (Excluding Aviation) module. Note that aviation for both passenger and freight transport demand are considered. Decarbonisation can be achieved through the use of biofuels, electrification, hybridization, and efficiency improvements to aircraft and operations.

Figure 6.6: Transport – high level logic



Source: Climact

6.4 Industry

The UK MacKay Carbon Calculator models the industry sector by categorising industries as follows:

- Ferrous and non-ferrous metal production
- Cement, ceramics, and glass
- Refineries
- Chemicals
- Other industries.

6.4.1 Energy demand

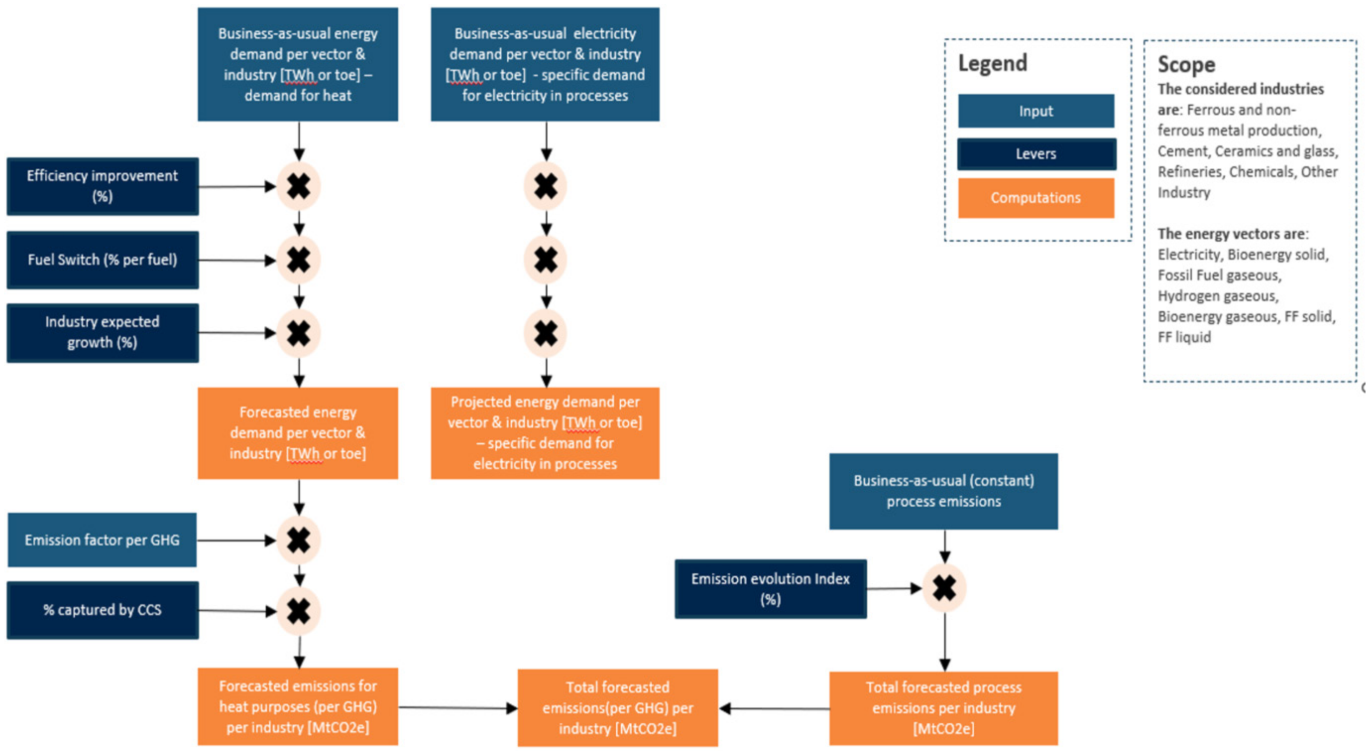
The energy demand in the base year for each fuel and industry type is calculated from the respective energy consumption and efficiencies in the base year. For heat processes, these are summed to give a total demand for each industry type.

The evolution of energy demand depends on a lever that influences the efficiency for each industry type (see Figure 6.7).

A lever then controls the evolution of the share of fuels (see Figure 6.7). The lever controls the ambition shares for electricity, bioenergy, and gas. All other fuels are calculated as residual shares. The shares are applied in hierarchical order – electricity first, then bioenergy, then gas, and finally all others. The actual share is calculated as the minimum between the ambition share and the residual share after shares for fuels higher in the hierarchy are applied. The residual share after electricity, bioenergy, and gas is assigned as either fossil fuel solid or fossil fuel liquid and is split according to the respective proportion in the baseline shares.

The demand for heat and process electricity is calculated using the demand in the base year and multiplying it by the expected sector growth (Figure 6.7). The demand for heat is then divided into fuel demands according to the fuel shares. For each fuel, the demand is further divided into combined heat and power (CHP) and non-CHP using the baseline CHP share per fuel (share of fuel which is used for heating in CHP plants). The electricity produced by CHP plants is calculated taking the total CHP heat production and dividing it by the heat to power ratio. The net electricity consumed from the grid is the total electricity demand for electrical process and heat processes minus the electricity produced by CHP plants.

Figure 6.7: Industry – high level logic



Source: Climact

6.4.2 Emissions

Process emissions are calculated by multiplying process emissions in the base year by the emissions intensity index (emissions factor index) and the sector growth (demand index).

Greenhouse gas emissions related to fuels consumption are calculated as the energy balance multiplied by the global greenhouse gas emissions factors for each fuel.

The emissions captured with CCS are calculated as the emissions released multiplied by the share of emissions that have CCS applied and the capture rate of the process.

6.5 Land use, bioenergy, and waste

Calculation of emissions in the land use sector should be consistent with the calculation of emissions from the agriculture, forestry, and other land use (AFOLU) sector in the IPCC Guidelines for National Greenhouse Gas Inventories . Figure 6.8 shows how emissions in this sector are calculated in the MacKay Carbon Calculator, which is mostly consistent with the nomenclatures used in the IPCC guidelines (Table 6.1).

Figure 6.8: Land use – general scheme

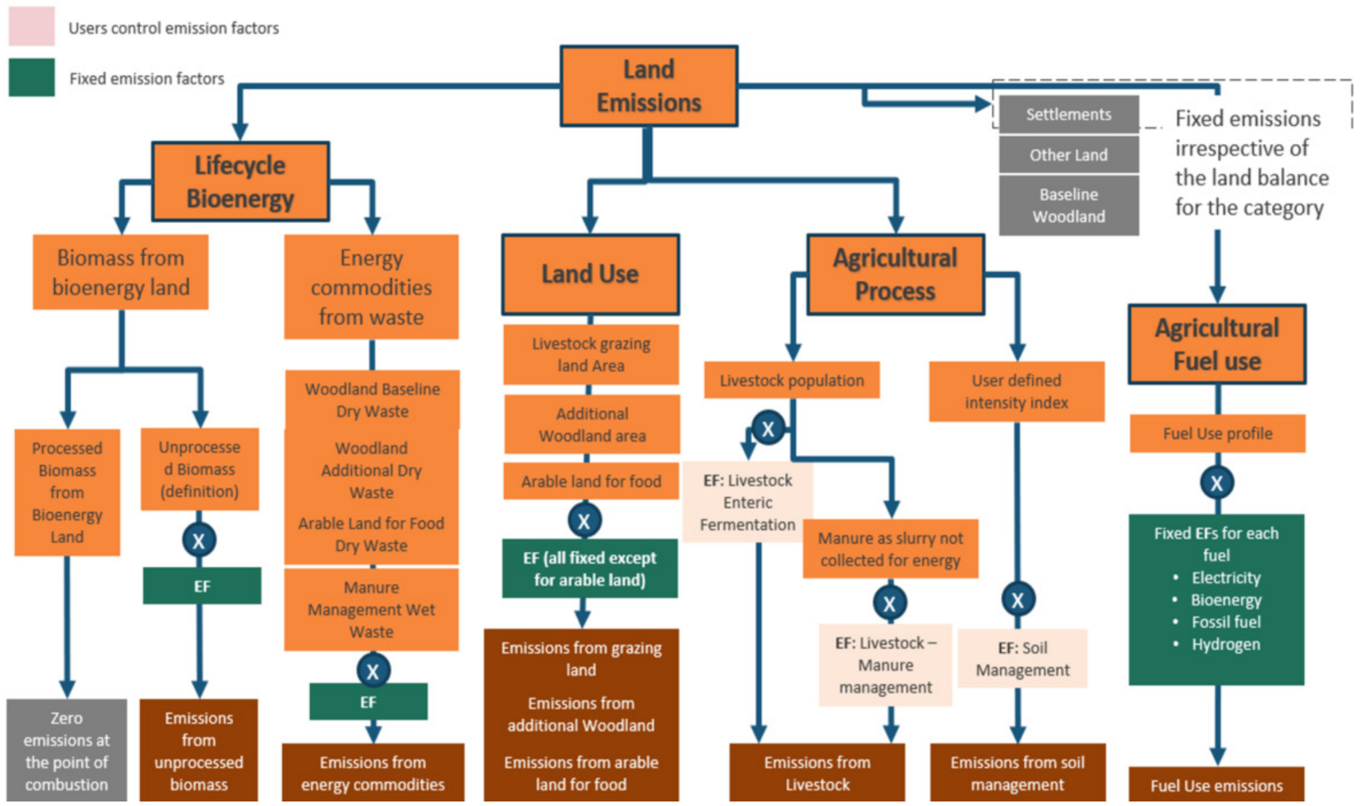


Table 6.1: Nomenclatures in the IPCC guidelines versus the MacKay Carbon Calculator

IPCC AFLOLU categories	IPCC sub-categories	MacKay Carbon Calculator
3A Livestock	3A1 Enteric fermentation	Enteric fermentation
	3A2 Manure management	Manure management
3B Land	3B1 Forest	Baseline woodland + additional woodland
	3B2 Cropland	Arable land for food + bioenergy land
	3B3 Grassland	Grazing land for livestock
	3B4 Wetland	(Included in 'Other land')
	3B5 Settlements	Settlements
3C Aggregate sources and non-CO_2 emissions on land	3C1 Greenhouse gas emissions from biomass burning	Agricultural fuel use + woodland dry waste + arable land for food dry waste + bioenergy land biomass
	3C2 Liming	-
	3C3 Urea application	-
	3C4 Direct N_2O emissions from managed soils	Soil management
	3C5 Indirect N_2O emissions from managed soils	Included together with soil management in 3C4
3C Aggregate sources and non-CO_2 emissions on land	3C6 Indirect N_2O emissions from manure management	Manure management – wet waste
	3C7 Rice cultivations	-
	3C8 Other (please specify)	-
	3D1 Harvested wood products	Included in 3C1
	3D2 Other (please specify)	-

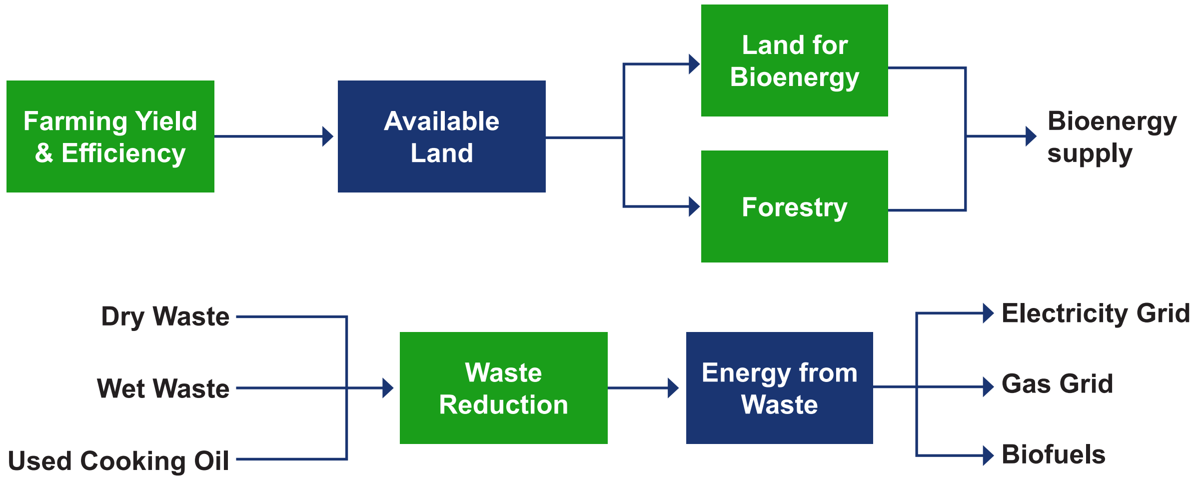
Your country's greenhouse gas profile from the AFOLU sector may constitute a different set of emission categories, thus the structure of the emission calculations shown in Figure 6.8 will need to be modified to reflect emission sources from this sector. An example is rice cultivation emissions – this is absent from the UK's AFOLU emission profile but will be important in countries where rice cultivation is a significant part of the economy.

In the MacKay Carbon Calculator's land, bioenergy, and waste sectors (Figure 6.9), decarbonising land improves efficiency in agriculture, thus less area is required to provide the same amount of food which improves food security. In turn, the land area freed from improved efficiency can be allocated to forests or dedicated bioenergy land.

The 'farming yield and efficiency', 'land for bioenergy', and 'forestry' levers control how land is allocated and calculate the emissions or sequestrations from land-use change.

The 'waste reduction' lever increases action in recycling as well as the share of the energy from waste via landfill gas collection and anaerobic digestion. The energy collected from waste is then fed to various grids accordingly (electricity, gas, or biofuels).

Figure 6.9: Inter linkages between the land-use, bioenergy, and waste sectors and other sectors in the UK MacKay Carbon Calculator



The MacKay Carbon Calculator's logic presents a template to follow for emissions that are also relevant for your country. For additional emissions, additional emission calculations can be added to the existing structure.

The sections below summarise the land use, bioenergy, and waste modules in the MacKay Carbon Calculator, based on the descriptions given in the 'method' worksheet of the Excel model (where further detail can be found). The land, bioenergy, and waste sectors are divided into two modules within this model – 'Farming and forestry' and 'bioenergy and waste transformations'.

6.5.1 Farming and forestry

6.5.1.1 Livestock numbers

The MacKay Carbon Calculator classifies livestock into three categories – poultry, cattle, and other. Each livestock category emits differently. 'Poultry' is accounted for in the emissions that impact air quality only; while 'cattle' and 'other' categories emit both greenhouse gas and air pollutants as well as manure that can be collected for energy and is considered as a 'bio resource' in the model.

The number of animals in each livestock category is calculated based on the user's lever selections. Reducing the number of livestock reduces emissions from enteric fermentation (digestive processes resulting in methane). It also reduces the amount of manure produced by cattle and other livestock, and thus the greenhouse gas emissions through manure management and bioenergy availability.

6.5.1.2 Land balance

The total UK land area is fixed in the MacKay Carbon Calculator and is divided into six land types:

- Woodland (i.e., forest)
- Bioenegy land (used specifically for growing energy crops)
- Livestock grazing land
- Arable land for food
- Settlement land (all developed land, including settlements and transport infrastructure)
- Other land (land that cannot be described by any other land type, including rock, bare soil, and ice).

The user can directly control the land area they wish to dedicate to woodland ('forestry' lever) and bioenergy ('land for bioenergy' lever). The model will limit the land dedicated to these purposes based on how much land is available. Unless the user has improved the yield of land and/or reduced the number of livestock ('farming yield and efficiency' lever), it will be impossible to achieve the most ambitious levels.

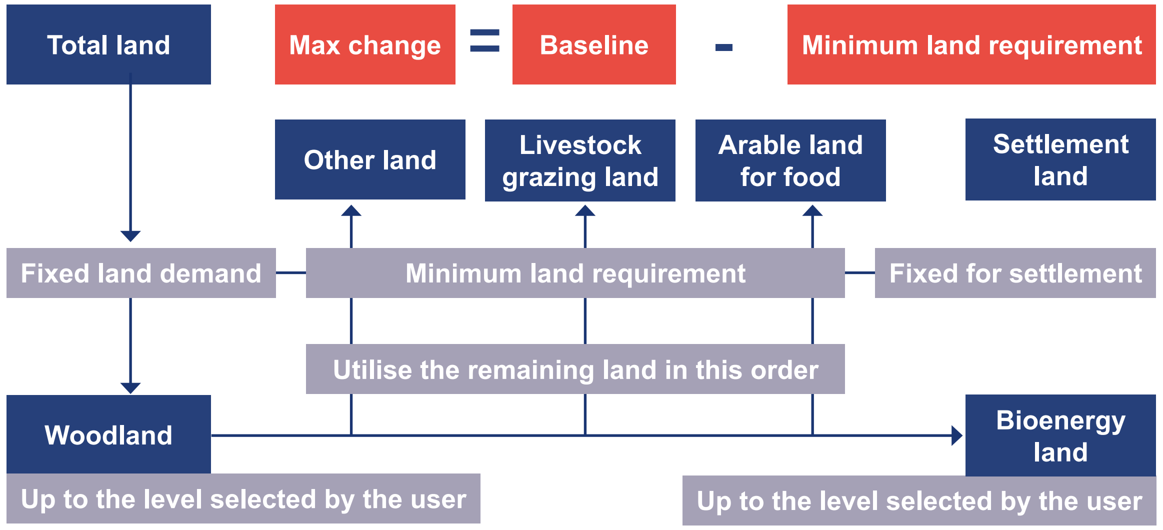
A minimum area of land is required for:

- Other land – a fixed area of land which is not suitable for any other purpose
- Livestock grazing land – the model is constrained to ensure enough land is dedicated to grazing to support the livestock population

- Arable land for food – the model is constrained to ensure enough land is dedicated to arable land for food so that a domestic food security constraint is met.

A summary of how land is allocated in the MacKay Carbon Calculator is shown in Figure 6.10.

Figure 6.10: Land allocation summary



6.5.1.3 Bioenergy resources

The model calculates the total amount of waste produced by various agricultural processes and how much will be diverted into energy. The resulting bioenergy resources include:

- Wood arising from baseline and additional woodland
- Straw arising from arable land for food
- Manure from livestock.

You can modify bioenergy resources in your model to have a comprehensive list of agricultural waste and associated bioenergy for your country.

6.5.1.4 Emissions

Types of emissions considered:

- Lifecycle emissions from collected bioenergy
- Land use emissions
- Agricultural process emissions
- Fuel use emissions.

6.5.2 Bioenergy and waste transformation

This module in the MacKay Carbon Calculator:

- Defines the total production of waste and whether it's recycled, used for energy purposes, or sent to landfill
- Calculates the emissions and energy resources produced by landfill
- Captures the conversion process of biogenic feedstock and waste resources into useful biogenic fuels
- Captures international trade of biomass feedstocks and fuels.

The scope of the MacKay Carbon Calculator can be used as a template to develop your Calculator as the modelling approach is quite generic. It's advisable, however, to modify the structure in areas that aren't applicable to your country.

The module influences the electricity supply from energy from waste and reduces demand for supply from other electricity generation technologies. It's influenced by:

- Fuel demand for solid, gaseous, and liquid biogenic fuel in various modules
- The availability of domestic bio resources in the 'farming and forestry' module
- The share of biomass gasification, biofuel production, and energy from waste plants with CCS in the 'greenhouse gas removal and CCS' module
- Capture rates and efficiency penalties for CCS processes in the 'greenhouse gas removal and CCS' module.

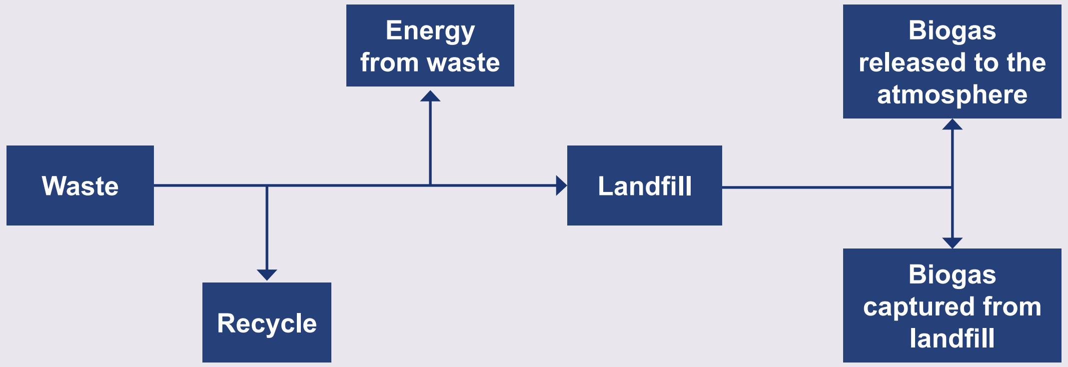
In terms of waste availability, the MacKay Carbon Calculator considers three categories of waste:

- **Dry waste**
  - Includes municipal solid waste (excluding food and garden waste), construction and demolition waste, and commercial and industrial waste
  - Possible actions: Recycle; Incinerate to generate electricity in an energy from waste facility; Landfill
- **Wet waste**
  - Includes food waste, garden waste, agricultural waste, slurry, and manure
  - Possible actions: Recycle; Convert to biogenic gas energy resource in an anaerobic digestion facility; Landfill
  - Note: Wet waste availability in this module excludes manure which is represented directly as a function of livestock numbers in the 'farming and forestry' module.
- **Used cooking oil**
  - Includes used cooking oil and tallow
  - Possible actions: Recycle; Convert to biogenic liquid energy resource; Landfill.

Users can control the total waste production, applied via a waste resource activity index controlling the amount of waste as a fraction of base year production; the proportion recycled (avoiding landfill emissions); and the proportion diverted into energy purposes. If the user selected 'proportion for recycling and diversion to energy processes exceeds 1', then recycling is prioritised as it's higher in the waste hierarchy and usually has a more positive environmental impact. Figure 6.11 shows a sequential chain of actions that are caused by the user selecting shares of recycling and energy use.

The waste left after being allocated for recycling and energy from waste is assumed to be sent to landfill where the gas from landfill can be captured.

Figure 6.11: Waste selection actions



6.5.2.1 Energy balance

The total demand for each state (solid, gaseous, liquid) bioenergy fuel resource is summed across the whole energy system. It's assumed that the available bioenergy resources from farming, forestry, and waste are processed in the most appropriate fashion to satisfy these demands. When domestic bioenergy resources are insufficient to meet the demand selected for bioenergy fuels, it's assumed that imports can be used to satisfy the remaining demand.

The demand for each state (solid, gaseous, liquid) bioenergy has a priority order for satisfying demand as follows:

- **Solid biomass**
  - Domestic solid biomass feedstock
  - Imported solid biomass feedstock
- **Biogenic gas**
  - Landfill gas
  - Wet waste – anaerobic digestion
  - Domestic solid biomass feedstock gasification
  - Imported solid biomass feedstock gasification
- **Biogenic liquid fuel**
  - Used cooking oil
  - Wet waste
  - Domestic solid biomass feedstock gasification
  - Imported biogenic liquid fuel.

All remaining feedstocks are either used to generate electricity in energy from waste facilities (dry waste, wet waste, used cooking oil, and landfill gas), or exported (domestic solid biomass feedstock).

For CCS, it's assumed that it's possible to capture and store carbon emitted during the following processes by applying CCS – biomass gasification, biogenic liquid fuel production; and energy from waste. The share of the output fuel produced from CCS processes is controlled in the greenhouse gas removal module. The efficiency of CCS processes is calculated by applying an efficiency penalty (dependant on the process capture rate) to the efficiency of the equivalent process without CCS.

6.5.2.2 Emissions

The general approach to emissions accounting for bioenergy is that each biogenic fuel has two emissions factors – combustion emissions factor, associated with combusting bioenergy according to accounting rules; emissions (carbon) content factor, stored within the resource. The biogenic resources also have a third emissions factor – the lifecycle emissions factor, from the management or harvesting of the bioenergy feedstock.

Under accounting rules, bioenergy emissions at the point of combustion are assumed to be zero. This is because any carbon released on combustion of the bioenergy was sequestered during the growth of the associated organic matter. This assumption includes, for example, conversion processes such as the Fischer–Tropsch process. In reality, the carbon contained within the bio feedstock/fuel is released on combustion and is therefore available to be captured (in CCS). As such, applying CCS when combusting bioenergy can generate net negative emissions when the process is considered as a whole. The process of growing/managing, harvesting, and transporting bioenergy may also incur emissions which are termed lifecycle emissions.

Adding other outputs

7.1 Costs in the 2050 Calculator

7.1.1 Why include costs?

> The first version of the UK 2050 Calculator didn't include any cost information, but several versions do include costs – for example, intermediary versions of the UK MacKay Carbon Calculator, the Global Calculator, the ECF, and Climate Work Foundation Calculators.

Including cost analysis extends the feasibility debate, allowing users to consider the economic implications of their choices. Cost analysis can tell the user how their pathway compares to other mitigation pathways and to not tackling climate change at all.

The four effort levels of choice that are available to the user are based on what's possible from a technical and behavioural point of view, without consideration of the financial consequences.

Cost modelling and interpretation should always be performed cautiously for the following reasons:

- There are multiple ways to define the scope of a cost specification, e.g., do you include all the cost of cars or building renovations? The cost of a pathway using one model should never be compared to the cost of a pathway using another model. Cost comparisons should only be undertaken for different pathways within the same model
- Among the model inputs, costs tend to be the data with the weakest precision
- Large scope overlaps typically exist, e.g., modelling car purchase prices and steel manufacturing purchase prices, and adding them up. Ideally, costs should only be summed up by factors such as the public, the government, and business.

7.1.2 Cost data

In Calculators which specify costs, a 'cost' is associated with the use of each technology.

The cost analysis is intended to encompass the entire energy system, so that all financial implications of choices are accounted for. Societal costs are not covered, meaning we cannot say which pathways would be cheaper for our children in future. The costs are categorised into three types:

- Capital expenditure – the full cost of all capital components, from heat pumps installed in individual homes, through to large infrastructure projects
- Operating and maintenance costs – the full cost of running and maintaining all required technology and infrastructure, again from individual homes to the national level
- Fuel costs – the cost all involved fuels, from municipal sewage to enriched uranium.

Cost ranges are specified in some Calculators, rather than focusing on a single cost per technology. Costs typically evolve over time and, in some cases, the cost evolution is a function of a learning curve, i.e., each time the production doubles, the cost is reduced by x%.

7.1.3 Presentation

7.1.3.1 UK MacKay Carbon Calculator

The current UK MacKay Carbon Calculator doesn't present costs in its the web tool. Nevertheless, the Excel model does take into consideration various cost elements associated with technologies and associated pathways.

The cost estimates in the MacKay Carbon Calculator are summarised in various ways to better compare pathways. In the Excel model, all costs and capacity are summarised in the 'FullTimeSeries' worksheet. Capacity and costs are calculated at single year-time intervals to allow accurate stock tracking when working with technology lifetimes that are not a multiple of the model period (five years).

Various variables are imported from the 'model' worksheet into the 'FullTimeSeries' worksheet. These variables include capacity required, technical lifetime, economic lifetime, cost per unit, etc. Variables exported to the 'model' worksheet include new capacity installed per period, total capacity, and costs per given period.

The cost calculations include capital costs, operations and maintenance, learning, and development costs that consider investment associated with energy efficiency improvements applied via capital costs. The set of cost equations for each technology is repeated three times for point, high, and low-cost estimates.

7.1.3.2 Older version of UK 2050 Calculator

In the older version of the UK 2050 Calculator, where costs were taken into consideration in both the Excel model and the web tool version, all of the costs from the individual sectors are drawn together in the 'CostAbsolute' worksheet.

Further calculations are performed to reveal:

- Cashflow implications
- Net present value (NPV)
- Financing costs
- Amortised cashflow
- Amortised NPV.

The amortised costs show the total costs over the entire modelled period to 2050, pro-rated to give an annual average.

In the ‘CostPerCapita’ worksheet, the above cost summaries are divided by the population projections shown in the ‘Global assumptions’ worksheet to give per person estimates. Among these results is the amortised per capital cashflow summary over all sectors, which serves as a convenient single figure with which to represent an entire pathway’s costs.

On the web tool, there were three main graphical representations of the costs:

- **Costs in context** – This shows the single amortised cost per capita figure for all example pathways, with estimates of today’s energy costs and GDP in 2050 for context
- **Costs compared** – Amortised cost per capita is split by broad category, revealing the main drivers of cost
- **Costs sensitivities** – This allows users to flex the assumptions behind the cost analysis by choosinghigh, medium, or default estimates for each sector. The impact each has on the cost calculation is highlighted.

7.2 Air quality

Epidemiological studies have shown that there’s a high risk of adverse health effects associated with air pollution. Exposure to air pollution has both long-term and short-term health effects. The long-term effect on health relates to premature mortality due to cardiopulmonary (heart and lung) effects. In the short-term, high pollution episodes can trigger increased hospital admissions, while contributing to the premature death of people more vulnerable to daily changes in the levels of air pollutants.

A Calculator can be designed to allow users to explore routes to reduce greenhouse gas emissions and to inform what the wider impacts of choices may be on air quality.

The main objectives of an air quality module in the Calculator is to provide quantitative estimates of the air pollution impacts of the various Calculator pathways for a given country; to enable end users to interpret the air pollution impacts with existing policy relevant metrics; and to potentially account for ongoing improvements in emissions control technologies. A systematic approach is used to identify and trace the effects of air pollution, from changes in emissions that result from changes in human activity in each module.

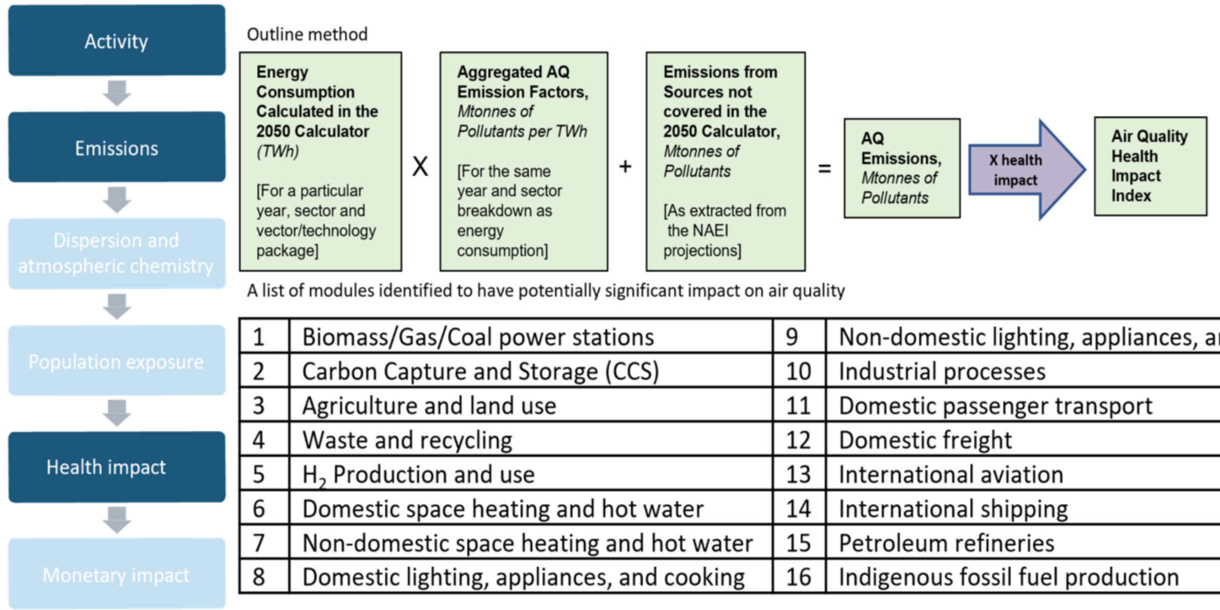
The air quality emissions in the Calculator model are calculated for several different air quality pollutants based on fuel combustion – nitrogen oxides (NOX), particulate matter (PM2.5), particulate matter (PM10), sulphur dioxide (SO_2), non-methane volatile organic compounds (NMVOCs) and ammonia (NH_3).

The Calculator is split into various modules covering energy supply, energy demand, and non-energy sectors. Estimates of emissions of air quality pollutants are derived through a set of air quality emission factors specific to the various sectors in the Calculator. The emission factors are based on the UK National Atmospheric Emissions Inventory program. Figure 7.1 shows how the air quality emission factors are combined with the energy consumption data calculated within the Calculator to produce the final air quality emission and resulting air quality health impact index.

The steps involved in deriving the air quality emission factors are summarised below:

- Assess a list of modules in the Calculator that have potentially significant impact on air quality (Figure 7.1)
- Map the sectors in the Calculator against the National Atmospheric Emissions source sectors. If a sector in the Calculator doesn’t correlate exactly or is not considered in the National Atmospheric Emissions, the nearest source sector (based on expert judgement) or emission factors from an alternative data source is used
- Develop appropriate emission factors expressed in Mtonne of emissions per TWh of energy consumed. Assumptions behind the development of these aggregated emission factors are discussed below
- Calculate emissions from non-energy related sources that are currently not covered in the Calculator because they don’t have a direct impact on greenhouse emissions, e.g., solvent use
- Calculate the final air quality emission projections for a 2050 Calculator by adding emissions from missing sources to the air quality emissions calculated within the Calculator (using the air quality emission factors developed above)
- Convert the air quality emissions into an air quality health impact index.

Figure 7.1: Diagram outlining the air quality methodology



1	Biomass/Gas/Coal power stations	9	Non-domestic lighting, appliances, and cooking
2	Carbon Capture and Storage (CCS)	10	Industrial processes
3	Agriculture and land use	11	Domestic passenger transport
4	Waste and recycling	12	Domestic freight
5	H_2 Production and use	13	International aviation
6	Domestic space heating and hot water	14	International shipping
7	Non-domestic space heating and hot water	15	Petroleum refineries
8	Domestic lighting, appliances, and cooking	16	Indigenous fossil fuel production

7.2.1 Pollution health impact index

The total emissions calculated using the method outlined in Figure 7.1 are converted into an air pollution health impact index using known relationships between changes in emissions of pollutants and health impacts developed by the Interdepartmental Group on Costs and Benefits – an air quality subject group.

The model estimates the marginal change in years of life lost caused by each additional tonne of pollutant emitted, or conversely, the years of life gained through reducing one tonne of a pollutant. The index uses 2015 as the baseline year and gives this a figure of 100 with all changes in years of life gained and lost being proportionate to the total number of years of life lost from air pollution estimated for 2015. A number lower than 100 indicates a reduction in average air pollution and associated health impacts, while a higher number indicates an increase.

The health impact index reflects changes in the average concentration of air pollutants across the UK. Importantly, it doesn’t provide information on the number or severity of pollution hotspots.

7.2.2 Limitations

There are limitations to the approach taken for the air quality computation in the Calculator, as discussed below. Because of these uncertainties, it was decided not to present air quality results on the web tool version of the UK MacKay Carbon Calculator.

The air quality emission factors derived for the model have been generalised according to the aggregated fuel and sector breakdown; for instance, the air quality emission factors on total energy demand for liquid hydrocarbons consumed by four types of domestic passenger transport (car, bus, rail, and air) have been developed and aggregated based on this same breakdown. In this example, liquid hydrocarbons cover both petrol and diesel fuels while the transport mode ‘CAR’ covers all cars, vans, and motorcycles. The level of air quality emissions, however, is dependent on the vehicle type and fuel type, hence the aggregated emission factors will only provide approximate estimates of air quality emissions if future choices of vehicle fuel change from the current mix.

This limitation in the accuracy of air quality emissions results applies to other sectors in the Calculator as well; for example, energy demand by industrial processes is disaggregated into gaseous, liquid, and solid hydrocarbons, and is further disaggregated by industrial sub-sector. Emissions of air quality pollutants are also highly dependent on the type of combustion device being used however (boilers, furnaces, engines, gas turbines, etc) and sub-divisions thereof, as well as the presence of any abatement systems. The Calculator doesn't disaggregate energy use to this extent.

Individual fuel types in the Calculator can also have very different emission characteristics, particularly for SO_2; for example, heavy fuel oil (high sulphur) and liquefied petroleum gas (very low sulphur) are both liquid hydrocarbons in the Calculator.

The methodology used to account for emissions from combustion of biofuels is also limited in accuracy as it doesn't consider different combustion technologies and fuel type mixes in sectors. It's considered an appropriate approximation, however, since the model applies a universal percentage of biofuel usage across all sectors.

The structure of the model doesn't allow for the effect of combustion of blended fuels, which in some sectors (e.g., road transport) has been shown to have a significant impact on emissions.

The analysis of future air quality makes some assumptions about the future which won't likely be borne out by events; however, they're based on the information available now and are usable without adding excessive computational complexity to the model. As an example, currently most electricity generation occurs some distance from major centres of population for historic reasons. Future combustion derived electricity may be generated in city centres. If emitting the same amount of pollution, this would lead to higher pollutant exposure to population centres. This potential change in the spatial relationship between emission location and population is not addressed in the Calculator for any sector.

The air quality index as a measure of health impacts is based on current knowledge, population sensitivities, and age profile. These will change over the period to 2100 in ways which may alter the relationship between emission of pollutants and their impacts on health. Any analysis looking forward is subject to uncertainty. At this distance, it's hard to predict the changes in society that may lead to changes in the impact of air pollution.

Putting the Calculator online

8.1 Overview

One of the positive and unusual things about the 2050 Calculator is that it can be accessed and used over the internet, via a web app.

Why build a web interface?

Benefits of a web app:

- More people will use the model
- The model can be used in interactive presentations and debates
- The model will run faster
- It will be easier to share results.

What sort of web interface should be built?

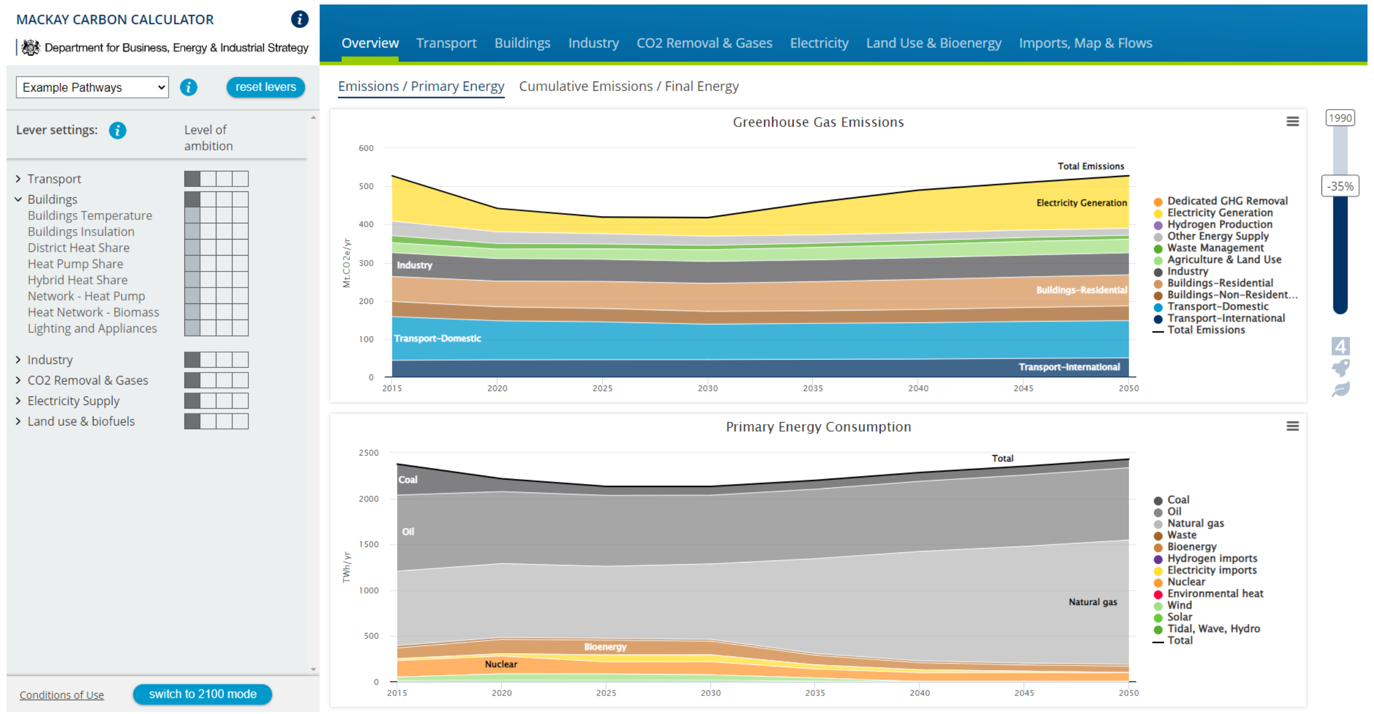
Web interface choices are based around:

- The number of choices presented
- The range of consequences presented
- The balance between presenting numbers and presenting an impression.

Two different web interfaces were chosen for the UK MacKay Carbon Calculator:

- The first one closely mirrors the Excel spreadsheet, presenting 45 choices and many consequences, primarily using numbers rather than graphics. The target audience is those who're already interested in the subject and have a relatively good understanding of the issues. In the UK, this web app is called the web tool.
- The other has only 15 choices, displaying only a few consequences and mainly presenting attractive graphics. The target audience is those who're not initially interested in or have a less in-depth understanding of the issues. In the UK, this web app is called My2050.

Figure 8.1: UK MacKay Carbon Calculator web tool



Source: Click here

Figure 1.3: My2050

Source: Click here

What's needed to build a web tool?

There's a template available to automatically convert 2050 Calculator Excel models into web tools – see link in 8.2 below. Template steps require only basic programming and web development skills and should take a few days. With more time and advanced skills, you can carry out more complex customisation to meet the needs of your country.

To build a 'My2050', additional skills and specialisms, e.g., animation, are required and it may take several weeks; but the sky's the limit in terms of customisation/look and feel.

When to start?

You can start to build a web tool app as soon as there's a more or less complete spreadsheet. The spreadsheet doesn't have to be finished – it's okay if the numbers and formulae change; however, it's best if the structure of the spreadsheet (e.g., number of years, number of sectors, output tables wired up) is more or less finalised.

8.2 Conversion template

A template to automatically convert 2050 Calculator Excel models into web tools can be found at this **link.**

The template works for 2050 Calculators built using the UK Mackay Carbon Calculator as a base. It provides a layout with a simple design that can be customised further and uses Anvil (a free Python-based drag-and-drop web app builder) to create the web app.

To develop from a functioning Excel model to a web app requires two main steps before you're ready to deploy – convert the model into an executable web app, test it locally, and then customise as desired.

There are a few parts to each conversion step as summarised below. Full instructions can be found at the link above.

8.2.1 Convert the Excel model

As a first step:

a. Prepare the Excel model

To convert the spreadsheet successfully, certain named ranges are required to be present. The named ranges specified in the instructions contain the necessary data and metadata for the conversion process.

b. Run the conversion

This will take a few hours to finish and will consume several gigabytes of memory.

8.2.2 Run the app and customise

a. Extract the metadata

The above conversion process focuses on extracting the details of the computational model; however, there is additional metadata in the spreadsheet that's needed by the web app. Getting this metadata is much faster than the conversion process, so wherever possible, static data from the spreadsheet is extracted in this step.

If you make changes to data in the spreadsheet, for example, changing a lever description, you'll need to re-run this step to update the web app. This will be much faster than re-running the conversion process, which should only be needed if changes are made to the computational aspects.

b. Update configuration file

Several aspects of the site can be configured to alter settings that are expected to change between models from different countries; for example, the longitude and latitude used for map outputs. Each setting must be adjusted to match the new model.

c. Test the app

Run a test server locally. All being well, the app should load and you will be able to try it out.

Check that each output is behaving as expected. This provides a good opportunity to pick up errors in the Excel model which may only become apparent once outputs can be scrutinised in graphical form on a functioning web app.

d. Customise the app

You can now start changing the appearance and behaviour of the web app as desired. Use the Anvil documentation to get familiar with the framework.

This template is fit for use as a fully functioning web app out of the box; however, it's intended to be customised.

There are two main ways to edit what appears:

- Edit the metadata in the spreadsheet
- Edit the Anvil app itself.

The spreadsheet metadata includes:

- WebOutputs summary table – graph title, position, tab, subtab, axis unit, named range
- Example pathways
- Output lever details – names, groups, tooltips.

The Anvil app can be edited by using the online Anvil editor. This will require registering for a free Anvil account and creating your own project.

Quality control and quality assurance

Quality should be built into the thinking behind a Calculator and work to create and gather data from the start. The terms 'quality control' and 'quality assurance' are often used interchangeably, but we propose using the definitions that the Intergovernmental Panel on Climate Change (IPCC) have adopted because it helps clarify activities, roles, and responsibilities.

Quality control is a system of routine technical activities to assess and maintain the quality of a Calculator as it's being compiled. It's performed by individuals directly involved in creating and updating the Calculator. The quality control system is designed to:

- Provide routine and consistent checks to ensure data integrity, correctness, and completeness
- Identify and address errors and omissions
- Document and archive material related to the creation and any updates of a Calculator and record all quality control activities.

General quality control procedures include generic quality checks related to calculations, data processing, completeness, and documentation. Documenting and archiving material related to the creation and updates of the Calculator are critical so that a record of the activities is available to future members of the Calculator team. If the documentation and archiving are not available, then institutional memory is jeopardised and can be easily lost.

Quality assurance is a planned system of review procedures conducted by individuals not directly involved in the creation or update of a Calculator. Reviews, preferably by independent third parties, are performed on a completed Calculator following the implementation of quality control procedures. Quality assurance activities are extremely useful because they provide an independent assessment of the functioning of a Calculator – and provide confidence that the Calculator is working as it should be.

It's important to have a simple quality control/quality assurance system for a Calculator – it's not necessary to start with anything complex. It's important to ensure an individual is nominated as the quality control/quality assurance manager – and that they understand what their responsibility means in practice.

9.1 Creating a simple quality system

The following summarises the major elements of a quality control/quality assurance system that would be suitable for a Calculator programme.

Activities and definition of roles/responsibilities within a Calculator programme:

- A quality control/quality assurance plan
- General quality control procedures that apply to the Calculator as a whole
- Source-specific quality control procedures
- Quality assurance review procedures
- Quality control/quality assurance system interaction with uncertainty analyses.

For more detail on quality control/quality assurance systems in principle and in practice, please refer to the IPCC 2019 Refinement, Volume 1.

We have seen from our own experience with Calculators that it's far too easy for small errors to cause big problems in results. In the Calculators launched to date, we've also found a range of issues which can occur in the Excel file, such as:

- Simple typing mistakes
- Missing units when entering data
- Labelling left from the UK version
- Documentation that isn't complete or easy to understand
- Formula errors, which are often subtle to spot.
- Most of these problems are preventable with a simple and effective quality control/quality assurance system.

Calculator launch

Congratulations on producing a working Calculator and web tool!

It's now time to let the world see it, improve it, and use it. The first step is to release a prototype version of the Calculator, with a 'call for evidence', so that experts and stakeholders can provide comments on its usability. Action this first step as soon as possible, as it's more difficult to make changes the longer you wait.

10.1 Transparency

It's worth reiterating that, by publishing the full model, the chances of its success will be increased. Here are a few reasons why:

- Stakeholders may have some good ideas. By letting the target audience make comments and suggestions before a Calculator is completed, can improve the tool and also make it more likely that it will be used in future.
- Every model, no matter how careful its creators are, will have bugs. These are more likely to be found if the model is open to allow others to investigate – it's best to find any errors and correct them as soon as possible. The impact of a mistake is much lower if it's found before a policy has been based on the model's results.
- Stakeholders will trust the results more if they understand how the model works and know what data it's based on. This is true for policy professionals, politicians, journalists, and members of the public alike.

10.2 Example pathways and key messages

Consider publishing some example pathways at the same time as the actual model. Although one of the benefits of the Calculator is that there's no 'right' answer, supplying users with options is a good way to promote thinking about the model's implications. Example pathways could be to have a 'maximum supply effort, no demand effort' and conversely 'no supply effort, maximum demand effort', and also pathways that meet national targets. Pathways don't need to be labelled as officially approved if politically difficult. Instead stress that they're examples only. Key stakeholder groups could even design their favourite pathways for the future. This will provide stakeholders with a concrete way to engage with the Calculator project, and to show that the tool is useful for a variety of audiences.

It can be extremely powerful to publish key messages that have been learned from the Calculator. The team that developed the model will have spent a lot of time exploring the impact of various levers and combinations of levers, as well as the possible overall trajectories for supply, demand, and emissions. These messages are particularly useful for policy makers who have limited time to use the Calculator, as they can benefit from the experiences of the development team when planning policy.

10.3 Launch success

The tactics used for launching a Calculator's 'call for evidence' will vary depending on your country or region's specific circumstances. A 'soft launch' could be held, where the model is published with little fanfare and particular experts or organisations are invited to provide comment. Refer back to your stakeholder mapping to help decide who to invite (see section 2.5). In this case, a public launch could then be held for the second, improved version of the Calculator. Alternatively, you could launch the initial version publicly to allow as many people as possible to use and comment on the Calculator in the shortest time frame. Think about what's most appropriate for your circumstances.

For a public launch, we suggest holding a press conference or more informal launch event that the press is invited to. The presence of senior officials, including ministers, sends a message that this is an important tool and it has the support of the government. When holding a press conference, it's important to think about the implications of the model – journalists are more likely to be interested in what the tool implies for a country, rather than the fact that the tool exists.

It's important to make it easy for individuals to provide feedback on the Calculator; for example, have a link on the web tool to the 'call for evidence' page, or provide an email address to make it easy to comment.

10.4 Communications strategy

It will be important to develop a communications strategy in the lead up to your launch. You should aim to have a basic communications strategy in place at least 12 weeks in advance of the launch which you can refine as you get close to the actual event.

A communication plan should include:

- Specific, Measurable, Attainable, Relevant, and Timely (SMART) objectives – be clear about your overall communication objectives.
- Your target audiences – identify and list the different stakeholders you want to know about the Calculator. Refer back to your stakeholder mapping.
- Messaging – be clear and consistent in your messaging – we suggest creating a media pack, which includes key messaging, facts and Q&A related to the Calculator. This can be sent out to stakeholders as part of the launch.
- Channels – how are you going to communicate the launch? Examples include a press release to target traditional local media; social media; an in-person and/or virtual launch event; articles/blogs; promo video; infographics. All of these activities take time, so will need to be planned accordingly, and with the right stakeholders involved, e.g., do you want to issue a joint press release with others involved in your Calculator development?
- Monitor effectiveness – use evaluation measurements linked to your objectives.
Keep it simple.

10.5 Improve and re-launch

It's imperative to read the comments from the 'call for evidence' and make changes as appropriate. It's likely that others will have suggestions that would improve the Calculator and make it more relevant for the target audience. Set aside time to review and make changes. Use this opportunity to expand the Calculator significantly, perhaps by adding new sectors like land use or air quality, which will require further engagement with experts and stakeholders.

Once updated, re-launch the new, improved version of the Calculator. If the first launch was low-key, then the next could be considered as the main launch, with as much press coverage as possible. Or perhaps the changes have been relatively minor, in which case, update the online version.

10.6 Case Study: Kenya's validation workshop and launch

Kenya publicly launched its 2050 Calculator, the Kenya Carbon Emissions Reduction Tool 2050 (KCERT 2050), in July 2022 to much fanfare at an event attended by senior officials. It was a short event with a focus on celebration, rather than a deep dive into policy implementation. Focus on policy was the basis of a validation workshop a month earlier, which was critical to the success of KCERT 2050. We strongly suggest that other Calculators consider a similar approach in advance of a public launch.

To sensitise key government stakeholders, foster their buy-in, and validate the data in the draft tool, a pre-launch validation workshop was held with government stakeholders. Strathmore University supported the Government of Kenya's Ministry of Energy to organise a validation workshop over in Nairobi over two days in June 2022.

The validation workshop was a major success and positioned KCERT 2050 as a tool that can break down silos and create genuine climate policy impact across government in advance of the launch, paving the way for the public launch a month later. Key highlights included:

- Over 60 delegates from over 20 government departments attended each day of the workshop. Delegates were typically from the mid-senior management layer of government, which was critical as these are the individuals who will be using the tool on a daily basis.
- There was unanimous validation from stakeholders that KCERT 2050 was fit for purpose, with only minor changes required. The power of data to improve Kenyan policymaking was a recurrent theme, demonstrating the significant ambition and potential of KCERT 2050. It was noted that a key reason why the KCERT 2050 tool is so in-demand is because it is publicly accessible and verifiable.
- The level of debate was extremely high in both the plenary breakout sessions, embracing both Kenyan and international best practice on climate data. The design of the agenda included four networking sessions per day, resulting in high-quality engagement and exploration of KCERT 2050 applications.
- Numerous delegates expressed how excited they were to use the tool as soon as it is launched. This included the National Environmental Management Agency (NEMA) and the Kenya Electricity Transmission Company (Ketraco), both key stakeholders for climate impact.
- Public Universities were also in attendance. All Universities were interested in KCERT 2050, particularly as a teaching and research tool and all are willing to include it in their curriculum.
- The level of patriotism and pride in the tool was palpable; indeed, it was built for Kenyans by Kenyans in Kenya.
- The webtool was made available for the duration of the workshop and experienced no problems, demonstrating that it was ready for launch.

A networking session during the validation workshop in Nairobi. June 2022

Influence policy

The finished Calculator should be interesting and reveal important insights for those working on energy and climate change issues. To make it more than just a tool, however, it needs to be used by the policy makers. It should be used to bring real scientific evidence into the debate around energy issues, and in turn to inform decision making.

When discussing strategy and policy, the Calculator tool can be used to create a common language to test various scenarios. By laying out all options that are technically possible, it allows comparison of various and their implications.

11.1 Existing policies

A good starting point is to use the Calculator to evaluate policies already in place. Do these policies align with the key messages of the Calculator? Are the policies aimed at the right things, and are they ambitious enough? Are polices promoting technologies or interventions that will have little impact, or even a negative impact, in the future? A short analysis looking at these questions could be circulated to policy teams to create awareness.

Alternatively, a 'current policies' pathway could be created using the Calculator. To do this, you could convert government aims or progress into choices on each of the levers. In practice this can be quite difficult, as the aims of each policy may not have been expressed in terms that the Calculator uses. Quantifiable predictions in terms of efficiency, supply, or demand may not have been released, and adding up the impacts of various policies can be complicated; however, even a rough pathway can be useful in internal discussions to help find gaps in the plan.

11.2 New plans and policies

The Calculator can be used to inform the strategic direction of a country or region's energy or climate change policy. The key messages learned from the Calculator should be the starting point. If the existing strategy doesn't match, then consider changing it. Policies should concentrate on the levers that make the most difference.

Because of the huge uncertainty around many of the options available in the Calculator (for example, the deployment of CCS technologies at scale), it may be best not to set a strict pathway for a country or region. The year 2050 is still quite a long way off; consider releasing a few possible pathways instead.

Consider a range of factors when developing plans, as there are trade offs that need to be balanced in a lot of areas. Potential co-benefits (for example, around energy security, forests, air quality, and gender equality) should be considered when choosing a pathway and plan to implementation.

11.3 Data management and reporting

Many countries, particularly developing ones, have limited emissions and energy reporting capability. A Calculator can provide an easy way to record the past and reporting progress.

In most Calculators, the modelling begins at a single base year, which is as close to the present day as possible; however, there's no reason why historical information can't be added into the model so that it stretches back in time with real data, as well as looking to the future. Once complete, it could be updated regularly as each year's statistics become available, so that the model becomes a record of the country or region's energy and emissions. As well as making reporting easier, this could improve the user experience with the traditional forward-looking aspects of the Calculator, as future scenarios could be easily compared to past trends.

11.4 The Calculator and United Nations reporting

The Paris Climate Agreement requests each country to outline and communicate its post-2020 climate actions, known as nationally determined contributions (NDCs). NDCs are at the heart of the Paris Agreement and the achievement of country long-term goals. NDCs embody efforts by each country to reduce national emissions and adapt to the impacts of climate change. The Paris Agreement (article 4, paragraph 2) requires each party to prepare, communicate, and maintain successive NDCs. Parties are required to pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions.

The Calculator can be used to underpin the selection and achievement of NDC mitigation measures. A country can use its Calculator to show how it will reduce emissions relative to a 'business as usual' scenario. The Calculator can be a useful tool for countries to help create plans in accordance with these United Nations requirements. The Calculator can model the current energy requirements and emissions profile, map the 'business as usual' scenario, and monitor progress against set goals. All options are shown, with those that make the most difference identified. You can also examine the cost associated with each. Evidence from the Calculator can make plans more credible and accurate, and increase the likelihood of implementation.

Engagement and education

Climate change and energy security are two of the greatest challenges we'll face in the coming decades, but there's still not enough understanding of the impacts they could have or possible solutions. This lack of awareness is a problem for everyone, including those in business, industry, government, and politics, and the Calculator can be used as an interactive educational tool to get individuals thinking and sharing.

12.1 Influencing the influential

The web tool version of the Calculator is great for those who work in energy, industry, transport, housing, and the environment, as it includes all lever options in an easy-to-use format. It can help people understand the energy system, identify the choices that make the biggest difference, and understand their preferences. The tool can be promoted within your own organisation, other government agencies, universities, and companies. There are many ways to reach audiences:

- Face-to-face approaches, including one-to-one briefings, workshops where people build a pathway together, or presentations. There are a lot of existing events that target audiences will be attending, where the Calculator and its key messages could be presented.
- Help others to talk face-to-face about the Calculator by holding 'teach the teachers' events or producing toolkits to help individuals demonstrate the Calculator.
- Get individuals reading about the Calculator by including key findings in wider documents, seeking press coverage and/or writing blogs.
- Hold a competition within your organisation to encourage individuals to submit pathways. The winner could either be randomly selected or could have produced the 'best' pathway in a particular way.
- Make the Calculator part of an induction programme for new colleagues in your organisation.

12.2 My2050 – a tool for public engagement

My2050 is a simplified version of the full Calculator with an attractive user interface. It's designed to be used by members of the public, including children, to promote interest and engagement in energy and climate change issues through interaction with the tool.

The My2050 version of the model has far fewer levers to play with – for example, the UK's My2050 has 15 levers, while the full web tool has 45. Think carefully about which levers to include. As a group, the levers should cover all major parts of the energy system and all the big choices needed (ignoring the levers that have a low impact). Individually, they must be engaging and easily understandable for someone with no background in energy and climate change. Sometimes a few of the full Calculator's levers need to be combined to make sure all available choices are covered.

Generally, it's a good idea to choose levers that relate to an individual's daily life, like transport or home energy efficiency, as well as those that get conversations going, like whether to use nuclear power or renewables. The My2050 user group may be less interested in something like 'the exact fuel mix used in bio energy power stations', important though this is.

The user interface should be straightforward to use but also engaging and fun. Graphics are important – think about the best way of displaying the data and results. Graphs can be effective, but animation will better show the impact of the user's choices; for example, animate a landscape where solar farms or electric vehicles appear, or a house which the user could make more efficient. The secondary results of the user's pathway, like air quality or temperature changes, could also be displayed. Be creative!

You could also make My2050 into a game by having a target or goal that the user has to reach. In the case of the UK My2050, the goal was obvious – the country has an emissions reduction target set in legislation. In other countries, it could be more difficult to define. Ask individuals to create a My2050 world that they would like to live in.

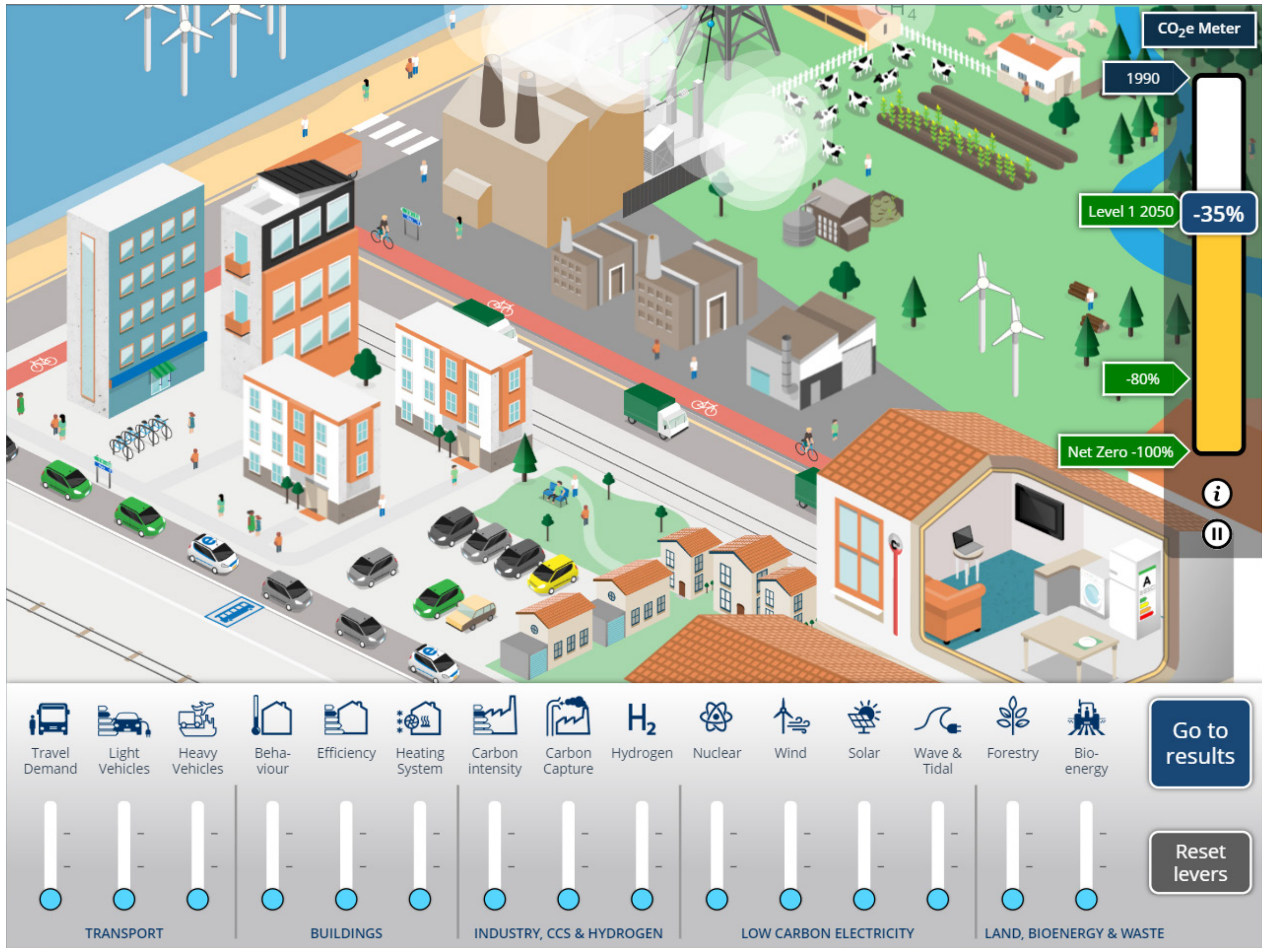
Enable users to submit their pathways to the modelling team. This sharing provides a better idea of what the public are thinking, while also making the user feel their voice is being heard and that they've accomplished something.

12.3 Using My2050

Once your My2050 is ready, it's time to get people using it. There are many tactics that could be employed – here are a few ideas:

- Use the press to spread the word – position a few articles in newspapers, magazines, or on popular websites, to increase the potential audience. Although there are individuals who're already interested in energy and climate change, the My2050 tool will have the most impact for those who don't usually think about such issues.

Figure 12.1: My2050



Source: Click here

- Use social media – make sure that individuals can share their finished pathway on social media channels, like Twitter and/or Facebook, so that their friends can see it and have a go.
- Run a competition – offer a prize to one lucky user picked at random, or perhaps to the individual who gives the best answer to the question 'I chose my 2050 pathway because...'
- Hold workshops – arrange workshops for interested members of the public across the country or region, or perhaps hold small workshops at existing conferences.
- Have a stand at an exhibition – My2050 is quick and fun to use, so it works well as a drop-in activity. Consider having a stand at a science, technology, or education exhibition where delegates can try the tool in passing.
- Encourage its use in schools – My2050 is a great way for children of secondary school age to explore issues around energy and climate change, and it's relevant to subjects like geography, science, and math, as well as social sciences. Create a website or resource aimed at teachers to show them how they can use the tool in classrooms and explain what pupils can learn from the experience.

12.4 Case Study: Public workshops – deliberating energy futures

A UK Energy Research Centre study led by Cardiff University found that the public wants and expects change and will support change which reduces energy use overall and reduces the use of finite resource.

The research included six in-depth deliberative workshops each held with 11-12 members of the public in the capital cities of London, Edinburgh and Cardiff, and three locations selected as sites of specific interest with regard to energy – Methyr Tydfill (coal), Cumbria (nuclear) and areas south of Glasgow (wind).

Each workshop met for a full day to discuss whole energy system transitions. In small groups discussion were facilitated using the My2050 tool. Through this process they were encouraged to create their own 2050 scenarios. Further dialogue was prompted using vignettes detailing 'a day in the life' of an ordinary person living in different energy futures.

The study found that the design of future energy systems should take into account core public values such as environmental protection, safe and secure energy supplies, freedom of choice and autonomy, and social justice.

Source: Click here

12.5 Case Study: Using My2050 in South Africa

A 2009 white paper in South Africa called for inclusion of climate change into formal education curricula. In response, a My2050 game was developed by the Department for Environmental Affairs with support from educations NGOs. The My2050 which was a simplified version of the country's 2050 Pathways Calculator.

The game was designed for schools with low bandwidth internet by simplifying graphics. It was made interesting for children by using sound effects, bright colours and the use of motion. A printed version was created on climate change and the tool for schools with no internet access.

Figure 1.1: South Africa MY2050 Calculator

Source: Click here

Keep the Calculator alive

The Calculator should be a living tool that's added to and updated to suit all needs. Perhaps there's a new question that needs answering, or opinion has changed about how ambitious trajectories should be. Maybe more recent data has become available that could be used as a new baseline to make the results as accurate as possible. Through continual improvement, the tool will keep having an impact.

13.1 Institutionalise the 2050 Calculator

The institutionalisation of the 2050 Calculator is one of the most important aspects of a Calculator project. How can the effort that has been invested to develop and promote your Calculator best be maximised? How can the investment have an enduring effect, and not be lost when teams in government change?

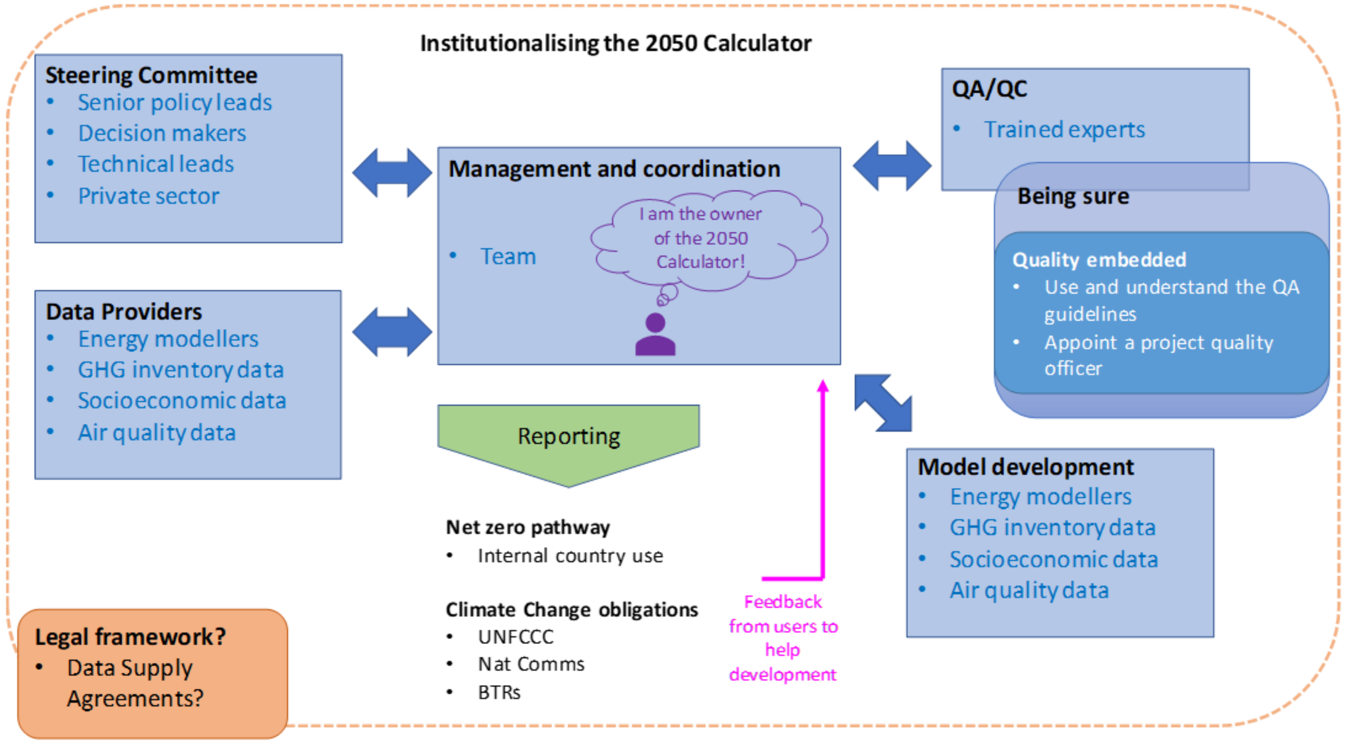
One of the most effective ways of keeping a Calculator alive is to 'institutionalise' the knowledge and insights gained during its development. Put simply, 'institutionalisation' is the action of establishing something as a convention or norm in an organisation or culture. Thinking about this slightly differently in the context of the Calculator, the essence of institutionalisation is about embedding the Calculator in a country's greenhouse gas mitigation thinking and planning, and putting the Calculator at the heart of the development of pathways to net zero.

To highlight just how important institutionalisation of the Calculator should be, we looked back at the lessons of the past that helped shape the current 2050 Calculator programme. One of the 'big 5' lessons of flawed projects is '[They] fail when key people leave'.

Institutionalisation is the key to help prevent failure when people leave, and to help preserve the memory of the Calculator for the future.

The diagram below sets out our thoughts on institutionalisation of the Calculator. Note that a legal framework could encompass the whole Calculator system to ensure compliance or perhaps only the data supply agreements would have a legal basis. Every country is likely to have an implementation that suits its unique circumstances, but some features will be common to all countries, such as quality control/quality assurance.

Figure 13.1: Institutionalise the 2050 Calculator



13.1.1 How to institutionalise

Institutional arrangements should build on existing national arrangements, where you restructure to promote effectiveness. The Calculator should already have 'an institutional home' – a ministry, department, or agency that is responsible for it – see section 2.3 on finding a government body to sponsor the project and take eventual ownership of the Calculator.

The Calculator should also have an 'owner'. The owner should be a person, not a team, and the owner should have overall responsibility for the Calculator. They should know who built it and where the records describing how it works are kept. If the owner leaves, a new owner should be appointed, and the Calculator handed over.

The institutional arrangements should ensure that all data for the current and future iterations of Calculator are understood, recorded, made available, and backed up. The owner should facilitate important data flows and make sure skilled resources are available to work with stakeholders.

Some countries may find a legal framework is useful – to make the use of the Calculator mandatory and to secure the data needed for it through data supply agreements.

13.1.2 Promotion

The owner and ministry, department, or agency should promote the Calculator. Understanding and communicating the objectives of the institutional arrangements and clearly presenting the related organisational structures are critical. The owner should facilitate the use of the Calculator, ensuring it's recognised in all levels of government, and ensuring that it's embedded in all policy thinking, not just policies related to climate change.

13.1.3 Timescales

It'll take less time than you think. If you've already developed a Calculator, the key additional aspects needed will be time to document all the systems and procedures and to maintain it. Make it easy for the next 'Calculator generation' to continue the good work.

13.1.4 Co-benefits

There are other important co-benefits to institutionalising a Calculator. Thinking of the climate reporting obligations that all countries have under the United Nations Framework Convention on Climate Change, the Calculator is likely to support efforts to develop and enhance monitoring, reporting, and verification as well as transparency systems of climate action and support. It provides clear evidence that a country is making ambitious plans to tackle climate change, and the work it supports can be presented in an enhanced transparency report. As well as providing insight into greenhouse gas emissions, the Calculator can help to understand the sources of air quality emissions and support mitigation.

The handbook on institutional arrangements to support monitoring, reporting, and verification/ transparency of climate action provides some good guidance on institutional arrangements.

13.2 Beyond energy and climate change

The Calculator approach was developed to answer questions about energy, but there's no reason why it couldn't be used in other spheres of government, business, or even everyday life. The Calculator approach does two things well which are easily transferable to other models:

- It models each sector using a 'logic tree' approach, showing the major forces that produce overall figures. Such an approach could be useful in understanding anything with a quantitative description
- It brings all sectors together in a common framework. This could be useful for any subject that involves trade-offs, for example:
  - Land use – with a limited amount of land available in each country, there are likely to be trade-offs around how that land is used as populations grow and economies develop. A land Calculator could ask how much land should be devoted to agriculture or housing; or how much food could be grown using different farming techniques
  - Taxation – a tax Calculator could help understand how different combinations of tax policies affect overall tax revenue
  - Government spending – a government budget Calculator could help explore per capita spending in various sectors and compare outcomes. It could give some quick insights into how effective spending is, which areas could be prioritised, and an estimate of future subsidies.

Appendix A. example one pagers

MacKay Carbon Calculator

Transport: UK Transport Demand

This lever controls the sub-levers listed in the table, and ambition levels are for the end year shown on the right-hand side.

On average, each of us currently travels about 10,900 km per year (excluding trips abroad) by various modes of transport. These different modes all have different emissions associated with them. This lever therefore changes both the total demand for travel in km per person and the proportion of this distance travelled by each mode to explore how such 'modal shifts' can contribute to the UK's overall emissions.

Other factors affecting emissions from this sector are the occupancy (number of people sharing the same vehicle on a journey) and range (how much distance can be covered by one vehicle) of each mode.

Key Interaction

Transport emissions depend not only on demand but also on the carbon intensity of the technology used to drive them. Today we have the technology to power vehicles using fossil fuels, biofuels, electricity and hydrogen and various combinations of these. The remaining non-aviation levers allow us to see the potential impact of adopting different shares of these technologies.

Level 1

People increase the total distance they travel each year but have no ambition to change the way in which they move around the country. Sharing of car journeys decreases, based on Department for Transport forecasts.

Level 2

Travel demand remains the same as the base year. Incentives such as the Cycle to Work Scheme encourage people to shift from car travel to cycling and rail.

Level 3

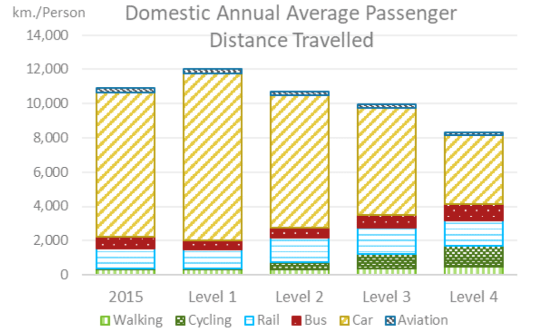
People are more willing and able to work from home and use delivery services, and so reduce the amount they travel. There is a substantial shift to public transport, and rates of cycling becomes comparable with The Netherlands. There is a small increase in sharing of car journeys.

Level 4

A greater shift to cycling is made possible by e-cycles (push bikes fitted with electric motors) increasing trip distance, and incentives for cycling. Rail travel exceeds levels seen in rail-focused countries such as Switzerland and extensive use of public transport reduces the reliance on car travel. For the remaining car travel, there is a higher degree of car sharing.

Default Timing Start year: 2020, End year: 2050

Sub-Lever	Units	2015	Level 1	Level 2	Level 3	Level 4
Domestic passenger travel	Psg km. / person	10,900	12,000	10,700	10,000	8,300
Share of passenger travel						
Walking	share	3%	3%	3%	4%	6%
Cycling	share	1%	1%	4%	9%	15%
Car	share	78%	79%	72%	62%	47%
Bus	share	6%	5%	5%	8%	12%
Rail	share	10%	10%	14%	15%	18%
Aviation	share	2%	2%	2%	2%	2%
Car Occupancy/ sharing	Psg / Vehicle	1.53	1.45	1.55	1.60	1.80
Car average annual mileage	km. / Vehicle	11,066	13,700	18,200	22,800	27,300



MacKay Carbon Calculator

Electricity: Nuclear

This lever controls the sub-levers listed in the table, and ambition levels are for the end year shown on the right-hand side.

Nuclear power generation, once constructed, is almost zero-carbon and therefore could play a key role in decarbonising the power generation sector.

The UK started using nuclear power generation in the late 50's. In 1994, the UK reached its peak nuclear capacity at 12GW. Today there is around 9GW operating. Most of these existing power stations will soon be retired leaving 1.2GW of legacy capacity (Sizewell B in Suffolk).

The UK is pursuing new nuclear power generation with Hinkley Point C, a 3.26GW plant, where the first unit is due to start generating b in 2025.

Small modular reactors (SMR) are typically up to 300MW in capacity and some aspects can be manufactured in factories to reduce the cost of onsite construction. The modular nature of these reactors means that although each module is small in capacity, multiple units can be used for larger capacities.

Level 1

Legacy power stations are retired as planned. Sizewell B remains in operation, supplemented Hinkley Point C, together capable of generating up to 35 TWh per year.

Level 2

Legacy power stations are retired. Nuclear power stations are built at four or five more sites, giving a capacity of 15 GW and capable of generating up to 120 TWh per year.

Level 3

All suitable existing sites have power stations similar to Hinkley Point C, giving a capacity of 30 GW and capable of generating up to 230 TWh per year.

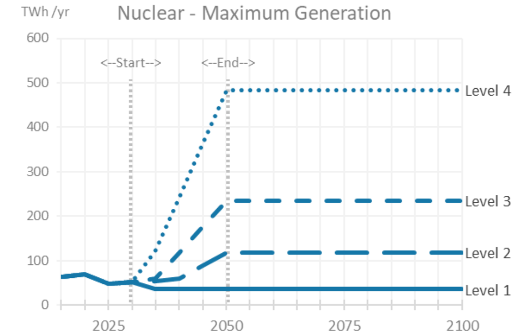
Level 4

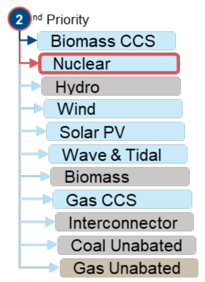
The maximum potential for new nuclear and SMR power stations is reached, involving multiple reactors at existing and new sites, totalling 60 GW[1] and capable of generating up to 480 TWh per year.

[1] http://d2umxnkyjne36n.cloudfront.net/insightReports/Nuclear-Insights-%E2%80%93-Midres-AW.pdf?mtime=20160908152349

Default Timing Start year: 2030, End year: 2050

Sub-Lever	Units	2015	Level 1	Level 2	Level 3	Level 4
Nuclear Capacity	GW	9.6	4.5	15.0	30.0	60.0





Lever Priority

Nuclear power is second in the priority order for generating electricity, ahead of renewables because nuclear cannot be switched on/off easily.

Where supply would otherwise exceed demand, measures lower in the priority order will be superseded by those above them. Unabated gas will meet any shortfall in demand.

MacKay Carbon Calculator

Industry: Industry Shift to Biomass

This lever controls the sub-levers listed in the table, and ambition levels are for the end year shown on the right-hand side.

The use of biomass in industry has the potential to reduce carbon dioxide emissions because most of the CO_2 emitted from the combustion of biomass has been previously absorbed by the crop.

If the biomass used in industry is also combined with carbon capture and storage (controlled by the industry CCS lever), this has the potential to remove CO_2 from the atmosphere ('negative emissions').

Industries that make use of solid fuel burners and boilers are more readily able to switch to solid biomass as a fuel source whereas natural gas fired processes are less likely to be switched over to biomass, due to the disruption and cost to change the technology. There may be issues in some industries with biomass not reaching high enough temperatures for high-temperature processes – this is most likely in the metals and cement industries. Ash collection also represents a logistical issue with biomass.

Key Interaction

Biomass supply must also be considered. Biofuels can be created from waste and biomass grown in the UK, but these have limited availability. Any demand not met by UK biomass is satisfied by imports. However, dependency on large quantities of imported biomass may not be possible in reality and would result in a less robust energy system. UK bioenergy production can be controlled through the Land Use & Biofuels levers.

Level 1

The use of biomass throughout industry remains the same as 2015 levels.

Level 2

Ambition level is 1/3rd of the difference between Level 1 and Level 4. Approximately a third of industrial heat demand is satisfied by biomass.

Level 3

Ambition level is 2/3rds of the difference between Level 1 and Level 4. Over half of industrial heat demand is satisfied by biomass.

Level 4

Biomass switching in industry reaches maximum potential suggested by expert opinion. In some instances, this would require a move away from existing gas fired processes to biomass. Unless industrial heat demand is reduced, this would require nearly all the maximum available raw biomass of around 300 TWh/year (CCC 'Global governance and innovation' scenario[1]).

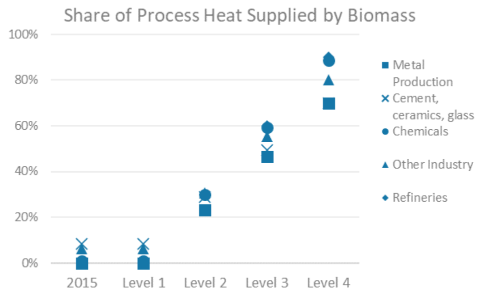
[1]https://www.theccc.org.uk/publication/biomass-in-a-low-carbon-economy/

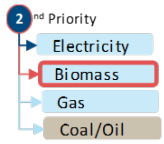
Default Timing

Start year: 2020, End year: 2050

Share of process heat supplied by Biomass

Sub-Lever	Units	2015	Level 1	Level 2	Level 3	Level 4
Iron, Steel & other metals	share	0%	0%	23%	47%	70%
Cement, ceramics & glass	share	8%	8%	29%	49%	70%
Chemicals	share	1%	1%	30%	59%	88%
Other industry	share	6%	6%	31%	55%	80%
Refineries	share	0%	0%	30%	60%	90%





Lever Priority

Biomass is second in the priority order for supplying process heat to industry.

Where supply would otherwise exceed demand, measures lower in the priority order will be superseded by those above them. High carbon fossil fuels coal and oil meet any shortfall in demand.

MacKay Carbon Calculator

Land, Bioenergy & Waste: Forestry

This lever controls the sub-levers listed in the table, and ambition levels are for the end year shown on the right-hand side.

In 2015, there were 35,000 km^2 of woodland and small woods in the UK, making up 14% of the land area. By comparison, 197,000 km^2 of land was used for arable crops, livestock, and other land use. Woodland cover has more than doubled from 5% at the beginning of the 20th century.

Afforestation (increasing woodland area) provides the UK with a way in which to reduce net CO_2 emissions by absorbing CO_2 from the atmosphere through photosynthesis. However, in reality there is a time lag between planting forest and seeing meaningful reductions in CO_2 as trees grow, and the way we manage the forests affects how much they absorb.

Greenhouse gas inventory projections show a decrease in absorption up until the 2030s, due to low planting in the 1990s and 2000s coupled with thinning and harvesting of mature trees planted in earlier decades. However, harvested forests have to be re-planted and these trees, coupled with higher anticipated afforestation rates lead to CO_2 absorption by forests increasing again after 2040

Key Interaction

The land area of the UK is finite and the way in which it is used has an impact on the emissions released into the atmosphere. The land area needed for livestock and food crops can be reduced using the Farming Yield & Efficiency lever, so freeing up this land for Forestry.

Woodland also provides bioenergy material in the form of saw dust from saw mills, and branches and saplings that are trimmed away as part of managing the forest. The amount of forest material collected for bioenergy is controlled by the Land for Bioenergy lever. Further emissions savings are possible through using wood as a carbon store (for example timber in construction) and hence avoiding emissions associated with the products that are replaced.

Level 1

After 2020 planting of forest ceases, and current levels of forestry remain the same.

Level 2

Afforestation of 280km2/year (roughly double the rate over the past 30 years) is maintained.

Level 3

The historic maximum afforestation rate of 400km2/year (achieved in 1972) is maintained.

Level 4

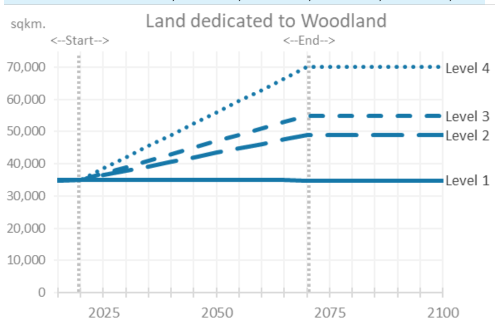
Afforestation of 700km^2/year is maintained long-term. Changes to the regulatory framework are made to promote forestry over other land uses and leads to a doubling of current woodland cover by 2070. This large change in forest cover would represent a land-use change mostly away from land for livestock.

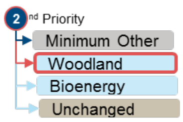
[1]https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1703161052_LULUCF_Projections_to_2050_Published_2017_03_15.pdf

Default Timing

Start year: 2020, End year: 2070

Sub-Lever	Units	2015	Level 1	Level 2	Level 3	Level 4
Land Area - Woodland	km^2.	35,000	35,000	49,000	55,000	70,000





Lever Priority

Land for Woodland is the second priority, after land for food, livestock and settlements ('Minimum Other').

If insufficient land is available, land for forest will not be applied. If lever settings do not require land to be converted it retains its original usage.

2050 Calculator Guide