

How to build a 2050 calculator

By the UK 2050 team

2014

Contents

Introduction	8
Who is this book for?	9
What does this book contain?	9
A brief history of the calculator	9
What is a calculator?	10
What makes the calculator different?	12
Getting started	13
Building support	13
Finding funding	14
Building a team	14
Developing a project plan	15
Resources	16
Mapping your emissions	16
Mutually exclusive, collectively exhaustive (MECE)	17
Keeping it simple	17
Building driver trees	17
Choosing your levers	18
Choosing your outputs	19
Finding data	19
Resources	19

Setting levels 1 to 4	20
The forces at work	20
More about level 1	21
More about level 4	21
Levels 2 and 3	22
Engaging stakeholders	22
Writing your one-pagers	23
Resources	24
Building the calculator spreadsheet	24
Common Excel errors and how to avoid them	25
Errors in the excel formulae	26
Errors in the excel layout, documentation, labelling, supporting documents	30
Errors in the assumptions	32
Putting the calculator online	33
Why build a web interface?	33
What sort of web interface should you build?	34
What do you need to build one?	34
What steps should you take?	34
When should you start?	35
Things you might be tempted to do (but perhaps shouldn't)	35
Reducing the number of choices you present to the user	35
Resources	35
Launching your calculator	36
The benefits of being open and transparent	36
Example pathways and key messages	36
Holding a successful launch	37
Improving and re-launching the calculator	38

Influencing policy	38
Testing existing policies using the calculator	38
Developing new plans and policies	39
Data management and data reporting	39
Box: The calculator and UN reporting	39
Box: Case study – China	40
Engagement and education	40
Influencing the influential	40
My2050 – a tool for public engagement	41
Using My2050	42
Case study: the Taiwan My2050	42
Resources	43
Keeping the calculator alive	43
The calculator network	43
Beyond energy and climate change	43
Case study: Vietnam	44
Case study: South Africa	45
Using the 2050 Calculators	46
Lessons learned: Effectively rolling out the 2050 Calculator	47
Case study: The nuclear sector in the Japan 2050 Low Carbon Navigator	48
Introduction	48
Post-Fukushima uncertainties in Japan’s nuclear power sector	49
Assumptions and trajectory setting	50
Impact of restart policy	50
Trajectory A	50
Trajectory B	51
Trajectory C	51

Trajectory D	51
Trajectory E	51
Data and calculation procedures	52
Cost assumptions	52
Conclusion	52
Appendix 1: The Excel model structure	53
Introduction	53
Overall structure	53
The control sheet	54
Sectors	55
Choice of trajectory	55
Trajectory assumptions	56
Fixed assumptions	56
Derived assumptions	58
Calculation section	58
Outputs	59
Year sheets	60
Intermediate output	62
Appendix 2: Complex Excel formulae	63
Index	63
Match	64
Index and match	64
Structured table references	65
Putting it all together: index, indirect, match and structured references	65
Appendix 3: Vectors	66
Appendix 4: Units	68

Appendix 5: What happens when supply exceeds demand?	69
For solid/liquid/gaseous fuels	70
For electricity	71
Other approaches	71
Appendix 6: Calculating emissions	72
Combustion emissions	72
Other emissions	72
Appendix 7: Stress test	73
The worst-case scenario:	73
Sector VII.c – storage, demand shifting and interconnection	73
Methodology	74
Appendix 7b: In my country, there are power cuts / there is unserved demand	75
Demand side modelling of unserved demand	75
Supply side modelling of unserved demand	75
Implications for fuel exports	76
Appendix 8: Bioenergy	77
Domestically produced biomass	77
Imported biomass	78
Converting total biomass into solid, liquid or gaseous forms	78
Uses of biomass	78
Allocation of biomass to sectors	79
Costs in the 2050 Calculator	80
Objectives: why include costs	80
Gathering costs data	81
Technology example	83
Presenting costs	85

How the webtool works	86
Overview	86
Getting set up	86
Contents of each of the folders	88
Turning the Excel spreadsheet into code	90
Getting from the model to json	91
Getting from json to a chart on screen	92
Getting from the user's clicking to a new pathway	92
Updating the webtool for your country's model	93
Modifying the webtool	94
Adjusting the scales on the charts	94
Removing the 'shadows' on the electricity charts	94
The energy security table total line is not at the bottom	94
Getting the map view to work	95
Adding a completely new set of charts	95
Appendix 10: Going further: energy, vectors, and models	96
Overview	96
Energy	96
How to read this Appendix	97
An example energy system	97
Workings of the Calculator	98
Fuel types and sectors	98
The energy balance principle	99
Accounting for energy	101
Hierarchies of energy types	103
Nominal fuel types	104
Comparison with national energy balance tables	105
Design principles	106
Prolegomenon to any future Calculator	108
Communication between sectors	108

Output from the model	109
Hierarchies of fuel types	110
Fuel types	110
Appendix X: Whitehalls School conference	112
Appendix 12: Quality Assurance checklists	114
Checklist 1: Avoiding formula problems	114
Checklist 2: Avoiding issues with documentation and labelling	117
Frequently Asked Questions	123
Technical	123
Agriculture & waste	136
All sectors	139
Balancing	143
Bioenergy	147
Buildings	151
CCS	159
Conclusions	160
Cost	161
Emissions	168
Fossil fuels	169
Industry	173
Nuclear	175
Renewables	175
Sector sheets	175
Summary sheets	175
Transport	176
Units	179
Year sheet	180

How to deploy the webtool on the AWS EC2 - a guide to getting your Calculator online for public use	181
Introduction	181
Step-by-step instructions	181
Trouble shooting:	184
Todo	185
Adding in costs:	185
Where to get data	185
How to work costs into spreadsheet	185
Adding other sectors:	185
Land use – South Africa	185
Air quality	185
Waste	185
Geosequestration	185
Energy security – India	185
More possibilities – water and biodiversity	185

Introduction

Energy is essential to civilisation. In many countries the way we get and the use energy has to change: either because more energy is needed to develop; or the current approach to energy is insecure, expensive, unpopular or polluting.

Much of the infrastructure that uses, supplies and transmits the energy we use has a very long life, therefore we need to think long-term when we decide what to do about it.

Many sources of energy are unpopular: they are expensive, they cause pollution, they are considered unsafe, they are unsightly, they are a hassle to use. Many ways that energy might be used or conserved are also unpopular for similar reasons. Trade-offs between these different consequences have to be made.

The 2050 Calculator approach to energy and emissions modelling is about understanding how a group of people – whether at the regional, country or even global level – use energy, and then identifying the real changes that could be made to supply and demand. Discussions with experts help to prioritise a small number of simple choices (or levers) which are then translated into an

interactive tool to allow people to explore all the different options. The impact of people's choices on emissions, land use, air quality and energy security can be displayed instantly. A calculator gives people a platform to have more informed conversations, and those in power the information to make better decisions.

This book will take you through the process of building a calculator step by step based on the experiences of teams around the world who have already built their own. Compared to most energy models, a calculator is relatively simple to build, use and understand, but each city, region or country will have its own specific challenges. We therefore cannot hope to answer every question you may have in this book. This is why we also developing an online community, so that people can share their experience and expertise.

Who is this book for?

This book is aimed primarily at people thinking of building a calculator, but is also for anyone wanting to explore whether a calculator may be of use to them, or for those that are just interested in the approach – this could be policy makers and analysts working in government, but equally those working in industry or academia.

What does this book contain?

This book starts with a chapter on each step of the process we went through to build a calculator. It then has a series of appendices that describe some of the trickier aspects in more detail.

This book isn't finished. The latest version is available online at <http://book.2050.org.uk> as a [pdf](#), a [webpage](#), an [ebook](#) and [word](#) document. The source material used to create the book is available under an [open source](#) licence on [github](#). If you have comments or questions, please contact us at 2050pathways@decc.gsi.gov.uk.

A brief history of the calculator

The calculator story began in the UK in 2009, when the government's Department of Energy and Climate Change (DECC) was tasked with coming up with a plan to meet the world's first legally binding emissions target (an 80% reduction based on a 1990 baseline by 2050, as laid out in the Climate Change Act 2008).

The traditional approach to such a policy problem is to use economic modelling techniques to set the strategy by finding the optimum cost-efficient pathway, and then develop policies to bring this change about. In this case, coming up with a single pathway for the country just didn't seem appropriate. Firstly, the issue was so multi-faceted; any transition to a low-carbon economy would affect not just the type of power stations that will be built, but also the decisions

people make in their daily lives, like how to travel to work or how to heat their homes. There was also a lot of uncertainty about what technologies would be available or affordable 30 or 40 years into the future. Taking bets now on which technologies will win is too risky when you are dealing with public money.

At the same time, Professor David MacKay at the University of Cambridge published the book *Sustainable Energy Without the Hot Air* (available for free at www.withouthotair.com), which explores the technical and practical limits of all low-carbon technologies and how this compares to the amount of energy we currently use. This provided inspiration for the team – an interactive version of the book would allow policy makers to explore what is possible for the UK using real scientific evidence. Instead of providing a definitive answer, it would make the debate more informed.

The first version of the calculator was released in July 2010 as a work in progress with a call for evidence (a consultation asking experts for feedback) to help improve it. A conscious decision was made to be as open and transparent as possible, so the full model and all its assumptions were published at the same time for everyone to see. Instead of releasing an approved government pathway, a number of “key messages” from the calculator were published – lessons learnt from all pathways that meet the 2050 target. These were then used to develop 2011’s Carbon Plan, the government’s overall emission reduction strategy, which included a number of example pathways created using the calculator.

DECC was approached by an organisation called ScienceWise-ERC, which promotes public dialogue in policy making. They wanted to build a simplified version of the calculator aimed at the general public, particularly children and young people, to help spark a debate on energy and climate change. This became the My2050 game (which you can play at <http://my2050.decc.gov.uk>). Over 17,000 people have submitted a pathway using this tool so far, giving a unique insight into public opinion on the issue.

An unintended (but very welcome) side-effect of being open and transparent was that analysts in other countries heard about the calculator and decided to make their own. The first was the region of Wallonia in Belgium, closely followed by China. Now over 10 more countries have either completed their calculator, or are in the process of building one. DECC won funding from the UK’s International Climate Fund to support this work in developing countries.

The calculator approach has truly gone global, but there are many more cities, regions, or countries out there who could benefit.

IMAGE – Timeline of the calculator project

What is a calculator?

The 2050 Calculator is an open source model of energy and emissions 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. Most calculators built so far have used the year 2050 as the end point, but in theory any year could be chosen (for example, India used 2047 as it is the 100th anniversary of their independence). Almost all of them have covered a single country each, as that is level that decisions tend to be made, but there is no reason why cities or regions can't have their own calculators. A calculator can answer questions like:

- How much energy can we supply from different technologies?
- How much energy do different sectors use and how can we change this?
- What is the cost of different energy pathways?
- Which sectors are the ones we should focus on? Which are less important?
- How can we achieve our emissions targets?
- What impact would different pathways have on our air quality and land area?
- What could happen to our energy dependency and security?
- What technology options are publically acceptable?

Users control the calculator by making choices using a number of “levers” (usually between 30 and 50). These levers make a change in 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. You can also include changes to energy infrastructure like adding electricity storage, or technologies like geosequestration, which don’t quite fit under demand or supply. The combination of these choices creates a “pathway”, and the calculator then displays the implications of the pathway over time (for example in terms of energy demand, emissions, land use or air quality).

For each lever you have a number of options to choose from – most will have four possible “levels” labelled 1, 2, 3 and 4. These relate to the amount of effort being used, ranging from doing nothing to putting in the maximum amount of effort or going to the limit of technical feasibility. This allows the user to see the range of opinion from experts as to what is possible in the future. If there is a choice between different options with similar levels of effort or where the concept of “effort” doesn’t really apply, then the levels can be 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 calculator comes in three different versions aimed at different audiences. Other countries have tended to adopt a similar approach:

- The full model, built in Excel 2007, which contains all the calculations and assumptions. This allows expert users to examine pathways in more detail or to change assumptions or data to suit their needs.
- The web tool, an interactive and user-friendly web interface that allows users to explore all the options in an easy way. This is aimed at policy

makers and stakeholders, but is also suitable for members of the public who are very interested in the subject.

- My2050, a simplified, game-style version that is aimed at the general public. Users can make fewer choices, but it provides an overview of the main issues and trade-offs

The calculator is an extremely accessible, open and transparent model. It is open in three ways:

1. The basic model is built using Excel, which is widely used all over the world, and the software for the web tool is open source. This makes it much easier for people to use and even to develop their own versions.
2. The full model has been published online and is fully documented so that anyone with an interest can explore how it works and comment on it if they disagree with anything. Calculators work best if they are produced in this way; by publishing the full model and actively asking for feedback, stakeholders and experts can help improve it.
3. The model's functionality itself is more accessible and open than most energy models, allowing people to play around and try out new ideas rather than the model itself working out a "right" answer.

What makes the calculator different?

Some models only include the power sector, or do not include process emissions from industry or from land use. The 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 you can really see all the options available to you, and all their impacts.

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. These models use complex equations and assumptions about the behaviour of individuals and firms. They are sometimes called "black box" models because inputs go in and outputs come out, but it is not clear what is happening in the middle because they are so complicated. This means that typically only a few experts can properly use them, and consequently trust in them can be low.

The calculator is different in that it is based more on engineering and physics than on economic forces. Users choose from a range of options for the future without really 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 behaviour directly would be. It is about what is possible, not what is probable.

The calculator also differs from most models in that it is not a black box. It is as simple as possible, and also as transparent as possible, so the inner workings are not a mystery. Because it is built in Excel, people with no specialist training can open up the model 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 is often used by economies to look at the mitigation options they have available. This gives a good overview about which options are cheapest, but because it looks at each technology separately, it does not take into account the co-benefits of combining different actions together. For example, shifting to electric transport can increase emissions if it is not combined with decarbonising the electricity supply. The calculator allows you to see how demand, supply and emissions interact dynamically across sectors, and you can build entire pathways.

While the calculator approach has these advantages over conventional modelling, it does have its drawbacks:

- It makes no predictions about what will happen in the future. Instead the user can explore their own predictions about the next few decades.
- Because it is not an economic model, it cannot directly model the potential impact of changes in fuel or carbon prices, new policies or international agreements. This is because there are no automatic correlations between sectors (for example between industrial activity and freight demand) or between cost per unit and energy demand). However, a user could build a pathway that reflected the results of these correlations. Traditional economic models still have an important role to play in policy development, and the UK government continues to use them. The calculator should be seen as another tool in the policy maker's armoury, rather than a replacement for everything else.
- Because it has been built as simply as possible, the calculator does remove the fine detail from each sector. For those looking at a particular sector closely, it may not be the right tool to use. The calculator is most valuable when looking at large-scale changes and overall trade-offs, rather than sub-sections of the energy economy.

TABLE showing when we recommend using the calculator and when recommend using something else.

Getting started

Building support

Theoretically a calculator-style model could be built for any country, region or even city by anyone with the necessary time, money and modelling skills; once

completed, there is probably an audience that would find such a tool useful, or at least interesting. However, a calculator is really powerful if it is built with support from government from the outset. This focuses the project on the questions that those with influence really want answers to, and also creates a ready-made audience keen to take on board the key messages once it is finished.

Finding the relevant organisations to engage 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. Ask yourself which organisation has responsibility for energy or environmental policies. Perhaps there is one department that has responsibility for long-term planning in general.

Getting a government body to take ownership of the project is extremely important, but remember that you will still need to consult other organisations across government, since the calculator covers everything from building regulations to public transport policy. Involve these people as early as possible so that they feel part of the project. If you only start consulting them once the calculator is built, it is likely that you will not only annoy them, but that you will miss out on the opportunity to learn from their expertise. Using their knowledge to build the calculator is much easier than finding out you've made a mistake once it is completed, when it is much harder to change.

It is likely that a lot of knowledge about the energy system and modelling expertise is held not just in government, but in universities 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 them. For example, the University of Cape Town has built the South Africa calculator in partnership with their Department of Environmental Affairs.

Finding funding

suggestions of organisations who may be able to help (research bodies and NGOs?)

Building a team

In our experience, a calculator can be built by a core team of between four and seven people. They do not necessarily all have to work full time over the whole of the project – many teams have developed a calculator while continuing to work on other things.

The team is usually made up of:

- A project leader – focused on political and stakeholder leadership
- An Excel expert – to bring all the sectors together in to a working tool
- A number of sector leads – to find evidence on one area and engage with expert stakeholders

The project leader will take on a project management role, and will lead on engagement, both within government and with outside stakeholders. They must be able to convince others to get involved and support the work, and must make sure that the calculator is aligned with other government priorities to make it as successful as possible. Organisation and communication skills are very important, and experience of working within government is useful to help understand who needs to be consulted and when.

When choosing an Excel expert, it is perhaps most important to find someone who is very logical and skilled at using Excel, rather than an expert in energy – although if they don't have a good understanding of how the energy system works before they start, they will have to learn very quickly. Attention to detail is obviously a necessity, as small errors in the detail of the model can become magnified in the final results.

Sector leads should have good research skills, and be able to quickly develop understanding of a particular sector (e.g. transport or electricity generation). They should be able to synthesise a lot of expert views and present their results clearly. The number of sector leads you will need will depend on how you are dividing up the energy system and the particular aims of your model.

FIGURE – Include examples of team structures (Ed has them)

Developing a project plan

The teams who have successfully built calculators have found that it takes around nine months to build a working first version: three months to secure support and put together a team, and then six months working on the model itself.

The emphasis should be on launching the calculator as early as possible. One of the great strengths of the calculator approach is that it is open, allowing others to view the whole model and suggest improvements. Releasing it early as a “work in progress” rather than as a finished product means that errors can be found and corrected before any policy is based on its results. Most teams choose to release the first version with a “call for evidence” or a consultation, allowing them to get comments directly from experts in a collaborative (rather than adversarial) way. The model can then be improved and a new version released.

When drawing up a project plan, it is important to take into account other events that may impact the timeline. Perhaps there is an existing conference that would be perfect to launch the calculator, or perhaps there is a busy period coming up that is best avoided.

Resources

- Introductory slide pack for use in meetings
- Draft job descriptions and person specifications
- Project plan template

Mapping your emissions

The 2050 Calculator works by splitting up the energy and emissions system of a country or region into different sectors, modelling the energy demand, supply and emissions in each across a 40 year period, and then adding them all together to show the total figures.

The first step is to decide how to divide up the energy and emissions system, and this will depend on the particular economy you are looking at and what you want to find out. For example, residential heating is a major source of energy demand in the UK due to the mild climate. In a country like Thailand, air conditioning will be a more important area to focus on, so cooling would be a more appropriate choice. If a sector is not relevant to you (for example wave power in a land-locked country), do not include it.

In the UK calculator, industry was modelled as one sector, but the calculator of the Belgian region of Wallonia split industry into a variety of sectors so it could be more accurately modelled. The Indian calculator splits electricity supply into low-carbon technologies and conventional technologies, which the team decided was a very useful distinction for reporting results. Or the Chinese split of rural and urban transport. NEED TO ADD MORE INFO HERE

In general you should aim to have:

1. as few sectors as possible so that it is quick to use the tool,
2. but covering the whole economy and all emissions (it is best *not* to ignore land use or industrial process emissions)
3. but you must include all the sectors that people expect, even if they are 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 is about right. In approach, we recommend starting top down, rather than working bottom up (i.e., don't start my thinking of all the possible types of vehicle and how they might be modelled, start by thinking about the transport sector, and what are the fewest sub-divisions that are possible)

For reference, here is a list of the sectors that most calculators so far have used:

- GREG TO ADD

Mutually exclusive, collectively exhaustive (MECE)

The different sectors in the energy economy obviously overlap and interact with each other to produce overall supply, demand and emission figures. It is 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. The MECE principle (mutually exclusive and collectively exhaustive) should become a mantra for the project, so that the same energy or emissions inputs do not 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 is no right or wrong answer.

It may be helpful to consider linked technologies together, as this will minimise interaction between sectors. For example, you could include one sector for heating and insulation, as they interact so much.

Keeping it simple

The abiding principle when building a calculator is the model should be “as simple as possible, but no simpler” – you have to strike a balance between making sure it is easy to understand yet still analytically robust.

If you can simplify the way in which you model a sector without compromising accuracy too much, do. The overall figures, and the major driving forces in supply and demand behind them, are what you need to get right. Modelling the intricacies of each sector can end up making it more difficult for non-experts to understand what is going on. Understandably, experts may not like this approach initially, but it has been key to the calculator’s success.

Building driver trees

Once you have divided the energy system into sectors, it is time to look at each sector in more detail and identify the major drivers behind them. This will help you identify what levers you can pull to change demand and supply. You can do this by drawing “driver trees”. These are simple diagrams that show the way in which supply and demand for energy relate to produce outputs – at the top of a driver tree should be the output the calculator is focusing on, like emissions or fuel use.

Basically, driver trees are another way of displaying the data and calculations you will need in the model. If you get them right, building your model will be a lot easier.

For example, below is a driver tree for international aviation in the UK:

[driver tree] - Another example? - Case study Mexico or Colombia?

Choosing your levers

Once you have a driver tree for each sector, you can quickly see how changes in supply or demand can affect your outputs. Now you must choose which factors you think are the major drivers of change in the sector, and therefore which levers you would like to have in the model. Each lever will allow users to make a choice about what happens in the future.

You can have any number of levers, but somewhere between 25 and 40 is particularly effective. The exact number will depend on your target group and how much time you want them to spend (or how much time they are willing to spend) using the tool. It is unlikely that a decision maker will be able to spend more than 30 minutes 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, you must ask yourself:

- 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 behaviour?

Generally, each sector should have between one and three levers. If there are a few sectors that you really want to focus on, then you could have more. However, remember the calculator's audience. If you choose an obscure variable to change, will a policy maker or an interested member of the public be knowledgeable enough to understand what they are changing and what the different options are? Choosing variables that are relevant to people's lives is much more effective.

For example, if you are looking at international aviation, you could consider the following questions:

- Will people fly more in the future?
- Will more people fly?
- 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 is best to combine related technologies or behaviours together into one lever to make the model easier to use. For example, you could use one lever for the deployment of all small-scale micro-generation, rather than separate levers for micro wind, solar and hydro. Or you can combine demand for lighting and appliances into one lever because they are usually covered by similar policies.

Choosing your outputs

The calculator can show many different impacts of the energy choices that are available. What outputs you choose to include or exclude will depend on what is most important for you. 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.

Finding data

Once you have driver trees for all the sectors, it should be clear what data you will require to populate your model. When building an open model like the calculator, the data you use must be either publically available already, or you must have permission to make it publically available. If you use anything confidential, you will not be able to publish the model. You must 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 you could use. 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 you will need is country specific. The laws of physics are universal, so you will be able to use many of the same assumptions and figures as previously completed calculators. 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 your geographical location.

Sometimes it can be very difficult to get the data you need – perhaps you have split sectors up differently from the data sources so you cannot get the data to match, or the information just isn't collected in your country. In these cases, it is very important that you do not compromise the logic of the model to fit the data. Instead, bend the data to suit the model. Use proxies, estimates and international precedents. Just make sure you document all these assumptions so users can see what you are doing and assess its suitability.

Resources

- Driver tree template
- Decision tree for structuring levers template
- Excel table to choose what sectors/technologies to include

Setting levels 1 to 4

Each lever in the calculator will have four different options available to users, called level 1, level 2, level 3 and level 4. These represent trajectories for increasing levels of “effort” over the period from now until 2050. What this effort means will depend on the aims of the individual calculator. For example, in the UK 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 Indian calculator, effort on the supply side was targeted at increasing energy security rather than reducing emissions per se, as 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 your levers is a challenge, but one that is made a lot easier if you consult experts from government, academia, industry and NGOs. By crowdsourcing opinion in this way, your conclusions will be a lot more robust and confidence in your calculator will grow.

The forces at work

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

- Geographic constraint – for example, the number of houses that could have solar panels installed on them, the amount of land available to grow biocrops, or 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, or 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 your thinking when setting each level.

More about level 1

At first glance, level 1 seems the easiest of the four to pin down. 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 we do nothing, 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 government announced that X technology would no longer be supported, and it was clear that the private sector would not do it alone. In this case, the technology would be quickly phased out, or never deployed in the first place if it is 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 is tempting to make level 1 a “business as usual” scenario that reflects current policy. However, defining it as “no effort” instead allows you to show what would happen without your policies, therefore showing where they add value. It also acts as a baseline that gives people more choice, enabling those with strong views to reflect their opinions (for example, people who are against nuclear power).

More about 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 is 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 programme for the behaviour or technology in question. What could be achieved?
- The opinion of your most ambitious credible expert (perhaps an “evangelist” for a particular technology), backed up by some evidence either from their own calculations or published work.
- Drawing an example of something achieved in another country. If they did 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 advantage of including these difficult options is that the model is able to span the full range of opinion, so it can be supported by a bigger number of organisations. If you do not include the full range of options, the calculator will no longer be a tool exploring the question “what if?”.

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 your existing policies for a sector i.e. you are already taking action 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.

Engaging stakeholders

Once you have formulated draft levels 1 to 4 of all your levers, it is time to go out and ask the experts what they think. We suggest holding a half-day or whole-day workshop for each sector to gather the experts together and get the debate going.

So who should you invite? You want to get a range of opinion, from the more conservative to the more extreme end – there will be people who believe passionately in a particular technology, or the potential for behaviour change. These voices should be welcomed, as long as they have good evidence to back up their claims. The sort of people you may want to invite include:

- Representatives of major companies
- Representatives of professional or trade bodies
- Academics
- Representatives of environmental NGOs or action groups
- Those working in government

The focus should be on setting the levels, and perhaps some of the assumptions you have used. You should avoid discussing the underlying methodology of the model. This should already have been informed by stakeholders at an earlier stage, and opening up the debate again can be very time consuming. At the start of the workshop, you should introduce the calculator project and its aims. The main messages you want to get across are:

- The 2050 Calculator is designed to simulate different possible futures.

- It needs to take into account 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:

- You could 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 you haven't taken into account?
- Specify what assumption you are exploring, 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-its together grouped by level, and discuss areas of agreement and disagreement.
- use an example from one of the existing countries

If you do not want to host large workshops, you can instead hold a series of smaller or 1:1 meetings with experts. The calculator team in Mexico have used this approach. It takes longer, but you may get more honest or focused feedback.

Writing your one-pagers

Every lever in the calculator has something called a “one-pager” that the user can refer to. This explains the background to the lever and what each level means. They are usually 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 is extremely important to be clear and concise – remember that your audience may not be energy experts, and so technical terms 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 that level of deployment. This should include all the main figures involved (being consistent with units so that they can be compared), but not so much detail that the reader will become bored or confused.
- 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. This bar chart should have the same scale across every one page note, so 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 them out on colleagues who are not working on the project early on, to make sure they are easy to understand.
- Need examples of whole one-pagers, e.g. South Africa and India. Include a case study like Mexico? China hydro a good example.

Resources

- One-pager template
- Template presentation for workshops

Building the calculator spreadsheet

The master version of the calculator model is developed entirely in a single, stand-alone Excel workbook. The workbook therefore contains its own user interface and all of the assumptions and modelling methodologies required to calculate the implications of the user's selected pathway for energy, emissions and all other implemented outputs.

Building the Excel model is a sizable task, which requires knowledge of a number of specific concepts that are unique to the calculator. These are perhaps best learned in turn, and to reflect this, the explanation of each concept is presented here within its own appendix. A list of these appendices is given below, with an outline of its content.

- Appendix 1: The Excel^{**} **model structure** – a full description of the different components of the model and how they fit together. Firstly, we introduce the user interface, or ‘control’ worksheet. Then we explain the concept of ‘sector’ worksheets sheets, using the offshore wind sector as an example. Finally, we describe the process used to combine all the sector outputs to form concise results for the full energy system, with the use of ‘year’ sheets and then the ‘intermediate output’ worksheet.
- Appendix 2: Complex Excel^{**} **formulae** – here we explain the more difficult Excel conventions used in the calculator, which experienced Excel users may not be familiar with, and show how they are used in the calculator.
- Appendix 3: Vectors^{**} – this explains the system used in the calculator to categories quantities of energy or emissions by type.
- Appendix 4: Units^{**} – detailing the calculator’s approach to handling units in a flexible way.

- Appendix 5: Balancing^{**} **mechanism** – this explains the way in which the UK calculator ensures that supply and demand in the electricity sector are balanced.
- Appendix 6: Calculating^{**} **emissions** – shows the simplified approach used in the model to estimate GHG emissions.
- Appendix 7: Stress test^{**} – an explanation of the way in which the model accounts for intermittency in the electricity sector and calculates any backup generation requirements.
- Appendix 8: Bioenergy^{**} – how the amount of bioenergy in the energy mix is calculated, how this is converted for different types of usage and how the impacts on emissions are calculated.

NB: these appendices are designed so that they can be read in order or can be dipped into to retrieve particular details.

Common Excel errors and how to avoid them

We have seen from our own experience with the UK 2050 Calculator that it's too easy for small errors to cause big problems in results. In the calculators launched so far, we have also found a range of issues which can occur in the Excel file. These include problems such as:

- Simple typing mistakes
- Missing units when entering data
- Labelling which still talks about UK version
- Documentation that isn't complete or easy to understand
- Formula errors, which are often subtle to spot

However most of these problems are preventable. We've put a lot of work into helping teams to avoid making those errors, and creating systems to pick up issues when they do occur.

This section (and the accompanying slide-pack available on request from the 2050 team) give a quick overview of the three main types of common issues we've seen, and some checklists of actions that you could take to avoid them.

- Errors in the excel formulae (e.g., use of units)
- Errors in the excel layout, documentation, labelling, supporting documents (e.g. referencing sources; labels that relate to the UK version but not the local version)
- Errors in the assumptions (e.g., the different levels for nuclear build)

Errors in the excel formulae

Errors here mean that the answer will be wrong.

The first type of problem is when data is entered incorrectly into the model. This is most likely to happen in the Trajectory assumptions or Fixed assumptions parts of the spreadsheet.

In other models we have seen errors such as the following:

Issue	How does this cause problems
Numbers entered without multiplying by the relevant units	As an example, you cannot just enter the number 0.6 into a cell, as this will cause problems in future calculation (especially if you ever change the preferred unit). Best practice is that you must always multiply an input value by a unit: See 4 (Units) for guidance about how this should be done
Missing data in certain years	Having blank cells rather than numbers in a baseline year or the final year could make a big difference in the charts, E.g. when you're using 2010 and 2050 values to estimate values in earlier years, a missing number in each cell could cause errors

The next type of issue is when formulae refer to the wrong input value, giving an incorrect calculation and results.

Issue	How does this cause problems
Numbers entered without multiplying by the relevant units	Inconsistencies: E.g. a formula which referred to cement, but it gathered the data for 'Chemicals & petrochemicals' E.g., one model was referring to new capacity where it should be cumulative (or vice versa)
Linking up levers to the wrong user input setting	For example, in one model, the sub-lever for carbon capture and storage efficiency was incorrectly linked to fossil fuel efficiency, rather than 'carbon capture and storage'

Links to named ranges that no longer exist	References to deleted cells – these will cause #REF errors) e.g. Global hot water and Global cooking calculations gave #REF errors, as they refer to now nonexistent non-residential cells
Errors with sums that refer to incorrect rows or miss out a row)	When copying a formula down, it's easy to accidentally cause errors: e.g. In one model, a row was supposed to sum all rural passengers, but excluded the last two types of transport (global rural trains) e.g. A household total double-counted the rural households by including the rural subtotal in the sum.
Looking up values incorrectly	Looking up a value by only one variable, when it needs to match against another variable too e.g. The costs are looked up by fuel type, but not the selected cost estimate (point/high/low)
External link errors	Sometimes formulae showing as #REF or with outdated numbers because they link to a separate workbook) Appendix xxx gives guidance on this
Incorrect totalling	e.g. Numbers should add to 100% for different types of transport. If they don't, subtle problems will appear later To solve this, we advise setting up a formula so that one of your values is set to be 100% - the sum of the others Alternatively you could add checksums below each table, to show the sum of all values, and display an error message if the total isn't 100%

The third type of formula errors are calculations that are incorrect. These are logical errors in the steps of a calculation, and are often subtle to spot. For this reason, it's good to get other people to look at your work, and look for errors such as these below:

Issue	How does this cause problems
Formulae with hardcoded numbers	When formulae use hardcoded numbers, small changes can overwrite them e.g. A formula that hardcoded growth rates which varied over the time period. This became wrong when copied to the right, as the hardcoded value for later years was overwritten by earlier years of data
Duplicate and inconsistent data	For example, population figures used frequently should be looked up from global assumptions. Then changes only need to be made in one place
Using figures as if they are a different unit	It is important to double-check that you know the units of all input data: e.g. In one model, a calculation tried to use cost data related to manufacturing, but this was actually still in units of energy. e.g. A cell accidentally used unit.minute, instead of unit.m e.g. One model calculated area by multiplying by a ‘per GW’ figure. However because this calculation was for just one plant (which could be 1/1,000 GW) the order of magnitude was very wrong

Using the MATCH function with only 2 arguments, rather than the 3 needed

The MATCH function behaves strangely when the third (optional) argument is missing: 'match type':
MATCH (*lookup value, lookup array, match type*)

If the third argument is missing, it defaults to 1, finding only 'the largest value that is less than or equal to the lookup value'

Best practice is:

Never leave a MATCH formula with only 2 arguments

Always use 0 as the last argument, so your formulae should look like this:

MATCH (*lookup value, lookup array, 0*)

This means finding "the exact match of the lookup value, and in this case the values in the lookup array can be in any order"

Extrapolating incorrectly

Many formulae in the calculator use interpolation: this means using the values of two years (e.g. 2010 and 2050) and calculating other figures based on a straight line increase between these numbers.

One problem is that numbers that can become negative when they shouldn't be able to. For example, production numbers which are decreasing, and went below zero when extrapolated into the future e.g. for calculations which multiply the average yearly use by the number of years, make sure that they adjust to intervals less than 5 years (e.g. 2011 to 2015 should use 4 years)

Formulae copied to another place without crucial changes

When copying a formula to be used in a slightly different way, make sure that any necessary changes are made: E.g. In a calculation where number of households is always urban- the reference didn't change for the urban calculation

INDEX/MATCH formula refers to different tables	E.g. a formula which uses the ‘index’ function, but matches against a different table to where the data is coming from
Forgetting to use weighted averages	Forgetting to use weighted average (or weighting by the wrong variable) e.g. when taking an average of 3 technology costs, you will probably want to weight them by energy use or capacity, rather than a straight average.
Unclear Changes in formulae	Ideally avoid formulae that change midway through an array, row or column. But if critical, use comments to state this has happened and why

There are also issues with vectors that are well worth checking (see Appendix 3 - Vectors for details of how vectors work within the model).

Issue	How does this cause problems
Vectors that don’t balance	You can check this by looking at the row that should be zero in intermediate output sheet
Invalid conversions	Conversions between vectors (e.g. solid-liquid biocarbons) without the corresponding calculation of energy loss
Vectors not Exhaustive/ mutually-exclusive	Good practice is that vectors are distinct, and any type of energy is clearly allocated to one vector (unless it’s deliberately converted to another type)

Errors in the excel layout, documentation, labelling, supporting documents

Errors here mean that others won’t be able to follow the work, and will have lower confidence in the answers

The types of error that we have seen in documentation are the following:

Issue	How does this cause problems
References left from the UK version	<p>It can get confusing when references are left from the UK version, especially if it's not clear whether the numbers have changed:</p> <p>e.g. Mentions of oil/coal in a sheet which now only includes calculations for gas</p>
Leaving calculations blank	<p>Good practice would be to either: delete calculations if they will never be used</p> <p>leave the calculations in the file, but clearly label that they are out of scope for the first phase of the calculator launch</p>
Incorrect table titles	<p>e.g. Table title is “per year”, but the descriptions are “per day” and the equations calculate figures per day</p>
Incorrect documentation	<p>Unclear or ambiguous documentation about assumptions</p> <p>e.g. what counts as import vs. domestic</p>
Incorrect units	<p>Incorrect units (e.g. figures which are expressed as % but the unit of the table is listed as households)</p> <p>Descriptions e.g. 1 years, when it's 5-year incremental capacity</p>
Incorrect rounding	<p>Is rounding performed in a correct way? Are rounded numbers and original numbers used in the correct places?</p>
Sector sheet names	<p>Sector names can be hard to understand,</p> <p>We have also seen cases where they don't match the names of the levers</p> <p>e.g. the name of the sheet might be Iv.a but the label at the top of the sheet says Iv.b</p>

Complex and undocumented calculations	When complex calculations aren't described fully in methodology, it becomes very difficult for other people to understand what has been done. It will also make future updates by your team much more difficult
Wrong sections of sector sheet	For example, if numbers are listed in fixed assumptions section but depend on settings for trajectories, changes could be made incorrectly
Inconsistent structure between worksheets	It gets difficult to understand workbooks if the structure is inconsistent across worksheets E.g. do similar worksheets have similar structures? Are similar tables laid out in similar way?

Errors in the assumptions

Errors here mean that the answers given by the model won't reflect the true breadth of opportunity the country face

Issues in the level of ambition of levels 1 and 4 can include:

Issue	How does this cause problems
Lack of ambition in level 4	Level 4s which don't seem as ambitious as they could be e.g. some of the transport levers in the UK model
Jumps in one or more years	In general, trajectories seem most believable when they increase in a straight line, or in a curve. At times, it is understandable that some trajectories may increase rapidly towards later years, or have a delay in starting. However when a particular year is unusually high/low, and the years immediately before and afterwards are inconsistent, it tends to indicate an error

Surprisingly high level 1s	Level 1 should represent a ‘do nothing’ option. For example, this may involve closing existing/planned capacity early.
Incorrect overlap between levels	Trajectories where level 3 is sometimes more ambitious than 4 (like the example below)
Missing inter- relationships between levers	Missing out dependencies between different trends (e.g. if household numbers rise, everything depending on those should rise)
Putting key figures as fixed assumptions	For example, assuming a certain figure (e.g. industry growth) is a particular level, without giving the user a choice in varying this
Assumptions that aren’t documented	e.g. if biofuels count as zero emissions, this must be documented and implemented in all relevant sheets

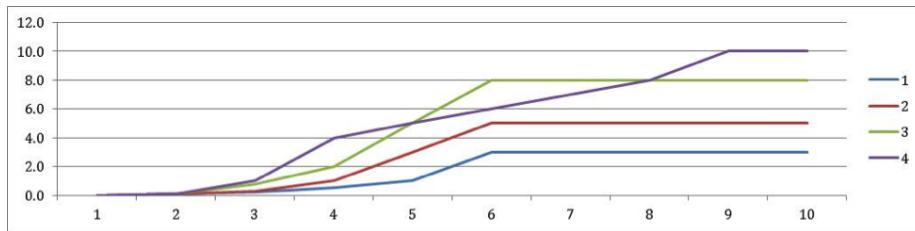


Figure 1: Image showing a situation where level 3 is more ambitious than level 4

Putting the calculator online

One of the unusual things about the 2050 calculator is that you can use it over the internet. This section describes why we did this, and what is needed for you to do it. Detailed instructions are in an [appendix](#).

Why build a web interface?

1. More people will use the model.
2. The model can be used in interactive presentations and debates.
3. The model will run faster.

4. It will be easier to share results.

What sort of web interface should you build?

Choice around:

1. number of choices you present
2. range of consequences you present
3. balance between presenting numbers, and presenting impression

We went for two different web interfaces:

1. One that sticks very closely to the Excel spreadsheet, presenting 40 or so choices, many consequences, using number and being quite dry. Target is people who are already interested in the subject. (In the UK, we call this [the webtool](#)).
2. One that has only 14 choices, displays only a few consequences, mainly presents pretty graphics. Target is people who are not initially interested. (In the UK we call this [my2050](#)).

What do you need to build one?

Skills required: 1. Some Javascript 2. Some ability with ‘the command line’ 3. Ideally, some ruby, but not too important

Level required: 1. Someone who is enthusiastic about programming and has done some before (perhaps as part of an engineering or science degree) is sufficient.

Time require: 1. If it is very similar to the UK version, then it can be ready in a couple of weeks of amateur time. 2. If it is different to the UK version, then may take some months.

What steps should you take?

1. Decide what consequences are important to your users
2. Decide what choices are important to your users
3. Get the UK version working on your system
4. Replace the UK model with your model
5. Adapt the first screen of the online tool to fit your needs
6. Gradually introduce other charts and views

When should you start?

Start as soon as you have a more-or-less complete spreadsheet. The spreadsheet doesn't have to be finished: it is ok for the numbers and formulae to change. However, it is best if the structure of the spreadsheet (e.g., number of years, number of sectors, output tables wired up) is more-or-less finalised.

Things you might be tempted to do (but perhaps shouldn't)

You may be tempted to:

1. Try and drive the Excel spreadsheet directly, using Microsoft interfaces. We've found that this is too slow and too unreliable for a good user experience.
2. Put more than 40 levers on the online interface. We found that this means you can't get a good overview of what is going on, and takes too long for people to use.

Reducing the number of choices you present to the user

You will probably want to have a version of the web interface for experts, that pretty much exactly replicates the Excel, but in a quicker, easier to use form. You may also want to have a simpler web interface for non-experts (in the UK we call this [my2050](#)). To make it simpler, one of the things that you may need to do is to reduce the number of choices you present to the user.

This involves going through each choice in the Excel and deciding whether to:

- A. Keep the choice in the simple interface (e.g., Nuclear power was kept in the UK my2050 version)
- B. Not include the choice, but instead leave it set at one level (e.g., Geosequestration is always set at level 1 in the UK my2050 version)
- C. Combine the choice with another choice (e.g., The Heating Choice lever in the UK my2050 version actually controls 4 levers in the Excel spreadsheet at the same time).

Resources

1. The source code to the UK interface is available at <http://github.com/decc/twenty-fifty>.

Launching your calculator

Congratulations on producing a working calculator and web tool! But your work is not over. It is now time to let the world see it, improve it and use it. The first step is by releasing it as a prototype version with a call for evidence, so that experts and stakeholders can comment on it. We would recommend that you do this as soon as possible – the longer you wait, the more difficult it will be to make changes.

The benefits of being open and transparent

It is worth reiterating that by publishing your full model, you increase the chance of its success. Here are a few reasons why:

1. There may be ideas you haven't thought of yet. By letting your target audience make comments before it is completed, they can make suggestions that can improve the tool and also make it more likely that it will be used in the future.
2. Every model, no matter how careful its creators are, will have bugs in it. You are more likely to find them if you open up the model and allow others to look inside. You shouldn't be scared of this – it is better to find them and correct them rather than to leave them in there. The risk of finding a mistake is much lower if you find it now before you have based any policy on the model's results.
3. People will trust the results of the model more if they understand how it works and know what data it is based on. This is true whether they are policy professionals, politicians, journalists or members of the public.

Example pathways and key messages

You may want to consider publishing some example pathways at the same time as the actual model. Although one of the benefits of the calculator is that there is no “right” answer, supplying your users with some options is a good way to get them thinking about the model's implications. For example, you could have a “maximum supply effort, no demand effort” and the converse “no supply effort, maximum demand effort” pathways, and also some that meet your national targets. You do not have to label them as officially approved pathways if that would be politically difficult, and can instead stress that they are just examples. You could even get some of your key stakeholder groups to design their favourite pathways for the future. By doing this, you will give your stakeholders a concrete way to engage with the calculator project, and you will show that the tool is useful for a variety of audiences,

It can be extremely powerful to publish the key messages you have learned from the calculator. As the team that developed the model, you 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 those policy makers who have limited time to use the calculator themselves, as they can benefit from your experience when developing policy. You could answer questions such as:

- How much could fossil fuels cost the country in 2050?
- How much demand for electricity could there be in 2050?
- Can you decarbonise the electricity grid?
- How much can you achieve with energy efficiency alone?
- What are the limitations of bioenergy?
- More?

Holding a successful launch

The tactics you use for launching your calculator's call for evidence will vary depending on your country or region's own circumstances. You may want to have a very "soft launch", publishing the model with little fanfare and inviting particular experts or organisations to comment on it. In this case, you can hold a public launch for the second, improved version of the calculator instead. Or you may want to launch your initial version very publically to get the largest number of people using and commenting on the calculator in the shortest time frame. Think about what is most appropriate for you.

If you want a public launch, you could hold a press conference or more informal launch event that the press is invited to. The presence of senior officials like ministers sends a message that this is an important tool and that it has the support of the government. If you decide to hold a press conference, it is important to think about the implications of the model that you would like them to cover – journalists are more likely to be interested in what you have found out by using the tool than in the fact that the tool exists.

It is important to make it easy for people to give you feedback. For example, you could have a link on the web tool to your call for evidence page or an email address so that any visitors to the page can respond easily.

- More tips for launching your initial version

Case study – Taiwan. Information on launch event (with picture of their light up desk), and their communications strategy, including the FB competition

Improving and re-launching the calculator

When you receive responses to your call for evidence, it is of course imperative that you read the comments and make changes as appropriate. It is likely that others will have found mistakes or will think of new ideas that will improve the calculator and make it more relevant for your target audience. Set aside time for this process. You may want to 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 to get right.

You can then re-launch your new, improved version of the calculator. It is up to you to decide how big your re-launch should be - if your first launch was low-key, then you could consider this as the main launch and try to get press coverage. Or perhaps your changes have been relatively minor, in which case you can quietly update the version available online.

Influencing policy

The finished calculator should be interesting for everyone working on energy and climate change issues, but to make it something more than just a fun tool, it needs to be used by those with power and influence. 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 out different scenarios. By laying out all the options that are technically possible in front of you, it lets you easily compare different combinations and see their implications.

Testing existing policies using the calculator

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

Alternatively, you could create a “current policies” pathway using the calculator. To do this you need to 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 different policies can be very complicated. However,

even a rough pathway can be useful in internal discussions, helping you to find gaps in your plan.

Developing 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 you have learnt from the calculator should be your starting point. If your existing strategy does not match these, then consider changing it. You want your policies to 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 carbon capture and storage technologies CCS at scale), it may be best not to set a strict pathway for the country or region at this point. 2050 is still quite a long way away. Consider releasing a few possible pathways instead.

Data management and data reporting

Many countries, particularly developing ones, have limited emissions and energy reporting capability. A calculator can provide an easy way of recording the past and reporting progress.

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

Box: The calculator and UN reporting

Under UNFCCC agreements, developed countries are required to submit economy-wide emission reduction targets, which include plans for how this will be split between different sectors and the assumptions that have been used to set the ambition of the targets. Developing countries have agreed to take nationally appropriate mitigation actions (NAMAs), and can voluntarily report these to the UN. They should show how the country will reduce its emissions relative to a "business as usual" scenario. The calculator can be a very useful tool for countries in drawing up their plans in accordance with these UN agreements. With the calculator you can model your current energy requirements and emissions profile,

map your business as usual scenario, and monitor progress against your goals. You can then see all your options and identify those that make the most difference, and even examine the cost associated with them. Evidence from the calculator can make your plans more robust, accurate and credible.

DO WE NEED UNFCCC AGREEMENT THAT THE CALCULATOR IS USEFUL?

Box: Case study – China

Examples of how the Chinese calculator has influenced policy

Engagement and education

Climate change and energy security are two of the greatest challenges we face in the coming decades around the world, but there is still little understanding of the impacts they could have and the possible solutions. This lack of awareness is not just a problem among the general public, but also for those in business, industry and even in government and politics. The calculator can be used as an interactive educational tool to help get people thinking about these issues, and also to show that the government is thinking about them too.

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 the lever options in an easy to use format. This can help people understand the energy system, identify the choices that make the biggest difference, and let you know their preferences. You could promote the tool within your own organisation, other government agencies, universities and companies. There are many ways you can reach your audience:

- Face-to-face approaches, which could be one-to-one briefings, workshops in which people build a pathway together, or presentations. There are probably lots of existing events that your target audience will be attending, and you could present the calculator and its key messages at these.
- Help others to talk face-to-face about the calculator by holding “teach the teachers” events or producing toolkits to help people demonstrate the calculator.
- Get people reading about the calculator by including your key findings in wider documents, getting press coverage or writing blog posts.

- Hold a competition within your organisation to encourage people to submit pathways to you. The winner could either be randomly selected or could have produced the “best” pathway in a particular way
- Make the calculator part of the induction programme for new staff in your organisation.

My2050 – a tool for public engagement

My2050 is a simplified version of the full calculator with an attractive user interface. It is designed to get members of the public, including children, interested and engaged in energy and climate change issues through interaction with the tool.

This version of the model has far fewer levers to play with – for example, the UK’s My2050 has 14 levers, while the full web tool has 42. You have to think carefully about which levers to choose. As a group they should cover all the major parts of the energy system and all the big choices we need to make (ignoring the levers that have a low impact), and individually they must be engaging and easily understandable for someone with no background in energy and climate change. Sometimes you may have to combine a few of the full calculator’s levers together to make sure that you cover all the choices that are available.

Generally it is a good idea to choose levers that relate to people’s daily lives, like transport or home energy efficiency, as well as issues that really get conversations going, like whether to use nuclear power or renewables. This 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 very important. Think about the best way of displaying the data and results. Graphs can be very effective, but you may want to use animation to show more directly show the impact of the user’s choices. For example you could show a landscape where solar farms or electric vehicles appear, or a house which the user could make more efficient. You could even display the secondary results of the user’s pathway, like air quality or temperature changes. This is a chance to be really creative.

It may be a good idea to make My2050 into a game by having a target or goal that the user has to reach. In the case of the UK, the goal was obvious the country has an emissions reduction target set in legislation, but in other countries it could be more difficult to define. You could always just ask people to create a 2050 world that they would like to live in.

Users should be able to submit their pathway to the modelling team. This is both so you can get a better idea of what the public are thinking, but also so that the user feels that they have a voice and that they have accomplished something.

The UK My2050 website was developed by an external agency (Delib). All of the images and back-end code are owned by DECC and can be shared. However, some countries have subsequently used a slightly different approach to producing their My2050s which may be more quickly and easily adopted by other countries.

CAN WE INCLUDE ANY MORE ON THIS? Ed has a project spec for Colombia. Could be included.

Using My2050

Now your My2050 is ready, it is time to get people using it. There are many tactics you could use, but here are a few ideas:

- Use the press to spread the word – getting a few stories into newspapers, magazines or on popular websites will increase your potential audience. Although there are people who are already very interested in energy and climate change, your tool will have the most impact if you can get people to use it who don't usually think about these issues. For example, the BBC News website include an article about the UK's My2050 and xxxx people submitted pathways within a few days.
- Use social media – make sure that people can share their finished pathway on Twitter and Facebook, so that their friends can see it and have a go.
- Run a competition – you could offer a prize to one lucky user picked at random, or perhaps to the person who gives the best answer to the question “I chose my 2050 pathway because...”.
- Hold workshops – you could arrange workshops for interested members of the public across your 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 science, technology or education exhibitions so that people passing can have a go at using the tool.
- Encourage its use in schools – My2050 is a great way to explore issues around energy and climate change for children of secondary school age, and it is relevant to subjects like geography, science and maths, as well as the social sciences. Create a website or resource aimed at teachers to show them how they can use the tool in class and explaining what the pupils can learn from their experience.

Case study: the Taiwan My2050

To add. Ask for technical spec.

Resources

- Is there software you could use or something?
- Colombia call for bids

Keeping the calculator alive

Your calculator should be a living tool that is added to and updated to suit your needs. Perhaps there is a new question you want to answer, or opinion has changed about how ambitious your trajectories should be. Maybe more recent data has become available that could be used as a new base line to make sure your results are as accurate as possible. Keep improving the tool, and it can keep having an impact.

The calculator network

With so many teams around the world building their own calculators, there is a great opportunity for people to share their experience and expertise with others, and help spread the calculator message of transparent modelling and evidence-based policy making. That's why we've created a website with resources and an online community – www.2050calculator.net. We hope you will use it not only to ask questions and get support, but also to support others. Every team building a calculator has unique challenges and also brings their own skills and ideas. These may be very useful for someone just starting out or facing similar issues.

Beyond energy and climate change

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

1. It models each sector using a “driver-tree” approach, showing the major forces that produce overall figures. Such an approach could be useful in understanding anything with a quantitative description.
2. It brings all the sectors together in a common framework. This could be useful in any subject that involves trade-offs. Here are some ideas for ways the calculator could be used:
 - Land use – with a limited amount of land available in each country, there are likely to be trade-offs to be made about how that land is used as

populations grow and economies develop. A land calculator could ask how much land you should devote to agriculture or housing, or how much food can be grown using different farming techniques.

- Taxation – a tax calculator could help you understand how different combinations of tax policies affect overall tax revenue. ED QUESTIONS THIS BUT JAMES LIKES THE IDEA.
- Government spending – a government budget calculator could help explore per capita spending in different sectors, and compare this to outcomes. This could give some quick insights into how effective spending is, which areas could be prioritised, and an estimate of future subsidies.

You may have your own ideas – please let us know on the forum at www.2050calculator.com

Case study: Vietnam

by Hoang Van Tam, Head of Climate Change Division, Ministry of Industry and Trade, Vietnam

The controversy of climate change has been debated in this country. The adaptation and mitigation issues are difficult to decouple in the context of development progress in Vietnam. My colleagues from Ministry of Planning and Investment found out about the 2050 Calculator by chance by attending a workshop in 2012 in Manila, Philippines where I learnt about the tool. So, while visiting the UK in the middle 2013, I got detailed information about the 2050 Calculator from DECC's experts and more understanding about the application of the tool. I decided to set up a local team to develop the Vietnam 2050 Calculator with the help of DECC's colleagues.

Most of the difficulty in building the national team was in selecting the Excel expert, co-ordinator and team leader. I understood that the Excel expert has to be not only good at Excel or information technology, but must also have good knowledge of the energy system. And the team leader has to have a wide understanding of energy and also a lot of experience of climate change issues. The co-ordinator is a very important role for the project's progress, as they have to have good relationship with team members and officials in the line ministries. So, fortunately with my experiences of project management, I found them and am very happy with my selection because they addressed all my requirements.

For other team members, I selected them based on the suggestions of the various line ministries, who knew the appropriate sector experts and could introduce them to me.

I have been the climate change focal point for the Ministry of Industry and Trade for many years, and so it was easy for me to communicate with line ministries and experts. Actually, most of representatives from ministries and experts have

been working recently on climate change and green growth issues, and were very open to sharing, exchanging ideas and working together. This may be one of reason for facilitating the progress of the project and its successful outputs.

Beside the Vietnamese team's efforts, the most important thing was the strong support from DECC and the flexibility of co-operation from the British Embassy in Hanoi during the project implementation.

- Contact Hoang Van Tam by email: tamisea2011@gmail.com
- [Visit the Vietnam 2050 Pathways Calculator](#)

Case study: South Africa

by Kent Buchanan, Control Environmental Officer, Department of Environmental Affairs, South Africa

South Africa is one of the few countries within the 2050 Calculator community to boast the completion of three outputs: the [2050 Pathways Calculator](#), the 2050 Excel workbook and the MY2050 Calculator. These are available online for anyone to access. The 2050 Pathways Calculator and the complementing 2050 Excel workbook, released in March 2014, are aimed for those with a more technical background while the MY2050 Calculator is aimed at people without a technical background including students.

The journey began in 2012 when representatives from the South African Department of Environmental Affairs (DEA) climate change mitigation team (Ms Deborah Ramalope, Chief Director: Climate Change Mitigation and Ms Olga Chauke, Director: Energy Mitigation) were invited to participate in the International 2050 Pathways Conference in China. The South African government found value in the calculator as it provides a user-friendly approach to analysing energy systems at a national level. Because DEA has been entrusted with the national responsibility of sensitising citizens of South Africa around climate change issues, the 2050 pathways Calculator provided an opportunity to do exactly that: it enables users to explore the options for reducing emissions and understanding the impact of their choices associated thereof.

When DECC expressed its willingness to provide funding and technical support for countries to adapt the tool, South Africa jumped at the opportunity. Subsequently the DEA signed a memorandum of understanding with the British High Commission and the UK Department of Energy and Climate Change(DECC) to develop the 2050 Pathways calculator for South Africa in January 2013. Some of the key activities undertaken during the process of developing the tool included:

- Dividing the energy system into four sectors (energy , transport, industry and agriculture forestry and land use (AFOLU)

- Developing an Excel model structure for South Africa (supported by the DECC team) that includes sector specific Excel sheets (compiled by the ERC)
- Conducting sector specific research (sector leads within the DEA led the process)
- Stakeholder engagement with sector experts within and outside government to further develop the tool, for example defining levels 1-4. Three workshops that included business, civil society and government officials occurred.
- Appointing sector experts to review the 1 pagers and datasheets
- Building the online webtool

After a year and months of hard work the 2050 Pathways Calculator for South Africa was officially launched by the Director General of the Department of Environmental affairs on the 26 of March 2014. The development of the 2050 Pathways Calculator was supported by the University of Cape Town's Energy Research Centre (ERC) who were contracted to build the 2050 Calculator model. Much of the data was based on the South African TIMES model, which is housed at the ERC, and most assumptions were based on specific policy documents.

Our greatest challenges during the development process included gaps in primary data as well as adapting the UK Excel template to suit the context of South Africa.

The MY2050 Calculator is to be released at the end of March 2015. This version of the 2050 Calculator sees a reduction in lever options and a bold and attractive online interface where the focus is specifically on greenhouse gas emissions. A thermometer gauge allows the user to track how close they are to the South African GHG emission reduction trajectory Range, commonly known as South Africa's Peak, Plateau and Decline (PPD) GHG emission trajectory as they try different lever combinations. The MY2050 application is directly connected to the 2050 Pathways system.

Using the 2050 Calculators

The 2050 Pathways Calculator as well as the MY2050 Calculator are valuable tools to be used in the public. A primary use of the 2050 Pathways Calculator is to gather input from stakeholder groups on how they envision a low-carbon trajectory up to 2050. This input comes in the form of user-pathways that have been workshoped by the respective stakeholder group. The MY2050 Pathways Calculator is currently being emphasised as a tool to complement Grade 9, 10 and 11 students' life sciences and geography curricula. A partnership with a government programme that is training teachers in the new environmental education curriculum, Fundisa for Change, is being pursued.

Lessons learned: Effectively rolling out the 2050 Calculator

- Before you build the 2050 Calculator have a clear idea of how you want to use the calculator. Is it an educational tool? Is it to assist policy development? Is it a research tool?
- Early on in the development process investigate synergies with other organisations and government departments. As we have found, there are many initiatives out there that promote low carbon energy futures and partnering with relevant projects or programmes can mutually benefit both.
- Develop a ‘living’ communications strategy early on in the development process once the target audience and impact of the calculator has been identified. This strategy will constantly evolve, but the earlier you start, the more advanced the strategy will be to roll out the calculator once it is ready.
- Our calculator team does not have the resources to efficiently share the calculator at the individual level. We therefore strive to target specific nodes that can further share the calculator with their constituency. For example, we plan to train teachers in charge of relevant subjects (e.g. geography, life sciences etc.) at the provincial level who can then disseminate the calculator to the teachers at the local level.
- The 2050 Calculator is a complex energy model that contains a certain degree of data gaps and it relies on many assumptions. Framing the calculator accurately for the target audience when it is communicated is important to optimise engagements into being constructive. For example, it is important to be transparent with the limitations and remind the audience that this is a scenario building tool.

Project Management team for South Africa:

- Project Leader: Deborah Ramalope, Chief Director Climate Change Mitigation, contact email: Dramalope@environment.gov.za Tel: +27 12 399 9160
- Project Manager: Olga Chauke, Director: Energy Mitigation, email: Ochauke@enviroment.gov.za, Tel +27 12 399 9161, supported by Kent Buchanan, Control Environmental Officer: Energy Mitigation, email: Kbuchanan@environment.gov.za Tel: +27 12 399 8868
- The modelling support team was led by Andrew Marquard, email: andrew.marquard@uct.ac.za Tel: +27 21 650 3230

Case study: The nuclear sector in the Japan 2050 Low Carbon Navigator

by Mustafa Moinuddin and Takeshi Kuramochi, Institute of Global Environmental Strategies (IGES)

Introduction

Japan is at a crossroads in choosing its future energy and emissions reduction policies. The 2011 earthquake and subsequent accident at the Fukushima Daiichi nuclear power plant compelled the policymakers to rethink the country's previously-adopted energy policy which was based on nuclear power as the mainstay of Japan's energy supply. Ensuring Japan's future energy security thus has become a major policy issue. At the same time, Japan's commitment to reduce its greenhouse gas (GHG) emissions by 80 per cent (below the 1990s level) by 2050 is faced with challenges, since a decreased dependence on nuclear power has already increased Japan's use of fossil fuels for power generation at least in the short term. The choices Japan faces now include, among others, whether to focus more on cutting its energy demand or relying more on decarbonising on the supply side, how to generate electricity, and what types of technologies to use.

The Institute for Global Environmental Strategies (IGES) and the National Institute for Environmental Studies (NIES) jointly started working on developing the Japanese version of the 2050 Pathways Calculator in 2013 with technical support from the UK Department of Energy and Climate Change (DECC) and the British Embassy Tokyo. The prototype of the Japanese version, known as Japan 2050 Low Carbon Navigator (Low Carbon Navigator), was pre-launched during a trial session with different stakeholders in May 2014. The full version was launched for the general public in July 2014. Two versions of the Low Carbon Navigator have been developed. An Excel version provides a complete picture of the model including data and underlying assumptions, and is useful for expert audience (the model can be downloaded from <http://www.2050-low-carbon-navi.jp/web/en/>). A more simplified Web Tool is for policy makers and general audience, and can be accessed at <http://www.en-2050-low-carbon-navi.jp/>.

The Low Carbon Navigator provides a platform for engaging in dialogues on the challenges and opportunities of the future energy system and the responses to climate change. This transparent and handy tool can help answer the key questions of how Japan's energy system may evolve over the next few decades and how it will affect the country's GHG emissions, energy security and import dependence, electricity systems, energy development and related costs.

Post-Fukushima uncertainties in Japan’s nuclear power sector

Japan has a long history of nuclear energy, dating back to the 1950s. Decades of aggressive deployment of nuclear energy made Japan a leading producer of nuclear power of the world both in terms of the total number of reactors and net electricity capacity. Before the Fukushima Daiichi nuclear accident in 2011, Japan’s nuclear sector had a capacity of 49 gigawatt (GW), which produced around 288 terawatt-hour (TWh) of electricity in 2010 (International Energy Agency, 2013). Not surprisingly, nuclear energy became a significant contributor to the country’s energy and electricity sector. For example, the nuclear sector accounted for around one-fourth of Japan’s total electricity generation in 2010 (Energy Data and Modelling Center, 2014). Nuclear power supported meeting Japan’s growing energy demands during the country’s rapid economic growth, and helped reduce the dependence on the import of conventional/fossil fuels. In addition, Japan’s ambitious emissions reduction targets have also been set assuming increasing dependence on nuclear power.

Japan’s pre-Fukushima energy policy aimed for further expansion of nuclear power in the future. Japan’s 2010 Basic Energy Plan called for the construction of 14 new nuclear power plants between 2010 and 2030—this in addition to the 54 reactors already existing (Ministry of Economy, Trade, and Industry of Japan, 2010). This nuclear power expansion plan would have increased the installed capacity from 49 GW in 2010 to 68 GW in 2030, and the electricity generation from 288 TWh in 2010 to around 540 TWh, or nearly half of total centralized power generation (from “general electric utilities”) in 2030 (Ministry of Economy, Trade, and Industry of Japan, 2010).

However, Japan’s nuclear power sector received a major blow when the 2011 earthquake and the resulting Tsunami severely damaged the Fukushima Daiichi nuclear plant. The disaster raised safety concerns of other nuclear plants in Japan, which prompted the government to enact stringent safety regulations and to initiate temporary shutdown of all the existing plants for inspection. As of April 2015, none of Japan’s nuclear power stations are in operation. Consequently, for the first time in several decades, Japan is now generating power without any contribution from the nuclear sector. The gap has been filled up with imported fossil fuels with implications for Japan’s import dependence as well as energy costs.

Some drastic changes in the country’s nuclear power production are expected. Two major policy decisions will affect the future of Japan’s nuclear energy. The first one is related to the restart policy of the existing nuclear power plants. The second issue concerns the impact of new-build policy on future capacity. These policies are likely to be decisive in Japan’s future energy supply mix, and hence will have significant consequences for the country’s energy security, self-sufficiency and import dependence, and emissions reduction efforts.

Assumptions and trajectory setting

Against the changing landscape of Japan's energy sector in general and nuclear sector in particular, the Low Carbon Navigator development team felt that the nuclear energy supply trajectories should reflect the challenges that Japan faces now. Thus the ensuing levers under this sector need to incorporate options beyond mere generation capacity potential. We therefore took a unique approach to allow the users to reflect their opinions through the Low Carbon Navigator's levers under the nuclear sector.

The trajectories have been set up on the basis of progressively higher efforts toward transition to a low-carbon society. For example, Trajectory A in the nuclear sector represents low efforts and continuation of existing capacity and technology, whereas Trajectory D represents great efforts leading toward increased use advanced technology. Trajectory E in nuclear power generation represents the physical limit/technological potential.

Impact of restart policy

The restart policy affects all the existing nuclear plants in operation before the Fukushima accident. For Fukushima Daiichi and Daini plants, it is clear that all the reactors will be decommissioned. However, for other plants (i.e. not in Fukushima) that were hit by the earthquake in 2011 and currently under temporary shutdown, the question is whether they will resume operations in the future or whether they will be decommissioned. For the plants which were not hit by the earthquake, the question is when they will resume operations. These are difficult questions but are important in formulating Japan's future nuclear energy pathways. Based on these, the Low Carbon Navigator has developed the following five trajectories. The users of the Low Carbon Navigator will be able to input their opinion by choosing their preferred restart policy and see its effect on Japan's energy and emissions future. The users can choose among complete abandonment of nuclear capacity, limited restart or full restart. The options for restart policy also differentiate the plants according to plants' lifespan (40 years, 50 years, or 60 years). Currently, the lifetime of existing nuclear reactors is regulated to 40 years. The reactors may extend their lifetime by another 20 years only if they pass the special examination by Japan's Nuclear Regulation Authority. By combining the lifespan input with the other lever (i.e. new build policy) the users can reflect their views on phasing out nuclear power generation some time in the future. Five different trajectories are provided under this lever, which are explained below along with the illustration in Figure 1.

Trajectory A

Trajectory A assumes that Japan will shut down all of its nuclear power plants from 2010 onwards and they will never be restarted. In other words Japan will

phase out its nuclear capacity completely and focus on other sources of energy.

Trajectory B

Trajectory B for restart policy assumes that only half of the existing nuclear plants will be restarted. With no new-build rate, nuclear capacity will come down from 49 GW in 2010 to below 10 GW in 2030 and to zero by 2050.

Trajectory C

Trajectory C assumes a restart policy where Japan only allows all existing nuclear plants with a 40 year lifespan to operate. With the retirement of exhausted plants and no new-build, Japan's capacity will gradually decline, but at a slower pace than Trajectory B. By 2030, capacity will be around 19 GW and eventually zero by 2050.

Trajectory D

Trajectory D assumes a more aggressive new-build policy. The operation of new-builds will take place from 2035 with a new capacity installation rate of 1.5 GW/y from 2040 onwards. It will mean that with full restart policy (40 year lifespan) Japan's nuclear capacity will be 22.9 GW in 2050. The resulting generation will be 164 TWh/y.

Trajectory E

Trajectory E assumes the most aggressive new-build policy. The operation of new-builds will take place from 2035 with a new capacity installation rate of 2 GW/y from 2040 onwards. It will mean that with full restart policy (40 year lifespan) Japan's nuclear capacity will be 29.1 GW in 2050. The resulting generation will be 208 TWh/y. Thus, even with the most optimistic assumptions, nuclear power will only contribute to less than one-third of Japan's total electricity generation in 2050. Together with the restart policy lever, the new-build policy lever helps the users to input their views on the extent of emphasis Japan should give on the nuclear sector. For example, even with a full restart policy, Japan will eventually phase out its nuclear capacity if a user selects no new build option (Trajectory A). This will mean that unless the country puts significant effort in developing the renewables sector, its dependence on fossil fuels will increase significantly, resulting in increased import dependence as well as higher level of emissions from the fuels. On the other hand, if a user chooses an aggressive new-build policy, for example, Trajectory D, then nuclear power will continue to be a major contributor in Japan's energy and electricity sector, and in controlling the country's GHG emissions as well as import dependence.

Data and calculation procedures

All these trajectories have been developed after rigorous review of existing literature and then through feedback from several expert review meetings. The trajectory assumptions interact with the fixed assumptions under this sector. Fixed assumptions are also based on existing literature and data, and include own-use requirements (as percentage of generated electricity), average transmission loss, thermal efficiency (based on gross calorific values), and legacy plant capacities (built prior to 2010). In addition to the trajectories and fixed assumptions, the Low Carbon Navigator also includes five load factor assumptions ranging from negative to aggressive.

Cost assumptions

Although the Low Carbon Navigator does not adopt a cost-optimisation approach, it allows the users to see the incremental cost to the society of their chosen pathways, and to make sensitivity analysis by comparing the costs of their selected pathways with other pathways.

Six different types of costs have been assumed for the nuclear sector: capital cost, fixed operating cost, cost of uranium (including spent fuel recycling), decommissioning cost, safety cost, and cost for policy measures. All these cost categories and reference data come from governmental sources (Cost Committee Report of Japan's National Policy Unit). For each category, the Low Carbon Navigator provides low, point (average) and high estimates of costs. However, costs are assumed to be time-invariant in the sense that under each of the three estimates, the costs remain the same throughout the period from 2010 to 2050. Biggest differences are assumed among the three estimates for capital cost, whereas for other categories of costs, differences are minimal or negligible. Table 1 provides the data under the six cost categories and under the three estimates.

Conclusion

The Japan 2050 Low Carbon Navigator has been developed to demonstrate the scale of changes that are likely to be required for Japan to make the transition to a low carbon economy. The Low Carbon Navigator takes into account all the energy supply and demand sectors. This brief report focuses exclusively on how the nuclear power sector has been incorporated in the Low Carbon Navigator. With uncertainties surrounding the future of Japan's nuclear sector, a number of complex, unprecedented issues need to be taken into account for developing the trajectories and making the assumptions within the Low Carbon Navigator model. These assumptions and trajectories are very different from the ones in the other energy supply sector. This report attempted to explain these issues, highlighting the complexities and uniqueness of the nuclear energy sector in the Low Carbon Navigator.

Appendix 1: The Excel model structure

Introduction

This appendix provides an overview of the Excel calculator structure, followed by a more detailed explanation of each section. Finally, it explains the Excel formulae that are used extensively to ‘glue’ the model together, by passing relevant values to required places.

Overall structure

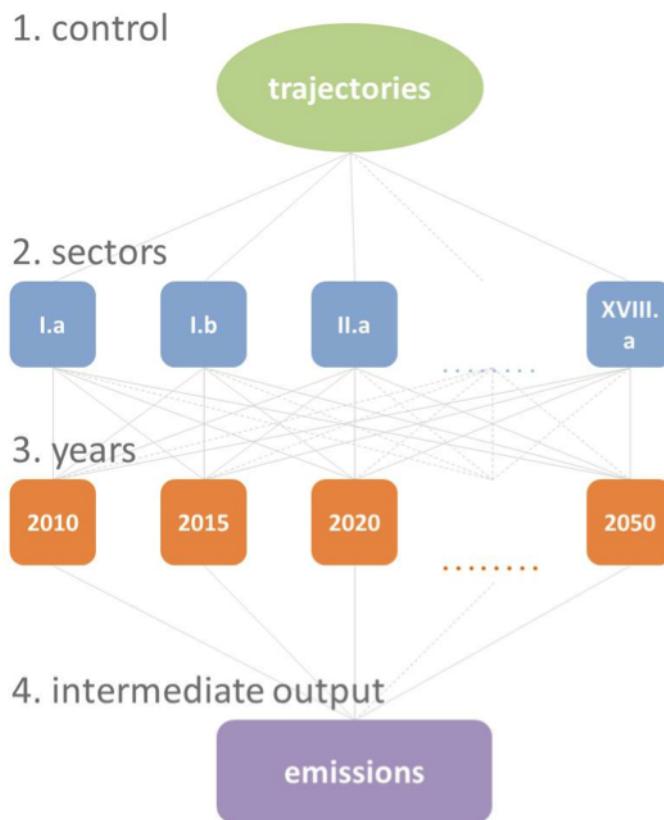


Figure 2: Over-arching structure of the calculator Excel model

Figure 0 above provides a summary of the way in which the Excel model is structured and how the user’s choices flow through the chain of calculations. The user interacts with the ‘control’ worksheet, where they make level selections (from 1 to 4) for all of the mitigation options. Broadly, these level selections feed

through to separate sector sheets where the implications of the user's choice (in terms of energy supply/demand and any associated emission)are calculated. The results for each sector are then pulled together to produce a full-system overview. This is done in two stages, firstly by each of the five year intervals in the 'year sheets'. Finally,all of the sectors for all of the time intervals are drawn together in the 'intermediate output' worksheet. The four main sections as shown above are described, in turn, below.

The control sheet

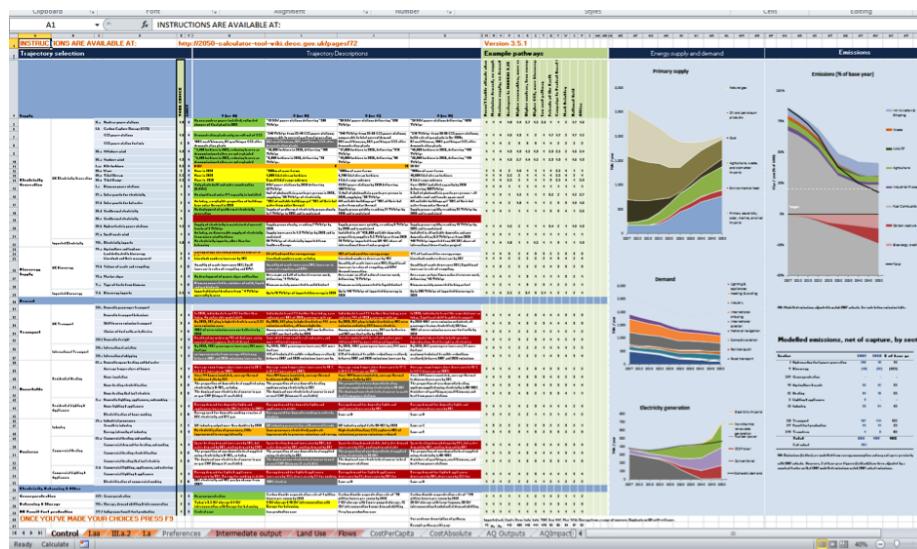


Figure 3: The Excel control sheet

The control sheet is the main user interface. From this single worksheet the user can develop their pathway and see the implications in charts showing energy demand, energy supply and emissions.

The different greenhouse gas (GHG) mitigation actions, or 'levers', are listed in columns A to D (see the area labelled 'A' in figure 1). The levers are organised by category, with each having its own Roman numeric code (e.g. III.a.1 for onshore wind).

The user assigns their choice of level against each lever by entering a number from 1 to 4 into column E. The supply side levers allow integer choices (e.g. level 1.7). (It is possible to use integers for the demand levers if implemented within the sector sheets, but this has not been done in the UK Calculator demand sectors.) The cells into which the numbers are entered are 'named cells', e.g. cell E10, in which the chosen level for onshore wind must be entered is named

‘III.a.1.Scenario’. This allows this cell to be referenced from elsewhere, using this label, e.g. ‘=III.a.1.Scenario’, rather than ‘=Control!E10’.

Columns H to K provide descriptions of each level to assist users in their choice (see area C in figure 1below). For example, with the III.a.1 lever, the user is choosing the capacity of onshore wind to be installed by 2050, from 0 turbines (level 1), to 20,000 turbines (level 4).

The implications of the user’s choices, in terms of primary supply, demand, electricity and emissions appear in the charts (shown in area E in figure 1 below).

Example pathways are shown in columns M to Y (see area D in figure 1below). To enter these, the user must copy the values from the desired column into column E.

Sectors

The 2050 Calculator is split into different supply- and demand-side ‘sectors’. There are, broadly, separate sectors for each supply technology and each area of demand, with each having its own worksheet, or ‘sector sheet’, within the Excel workbook. There are around 40 sector sheets in the model; each worksheet tab is labelled with the Roman numeral identifier that corresponds to those given in the control worksheet (column C). The sector sheets are all grouped together in the workbook and have orange tabs.

When a user specifies a level of effort against a particular lever (by entering a value from 1 to 4), this is passed to the model’s ‘sector sheets’. Each sector sheet contains a mini model that calculates the implications of the level selected by the user. The principal function of the supply side sectors is to calculate the resulting amount of electricity generated by the technology in question, given the capacity of that technology specified by the user when they make their level choice against it. The demand side sectors similarly calculate the energy/fuel requirement associated with the user’s choices, but also calculate any resulting emissions.

The sector sheets are split up into a number of different sections. The same sections are used consistently and are common to all of the sectors. Accordingly, all of the sector sheets look very similar and work in a standardised way, making it easier to understand the model. Each of the standardised sections is explained in more detail below, using onshore wind (worksheet III.a.1), as an example.

Choice of trajectory

For example, when the user enters a level (here 1.3) into cell E9 of the control sheet (named III.a.2.Scenario), it feeds through to cell E7 of the ‘choice of trajectory’ section of the III.a.2 worksheet, as can be seen from the formula in the screenshot below (figure 2).

The screenshot shows an Excel spreadsheet titled 'Excel_3.4.xlsx - Microsoft Excel'. The active sheet is 'III.a.1.Scenario'. The table below shows the trajectory assumptions for onshore wind, new build.

	Component	Trajectory
7	Trajectory	1.3

Trajectory assumptions			
Onshore wind, new build			
Trajectory	Description	Notes	2007
15	1		0.61
16	2		0.76
17	3		0.76
18	4		0.76

Figure 4: Choice of trajectory

Trajectory assumptions

Each sector sheet also has a ‘trajectory assumptions’ section, where the level selection number (1-4) is converted into what the lever actually specifies. For the onshore wind example, this is the GW of capacity installed. It is important to note that the capacity values in the table are multiplied by a named cell (here ‘unit.GW’), which corresponds to the units which the values represent. See the [appendix on units](#) for a full explanation.

Fixed assumptions

The ‘fixed assumptions’ section is where all required assumptions are stated that are outside of the user’s choice.

Legacy capacity : the existing installed capacity of onshore wind turbines already existing at the start of the modelling period.

Capacity factor : the average proportion of time that the turbines operate at their quoted capacity, incorporating both down-time for maintenance and fluctuations in wind speed over the year.

Implications : details about the assumed size of wind turbine and the amount of land area required for each unit of energy produced.

Trajectory assumptions										
Onshore wind, new build										
GW per annum, for subsequent period; nameplate capacity										
Trajectory Descriptive Notes	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
1	0.61	0.55	0.55	0.55	-	-	-	-	-	-
2	0.76	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3	0.76	1.44	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60
4	0.76	1.52	2.10	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Chosen	0.66	0.69	0.69	0.69	0.30	0.30	0.30	0.30	0.30	-

Onshore wind, retirement										
GW per annum, for subsequent period; nameplate capacity										
Trajectory Descriptive Notes	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
1	-	-	-	(0.23)	(0.55)	(0.55)	(0.55)	(0.55)	-	-
2	-	-	-	(0.23)	(0.64)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
3	-	-	-	(0.23)	(0.64)	(1.44)	(1.60)	(1.60)	(1.60)	(1.60)
4	-	-	-	(0.23)	(0.64)	(1.52)	(2.10)	(2.50)	(2.50)	(2.50)
Chosen	-	-	-	(0.23)	(0.57)	(0.69)	(0.69)	(0.69)	(0.30)	-

Figure 5: Trajectory assumptions

Fixed assumptions												
Legacy capacity (built prior to end 2007)												
Fuel	Plant type	Notes	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
R.02	Onshore wind	[1]	2.1									

Capacity factor												
Fuel	Plant type	Notes	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
R.02	Onshore wind	[2]	27.3%	30%	30%	30%	30%	30%	30%	30%	30%	30%

Implications												
Unit												
Assumed typical turbine size			0.0025	GWpeak								
Energy/unit of area		[3]	0.022	TWh/km ²								

Figure 6: Fixed assumptions

Derived assumptions

The trajectory assumptions and fixed assumptions mentioned above are combined to produce the values contained within the next section of the sector sheet, the ‘derived assumptions’.

Derived assumptions												
Total wind capacity												
Fuel	Description	Notes	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
R.02	Onshore wind		2.08	4.06	7.48	10.91	13.17	11.81	9.88	7.96	6.03	6.03

Figure 7: Derived assumptions

In our example case of onshore wind, the derived assumptions section is very brief, showing only the resulting capacity of installed wind in each of the modelled periods out to 2050. This is calculated by starting with the existing legacy capacity stated in the fixed assumptions and then applying the quantity of newly built capacity from the trajectory assumptions section, as determined by the user’s chosen level of effort (1-4), as displayed in the choice of trajectory section. The corresponding retirement rate from the trajectory assumptions section is also applied, to account for the assumption that wind turbines have a finite lifetime.

Calculation section

The calculation section (which isn’t really labelled, but sits below the derived assumptions section) is where the main energy arithmetic takes place, to calculate the pertinent implications of the user’s choice. In our onshore wind example, we are primarily interested in the amount of electricity supplied to the grid that results from the chosen wind turbine generation capacity. The calculation steps required are set out in such a way as to keep them as simple as possible, by using a few guidelines:

- The flow of calculations is from top to bottom, with all references being made to cells above
- Where useful, values are restated from above, making them visible within the main block of calculations, preventing the user from needing to scroll up the worksheet
- Each step logically follows the previous step, creating an intuitive calculation path
- The values in each row are labelled so the user can easily see to what they refer
- A new row is used for each calculation step, so that only one identifiable function is being performed in each

Some of the more complex sectors have many rows of calculations in this section, but following these principles, it is intended that the user can follow them as easily as possible. In our example case of onshore wind a small number of calculations are required to arrive at the desired results, which are outlined below:

1. The installed capacity as calculated in the derived assumptions is restated, enabling the user to view this key value without having to scroll up the worksheet
2. The capacity factor, as stated in the fixed assumptions section is restated, again allowing the user to view this without the need to look further up the worksheet
3. The ‘available supply’ is calculated by multiplying the two values above (the installed capacity and the capacity factor)
4. The electricity generation resulting from the ‘available supply’ is then calculated. This a typical power to energy conversion where:
5. The ‘actual supply’ is multiplied by the Preferences.Unit.Power named cell, to account of the unit of power in which the value is quoted
6. The result from step ‘a’ is then multiplied by the number of seconds in a year, by utilising the ‘unit.year’ named cell. This yields the number of joules produced by the capacity each year.
7. The result of step ‘b’ is then divided by the named cell ‘Preferences.Unit.Energy’, which converts the result into the energy units that the user has chosen. (The ‘Preferences.Unit.Energy’ named cell effectively holds the number of joules contained within one unit of the user’s preferred unit of energy.)
8. This provides an estimate, in TWh (or whatever the chosen preference unit of energy is), of the electricity generated within the sector, that results from the user’s choice of capacity

Outputs

At the bottom of the sector sheet the key results are gathered into a single location, the ‘Outputs’ table, so that they can be easily located.

Outputs		TWh										
Energy produced and required		Notes	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
Vector	Name											
V.02	Electricity (supplied to grid)		5.0	10.7	19.7	28.7	34.6	31.1	26.0	20.9	15.9	15.9
R.02	Wind	(5.0)	(10.7)	(19.7)	(28.7)	(34.6)	(31.1)	(26.0)	(20.9)	(15.9)	(15.9)	
	Total	-	-	-	-	-	-	-	-	-	-	-

Figure 8: Example of an outputs table

There are several key features to note about this table

- Like the rest of the sector worksheet, it is arranged with the time periods across the columns
- The rows of the table are organised according to ‘vector’, which, broadly, are labels given to particular types of energy (see Appendix 3 for a full explanation). The vectors that appear in the onshore wind sector outputs table are: – V.02: Electricity (supplied to the grid) – R.02: Wind
- The table is formatted specifically as an Excel table, allowing ‘structured references’ to be used. See the section on structured references in Appendix 2 for the full details of what this entails.
- The table has a name. In the onshore wind sector, it is called III.a.1.Outputs.
- The total row nets to zero, as the output of the sector (electricity) is balanced by the primary energy input (wind).

Below the ‘Outputs’ table are a couple of additional results tables that show additional information. The first, ‘information’, presents details about the resulting capacity, the land area requirement and the number of individual turbines. The second, ‘costs’, presents the sector’s cost estimates. For a full explanation of how the calculator’s cost estimates are put together, see Annex X.

Year sheets

Each of the sector sheets, like that for onshore wind as described above, effectively exist in isolation. The primary function of the ‘year sheets’ is to bring all the key outputs from the sectors together, creating a full system overview. There is a separate year sheet for each of the five year intervals modelled within the calculator; each of these shows how the energy system balances at that point in time.

As figure 7 above suggests, the year sheets contain a large table, with all of the sectors represented in the rows, and all of the vectors represented across the columns. The table displays the values for all the relevant vectors for all of the sectors. These values link through from the outputs tables at the bottom of each sector sheet (using a somewhat complex formula, which is explained in Appendix 2). This link between the sector outputs tables and the year sheets can be seen above: the 10.7TWh value for vector V.02 (electricity delivered to the grid) for onshore wind in 2010, as shown in figure 6, is also visible in figure 7, in the onshore wind row of the V.02 column. As can also be seen in figure 7, the electricity generated by all of the relevant sectors appears in the V.02 column of the year sheet. This allows the generation total, across all sectors, to be calculated for the particular year shown in the year sheet (here 2010). The same is done across all of the vectors, which in combination yield an energy balance for the whole system. This balance shows the input of energy via the ‘primary sources’ vectors, its conversion into usable fuel types via the ‘secondary sources’ vectors, through to the final consumption of energy in each demand

		2010		Uses									
		TWh		National navigation	International aviation	International shipping	Food consumption [UNUSED]	Total uses	Electricity (delivered to end user)	Electricity (supplied to grid)	Solid hydrocarbons	Liquid hydrocarbons	Gaseous hydrocarbons
Sector		T.04	T.05	T.06	F.01			V.01	V.02	V.03	V.04	V.05	
XV.a	Petroleum refineries	-	-	-	-	-	-	(6.5)	-	-	(53.0)	-	
XV.b	Indigenous fossil-fuel production	-	-	-	-	-	-	(1.5)	-	(0.0)	-	-	
XV Fossil fuel production		-	-	-	-	-	54.4	(7.9)	-	(0.0)	(53.0)	0	
III.a.1	Onshore wind	-	-	-	-	-	-	-	10.7	-	-	-	
III.a.2	Offshore wind	-	-	-	-	-	-	-	4.1	-	-	-	
III.b	Hydroelectric power stations	-	-	-	-	-	-	-	5.3	-	-	-	
III.c	Tidal & Wave	-	-	-	-	-	-	-	0.0	-	-	-	
III.d	Geothermal electricity	-	-	-	-	-	-	-	-	-	-	-	
III.e	Tidal [UNUSED - See III.c.]	-	-	-	-	-	-	-	-	-	-	-	
III National renewable power generation		-	-	-	-	-	-	-	20.1	-	-	-	
IV.a	Solar PV	-	-	-	-	-	-	-	0.0	-	-	-	
IV.b	Solar thermal	-	-	-	-	-	-	0.1	(0.1)	-	-	-	
IV.c	Small-scale wind	-	-	-	-	-	-	-	-	-	-	-	
IV Distributed renewable power generation		-	-	-	-	-	0.1	(0.1)	0.0	-	-	-	
XVII.a	Total heatupply [demand] to this point	-	-	-	-	-	-	-	-	-	-	-	
XVII.b	District heating effective demand	-	-	-	-	-	-	-	(1.2)	-	-	-	
XVII District heating		XII.c	XII.e	XIV.a	XV.a	XVI.a	XVII.b	XVII.c	2007 (Actual, frozen)	2007 (Consistent)	2009	2010	2015

Figure 9: Example of a year sheet

category via the ‘uses’ vectors. The principle that energy cannot be created or destroyed is visible here, as together the vectors net to zero.

All of the year sheets operate in the same way, and are essentially identical, apart from the year which they represent. Indeed, simply changing the year displayed in the top left-hand corner of the worksheet (cell E2) will cause the formulae to update so that the entire year sheet will then show data for the newly entered year. This property can be very useful when constructing a new version of the calculator, as any changes made to one year sheet can be quickly replicated across all the year sheets simply by deleting all but the updated year sheet, then duplicating it the required number of times and then entering the required years (2010, 2015, . . . , 2050) in cell E2 of the corresponding sheets.

The vast majority of the information shown in the year sheets links directly from the sector sheets as described above. There are however a couple of exceptions where additional calculations are performed, which are listed below:

- For the electricity vectors (V.01 and V.02) in the row labelled ‘Subtotal.I.a’, a calculation required for the model’s balancing mechanism is made. This calculates the difference between the total amount of electricity demanded and the amount supplied by low carbon technologies, to reveal any shortfall that is met by generation using the model’s default technology (gas-fired power stations, in the case of the UK model).
- The model contains a number of supplementary vectors, Y.02-Y.06, for handling any required balancing imports/exports for a selection of primary energy inputs (e.g. gas, coal etc). Within the year sheets the difference between demand for these inputs and their indigenous production is calculated, revealing any required import/export quantities. This can be seen in the row labelled ‘balancing imports’ (row 103) for this selection of vectors.

To the right-hand side of the vector tables, the year sheets contain a table that aggregates the emissions data across the sectors in a similar fashion. N.B. in the UK model there are two additional year sheets, labelled ‘2007 (Actual, frozen)’ and ‘2007 (Consistent)’. These worksheets are used to populate the UK model’s 2007 base year, and contain actual, rather than modelled data. The data within these two year sheets links from various published data tables, which can be seen in the right-most worksheets in the workbook, which come from the Digest of UK Energy Statistics (the UK’s flagship official energy statistics publication).

Intermediate output

The intermediate output worksheet represents the final point of the model’s calculations, where the key results are drawn together and presented in an organised tabular fashion. In a similar way to how the year sheets draw all the sectors together, the intermediate output worksheet brings together the contents of the year sheets to a single place.

Energy source / use charts		2050 Calculator calculations									
TWh / year	2007 (Consistent)	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
Use											
T.01 Road transport	502.5	490.9	451.2	406.9	353.9	265.2	188.4	171.2	153.9	133.7	115.9
T.02 Rail transport	16.2	15.9	18.1	18.4	17.9	17.6	16.7	15.9	15.0	14.0	13.0
T.03 Domestic aviation	0.5	0.6	0.4	1.0	1.6	1.8	1.2	1.5	1.3	1.5	1.5
T.04 National navigation	18.8	15.8	27.1	27.5	27.9	25.6	29.7	30.7	31.8	32.9	34.0
T.05 International aviation	153.0	152.8	153.0	146.4	152.1	156.4	156.9	157.1	145.7	139.4	135.8
T.06 International shipping	28.2	34.2	57.3	52.4	42.4	39.9	37.5	35.3	33.2	31.3	29.4
Transport	728.5	741.5	688.2	655.4	605.0	519.3	441.4	422.9	390.7	364.6	336.6
I.01 Industry	443.3	484.9	448.4	399.5	355.4	317.0	283.2	254.2	228.7	206.3	186.7
H.01 Heating & cooling	544.7	498.4	489.9	441.3	399.0	368.8	339.5	314.5	291.7	274.2	257.8
L.01 Lighting & appliances	184.0	176.4	157.8	148.9	141.0	134.0	127.7	122.2	117.2	112.8	108.9
F.01 Food consumption [UNUSED]	59.1	-	-	-	-	-	-	-	-	-	-
Total	1,959.6	1,901.2	1,784.2	1,645.1	1,500.5	1,339.1	1,191.8	1,113.8	1,028.2	957.9	890.0

Figure 10: The intermediate output worksheet

As shown above in figure 8, the intermediate output sheet shows a time series across the columns of the mode’s five year intervals from the base year (here 2007) up to 2050. The data is presented at a vector total level, showing the aggregated total across all of the relevant sectors. The table shown in figure 8 has been populated by formulae that return values from the vector ‘Net balance’ (row 109) of the corresponding year sheet. The intermediate output worksheet contains several summary tables that present headline information drawn together from the year sheets. These include:

- Energy use
- Energy source (primary energy)
- Conversion losses, distribution, and own use
- Supply/demand not accounted for
- Electricity grid (net of distribution losses)
- Electricity generation
- Emissions by sector

The intermediate output worksheet also presents some additional information, which is not linked directly from the year sheets. These are outlined below:

- Electricity generation: the capacities of the various electricity generation technologies are linked directly from the info tables at the bottom of their respective sector sheets.
- Emissions as % of base year, adjusted so that 2007 matches actuals: the emissions by sector are represented as a % of the base year, adjusted to match actual published figures from the GHG inventory.

Appendix 2: Complex Excel formulae

The calculator makes extensive use of complex formulae which combine a number of different worksheet functions. A common example can be seen in the year sheets, where information is gathered together from across all of the sector sheets. This is done by way of a ‘lookup’ based on three criteria, which specify the point from within the model that a value should be returned. In the case of the year sheets the three criteria are the sector (e.g. II.a), the vector (e.g. V.02) and the year (e.g. 2010). In order to perform a lookup in Excel based on three criteria it is necessary to use a number of worksheet functions in conjunction. Below some of the commonly used Excel formula and formatting conventions are explained in isolation and then in combination.

Index

	A	B	C	D	E	F	G	H	I	J	K	L
1	Name	2010	2015	2020	2025	2030	2035	2040	2045	2050		
2	Car	5	10	15	20	25	30	35	40	45		
3	Walk	1	2	3	4	5	6	7	8	9		
4	Bus	2	4	6	8	10	12	14	16	18		
5												
6												
7	C4	=INDEX(C3:K5,3,6)										
8												
9												
10												
11												

The index function has three arguments. This first argument is an array (C3:K5 in the example here). The second and third arguments respectively are row and column indexes which specify an element from the array that should be returned. Here, the index function returns the value 12, which is in the 3rd row and 6th column of the C3:K5 array.

Match

	A	B	C	D	E	F	G	H	I	J	K	L
1												
2	Name		2010	2015	2020	2025	2030	2035	2040	2045	2050	
3	Car		5	10	15	20	25	30	35	40	45	
4	Walk		1	2	3	4	5	6	7	8	9	
5	Bus		2	4	6	8	10	12	14	16	18	
6												
7	C4		=MATCH(B9,C2:K2,0)									
8			K6									
9			2035									
10			Bus									
11												

The match function returns the position of the item specified by the first argument (here the year 2035, as stipulated in cell B9), within the range (here C2:K2) specified by the second argument. The third argument (here 0) determines that a precise match is required when the function is searching for the item in the range.

Index and match

	A	B	C	D	E	F	G	H	I	J	K	L
1												
2	Name		2010	2015	2020	2025	2030	2035	2040	2045	2050	
3	Car		5	10	15	20	25	30	35	40	45	
4	Walk		1	2	3	4	5	6	7	8	9	
5	Bus		2	4	6	8	10	12	14	16	18	
6												
7	C4		=INDEX(INDIRECT(B7&"."&B8),MATCH(B10,B3:B5,0),MATCH(B9,C2:K2,0))									
8			K6									
9			2035									
10			Bus									
11												

In the above example the row and column arguments of the index function have been substituted with match functions. Using index and match in combination like this is useful, as it allows you to return an element from a table by knowing the corresponding row and column labels (here ‘Bus’ and ‘2035’), without the need to know the precise row and column numbers of the element. This example also contains an index function, which here is used to specify the index function’s array indirectly via the contents of cells B7 and B8 – note that the formula makes use of some string manipulation syntax (i.e. B7&“.”&B8) to construct the required Excel range reference (C4:K6). The resulting function returns the value 10, i.e. the value in the 2010 column of the Bus row.

Structured table references

SUM	x	✓	f _a	=Table2[@2045]									
A	B	C	D	E	F	G	H	I	J	K	L	M	N
1													
2													
3	Name	2010	2015	2020	2025	2030	2035	2040	2045	2050			
4	Car	5	10	15	20	25	30	35	40	45			
5	Walk	1	2	3	4	5	6	7	8	9			
6	Bus	2	4	6	8	10	12	14	16	18			
7													
8													
9													

In Excel 2007 a new way of formatting tables was introduced that makes it possible to format a block of data so that Excel will recognise that it is a table. This can be done using the ‘format as table’ button on the ‘home’ tab of the ribbon. Once a table has been formatted in this way, it is possible to refer to components of the table using ‘structured references’. This is demonstrated in the example above, where the formula in cell M5 is referring to a specific column, i.e. the 2045 column, as specified in the square brackets, of the table. The name of the table, here ‘Table2’, is also referred to explicitly in the formula.

Putting it all together: index, indirect, match and structured references

Many of the formulae in the calculator make use of the functions listed above in combination with structured references. This section provides an example to-

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1				2010										
2				TWh										
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														
21														
22														
23														
24														
25														
26														
27														
28														

gether with an explanation.

The formula in cell N26 of the 2010 year sheet as shown in Figure X above reads as follows:

```
=IFERROR(INDEX(INDIRECT($C26&".Outputs[\"&this.Year&\"]")),  
MATCH(N5, INDIRECT(C26&".Outputs[Vector]"), 0), 0)
```

The formula is broken down into two sections, purple and green, which are explained in turn below:

`INDEX(INDIRECT($C26&".Outputs["&this.Year&"]")`) : This provides the array to be used in the overall index function. Firstly, the contents of cell C26 (XII.c) is appended, using the ‘&’ string manipulation syntax, to the string, ‘Outputs[‘. This is then appended to the contents of a cell named ‘this.year’, which here contains the year ‘2010’. Finally a closing square bracket ‘]’ is appended. The result effectively yields the following structured reference: ‘XII.c.Outputs[2010]’, which refers to the 2010 column of the named outputs table at the bottom of sector XII.c. This is all done within an indirect function, which is not in itself theoretically required, but is included as a workaround (the formula for some reason doesn’t work without this).

`MATCH(N5, INDIRECT(C26&".Outputs[Vector])")`: This match function which specifies the row from which the overall index function should return a value. (As the range from which to return the value is only a single column, a column reference is not required). The match function looks for the contents of cell N5, which here is the vector label ‘T.05’. The range in which the match function looks for ‘T.05’ is constructed in exactly the same way in which the array for the index function above. This effectively yields the following structured reference: ‘XII.c.Outputs[Vector]’. The match function therefore returns the position of the text ‘T.05’ within the column labelled ‘Vector’ in the outputs table of sector XII.c.

In effect, the formula is completing a lookup based on the three criteria: the year, the sector and the vector. It retrieves a value from the outputs table of the specified sector according to the row and column that correspond to the respective specified vector and year.

The index function is nested within an ‘iferror’ function, which returns a ‘0’, rather than an error message if the formula cannot find a value that corresponds to the year, sector and vector criteria specified.

Appendix 3: Vectors

The vector convention is essentially a means of categorising energy into different types. Vectors enable quantities of energy to be organised and passed through the various calculation stages of the model in a simple, logical fashion.

The idea of vectors is perhaps best explained by way of an example. A commonly used vector within the model is vector V.02, which is used to represent quantities of electricity that are generated for delivery to the grid. All of the supply sectors that model the electricity generation by various technologies (e.g. solar, wind, nuclear) all assign the quantity of electricity generated to this specific vector (V.02). This allows the generation total across all the technologies to be calculated easily, simply by summing all the quantities assigned to this specific sector together.

The calculator makes use of three separate independent vector categorisations:

1. Uses
2. Primary sources
3. Secondary sources

The **uses** vectors are analogous to broad categories of demand, e.g. industry, road transport, and heating and cooling. They are used to show energy demand/use from these aspects of the economy. The uses categorisation is ‘MECE’ (mutually exclusive, i.e. there is no overlap between them, and collectively exhaustive, i.e. all areas of demand fit into one of the available categories), so that in total they sum to total demand.

The **primary sources** vectors are, as the name suggests, used to represent all sources of primary input energy. The categories included cover everything from fossil fuel reserves (e.g. coal, oil and gas) to renewables (e.g. wind, solar and wave). Again, these vectors are MECE, so all primary energy sources can be represented by one of the available categories, but only one. It should be noted that within the primary sources vectors there are some supplementary vectors Y.01-Y.06, that are used to handle the import/export mechanism that allows the primary energy demand within the system to be matched by supply (e.g. if more gaseous hydrocarbons are required than are produced indigenously, the required quantity is assumed to be imported).

The **secondary sources** vectors are less easily defined. They represent all intermediate stages of energy between the primary sources and the final uses vectors. The closest, although still rough, description of these secondary sources vectors might be _fuel types (in the calculator, electricity is treated like a fuel). The secondary sources vectors do, however, include some energy sources that might be converted prior to consumption (this is perhaps especially true of the bio energy types included).

In any given sector, the relevant vectors that are used net to zero. For example, in the onshore wind sector, the electricity generated, as shown in vector V.02, is balanced with an equal quantity of primary input energy, using the R.02 ‘Wind ‘Primary Sources vector. The input energy is denoted by the use of a negative value, which results in all the sector’s vectors summing to 0. This treatment was inspired by the ‘double entry’ bookkeeping system used in financial accounting, where all entries have an equal but opposite entry associated with them.

Within the calculator, the vector system can be most easily observed in the year sheets. Here the full categorisation of all three vector types is set out, forming the column headings for the energy balance tables. In combination with the full sector categorisation, which constitutes the row headings, the year sheets provide a full overview of all energy types across the complete energy system. The year sheets also demonstrate the principle that energy cannot be created or destroyed, but only converted to another type; all energy inputs are given positive values, while outputs are given negative, resulting in a system total of zero.

An almost identical approach is used in the year sheets to organise the emissions data. Here the categories used are the standard IPCC emissions sectors. Similar approaches are also used to handle the calculator's costs and air quality components (see Appendix xx).

Appendix 4: Units

The calculator allows users to choose the units in which certain key values are displayed. This enables users to view quantities in the unit to which they are most accustomed; some people typically use petajoules (PJ), while others might prefer terawatt-hours (TWh).

The 'preferences' worksheet (next to the control sheet) provides four drop-down menus where users can specify their unit preferences, for the following four types of value:

1. Energy
2. Power
3. Area
4. Money

When a user changes the selected unit all relevant values in the calculator update, so that they are displayed in the chosen unit.

Whenever a quantity of energy, power, area or money is entered into the model, the associated unit must be specified. For example when entering a value of 1,000 kWh, the `unit.kWh` named cell must be used, so the cell entry would read: '`=1000*unit.kWh`'. If done correctly, the value entered will be displayed in the preferred energy unit specified by the user, rather than in kWh.

This functionality is enabled by a number of calculations on the 'conversions' worksheet, which contains a named cell for each unit, the value of which adjusts dynamically when the user changes their unit choices on the 'preferences' worksheet. The value in the named cell is essentially a conversion factor between the unit in which the value was added and the preference unit chosen for that type of value. This value then has to update when the preference unit is changed. For example:

Assume the user has selected TWh as their preference energy unit on the 'preferences worksheet'. A cell in the model has a quantity of energy, say 1.5 petajoules, written using the method described above (i.e: '`=1.5*unit.PJ`'). *The value in the named cell 'unit.PJ' (found on the 'conversions' worksheet) will have dynamically altered to reflect the choice of energy preference unit (here TWh), to contain the conversion factor between PJ and TWh (0.27). Therefore the result of the cell containing `=1.5*unit.PJ` will appear in TWh.* If the user

changed their preference unit to boe (barrels of oil equivalent.), the conversion factor contained within the cell named unit.PJ would again adjust to show the PJ to boe conversion (170,604), and all energy results would update and appear in boe.

In the case of the energy unit, conversion factors are based on the number of joules in a single unit. The mechanism used for all the other unit systems (e.g. power, area, land and money); see the ‘conversions’ worksheet to examine how they work.

This also makes it easy to enter input data, as any required conversions are done very simply using this approach.

Appendix 5: What happens when supply exceeds demand?

When using the calculator, through your choices you specify:

- The demand for energy (e.g., by indicating how far people will travel)
- The type of energy demanded (e.g., by specifying electric cars, the demand will be for electricity, otherwise it will be for liquid fuels)
- The amount of low carbon generation that will be built or imported (e.g., nuclear power stations)
- The area of biomass that will be planted
- The amount of bioenergy that will be imported
- (In the spreadsheet only) the quantity of fossil fuels that will be dug from the ground.

However, it is interesting to see what you haven’t specified:

- The amount of coal or gas generation that will be built
- The amount of coal, oil and gas that will be imported

Which is surprising, since in the UK coal and gas supply most of the electricity, and imported fossil fuels supply most of our energy needs. You’d therefore expect that the demand for energy would exceed the supply of energy that you have chosen.

So, what happens when the supply you choose isn’t enough to meet the demand you’ve chosen?

The answer is slightly different depending on whether the imbalance is in:

1. gas/oils/solid fuels, or

2. in electricity

which are described in turn next.

The calculator mostly worries about long term permanent imbalances between supply and demand. It is also possible that very short term imbalances could occur (for instance, during moments when the wind doesn't blow). These short term imbalances are dealt with through a 'stress test' which is described in [Appendix 7](#).

For solid/liquid/gaseous fuels

If you demand gas, then it will be met:

1. First, by any biogass
2. Then, by any domestic natural gas
3. Then by importing natural gas to balance

If you demand solid fuels, then it will be met:

1. First, by any domestic biomass
2. Then, by any imported biomass
3. Then, by any domestic coal
4. Then, by importing coal to balance.

If you demand liquid fuels, then it will be met:

1. First, by any domestic biofuels
2. Then, by any imported biofuels
3. Then, by any domestic oil
4. Then, by importing oil to balance.

There is therefore never a shortfall fo energy in our calculator – it assumes that, if needed, energy can always be imported.

If there is too much energy then it is just noted as being "over generation / exports"

This balancing mostly happens in the year sheets. In particular, the line marked 'Balancing imports' (about row 103) works out the shortfall that must be met by importing fuels.

For electricity

In the UK calculator, if you demand electricity, but there isn't enough: gas generation is built to fill the shortfall. To adapt this approach to a different country, the most important thing to do is to decide whether gas, coal or oil generation would be used to cover the shortfall.

The calculations happen in sheet I.a which, at the top:

1. Reads the demand for electricity from the year sheets – V.01 Electricity (delivered to the end user)
2. Reads the supply of electricity provided by the other electricity supply sectors from the year sheets – V.02 Electricity (supplied to grid)

Both of these are taken from the row labeled 'Subtotal.I.a' in the year sheets (about row 80), which you will see calculates the total before the values from sheet I.a. are included.

Working down sheet I.a., rows 229 and 239 deduct the electricity supplied by legacy oil and coal generation from the demand and then row 249 works out how much gas generation is therefore needed in rows 251, onwards. The demand and supply from I.a. is then picked up by the Year sheet below the 'Subtotal.I.a.' line to give the actual total demand and supply of electricity in that year, which should balance.

The India calculator follows a slightly different approach. They choose coal as the type of generation that makes up a shortfall in demand. They implement this in sheet I.d which is like the UK's I.a worksheet, but simpler because it only considers coal.

The difference from the UK arises because they also have a sheet I.b., where the user can choose how much coal generation should be built. There is no problem in doing this. All that happens is that, when the user makes their choice about how much coal generation to build, instead of specifying exactly how much should be built, they are specifying the minimum that must be built. Sheet I.d. may increase the total, beyond what the user has asked for, if that is what is needed for electricity supply to meet demand.

Other approaches

For the situation where the user's choices result in not enough energy being supplied to meet demand, instead of automatically building new generation, an alternative would be to allow there to be a shortfall of energy (which would be equivalent to a black-out in some parts of the country), but signal this very strongly to the user. This is acceptable, but will make things more complicated for the user and means the default (all at level 1) pathway will look odd to users, because it will start with a shortfall of energy.

For the situation where there is too much energy, an alternative is to overrule a user's choice so that, for example, even though they have chosen Level 4 nuclear the system only builds Level 2 nuclear because that is all that is needed. We strongly recommend that this is NOT done:

1. it can be confusing to users and
2. it requires the tool to have a preference between, say, wind energy and nuclear energy, which may not be shared by the user.

Appendix 6: Calculating emissions

Combustion emissions

Within the calculator the general approach to calculating combustion emissions is by multiplying quantities of fuels used by a relevant emissions factor. A simplification of this approach is enabled by the fact that, *on an energy basis*, fuels of the same physical state have the same emissions factor (or similar enough to ignore the difference).

This fact may seem somewhat unintuitive, as correctly one would expect that burning a tonne of coal would produce more emissions than burning a tonne of wood. Burning a tonne of coal would, however, generate far more energy as the calorific content per gram is far higher. By considering this on an energy basis, effectively normalises by the energy output, such that burning 1kWh of coal produces the same emissions as burning 1kWh of wood. (The mass of the kWh of wood would be greater than the 1kWh of coal.)

The same logic applies across all solid fuels, and the same principal applies to liquid and gaseous fuels. This allows for a simplified set of emissions factors to be used within the model, with just one for each GHG (CO₂, CH₄ and N₂O) for each physical state of fuels. The emissions factors are stated on the 'constants' worksheet and referenced where required from this single location. This approach allows these factors to be edited easily, as they only need to be changed once (rather than multiple times as would have been the case had the factors been stated separately within each relevant sector worksheet).

NOTE FROM ED: Need something here about how this is different from the UNFCCC reporting basis. Why we are confident this is a valid methodology and some of the questions we often get asked.

Other emissions

[need to add something here]

Appendix 7: Stress test

The UK 2050 Calculator takes a broad view of the energy system, modelling five-year intervals. This allows you to reach some high-level conclusions, but there are instances where a more additional detail would yield some useful results. For example, a detailed minute-to-minute assessment of the balancing requirements within the electricity sector, taking all variables into consideration, is not possible. It is therefore not ideally suited to make assessments of the required back-up generation (or capacity margin) of the electricity sector at any given time. To mitigate this problem, the model does attempt to make this type of assessment under the worst-case scenario, thus providing an estimate of maximum requirement for stand-by generation capacity.

The worst-case scenario:

The 2050 Calculator tests the ability of the system to meet demands for electricity during a five-day anti-cyclone blocking event, with five days of low wind output and a peak in heating demand associated with the cold weather. This is used by many experts in the UK as a ‘worst-case scenario’ for energy balancing in the future. If sufficient flexibility is available to meet the winter low-wind period, then it is expected there will be sufficient capability to manage more routine, shorter-term fluctuations from day-to-day and hour-to-hour.

To ensure the test fully reflects these supply and demand conditions, it additionally assumes that a portion of the increase in electricity demand resulting from colder-than-average weather during the five days would have to be met by flexible sources. In all levels it assumes that this increase during an occasional cold spell is equal to 20% of annual average daily domestic and commercial heating demand, or approximately 10% of peak daily heating demand.

Sector VII.c – storage, demand shifting and interconnection

This sector is driven by a single composite lever, which enables the user to determine several factors:

- The peak power of the UK storage system
- The total amount of energy that can be stored by the UK storage system
- The peak power capacity of interconnections with other countries
- The sustained power capacity of interconnections with other countries
- The proportion of the UK’s electric vehicles that are available for demand shifting

The sector also has an ‘inputs’ section that feeds in various relevant values from elsewhere in the spreadsheet that have an impact on the electricity system’s balancing requirement. These include:

- The capacity of intermitting renewable generation technologies: – Onshore wind – Offshore wind – Wave – Distributed solar PV – Micro wind
- Additional peak demand estimates from residential and commercial sectors that are both independent and dependent on the external temperature (these requirements are calculated from within these worksheets)
- The seasonal external temperature
- Electricity exports
- ‘Boostable’ capacity, i.e. the installed capacities of generation technologies that can be increased on request: – Gas CCGT – Oil-fired – Coal/biomass – CCS – Nuclear
- The current load factors of the above ‘boostable’ generation technologies
- The numbers of electric and hybrid vehicles available to enable demand shifting

The sector also has a ‘fixed assumptions’ section that provides additional information around the worst-case scenario, including the duration, incidence, external temperature and percentage decrease assumed for the intermittent renewable generation technologies.

Methodology

The ‘methodology’ section of the worksheet combines the information outlined above to calculate:

- Available balancing power and energy under trajectory
- Size of shock (in terms of total additional demand)
- Whether the pathway has sufficient balancing to deal with peak power required
- Whether the pathway has sufficient balancing to deal with total energy required
- The total utilisation of the balancing
- The standby gas capacity that would be required for any outstanding power of energy requirements
- The consequences for greenhouse gas emissions

It is assumed that if back-up generation is required, this would entail additional CCGT gas power stations to be built. This backup capacity appears in the total generation table on the intermediate output worksheet. The costs of building these power stations also feeds in to the model’s energy system cost estimates.

Appendix 7b: In my country, there are power cuts / there is unserved demand

In some countries, there is a short-fall in power. When people want electricity, or oil, or gas, they can't get it (i.e., unmet or unserved demand). Some countries are even in the situation where they both export fuel, and don't have enough to meet their domestic needs.

There are two ways this could be modelled:

1. On the demand side (which we prefer)
2. On the supply side

Demand side modelling of unserved demand

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

For the future, either:

1. 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,
2. Give the user a choice about how fast demand grows, that reflects different options for how fast their 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 is needed (ranging between, say 100% at level 1 and 60% at level 4). This would 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.

No adjustments to supply worksheets are needed in this approach.

This approach is preferred, because:

1. its estimates for today will match, roughly, National Statistics and
2. it will prevent the user from creating any impossible pathways (see below).

Supply side modelling of unserved demand

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 isn't met, because people can't get the energy they need.

Then, add a new energy vector “unserved demand” to the vector table, and to the supply columns in the year sheet and to the energy demand output tables.

Then, add a new supply sector worksheet, called something like “VII.e unserved demand” that is used to calculate the amount of energy supplied to that new “unserved demand” energy vector.

Insert in that worksheet the amount of energy by vector that is not supplied, because there isn’t enough fuel or electricity. You will then need to wire the supply worksheet up to the year sheets and intermediate output sheet (just like any other supply sheet) so that it appears on supply graphs as “Unserved demand / power-cuts” or similar.

The value that you put in the worksheet for today can be whatever is required to make the supply total match whatever is in the National statistics for the supply of that fuel.

For the future, you can either have this value declining to zero (if you assume that the problem of power-cuts will be fixed at some point) or you could introduce a choice and level 1-4 trajectories reflecting different levels of effort to fix this problem.

As a final step, it will be important to wire up 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:

1. It is more complicated: it requires a new energy vector and a new supply worksheet
2. It will result in demand totals that don’t match national statistics
3. It allows the 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).

Implications for fuel exports

In both approaches, fuel that is available to export will be calculated automatically, based on the assumption that whatever hasn’t been used domestically, can be exported. That means that if you assume, or allow the user to choose, a fall in the amount of unserved power, the user should also see a fall in the volume of exports. If it is topical, then it might be worth showing the reduction in export income as a display in the tool.

Some people might want to make it so that the user chooses what proportion of fuel is exported, and from that work out the unserved domestic energy. That is much more complicated, but just about possible using the supply side approach.

First, make sure there is a new vector called “unserved demand”, as outlined in the previous section, and that this vector is wired into the year sheets and the output sheets.

First, there needs to be a fuel exports sheet. This could be a supply or a demand sheet – whatever feels right in your country. In the UK it would probably be a supply sheet. This would need to have one or more controls and one or more trajectories for the amount of fuel that is exported. The trajectories could either be in absolute TWh (but watch out that exports can't go higher than domestic production) or as a percentage of domestic production (in which case the supply of each vector will need to be brought into the worksheet, much as in the grid worksheets).

This fuel export sheet needs to be wired up to the year sheets, as is done with any other supply or demand sheet.

Then, the year sheet needs to be altered to change the standard balancing approach (described in [Appendix 5](#) which is on the row marked ‘Balancing imports’ (about row 103). Instead of debiting the fuel imports columns to credit the demand columns, this should be changed to debit the new ‘unserved demand’ vector.

This should mean that a choice about exports has consequences for unserved demand. But it is even more complex than the standard supply side method outlined above.

Appendix 8: Bioenergy

In the UK calculator, biomass is produced in the spreadsheet as a result of a combination of user choices across a number of sectors. The user specifies the amount of domestically produced biomass and how they want this to be converted into different forms (a mix of gaseous, liquid and solid). This is combined with imported biomass to provide the total available biomass. This total biomass is then used up by the sectors that use the corresponding end use forms of fuel. The process works as follows:

Domestically produced biomass

The quantity of domestically produced biomass is determined by the user's choices in the following sectors in the “control” worksheet:

- “land dedicated to bioenergy”, cell E22 (with calculations performed in worksheet “V.1a”);
- “livestock and their management”, cell E23 (with calculations performed in worksheet “V.1a”);

- “marine algae”, cell E25 (with calculations performed in worksheet “V.1c”)
- “volume of waste and recycling”, cell E24 (with calculations performed in worksheet “V.1b”).

Imported biomass

Biomass imports are determined by the user in the “control” worksheet, cell E27 (with calculations performed in worksheet “V.b”).

Converting total biomass into solid, liquid or gaseous forms

Domestically produced biomass is combined and drawn into the worksheet “V.a” as either dry or wet biomass and waste, gaseous waste or first- or second-generation energy crop inputs. The biomass is converted into either solid, liquid or gaseous hydrocarbons, depending on the trajectory specified in the “type of fuels from biomass” trajectory in cell E26 in the “control” worksheet. Some energy is lost in the conversion process. The net gaseous, liquid and solid biomass, along with the imported biomass (outlined above), gives total biomass in different forms.

Uses of biomass

The calculator assumes that solid biomass can be used in any situation that uses coal (such as a coal power station), liquid biomass can be used in any situation that uses oil (such as a car engine), and gaseous biomass can be used in any situation that uses natural gas (such as heating). Each sector can only use specific forms of energy (such as electricity or liquid hydrocarbons), and these are denoted in each sector’s worksheet in the “outputs: energy produced and required” section. For example, the sectors (and their worksheets) that use liquid hydrocarbons are as follows:

- Biomass/coal power stations (“I.a”)
- Agriculture and waste (“VI.a”)
- Domestic space heating and hot water (“IX.a”)
- Commercial heating and cooling (“IX.c”)
- Industrial processes (“XI.a”)
- Domestic passenger transport (“XII.a”)
- Domestic freight (“XII.b”)
- International aviation (“XII.c”)
- International shipping (“XXI.e”)
- Fossil fuel production (“XV.a”)
- Fossil fuel transfers (“XVA.a”)

When the user selects options that need a solid fuel in the calculator, the fuels available are used up in a particular order, as follows: domestic biomass and imported biomass; then domestic coal; and finally imported coal. If a preferential fuel type is not available then the calculator uses the next type. The same order of preference is assumed for oil and liquid biomass and for natural gas and gaseous biomass, where biomass is used ahead of fossil fuel sources when it is available.

This order of this consumption can be seen in each of the “year” worksheets, highlighted as follows with an example from the “MARKAL 3.26 Analog” pathway (which can be selected in the “control” worksheet by ‘copying’ and ‘pasting’ column T into column E).

In worksheet “2050”, the “MARKAL 3.26 Analog” pathway has 134 TWh of liquid biomass in 2050 available to distribute among the end-use sectors that require liquid hydrocarbons, as shown in cell V99 (total liquid biomass is the sum of cell O384 in the “V.a” worksheet and cell O108 in the “V.b” worksheet).

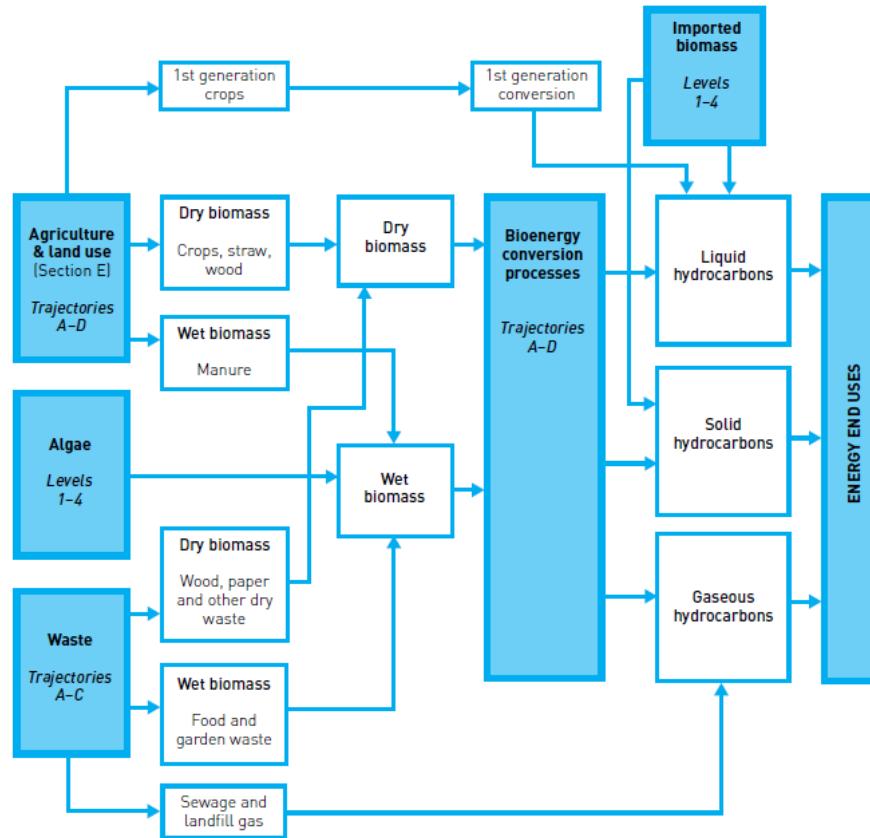
The total demand for liquid hydrocarbons from the sectors in 2050 is 538 TWh (cell V95 in the “2050” worksheet).

404 TWh of non-bio liquid hydrocarbons are “requested” by the model and consumed, which is the difference between the amount of bio and the amount consumed. This is given in cell V104.

Allocation of biomass to sectors

Therefore the calculator does not allocate biomass to specific sectors. The calculator determines the total demand for each fuel type (such as liquid hydrocarbons) by summing the demand across all sectors. The calculator then ensures that there is sufficient supply to meet this demand, subject to the choices made by the user of the calculator (see above “uses of biomass” and Appendix 5 on the balancing mechanism). The biomass supply that is determined by the user, as outlined above, is allocated to meet the total demand.

The process outlined above is outlined below in figure 6.



Costs in the 2050 Calculator

Objectives: why include costs

The first version of the UK 2050 didn't include any cost information. As a result, common reactions were 'how much will tackling climate change cost?' and 'how much will my pathway cost?' In response, an exercise was undertaken to add this capability to the tool. The objective was to reflect all of the monetary impacts of the users choices, with the analysis covering all aspects of the energy system. The four effort levels of choice that are available to the user are based on what is technically possible, without any consideration of the financial consequences. Including the costs analysis extends the feasibility debate, allowing users to consider the economic implications of their choices. The costs analysis answers the questions raised above, telling the user how much their pathway costs compared to other mitigation pathways, and compared to not tackling climate change.

Gathering costs data

The costs analysis is intended to encompass the entire energy system, so that all of the financial implications of the users choices are accounted for. Costs are categorised into three types:

1. **Capital expenditure:** the full costs of all capital components, from the heat pumps installed in individual homes, through to large infrastructure projects.



2. **Operating and maintenance costs:** the full cost of running and maintaining all of the required technology and infrastructure, again from individual homes to the national level.



3. **Fuel costs:** the costs of all involved fuels, from municipal sewage to enriched uranium.

An open online wiki was used in the development of the UK Calculator costs analysis, allowing interested parties from industry, academia, NGOs and civil society to submit cost information. The wiki provided entry field for all required supplementary information and contextual help to ensure that users submitted evidence consistently. For example, when submitting data for the cost of an offshore wind turbine, it was necessary to specify a number of details:



1. the capacity of the turbine in question
2. whether the estimate was for the capital (i.e. the turbine itself) or for operation / maintenance
3. the year for which the estimate was being made (either 2010 or 2050)
4. the year in which the price was valid (e.g. 2010), to allow for inflation to be accounted for. This approach allowed the costs data to be efficiently gathered and organised in a standardised fashion.

The UK 2050 Calculator Web Flash Excel Wiki <http://2050-calculator-tool-wiki.decc.gov.uk/costs/>

This is a wiki. Anyone can contribute, therefore we don't vouch for its accuracy.

Category: Onshore Wind	CAPITAL COST
Source	Capital costs are the one off costs that occur irrespective of how long a technology operates.
Label	The costs should include:
Type of cost: <input type="radio"/> A fuel, such as oil, gas, or imported biocrops <input checked="" type="radio"/> A technology, such as a nuclear power station, car, or insulation	<ul style="list-style-type: none"> The cost of installation The cost of connecting electricity using or producing equipment to the electricity grid
Capital cost	The costs should not include:
Operating cost excluding fuel	<ul style="list-style-type: none"> The cost of financing the development Research and development costs
Year in which cost is valid	The cost should be given with their units. For example:
Typical capacity	<i>£3bn (2009) 1GW</i> which means the cost is £3bn per GW of capacity, in 2009 money.
Typical average output	<i>£3bn (2010) 1GW/1500 MW</i> which means the cost is £3bn per 1500 MW facility, in 2010 money.
Typical average efficiency	<i>£3.6 (2009) 1/GW</i> which means the cost is in the range of £0bn to £6bn per GW of capacity, in 1990 money..
Typical life	If you don't specify otherwise, it is assumed that costs per W, kW or GW are peak powers, and anything else is an average over the lifetime. For example, if telling the power unit with 'peak', and average by telling the power unit with 'average'.
Notes, comments & h2 Items that this cost includes limitations:	<i>£3bn (2009) 2/GW</i> which means the cost is £3bn per GW of average output, in 2009 money.
h2 Items that this cost excludes	If you specify average power and the average output is any less than the peak output, please also enter an appropriate typical output value, and then tell the field lower down, to what the cost to be converted into amount per unit of peak capacity if required.
h2 Detail on the conditions under which this cost is valid	KNOWN UNITS
h2 Explanations as to why this cost differs from others	Prefixes: tn tr bn p t g m k Currencies: £ \$ € p 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 Currency: £\$€p tntrbnptgmk
h2 Limitations of this cost estimate	
Category: Cost data points; Onshore Wind cost data points	

Figure 11: Figure X: The UK 2050 Calculator Costs Wiki

Predictable, there is a high degree of uncertainty around many of the cost estimates required for the analysis, particularly in 2050. In order to account for this, submitters were asked to enter their estimates as a range, by specifying

both high and low estimates for each entry. The cost ranges submitted were then combined to form an overall range for each technology and type (e.g. maintenance costs), with the bottom of the range being based on the lowest of all of the estimates submitted and the top of the range being based on the highest. This was repeated for both 2010 and 2050. A few refinements were then made to supplement this approach:

1. To fully account for any up-side risks related to the uncertainty of costs in 2050, it was assumed that there would be no decline in costs in the period to 2050 (i.e. the high estimate for 2050 was set equal to the high estimate for 2010).
2. In order aid comparability a ‘default’, or ‘point’ cost estimate was constructed. This was done by aligning the default with a comparable estimate the established MARKAL technology costs database. Where no appropriate comparison was available from MARKAL, the default was set at the 35th percentile within the range (as where matches were found in the MARKAL database, they tended to be in this vicinity).
3. It was assumed that the costs follow a linear path between 2010 and 2050

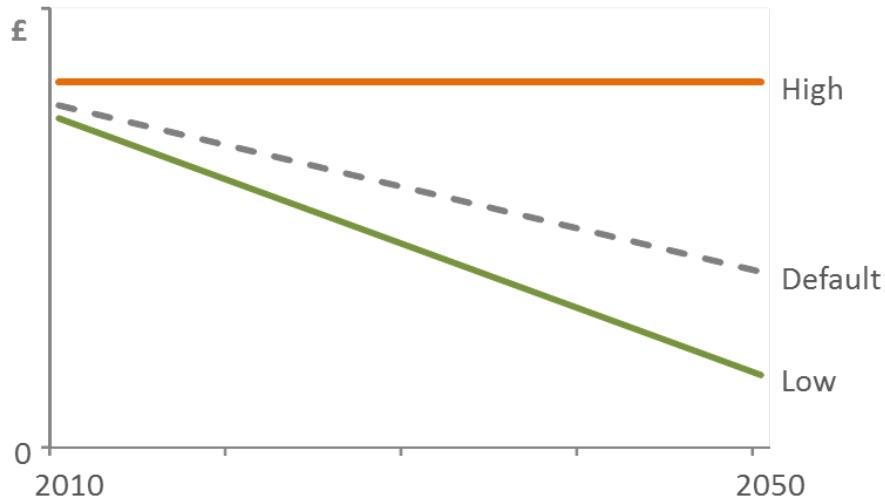


Figure 12: Figure X: constructing cost estimate ranges

Technology example

To illustrate the approach above, the following steps outline the process used to construct the capital cost range estimates for a particular technology: Electric

Vehicles

1. Estimates are gathered via the wiki Participants enter their estimates using the form provided, including:

- a. The source of their evidence
- b. A label for the estimate
- c. The capital cost in the format specified by the contextual help window, e.g. ‘£(2011) 30990/car’, which includes details of the currency (£), the year in which the nominal value is based (2011 money), the actual estimate (30990), and the unit for which the estimate is based (1 car).
- d. The year in which the cost is valid, i.e. is this an estimate of the cost of an electric vehicle in 2010 or in 2050?
- e. Some additional supplementary information, e.g. the typical life

2. Create ranges for the capital cost estimates for 2010 and 2050

- a. To construct the range for 2010, gather all of the 2010 based estimates
- b. Set the bottom of the range equal to the lowest estimate received (from wiki: £28,990).
- c. Set the top of the range equal to the highest estimate received (from wiki: £ 59,440), to yield a range from £28,990 to £59,440.
- d. The 2050 range is constructed in the same way, except as described above, the top of the range is set equal to the top of the 2010 range (to cautiously assume that the technology costs do not fall). This yields a range of £14,125 to £59,440 for 2050.

3. Create a linear cost profile from 2010 to 2050 This done in the Excel workbook, using a ‘delta’, which represents the change in cost per period, i.e. the cost in 2050 minus the cost in 2010 divided by 40 (the number of years in the period). For 2020, the estimate is equal to the 2010 estimate plus ten (the number of years from 2010 to 2020) times the delta. This is only done for the low estimate cost profile, as the high estimate remains constant from 2010 to 2050.

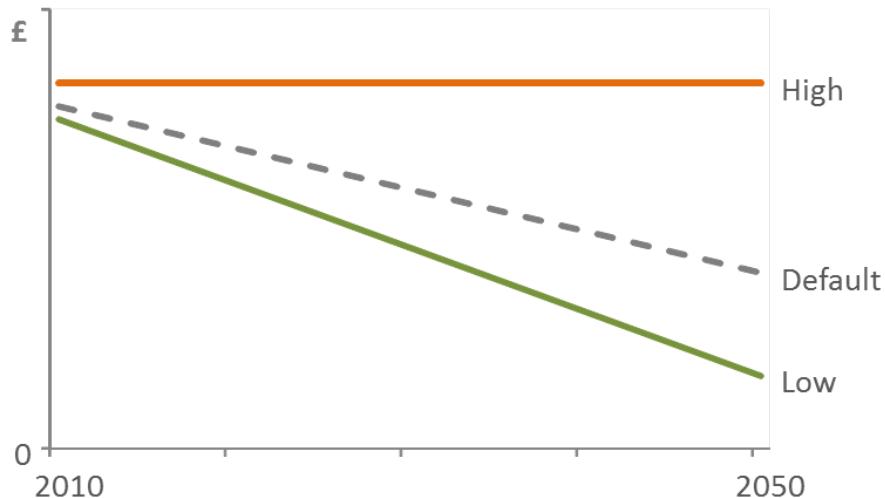
4. Create a default cost curve The default may be set at the 35th percentile between the high and low cost curves. If there is particularly strong evidence to suggest what the default cost will be, this can used instead.

Presenting costs

The cost estimates in the UK Calculator are summarised in different ways in order to more easily make comparisons between pathways. In the ‘CostAbsolute’ worksheet all of the costs from the individual sectors are drawn together. (This is done using index match formula similar to those used in the year sheets; see the ‘Complex Excel Formulae’ section of Annex 1 for more details.) Further calculations are performed to reveal:

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

The amortised costs show the total costs over the entire modelled period to 2050 prorated 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 summed over all of the sectors, which serves a convenient single figure with which to represent an entire pathways costs.



On the webtool, there are three main graphical representations of the costs:

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

How the webtool works

Overview

The 'Webtool' is a browser-based version of Excel model that can be accessed by the public over the internet: <http://2050-calculator-tool.decc.gov.uk>. It performs the same functions as the Excel model and produces identical results.

The webtool was developed to provide improved experience for users of the Calculator. It has several advantages over the Excel version:

Simpler: a pathway can be constructed simply by clicking a few buttons. There is no need to be a confident Excel user (or even have a copy of Excel).

All on one page: the controls and results can be seen simultaneously on one page (unlike the Excel version which requires a lot of scrolling around) Faster: the model recalculates in microseconds, giving the user instant feedback on their pathway choices

The webtool is based on a C version of the Excel model, which is translated automatically using some custom software, which is open source and available from DECC's GitHub page.

Getting set up

The webtool is based on a translated version of the Excel model, so this must be finished (or very close to) before the webtool can be put together. As well as providing the calculation engine for the model, many other aspects of the webtool also pass directly from the Excel version. This includes all the labels for the levers, the level descriptions and the example pathways. There are a couple of pitfalls to avoid with the Excel file, which can cause issues with the webtool creation process. Most notably, the Excel file should contain no VBA macros, and no links to external Excel files, either within formulae or named cells/ranges. A macro that lists any remaining external links is available here: <http://2050-calculator-tool-wiki.decc.gov.uk/pages/217> (Links to external

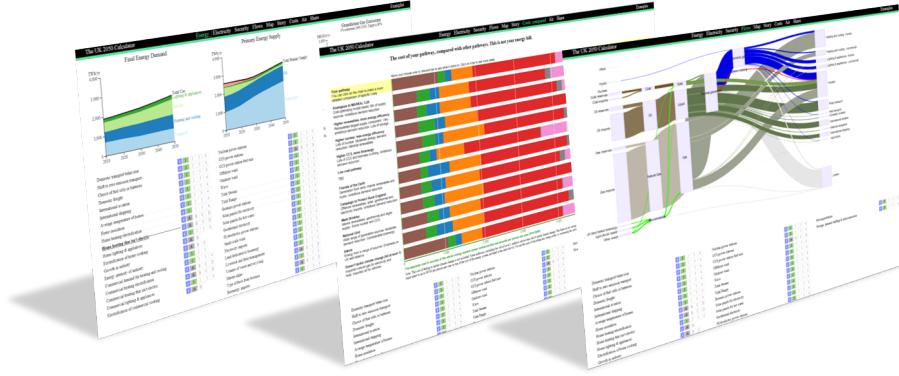


Figure 13: Figure X: The Webtool

named cells must be identified manually using the ‘name manager’, which is accessed via the formulas toolbar.) All of the development of the webtool was done on the unix platform, i.e. a Macintosh or linux (we recommend Ubuntu 12.04, 64 bit). To avoid compatibility issues, it is highly recommended that further development for other country webtools should continue on this platform. No successful attempts have been made to use this system on Windows (although a Windows computer running an Ubuntu virtual machine would be an option).

Some previous experience of programming is beneficial, as although much of the process is automated, some editing of the underlying code will probably be required. The backend of the model is written predominantly in the ruby programming language, while the front end is largely JavaScript based. Familiarity with these two languages would be particularly beneficial. The extent to which the Ruby code needs to be adapted depends on how far the new Excel model deviates in structure from the UK model. Similarly, more adaptation of the JavaScript is required if it is intended to diverge from the UK webtool front end.

The webtool source code freely available on GitHub (a web-based hosting service for software development projects that uses the Git revision control system), at the following address: <https://github.com/decc/twenty-fifty>. Some knowledge of this platform would be useful, particularly the unix terminal commands that can be used to interact with it. Before making any edit to adapt the UK code, it is necessary to set up a GitHub account and make a ‘fork’ of the UK twenty-fifty code repository, by clicking the ‘fork’ button in the top right hand corner of the UK twenty-fifty page. This will create a copy of the UK code within your user area of the GitHub site, that will act as the starting point for your version of the webtool.

The fastest way to get started with the webtool process when using Ubuntu is to run a pre-prepared set-up script that automatically performs a number of initial steps. This script is available on the webtool GitHub repository, within

the ‘util’ folder: <https://github.com/decc/twenty-fifty/blob/master/util/setup-2050-server-script.sh> When run, the script performs the following actions:

- downloads and installs all required dependencies
- downloads and installs ruby (version 2.1)
- downloads all the source code from GitHub (You will be prompted to enter the address of the repository to clone. Use the address created when you ‘forked’ the twenty-fifty repository. This is labelled ‘HTTPS clone URL’ on the front page of your repository.)
- compiles the c version of the UK model
- downloads and installs the required webserver software
- installs the interface between ruby and the server

If run successfully, the script should create a working local server version of the webtool. To start the server, navigate to the twenty-fifty folder created by script and enter the terminal command ‘rakeup’. The terminal will then return the port number (e.g. 9292) required to interact with the server in a browser. The port number should be appended to the IP address of your local machine, which should be 0.0.0.0, to form a URL as follows: 0.0.0.0:9292. When entered into your browser, this URL should open a functioning version of the UK Calculator running locally on your computer (as opposed to the UK Calculator remote webserver). If this opens and runs successfully all of the required components are in place and ready to be adapted for a new version for the county in question.

Separate instructions for getting set-up on OS X are available here:
<https://github.com/decc/twenty-fifty/blob/master/README.md>

Contents of each of the folders

When the twenty-fifty GitHub repository is cloned (as occurs when the above script is run), a number of directories and folders will be downloaded to your computer. These are listed below

In the top level of the twenty-fifty directory, there are a number of files and folders - the contents of which are as follows

Files:

- config.ru - sets up the server and loads the default view
- CREDITS - a list of people who helped build the Calculator
- Gemfile - a list of Ruby Gem dependencies required for the webtool (installed when bundle is run)

- HACKING.md - instructions for adapting the webtool
- README.md - an explanation of the webtool
- Dockerfile - a quick way of getting a server running with this code
- Gemfile.lock - shows successfully installed Gems once Bundle had been run
- LICENCE - details of the webtool's copyright

Directories:

- model
 - compile_c_version_if_needed.rb - compiles the translated C code if needed
 - model.o - an intermediate of the C version of the model
 - test_model.rb - makes comparison of new version vs. the previous version for change confirmation
 - compile_c_version_of_excel.rb - compiles the C translated from the Excel model
 - model.rb - an interface between the C model and the Javascript front end
 - tests - output from the tests
 - data_from_model.rb - specify data inputs and outputs from the C model
 - model_version.rb - shows the version number from the Excel model
 - translate_excel_into_c.rb - translates the Excel model into C code
 - libmodel.so - an intermediate of the C version of the model
 - model.xlsx - the Excel version of the model
 - model.c - the C code translated from the Excel model
 - README.markdown - an explanation of how to update the webtool
- src
 - compile_template.rb
 - index.html.erb
 - javascripts
 - * application.js - all JavaScript is assembled into this file
 - * controller.js - JavaScript for the lever/level controls and ensures the right view is displayed
 - * util - some shared methods used by the charts
 - * views - the JavaScript files for the views (one file for each view)
 - server.rb - deals with different browsers and old URLs
 - stylesheets - the style sheets for the views
- util
 - setup-ubuntu-12.04.sh - a script for setting up a local version of the UK webtool

- generate_fractions.rb - handles appearance of the level buttons when a decimal is selected (e.g. level 2.7)
- generate_hatches.rb - generates striped hatches for use in the charts
- public
 - assets - directory containing one pagers, pictures and assembled application JavaScript and CSS files
- contrib - directory containing 3rd party JavaScript libraries used by the webtool

Turning the Excel spreadsheet into code

The Excel model (from version 3.5.2) uses a series of named ranges to identify the data inputs and outputs that interface with the webtool. The ranges are named to reflect their purpose, with the input tables being named, for example ‘input.choices’ (which contains the users level 1-4 choices for all of the levers), and the ouput tables being named, for example, ‘output.finalenergydemand’ (which contains a time series from 2010 to 2050 of final energy demand split by the broad categories that appear in the webtool headline results charts).

All of these tables are in a ‘dense’ format, meaning that they contain no superfluous blank rows or columns.

A list of all the relevant named ranges in the Excel file is given below:

inputs named ranges	Outputs named ranges
input.choices	output.airquality
input.descriptions	output.areas
input.example.pathways	output.capacity.automaticalybuilt
input.long_descriptions	output.costpercapita.detail
input.names	output.diversity
input.onepagenotes	output.finalenergyde
input.types	output.finalenergydemand
	output.flows
	output.heating.mix
	output.imports.proportion
	output.imports.quantity
	output.primaryenergysupply
	output.shannonweinerindex

inputs named ranges	Outputs named ranges
	output.version

Table 7: Input and Output named ranges that receive / pass data to from / to the webtool front end

Within the ‘twenty-fifty’ directory, created by the set-up script above, there is a sub-directory called ‘model’, and within this there is an Excel file: ‘model.xlsx’. This is the Excel file on which the webtool is based, which is picked up from this location when the translation is run. This Excel file should be replaced with the new version of the Excel Calculator for which the webtool is being converted. The new Excel file should also be named ‘model.xlsx’. Once in place this file is ready to be translated to the C version of the model - but before doing so, a couple of configuration files need to be edited to reflect any changes to the structure of the Excel model compared to the current UK version. There is a single configuration file which contains the bulk of the edits required for the back-end of the model: ‘data_from_model.rb’. This file creates the interface that enables the JavaScript used for the front end to communicate with the C model running on the webserver. NB The translation can actually be run before editing the configuration files to check that the translation actually runs. It is a good idea to try this at an early stage to allow time to fix any issues with the spreadsheet that upset the translation process (like the macros and external references mentioned above).

Getting from the model to json

The interface between the webtool front end and the back end model is set up in a single Ruby file, `data_from_model.rb`. Within this a class called `DataFromModel` connects to `model.rb`, which connects to `model.c` (which is a translation of the Excel model).

Getting from json to a chart on screen

This explanation continues to use the final energy demand data as an example, but applies generally to all charted data. Within data_from_model.rg, an array (nested within the larger array) called 'final_energy_demand' is created and set equal to the contents of the output.finalenergydemand named range in the Excel file. This is done with the following line of code:

```
'final_energy_demand' => excel.output_finalenergydemand
```

The next stage of the process occurs in the relevant javascript file where the chart is to be created. For example, final energy demand is charted in the primary_energy.js JavaScript file.

At the top of this file (primary_energy.js) a setup function creates three empty charts (for energy demand, primary supply and emissions), making use of the D3 JavaScript library, which allows the control of visual objects using data.

The final energy demand data is converted into a ‘hash’ called ‘demand’ which is required before it can be charted. (NB a hash is an array where each element has an associated key or index.) This is done using the following line of code, which makes use of `convert_table_to_hash` function, which is defined within the file

```
demand = convert_table_to_hash(pathway.final_energy_demand);
```

The chart drawing function is then called, specifying that the ‘demand’ hash be used to provide the data. When a user changes their pathway the hash is updated from the new results and the chart is redrawn with the new data.

The primary_energy.js file also contains a ‘Teardown’ function which is called when the user selects a new view (e.g. costs in context). This function stops the chart drawing functions and tidies up ready for the new view to be loaded.

Getting from the user's clicking to a new pathway

The users selected pathway is encoded into the webtools URL (NB: this isn't visible when using Internet Explorer). For example, the 'all level 1s' pathway looks like this: <http://2050-calculator-tool.decc.gov.uk/pathways/11111111111111111111>

Each of the 1s indicate that level 1 is selected for a particular lever. If the user selects, for example, level 2 for one of the levers the URL will update, and the corresponding 1 will change to a 2. For example, if the nuclear lever, which corresponds to the first of the 1s is changed to level 2, the URL becomes:

When a user chooses a non-integer level (by repeatedly clicking on the level buttons to increment the level by 0.1) this is encoded as a letter within the URL, e.g. 1.1 is encoded as ‘b’. This process is contained within the twenty-fifty/src/javascripts/controller.js JavaScript file, the excerpt from which below, shows the full decimal to letter mapping:

```
float_to_letter_map = { “”: “0”, 1.0: “1”, 1.1: “b”, 1.2: “c”, 1.3: “d”, 1.4: “e”,  
1.5: “f”, 1.6: “g”, 1.7: “h”, 1.8: “i”, 1.9: “j”, 2.0: “2”, 2.1: “l”, 2.2: “m”, 2.3: “n”,  
2.4: “o”, 2.5: “p”, 2.6: “q”, 2.7: “r”, 2.8: “s”, 2.9: “t”, 3.0: “3”, 3.1: “v”,  
3.2: “w”, 3.3: “x”, 3.4: “y”, 3.5: “z”, 3.6: “A”, 3.7: “B”, 3.8: “C”, 3.9: “D”, 0.0:  
“0”, 4.0: “4” };
```

The string of characters within the URL that represents the selected pathway is stored in an array called ‘code’. This array is then picked up in the data_from_model.rb Ruby file, where it is converted back into a series of numbers in an array named ‘choices’, to match the format in which the level selections appear in the Excel model:

```
choices = convert_letters_to_float(code.split(''))
```

The named range within the Excel model, input.choices (or the C translation equivalent) is then set equal to the new pathway as contained in the ‘choices’ array:

```
excel.input_choices = choices
```

With the new pathway selection in place the model is recalculated and the new results are ready to be picked up.

Updating the webtool for your country’s model

1. Finalise you Excel model
2. Read all of this appendix
3. Set up a laptop with a local version of the UK webtool (e.g. using the script mentined above)
4. Make sure all required model inputs and outputs implemented in the Excel file (see detail above)
5. Edit data_from_model.rb with details of changes to the named ranges in the previous step
6. Run translate_excel_into_c.rb to translate the Excel model into C
PORTEGE-Z830:~/twenty-fifty/model\$ ruby translate_excel_into_c.rb

7. Run `compile_c_version_of_excel.rb`
 PORTEGE-Z830:~/twenty-fifty/model\$ ruby compile_c_version_of_excel.rb
8. Edit the JavaScript views to reflect any desired presentational changes
9. Run ‘rbackup’ command from the top of the twenty-fifty directory
 PORTEGE-Z830:~/twenty-fifty\$ rbackup
10. Navigate to `http://0.0.0.0:9292` in your browser (or `http://localhost:9292/`)

Modifying the webtool

Below are some tips on how to modify the web tool to suit different needs. They are not fully worked out instructions, you will need to get to know the code and figure things out for yourself.

Adjusting the scales on the charts

For instance, the UK energy supply and energy demand charts are labeled as being in TWh/yr and go up to 4000. You might want them to be in PJ and go up to 10000. To make the change, open the javascript file for the particular view, in this case `src/javascripts/views/primary_energy.js`, look inside the `setup()` function, find the lines that define the `timeSeriesStackedAreaChart()` and change the text inside the `unit()` to, for instance, `unit("PJ")` and the number inside the `max_value()` to, say `max_value(10000)`.

Removing the ‘shadows’ on the electricity charts

In the UK calculator, there are `shadows` on the electricity charts that allow you to visually compare the electricity demand and supply with the total energy demand and supply. That might not be appropriate for other calculators. You can change it in `src/javascripts/views/electricity.js` by removing all the lines that call the `context()` function, for instance `this.demand_chart.context(total_final_energy)`.

The energy security table total line is not at the bottom

In some situations the energy security table total line is not always at the bottom of the table. This has been fixed in the new version of the javascript:

https://github.com/decc/twenty-fifty/blob/master/src/javascripts/views/energy_security.js#L148-L154

Getting the map view to work

The first task in getting the map view to work is to find a map that is the right size. The UK one was 492 pixels by 725 pixels. The new map doesn't have to have an identical size, but shouldn't be too different. This needs to be put in the `/assets/images/` folder.

The settings in `src/javascripts/views/map.js` then need to be changed to make the scales work:

1. The `mapimage_url` needs to be given the name of your new map image.
2. The `map_width` and the `map_height` need to be set to the size of your map image in pixels
3. The `map_offset_x` and `map_offset_y` can be adjusted so the map is in the right sort of location on screen.
4. VERY IMPORTANT: the `km` variable needs to be changed to the number of pixels per km on the map. This can be worked out fairly laboriously by counting the number of pixels on the map that a feature that you know the size of covers.
5. If you have different codes for elements of the maps (e.g., you have a `IV.c` for concentrated solar power) then you need to give the new label a colour and a label in the `colours` and `labels` hashes respectively.
6. The `pointSizes` hash specifies the size in pixels of the items that are drawn as circles rather than areas. You may want these to give a sense of the relative size of, say, a nuclear plant compared with a geothermal plant.

Next, the items have to be placed on the map. That is done by changing the codes in the `land_box_names`, `sea_box_names`, `overseasiand_box_names` and `point_cluster_names`.

These stacks of boxes may not end up in the right place on your map. These will require adjusting of the x and y values in the `updateResults` section. Getting it right is usually a matter of trial and error.

Adding a completely new set of charts

For instance, you would like to add a new view containing detailed charts on energy security, or a new view containing per capita information.

In outline, you need to:

1. Get all the calculations working in Excel
2. Produce the charts you would like to see in Excel, linked to those calculations

3. Arrange the data in the Excel into a neat table, and create a named reference to point to it (copy what has been done for one of the existing outputs).
4. We recommend that the named reference should start with the word `output.`, like `output.percapitaemissions`. If you have used a different sort of name, you will need to modify `model\translate_excel_into_c.rb` to add the name to `named_references_to_keep`.
5. Run the `translate_excel_into_c.rb` code as you have done before, to get the change into the C version. Modify `model\data_from_model.rb` to change the `calculate_pathway()` function to include the new data. For example, to insert '`percapitaemissions' => excel.output_percapitaemissions`'.
6. Duplicate whatever existing view is closest to what you are looking for. e.g., copy `src/javascripts/views/primary_energy.js` and call it `src/javascripts/views/per_capita_energy.js`.
7. Add a reference to the new file in `src/javascripts/application.js`, e.g., `//= require views/per_capita_energy`.
8. Edit `src/index.html.erb` to include the new view in the drop down menu by adding a line to `<div id='views'>`, e.g., `Per Capita Energy & Emissions`
9. Edit your new view javascript (e.g., `src/javascripts/views/per_capita_energy.js`) to use the new data. For example, in the `updateResults()` function you might change the reference to `pathway.final_energy_demand` to `pathway.percapitaemissions`. You would probably change the chart's `title`, `unit`, `min_value` and `max_value` in the `setup()` function higher in that file.

Appendix 10: Going further: energy, vectors, and models

Overview

Energy

Energy is the capacity to do work. We make our lives easier by using energy to do work for us. In so doing, the energy is transformed: from natural gas to heat, from coal to electricity, from electricity to light. Any model of the energy system is therefore necessarily a model of the transformation of energy from one form to another.

The 2050 Calculator is such a model. It tracks the energy used by a country from its original sources to its final uses. This note explains how the Calculator

keeps track of energy, what the different kinds of energies mean, and the physical principles the Calculator models.

How to read this Appendix

You can read this note either before you have opened the Calculator or after you have looked at it for a bit. If you have never opened the Calculator then you should read the first few sections, at least until you have an idea what a “fuel type” is. Then look at one of the annual summary worksheets in the Calculator (the tabs labelled by years) so that you can make these ideas concrete.

If you have already opened the Calculator then you will likely have a number of questions—among them, I suspect, “why is there a ‘gaseous hydrocarbons’ fuel type?”, and “what’s up with bioenergy?” Those questions are answered below but it is nonetheless worth reading the first few sections. Knowing the precise meaning of “fuel type” is helpful to understanding the answers to those two questions.

The rest of this note is structured as follows. First, I describe a simplistic energy system, used in the subsequent sections as an example. The main section explains the entities found in the Calculator. Then there is a short comparison to the usual way of presenting national energy accounts. Finally, there is an explanation of some of the design principles which motivated the workings of the Calculator, and a discussion of the ways in which original Calculator falls short of those design desiderata.

An example energy system

In order to get a feel for the sort of system the Calculator models, it’s instructive to consider a very simplistic energy system and to follow one particular flow of energy all the way through that system. The diagram below shows a simplified version of that part of the energy system which involves gas as a fuel for power generation. I shall describe the steps in this system one by one.

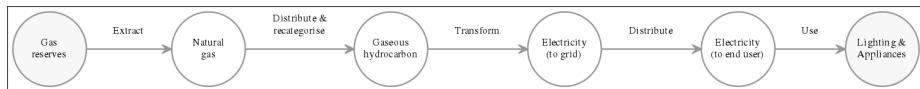


Figure 14: An example of an energy flow, showing the forms that energy takes as it passes through the energy system. See the text for an explanation. Those types of energy which are primary sources and final demands are shown lightly shaded.

Buried under the North Sea are reserves of methane, a source of chemical energy. For this gas to be of any use it first has to be got out from under the North

Sea. In the Calculator, extracting gas from under the North Sea is modelled as a transformation of “gas reserves” into “natural gas”.

Of course, gas under the North Sea *is* “natural gas”, so there is a sense in which no fundamental transformation has taken place. Nonetheless, for the purposes of the energy system, gas under the North Sea is a very different thing to gas in a pipe. In particular, there are sources of natural gas other than gas reserves (for example, imports) and these must be distinguished to allow proper reporting. In addition, some energy is required to extract the gas (more on this later). So it is important to keep separate the two forms of gas and this is what the Calculator does.

Before being used as a source of energy, gas in the Calculator is first transformed into “gaseous hydrocarbons”. That transformation might seem silly as well. After all, natural gas just *is* a gaseous hydrocarbon, so why not just model its consumption directly?

The reasoning is the same as above. There are sources of methane other than natural gas, such as gas created by the anaerobic digestion of biomass. Methane from recent biogenic sources is just as good, to a user, as methane which came from more distal sources and was buried underground. We need to keep track of these sources but we don’t want to add unnecessary complexity to a sectoral model by requiring it to know the difference. I will say more about this later.

The next step in our example more what one would consider a real transformation of energy: The gas is burnt, in power stations, to produce electricity, which is carried to homes by the National Grid. And at this point in the model, something odd appears to happen.

We must account for the use of energy to produce something useful, such as illumination. Now, light is of course a form of energy. However, most national energy statistics make no attempt to quantify the energy produced *in the form* of light. Instead, they capture only the amount of electricity *used by* the light bulb. The Calculator does something similar. The final form of energy captured by the Calculator, “lighting and appliances”, represents the total energy *used* in the production of those services, not the energy *of* those services.

In summary, the diagram above shows the physical reality of one particular energy flow in the UK’s energy system. The next few sections explain how this reality is captured in the calculator.

Workings of the Calculator

Fuel types and sectors

Now, the Calculator is a model, and a model must be precisely specified. Up to now I have described the different kinds of energy in English, but that is insufficiently precise for a computer model. Therefore, the Calculator gives a

code to each kind of energy and insists that only energies with codes are allowable as energy kinds.

The codes for the previous example are shown in the figure below.

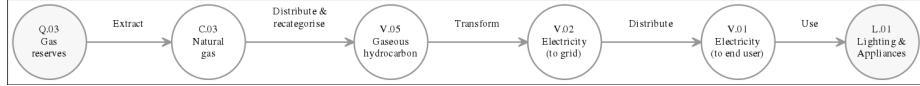


Figure 15: The example flow from the first section with the fuel type codes added.

There is obviously some structure to these codes: they consist of a letter followed by a two-digit number. One might suspect that energies whose codes have the same letter have something in common, and that is correct; but note that this fact is not used in the Calculator. To the Calculator, all codes are *opaque*; that is to say, meaningless.

A form of energy as the Calculator understands it—that is, a form of energy with a code—is called a *fuel type*. (Occasionally fuel types are referred to as *energy vectors*; “vector” in the epidemiological sense of “carrier of something” rather than in the mathematical sense.)

The Calculator treats fuel types in a very formal way. The result of any activity modelled by the Calculator must be a set of energy flows, where each energy flow is to or from a particular fuel type. Fuel types are the fundamental unit of account in the Calculator.

The activities which convert energy from one fuel type to another are also codified. A group of related activities, modelled on a single worksheet, is called *sector*. Sectors also have codes. The figure below shows the sectors that are used to implement the transformations in the example.

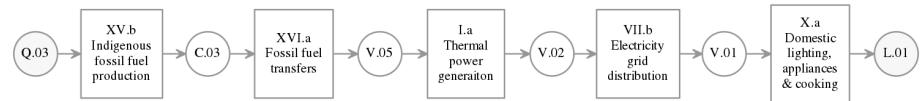


Figure 16: The example flow, now showing the sectors in the Calculator, which do the actual modelling work of computing how much energy is used.

The energy balance principle

There is something missing from the diagrams I have drawn so far. They show only a part of the story. For example, the production of gas from gas reserves itself consumes gas, but that consumption is not shown above; the production of electricity from gas does not produce as much electrical energy as chemical

energy in the gas; the Grid does not transmit to consumers the full amount of electrical energy sent into it.

In other words, there are flows of energy that are present in the physical system but not shown in the previous diagram. The figure below shows the diagram with the missing flows included. I've included example energy flows—these flows have physically reasonable relative sizes but are otherwise invented for the purpose of this example.

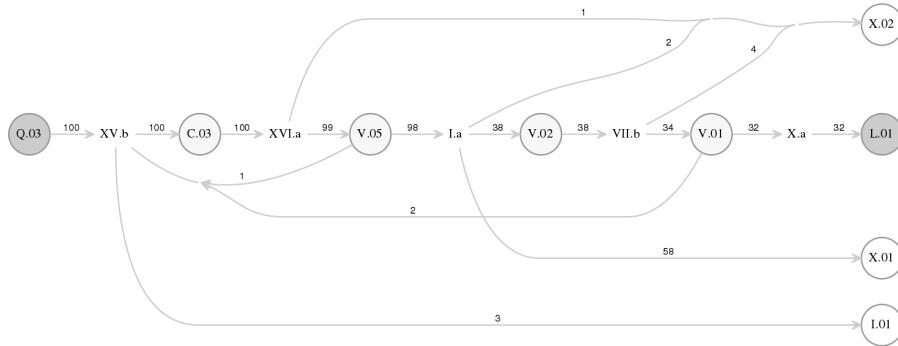


Figure 17: The example flow in full so that the energy balance principle is satisfied. Sectors are shown without boxes to save space. Figures on the arrows show example energy flows for illustration.

Fuel type **X.01** captures conversion losses such as energy lost as waste heat in a power station. Fuel type **X.02** captures distribution losses and “own use”. There is a distribution loss in sector **XVI.a** (which transforms natural gas into gaseous hydrocarbons) because, in the Calculator, this sector also models the gas distribution network.

Fuel type **I.01** represents energy consumed by industry and is included because, in the Calculator, energy consumed by the extractive sectors counts as industrial demand.

The Calculator insists that *all* flows of energy are captured in the model. It is straightforward to check whether all flows have been captured because it's a physical principle that energy can't 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”¹.

It turns out that, if nothing else, checking whether or not the energy balance principle holds for each sector is a very good way to find bugs.

¹There's a second kind of energy balancing idea in the Calculator. The model is not allowed to “carry over” energy from one year to the next, so the total production of to, say, **C.03** in one year must equal the total consumption of **C.03** in the same year. This point is discussed later.

Type	Code	Description
<i>Primary sources</i>	Q.02	Oil reserves
	Q.03	Gas reserves
<i>Secondary vectors</i>	C.02	Oil and petroleum products
	C.03	Natural gas
	V.01	Electricity (delivered to end user)
	V.02	Electricity (supplied to grid)
	V.04	Liquid hydrocarbons
	V.05	Gaseous hydrocarbons
	V.07	Heat transport
<i>Final demands</i>	X.01	Conversion losses
	X.02	Distribution losses and own use
	I.01	Industry
	L.01	Lighting & appliances

Table 8: Fuels types used in the example, for reference.

Code	Description
XV.b	Indigenous fossil fuel production
XVI.a	Fossil fuel transfers
I.a	Power generation
VII.b	Electricity grid distribution
X.a	Domestic lighting, appliances, and cooking

Table 9: Sectors used in the example, for reference.

Accounting for energy

One way to think about a 2050 Calculator is as a sort of accounting system for energy. Energy is converted from one form to another by the sectors; the point of the rest of the Calculator is to keep track of where the energy comes from and where it goes.

The diagrams in the example above show graphically how energy flows through

the real system. But there aren't any circles or arrows in the Excel model: there are just numbers. This section describes the way in which the energy flows are laid out in the Calculator.

There are two kinds of entity in the Calculator (fuel types and sectors) so it is natural to arrange the energy flows in a two-dimensional table, whose rows and columns are indexed by the sectors and the fuel types. That is precisely what is done in the “annual summary” sheets. Here are the full flows from the example, rewritten as a table in the style of the annual summary sheets:

Energy	Q.03	C.03	V.01	V.02	V.05	I.01	L.01	X.01	X.02
XV.b	(100)	100	(2)	—	(1)	3	—	—	—
XVI.a	—	(100)	—	—	99	—	—	—	1
I.a	—	—	—	38	(98)	—	—	58	2
VII.b	—	—	34	(38)	—	—	—	—	4
X.a	—	—	(32)	—	—	—	32	—	—

Table 10: Tabular summary of the same energy flows as in the flow diagram. Parentheses indicate negative values. Note that the “natural direction” is left-to-right, in contrast to the annual summary worksheets in the Calculator which flow right-to-left. Rows may not sum exactly to zero due to rounding.

The sum of all flows of energy in each row of the table is necessarily zero. In the Calculator, this sum is computed explicitly to make it clear whether the model is obeying the energy balance principle or not.

The total of a column is not necessarily zero. Typically, the total of a primary source (or final demand) fuel will be non-zero and will indicate the total energy produced (or consumed) by that source (or use). For example, in the table above, the total of L.01 is 32, and indicates that 32 units of energy were consumed for lighting an appliances.

Fuel types representing real fuels do sum to zero in the Calculator, as the Calculator does not “carry over” an energy balance from one year to the next.²

In the final part of this note I want to explain the relationship between the tabulation described above and the arrangement that is usually used to present a country's national energy accounts. Before doing so, however, there are two oddities that the reader might be puzzling over. The first concerns the

²This is not quite true. The totals of V.01 and V.02, the two electricity fuel types, are not zero, for technical reasons which now seem much less compelling than they did at the time. If you are building a Calculator and would like to fix this, please do so.

hierarchical nature of fuels; the second is about the meaning of “primary source” and “final demand”. I shall take these in order.

Hierarchies of energy types

The Calculator has no sense of “similarity” of fuel types. To the model, the difference between “natural gas” and “electricity” is no greater and no less than the difference between “electricity (delivered to grid)” and “electricity (delivered to consumer)”.

However, looking at the complete list of fuel types (at the end of this Appendix), you will see a number of fuel types that appear not only to be similar but even to overlap. For example, “coal and fossil waste” is presumably a subcategory of “solid hydrocarbons”; “natural gas” is definitely a subcategory of “gaseous hydrocarbons.” What is going on?

The first thing to note is that there is naturally a hierarchy of fuels. Lignite, for example, is a kind of coal, which is a kind of solid hydrocarbon, which in turn is a kind chemical energy. However, I do not know of a usable method of managing hierarchies of categories in Excel.³ We got around this problem in the original Calculator simply by not explicitly representing the hierarchical relationship, which is why apparently overlapping fuel types coexist. Perhaps it’s more correct to say that we ignored the problem.

But why did we bother having these overlapping types at all? Why have the “higher level categories”, such as natural gas? After all, actual, real fuels are always of a *particular* type, such as lignite. Why not just record these in the Calculator and ignore the general kinds?

The answer is that it helped to simplify the sectoral models. Consider transport, for example. Cars typically use specific kinds of liquid fuel: either petrol or diesel. But the technologies which use these fuels (variations on the internal combustion engine) are for all intents and purposes identical. Yes, there are engineering design differences, but the efficiency is about the same, as are the emissions for a given energy consumption. So there’s no need to model both these kinds of technology in the calculator. Since there’s no need, we shouldn’t do so; it would only introduce unnecessary complications.

Indeed, for the purposes of the transport sector, even liquid biofuels count as the same kind of energy and the technology which uses them is the same technology. There’s no point in distinguishing biofuel powered cars from petrol or diesel powered ones. We don’t need to maintain tables of efficiencies and emissions intensities for all three; we just assume there’s one kind of car which uses “liquid hydrocarbons” as a fuel.

³Hierarchies are difficult in general. I don’t think I’ve seen any system for managing them which has struck me as the “right way”. For some discussion see, for example, *Trees and Hierarchies in SQL for Smarties* by Joe Celko.

On the other hand, energy is produced in these different forms and there are usually constraints on the production of different forms, not to mention that users of the model typically like to know how much comes from each. For example, some liquid hydrocarbons are, in fact, petroleum based whereas others are biogenic. There are limits on biogenic fuels chosen by the user; the balance must come in the end from oil reserves.

All of this goes some way to explaining why there are some sectors (such as XVI.a, “Fossil fuel transfers”), which don’t seem to implement a particular *transformation* or *use* of energy, but instead *recategorise* energy from a more specific form to a more general one.

If there is a general principle, it might be this: in the model, energy is produced in the most specific form appropriate and consumed in the most general form possible. It would be nice if the model could do the recategorisation automatically, as required, but it doesn’t.

Nominal fuel types

I have alluded briefly to the different nature of “primary source” and “final demand” fuel types: they represent the point where the model stops tracking the nature of the energy. The value of the “lighting & appliances” fuel type, say, refers to the total energy consumed by this sector, rather than the energy in light.

For certain sectors this difference is starker. It is hard even to say what energy one should count in measuring “transport”. Kinetic energy of the car, perhaps? Yet the car eventually stops. An initially promising approach is to measure final demand in terms of the theoretically minimum energy required to achieve the observed service demand. (The difference between the energy entering the sector and the minimum required would be captured in an “inefficiency” fuel type.) But even that doesn’t work for transport: the energy theoretically required to transport something from A to B can be made as close to zero as you like (ignoring friction in the mechanism of the car) simply by going slowly enough.

The choice of where to stop tracking energy flows is somewhat arbitrary. Stopping too soon introduces challenges of interpretation. In the current calculator, the “final demand for lighting” is the energy consumed by lights, not the “service demand” (which would presumably be the energy of light emitted). Suppose that lighting demand decreases in some pathway. It’s not possible to tell, from the output of the Calculator, whether lighting demand is decreasing because the demand for illumination is lower, or because lights are becoming more efficient. But we have to stop somewhere, at least if we want to quantify service demand in some way, lest the entire Calculator simply become a method of converting nuclear energy into heat.

Those fuel types which represent energy in a form that doesn’t have a counterpart in the real world are called *nominal* fuel types. In contrast, fuel types which

represent energy that one could, in principle, point to, are called *real* fuel types.⁴

Nominal fuel types are a consequence of insisting on the energy balance principle. We have to stop tracking the energy flows somewhere, but the energy balance principle mandates that the energy has to come from, or go to, *somewhere*—so we invent a fuel type to act as the source or the destination. Nominal fuel types therefore represent the initial, “primary”, source of energy in the model; and the final destination of all energy.⁵

Comparison with national energy balance tables

The table in the figure shows a traditional presentation of the energy system described in the example above.⁶

	Natural gas <i>(C.03 V.05)</i>	Electricity <i>(V.02 V.01)</i>	Total
Indigenous production (<i>XV.b</i>)	100	-	100
Primary supply	100	-	100
Primary demand	100	0	100
Transformation	-98	40	-58
Electricity generation (<i>I.a</i>)	-98	40	-58
Energy industry use	1	4	5
Electricity generation (<i>I.a</i>)	-	2	2
Oil and gas extraction (<i>XV.b</i>)	1	2	3
Losses	1	4	5
Final consumption	-	32	32
Industry	-	-	-
Domestic lighting & appliances (<i>X.a</i>)	-	32	32

Figure 18: Traditional energy balance presentation of the example energy system.

⁴In the Calculator, real fuel types are sometimes called “secondary vectors”. Sorry about that.

⁵Interestingly, it is in the introduction of nominal fuel types that the Calculator starts to look most like an accounting system. Accounting systems track the flow of money from one kind of “account” to another. There are real accounts, representing actual piles of money (or assets), and then there are nominal accounts which are used to hold income and expenses. (There are also “personal” accounts, or liabilities, but they don’t seem to exist in the Calculator version of things.)

⁶See the [Digest of UK Energy Statistics](#) for other good examples. The traditional approach is described in *International Recommendations for Energy Statistics*, <http://unstats.un.org/unsd/energy/ires/>

On the face of it, this presentation looks similar in some respects to the tabular view used in the Calculator. There are descriptions of activities down the left hand side, and the columns are labelled by types of energy. However, there are two obvious differences: First, only the real fuel types are shown; and, second, those sectors that are part of the “energy system” are treated specially.

These traditional presentations should be read from top to bottom. The top section shows the production of energy from “primary sources”; the middle section shows the transformation of energy from one real form to another; and the bottom section shows the uses of energy. (The sign convention is somewhat confusing, and I am not convinced about the placement of the subtotals, but the meaning can usually be understood from the context.)

The connection between these two presentations can be made closer by imagining that the “total” column in the traditional view is really a catch-all term for various nominal fuel types. So, for example, in the top section, “total” really refers to a primary source; in the middle section it means either losses or final demand, depending on the nature of the activity; and in the bottom section it means final demand.

Design principles

In this section I outline some of the design choices we made in developing the Calculator and describe the reasoning behind them. Some of these decisions stem from the nature of the problem, others arise from quite abstract design principles, and some simply from the author’s previous experience.

The first rule of modelling that one learns is “divide and conquer”. To follow this rule is to decompose the full problem into a number of smaller problems which are (ideally) easier to solve.

In some sense, the application of this rule to energy system modelling is almost trivial. The energy system is *naturally* made up of individual parts—power stations, light bulbs, cars, and so on—and so that is typically how it is modelled. In the Calculator, we follow this principle by decomposing the energy system into sets of related activities, called sectors, and model each sector on a separate worksheet.

Of course, once the model becomes a collection of smaller models, the question arises of how to re-integrate the component parts. It is necessary to define, for each sub-model, an *interface*. An interface is an agreement between the submodel and the rest of the model about how the two parts will interact.

The general principle here is that the fewer things there are for the modeller to worry about the better. So the ideal is for different component parts to have the same interface, so far as possible, and for this interface to be as simple as possible. In other words, one should try to *abstract* the nature of subparts of the model so that they are all examples of the *same* kind of thing.

This principle is followed in the Calculator in the following way. The model is decomposed into sectors (which are really collections of related activities); all sectors are the same kind of submodel in that they all compute energy flows. These energy flows must be given as increases or decreases of energies of particular fuel types, and the fuel types are universal within the model.⁷ Under this view, a sector is simply a way of computing a set of energy flows. The interface to each sector is just the set of such flows.

Indeed, it was a design desideratum that the *only* interaction between sectors should be by way of the energy flows. This principle was for the most part followed. For example, the “last resort” power sector—gas-fired power generation—“decides” how much electricity to generate by producing whatever is required to make up the difference between total consumption and all other forms of generation.⁸

The principle of abstraction also goes some way toward motivating the introduction of nominal fuel types. With these fuel types, all sectors are the same kind of thing; without those fuel types, the supply sectors would be different entities to the transformation sectors and to the demand sectors.

In a model with only real fuels, the calculation of total demand requires the model to sum the total fuel used by the demand *sectors*, excluding the other two kinds of sector. With nominal fuel types, the model instead adds up the total flows of all final demand fuel types, regardless of sector. That might not seem like an improvement but it does have the very important implication that adding a new sector is more straightforward. The modeller only needs to specify which fuel types are used; it is not necessary to identify the sector as demand-side, supply-side, or part of the “energy system” somewhere else in the model. Since adding sectors is a more common occurrence than modifying fuel types, this would appear to be a good trade-off.

We introduced nominal fuel types for another reason which is that the author already had some experience with bookkeeping systems. Financial systems and energy systems are similar: they value everything in the system using the same measure (either by money or by energy) and you can’t create or destroy that measure overall. Bookkeeping systems—proper ones—universally use “double-entry accounting”. All that means is that every credit or debit of money must be matched by a corresponding debit or credit. If you receive money into your bank account, there must be somewhere for it to have come from; if you spend money, there must be somewhere for it to go. One necessarily arrives at nominal accounts.

Another way of looking at this comes from the idea of a *conserved quantity*. A conserved quantity is a quantity that is guaranteed to be unchanged by the

⁷It is also true that the sectors compute emissions—I am ignoring these here, but note that emissions, too, come in well-defined types such that emissions may be aggregated over all sectors.

⁸I am sure that there is at least one exception to this principle in the UK Calculator but I have forgotten what it is.

action of the model. Therefore, by checking that it *is* unchanged, we can test whether the model is working as expected. In the case of the Calculator, that conserved quantity is energy, and the principle of conservation of energy is what we have called the “energy balancing principle”. The nominal accounts allow us to define and compute a conserved quantity.

In summary, the principles we have tried to follow are:

1. All sectors are equivalent (to the model).
2. All fuel types are equivalent (to the model).
3. All interactions between sectors are through the energy flows alone.
4. All output from the model can be derived from the totals of the energy flows for each fuel type (this principle was not universally followed; see later).

Prolegomenon to any future Calculator

In this final section, I’d like to talk about what improvements one could imagine making to the Calculator; improvements, at least, that one could make to the conceptual framework, without delving into the details of any particular sector. Most of these thoughts are attempts to narrow the gap between the ideal design principles set out above and the reality of the Calculator. Some of that gap stems from the limitations of Excel. But some of it arises because we didn’t manage to solve all the conceptual problems that came up. I think it’s certainly possible to do better in two areas and perhaps possible to do better in a third, but maybe not in Excel. Those three areas are: (1) Communication between sectors; (2) Output from the model; and (3) Hierarchies of fuel types.

Communication between sectors

There are a number of places where an apparently *ad hoc* energy flow calculation is performed within the annual balance sheets rather than in a sectoral worksheet. In particular, you will notice that subtotals are calculated for certain fuel types and used by the heat supply (XVII.a), power generation (II.a, I.b, I.a), electricity distribution (VII.b), and biomass (V.a and V.b) sectors, a subtotal is computed. This subtotal is the total energy flow, of a particular fuel type, from a subset of the sectors. (There is a similar calculation done for XVI.b, balancing imports, which really should have been done in its own sectoral worksheet).

What is going on turns out to be straightforward, although it certainly doesn’t appear so at first glance. The job of certain sectors is to supply (or demand) an amount of energy that is not fixed by the assumptions, but depends upon what is demanded by the rest of the model. For example, electricity from gas

generation is produced in whatever quantity is required to meet the total demand for electricity. So somehow the amount of electricity demanded needs to be passed to that sector. The subtotal adds up all the flows except those from one particular sector.

We should have formalised this calculation. Here is one approach to doing so. For each real fuel type, the modeller would designate a single sector as the “balancing sector” for that fuel type. (The designation might be done in one of the front worksheets.) In the annual summary worksheets, introduce a “Total of fixed flows” row beneath all the sectoral rows. The cells in the “Total of fixed flows” row contain a formula to add up all flows from the rows above *except* that from the designated sector. Finally, all balancing sectors, which require this total as an input, could obtain it with a common lookup.

Output from the model

The original plan was that all output from the model (at least, that relating to energy flows) would be derived from the total energy flows in each fuel type, without reference to any particular sector. I wanted the model to produce a summary of all total energy flows, by fuel type, and for all output to come from this summary. My reasoning was similar to that which produced nominal fuel types: that sectors wouldn’t have to “know” about anything other than their inputs and outputs (which is, really, all they ought to know about) and this would make building the model easier and less error-prone.

There are, I think, two reasons that this plan failed. First, it turned out that we often wanted to know the *gross* flow through a particular fuel type. As a good example, the Calculator reports total electricity flows “over the grid”, although the net balance of electricity at the end of each time period is zero.⁹ Since the Calculator doesn’t carry over energy from one period to the next, net flows (in real fuel types) are always zero. We ended up “looking inside” particular sectors to see their total inputs or outputs.

The second reason is related to the hierarchy problem. We often want to extract quite detailed information from the model—for example, energy lost in conversion by power stations. That kind of detail isn’t available if one restricts oneself to broad fuel types, unless the fuel types are subject to a rich and detailed classification. But in the current approach, where each level of the fuel type hierarchy requires its own fuel type, that would mean lots of very similar fuel types, not to mention multiple “little” sectors to recategorise energy from one to another.

At any rate, a partial solution would be to record, for each fuel type, not just the net flow but the gross flow: that is, the total inflow (or outflow) only. To do so, each sector would specify not just a flow for particular fuel types, but also

⁹Which also, in part, explains why the electricity fuel types break the rule that real fuel types should sum to zero.

whether those flows were “production” or “consumption”.¹⁰ I think this would be a good start, even though a full solution seems to require a solution to the hierarchy problem.

Hierarchies of fuel types

It would be nice to classify fuel types in their natural hierarchies. It’s just hard to see how that would be done in Excel. But suppose, for the sake of discussion, that there was a version of the Calculator which could support hierarchies. How might we use that facility?

I think one interesting improvement would be to have the model automatically convert between subtypes and more generic types. If you were writing a sector which consumed a particular fuel, you would specify the most general form of that fuel: for example, “gaseous hydrocarbons” for a gas-burning technology. The model would then “look for” any subtype of that fuel, such as “natural gas”, if it were needed.

There’s a question, of course, of how the model should decide which subtype of the fuel it should use and that in turn raises a wider issue. In the model as it stands, there are two kinds of sector: those for which the input and output energy flows are fixed (at least once a particular trajectory is chosen) and those whose activity level, and therefore input and output, varies to match what is going on in the rest of the model. For example, the transport sector is one whose flows are fixed by the trajectory; whereas the import sector varies to balance supply and demand.

In some imaginary, future Calculator, the designer should specify which kind of sector is which, and the model should report whether the collection of all sectors forms a soluble model; neither underspecified nor overspecified.

Fuel types

The following table lists all the fuel types in the current version of the UK Calculator. (Other versions and other Calculators may well have a different list, as there is nothing fundamental about these.)

Code	Description
<i>Primary Sources</i>	
N.01	Nuclear fission

¹⁰It might well be suggested that there’s no need for each sector to specify the direction of each flow since that information ought to be encoded in the sign of the energy flow. In other words, one could simply compute $\sum |flow|/2$. Well, yes, and no. For some reason, I feel that the direction of the flow is something different from its sign. I don’t have a coherent reason for this.

Code	Description
R.01	Solar
R.02	Wind
R.03	Tidal
R.04	Wave
R.05	Geothermal
R.06	Hydro
R.07	Environmental heat
A.01	Agriculture
W.01	Waste
Y.01	Biomass oversupply (imports)
Y.02	Electricity oversupply (imports)
Y.03	Petroleum products oversupply
Y.04	Coal oversupply (imports)
Y.05	Oil and petroleum products oversupply (imports)
Y.06	Gas oversupply (imports)
Q.01	Coal reserves
Q.02	Oil reserves
Q.03	Gas reserves
<i>Secondary vectors</i>	
C.01	Coal and fossil waste
C.02	Oil and petroleum products
C.03	Natural gas
V.01	Electricity (delivered to end user)
V.02	Electricity (supplied to grid)
V.03	Solid hydrocarbons
V.04	Liquid hydrocarbons
V.05	Gaseous hydrocarbons
V.06	Blast furnace gas
V.07	Heat transport
V.08	Edible biomass
V.09	Dry biomass and waste

Code	Description
V.10	Wet biomass and waste
V.15	Gaseous waste
V.11	Domestic solar thermal
V.12	H2
V.13	Energy crops (second generation)
V.14	Energy crops (first generation)
	<i>Final demand</i>
X.01	Conversion losses
X.02	Distribution losses and own use
Z.01	Unallocated
T.01	Road transport
T.02	Rail transport
T.03	Domestic aviation
T.04	National navigation
T.05	International aviation
T.06	International shipping
I.01	Industry
H.01	Heating and cooling
L.01	Lighting & appliances
F.01	Food consumption [UNUSED]

Table 11: Fuel types used in the Calculator.

Appendix X: Whitehalls School conference

The 2050 Calculator team were asked to partake in the annual ‘Whitehall Schools Conference’, delivering an engaging and fun workshop for more than 120 13-14 year olds. They had come from across the country to participate in the event as part of a program to provide talented students from under-represented socio-economic backgrounds an opportunity to visit Whitehall and develop their knowledge of the civil service.

Our role was to present the UK calculator to these school children as part of a

group activity in a way to teach them about the effects of climate change and to understand a bit about the UK's 20% emission target. We were given three sessions with over 30 children, including some teachers, and half an hour to take part in the game.

Using the 'My 2050' online tool, we introduced to the group the efforts that the UK government was making to combat carbon emissions. This included the target of reducing carbon emissions by 20% - which was the aim of the game. Simply trying to change the levers to get to this target and explaining why this was necessary.

We started with the 'Supply' part of the simplified tool, going through the more exciting types of clean energy such as wind power, solar and explaining carbon capture. Throughout asking them questions on what they thought was good or bad about each – for example "What are the advantages and disadvantages of nuclear power?" We got some very good answers and managed to engage quite a few of the children in each of the groups. We then moved onto the 'Demand' side of the tool which looked at transport, heating and business greenness. It was good to get the audiences opinions on what they thought was a good idea on how to save energy and use the green electricity we would hope to be making.

To do all this and to get a successful outcome, we went through each category on the two supply and demand sections. These categories have levers that you can adjust that will affect the game and reduce the carbon emissions if moved in the right way. So we used a voting system for how far the school children wanted the levers to go up or down; for each category there are 4 levels for how far this will go. Therefore we presented 4 questions to for voting. We had around 16 questions in total, and for some levers we spent more time than others. We spent roughly two minutes on each category, and a bit longer for the more engaging questions at the start about what they understood on climate change. For example, for the category on wind turbines we presented this question to them:

How many wind turbines should we have in 2050 in the sea? Now we have around 1,000.

- A - None
- B - 10,000
- C - 17,000
- D - 40,000

They all had small remote control buttons to cast their vote (A, B, C or D) and then had 10 seconds to decide. After the countdown the results of the votes appeared on the screen as a chart showing the percentage result of each option. The highest percentage from that was then used to adjust the lever on the 2050 tool. So if it was 2 times more, 3 times more or 4 times more than what the lever was on.

(Voting buttons can be bought or hired, and were supplied for by the event

organisers. Here is an example of what kind of system you would need (<http://quiztime.biz/voting.html>)

By changing the levers we could see the 100% bar begin to drop, this 100% was the amount of carbon emissions that would be in the atmosphere If the government did nothing to try and change the way we use energy. The aim therefore, is to reduce carbon emissions to 20% or less of 1990 by the year 2050. We were able to use this tool to explain this process to them and managed to achieve this 20% goal with all three groups. It was encouraging to see them begin to pick up some of the important ways to reduce emissions, and even more encouraging hearing that some of them had heard of carbon capture, smart meters and loft insulation grants.

Overall the discussion was successful and was a really interesting and convincing way to demonstrate the tool. It presented, what could be dull information, in a colourful and interactive way. Although we only had half an hour, we think with an hour – and we've seen in the past this is the case – that with more time you could engage in better discussions about climate change. The website tool was received well, and next time we will endeavour to promote our 'My 2050 school toolkit' (<https://www.gov.uk/government/publications/my2050-schools-toolkit>) which is an excellent resource for schools to use.

Appendix 12: Quality Assurance checklists

Checklist 1: Avoiding formula problems

Stage	Check	Tick
Planning	Design sheets so that your calculations flow downwards	
Planning	Minimise calculations that need to look up from other sheets If you must do this, try to use named tables or named ranges, and INDIRECT formula as much as possible	

Planning	Plan your spreadsheet so that the global assumptions sheet stores any commonly-used figures (e.g. population, households, GDP)
Development	Always use units when entering raw data! E.g. =(Unit.GW)*0.5
Development	Take particular care with vectors: Make sure that your vectors balance as early as possible Check all conversions make sense from scientific perspective If you add or delete vectors, check with UK team, and add to year sheet & intermediate output
Development	Use named ranges used to aid user understanding and simplify formulas. Ensure that names follow a common convention. Use the Name Manager, to avoid corrupted or wrong ranged names.
Development/ Documentation	For any complex calculations, make the approach really clear: Write quick summary of what it's doing (e.g. methodology) Divide up any complex calculations in separate rows

Documentation	Record the units at the top right of every table, and make sure that any data referring to this is also in the same unit (unless it's deliberately converted to something else)
QA	<p>Get a good process for Quality Assurance:</p> <p>Get a second person to proofread (and sign-off) each sheet</p> <p>Use a clear and logical version numbering system</p> <p>Send the UK team versions as early and frequently as possible so that we can help</p> <p>Keep an issues log, prioritise it, and tick off resolved problems</p>
QA	<p>Use the 'formula auditing' tools to make sure that important formulae are right: particularly trace precedents/dependents</p> <p>Investigate any #REF, #DIV/0, #VALUE errors in the model</p>

QA	<p>Check that all figures should add up to 100% when they are meant to (and add checksums to confirm this)</p> <p>Sometimes it's good to put a formula as the last number in this set which subtracts all other numbers from 100%</p> <p>Check you don't have rows of data that are calculated but never used: This could mean that the user's trajectory doesn't properly feed into choices, or other errors</p>
QA	<p>After updates, Check Data>Edit links to check for external links (see Appendix xxxx for instructions on how to remove these if found)</p>
QA	<p>Add subtotals/comparisons against earlier totals (and tell people when should be zero) so that errors can be spotted</p>

Checklist 2: Avoiding issues with documentation and labelling

Stage	Check	Tick
-------	-------	------

Planning	<p>Try to stick to the structure and sheet layout of UK calculator where you can. This avoids introducing new errors and will make it much clearer for people who are used to other versions of the calculator</p> <p>In particular, the Control sheet and Intermediate Output Sheet have many outputs that feed to the webtool, so changes here should be minimised</p>
Planning/ Development	<p>Add quick descriptions of the content and logic of every sheet. Make sure your sector names are clearly described, and consistent when used elsewhere</p>
Planning/ Development	<p>Whenever you temporarily keep a label or documentation from UK version in your spreadsheet, make sure it is clearly marked so that it can't be confused with data that has been updated.</p> <p>We recommend marking old text or calculations in red so you know it's old. You can also add a note that it needs updating</p>

Development	Each time you copy data into your master spreadsheet, make sure you carry out your checks for external links (see Appendix xxxxx)
Development/ Documentation	Use colour coding in a consistent way within your team – for example, to show data updated, issues or old data.
Development/ Documentation	<p>For complex or contentious issues, provide as much documentation as you can about where the data comes from. For example, show a link to the original source, the date when accessed, and an explanation of any caveats, extrapolations made into the future.</p> <p>To highlight the quality of the assumption, you may want to give a rating for it. For example, the 2050 Global Calculator uses the following ratings for data:</p> <ul style="list-style-type: none"> Red: unpublished assumption or 10 years out of date, or a proxy from similar type of data Amber: published or slightly relevant source, or proxy data Green: published source from last 2 years with a link we can access and it's relevant

Development / Documentation	When writing your explanations and documentation, it is good practice to spell out any acronyms in full – don't expect that all users will understand any technical or country-specific terms
Process	Whenever you have finished your draft or final version of a sheet, ask someone else in your team to double-check: Your units Your time periods Any ambiguities or typing errors (e.g. 'net' instead of 'new') As well as catching errors, this will also make sure that more than one person in the team is familiar with each part of the spreadsheet

Checklist 3: Recommendations on assumptions and ambitious

Stage	Check	Tick
-------	-------	------

Development	If any details of the UK calculator's assumptions are unclear, the following resources may help you: The Excel file itself has references for most data, and includes footnotes in Excel There are a range of resources at our websites: If you still can't find what you need, please contact a member of the UK's 2050 team.
Development	Make sure that the model matches historical results for the base year when using historical input data (to within an agreed tolerance level)
Development	Get another opinion. Ask people if this is surprising and why
Development	Share these with stakeholders and expert to sense-check, particularly for level 1 and level 4: Are there any negative scenarios (could be political, economics, technical) under which you would have less or more effort than these extremes? Are there stakeholders who would disagree with ambition?

Development	<p>Think about assumptions as early as possible, and ideally explore them through driver trees to simplify them as much as possible:</p> <p>Talk within the team about difficult assumptions</p> <p>Test them as early as possible with your expert stakeholders.</p>
QA	<p>Always chart your trajectories 1-4 (or A,B,C) so that you can see if anything is wrong. We're trying to develop some ways to make this easier.</p>
QA	<p>Check that the model produce logical outputs (i.e. what you expect) –for example, values in the direction of travel and of the right magnitude when subject to sense / reality checks. Check model outputs have been sense-checked and agreed with stakeholders</p>

QA	<p>Consider doing extreme values testing / model breaking</p> <p>Does the model respond as expected to extreme values, zeroes, negative values, critical limits?</p> <p>Is it possible to 'break' the model or get implausible outcomes (e.g. percentages adding to more than 100%, people adding up to more than the population)?</p>
QA/Documentation	<p>Check that appropriate data has been used:</p> <p>E.g. are the quality, characteristics, strengths and limitations of the data set fully understood and recorded? Has data quality been assessed and given a RAG rating?</p>
Documentation	<p>Document all data/assumptions clearly in the spreadsheet and supporting material.</p> <p>Make sure any actions are also implemented.</p>

Frequently Asked Questions

Technical

Q188) Why do we model a past year, as the total energy figures are already known? The final version of 2007 shows modelled data for the same time period. So when you look at each sector, e.g. the nuclear sector, you have already got legacy capacity in the system

As we already know what happened in 2007, this means that you can use existing capacity to work out what generation would have been. It's quite interesting to see how close that gets to the published statistics, and making that comparison is a very good way to check the sector you're constructing is working correctly. You'll have published data then modelled data

If it's wrong, maybe load factor is wrong. Or it could be that a power station was being shut down for x weeks. Or for example, a coal fired power station had a different kind of imported fuel.

All this allows you can make assessment to how close model matches the outputs just for that one year period. This then gives you confidence in your future results.

Q109) What is the reason behind the distinction between primary and secondary energy? Would there be problems if the Colombian team wanted to change these definitions? Primary sources refer to energy vectors in their initial state as they enter the system. Secondary sources refer to any primary source that may have undergone a change of state, before it is consumed e.g. solar electricity – electricity from the grid. These vectors (both primary and secondary) aim to be mutually exclusive and comprehensive of the whole energy system.

It would be ok to change definitions to better fit Colombian statistical conventions, but you would need to be very careful that you were not going to double count anything (e.g. make sure everything is mutually exclusive). If you wanted to add any additional primary or secondary sources as vectors in the technology sheets, and then also add these to the year sheets.

Q162) How consistent do we need to be with IPCC categories? TBD

Q140) What is DUKES, and why is it referenced in so many places? DUKES is the UK's Digest of UK energy statistics, and summarises all relevant figures for each year. This was one of the main resources used for the 2050 calculator.

<https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes>

Q74) Are all the numbers and calculations inside the sheets are accumulated for five years, or is it only data for each year? The aim of the year sheets within the calculator is to give a picture of how the energy system looks in each of those years - e.g. the year 2040, 2045 etc.

In each of these, we work out all the input data and assumptions and all of the outputs just for that year, so all numbers should be by year unless it's specifically stated otherwise.

Occasionally calculations are by 5-years (for example when working out the new capacity that will be added between one year and 5-years later), but the units should indicate that.

A couple of ways the sheet is designed around this by-year approach are:

- The base year calibration (2007 in the UK's case) which matches up actual reported figures for that year, against modelled figures
- In the Intermediate output sheet : the heading (D4) says TWh per year
- And anywhere that cumulative calculations are done, approaches such as the following are taken:

"Cumulative emissions are estimates based on a linear trajectory between the 5 year time periods" (e.g. intermediate output sheet, cell C198)

Q78) Could you please give us some more detailed information about vectors? This page gives a summary of vectors:

<http://book.2050.org.uk/calculator-book/appendix-3-vectors.html>

Q116) Apart from the level of accuracy of statistic input, what has been the criticism or main weakness of this model? Some people think that there are technologies or choices not included which should be, for example more options in transport sector to lower demand. Ideally level 4 should be very ambitious, and roughly equal effort across all sectors - although we're not quite there yet in the UK version, we recommend that you use your stakeholder consultations to do this.

We receive complaints asking where shale gas is within the model, and asking about options to increase domestic gas in future (however several other countries have made it easier to increase production of any fossil fuels)

People also sometimes like to be able to change more than just the levers – for example, when a particular technology will be launched. However, because the fixed assumptions are always in the Excel file, some people have adapted this to explore questions of their own.

People sometimes ask what do we do with all public comments and how can people feed into the model. Although we invited comment through the Call for Evidence, there is always more we would like to do here.

The 5-year modelling periods have been questioned - this approach lacks the detail of the 30 minute based model. (Can we give example?)

The Calculator has been criticised for not being an economic model, i.e. costs are treated as exogenous, which is arguably unrealistic.

Q124) For teams working on the Calculator so far, what aspects of the UK structure have they most needed or wanted to change? In general, teams have made fewer changes to the renewable supply sectors – they have removed some technologies, and sometimes merged technologies (e.g. treating onshore and offshore wind together), but broadly they have left the same.

For fossil fuel production and generation, there have been some changes: for example, several countries have changed the default fuel to coal (rather than gas as used in the UK).

For demand sectors, there has often been more change. For example, within transport the Chinese calculator team have made a few big changes. They've divide transport into urban and rural to reflect the very different patterns of travel, and the shorter distances travelled.

In your transport sector, you'll also need to think about what you want to include and how you want to split it. You could also decide to include international transport, even though not accounted in official inventory, because you often need to consider implication of those data when discussed internationally.

Q128) What GDP growth rate assumptions have you used and how do you change them? For the UK, GDP growth is assumed to be 2.0% in each year from 2007 to 2050, based on HM Treasury's view of long-term growth in the UK. This assumption can be changed by altering the "GDP (2005 £m)" column in the "Global.Assumptions" 'Table', in the "Global assumptions" worksheet.

We recommend that you choose a GDP which seems sensible over the long-term, even if this might be slightly lower than recent trends. You may want to discuss this with stakeholders early in the process of building your model. You may also want to compare your assumptions on levers such as industry growth, to make sure these are consistent with your GDP assumption.

Q161) Why do the numbers not update in the spreadsheet when I change them? You need to press F9 whenever you change anything, and this will recalculate the entire spreadsheet. It can take a few seconds, so make sure you wait until all the calculations have been updated (you'll see a percentage counting up to 100%, when it is ready).

The reason it doesn't automatically recalculate is that this would make the Excel spreadsheet much slower to use. So we always save it in a mode called 'manual recalculation', where F9 triggers all the calculations.

Q127) What population figures have you used and how do you change them? The population projections used in the UK's Calculator are central projections sourced from the Office for National Statistics, and are given in a 'Table' called "Global.Assumptions" in the "Global assumptions" worksheet. The figures in this 'Table' can be edited if the user wants to use different population assumptions.

Other countries have used sources from their own countries, but we always recommend using this as Global Assumptions.

Q2) Where do I find the Excel model? The Excel model is self contained and available here:

<http://2050-calculator-tool-wiki.decc.gov.uk/pages/140>

Q37) How does the 2050 pathways model relate to other energy models The short answer: There is no perfect model. The 2050 pathways model is playable & transparent but simplistic. Markal, ESME, the DECC Energy Model are rich & powerful in different ways but complex and limited in others. DECC uses all four.

For a longer answer, see the page here:

<http://2050-calculator-tool-wiki.decc.gov.uk/pages/60>

Q35) Why doesn't the spreadsheet work in older versions of Microsoft Excel or in other spreadsheet programs such as open office The only software that the Calculator can run on is Microsoft Excel for PCs 2007 and 2010, and Microsoft Excel for Macs 2011.

The reason is that the model includes "structured references" and these have not been implemented in earlier versions or in open source Excel alternatives.

Possible work arounds:

- Download trial copies of the latest version of Microsoft Excel
- Programmatically drive the ruby version of the calculator, distributed as part of the source code to the web interface

Q3) What version of Excel do you need? The Excel model requires Microsoft Excel, 2007 or later (sadly it doesn't work in Open Office or older versions of Excel, because of its use of structured references).

Q6) Who do I contact for technical help? If you want to talk about what you are trying to do, or find out about our experiences in developing the tool, please get in touch at 2050pathways@decc.gsi.gov.uk

Q131) Does each lever correspond to a sector/sheet within the spreadsheet? The list of levers doesn't directly correspond to the list of sectors.

Some sectors have no lever (e.g. unabated thermal generation). Whereas some sectors have more than one lever (e.g. the heat sector which has four)

Levers represent the complete list of main actions to target emissions: they control the main drivers for each sector.

Q136) What is the difference between sectors which are numbered 1-4, and sectors which are called A, B, C? Where factors can be considered as changing levels of effort or ambition, these are described in the analysis as levels 1-4 on a

similar basis to the supply side sectors.

Where the changes described reflect a choice rather than a scale (for example choices of fuel or technology), they are described as

trajectories A, B, C, D; these choices cannot be compared between sectors.

Q108) How easy is it to add air quality? For the details on air pollution, look at the "air quality" sheets in the Excel. They come after the costs work, and all start with AQ e.g. 'AQ Outputs'. Here's detail on the methodology – as Johanna mentioned it would be possible from this to work out the direct impacts on health. For other co-benefits we have attempted to add biodiversity impacts to the UK Calculator to the UK Calculator, but this has been very difficult due to lack of data, and the complex nature of the issue. We have been more successful adding water consumption of each pathway, and would be happy to share with you the methodology there (as we mentioned, it is not yet published in the live spreadsheet). Any work on co-benefits brings extra work, so happy to provide guidance on what this might mean for you if you want to add anything.

Q163) How is the web tool hosted? TBD

Q192) How many stakeholders should be used for this to be trustworthy? If we see 2 or 3 people, is that not enough? For example, in the carbon sequestration it was hard to gather 2 or 3 experts. TBD

Q114) How do I find out more about structured table references?

This section of the book explains in detail what structured table references are, and how to use them:

<http://book.2050.org.uk/calculator-book/appendix-2-complex-excel-formulae.html#structured-table-references>

Q89) How does the new (as of July 2014) webtool production process work? Please see the relevant chapter of the Calculator Book:
<http://book.2050.org.uk/calculator-book/how-the-webtool-works.html>

But, here's a quick summary list of the required webtool production steps:

1. install Ubuntu 12.04 64 bit
2. run the set up script <https://github.com/decc/twenty-fifty/blob/master/util/setup-ubuntu-12.04.sh>
3. (run bundle exec rake, and see 0.0.0.0:9292 to check if the UK version runs properly)
4. start a new branch / fork (might need to look at git help to see how)
5. edit the spreadsheet to contain the named ranges (see the more up to date versions, e.g. 3.6.0 of the UK model for inspiration - and please ask the UK team for help if you need to)
6. replace the spreadsheet in the model folder with the Colombia version, and name it model.xlsx
7. edit data_from_model.rb to list all of the relevant named ranges
8. run model/translate_excel_into_c.rb \$ruby translate_excel_into_c.rb
9. run model/compile_c_version_of_excel.rb \$ruby compile_c_version_of_excel.rb
10. bundle exec rackup (starts the local server)
11. navigate to 0.0.0.0:9292 in your browser

Assuming this all works, the next step is to make cosmetic changes to the front page by editing index.html.erb, and then the JavaScript files if you want to change the charts.

Q86) We want to use 2010 as base year and then use the standard incremental steps of 5 years, plus maybe adding 2012 as the first simulated year for comparison (i.e. the equivalent to 2010 in the UK calculator). I can't recall if this must be done by editing all sheets by hand and updating the trajectories accordingly, or if there is a "master" location where this editing can be done. To edit the time periods covered, each sector sheet must be edited individually.

Unfortunately there isn't a master location for setting this.

Q87) The series of “DUKES” sheets is, as far as I can figure, mainly a central database which is referred to in other spreadsheets. Assuming that all references in all sheets are updated with the correct numbers, is it safe to remove these sheets? This is part of my effort to produce a lighter, hopefully faster version of the workbook, and according to the Wallonia version it seems possible to do so (their numbers are written directly in the sector sheets, as far as I can see). The ‘DUKES’ worksheets are from the department’s ‘Digest of UK Energy Statistics’, a publication covering all the main aspects of the UK energy system. We decided to include these worksheets within the Calculator workbook so that users could more easily see where our base year numbers came from.

Whether you maintain this aspect is a decision for you and your team, but please take note of the benefits of being transparent about your data sources.

Q127) We have 20 years of data where we've reflected energy consumption, demands, and of course emissions. If we take this baseline then hopefully calculations will match the baseline data we have got. **Should we include historic data in the tool?** The historic emissions are used as a starting point for many trajectory assumptions. So for example, if we look at domestic transport starting in 2007, levels 1 to 4 dictate what happens from that point onwards. The user has the opportunity to say what will happen to demand afterwards.

In terms of including historic data, with hindsight maybe this would have been good idea. Historic data would help the user when they're trying to determine chosen pathway to see what happened historically. This is what we have done in some of the one-pagers: for example, showing the rate of nuclear build in various countries historically, which helps to show how ambitious the UK's levels 1 to 4 are.

It's possible to have as much historic data in calculator as you like. You just need to pick date in history where that stops and modelling starts.

Q193) Why do you use a complicated process where the model is converted from Excel to the webtool? Why not just keep them separate.
TBD

Q194) What made you choose a separate web-hosting service, rather than just on DECC's server? Are there other considerations? TBD

Q154) How do I make a pathway in the spreadsheet? Users of the 2050 Calculator spreadsheet (referred to as “the Calculator” from here on) can create their own pathway to 2050 as follows:

1. Go to the “Control” worksheet and enter your pathway choice into column E. You can ‘copy’ and ‘paste’ an example pathway (choosing one from columns M to AB) or enter your own. You can use decimals.
2. Press F9 to refresh the Calculator
3. View the results of your pathway on the “Control” worksheet, from rows AF onwards.
4. For tips on how to make a good pathway, see: the “Create your pathway” section at: http://www.decc.gov.uk/en/content/cms/tackling/2050/calculator_on/calculator_on.aspx
5. You can paste your pathway from Excel to the Webtool and from the Webtool into Excel (see the answer to “How do you paste a pathway between Excel and the web tool?” below).

Q155) How does the Calculator model air quality? Details about air quality impacts can be found on the following website page: <http://2050-calculator-tool-wiki.decc.gov.uk/pages/80>

Q156) How do you change the trajectory definitions (e.g. how can I redefine level 4)? Each sector has a dedicated worksheet (for example, hydrocarbon fuel generation is in a worksheet called “I.a”). For each sector, the trajectories are defined near the top of the worksheet under a “trajectory assumptions” heading and marked in orange. The trajectories can be redefined by changing the values in each of the rows against each of the trajectories. For example, trajectory 4 of the installed biomass capacity can be amended by changing cells G27 to O27 in the hydrocarbon fuel generation worksheet “I.a”.

Levels 1 to 4 are designed to cover a broad range of possibilities and to test the boundaries of what might be possible. They are intended to reflect the whole range of potential futures that might be experienced in each sector. They are illustrative and are not based on assumptions about future policy and its impacts, and should not be interpreted as such. These levels were agreed following an extensive call for evidence in Summer 2010 and represent a shared view between the UK Government, businesses, academics and green groups on the minimum and maximum effort across sectors. Users are of course free to change these trajectories but they should bear in mind where the level definitions came from.

Q158) Why are there three 2007 worksheets? The UK has three worksheets that contain data for 2007 (our base year). The reason for this is to be able to compare modelled data from DUKES (our official energy statistics) with the modelled values for the same year. The 2007 (consistent) sheet is an intermediate stage where the data from DUKES is grouped by the calculator’s categories - this is because our decision throughout the model was to use groupings that

made sense for the Calculator, even if this was slightly different to the official statistics.

- “2007 (actual, frozen)” contains Historic data from Digest of United Kingdom Energy Statistics (DUKES). This is grouped according to the DUKES definitions.
- “2007 (consistent)” contains Historic data from (DUKES). This is grouped according to Calculator definitions
- “2007” contains Calculator projections, grouped according to Calculator definitions

Q118) How could we represent cogeneration/CHP in our model?

There is scope to use CHP/district heating technologies in the Calculator. See the “home heating that isn’t electric” and “commercial heating that isn’t electric” options. For a full discussion of these technologies, see section D of the report published in July 2010 (<http://www.decc.gov.uk/assets/decc/What%20we%20do/A%20low%20carbon%20UK/2050/2050-pathways-analysis-report.pdf>).

For a table showing how CHP and district heating is reflected in the Calculator, see page 123 of Part 2B of the subsequent report: <http://www.decc.gov.uk/assets/decc/Consultations/2050/1344-2050-pathways-analysis-response-pt2.pdf>

Other countries have also considered cogeneration. For example, India’s calculator said “Industries in which both process heat and electricity are needed are well suited for cogeneration of electricity. A significant potential for cogeneration exists in the country, particularly in the sugar industry. SERCs may promote arrangements between the co-generator and the concerned distribution licensee for purchase of surplus power from such plants. Cogeneration system also needs to be encouraged in the overall interest of energy efficiency and also grid stability.”

Q134) What does the model consider for industrial energy intensity?

There are four variables which comprise the three energy intensity scenarios:

- deployment of CCS
- the extent to which industries switch fuels
- the level of process emissions
- and energy intensity by sector.

Like output growth, these are grouped in the Calculator to create three scenarios with high, medium and low possibilities.

- For CCS and fuel switching, the assumptions used are applied equally to all industry sectors.

- For process emissions and energy intensity, the model makes specific judgements based on sector.

Q153) What does capacity factor mean? The capacity factor is the actual power produced over a period of time, expressed as a percentage of the power that may have been produced if the station was running at full power for that period. e.g. a 10MW rated wind farm could theoretically produce $10 * 8760 = 87,600,000$ kWh/year but if it only produces 3,066,000 kWh/year it has a capacity factor of 35%.

These pages give more detail: http://en.wikipedia.org/wiki/Capacity_factor or http://www.esru.strath.ac.uk/EandE/Web_sites/01-02/RE_info/interesting.htm

Q113) The INDEX/MATCH formulae used to look up data are so complicated! Why don't you just use VLOOKUP? VLOOKUP formulae are useful, but for a large spreadsheet they are slow, and more likely to cause errors if columns are moved or deleted. For this reason, the Calculator uses the much quicker and more reliable combination of Index and match formula. By using index and match together in Excel, you can match a cell based on 3 criteria, but it's complex which is why formulae can seem complicated and fiddly at first. However there are only a few variations of the formulae that you will need to understand.

You can read how this works at the following link: <http://book.2050.org.uk/calculator-book/index.html>

But in brief, 'Index and Match' formulae combine two Excel worksheet functions ('Index' and 'Match') to provide a flexible way of performing a 'lookup'. The 'Index' function returns a specific value from a specified array, according to the row and column numbers stipulated in the formulae. The 'Match' function returns the relative position of a given value within a specified array.

The 'Match' function can be used in place of either the column or row reference (or both) within the 'Index' function. This enables the return of a value within an array by referring to a particular value in the column or row heading (rather than referring to a the row number or column number). Within the Calculator, index and match formulae are largely used in conjunction with other functions, as shown in the example immediately below, where the approach is used together with structured table references.

Q79) Can we add new vectors? If so, how? These vectors (both primary and secondary) aim to be mutually exclusive and comprehensive of the whole energy system (i.e. collectively exhaustive, so that in combination they cover the whole energy system). It would be ok to change definitions to better fit Colombian statistical conventions, but you would need to be very careful that you

were not going to double count anything (e.g. make sure everything is mutually exclusive).

You would need to add any additional primary or secondary sources as vectors in the technology sheets, and then also add these to the year sheets. We'd be happy to advise if you do decide that you'd like to add any new vectors, just to make sure that there are no conflicts with anything else.

Q117) Does the model include the impacts of climate change on water levels? We don't have any climate feedbacks currently in the UK model. This is largely because reducing emissions in the UK alone (which accounts for less than 2% of global emissions) will not in itself reduce climate impacts - this would require global action.

Our team's Global Calculator could now help you to explore climate impacts of global choices though. The webtool is available at the link below (along with the spreadsheet and other supporting materials): <http://tool.globalcalculator.org/>

Q4) What programming software/tools do I need to update the webtool or wiki? You need to use a Unix based computer (so, a mac or Linux - we recommend Ubuntu 12.04 64 bit), and some resources that can be downloaded from our GitHub page. You also need to install a few existing open source products.

Details of these and the process more widely are explained in the Book: <http://book.2050.org.uk/calculator-book/how-the-webtool-works.html>

Q5) If I want to recompile the tool to reflect changes to the Excel model, how can I do this? Place your new spreadsheet in the twenty-fifty/model folder, run translate_excel_into_c.rb then run compile_c_version_of_excel.rb. For full details see: <http://book.2050.org.uk/calculator-book/how-the-webtool-works.html>

Q48) Is the 2050 Calculator an optimisation model? No, the 2050 Calculator is a user driven model. The user specifies energy supply and demand across the economy by selecting effort levels for around 40 sectors. In this respect, the Calculator is fundamentally different from cost optimisation models such as MARKAL. Models such as MARKAL examine the costs of different technologies and work out the least cost pathway to achieving an emissions reduction target.

It is possible to identify low cost pathways using the Calculator, but the user has to do this manually through an iterative process. An example of a very low cost pathway is the Analogous to MARKAL pathway (<http://2050-calculator-tool-wiki.decc.gov.uk/pages/170> describes a representation of a least cost pathway from MARKAL).

However, if you wish to use the 2050 calculator as an optimisation model, you can. You need to use the code from here: https://github.com/decc/decc_2050_optimizer

Q1) Where do I find the source code? The source code for the web front end is available here: <http://github.com/decc/twenty-fifty>

The source code for this wiki is available here: <http://github.com/decc/twenty-fifty-wiki>

Q68) As another country developing a calculator, what *stress test* should we use to examine balancing needs? In the UK we use an example of 5 days of bad UK weather (no sun so no solar energy, no wind so no wind energy, cold weather so high heat demand). Think about what a “period of bad weather” might look like in your country?

Q69) As another country developing a calculator, what *sectors* might we need? In the UK Calculator we include sectors which correspond to energy options that may not exist in your country. For example, do you have any tidal stream potential? If not, remove the sector.

Q70) As another country developing a calculator, what technologies might you need to include? In the UK we use technologies that may not be used in your country. If they are not (and will never) be used in your country, then you can remove these.

Q71) As another country developing a calculator, what *outputs* should we be interested in? We look at emissions, costs, energy security (imports and exports, energy mix), air quality and are considering water and biodiversity impacts. Which of these are important for you? (If they are not needed, it's worth removing them to make the model more simple) What have we missed?

Q96) What kind of team structure works best for building an Excel model? How many people are needed, and what kind of roles & experience are most important. For the sector work, it's really helpful to have a range of different experiences on the relevant sectors. The text here should help you:

<http://book.2050.org.uk/calculator-book/getting-started.html#building-a-team>

We strongly recommend having someone in a Central Coordination role, and it's very helpful for them to have Excel expertise so that they can take charge of merging the Excel spreadsheet.

Q110) As a team working on the Excel model, what should we think about when the team is restructured? From our experience with other teams it can cause delays when a team is restructured. The most important considerations are:

-the overall time given to the project: Can the new team devote as much time to the project as is needed. Are there any milestones which are likely to be missed, and how can you plan work to get back on schedule?

-training: It's important to give time for any new people to learn about the 2050 calculator and the parts relevant to their sector. We recommend new people read the 2050 book and this set of Frequently Asked Questions. The 2050 team would also be happy to help new people, either with a training session or by reviewing their work in more detail.

Q125) Should we treat the whole of Mexico as a single unit, or divide by north/SouthGiven that Mexico is already divided by electricity tariff, would it make sense for buildings sector to be divided? TBD

Q135) How does the UK Calculator deal with grid connectivity and transmission? Transmission: The UK 2050 Calculator assumes that there is one national electricity grid that can connect to all electricity generation technologies (e.g. micro-wind to nuclear power). It also assumes that all electricity consumers within the economy have access to this grid. To give an extreme example – if offshore wind is built in a potentially remote area (e.g. far off the Scottish coast) the Calculator assumes that this electricity will just go into the general pool of electricity generation, to be consumed by the overall total demand for electricity (i.e. it does not assume that this electricity will be consumed by a particular actor or in a particular geographic area). This is a modelling simplification that was deemed reasonable given that the 2050 Calculator looks to provide a simple, but credible, macro-view of the UK.

Agriculture & waste

Q101) In waste management (sheet name) what do the following abbreviations stand for?MSW, C&I, CDW, EFW, odt, GCV The abbreviations are:

- municipal solid waste (MSW)
- commercial and industrial (C&I) waste
- construction and demolition waste (CDW)
- energy from waste (EFW)

- odt (oven-dry tonnes) - this is a unit to express the dried weight of an agricultural commodity such as biomass that contained significant water weight when harvested
- Gross Calorific Value (GCV)

Note: the latest version of the UK's 2050 calculator spells out these abbreviations in more detail.

Q19) Regarding land use change, how do the different uses (1st gen, 2nd gen.etc.) of grasslands and arable lands affect emissions? (VI.a sheet) Farming and biofuels production require energy and this has associated emissions. Crop land and grassland have different emissions factors but emissions are not differentiated by crop type.

Q173) In the UK, agriculture is in the demand sector, but should we divide into supply & demand? TBD

Q75) In the sheet, there are only dairy cows while in Vietnam (2010) we have about 130,000 dairy cow heads and about 5,000,000 non-dairy cow heads and 2,913,000 buffalos. Do you think we are missing some GHG from these cattle? The goal of the UK version was to include the main categories of farm animals without getting into too much detail. If you think the emissions factor is very different for dairy, non-dairy and buffalo, then you might want to have a category for each one.

What we'd recommend though is to have one category in the Calculator for all cattle/buffalo (dairy, non-diary, buffalo), e.g. add up the totals you mentioned in your email ($130000+500000+2913000= 8043000$) and multiply these by a single emissions factor. This will save you work, and will make the model easier to manage.

Q76) In the Vietnam model, for the first generation energy crops I count: sugarcane, soybean, peanut, coconut and sunflower (but no data for sunflower)Same for second generation energy crop I count: rice straw, maize straw, peanut and soybean residue, sugarcane residue and cassava root, (there is jatropha but no data about it) Your work on first and second generation biocrops sounds correct. For sunflower and jatropha even if there is no data for Vietnam at the moment, you might still want to include scenarios out to 2050 for what could be achieved with these crops.

When you have your workshops, some questions you might want to ask your experts would be: Will sunflower/jatropha be an option in Vietnam in the next

30 years? Are there any other 1st or second generation biofuels that should be considered in the Vietnam Calculator?

Q171) We included a trajectory of meat consumption. How should it be calculated in terms of the reduction of cow production? TBD

Q139) What assumptions are made about landfill gas? The capture rate of landfill gas was assumed to be 75% in 2007. Half of this was assumed to be flared, and half used for energy, in order to match the levels of landfill gas recovered for energy as reported by DUKEs.

Q53) What does biogenic mean? A biogenic substance is a substance produced by life processes. It may be either constituents, or secretions, of plants or animals. A more specific name for these substances is biomolecules. You can read more at the Wikipedia page below:

http://en.wikipedia.org/wiki/Biogenic_substance

Q18) With considering the forest area – is it only because of bioenergy uses or also adding the total CO₂ absorption capacity of plants? We include the CO₂ sequestered by forests. The model covers all emissions and should reflect aggregate net emissions data.

Q17) The agricultural practices, such as N (nitrogen) fertilizer use, have large impact on emission. How is Nitrogen fertilizer use taken into account? (If it is the soil management practice what does the annual change mean (%pa): What is changing at that rate?) We capture the total emissions per km² of land farmed in the “soil management” assumptions in sheet VI.a. We do not look at choices on specific fertilizer.

The change in emissions from soil management reflects changes through continued improvement in nutrient management practices on farms (declines are limited by an increase in bioenergy crop land in the scenarios where this occurs).

Details from the Pathways analysis report:

- Compared to other sectors of the economy there is much greater scientific uncertainty in estimating emissions from agriculture and land use and predicting the effects of changing practices and drivers. For example, the amount of N₂O released from spreading fertiliser can depend on soil type, the weather, and when and how the spreading was done. The Government is working with the research community to improve the UK's inventory of GHGs within the agriculture and land use sector so that our future policies are guided by the best evidence available and so farmers and land managers are properly credited for improvements in farming practice.

- The dominant source of agricultural N₂O emissions is the breakdown of fertilisers and manures applied to the soils (33%), with significant contributions from indirect sources, notably from leaching and runoff (26%). Significant reductions to agricultural N₂O emissions have been achieved since 1990,¹⁹⁶ largely through more efficient use of fertilisers and reduced application to grasslands. The current methodology employed to estimate emissions of N₂O from soil in the UK inventory is imprecise – soil characteristics, land use and fertiliser type are not currently differentiated and calculations are based on total tonnes of nitrogen applied. There is therefore much uncertainty around soil emissions. Approximate assumptions have been made within the trajectories for this section, but this remains an area where further work is needed to improve the analysis.
- Note - UK manufacture of fertilisers is included within industry (in the Chemicals and petrochemicals sector).

Q20) At waste management what does the abbreviation CDW stand for? (VI.b sheet) Construction and demolition waste.

See question 101 for other abbreviations used in the waste management sheet.

Q165) How does the Excel manage land substitution? We reviewed the “Land Use” sheet, and as we understood, it only gets information of the sector sheets. But we couldn’t find how the land substitution is managed across the sectors. TBD

All sectors

Q185) how do we keep the level of ambition consistent between technologies? There’s no scientific way to ensure this. The most important is to keep well informed in team.

However the UK version isn’t always consistent. For example, looking at the change of transportation in future we needed figures from our department for Transport from their models. Their most ambitious scenarios were not so ambitious on energy.

Generally if you use different studies then you’ll find imbalance between different numbers, so the important thing is to use your team’s judgment and consult with expert stakeholders, to make sure that the level of ambition is as consistent as possible.

Q144) How did you decide which technologies to include within the calculator? For this analysis, we consider technologies that are either already available or could be expected in the next 10 years.

While we can reasonably expect substantial improvements in the energy efficiency of these products, and in technologies that help us manage our use of them, it is impossible to predict accurately all technologies that will be invented by 2050, let alone how quickly they can be rolled out or which of those could significantly reduce energy demand by 2050.

Q99) If we keep the same levers, how much can we change numbers from the UK version? It's up to your team to make a judgment about your trajectories and fixed assumptions, based on your country data and stakeholder expertise. But a few things to consider are:

-the UK's infrastructure (e.g. housing/transport) and trends may be very different to your country. Consider the differences currently, and think about what changes are most likely to happen in your country.

- avoid extreme figures which seem unlikely to be average for the whole country - e.g. bus occupancies of 45 may be very ambitious, given that there are times of day and parts of the country when vehicles will not be full to capacity
- be careful about extrapolating trends into the future: a small percentage increase now could make a very big difference in 2045, especially if you are assuming exponential growth. Make sure that you sense-check all your numbers, and discuss 2050 values with stakeholders.

Q98) Sometimes we don't have any accurate predictions about the future - when is it OK to just assume that current values will continue?

This is a really important question. For some assumptions, the difference they make is so negligible they will have no visible impact on any results. In this case, where there is no historic data available, it is reasonable to assume that today's values will continue into the future.

However for data that is likely to change results significantly, it might be better to:

- assume some level of sensible growth rather than none at all (this might involve projecting historical values into the future). You will need to decide whether this growth will be a straight line, or a curve
- you can also add this as an uncertain assumption where more stakeholder input is needed and open it out to stakeholder discussions.

In order to identify which assumptions are most critical to the final results, you could do sensitivity testing - this means just testing the most extreme values this assumption could take (for example, doubling and halving current values), and then seeing what effect this has on the end result. If it makes very little difference, then this assumption is less worth spending time on.

Q95) Initially we didn't quite feel to change the spreadsheet so much. At first we were quite cautious, didn't want to risk breaking some process. Now we're more confident, but could you give us any advice about where it's fine to change the spreadsheet, and where we should be more careful? We recommend keeping the same overall structure as the UK calculator, but there is plenty of flexibility to make changes yourself once you have familiarised yourself with the way the calculator works. The parts we would advise you not to change (because of the webtool) are: the Control sheet layout, the intermediate output sheet, and the key named ranges (everything to do with units, preferences, inputs and outputs).

We recommend using a colour-coding, so that your whole team uses the same conventions to mark areas of the spreadsheet:

- you may want to make that have been changed, are about to be changed
- you will want to indicate parts of the spreadsheet which are still using UK figures
- you might also want to use a consistent colour to mark numbers which have been changed as a rough estimate, but where you are still planning to go back and improve the figures.

Q166) For each sector the sum of the outputs is zero. We assume the output vectors calculate how much energy is used by sector, for example: heating, transport, etc. In the same way the calculator also estimate the sources of energy, for example: liquid hydrocarbons or gaseous hydrocarbons. This is correct- the distinction is between sources of energy and the uses of energy. This is represented by vectors which are either positive or negative (representing whether energy is being produced or used):

-vectors have positive numbers to represent energy produced in a sector (e.g. for the supply sector sheets like II.a, electricity is positive because it's energy produced)

-whereas in the demand sector sheets, values are shown as negative because these sectors require energy. For example the transport sector requires electricity and liquid hydrocarbons, shown as negative numbers.

Q167) At the moment we have a draft version of all the driver trees. But now we are going to start with the development of the sector sheets. Can you give us a list of possible rules, conditions or tips that we should consider in order to validate the integrity of the sector sheets? We have lots of guidance on Quality Assurance available, and this is summarised in the following links:

Tips and examples: <http://book.2050.org.uk/calculator-book/common-excel-errors-and-how-to-avoid-them.html>

Checklists you can use: <http://book.2050.org.uk/calculator-book/appendix-12-quality-assurance-checklists.html>

The rest of this FAQ summary will also help you with particular questions.

Q94) When should we use documentation/footnotes and when not? For example, we used other models to forecast the change in different Mexican cities. Should we include all of that detail in the main spreadsheet? The main reasons for using documentation are:

Simplicity - it makes the spreadsheet much easier to use and to follow (especially when you use clear labels, and put more detailed notes into footnotes so that it doesn't break up the page too much)

Transparency - any colleagues and stakeholders can immediately see your sources, recreate data or substitute their preferred data

To avoid confusion -for example, if someone might expect a calculation to use rural population, but you have decided to total population, you should explain the reasoning behind your decision. Without this, someone might misunderstand the numbers, or it might be picked up as an error in future, when actually this is what you intended to do

To enable stakeholders/future developers of the spreadsheet to track down the data that you used, or recreate the reasoning you have used.

So in this example, we would recommend using footnotes which describe your methodology in a sentence or two. Then (if possible) we'd suggest including a link to any separate spreadsheets you have used, so that people can see more detail. But this isn't essential, particularly in a first launch, as it can easily be added later.

Q164) At what stage should we write our one pagers? TBD

Q88) Is there any easy way to identify the location of external references in the Excel file so that we can remove them? Yes, you could try this macro: <https://gist.github.com/tamc/dc15127a0b7475689e4e>.

We also have a detailed set of instructions for merging sheets into the master spreadsheet, and identifying external references in named ranges or cells. Please ask the team for this. This includes details on how you can ensure that none of the named cells or ranges are defined in external spreadsheets. It is easy to spot incidences of this problem by looking at the 'Name Manager' in the 'Formulas' tab; in the 'Refers to' column the long file paths to the external sheet will stand out.

Q91) Could you please explain me in more detail which is the use of the subtotals in the years sheets?. Is it important to the calculations of the energy balance or is it only to make summary of the calculations? On your subtotals question, our 2050 book has an explanation which should be helpful for you:

<http://book.2050.org.uk/calculator-book/appendix-1-the-excel-model-structure.html#year-sheets>

There is also another part we haven't yet added to the book, but you might find useful:

Communication between sectors

There are a number of places where an apparently ad hoc energy flow calculation is performed within the annual balance sheets rather than in a sectoral worksheet. In particular, you will notice that subtotals are calculated for certain fuel types and used by the heat supply (XVII.a), power generation (II.a, I.b, I.a), electricity distribution (VII.b), and biomass (V.a and V.b) sectors, a subtotal is computed. This subtotal is the total energy flow, of a particular fuel type, from a subset of the sectors. (There is a similar calculation done for XVI.b, balancing imports, which really should have been done in its own sectoral worksheet).

What is going on turns out to be straightforward, although it certainly doesn't appear so at first glance. The job of certain sectors is to supply (or demand) an amount of energy that is not fixed by the assumptions, but depends upon what is demanded by the rest of the model. For example, electricity from gas generation is produced in whatever quantity is required to meet the total demand for electricity. So somehow the amount of electricity demanded needs to be passed to that sector. The subtotal adds up all the flows except those from one particular sector.

Q111) Why is such a complicated formula used. For example, in the UK's nuclear sheet II.a, row 28 has the following formula:=INDEX(G\$24:G27,ROUNDDOWN(E7,0)) * (1 - MOD(E\$7,1))+(INDEX(G\$24:G27,ROUNDUP(E7,0))*MOD(E\$7,1)) This formula allows people to enter any fractional levels between 1 and 4, so that people can choose any level of ambition that they want.

The way it does this is by interpolating between the two levels. So for example if someone selects level 2.25, the calculation will take:

the value for level 2 + 1/4 of the difference between level 2 and level 3.

Balancing

Q77) Did you design the year sheets according to the UK energy balance? Would we want to keep the same order of sectors and energy

sources, or should we customize the spreadsheet according to Colombia's energy balance. We arranged the UK version according to the way that our Calculator is structured, and to some extent, based on the way that our statistics are recorded. If you want to make changes to the year sheets for Colombia that is fine – particularly if it would make it more credible for experts in Colombia. The main rules you should follow is that you should account for all of the vectors in your individual sector/technology sheets, and you should be careful to make sure you don't double-count units of energy.

It's worth looking in detail at one of the UK year sheets if you have not done so already as there are some aspects of them that are based on how our energy system works. The link below explains how the year sheets work, or we'd be happy to do that with you if that sounds useful: <http://book.2050.org.uk/calculator-book/appendix-1-the-excel-model-structure.html#year-sheets>

Q187) From renewable tech sheet, e.g. solar you don't have any explicit inclusion of backup sources. How would that be done? TBD

Q190) What happens if we take level 4 for all technologies? We're going to have even more technology than we need, so what happens to remaining electricity? TBD

Q9) What is the default fossil fuel? In the UK we assume our default fossil fuel is gas. This may not be the case in other countries

If you wish to develop a Calculator for another country, it is worth considering what it is reasonable to assume for your default fossil fuel (i.e. would it be gas like for the UK?)

Q57) Do you account for the wind not blowing? We have a stress test that tells you based on your electricity generation mix and back up capacity choices (interconnectors, pumped storage and EV demand shifting) how much extra back up capacity is required given a 5 day cold snap with little wind and peak heating demand. This scenario was based on past wind data and peak demand for heating and it represents the harshest test to the grid we found in past data.

For most pathways with high intermittent renewables, back up capacity options are exhausted over the 5 day period and back up generation (we have assumed CCGTs) is meeting the gap in supply and demand. Therefore, we believe this test is suitably harsh that enough back-up capacity is built to cover intermittency and peaking problems (please tell us if you have evidence of a harsher test).

However, there are two areas we would like to improve going forward:

- Better data on the frequency of intermittency

- Forecasts of weather going forward rather than relying on past data

Q83) In the Control sheet, the Energy Demand plot contain a “Dummy” series, whose purpose (at least visually) seems to be balancing with supply, even when demand is actually lower. Where is this Dummy defined and controlled? The dummy is defined in row 20 of the intermediate output sheet. The series isn’t visible on the chart as it’s transparent – so isn’t really important. As you mention, this series shows the difference between total demand and total primary supply (more on this in question 84).

Q84) We were given to understand that the Calculator automatically balances demand and supply, but this does not seem the case from the plots (for instance, the standard scenario gives a much higher output supply than demand, with the Dummy series apparently compensating). Is balance only considered for the emissions? How are the various energy sources affected? The key thing here is that the demand plot shows final consumption and the supply plot shows primary supply.

This difference between these two is explained by losses (conversion, transmission, etc).

Q81) I have the problem of understanding functions in sheet I.a, table “Electricity required”. Could you please explain, preferably with example similar to those you used during your lecture. This sector forms part of the balancing mechanism within the calculator, which ensures that any shortfall in electricity supply is met by fossil fuels sector. Row 15 returns the total final electricity demand across all of the demand sectors. Row 16 calculates how much low carbon electricity is being generated by your pathway. Further down the sheet the difference between these two values is calculated, which is equivalent to the shortfall in electricity supply under the chosen pathway. This determines the amount of electricity that needs to be generated within sector 1.a, i.e. using fossil fuels.

The formulae used here are a little bit complex, e.g. from =I.a!F15:
 $=\text{INDEX}(\text{INDIRECT}(""\&I.a.\text{Inputs}[\#\text{Headers}]\&"!\text{Year.Matrix}"), \text{MATCH}("Subtotal."&$A\$2, \text{INDIRECT}(""\&I.a.\text{Inputs}[\#\text{Headers}]\&"!\text{Year.Modules}"), 0), \text{MATCH}([\text{Vector}], \text{INDIRECT}(""\&I.a.\text{Inputs}[\#\text{Headers}]\&"!\text{Year.Vectors}"), 0))$

This is essentially an index function, which allows you to return a value from an array based on a row and column that you specify. Here the row and columns references are specified using match functions, which effectively look through the row and column labels and return the position of the thing (i.e. vector/sector) that you are looking for. I’ve broken this down into its components below and tried to give an explanation of what is happening:

=INDEX(INDIRECT("'"&I.a. Inputs [#Headers]&"'!Year.Matrix") – this part of the formula specifies the array, by combining the corresponding header from the 1.a.inputs table (here 2007) with the text “!Year.Matrix” to look at the named range of cells called Year.Matrix on the 2007 year sheet. Referring to the name manager (access this via the formula tab in Excel) reveals that the range being specified here for the index function is 2007!G6:BL110.

MATCH("Subtotal. "&\$A\$2, INDIRECT("'"&I.a. Inputs [#Headers]&"'!Year.Modules"), 0) – here the row from which to return the value is specified. This is done via a match function that returns the position the text string Subtotal.“&\$A\$2 (which is equivalent to “Subtotal.1.a”), within the Year.Modules range (cells C6:C110, again as shown by the name manager) on the 2007 year sheet. To summarise, this is effectively specifying that the appropriate value be returned from the row of the year sheet that is labelled Subtotal.1.a (i.e. row 80).

MATCH([Vector], INDIRECT("'"&I.a. Inputs [#Headers]&"'!Year.Vectors"), 0)) - here the column from which to return the value is specified. This is done via a match function that returns the position the Vector, here 1.a, within the Year.Vectors range (cells G6:BL5, again as shown by the name manager) on the 2007 year sheet.

Q13) In case of electricity storage what do you mean by peak power? Is it the capacity of storage facilities (pumped hydro, batteries... etc.) or the possible peak power of peak power plants (natural gas based, below 1500 hours/a function)? (VII. c sheet) The capacity of the storage facilities

Q12) Regarding the electricity import-export balance why is only the CSP import taken into account? Does the fact that it is from CSP have any consequences on emission or not? If not, could we use it for any kind of electricity import? (plus please refer to questions 1-2) (VII. a sheet). We assumed that electricity imports would come from concentrated solar power, as this seems to be a reasonable assumption for the UK. We do not include the emissions from this sector as the emissions occur outside the UK.

You can use this sector for any type of electricity import – but make sure you reflect what is possible (i.e. how much would the exporting country need for themselves?)

Q16) Would it be possible to apply trajectories to electricity network losses? Since in the modelling network losses are as fixed indicators. Yes, if you think this is necessary. This would be simple to model if you can agree trajectories with stakeholders. This would be included in sheet V11.b.

Q43) On the “Energy flows” tab of the webtool, why do you show losses from thermal plants but not from other technologies such as renewables The methodology here (http://2050-calculator-tool-wiki.decc.gov.uk/pages/28?redirect_from=Methodology) is consistent with that used in DECC’s publication series Digest of UK Energy Statistics (DUKES).

The Calculator follows the transformation of energy from one type to another. The start and end points for these transformations are set to ensure that we capture the main aspects that we are interested in. On the supply side, for example, we are not necessarily concerned about the amount of lost wind, as this has no bearing on the headline results of the model. Similarly, on the demand side, we stop following the transformation of energy at the point of consumption; i.e. we have a final energy type ‘road-transport’ which marks the stopping point (we could have followed this further to calculate the energy being transformed into heat, noise etc, but again, this would have been surplus to the main aims of the model).

Q10) Regarding the electricity production mix, where is it possible to feed into the modelling the natural gas and coal based capacities (and their trajectories)? There is no assumed limit on the imports of gas or our capacity for gas-based generation in the UK. For coal, the model uses the current coal power and decommissions this over time. To incorporate a cap or trajectories on gas or coal capacities, amend sector “1.a”.

Q11) How is the total electricity demand calculated? How is the supply-demand matched (are there enough capacities)? The difference then could be compensated with the export-import balance. The user chooses how much electricity is demanded by selecting the effort to decarbonise in the demand levers. The Calculator then sums the electricity demand across the demand sectors. The Calculator meets this demand with supply.

Also see the answer to the question “Are the sectors connected (e.g. do supply-demand match)?” (number 8 in this list)

Bioenergy

Q120) Within the calculator, you use the basic assumption that biomass can replace any fuel of similar physical state. Why do you do this? Biomass is treated as a perfect substitute, in terms of energy content, for fossil fuels where:

- Solid biomass substitutes for coal
- Liquid biomass substitutes for oil, petrol, aviation fuel and diesel

- Gaseous biomass substitutes for natural gas

Note that coal and solid biomass are a substitute given the same energy content. So, 1kg of coal is not considered equivalent to 1kg of biomass but 1TWh of coal is considered equivalent to 1TWh of biomass. The original biomass extracted also faces conversion losses before it is used as a direct substitute.”

It is assumed biomass will be burnt ahead of fossil fuels in sectors which demand hydrocarbon fuel. An important choice for biomass is therefore which form to convert raw biomass into in order to substitute different fossil fuels. Therefore, in thermal power generation if a user chooses biomass to be supplied, it is assumed to be used wherever it can substitute for a fossil fuel. For coal/biomass plants, this could be 100% biomass or 100% coal depending on how much solid biomass the user supplies and the demands for solid hydrocarbons from other sectors (such as Industry).

Q39) How is bioenergy treated? The emissions from burning biomass are counted as fossil fuel combustion and then exactly offset by a ‘bioenergy credit’. This has the effect of making bioenergy zero emissions, except if it is used in carbon capture and storage, in which case it becomes negative emissions.

For example, on this pathway: Pathway e0d...141

If you hover your mouse over the bottom-most blue bar on the right hand chart you will see that it is labelled as bioenergy credit -48 MtCO₂e a year. This assumption is, of course, crude, because it assumes that:

1. There are no additional land use change emissions from the bio-energy
2. That the conversion of bioenergy from raw material to useful fuel is powered by bioenergy (so that there are no extra emissions in conversion).

Q141) Isn't it better to reduce waste, rather than to produce more waste for energy? The Government's overall objective is to work towards a zero waste economy where resources are fully valued – financially and environmentally – throughout the economy where we move towards zero waste to landfill. By prioritising waste management

activities according to the ‘waste hierarchy’ the Government aims to break the link between economic growth and the environmental impact of waste. Management activities towards the top of the hierarchy are more sustainable ways of managing waste than those lower down – for example, preventing waste from being created in the first place is more resource and carbon efficient than recycling it or disposing of it in another way. Disposal to landfill should be the very last option for dealing with waste.

Therefore, underlying the trajectories is the assumption that the primary aim of waste policy is the reduction of waste, not the production of bioenergy.

However, although they accommodate the major waste and landfill targets, these trajectories are high level and not intended as simulations of specific waste policies.

Q130) How is biomass allocated across the sectors? In the UK model, the use of biofuels in place of fossil fuel is done at an aggregate level, so the use of biofuels is not attributed to specific sectors. Biomass is produced in the spreadsheet as a result of a combination of user choices across a number of sectors.

The user specifies the amount of domestically produced biomass and how they want this to be converted into different forms (a mix of gaseous, liquid and solid).

This is combined with imported biomass to provide the total available biomass. (i.e.. the quantity of bio used in the system is calculated at an aggregate level, rather than at a sector level, and the implications for emission are calculated, via the bio-energy credit section of the years sheets.)

This total biomass is then used up by the sectors that use the corresponding end use forms of fuel.

When the user selects options that need a solid fuel in the Calculator, the fuels available are used up in a particular order, as follows: domestic biomass and imported biomass; then domestic coal; and finally imported coal. If a preferential fuel type is not available then the Calculator uses the next type. The same order of preference is assumed for oil and liquid biomass and for natural gas and gaseous biomass, where biomass is used ahead of fossil fuel sources when it is available.

The India Calculator has a more detailed approach, which, for example, allows the quantity of fuel wood used for domestic cooking to be identified.

Q122) How would we account for wood used for heating/cooking?
We don't really use wood as fuel source in UK

We treat biofuels as being carbon neutral, so any carbon used is sequestered. This is an assumption we might revisit (based on some biofuels work recently within DECC), as it may be that overall emissions are higher than we assumed when starting this.

Q123) You've included the technology of marine algae, does that exist in UK - has that been proven? If not proven, why have you taken it into consideration? There are many projects where we are still investigating if they're feasible - maybe in the same way as carbon sequestration it might be possible to work, but no-one knows yet for sure. The UK has a big coastline, so there was a lobby asking to include it in our model so that we can judge the effect in comparison to other options.

It's another example where the team had to take political criteria into account, and include something that is significant to some key audiences of the tools even though the impact may be small or uncertain.

Marine algae seem unlikely to offer a realistic source of energy, though some small scale PBRs are in existence for production of high value products. Micro-algae yields can be improved through the addition of CO₂ or nutrients, for example from power stations, factories or waste water treatment plants.

Due to the generally perceived lack of suitability of conditions in the UK for producing micro-algae on a scale required to make a significant contribution to energy supply, the UK calculator focuses on the production of macro-algae. Micro-algae is considered one of the processes which could contribute to the higher levels of global supply of biofuels considered in trajectory 4 of the bioenergy imports section below.

Q142) Is gasification a mature enough technology to include? During our Call for Evidence in 2010, a small minority of respondents suggested that gasification was not a sufficiently mature technology to be considered in the Calculator. However, we believe that given the technological progress made so far and the 40-year timeframe of the Calculator, inclusion of gasification is legitimate. Research literature indicates that although gasification has yet to be demonstrated at a large-scale level, there are already a series of successful small-scale demonstration projects taking place. An NNFCC roadmap looking at the technology suggests that entrained flow gasification plants capable of processing up to 3,000 tonnes of biomass per day could be online before 2015. This is a significant scale of activity, and it is quite possible to imagine this improving further out to 2050. We did not receive any responses suggesting we had missed other significant technology options that could affect our treatment of biomass conversion.

Q143) How does the UK Calculator model anaerobic digestion? Anaerobic digestion is considered as part of the technology packages for heating, improved manure management processes in land

use management and as part of the energy from waste generation process.

During our Call for Evidence in 2010, a small number of respondents suggested that biomethane and other forms of biogas are under-represented in the model. The Calculator does allow for the possibility of biogas in the model (indeed, it is possible to focus biomass conversion on to gas), but the treatment of it is slightly unclear. Once biomass has been converted to a usable form of energy in the Calculator, whether solid, liquid or gas, it is considered to be directly substitutable for fossil fuel hydrocarbons. Therefore biomethane is considered within 'gaseous hydrocarbons' and is transported to its end use as such. This is why it does not appear explicitly in the Calculator, even though it may form an important part of various 2050 pathways.

Q119) What's the order of preference for biofuels? The model has the following fuel preference order.

When the user selects options that need a solid fuel in the Calculator, the fuels available are used up in a particular order, as follows: domestic biomass and imported biomass; then domestic coal; and finally imported coal. If a preferential fuel type is not available then the Calculator uses the next type.

The same order of preference is assumed for oil and liquid biomass and for natural gas and gaseous biomass, where biomass is used ahead of fossil fuel sources when it is available.

Q54) Is it really possible to both increase land used for biocrops and increase livestock numbers Q: The calculator assumes that it is possible to both dedicate 17% of land to the growth of biocrops, and increase livestock numbers by 10%. Is it suggested that this would be achieved simply through increased intensity of farming?

A: Yes. “Level 4” effort for “land management” assumes an increase in land allocated to biocrops of 38,160 km² (so that 17% of land is used for biocrops) and an increase in land for forests of 10,913 km². This is brought about by a 13,671 km² fall in arable land for food crops, 32,812 km² reduction in land for grassland for livestock and fallow and 2,589 km² decrease in land for “other” uses. This implies an increased intensity of livestock farming.

Buildings

Q126) How can we work out the energy needed for cooling? The first thing you need to do is work out the amount of cooling demanded. This will mean working out the average external temperatures, and then you can compare this against the temperature people want their homes to be at

You can then convert into type of energy, and work out the amount of fuel required (electricity, or for heating this might be gas), by incorporating technology efficiencies.

Q107) As you know, Mr Khanh-Excel expert developed excel files for input data (data requirement) of each sector (energy demand side and supply side) that based on most of IEES-2047/India case. And then Mr Hoang Anh posted data on the Excel - data requirement-Resident-Cooking and Hot water sheet, We (Khanh and me) have reviewed and found that the Technology Efficiency of all energy/electricity devices/stoves is 100% (with approach based on energy demand in term of useful - see the attached). And then we also checked the India case. The situation is also the same, even the Technology Efficiency is more

than 100% (please check XIII.a-Excel file -India case). Technology efficiencies: I think some confusion may have arisen regarding the technology efficiencies. As you can see from the excerpt below from the UK model, we make use of both input and output efficiencies. In this instance the efficiency we're concerned about the output efficiency; in terms of the amount of heat we get from the electricity used. These are shown below in the H.01 column. Most of these are below 100% (e.g. Gas boiler old: 76%), except in the case of heat pumps, where the efficiency is exaggerated as environmental heat is also used. In the table below, the input efficiencies shown, which effectively show the input energy source, are commonly 100% (e.g. a gas boiler uses 100% gas). I suspect these input efficiencies may have been confused with the output efficiencies.

Q102) Where is public street lighting included? Where could they include it as an option? In the UK Calculator we only refer to “commercial lighting” in general i.e. all lighting that is not in the residential sector (and is dealt with in X.b in the Excel). There is not a separate breakdown for public street lighting. If you would like to refer specifically to street lighting you will need to include data on the electricity that this currently consumes, and different scenarios for how this could either increase or decrease depending on technology choices.

The UK's Level 4 assumes that for commercial lighting, LEDs could be introduced over time, reaching 90% of the stock by 2050. New lighting installations on major roads could be more efficient high pressure sodium (HPS) lamps and new installations on residential roads could be more efficient ceramic metal halides. This could help reduce demand for lighting by more than 50% by 2050.

Q80) I am now going through sheet IX.c commercial heating and cooling and have difficulty understanding the section on technology efficiencies in there (from line 96 down), Could you pls. explain their nature, in particular while some are negative and the other are positive and their magnitudes Some of the efficiencies represent energy inputs so have a negative sign some are outputs, so have a positive sign. For example, in the case of ‘Gas boiler (old)’, the energy input, gas V.05, has a negative sign (100%), while the outputs, heat H.01, 76%, (76% of the input energy is converted to heat), and losses X.01, 24%, are positive. The idea is that the output tables always net to zero, with the positive and negative values cancelling each other out.

Some of the magnitudes are very high (e.g. for heat pumps) because the efficiency is quoted in terms of the electricity used (i.e. the fuel input that we care about), while in reality they also make use of a secondary energy input, environmental heat.

Q184) What are the UK's main choices for heat levers? For the heat sectors the choices are broadly in terms of:

- Heat demand, determined in the domestic sector by the temperature that households set their thermostats and the amount of insulation installed (these are combined to a single demand lever for the commercial heat sector);
- The proportion of electrification (the prevalence of heating technologies, e.g. air source heat pumps, that rely on electricity); and
- The source of heat for non-electrified heat technologies (whether this comes from solid or gas fuels, or from a communal source, such as excess heat from power stations via a heat network).

There are four user choices for the domestic heat sector, including:

- Average temperature of homes: the change from the 2007 average of 17.5°C (also determines demand for hot water and air conditioning).
- Home insulation: the average thermal leakiness of homes based on the up-take of insulation measures.
- Home heating electrification: the proportion of households that use electrified heat sources to heat their homes.
- Home heating that isn't electric: the choice of heat source for households that don't have electrified heating.

Q145) What's the difference between domestic lighting and appliances, and non-domestic lighting and appliances? In the 2050 Calculator, we consider domestic lighting and appliances and non-domestic lighting and appliances separately. The broad range of products that are used in these sectors are categorised according to Energy Consumption in the UK 2009.

Broadly, domestic products include consumer electronics, home computing, cold appliances, wet appliances and lighting.

Non-domestic products include lighting, catering and computing, with other appliances grouped in a separate category.

Q146) How are computing and electronic products modelled within the calculator? Consumer electronics and home computing present the biggest challenges to reducing energy demand in the domestic sector. Ownership of these products is likely to continue to rise over the next 40 years. For example, televisions account for the largest share of the energy used by consumer electronics, and their number in households is expected to rise by 21% between 2010 and

2020. However, technological developments, such as new display technologies, reducing standby consumption and reducing on-power consumption, could curb increases in demand for electricity for these products.

New backlighting technologies and variable brightness control could double the efficiency of liquid crystal display (LCD) televisions. Likewise, the efficiency of plasma technology for plasma televisions is expected to double over the next few years. Some products, such as computer monitors and televisions, consume electric power while they are left on standby or even when they are switched off and plugged in. For some products this power enables useful features such as responsiveness to remote control, but in other products it does not offer any such advantages. The amount of unused power that these products draw could be reduced further through technological enhancements.

Q147) By having more efficient products (i.e.. emitting less waste heat), will households need greater heating in winter? The use of more efficient products could have an effect on other energy uses. Inefficient lights, computing equipment and poorly insulated ovens, for example, emit heat, which consequently warms our homes and buildings. Sometimes this heat is useful to maintain a comfortable indoor temperature. At other times the additional heat is not necessary and we use other technologies (such as air-conditioners) to bring the temperature back to comfortable levels.

As the efficiency of products improves, the amount of heat generated by lights and appliances will drop. When this heat is not useful to maintain comfortable temperatures, improving the efficiency of lights and appliances will have the additional benefit of there being less need for energy for cooling. In cases where this heat is used, the comfortable temperatures in our homes and buildings would need to be maintained in other ways. This is addressed in the heating and cooling part of the model.

Q148) How much difference do we assume that smart meters make? Smart meters show how much energy we use in our homes, thereby helping us to identify sources of energy wastage. It may be that at some point in the future, our homes, offices, vehicles and heaters are equipped with technologies that communicate as one integrated system, helping us to use energy more efficiently across the board.

Level 2 assumes that with the help of smart meters and other technologies, we could manage the use of lights and appliances in our homes (for example, turning lights and appliances off when we are not using them) such that we reduce total demand by 5%.

Levels 3 and 4 have more ambitious aims, but the model doesn't specify how much is directly driven by smart meters.

Q149) How do we calculate heat loss? The fabric of a building (including its level of insulation) determines how efficient the building is at keeping warmth inside. The rate of heat lost from a household is proportional to the difference in internal and external temperature, and the thermal ‘leakiness’ of households. The ‘leakiness’ is quantified by the ‘Heat Loss Coefficient’ (HLC) which takes account of both fabric losses and ventilation losses. The amount of heat loss can be obtained by multiplying the rate of heat loss by the length of time it persists.

The future average HLC of the UK domestic stock in a given year is influenced by:

- the demolition rate;
- the new build rate;
- the level of refurbishment in the remaining stock; and
- new build fabric thermal efficiency standards.

Q150) How do we model insulation measures? The uptake of insulation measures in the domestic sector can in practice be limited by a number of factors. Consumers are sensitive to upfront costs, even when a measure is cost effective. The type of building ownership can affect take up, with private landlords

having little incentive to invest in energy saving measures benefitting their tenants. There is a significant fraction of the population who do not take up measures regardless of how cost effective they are (estimated at 28% of the owner-occupier population).

People can be put off by the disruption associated with some measures, for example floor insulation and internal solid wall insulation. In the case of internal solid wall insulation there can also be a significant loss of floor area. The savings achieved by energy efficiency improvements can also be reduced by ‘comfort taking’, in which the measures partly support warmer internal temperatures rather than increased energy savings.

Q151) What types of electric heating technologies are modelled? The following electric heating technologies have been examined:

- resistive heating;
- ground source heat pumps; and
- air source heat pumps.

Q152) How do heat pumps work? The 2050 project divides heat pumps into air source heat pumps (ASHPs) and ground source heat pumps (GSHPs).

Heat pumps can be used with either wet heating systems (for example, radiators) or dry heating systems (for example, forced air blowers). Heat pump efficiency is usually stated in terms of a Coefficient of Performance ('CoP'), which is the ratio of useful heat output to electrical input.

The second law of thermodynamics limits the maximum CoP that can be achieved by a heat pump. The maximum CoP is dependent on the temperature difference between the cold body and the hot body. For building heating applications, this means that the CoP of the heat pump is reduced if the external temperature (of the ground sub-surface or air) is lower, or if a higher temperature needs to be achieved (for example, to heat hot water). The variation of heat pump CoP with temperature has a number of implications if heat pumps are to be used for building heating applications.

The rate of heat delivery required to maintain an adequately high internal temperature is dependent on the rate of heat loss from the building, which is in turn dependent on its levels of insulation and air-tightness. The first trade-off is therefore between insulation levels and the rate of heat delivery required. Although this is true for all heating systems, for heat pumps the variation in efficiency with delivered temperature makes this trade-off particularly acute.

— Better insulating buildings enables heat pumps with a smaller power rating to be used. This is beneficial, as the size and cost of a heat pump increase as the rated power increases. If buildings are well insulated then existing radiator systems could operate at lower temperatures and still meet the demand, which would improve CoPs.

— The noise generated by ASHPs also increases as the rated power increases (for the same size of air to refrigerant heat exchanger). Quiet ASHPs are less likely to be constrained in their deployment, particularly in higher density areas where buildings are in close proximity to each other and there is a greater potential for cumulative noise to become a problem. Future technology improvement may reduce the noise associated with ASHPs.

— Should electric heating achieve a high penetration in UK households, the smaller peaks in space heating demand associated with better insulated dwellings would help reduce the capacity of the electricity infrastructure required to meet peak heat demand, for example upgrades to local sub-stations and networks.

Possible constraints on the uptake of air-to-air systems include fan noise in quiet rooms (such as bedrooms) and different perceptions of thermal comfort compared to radiator systems.

Q168) For the use of renewable energy in the residential sector, we observed that solar thermal energy replaces conventional energies instead of water heating. In terms of solar photovoltaic and wind small scale, are these being replaced by a specific conventional energy? What about its distribution? TBD

Q170) 9. Can you give us a detailed description of the spreadsheet XVII.a? To understand sheet XVII, there's some background on what is meant by the assumptions (particularly complex parts such as the z-factor) in this file (pages 116-117):

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/42562/216-2050-pathways-analysis-report.pdf

Q21) How does the modelling take into account the different housing types (block house, family house, public buildings...etc.) in the building stock? They can differ very much in respective parameters and insulation. We have estimated the thermal leakiness of our housing based on a separate analysis of the housing stock of the UK (which takes into account the level of existing insulation, the building materials, building shape and size and so on).

Q22) On sheets IX. a and c what is the meaning of the technology codes (in rows 75 and 93) and the percentage in the columns? It seems like the codes do not follow any logic. The codes correspond to a lookup value to select a combination of electrification and non-electrification energy source (in the table at rows 15 -21).

Q23) The spread of district heating could decrease heat related emission considerably. How is the ratio of DHC supplied buildings taken into account? How is the fuel (gas, coal, RES) for DHC generation taken into account? The ratio of DHC supplied buildings considers what is physically possible within the UK. District heating has no emissions in the heating sector as the emissions are counted in the power generation sheets, depending on the type of fuel combusted.

Q24) Is the cooling demand (TWh) reflected in the electricity generation mix (summer peak load)? (Sheet IX a) There are user trajectories for the cooling technology which affects the energy demand in the heat sector. This demand affects the energy supply and so it can affect the generation mix (see answer to question 2)

Q42) I expected altering the level of insulation to make a bigger difference The difference in greenhouse gas emissions from the all at level 1 pathway[1] and a pathway whose only difference is level 4 effort on insulation[2] is only 3% of 1990 levels. This may appear smaller than expected. See the answer here for more detail:

<http://2050-calculator-tool-wiki.decc.gov.uk/pages/124>

It is worth noting that the calculator does not capture the full benefit of insulation. In particular, insulation may have a significant impact on the need to provide ‘peaking’ electricity.

Q51) Why does reducing thermal waste in all domestic buildings by 50% by 2050 have no apparent impact on oil use? In the UK’s 2050 Calculator, in the baseline year of 2007, oil-fired boilers account for 4% of heating technologies.

If the user of the 2050 Calculator reduces thermal waste in domestic buildings using the “home insulation” lever, this reduces oil use in the years 2010- 2045 (the 2050 Calculator assumes that oil boilers will be phased out by 2050). A 50% average reduction in thermal leakiness reduces oil use by around 0.3 - 1.3 TWh per year over the 2010 to 2045 period.

This reduction in oil use does feed through into the graphs in the 2050 Calculator Webtool and spreadsheet but it is not noticeable for two reasons:

- 1.The 2050 Calculator assumes that oil boilers will be phased out by 2050. Therefore, a reduction in the thermal waste of domestic buildings of 50% by 2050 will have no impact on oil use in 2050 in the 2050 Calculator; and
- 2.The reduction in oil use is small relative to the total oil use.

Energy supplied by oil and petroleum products is given in row 43 in the spreadsheet in the “Intermediate output” worksheet. The spreadsheet can be accessed here: http://www.decc.gov.uk/en/content/cms/tackling/2050/calculator_exc/calculator_exc.aspx

Q52) How does the user determine the level of district heating? The level of district heating to provide heat to domestic and commercial properties up to 2050 is determined by the user as follows:

1.Domestic heating:

- the user selects the level of electrification of domestic heating up to 2050, by using the “home heating electrification” lever (National Grid have selected level 4, the highest electrification); and
- the user selects the level of district heating for homes that are not electrified by 2050, by using the “home heating that isn’t electric” lever (National Grid have selected level A, where gas or gas CHP are the dominant non-electric sources).

2.Commercial heating:

- the user selects the level of electrification of commercial heating up to 2050, by using the “commercial heating electrification” lever (National Grid have selected level 4, the highest electrification); and
- the user selects the level of district heating for commercial properties that are not electrified up to 2050, by using the “commercial heating that isn’t electric”

lever (National Grid have selected level D, which uses a mixture of non-electric sources).

Q49) What are the exact numbers in Figure A3 in the 2050 pathways report for the levels of domestic lighting and appliances in 2007; 2010; 2020; 2030 and 2050 The TWh per year usage figures for sectors, for a given pathway and a given year, can be found as follows:

domestic lighting and appliances: cell H17 in each of the “year” worksheets (worksheets “2007” to “2050”)

In order to get the energy demand under each a given trajectory (1 – 4), you will need to set the trajectories to either level 1, 2 3 or 4 in the “Control” worksheet, column E.

Q53) Where did the u-values in the heat sector (IX.a) come from?

Typical U-values for various measures, for example, cavity wall insulation (by M2) are combined with the proportion of properties by age that have these measure (using data from the English House Condition Survey, by the UK’s Department for Communities and Local Government). These are then combined with information about the housing stock, e.g. wall area, to produce average heat loss estimates.

Q55) What is pumped heat on the Sankey diagram The Sankey diagram shows ‘pumped heat’ as a fuel source. This is the heat that a heat pump (a type of heater for homes and businesses) sucks from the atmosphere or ground and pushes into rooms.

Q172) For autogeneration solar thermal, we want to split out the commercial and the household calculations for this. How best can we model this? TBD

CCS

Q14) What is the connection between sheets I.b. and XIV.a regarding CCS? Is it not over determined? Once we know the capacities supplied with CCS and their parameters the captured CO₂ can be calculated. Why is sheet XIV.a necessary? These sheets show different kinds of Carbon Capture and Storage.

I.b is CCS on power stations.

XIV.a is stand alone geosequestration (for an explanation of the technologies, see page 237 of: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/68816/216-2050-pathways-analysis-report.pdf)

Conclusions

Q186) Are there any ways that the user can produce implausible pathways? There are a few ways the user can break the calculator, for example:

- if you don't produce biomass, won't get the benefit of lower emissions (as coal would be used instead)
- you can specify high degree of district heating, when you have no thermal generation (obviously it's not possible to do this with wind turbines)
- a user could also specify techs that need lots of interconnections but don't add enough on that lever

Q93) What feedback did you get through the call for evidence? How did this feed into the model? Our part 2 2050 calculator document gives lots of detail about sectors where we had feedback, and how the 2050 Calculator was changed because of it:

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/42545/1344-2050-pathways-analysis-response-pt2.pdf

You can see documents with all the feedback we received during the call for evidence here:

<https://www.gov.uk/government/consultations/2050-pathways-analysis>

Q160) Would you recommend adding a pathway that we've developed in another model into our version of the Calculator? I think it is a good idea to transcribe scenarios from other models into example pathways in your calculator and webtool.

In the UK, we carried out a similar activity, transcribing the results of different runs of our complex Markal and ESME models into the UK calculator. By doing so, we helped more people to understand what those models were actually saying. Better still, we helped people to understand where the cheapest option might not be the most appealing or politically feasible, by including the pathway and then allowing people to 'correct it' using the tool to do fewer things they consider undesirable. Furthermore, once the results of other models were included in the 2050 calculator as example pathways, we could easily carry out sensitivities to see what really mattered in those other model's conclusions – for example, how much difference did reducing level 4 to level 1 on any given technology actually make in the overall pathway.

As far as I know, no other country (apart from the UK) has yet done this sort of transcribing. It is normally easy enough to do, if the results of the complex model give you enough detail. The one tricky aspect is that you can often

replicate the results of the complex model in a particular year (e.g., 2047) but rarely can you replicate the results in all years at the same time. We took the approach of just trying to match the final year which is the easiest approach.

Q159) Where can I see key information about my pathway, such as total electricity generation and electricity capacities, and energy demand for heat and transport? Click on the “See implications” button in the top left hand corner of the webtool front page. This will reveal a drop-down menu, from which the “electricity” link can be used to access the results for electricity generation and electricity capacities, along with a selection of other information.

Q72) Does the UK calculator show we really need to increase electricity generation from todays levels to hit the 2050 target? From the UK’s 2050 pathway analysis to date, there is a clear trend that most pathways involve a large increase in electricity generation: 13 of the 17 involve an increase of more than 20% on 2007 production, and half of the pathways more than double. The consequences of not electrifying sectors and therefore not increasing electricity generation would be large requirements for bioenergy and heroic levels of behaviour change to reduce per capita energy consumption.

Therefore, although it is physically possible to reduce electricity generation and reach the UK’s 2050 target, it involves a large amount of heroic effort on demand and bioenergy that many stakeholders consider unrealistic. An increase in electricity generation has been one common message of the pathways analysis to date, and indeed work from the CCC and economic models, such as MARKAL, indicate a similar trend. As the department works towards producing a narrower set of plausible pathways, then we could begin answer with more certainty, but until then it remains true to say that the 2050 work indicates a need for an increase in electricity generation in the majority of pathways presented, with many pathways more than doubling current generation demand.

Cost

Q178) Within the calculator costs, which technologies are included? There are 130 technologies in the 2050 Calculator and capital, operating expenditure and fuel cost estimates are included for each of these to 2050. These cost estimates cover the whole of the energy system (everything from: power stations and industrial processes; to cars, planes and trains and the fuel they use; to gas boilers and cavity wall insulation). On the energy supply side, this includes power stations, primary energy sources (fossil fuels, uranium and biomass) and transmission networks. On the energy demand side, this includes energy users (heating systems, cars and industrial plants) and demand reducing equipment such as insulation.

The 2050 Costs Calculator has the following cost information for each technology and fuel in 2050:

- Low cost estimate – costs are the lowest that credible published studies suggest they could be by 2050, for example assuming technology breakthroughs and low cost material and labour.
- High cost estimate – costs in 2050 are frozen at today's levels (or even higher if credible published evidence suggests this could be the case). This assumes no technological breakthroughs over the next forty years and high labour and material costs.
- Within this low / high costs range a default point estimate – consistent with MARKAL.

Q179) Where does the cost data come from? The cost estimates in the 2050 Costs Calculator are drawn from a wide range of credible, published sources. Sources include economic and energy models (in particular MARKAL), sectoral analysis (Parsons Brinckerhoff, Mott MacDonald, AEA, NERA), UK Government Departments, independent analytical bodies such as the Committee on Climate Change and wherever possible the real world cost of technologies as reported by financial bodies or the media. The 2050 Calculator includes no new evidence about costs, it simply brings together existing published assumptions.

For full details of the costs methodology, see: <http://2050-calculator-tool-wiki.decc.gov.uk/pages/28>

Q180) What caveats should I use when presenting cost data? There are certain costs associated with the move to a low carbon economy, which this analysis does not capture (such as wider macroeconomic impacts and the inconvenience from living in cooler buildings). And, critically, this analysis does not take into account any of the benefits associated with the move to a low carbon economy. These include:-

1. The avoided devastating damages of climate change – the Stern Review estimated this environmental cost at up to 20% of GDP per year globally, a figure that helps contextualise the cost of mitigating climate change, which he estimated to be 1-2% of GDP globally.
2. The benefits of greater energy security. If the UK did nothing to tackle climate change, the proportion of our energy we get from imported fossil fuels will rise from around 23% in 2007 to 53% in 2020 and 88% in 2050, meaning that our spending on net imported fossil fuels would rise from around £10bn today to £32bn in 2020 to £86bn in 2050. This would leave the UK more vulnerable to fossil fuel shortages and price spikes. However, if we meet our 80% target, then by 2050 imported fossil fuels could account for only 7-30% of our energy, at a cost of £8-24bn.

3. Investment in the green economy is a strong driver of economic growth and jobs. The global low carbon market is projected to reach £4 trillion by 2015 as economies around the world invest in low carbon technologies. Investment in renewables, globally, already outstripping investment in fossil fuels. By 2015, over 1 million people in the UK are expected to be employed in the green economy.
4. Another important caveat to the analysis is that the costs the combination of technologies chosen by the user and does not take into account price interactions between supply and demand.

This link gives more information: <http://2050-calculator-tool-wiki.decc.gov.uk/pages/82>

Q181) How can we know what costs will be in the future? Future fuel and technology costs are highly uncertain. The following are just a few factors which could cause future technology costs to be lower or higher:

- The climate change policy of other countries. Lots of long term, predictable climate initiatives internationally could have a big effect on RDD&D expenditure globally which could bring down technology costs.
- Success of scientists and engineers in discovering better, cheaper low carbon technology solutions.
- Technology roll out in other countries. This could push prices up (e.g. if it results in a shortage of, say, CCS engineers), or push prices down (if learning by doing reduces unit costs). The UK is not a very large market and so could be a price taker for many technologies.
- Technology roll out in the UK. For example, the marginal cost of land used for wind turbines will increase as the roll out of wind increases. Alternatively, marginal cost of installing charging points for electric vehicles may decline as the number of electric vehicles in circulation increases through learning by doing / economies of scale.

The 2050 calculator's cost range is a simple way of attempting to capture all the above factors. The cost range for 2050 represents the highest / lowest that credible experts can foresee costs being. Specifically:

- Low cost estimate – costs are the lowest that credible published studies suggest they could be by 2050, for example assuming technology breakthroughs and low cost material and labour.
- High cost estimate – costs in 2050 are frozen at today's levels (or even higher if credible published evidence suggests this could be the case). This assumes no technological breakthroughs over the next forty years and high labour and material costs.

There are three advantages to this simple methodology for defining high/low costs:

- Simple – this is analytically simple and easy to understand. It is objective because technology costs today are a verifiable fact.
- Avoids false confidence – there is genuine uncertainty about whether scientists will achieve the technology breakthroughs necessary to bring down the costs of specific technologies. We should not presume that the cost of any technology will fall as a matter of course e.g. history shows that nuclear power costs have actually risen over the last forty years.
- Consistent with 2050 Calculator trajectory methodology – the technology trajectories reflect all credible views on the role of technologies. Similarly, our high/low range reflects all credible views on possible future costs.

Q182) Do costs for a technology become cheaper if it becomes more commonly used? (i.e.. learning rates) No. The high/low costs we use for each technology will be the same regardless of which pathway the user selects. In other words, costs are treated as exogenous to the model, not endogenous.

We have done this for two reasons:

1. To keep the simplicity of the Calculator. If we made the Calculator capable of modelling learning rates then it would be a less transparent, simple and accessible tool.
2. The UK is likely to be a price taker in many technologies. It would arguably be spurious accuracy because levels of technology R&D and roll out in other countries will arguably have more of an impact on the UK than our own choices (i.e. the UK is a price taker).

Although costs are exogenous, we do make a provision for minimal technological improvement over time. For most technologies, we assume incremental improvements in energy efficiency over time. So although the high, low cost estimates appear constant over time, on a like for like comparison prices are actually falling slightly.

Q183) What type of cost questions can be answered by the calculator?
The 2050 Calculator should be used to answer questions such as:

- What are the capital, operating and fuel costs of pathway X relative to pathway Y?
- What are the biggest component costs of pathway X?
- How might the capital, operating and fuel costs of pathway X change when, say, renewables costs are as cheap as credible experts believe possible, and nuclear costs are expensive?

But it should not be used to answer questions such as:

- What is the effect on energy demand of, say, switching to more expensive forms of electricity generation? (Because the 2050 Calculator does not have a price feedback.)
- What is the impact of policy X on energy bills? (Because the 2050 Calculator cannot say what the impact on an electricity or heating bill will be - this is mostly because we would need to make an assumption about the policy used to implement this change.)
- What is the expected cost of policy X over the next 10-20 years? (The Calculator is best suited to 2050 analysis, not short/medium term analysis.)
- What are the wider macroeconomic costs or welfare costs of policy X? (These impacts are excluded from the Calculator.)
- What's the optimal, least cost means of reducing emissions by 80%? (The Calculator cannot automatically work this out but the user can work out least cost pathways for themselves.)

Q36) How can one see the costs sections of the analysis on the webtool

The costs part of the analysis can be found by clicking on the “see implications” button in the top left corner of the webtool window. There are three different costs pages which can be chosen from the drop-down menu this button prompts.

Q46) Why are you using total costs to society rather than tax, subsidy and costs to consumers The Calculator works out the total costs to society as a whole of pathways generated by users essentially because working out the impacts of specific policies in terms of taxes or subsidies, and the costs and distribution of these policies, is beyond the scope of the model. The 2050 Calculator is intended to be a simple model; it does not model the markets and relationships which would be needed to work out this level of detail. Furthermore, the Calculator is designed to be policy neutral. The model does not inform on how pathways might be achieved, only the potential for what could be achieved. For this reason, it is more consistent to calculate costs at the broadest level.

Q61) Why are the cost ranges so large? Our initial approach has been to create a large cost range, encompassing all credible experts opinions and forecasts of costs over time. At this stage we have not attempted to add probability distributions to future costs, since we do not believe there is sufficient data or evidence in most cases to achieve this.

We wish to capture all credible experts views on costs, however if there are some cost estimates used which are widely discredited, please comment on those sources and add other cost sources. Equally, if you believe costs will fall with some certainty from today’s ‘high’ estimates please also inform us.

Q157) Where can you get total costs and cost/person/year? How can you graph these over time? The total costs are in the “Costs” worksheet (this may be called “CostAbsolute” if you’re working from an older version of the 2050 Calculator), and the costs per person are in the “CostPerCapita” worksheet. The costs are split from left to right by capital, operating, fuel and finance costs, and top to bottom by low, central and high cost estimates for each sector. Each of these cost type / cost range combinations by sector is provided for each 5 year interval up to 2050, to allow the user to create their own graphs or descriptive statistics (by highlighting the relevant data and inserting the desired graph).

Q65) For CHP, do you include the saving in producing electricity as well as heat Yes, the spreadsheet includes both of these.

Q66) Do you account for the damage cost of carbon? Not at the moment.

Q67) How are you accounting for the macroeconomic impact of climate change? We don’t include the impacts of climate change in the model.

Q41) Why have you included the total cost of vehicles? Question: “On the cost methodology, it appears that the total cost of vehicles in the transport sector is included. While one could understand including the incremental cost of, say, electric vehicles or plug-in hybrids over “conventional” petrol or diesel cars, to count in the total cost of the vehicles seems illogical.” The calculator gives the user the option of choosing to travel less, and to travel differently (for instance, for a greater proportion of journeys to be by train or bicycle than today). To fully account for the cost impact of this option, and its interaction with the choice about what sort of vehicle is used (conventional, electric or hydrogen) the total cost of vehicles was included.

Note that, at the moment, the total cost of aircraft and ships are not included.

Q44) You appear to have costs and cost ranges for 2010 and 2050, what are the costs you use for the intervening periods? The period between 2010 and 2050 is broken down into nine five year periods in the Calculator. We use one cost for each of these periods.

This cost is generally calculated by linearly interpolating between the 2010 and 2050 figures - that is to say for the middle period, 2030 to 2035, the cost will be half way be between the 2010 and 2050 costs; for the fifth period the cost is five ninths of the way between the 2010 and the 2050 costs.

In the case of the power sector we have followed the way the costs fall in the MARKAL model. The costs do not change in every period from this source, with typically three or so “vintages” of costs. For example one cost for the 2020s, another for the 2030s and then a third for the period after 2045.

The actual numbers for the costs and the calculations involved can be found in the excel spreadsheet version of the model, although the 2010 and 2050 costs displayed on the wiki give a good approximation of the trend.

Q45) Have you used a discount rate? What have you used if so? The costs we are currently presenting in the webtool are not discounted.

However, the excel spreadsheet model has the functionality to easily enable a discount rate. This can be done through the “Global Assumptions” worksheet. We have a 3.5 percent default loaded for this purpose. The reasons for this can be found on the Discount rate methodology page: <http://2050-calculator-tool-wiki.decc.gov.uk/pages/107>.

The CostPerCapita and CostAbsolute worksheets have NPV (Net Present Value) columns where the cost with the default discount rate are available.

Q56) Does the 2050 Costs calculator account for system costs? We have accounted for system costs and intermittency in the 2050 Pathways analysis, although any further evidence or comments on how we can improve our cost sources and methodology would be greatly appreciated.

See this page for a detailed answer:

<http://2050-calculator-tool-wiki.decc.gov.uk/pages/220>

Q59) How do you treat discounting? See question 45

Q60) How do you treat financing costs? Financing costs are a variable which can be defined by technology in the excel, both in terms of interest rate and duration of loan period. The question is how to present finance costs in the webtool, please see web interface to leave your thoughts and comments.

Q62) Do you account for nuclear waste costs? We have added a cost of uranium disposal and plant decommissioning as a function of the Uranium used in pathways. See Uranium Enrichment & Disposal cost data at: http://2050-calculator-tool-wiki.decc.gov.uk/cost_categories/20

Q63) Presumably if energy prices are rising people will demand less. Do you account for these dynamic feedbacks? There is no price elasticity function, which adjusts energy demands in response to prices in pathways. This is because the pathways are user led and the costs work, emissions and energy are shown as consequences of a users chosen pathway. Therefore, in a high-level way a user can decide to replicate demand side response by increasing the level of demand reduction through the user choices but we have not hard-wired this response, since the 2050 Calculator has no optimisation function

Q64) How will you measure the impact on bills? The model doesn't measure the impact on consumer bills. It works out the cost to society of a particular energy system, but doesn't specify who pays.

Q104) In Finance costs, why are there different years attributed here. The finance costs ('Global assumptions' row 31 onwards) are made up of two factors: the interest rate, and the period of time a loan is structured. This is to reflect the typical period of time loans are taken out for in an industry. The shorter the time period – the less interest you have to pay.

Emissions

Q126) Why are some emissions negative? In the emissions chart in the "Control" worksheet, you will see that some emissions are negative. The technologies that have particular characteristics that result in negative emissions are as follows:

- Carbon capture and storage (CCS) – when gas is burned in a CCS power station, the Calculator applies the natural gas emissions factor to the quantity burned and adds the resulting CO₂ to the model's total emissions. To account for the fact that these emissions are captured, an equivalent negative quantity of emissions is also added to the total.
- Biomass – like all other fuels, when biofuels' biomass are combusted, the model applies an emissions factor according to its physical state. However, unlike hydrocarbons, biofuels do not produce any CO₂ when burned. UNFCCC accounting guidelines state that countries should treat biomass as an emissions neutral energy source. This is because carbon from the atmosphere is sequestered into the biomass while the feedstock is growing. To account for this, an equivalent negative quantity of emissions is included in the emission calculation. When biofuels are combined with CSS, the above treatments combine, resulting in a negative contribution to the overall CO₂ emission calculation.
- Geosequestration - these technologies remove CO₂ directly from the atmosphere and store it in parts of the geochemical system. The amount of CO₂ removed appears as a negative quantity in the emissions calculation.

Q189) Looking at the emissions factors, there's quite commonly over time a reduction of emissions factor. What's driving the change in emissions factors? TBD

Q47) The calculator uses an average CO₂ emissions factor for solids, liquids and gas, how did you reach this value? I believe that, for CO₂, we used the specific emissions factor for the particular fuel listed in the table. (Eg, for solids, we used the emissions factor for industrial coal). These emissions factors are reported in DUKES (the Digest of UK Energy Statistics, published by DECC).

It turns out that emissions factors expressed as emissions per unit of energy (rather than per unit of mass or volume) are reasonably constant for all hydrocarbon fuels of a particular physical state – certainly within the limits of uncertainty expected of a model like this.

For the other gases, CH₄ and N₂O, we used the ratio of these gases emitted to CO₂ emitted from combustion (of the appropriate fuel) for the total UK emissions, as reported in the Greenhouse Gas Inventory, and assumed this ratio applied to all sources. In summary: for each physical state of hydrocarbons, we first estimated CO₂ emission as above, then applied a constant multiplier to obtain the emissions of the other gasses.

Fossil fuels

Q121) There are lots of types of coal - which type are you comparing to? In the UK's 2050 calculator, there are only 3 emissions factors: solid, liquid and gaseous hydrocarbons.

The emissions factor work on a ‘per unit of energy’ basis, which means that all fuels of same physical state have same emissions. These wouldn’t be the same on mass, but on a TWh basis, works the same.

Because this is done on an energy basis, we can use same emissions factor on all hydrocarbons. This is a very small simplification, applied generally, which keeps things a lot more manageable

So each type of hydrocarbons goes to the end use, and is not allocated to specific sectors. We just make a subtraction from solid, liquid gas, and then there’s an adjustment made

Q40) How is shale gas treated (From wiki page, written by Jan Kiso)

In December 2010, we updated our 2050 Pathways calculator to include costs estimates for the different choices facing the UK’s energy infrastructure . Although there are inevitably uncertainties about predicting costs of anything decades in

the future, we felt that in order to have an honest and fair discussion about the UK's energy future we needed to reflect the potential costs.

Since then the 2050 Pathways team have received comments about how shale gas is treated within the 2050 Pathways Calculator, with some people expressing concern that we were ignoring this source of energy.

Shale gas is a natural gas (predominantly methane) found in shale rock. Natural gas produced from shale is often referred to as 'unconventional' and this refers to the type of rock in which it is found. 'Conventional' oil and gas refers to hydrocarbons which have previously been in sandstone or limestone, instead of shale or coal which are now the focus of unconventional exploration.

The 2050 Pathways Calculator does not distinguish whether natural gas in the pathways originates from 'conventional' or 'unconventional' sources. It takes natural gas as a primary energy source.

If the Calculator user believes that shale gas will significantly lower the price of natural gas in the UK in the future, he/she can choose lower cost assumptions in the Calculator section 'costs sensitivity'. Users could look at the impact of gas being 45p/therm to 100p/therm in 2050. These high/low gas prices are taken from the DECC fossil fuel price projections published in October 2011.

The Calculator has no constraints on the amount of gas the UK can use. For example, in the "do not tackle climate change" scenario (defined as all level 1s), 66% of energy supply in 2050 is natural gas. The Calculator just assumes that gas imports are available.

Q106) Regarding the energy supply side, i need your support to have information and some data in term of general on oil refinery, e.g. i). refinery losses; ii). Energy own use in the refinery plant (electricity, heat, and oil products for processing, etc.); and iii). O&M cost-Refinery plant. Because, there is not available, confidence information and data on that although one oil refinery plant is operating with capacity at 6.5 mill. ton per year. I have to say that the data is not confidence enough due to the data collected from energy statistic that mentioned the refinery losses is 12%? 1. Refinery losses: Just to check that we understand the question – there is one refinery in Vietnam, but the data they have is confidential. You are looking for information on what assumptions you should use for costs and losses.

If the refinery is not absolutely huge, then you are probably ok using UK data for refineries (sheet XVa. in the UK Calculator).

The other option is to use data from a neighbouring country, or if that is too difficult to obtain you can use US data from the MARKAL user guide. We'd recommend using UK data, unless you think that this will really distort your results.

Q82) I have one more question which is about oil refinery module (XVa). I understand from the UK model that output products are not separate by types of fuel i.e., DO, FO, Gasoline etc. Could you pls. explain why it is so? Secondly, I do not see how these output are used (row 129). Could you pls. explain? The Calculator takes a simple approach where total energy demand and supply within the UK are calculated separately, and any difference between them is balanced with imports/exports. There is no attempt to show the path from extraction, to conversion and then consumption within specific sectors.

In the case of liquid hydrocarbons, as were the focus of your question, the total requirement is calculated in row 101, 'Subtotal.XVI.a Requested hydrocarbons' (e.g. 830.4 TWh in 2010) of vector V.04.

This demand is met with domestic production via sector XV.b, (802.5 TWh), with the remainder (27.9 TWh) being supplied via balancing imports in vector Y.05. These quantities enter via vector C.02, and are transferred to vector V.04 via the 'fossil fuel transfers' sector (XVI.a), so that supply and demand for sector V.04 net to zero.

Sector XV.a is essentially a subsidiary sector that exists primarily to calculate the costs, energy requirements and emissions associated with refining the domestically produced fossil fuels. The energy inputs and outputs of have already accounted for as described above.

To maintain simplicity, the Calculator treats all liquid hydrocarbons the same, whether they are diesel or petrol etc. The fact that the emissions factors for these different fuel types are, on an energy basis (i.e. MtCO₂/TWh), essentially the same, enables this simplified approach to work. Diverging from this approach would add a great deal of complexity to the Calculator.

Q195) For the Colombian model, how much can we change the UK's sheet on transfers of energy. Sheet XIII.a includes several calculations (especially emissions) that we had already done in our hydrocarbon generation sheets (ie, generation from gas/coal). Can we delete them from here, or should we keep sheet XIII.a the same and delete them from the sector sheet? What other changes do we need to consider I've attached the current version of the Indian calculator for you (they'll be doing an updated version in a few months though, so for future reference here is the link which will always be the latest version: you just need to click 'The model' at the top, then 'The Downloadable Excel Model'): <http://www.indiaenergy.gov.in/#>

In the Indian spreadsheet, the structure is:

- Hydrocarbon fuel power generation is in sheets I.a (gas) and I.b (coal)
- Their version of fossil fuel transfer (ie. your sheets XIII.a and b) are in their sheets XVII.a and b

- They also have fossil fuel production calculations in sheets XV.a to c

The important things are to avoid emitting or double-counting anything (ie. emissions for a particular energy should be done in one and only one place) and to make sure that your calculations are clear and consistent. The UK version isn't the only approach that you can use. For Colombia's spreadsheet, we recommend that you look at the Indian team's spreadsheet.

Here is the link to the Indian 2047 Calculator: you just need to click 'The model' at the top, then 'The Downloadable Excel Model'): <http://www.indiaenergy.gov.in/#>

Basically the Indian team's approach was:

- In the fossil fuel transfer sheets, the Indian sheet XVII.a is adapted from the UK's version, but removes the following parts:
 - o Cost assumptions
 - o Emissions
 - o Capacities
 - o Air quality
 - All of these calculations were included in the hydrocarbon sheets I.a and I.b (or not included at all). For example, in sheet I.a
 - o Cost calculations are not included in the Indian calculator but they're working now to add them to their second phase
 - o Emissions are calculated in rows 117 to 125
 - o Capacities on row 79
 - o Air quality also isn't included in the Indian calculator.

Q196) What does NMVOC stand for, and why are they modelled as if they are a greenhouse gas? This stands for Non methane volatile organic compounds. You can read more about them here:

<http://en.wikipedia.org/wiki/NMVOC>

It's worth noting that NMVOC is not classed as one of the six greenhouse gas (GHG) categories (in the UK spreadsheet, it has been incorrectly labelled it as this). The reason it's included in the UK version is because it is an important factor in air quality.

Q73) Why are oil demand projections from the DECC energy model so different from the 2050 analysis? The 2050 Pathways and the Energy Model are two separate models, and there is very little overlap in inputs. That explains why you are seeing different projections in oil demand.

You can read more detail here: <http://2050-calculator-tool-wiki.decc.gov.uk/pages/219>

Q58) It is very confusing having energy supply from coal and from biomass represented by the same block on chart two. Why is this done? The “UK Primary Energy Supply” chart in the 2050 Calculator Webtool shows the energy supplied from the available primary energy sources in the Calculator: the “coal” line shows the energy derived from coal; the “bioenergy” line shows energy derived from biomass. However, choices on solid biomass have an impact on coal use and this will be visible in the chart. This is because energy demand is always met in the 2050 Calculator, and if insufficient biomass is provided the corresponding fossil fuel is used. For example, if the user selects a higher level of biomass power plant deployment, then coal use will increase if there is insufficient solid biomass in the user’s pathway to satisfy the solid hydrocarbon demand.

A detailed breakdown of the energy supplied from the different sources is provided in the spreadsheet in the “Intermediate output” worksheet, rows 23 to 47. The spreadsheet can be accessed at: <http://2050-calculator-tool-wiki.decc.gov.uk/pages/140>

Q15) How does the fossil fuel production (NOT use) affect emissions? (sheet XV b) Fossil fuel production affects emissions in two ways: (1) from mining (fugitive emissions), and; (2) the energy required in the production process.

Q177) For oil and gas extraction, what are fugitive emissions and do we need to include them? TBD

Industry

Q132) How does the Calculator deal with imports of manufactured goods from other countries? It is important to bear in mind that while sacrificing output in the UK may help us achieve our 2050 targets, it does not rule out the possibility of these emissions simply being ‘offshored’ to another country – a consequence that the Calculator’s outputs do not account for.

Q27) Is it possible to use baseline year other than 2007? (sheet XI. a and other sheets also) Yes, you can start from any base year. We used 2007 since it was the most recent data point at the time of development, but other countries have used other years (for example 2010). It’s important that you have as much data as possible for the year that you choose as your base year. You want the year that is complete enough, but also recent enough.

Q174) What are process emissions? Process emissions from industrial processes are emissions from chemical transformations other than combustion.

For example, CO₂ from the calcinations step in cement manufacturing, CO₂ from catalytic cracking in petrochemical processing, Perfluorocarbons (PFC) emissions from aluminium smelting, etc.

The UK's trajectory assumptions about process emissions are described here:

<http://2050-calculator-tool.decc.gov.uk/assets/onepage/38.pdf>

Q92) How were the UK's industry sectors defined: what is included and what isn't included? To understand more about the UK's industry sectors and how these are classified, you can have a look at our part 2 2050 calculator document (pages 90-92 summarise how the levers for industry were changed from one to two levers):

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/42545/1344-2050-pathways-analysis-response-pt2.pdf

The link below also gives a summary of how industries are assigned to the categories we use, and might be a helpful check for you.

<http://2050-calculator-tool-wiki.decc.gov.uk/pages/131>

Q26) Is the industry emissions (and energy use) matched with the actual electricity generation mix? (on sheet XI. a. the electricity need of the industry is used as input – what is the fuel mix behind this electricity need?) No. Electricity demand and supply are matched at an aggregate level. No attempt is made to attribute electricity generated by particular technologies to being consumed by particular demand sectors.

Q25) Could you please indicate which industries belong to certain categories (chemicals, minerals, metals)? Is the refinery factor included in one of them? Why there is a distinct sheet for refineries (XV a.)? See the full answer here: <http://2050-calculator-tool-wiki.decc.gov.uk/pages/131>

Q28) Why is the growth in energy demand multiplier indicator missing between 2025-2050? (sheet XI. a.)? The energy demand multipliers are annual multipliers for the years 2007 – 2050 (whereas the output index has a growth rate for 2007- 2025 and then 2025 to 2050)

Q38) Where is industrial CHP? Industrial CHP is included, but it is not shown separately. Instead industry as a whole is modelled as taking in fuels (gas, coal, oil, electricity, some heat from district heating) and then doing useful stuff with it, including turning it to electricity and heat for their own use.

At some point, we'd like to separate out industrial CHP.

**Q175) How much potential is there with fuel-switching for industry?
How would we model this? TBD**

Nuclear

Q103) Nuclear is listed as having 3GW “peak” plant. What does this mean? “Peak” plant (II.a row 71 in the Excel) is used to describe the size of each nuclear plant included in the nuclear scenarios. We refer to “peak” to show the maximum generating capacity of the plant, which is the way that the industry talks about plant size. This is then combined with a capacity factor to calculate how much electricity it can generate.

Renewables

Q105) For wave and tidal energy what does availability factor mean?

2. Wave and tidal energy. What does “availability factor” mean?

“Availability factor” (III.a rows 67-71 in the Excel) is used to model the fact that you will need to maintain these renewables at some stage. Some more general background on this and the difference between availability and capacity factors is here: http://en.wikipedia.org/wiki/Availability_factor

An availability factor of 90% shows that of a development of 10 wave installations, at any time one will not be generating electricity because it is closed for maintenance. A higher factor e.g. 95% shows that more installations would be available to generate electricity e.g. of 10 installations at any time, 0.5 will not be working.

Sector sheets

Q7) Is it possible to turn a fixed assumption indicator to trajectories?
Yes: you can have any number of trajectory assumptions, within the limits of what is practical. Remember that it will make it harder for the users to understand the model if they have to make lots of choices; we have found that around 40 choices is about right. If you create more trajectories it also requires more stakeholder work to agree the range of change in that trajectory. You can combine multiple trajectory parameters within one lever (for example, occupancy and efficiency in the transport sector) but this becomes more opaque.

Summary sheets

Q8) Are the sectors connected (e.g. do supply-demand match)? Generally, all the sectors are independent. The user chooses what happens in each sector, and the Calculator adds up the supply and the demand for energy in the “year” worksheets (for example, worksheet “2007” summarises the supply and demand for energy for 2007).

However, there are some sectors that are dependent on others. Most notably, the fossil fuel electricity generation sector (1.a) calculates the any shortfall between demand and supply for electricity from the other sectors, and automatically generates any additional required electricity.

Additionally, if there is a shortfall of supply from domestic fossil fuel production, domestic nuclear, biofuels and renewables production, electricity imports and bioenergy imports, the Calculator “imports” gas to meet the excess demand. The other interactions are:

- bioenergy (see page 13 of the “How to Guide” https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/2050-calculator-spreadsheet-how-to-guide.pdf)
- fossil fuels (refinery activity, worksheet “XV.a”, depends on the amount of indigenous production of oil, as specified by the user.)

Transport

Q137) What transport technologies does the UK consider? The Calculator has four technology types for domestic transport. For “cars” (cars, vans and motorcycles) and “buses” these technology types are: internal combustion engine; hybrid electric vehicle; electric vehicle, and; fuel-cell vehicle. For “rail” the technology types are diesel and electric. The user decides the proportion of vehicles that will be electrified.

In 2007 it is assumed that all cars and buses use internal combustion engines, and rail is split between 35% diesel and 65% electric. The Calculator has four trajectories for the type of technology used in electric and hybrid vehicles: battery or fuel cell.

Q191) How do you account for bicycle in terms of emissions? TBD

Q138) What lifetimes are assumed for transport technologies? The Calculator includes life spans for each of the technologies, which are taken from MARKAL. The original source for this data is not documented. The life spans are: “bike” = 5 years; “cars” = 12 years; “buses” = 15 years; “rail” = 40 years; “air” = 30 years.

Freight lifespans are: “road” = 7 years; “rail” = 30 years.

Q176) How ambitious should we be on electric vehicles? TBD

Q100) Do we still need to include new vehicles in 2010, given that this is before the base year? If you are including costs in your calculator, the cost of cars in this year will be part of the total, so you will need to have a value for it. If no historic data is available, you could just extrapolate based on trends before and afterwards.

If your calculator's version does not yet include costs, it is not essential to give this figure, but it would still be good practice in case costs are added in the future.

Q169) In the one pager of domestic freight transport, levels one to four depend of the amount of cargo transported (ton-km/person/year) and the modal partition. However in those calculations it seems that is not taken into account these values. How does the calculator use those values?. TBD

Q30) In case of international shipping could we use the sheet XII. e to model emissions from cross-border waterways (rivers) (Hungary does not have sea shore but there is international shipping on Danube river through or into Hungary) Yes, if you can agree a method on how to apportion emissions and have data to estimate travel demand

Q29) Regarding aviation how are the international flights taken into account? What ratio of an arrival or departure flight is considered as local emission? (XII. c sheet) For the purpose of this 2050 analysis, international aviation emissions have been assigned to the UK on the basis of all flights departing from the UK.

Q31) The petrol and diesel demand is determined on transport sheets. Why is it necessary to deliver the oil product demand on sheet XV a? Is the demand for refinery products not matched with the transport energy demand in the model? Refinery demand is determined by the indigenous production of oil. This is a choice for the user. If there is excess demand for oil above this indigenous production (for example, from high transport demand) then the Calculator will "import" the oil.

Q32) Where are the emissions from H2 and electricity based transport allocated? (at transport or at electricity/H2 production)? The emissions from the H2 production are captured in sheet VIII.a. The emissions from electricity for transport are in each of the respective sector worksheets for

the technologies that produce electricity. The transports sector sheets capture the combustion emissions associated with vehicles that have internal combustion engines.

Q33) On XII. b sheet the equations seems like a little confused. Could you please explain the equations from row 32-43 (we do not see the connection between fuel use and distance) and rows 72-75? However, in our views the efficiencies (row 61 & 69) as defined on the sheet, could be delivered simply as the ratio of fuel use and distance – this equation is not provided, isn't? There is a full answer here:

<http://2050-calculator-tool-wiki.decc.gov.uk/pages/131>

Q34) Is the electricity need of transport matched with the electricity generation supply? Is the emission from EVs reflected by the electricity fuel mix? See answer to question 8. The emissions from electricity for transport are in each of the respective sector worksheets for the technologies that produce electricity. The transport sector sheets capture the combustion emissions associated with vehicles that have internal combustion engines.

Q50) Why does fuel cell technology in motor vehicles use gas? The adoption of fuel cell technology in vehicles in the 2050 Calculator is determined by the user of the Calculator as follows:

- 1.The user selects the absolute number of motor vehicles that will be driven up to 2050, using the “domestic transport behaviour” lever;
- 2.The user selects the proportion of vehicles they want to be electrified up to 2050, using the “shift to zero emission transport” lever; and
- 3.The user selects the technology they want electrified motor vehicles to adopt (hydrogen fuel cells or battery electric) in the “choice of car and van technology” lever.

The 2050 Calculator then “produces” enough hydrogen to provide the hydrogen demanded by hydrogen fuel cell vehicles (specified by the user in steps i to iii). This production requires gas and electricity in proportions that vary over time:

- 1.Hydrogen is produced either by “steam methane reforming” (SMR) using gaseous hydrocarbons or “distributed water electrolysis” (DWE) using electricity; and
- 2.the Calculator assumes that over time hydrogen will increasingly be produced by DWE, and so produced using electricity rather than gas (it is assumed that by 2050 100% of hydrogen will be produced by DWE).

Units

Q85) Under the individual Supply sheets, the “Fixed assumptions” section also has an “Implications” subsection (e.g. rows 70-71 in II.a (Nuclear), or 53-54 under III.a.2 (Onshore wind)). We notice that units there are somewhat misleading, sometimes quoting capacity and then giving actually energy values instead of power. How are these values actually entering the model? In the case of nuclear the ‘implications’ section is used to state the illustrative size of power station considered: 3GW. The lever for this sector allows the user to specify capacity in GW, so the illustrative station size is used to work out the number of power stations this would entail. The cost estimates we have for this sector are also on a 3GW station basis, so it’s necessary to know the number of stations to work out the costs. Precisely the same approach is used in the onshore wind sector.

(The ‘trace dependents feature on the ‘formulas’ tab is really useful for seeing how these figures are used.)

Q115) How do I add my currency to the Conversions sheet? The Conversions sheet is designed so that this should be very easy to do, and this summary should help you understand how the units work. (Also see question 90):

<http://book.2050.org.uk/calculator-book/appendix-4-units.html>

The easiest way to add a new currency unit is to follow these steps:

- Go to the Conversions sheet and scroll down to the title ‘Cost conversions’ which lists all currencies.
- We recommend keeping all the existing rows there (as someone may still want to use UK or other currencies), so the first stage is to copy an existing row to create a duplicate.
- Decide the name you want to use for your currency, and type this name into column D. We recommend using the standard prefixes (k for 1,000, then M for 1 million, G for 1 billion and T for 1,000 billion)
- In column E, set the named range to be the same as the name you typed in column D.
- Enter the conversion rate in column F. For the UK version, we have hardcoded this column as the £ conversion value (i.e.. the value for £1 is 1, and all other values are proportional to this). You could easily choose another currency (e.g. \$) here, but you just need to make sure your conversions are correct.

- The formula in column E should automatically be correct if you copied it from another row - this will adjust all numbers to be in your preferred currency (as set in the Preferences sheet).
- Test your currency is working by typing = [your named currency range] into a blank cell, and making sure this gives the expected value in the preferred currency. It's easy to get the conversion the wrong way round, so double-check that you are correct.

Q90) About units conversion in the excel, my question is: What is the unit of the fixed numbers in these formulas? For example: = (Unit.GW)0,6. What is the unit of 0.6?= 0.04(1/Unit.TWh). What is the unit of 0.04 ? I guess the unit of energy is TWh and the unit of power is GW. On your units question, I think the explanation here might be the best way to describe it.

<http://book.2050.org.uk/calculator-book/appendix-4-units.html>

To give some more explanation, in the UK calculator we use TWh as the energy unit preference (see the Preferences sheet). However the reason we always multiply any values by (Unit.name of unit) is that this allows people to enter numbers in any unit they choose, while ensuring that numbers are still displayed in the preferred unit through the spreadsheet.

So to take your example:

- 0.6 doesn't have a unit itself, but if you write it into the calculator as (Unit.GW)*0.6 then it will always be treated as 0.6GW, and the cell will show it as 0.6, because GW are the preferred units.
- However if you wrote it as (Unit.MW) *0.6, then the cell calculation would show it as 0.0006 instead (again because the preferred unit is GW).

Q129) How do you change the default units? The units of measurement are defined in the "Preference" worksheet. It is possible to change the energy, power, area and money units of measurement.

See this link for more information about units: <http://book.2050.org.uk/calculator-book/appendix-4-units.html>

Year sheet

Q112) I've changed the year sheet for one of the years. What do I need to do to update all the other year sheets? All the year sheets are designed to have the same structure. They are essentially identical, apart from the year which they represent.

Just changing the year displayed in the top left-hand corner of the worksheet (cell E2) will cause the formulae to update so that the entire year sheet will then show data for the newly entered year.

So once you have made changes to one year sheet, you can create all the other year sheets by:

- 1) deleting all year sheets, except the one you have just updated
- 2) copying (duplicating) your updated year sheet the required number of times. (You can do this by right-clicking on the sheet tab at the bottom of the page, clicking 'Move or Copy', selecting 'create a copy' then clicking OK)
- 3) then entering the required years (2010, 2015, ... , 2050) in cell E2 of the corresponding sheets.

You can read more about year sheets here: <http://book.2050.org.uk/calculator-book/appendix-1-the-excel-model-structure.html#year-sheets>

How to deploy the webtool on the AWS EC2 - a guide to getting your Calculator online for public use

Introduction

To get your Calculator online, it needs to be installed on a public webserver, where the public can access it via their browsers using a URL.

Amazon Web Services (AWS) provides a cost effective solution which is relatively easy to set up. The AWS EC2 (Elastic Cloud Computing) gives you access to a virtual computing environments, known as instances, on which you can install your calculator. You are able to specify the operating system you would like the instance to use (i.e. Ubuntu 12.04) and once connected it behaves and can be controlled just like any computer running Ubuntu. You can open a terminal of the instance on your local computer, and control it in the same way. At this point you will be able to set-up your Calculator on the AWS instance by using the existing 'setup-ubuntu-12.04.sh' script. Full, step-by-step, instructions are given below.

Step-by-step instructions

1. Setup an AWS account

Go to aws.amazon.com and select 'Create an account'

2. Login and select EC2. This opens the EC2 dashboard
3. Change the region from the drop-down in the top right and menu to the one that corresponds to your intended audience (e.g. for the UK we use EU-Ireland).
4. From the left hand menu select ‘Key Pairs’ (A Key Pair is a bit like a password for accessing your account/server, but it is stored in a file on your computer so you don’t have to remember it). Click - ‘Create Key Pair’ You will be prompted to choose a name for your new Key Pair. Enter a name of your choice, e.g. ‘myAWSEC2’. This name will be used to generate a file with a ‘.pem’ extension, e.g. ‘myAWSEC2.pem’, that will automatically be downloaded to your computer.
5. The following terminal command will change the permissions of your Key Pair file so that only you can read it (you may want to move this file from the default download folder to somewhere more appropriate).


```
$ chmod 400 myASWEC2.pem
```

6. On the dashboard, click Launch Instance.

This will open a wizard to help you get an instance running on which you can install your Calculator. You will need to search for an instance type. Search for ‘Ubuntu 12.04’ in the AWS Marketplace tab, and select an instance of the following type: ‘Ubuntu Server 12.04 LTS’ Select launch. You will be prompted to select a Key Pair. Choose the one you just created (myAWSEC2)

You will be prompted to choose an instance size, allowing you to pick the specifications (CPU/RAM etc) you would like. The UK Calculator uses a c1.medium instance (this costs \$0.13 per hour).

Having completed these steps, your instance should now be running and ready to access. Clicking on the ‘Instances’ link in the left hand menu should show a list of all running instances. There should just be one instance, with the ‘Instance State’ showing ‘running’.

7. Connect to your instance using SSH

SSH (Secure Shell) is a network protocol that allows you to access the command line of other computers, i.e. your AWS instance .

Your Mac or Linux computer most likely includes an SSH client by default. You can check for an SSH client by typing ssh at the command line. If your computer doesn’t recognize the command, the OpenSSH project provides a free implementation of the full suite of SSH tools. For more information, see [ht- tp://www.openssh.org](http://www.openssh.org).

Open a terminal on your local computer and enter the following command:
`ssh -i /path/key_pair.pem ubuntu@public_dns_name`

you will need to edit the path/file name to the Key Pair that you created above, and the public_dns_name to that displayed in the ‘Instances’ section of the AWS Console. The actual command should end up looking something like this:

```
ssh -i /etc/ssl/certs/myAWSEC2.pem ubuntu@ec2-54-74-14-220.eu-west-1.compute.amazonaws.com
```

If successful the terminal prompt should change to something like
ubuntu@ip-10-32-37-22:~

8. Set-up the Calculator on your instance

from this terminal it is now possible download and run the Ubuntu set-up script to set up your Calculator, using the commands below:

```
wget https://raw.githubusercontent.com/decc/twenty-fifty/master/util/setup-ubuntu-12.04.sh
```

```
bash setup-ubuntu-12.04.sh
```

During the set-up you will be prompted to enter the URL of your Calculators Git repository. This is available from your GitHub repository page, labelled ‘HTTPS clone URL’.

The script will also ask ‘Would you like to set up the nginx web server to run this? Not needed for development, just when you want to run a live version for the world (Y/N)’

As we are setting up the public version, enter ‘Y’.

If the message “The code should now be available on this computer” appears, the script has worked successfully.

9. Recompile the C model

Next run the ‘bundle’ command from the top twenty-fifty directory, which installs all of the required dependencies. When the bundle is complete navigate to the model directory (cd model/) and re-compile the C code (ruby compile_c_version_of_excel.rb).

10. Edit the Nginx configuration files

You may need to edit line 4 of the following files:

```
/etc/nginx/sites-available/2050.conf /etc/nginx/sites-enabled/2050.conf
```

so that they look like this:

```
root /home/ubuntu/twenty-fifty/public;
```

Now restart the nginx server (sudo service nginx restart).

11. Editing Security Groups

Edit the ‘security groups’ of your instance before the public can gain access to your Calculator

- Click on the security groups item in the EC2 Console left-hand menu.
- Select your instance
- click on the edit button
- alter the settings to match the image below

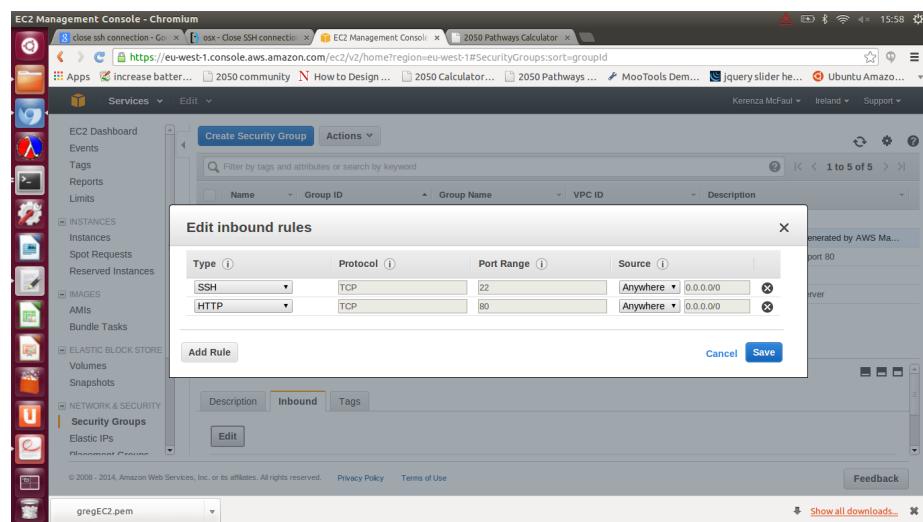


Figure 19: Security groups settings

12. Open the Calculator in your browser, using the ‘public DNS’ of your instance as a URL (e.g: ec2-54-74-14-220.eu-west-1.compute.amazonaws.com)
For a snappier URL, you will have to purchase a domain and map the IP to your new URL.

Trouble shooting:

The following file /etc/nginx/nginx.conf shows the location of the ‘enabled’ site, see line 4:

```
/home/ubuntu/twenty-fifty/public
```

This needs to be reflected in the /etc/nginx/sites-enabled/2050.conf file - it might be necessary to edit the file path shown below to match the file path above, i.e:

/home/ubuntu/twenty-fifty/public

Todo

- Sector-by-sector breakdown, covering important/difficult aspects of each.
Include something about energy balancing.

Adding in costs:

Where to get data

How to work costs into spreadsheet

Adding other sectors:

Land use – South Africa

Air quality

Waste

Geosequestration

Energy security – India

More possibilities – water and biodiversity