HM Government

2050 Pathways Analysis

Response to the Call for Evidence
March 2011

Part 1

Contents

Summary

Introduction

Climate change is a major threat to our future. The UK has a commitment to reduce its greenhouse gas emissions by at least 80% by 2050 relative to 1990 levels.[1] Carbon budgets have been set down in law to make sure the UK stays on track. We will need to achieve these emissions reductions while at the same time safeguarding energy security – so that supply meets demand and the lights stay on – and ensuring that the UK is able to seize the economic opportunities presented by global decarbonisation.

In July 2010, the Government published its 2050 Pathways Analysis work.[2] This analysis presents a framework through which to explore a range of potential pathways from today to 2050. It allows us to consider some of the choices and trade-offs that we will have to make in achieving our long-term greenhouse gas emissions reduction target and ensuring the UK's energy needs are met.

Given the uncertainties when considering investment over a very long timeframe, a scenario approach has been used in the 2050 Pathways work to illustrate potential outcomes under alternative assumptions. For each sector a range of four different future trajectories were developed, and these aim to reflect the whole range of potential futures that might be experienced in that sector. The trajectories are defined by factors such as the lead time and build rate of new infrastructure, improvements and changes in technology, levels of behavioural and lifestyle change, changes in fuel choices, and structural changes such as the shape of industry. For more detail on the analytical approach adopted and the findings, please consult the July 2010 publication on the DECC website.[3]

Unlike some other approaches, this 2050 Pathways analysis does not identify the least costly way of meeting the 2050 target. The aim instead is to look at what might be physically and technically possible in each sector over the next 40 years under different assumptions. A number of criteria would be important in understanding which of the potential pathways to 2050 is most desirable and most deliverable, for example: costs, public acceptability, wider environmental impacts, practical deliverability, international dependencies and business investment behaviour.

1 This is an 80% reduction in greenhouse gas emissions from the '1990 baseline' (as defined in the Climate Change Act, which means 1990 for carbon dioxide, methane and nitrous oxide and 1995 for hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride). For illustrative purposes, emissions from international aviation and shipping have been included in this 2050 pathways analysis. However, only domestic transport is currently included in the UK's carbon budgets, because there is no internationally agreed framework for allocating international aviation and shipping emissions to nations. Under the Climate Change Act 2008, the Government must either include these emissions in carbon budgets by the end of 2012 or report to Parliament on why they have not been included.

2 http://decc.gov.uk/2050

3 ibid

The Call for Evidence

The 2050 Pathways Analysis was developed with expert stakeholders. The trajectories have been put together with input from a large number of experts in business, NGOs, technical fields, and academia, through workshops and other discussions. Several hundred stakeholders were involved in the analysis and about 100 of those experts took part in detailed discussions about the trajectories.

The 2050 Pathways Analysis was published as a Call for Evidence, running from 27th July to 5th October 2010. The questions on which evidence was sought are set out in Annex A. We published the analysis as a Call for Evidence in order to test with a wider range of experts and stakeholders whether the assumptions and data underpinning the model were considered to be sound and based on the best available evidence. Our aim was to test that the 2050 Calculator was robust before we used the analysis more widely in engaging the public.

The response we received to the Call for Evidence was very positive. The overwhelming opinion was that the 2050 Pathways Analysis was a valuable tool and a useful contribution to the debate about our energy future. The transparency of the approach, in particular, was widely welcomed. The responses indicated that the 2050 Calculator was largely considered to be fully comprehensive, accurate and fit for purpose.

We are very grateful to all the respondents who took part in the Call for Evidence. We held discussions with over 350 stakeholders during the Call for Evidence period as part of our series of "2050 Pathways Surgeries" and at other meetings. We received 116 responses in all, very many of which were detailed and offered useful evidence and references. A list of all those who submitted evidence is attached at Annex B. The responses received have been published online at: www.decc.gov.uk/en/content/cms/consultations/2050pathways/2050pathways.aspx.

Our response to the Call for Evidence

Since the Call for Evidence period closed, Government has carefully examined the suggestions received, and we have revised aspects of the 2050 Calculator accordingly. This report sets out how we have revised the model, and the evidence and assumptions that underlie the changes we have made (see Part 2A). There are some areas where we are not persuaded of the need to amend the 2050 Calculator; this report sets out why we came to that conclusion (see Part 2B). Finally, there are some aspects of the 2050 Calculator which will need to be kept under review as the level of knowledge or evidence develops. These too are indicated in the report (see Part 1C).

However, having taken on board the revisions set out below, we are confident that we have sufficient consensus about the rigour and accuracy of the 2050 Pathways Analysis to take it to a wider audience.

Structure of this report

There are five main sections to this report:

- **Part 1A** sets out a series of illustrative pathways to 2050, based on the updated 2050 Calculator
- **Part 1B** explains how we would like to engage stakeholders and the public in discussing the merits of different pathways to 2050
- **Part 1C** sets out our plans for future work on the 2050 Calculator
- **Part 2A** sets out the changes made to the Calculator since the July 2010 publication. This section sets out the new assumptions in a comparable level of detail to that in the July report – please cross refer to the original report as required at: http://decc.gov.uk/2050
- **Part 2B** sets out some of the other suggestions received during the Call for Evidence and explains why these changes have not been made to the 2050 Calculator.

1A. Illustrative pathways

In the July 2010 report we set out six purely illustrative pathways, which described different potential directions of travel to 2050. Each of the pathways achieved the 80% emissions reduction target while ensuring that energy supply met demand. Pathway Alpha illustrated a pathway which spread effort across all sectors. Pathways Beta to Zeta looked at what could happen if a key technology or lever was unavailable, exploring in turn the challenges of losing: carbon capture and storage technology, new nuclear plant, new renewables capacity, bioenergy production and behaviour change. None of these pathways were necessarily desirable ways to achieve our long-term goals: the pathways did not represent policy decisions or government projections, but they did serve to map several corners of the set of possible pathways to 2050.

Having used the Call for Evidence to gain greater consensus about the value of the 2050 Calculator and the robustness of the input assumptions, we now hope to move this discussion about pathways forwards. In this report, we present an updated Pathway Alpha, to enable us to explain the updates that we have made to the model and the impact that these changes could have on a pathway. We also present a series of pathways that introduce some of the major choices and trade-offs that arise in discussions about the potential merits of different pathways to 2050. For example, how far might the UK reduce its demand for energy? How much bioenergy might the UK attempt to source, and in which sectors could it be used? How far might the UK attempt to electrify demand for energy, and in which sectors? How might we generate the electricity required? What is the future role for gas? The pathways illustrating these choices and trade-offs are set out in Part 1A.

1B. Engagement about pathway preferences

The illustrative pathways presented in the previous section (Part 1A) are an effort to highlight some of the key themes emerging from the 2050 analysis.

We believe the 2050 Pathways tools can be useful in helping to raise public awareness and understanding of the energy and climate change challenge; in stimulating an energy-literate debate about the options available to the UK over the next forty years as we transition to a low-carbon economy; and in facilitating public and stakeholder feedback about the relative merits of different pathways to 2050.

We strongly encourage readers to come up with their own pathway, and see whether it is possible to create a world in which you would be happy to live in forty years time. In Part 1B we describe the means we have set out for stakeholders and the public to engage in a dialogue about these important issues.

1C. Future work

This publication does not mark the end of the 2050 analysis. The Government is committed to further developing the 2050 Pathways Analysis in three ways:

Continuing to improve the analytical credibility of the 2050 Calculator

We plan to update the 2050 Calculator on a regular basis to take account of the latest evidence about what is physically and technically possible in each sector. Our next update to the Calculator, planned for summer 2011, will begin to integrate an analysis of the costs and some of the environmental impacts associated with choices in the 2050 Calculator.

We have begun the process of developing cost estimates for integration into the 2050 Calculator. Future costs will be uncertain, so we propose to provide cost *ranges*, rather than absolute figures. Where there is good data, we will make assessments of capital expenditure, operating expenditure and fuel costs, giving high and low scenarios for each. The initial work will help illuminate some of the key trade-offs in cost-effectiveness for both energy supply and demand.

Further public engagement using the 2050 Pathways Analysis

We set out in Section 1B our plans for engaging the public in the dialogue about the choices and trade-offs the UK faces as we transition to a low-carbon economy.

Using the 2050 analysis to support policy development

We will continue to develop our understanding of plausible pathways to 2050. This will be based on the further sources of analysis set out above (including the costs analysis) and the input from the public engagement opportunities we have outlined, as well as input from other sources and models.

We have set out the features that are common to successful pathways to 2050 in Part 1A of this report. We will continue to explore and test these common messages and ensure that these are fed in to development of policy within Government.

The analysis of pathways to 2050 is one source of evidence with which to explore the trade-offs that Government will need to consider, for example when setting the level of the fourth carbon budget.

2A. Summary of the updates to the 2050 Calculator

The 2050 Pathways Analysis report published in July 2010 was structured in two parts. The first part dealt with the methodology and the findings; the second set out, for each sector of the model, the detailed assumptions underpinning the trajectories in the 2050 Calculator. It was on the detail of these trajectories in Part 2, that the Call for Evidence focused.

To remind the reader, the 2050 Calculator sets out, for most sectors, four levels of change. These are defined as:

- **Level 1**: assumes **little or no attempt** to decarbonise or only short term efforts; and that unproven low carbon technologies are not developed or deployed.
- **Level 2**: describes what might be achieved by applying a level of effort that is likely to be viewed as **ambitious** but reasonable by most or all experts. For some sectors this would be similar to change expected with the successful implementation of the programmes or projects currently in progress.
- **Level 3**: describes what might be achieved by applying a **very ambitious** level of effort that is unlikely to happen without significant change from the current system; it assumes significant technological breakthroughs.
- **Level 4**: describes a **heroic** level of change that could be achieved with effort at the extreme upper end of what is thought to be physically plausible by the most optimistic credible observer. This level pushes towards the physical or technical limits of what can be achieved.

Changes to the inputs to the 2050 Calculator

As a result of the large number of high quality submissions we received during the Call for Evidence, we have made a number of revisions to the assumptions in the 2050 model.

Part 2A of the report provides detailed information on the amendments to the model. Where the assumptions and context remain the same as the July 2010 report we have not repeated the information here, and this report should be read alongside Part 2 of the July report.[4] We intend to merge the updates with the text of the original report, thereby providing one document with all the relevant assumptions as contained in the latest 2050 model.

Part 2A goes through the energy and emissions sectors in detail. In summary, the key changes we have made mean:

- We have four new sector choices in the 2050 Calculator offering users of the Calculator additional choices about the options for reaching the UK's long-term aims. These are:
  - a choice of fuels used in carbon capture and storage power plants (CCS plants) – the first version of the Calculator made a simplifying assumption that CCS could be fitted only to solid fuel power plants (coal or biomass), in this updated version we have allowed for CCS fitted to gas as well;
  - a disaggregation of the industry sector into two levers, one showing the size of the industrial sector in the UK, the other its emissions intensity;
  - a breakdown of the land-use and agriculture sector into two levers, one showing land-use management, the other showing livestock management;
  - a new biomass power plant option.
- We have added three additional scenarios for international shipping emissions. These illustrate the impact of alternative levels of shipping activity, although international shipping emissions are not currently included in the UK's 2050 emissions reduction target. These scenarios are place-holders at this stage and the aim is to refine them as more evidence becomes available.
- We have amended some of the boundaries of the choices, for example by updating the 'Level 4 trajectory' where appropriate; and by updating some of the fixed assumptions in existing trajectories. For example, the offshore wind Level 4 now reflects a higher capacity than the previous version of the Calculator; and some of the assumptions around bioenergy yields and conversion processes have been revised.
- We have updated the 5-day 'stress test' which checks whether the electicity grid can be balanced. This now better reflects empirical evidence. We have also added a 1-day stress test. These tests explore whether pathways would cope with extra demands for electricity in certain weather conditions.

The above is a summary of some of the bigger changes, and the full suite of amendments is set out in Part 2A. As well as making changes to the 2050 Calculator Excel model, we have also made improvements to the 2050 web tool and launched the new My2050 simulation.[5]

4 http://decc.gov.uk/2050

5 http://decc.gov.uk/my2050

Changes to the outputs of the 2050 Calculator

In terms of outputs, the changes we have made to the Calculator affect three key areas: gas, biomass and electricity grid balancing.

The addition of a gas CCS option indicates that gas could play a significant role in our energy mix to 2050, as emissions associated with the fuel can be more effectively abated. For example, Pathway 15 meets our 2050 emissions targets with 52 bcm of gas use in 2050 (compared to 88 bcm now). Given the expected decline in North Sea gas production, such an outcome would involve more than tripling our current gas import needs.

The changes to the biomass conversion rates have a small but important impact on the amount of energy that can be produced from domestic biomass sources. Because we have revised down the efficiencies associated with converting raw biomass to liquid and gaseous fuels, conversion to solid usable form becomes increasingly appealing. This is explored in more detail in illustrative pathways 8, 9, and 10.

Finally, the new and more stringent electricity grid balancing test means that successful pathways which may previously have met the target without requiring a source of backup electricity generation are now required to consider the implications of much more difficult weather conditions. The effect of this, particularly on pathways with a high dependence on renewable generation, is explored in illustrative pathways 1, 11 and 12.

The common messages identified in the July report hold true with these revisions.

2B. Where the existing analysis is robust and changes have not been made

Whilst changes have been made to the model to reflect some of the most pressing and well-evidenced revisions suggested during the Call for Evidence, there were some suggestions that we received which we have not reflected in the model. In Part 2B we summarise some of these suggestions and explain why we have not felt it appropriate to revise the model to accommodate them.

The original 2050 Calculator was put together using a large amount of evidence and analysis, as well as detailed engagement with a large number of expert stakeholders from academia, industry, and the third sector. For much of the model, we remain confident in the analysis presented in July 2010. We set out in Part 2B our response to some of the major themes in the evidence received.

Part 1A: Illustrative pathways to 2050

There are many pathways which would meet the 80% emissions reduction target and ensure energy supply meets energy demand. The July 2010 Pathways Analysis report presented six illustrative pathways showing different potential directions of travel: Pathways Alpha to Zeta.[6] These were designed to show how the Calculator could be used to explore options.

Pathway Alpha demonstrated a pathway where effort had been spread across many different sectors. The other five illustrative pathways explored what the implications might be if a key lever were unavailable. Pathway Beta explored one way to meet the target if CCS were unavailable, Pathway Gamma if no new nuclear was available, Pathway Delta if few renewables were built, Pathway Epsilon if bioenergy were constrained, and Pathway Zeta if behaviour change failed to manifest.

The illustrative pathways presented in the July 2010 report identified some common elements of successful pathways to 2050, and drew out some of the implications and uncertainties associated with different choices.[7] In summary, the common messages from that analysis were:

- Ambitious per capita energy demand reduction is needed
- A substantial level of electrification of heating, transport and industry is needed
- Electricity supply needs to be decarbonised, while supply may need to double
- A growing level of variable renewable generation increases the challenge of balancing the electricity grid
- Sustainable bioenergy is a vital part of a low carbon energy system
- Reduction in emissions from agriculture, waste, industrial processes and international transport will be necessary by 2050
- There will be an ongoing need for fossil fuels in our energy mix, although their precise long term role will depend on a range of issues such as the development of carbon capture and storage.

In this report, we update Pathway Alpha to illustrate how the changes we have made to the assumptions in the 2050 Calculator impact on the pathways. Pathway 1 is an updated Pathway Alpha.

In this report we also seek to bring out the different choices and trade-offs the UK will face through a selection of alternative pathways. These pathways consider a broader set of issues than the previous illustrative pathways, including pushing as far as possible in certain sectors to show some of the potential consequences of different routes. It might be expected that the trade-offs associated with a pathway containing Level 4 ambition across sectors would be particularly difficult.

6 HM Government (2010) *2050 Pathways Analysis*, pages 15–43

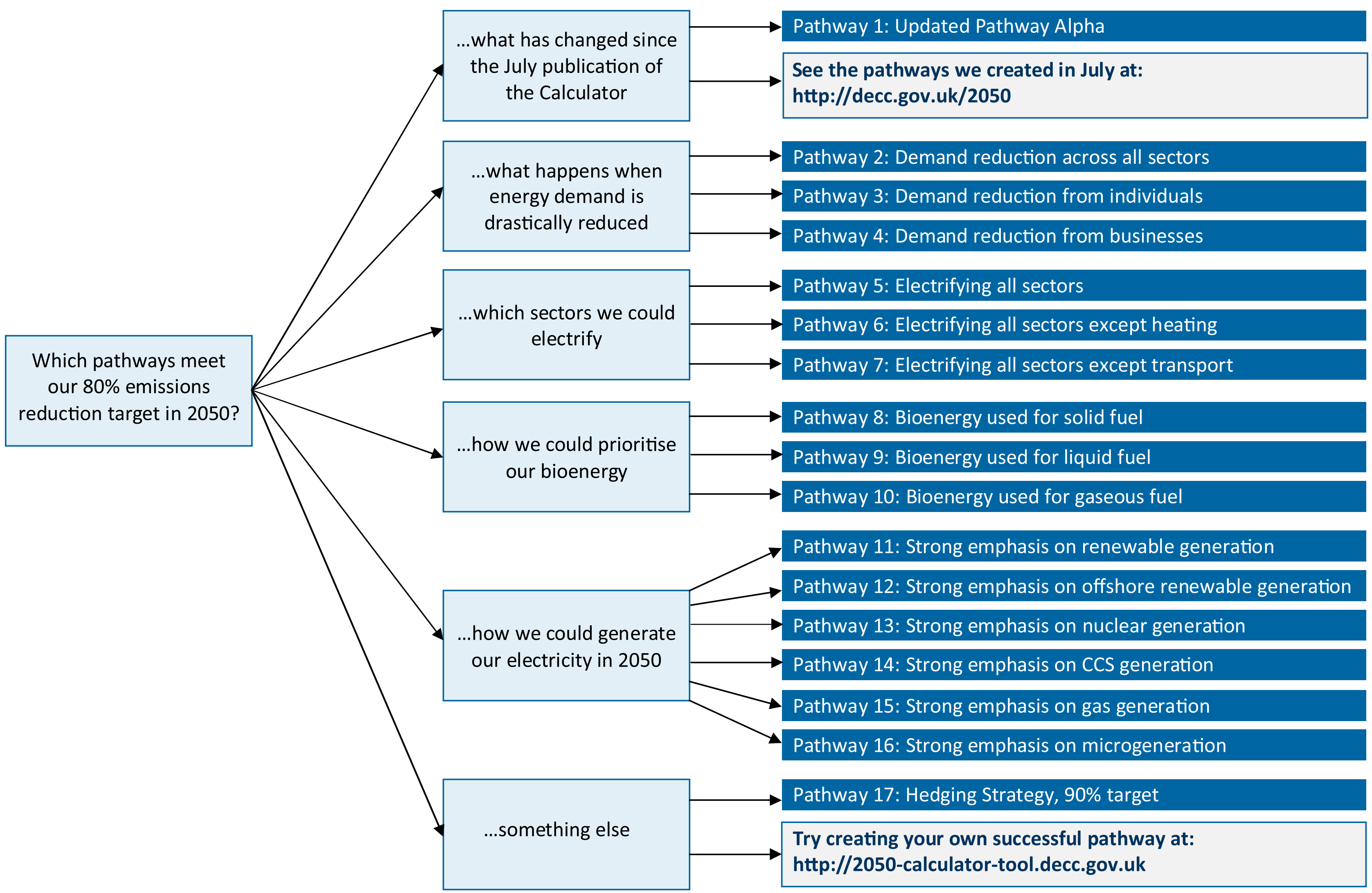
7 Ibid, page 34

As in the July 2010 report, **none of these illustrative pathways represents a preferred option or a lead scenario, and none represents Government policy**. It should also be noted that as the Calculator does not yet provide information about the costs of different choices, we are not able to say which of the many possible pathways would be expected to be most cost-effective.

And as in the July publication, although international aviation and shipping emissions are not currently included in the UK's 2050 target, they have both been incorporated into the 2050 Calculator to enable emissions from all sectors to be considered. The illustrative pathways therefore include these sectors. All of the illustrative pathways presented here would meet the UK's 2020 emissions reduction target on the route to 2050.

For each of the illustrative pathways below we provide a screenshot of the 2050 web tool, to give a summary of the energy demand and supply charts and the emissions chart. The web links provided take the online reader to the web tool itself for a clearer picture. All of these new illustrative pathways, and all the underpinning data assumptions are also included in the Excel version of the Calculator which is downloadable from http://decc.gov.uk/2050. We encourage you to test out these pathways further, and to explore your own preferred pathways to reaching the 2050 target.

Pathways Map

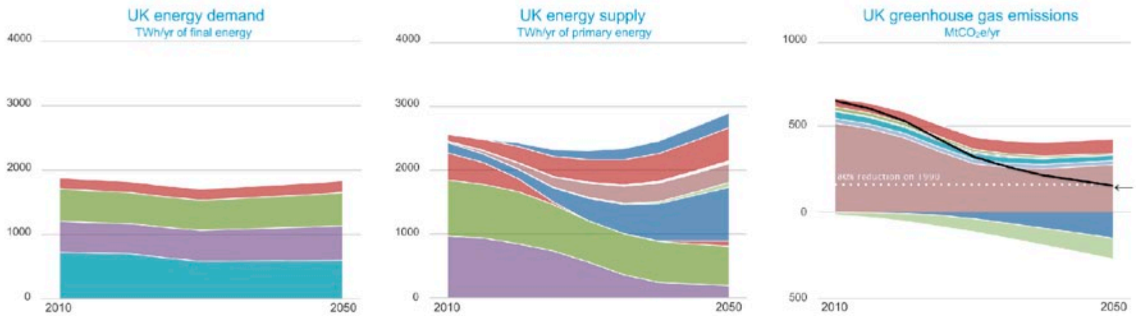


Pathway 1: Updating Pathway Alpha

Focus

Pathway Alpha was set out in the July report as a pathway which spread effort across many sectors and avoided extreme levels of ambition in any one area. A balanced approach is not necessarily the most cost-effective or desirable route to achieving the 2050 target, but it is useful to see how it is possible to reach an 80% emissions reduction target without having to stretch to the maximum physical ambition in any one sector.

See this pathway in the online web tool at www.decc.gov.uk/2050pathways/1 [8]



Demand

transport	Domestic transport behaviour	1	2	3	4
	Domestic transport electrification	1	2	3	4
	Domestic freight	1	2	3	4
	International aviation	1	2	3	4
	International shipping	A	B	C	D
households	Average temperature of homes	1	2	3	4
	Home insulation	1	2	3	4
	Home heating electrification	A	B	C	D
	Home heating that isn't electric	A	B	C	D
	Home lighting and appliances	1	2	3	4
	Electrification of home cooking	A	B		
industry	Growth in industry	A	B	C	
	Energy intensity of industry	1	2	3	
	Commercial demand for heating and cooling	1	2	3	4
	Commercial heating electrification	A	B	C	D
	Commercial heating that isn't electric	A	B	C	D
	Commercial lighting & appliances	1	2	3	4
	Electrification of commercial cooking	A	B		

In 2050, 53% of primary energy would be imported.

Supply

	Nuclear power stations	1	2	3	4
	CCS power stations	1	2	3	4
	CCS power station fuel mix	A	B	C	D
electricity generation	Offshore wind	1	2	3	4
	Onshore wind	1	2	3	4
	Tidal and wave	1	2	3	4
	Biomass power stations	1	2	3	4
	Solar panels for electricity	1	2	3	4
	Solar panels for hot water	1	2	3	4
	Geothermal electricity	1	2	3	4
	Hydroelectric power stations	1	2	3	4
	Small-scale wind	1	2	3	4
	Electricity imports	1	2	3	4
bioenergy	Land dedicated to bioenergy	1	2	3	4
	Livestock and their management	1	2	3	4
	Volume of waste and recycling	A	B	C	
	Marine algae	1	2	3	4
	Type of fuels from biomass	A	B	C	D
	Bioenergy imports	1	2	3	4

Other

Geosequestration	1	2	3	4
Storage, demand shifting & interconnection	1	2	3	4

Impact

There is little shift from Pathway Alpha in the July 2010 Calculator to the new 'Pathway 1'. The updated pathway still reaches the 80% target, albeit with a very small increase in total emissions. Three differences between Pathway Alpha and this updated version are responsible for this variation.

8 For the key to the pathway charts, please see Annex D.

The most important difference lies not in emissions, but in making sure that the lights stay on all the time. The new Calculator has adopted a more stringent balancing test than the July version, to better check for the possibility of difficult weather conditions. Pathway Alpha required an extra 2 GW of standby electricity generation capacity in 2050, to make up the shortfall in electricity generation. Under the updated conditions, this pathway's requirement is 4 GW of standby capacity in 2020, 26 GW in 2030 and 35 GW by 2050 – a significant increase. This stand-by capacity could be reduced somewhat by increasing the level of effort in the 'storage, demand and interconnection' sector which offer other solutions to smoothing the supply and demand of electricity. Balancing is discussed in more detail in Section 2A.C.

Emissions from electricity generation drop slightly between Pathway Alpha and Pathway 1. This is because of updates to the treatment of carbon capture and storage (CCS) in the Calculator. The new version allows users to make a choice in the fuel mix of CCS, and the fuel mix used here is a two-thirds solid fuel (coal and biomass), one-third gaseous fuel (natural gas and biogas), which produces slightly lower emissions than the 'all solid' fuel mix assumed previously. These changes are discussed in detail in Section 2A.B. The amount of bioenergy substituted for fossil fuels is reduced slightly in the new Pathway 1. This is due to changes in the conversion rates of raw biomass to usable fuel, and the lowering of yields from second generation energy crops. These numbers have been updated in light of new evidence, which is discussed in more detail in Section 2A.D.

We will use Pathway 1 as a point of comparison for other pathways in this section.

- **As most of the revisions to the analytical inputs to the Calculator are at the margins, Pathway 1 produces very similar results to July's Pathway Alpha in terms of emissions.**
- **The more stringent balancing test has profound implications for the system.**

New pathways

There are four main methods of decarbonisation available:

- **Energy demand reduction** – Ambitious per capita energy demand reduction is needed. The greater the constraints on low carbon energy supply, the greater the reduction in demand will need to be.
- **Electrification** – A substantial level of electrification of heating, transport and industry is needed.
- **Use of bioenergy** – Bioenergy is particularly important for areas which are hard to electrify, like high-heat industrial processes or aviation.
- **Low carbon electricity generation** – Electricity supply needs to be decarbonised, choosing from the range of available technologies and taking into consideration the need to balance the electricity grid.

The following set of illustrative pathways examines the implications of making major efforts in these four areas to see what impact they have on other energy system choices we would need to take.

Pathways 2–4: Reducing demand for energy

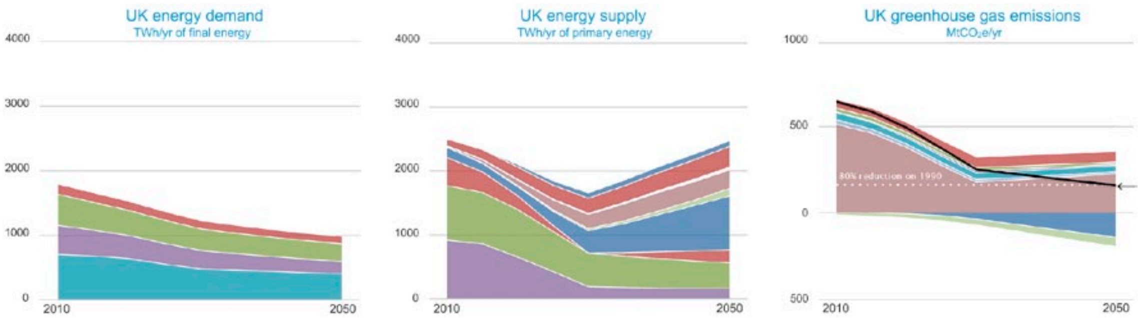
One major conclusion of the 2050 analysis in July 2010 was that decarbonising energy supply alone is not sufficient to meet our target – big changes in the type of fuel used and reductions in energy demand are also likely to be needed. Reductions in demand could be achieved across many different sectors, and varying levels of effort can be placed on changes individuals make (e.g. in their homes or how they travel), and what businesses do (e.g. in moving freight from road to rail or electrifying some industrial processes).

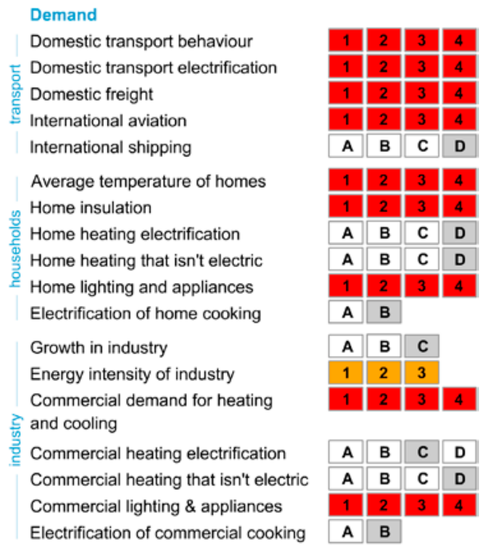
Pathways 2-4 show how the demand-side levers could be pushed, reducing the need to increase our electricity and bioenergy supply. To see more clearly what impact the distribution of efforts may have, and to see what must develop elsewhere to cover the gap, they look particularly at the effects of:

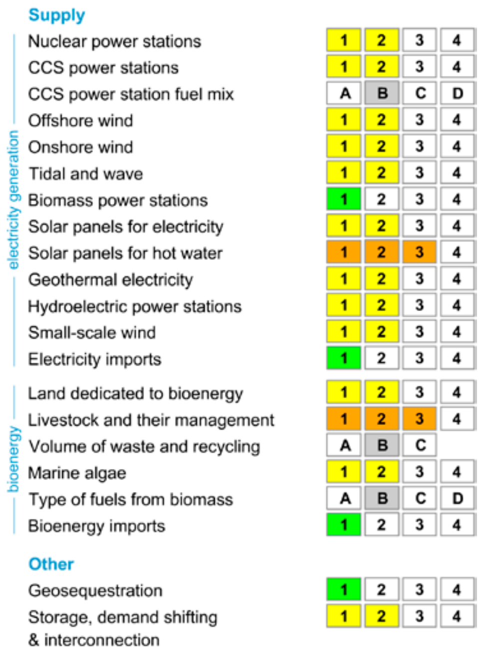
- strong effort in demand reduction across all sectors (Pathway 2),
- demand reductions by individuals alone (Pathway 3),
- demand reductions by businesses and industry alone (Pathway 4).

Pathway 2 – Energy demand reduction across all sectors

See this pathway in the online web tool at www.decc.gov.uk/2050pathways/2







In 2050, 65% of primary energy would be imported.

Focus

This pathway maximises efforts to reduce energy demand across all sectors and through both lifestyle change and technology change. This would mean that by 2050 for example: that mean home temperature would fall to 16 degrees - what it was in 1990; all possible efficiency improvements to existing homes would be made, with 24 million homes being insulated, and all new homes built to PassivHaus standards[9]; efficiency improvements would mean that energy demand for lights and appliances decreased by 60%; people would only travel as far as they do today by 2050, bucking historical trends for growth; there would be a significant switch from car travel to public transport and a tripling in bus use; industry energy efficiency would improve by 40% and almost half of industry emissions would be captured by CCS. This pathway would also include very strong electrification of heating, transport and appliances.

9 PassivHaus is a domestic thermal efficiency standard developed in Europe and representing close to the limit of what is physically possible in terms of energy demand reduction for heating.

Impact

This pathway shows that making efforts to reduce our energy demand is only one half of the picture: even if we were to maximise efforts on the Calculator's full range of demand side options, we would still fall 15% short of meeting our 80% emissions target if we were to make no effort to also decarbonise the energy supply side.

In Pathway 2, total annual energy demand falls to around a half of 2007 levels (from 1,889 TWh to 977 TWh), though electricity demand increases slightly as we change our heating systems and electrify some of our transport. This is the same as saying that per capita energy demand actually reduces by almost 60% – meaning we would use only 35 kWh per person per day.

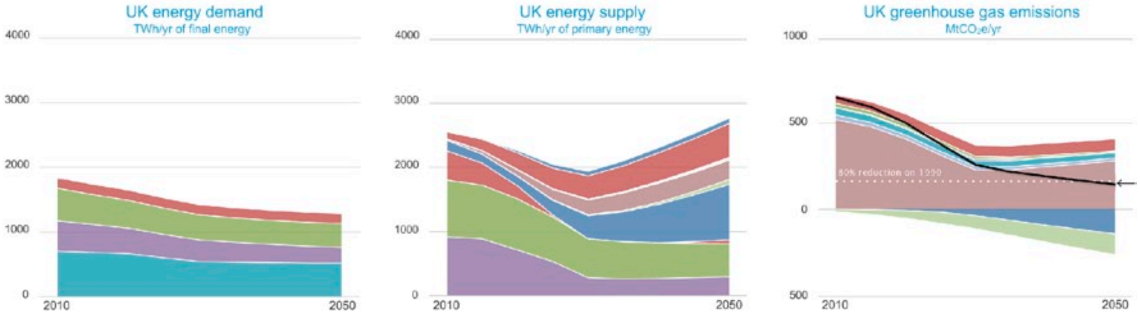
Making the pathway successful

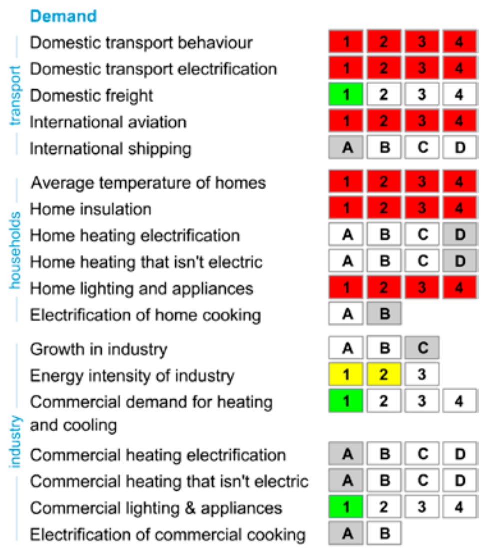
If we step up efforts across all demand side levers strongly whilst making Pathway 1 type changes on the energy supply side, we would comfortably over-deliver on the 2050 target. This allows us to reduce efforts on electricity generation and bioenergy production relative to Pathway 1; the screenshot above shows a reduced effort on bioenergy production.

This scenario would present some significant balancing challenges in the medium term, with a back up plant capacity of 37 GW needed in 2030 (around the size of our current gas power station fleet). However, as demand reductions take hold, this requirement is gone by 2050.

Pathway 3 – Energy demand reduction efforts from individuals

See this pathway in the online web tool at www.decc.gov.uk/2050pathways/3





In 2050, 67% of primary energy would be imported.

Focus

Pathway 3 examines the effects of focusing our demand reduction efforts just on individuals, rather than industry and business. That would mean making heroic efforts to improve home insulation and heating efficiency; travelling no more than we currently do. It would also include strong electrification of home heating and transport.

Impact

On their own, these actions would not be enough to get us to our target, even if electricity generation had been largely decarbonised. This is because these efforts would miss out on having an effect on some key emitters – particularly industry and freight transport.

Making the pathway successful

This pathway has tackled the remaining emissions by increasing effort on industrial emissions intensity – see the screenshot above. Total annual energy demand falls from 1,889 TWh in 2007 to 1,279 TWh in 2050 in this pathway – almost a third.

Pathway 4 – Energy demand reduction efforts from businesses

See this pathway in the online web tool at www.decc.gov.uk/2050pathways/4

Focus

It is worth examining whether it is more realistic to attain the target through the actions of business and industry than it is for individuals and consumers. In this pathway, extremely ambitious efforts are made towards reducing industry energy intensity, improving the efficiency and electrification of commercial heating, lighting and appliances, and reducing emissions from UK freight transport. This would mean that industry CCS is rolled-out quickly so that by 2050, 48% of emissions in the metals, minerals and chemical industries are captured; there would be a significant shift toward electrification of industry from 2025, meaning a much reduced dependence on gas; and energy intensity would reduce in the different industrial sectors (e.g. chemicals 50% lower, metals and minerals 30% lower, and wider industry 43% lower by 2030). It is also assumed that the industrial sector follows a low output trajectory, declining relative to current output.

Impact

Despite these efforts, commercial sector demand reduction alone is insufficient. The transport sector is an important element to this because individual demand accounts for a significant proportion of emissions. But the key difference from Pathway 3 is that heating becomes an increasingly considerable contributor to the emissions total. With domestic demand increasing unchecked, heating emissions would actually increase by 17% on 2007 levels.

Making the pathway successful

To address these problems, one solution is to step up the electrification of residential heating demand – see the screenshot above.

Oil imports are high under this scenario: by 2050 required net import levels hit 478 TWh per year to meet the demands of domestic transport. For comparison, in 2009 our net imports were 89 TWh of crude oil.[10] For more information about imports, see Annex C.

- **Ambitious per capita demand reduction is an essential part of a successful pathway to 2050.**
- **These reductions need to be made across the economy – efforts from just individuals or just businesses will not be sufficient as some significant emissions sources would be left unaddressed.**

Pathways 5–7: Electrifying energy demand

Decarbonising the electricity supply is a crucial step towards 2050, but it will only have the impact necessary if changes are made to the way we use energy, to allow greater electrification. Many of the demand sectors in the Calculator could switch fuels and be run using electricity rather than their current fossil fuel input. Road and rail transport, heating, industry and appliances are all potentially open to electrification.

One advantage of electrification is that in some sectors it can provide an alternative to bioenergy and fossil fuels. This is important, because as we will see in later pathways, bioenergy is a constrained resource and there will be strong competition for its use. Pathways 5-7 assess the effect of electrification, showing both what impact electrification has on the wider picture, and whether some sectors are more important to electrify than others:

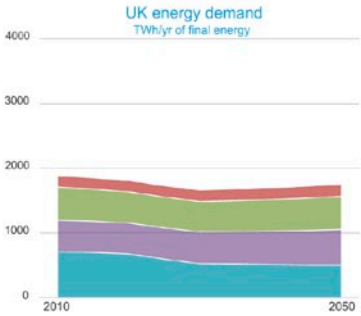
- maximum electrification for all possible sectors (Pathway 5),
- electrification of all sectors except heat (Pathway 6),
- electrification of all sectors except transport (Pathway 7).

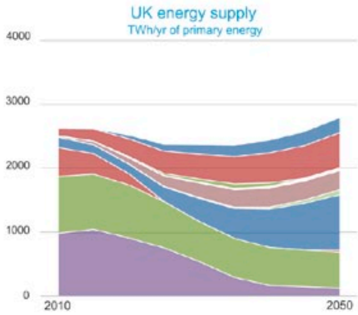
All the pathways involving a high degree of electrification require commensurately high levels of investment in electricity storage and interconnection if they are to keep the balancing challenge to a manageable level.

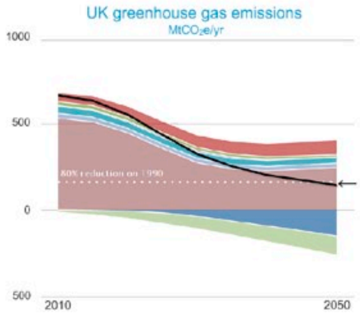
10 In 2009 the UK consumed 822 TWh of crude oil, imported 548 TWh of oil and exported 459 TWh (DUKES).

Pathway 5 – Electrifying all possible sectors

See this pathway in the online web tool at www.decc.gov.uk/2050pathways/5







Demand

transport	Domestic transport behaviour	1	2	3	4
	Domestic transport electrification	1	2	3	4
	Domestic freight	1	2	3	4
	International aviation	1	2	3	4
	International shipping	A	B	C	D
households	Average temperature of homes	1	2	3	4
	Home insulation	1	2	3	4
	Home heating electrification	A	B	C	D
	Home heating that isn't electric	A	B	C	D
	Home lighting and appliances	1	2	3	4
	Electrification of home cooking	A	B		
industry	Growth in industry	A	B	C	
	Energy intensity of industry	1	2	3	
	Commercial demand for heating and cooling	1	2	3	4
	Commercial heating electrification	A	B	C	D
	Commercial heating that isn't electric	A	B	C	D
	Commercial lighting & appliances	1	2	3	4
	Electrification of commercial cooking	A	B		

In 2050, 48% of primary energy would be imported.

Supply

electricity generation	Nuclear power stations	1	2	3	4
	CCS power stations	1	2	3	4
	CCS power station fuel mix	A	B	C	D
	Offshore wind	1	2	3	4
	Onshore wind	1	2	3	4
	Tidal and wave	1	2	3	4
	Biomass power stations	1	2	3	4
	Solar panels for electricity	1	2	3	4
	Solar panels for hot water	1	2	3	4
	Geothermal electricity	1	2	3	4
	Hydroelectric power stations	1	2	3	4
	Small-scale wind	1	2	3	4
	Electricity imports	1	2	3	4
bioenergy	Land dedicated to bioenergy	1	2	3	4
	Livestock and their management	1	2	3	4
	Volume of waste and recycling	A	B	C	
	Marine algae	1	2	3	4
	Type of fuels from biomass	A	B	C	D
	Bioenergy imports	1	2	3	4

Other

Geosequestration	1	2	3	4
Storage, demand shifting & interconnection	1	2	3	4

Focus

This pathway would see electrification across sectors. By 2050, all car and van travel would be electrified and all rail freight would be electrified; 80-100% of home heating would be supplied using electricity, mainly air source heat pumps; energy used for cooking would be entirely electric; and there would be a significant shift toward electrification of industry from around 2025.

Impact

Unsurprisingly, aiming to electrify so much of the UK's energy demand creates a very large increase in electricity demand – more than doubling from current levels by 2050 to nearly 820 TWh per year (from around 350 TWh in 2007).[11] Despite this increase in electricity demand, the screenshot above shows that total energy demand actually falls slightly by 2050, from 1,889 TWh to 1,731 TWh. When all of the electrification levers have been set to the maximum possible level of effort alongside efforts to decarbonise the supply side, we over-achieve against the 2050 target, with emissions reduced by 83% relative to 1990 levels. This means that were we to electrify to the maximum possible extent, we would be left with some flexibility to reduce levels of efforts in other sectors.

Making the pathway successful

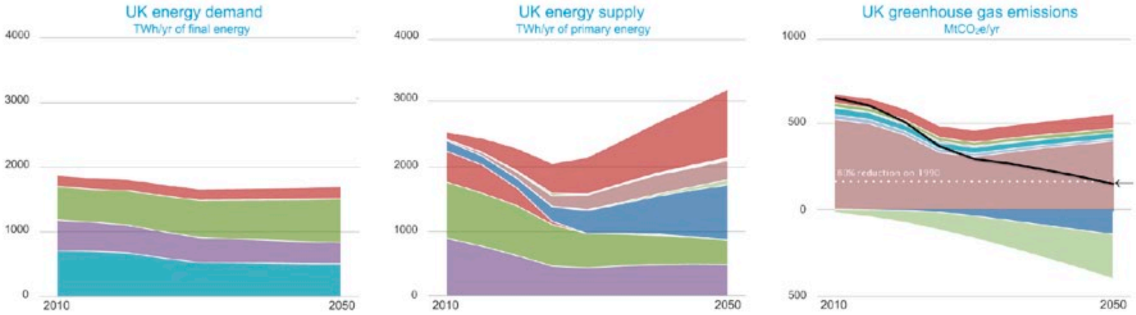
Under this scenario, because so many sectors are powered from electricity, the amount of bioenergy required in the system is reduced. It is therefore possible to lower efforts in bioenergy supply from those we see in Pathway 1, for example by cutting out imports of it altogether. Industry grows on a high output trajectory out to 2050, as shown in the screenshot above.

One final but important point to note on this pathway is the issue of balancing. This pathway would require us to have 20 GW of standby capacity available by 2020, rising to a very significant 55 GW by 2050. To mitigate this, this pathway maximises the possible storage and interconnection options, but even after doing this, 19 GW of backup plant capacity is needed in 2050. This balancing challenge is created by presence of a large amount of intermittent renewable generation – if we were to replace these technologies with generation from nuclear or CCS, this balancing requirement would be lower.

11 Depending on the choice of how electricity is supplied, the total nameplate capacity of electricity generation (measured in giga-watts) may need to more than double to be robust to all weather conditions. In some outer most circumstances, for example if there was very strong electrification of energy demand and a high level of dependence on intermittent electricity generation, then the nameplate capacity of electricity generation could need to triple.

Pathway 6 – Electrifying all possible sectors except heating

See this pathway in the online web tool at www.decc.gov.uk/2050pathways/6



Demand

transport	Domestic transport behaviour	1	2	3	4
transport	Domestic transport electrification	1	2	3	4
transport	Domestic freight	1	2	3	4
transport	International aviation	1	2	3	4
transport	International shipping	A	B	C	D
households	Average temperature of homes	1	2	3	4
households	Home insulation	1	2	3	4
households	Home heating electrification	A	B	C	D
households	Home heating that isn't electric	A	B	C	D
households	Home lighting and appliances	1	2	3	4
households	Electrification of home cooking	A	B		
industry	Growth in industry	A	B	C	
industry	Energy intensity of industry	1	2	3	
industry	Commercial demand for heating and cooling	1	2	3	4
industry	Commercial heating electrification	A	B	C	D
industry	Commercial heating that isn't electric	A	B	C	D
industry	Commercial lighting & appliances	1	2	3	4
industry	Electrification of commercial cooking	A	B		

In 2050, 67% of primary energy would be imported.

Supply

electricity generation	Nuclear power stations	1	2	3	4
electricity generation	CCS power stations	1	2	3	4
electricity generation	CCS power station fuel mix	A	B	C	D
electricity generation	Offshore wind	1	2	3	4
electricity generation	Onshore wind	1	2	3	4
electricity generation	Tidal and wave	1	2	3	4
electricity generation	Biomass power stations	1	2	3	4
electricity generation	Solar panels for electricity	1	2	3	4
electricity generation	Solar panels for hot water	1	2	3	4
electricity generation	Geothermal electricity	1	2	3	4
electricity generation	Hydroelectric power stations	1	2	3	4
electricity generation	Small-scale wind	1	2	3	4
electricity generation	Electricity imports	1	2	3	4
bioenergy	Land dedicated to bioenergy	1	2	3	4
bioenergy	Livestock and their management	1	2	3	4
bioenergy	Volume of waste and recycling	A	B	C	
bioenergy	Marine algae	1	2	3	4
bioenergy	Type of fuels from biomass	A	B	C	D
bioenergy	Bioenergy imports	1	2	3	4

Other

Geosequestration	1	2	3	4
Storage, demand shifting & interconnection	1	2	3	4

Focus

Pathway 6 pushes hard on electrification for everything except heating in homes and businesses.

Impact

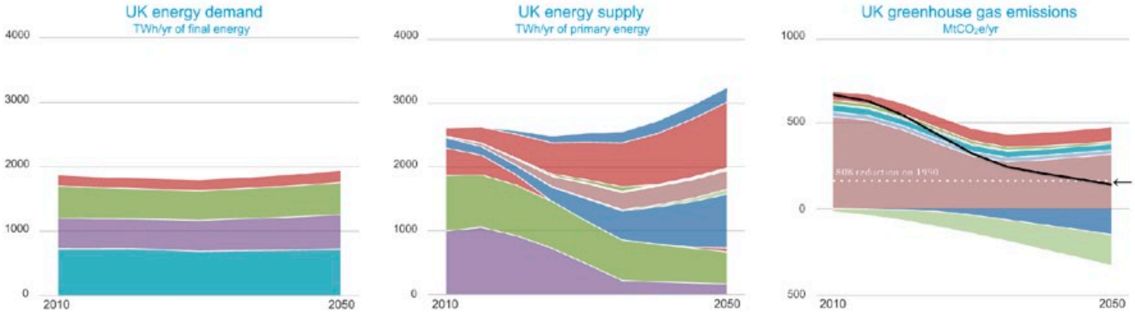
The difference between this pathway and the previous one (where all sectors have been electrified) is significant. Even with efforts made on the supply side and in other demand side sectors, emissions would be cut by just 59% on 1990 levels - a performance a full 22 percentage points poorer than that of electrifying all sectors, almost entirely because of the failure to deal with emissions from heating. The emissions generated from this sector are more than double from 2007 levels (from 84 to 174 $MtCO_2e$), eclipsing transport as the highest emitter in 2050.

Making the pathway successful

Given this shortfall, it is necessary to take further bold measures to close the gap needed to meet the emissions reduction target. The option presented in this pathway, as shown in the screenshot above, is to step up bioenergy imports and UK biocrop production to heroic levels. Industry growth has also been tempered back to the medium output case (compared to the high output scenario chosen in Pathway 1). There are other options for meeting the target, but failing to electrify heating demand by 2050 requires significant extra efforts to be made elsewhere.

Pathway 7 – Electrifying all possible sectors except transport

See this pathway in the online web tool at www.decc.gov.uk/2050pathways/7



Demand

transport	Domestic transport behaviour	1	2	3	4
	Domestic transport electrification	1	2	3	4
	Domestic freight	1	2	3	4
	International aviation	1	2	3	4
	International shipping	A	B	C	D
households	Average temperature of homes	1	2	3	4
	Home insulation	1	2	3	4
	Home heating electrification	A	B	C	D
	Home heating that isn't electric	A	B	C	D
	Home lighting and appliances	1	2	3	4
	Electrification of home cooking	A	B		
industry	Growth in industry	A	B	C	
	Energy intensity of industry	1	2	3	
	Commercial demand for heating and cooling	1	2	3	4
	Commercial heating electrification	A	B	C	D
	Commercial heating that isn't electric	A	B	C	D
	Commercial lighting & appliances	1	2	3	4
	Electrification of commercial cooking	A	B		

In 2050, 50% of primary energy would be imported.

Supply

electricity generation	Nuclear power stations	1	2	3	4
	CCS power stations	1	2	3	4
	CCS power station fuel mix	A	B	C	D
	Offshore wind	1	2	3	4
	Onshore wind	1	2	3	4
	Tidal and wave	1	2	3	4
	Biomass power stations	1	2	3	4
	Solar panels for electricity	1	2	3	4
	Solar panels for hot water	1	2	3	4
	Geothermal electricity	1	2	3	4
	Hydroelectric power stations	1	2	3	4
	Small-scale wind	1	2	3	4
	Electricity imports	1	2	3	4
bioenergy	Land dedicated to bioenergy	1	2	3	4
	Livestock and their management	1	2	3	4
	Volume of waste and recycling	A	B	C	
	Marine algae	1	2	3	4
	Type of fuels from biomass	A	B	C	D
	Bioenergy imports	1	2	3	4

Other

Geosequestration	1	2	3	4
Storage, demand shifting & interconnection	1	2	3	4

Focus

Pathway 7 pushes hard on electrification for everything except transport.

Impact

Decarbonising passenger transport plays a key role in our ability to meet our long term targets. Although failure to electrify transport has a less profound effect than failing to electrify heat, it would still leave us 8% short of reaching the 2050 target, even given a balanced effort on the supply side and heroic efforts to electrify all other suitable sectors.

Making the pathway successful

One solution for meeting this shortfall is to increase the supply of liquid bioenergy, which is then directed to the transport sector. Interestingly, despite the intuitive idea that placing an emphasis on liquid conversion of biofuels would be the most productive way to fix this problem, converting biomass to a balanced mixture of solids, liquids and gases as shown in the screenshot above, turns out to be the most effective of the four options. This is because the emissions credits gained from burning solid biofuel with CCS are another productive route for reaching the target, while biogas also goes some way to decarbonising heating.

- **A substantial level of electrification across the major sectors is needed. Alongside this, electricity supply needs to be decarbonised and supply will need to increase, possibly doubling in capacity.**
- **The electrification of heating should be considered as a high priority given its significant impact on total emissions, but this will only reduce emissions once the grid is extensively decarbonised.**

Pathways 8–10: Prioritising bioenergy

Bioenergy is a precious resource because it has many possible applications. However, it is necessarily limited given space and sustainability constraints.

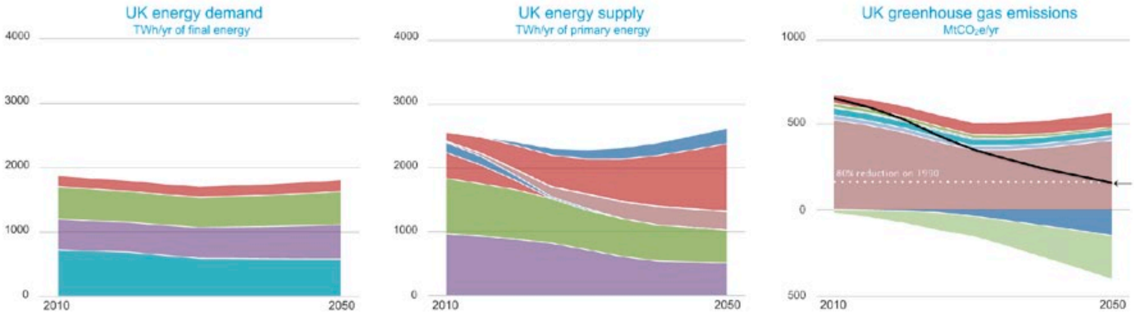
Given the current uncertainty associated with future levels of sustainable bioenergy, it is not yet clear how constrained bioenergy resources should be used most effectively and efficiently within the UK energy system. Determining the most effective allocation is a question with impacts for many sectors, including industry, heating, electricity generation and transport, with more detailed analysis required to understand its optimum use. There may also be competing demands for biomass resources in non-energy uses such as construction and chemical feedstocks, as well as important considerations around food prices and the effects of indirect land use change. The potential for innovative agriculture and chemical engineering to drive forward the productivity of bioenergy is a key factor in determining how important a role it is able to play in the future.

If we were to move to an economy reliant on substantial amounts of bioenergy, we might expect to switch large sections of UK's agricultural land to biocrops, and/or to import a proportion of the world's global supply of bioenergy. All three of the following pathways maximise availability of bioenergy supply from UK production and imports, and divert that supply in to different paths.

- Bioenergy used primarily for solid fuel (Pathway 8)
- Bioenergy used primarily for liquid fuel (Pathway 9)
- Bioenergy used primarily for gaseous fuel (Pathway 10)

Pathway 8 – Bioenergy used primarily for solid fuel

See this pathway in the online web tool at www.decc.gov.uk/2050pathways/8



Demand

transport	Domestic transport behaviour	1	2	3	4
	Domestic transport electrification	1	2	3	4
	Domestic freight	1	2	3	4
	International aviation	1	2	3	4
	International shipping	A	B	C	D
households	Average temperature of homes	1	2	3	4
	Home insulation	1	2	3	4
	Home heating electrification	A	B	C	D
	Home heating that isn't electric	A	B	C	D
	Home lighting and appliances	1	2	3	4
	Electrification of home cooking	A	B		
industry	Growth in industry	A	B	C	
	Energy intensity of industry	1	2	3	
	Commercial demand for heating and cooling	1	2	3	4
	Commercial heating electrification	A	B	C	D
	Commercial heating that isn't electric	A	B	C	D
	Commercial lighting & appliances	1	2	3	4
	Electrification of commercial cooking	A	B		

In 2050, 42% of primary energy would be imported.

Supply

electricity generation	Nuclear power stations	1	2	3	4
	CCS power stations	1	2	3	4
	CCS power station fuel mix	A	B	C	D
	Offshore wind	1	2	3	4
	Onshore wind	1	2	3	4
	Tidal and wave	1	2	3	4
	Biomass power stations	1	2	3	4
	Solar panels for electricity	1	2	3	4
	Solar panels for hot water	1	2	3	4
	Geothermal electricity	1	2	3	4
	Hydroelectric power stations	1	2	3	4
	Small-scale wind	1	2	3	4
	Electricity imports	1	2	3	4
bioenergy	Land dedicated to bioenergy	1	2	3	4
	Livestock and their management	1	2	3	4
	Volume of waste and recycling	A	B	C	
	Marine algae	1	2	3	4
	Type of fuels from biomass	A	B	C	D
	Bioenergy imports	1	2	3	4

Other

Geosequestration	1	2	3	4
Storage, demand shifting & interconnection	1	2	3	4

Focus

In this pathway, biomass is converted into solid form and is used primarily for generating electricity, heating homes and high-temperature industrial processes. The pathway maximises supply of bioenergy from UK land production, marine algae and imports. This would mean that: 17% of UK land is planted with biocrops by 2050; there would be highly effective management and collection of waste materials for bioenergy use; an area of 4,700 km^2 is used to cultivate algae; and that imported bioenergy rises to the equivalent of 200% of the UK's projected market share by 2050, based on IEA figures.

Impact

One of the biggest advantages of prioritising solid bioenergy is that the processes to convert raw biomass into a usable solid form are much more efficient than those used for liquids and gases.[12] That means that if we were to maximise our UK and imported bioenergy and direct it towards solid fuel, we create the largest possible amount of usable resource that can potentially replace fossil fuels. This is particularly important when CCS features in pathways, as the carbon captured from the atmosphere during the growth of biocrops can itself be captured upon burning the bioenergy in a power plant fitted with CCS. These net credits mean that given balanced efforts elsewhere in the system, we would comfortably over-perform against the 80% target.

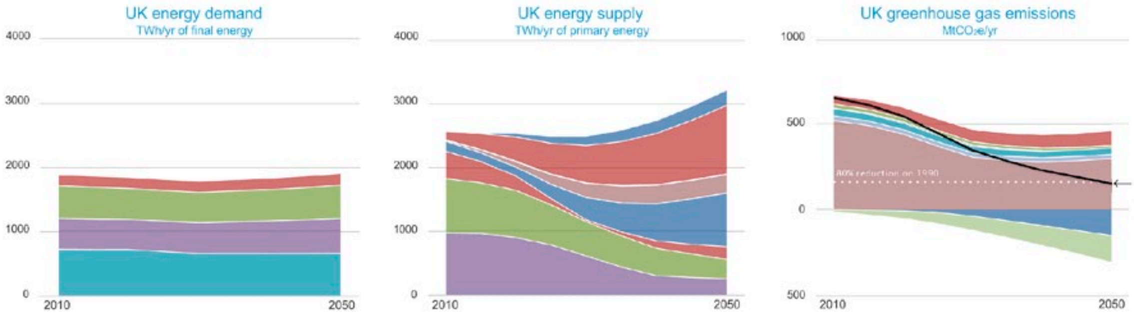
Making the pathway successful

This means that under such a scenario, we would have more flexibility to reduce efforts in other sectors. For example, the screenshot above shows how in this pathway we opt not to install any new nuclear power stations and instead build plants which burn solid biomass. We could also afford to reduce our efforts in some demand sectors, such as making less significant behaviour shifts in personal transport.

12 In some instances, the energy loss for converting biomass to solid fuel can be as little as 5%, whereas some biomass to liquid fuel processes lose over 60%.

Pathway 9 – Bioenergy used primarily for liquid fuel

See this pathway in the online web tool at www.decc.gov.uk/2050pathways/9



Demand

transport	Domestic transport behaviour	**1**	**2**	3	4
transport	Domestic transport electrification	**1**	**2**	3	4
transport	Domestic freight	**1**	2	3	4
transport	International aviation	**1**	2	3	4
transport	International shipping	**A**	B	C	D
households	Average temperature of homes	**1**	**2**	3	4
households	Home insulation	**1**	**2**	3	4
households	Home heating electrification	A	B	**C**	D
households	Home heating that isn't electric	A	B	**C**	D
households	Home lighting and appliances	**1**	**2**	3	4
households	Electrification of home cooking	A	**B**		
industry	Growth in industry	**A**	B	C	
industry	Energy intensity of industry	**1**	**2**	**3**	
industry	Commercial demand for heating and cooling	**1**	**2**	3	4
industry	Commercial heating electrification	A	B	**C**	D
industry	Commercial heating that isn't electric	A	B	**C**	D
industry	Commercial lighting & appliances	**1**	**2**	3	4
industry	Electrification of commercial cooking	A	**B**		

In 2050, 48% of primary energy would be imported.

Supply

electricity generation	Nuclear power stations	**1**	**2**	3	4
electricity generation	CCS power stations	**1**	**2**	3	4
electricity generation	CCS power station fuel mix	A	**B**	C	D
electricity generation	Offshore wind	**1**	**2**	3	4
electricity generation	Onshore wind	**1**	**2**	3	4
electricity generation	Tidal and wave	**1**	2	3	4
electricity generation	Biomass power stations	**1**	2	3	4
electricity generation	Solar panels for electricity	**1**	2	3	4
electricity generation	Solar panels for hot water	**1**	2	3	4
electricity generation	Geothermal electricity	**1**	2	3	4
electricity generation	Hydroelectric power stations	**1**	2	3	4
electricity generation	Small-scale wind	**1**	2	3	4
electricity generation	Electricity imports	**1**	2	3	4
bioenergy	Land dedicated to bioenergy	**1**	**2**	**3**	**4**
bioenergy	Livestock and their management	**1**	2	3	4
bioenergy	Volume of waste and recycling	A	**B**	C	
bioenergy	Marine algae	**1**	**2**	**3**	**4**
bioenergy	Type of fuels from biomass	A	B	**C**	D
bioenergy	Bioenergy imports	**1**	**2**	**3**	**4**

Other

Geosequestration	**1**	2	3	4
Storage, demand shifting & interconnection	**1**	**2**	3	4

Focus

In Pathway 9 we assume that bioenergy is converted into liquid fuels where possible. This liquid bioenergy is used primarily in the transport sector, though it could also be used in industry and oil and gas refineries. The pathway maximises supply of bioenergy from UK land production, marine algae and imports.

Impact

Given the lower efficiencies associated with converting raw biomass into liquid biofuels compared to their solid equivalent, the amount of bioenergy which can be substituted for fossil fuels in this pathway is less than under Pathway 8.

Nonetheless, using the same balanced effort starting point, maximising bioenergy for liquid conversion would still over-perform against the 80% target, as shown in the screenshot above.

Making the pathway successful

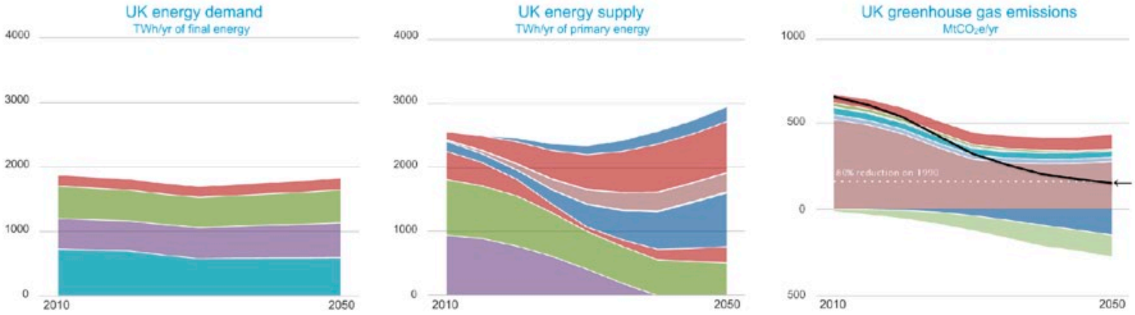
Liquid bioenergy is an important decarbonisation option for a number of sectors, particularly those where electrification is thought very challenging or impossible, such as long-haul road freight, aviation and shipping.

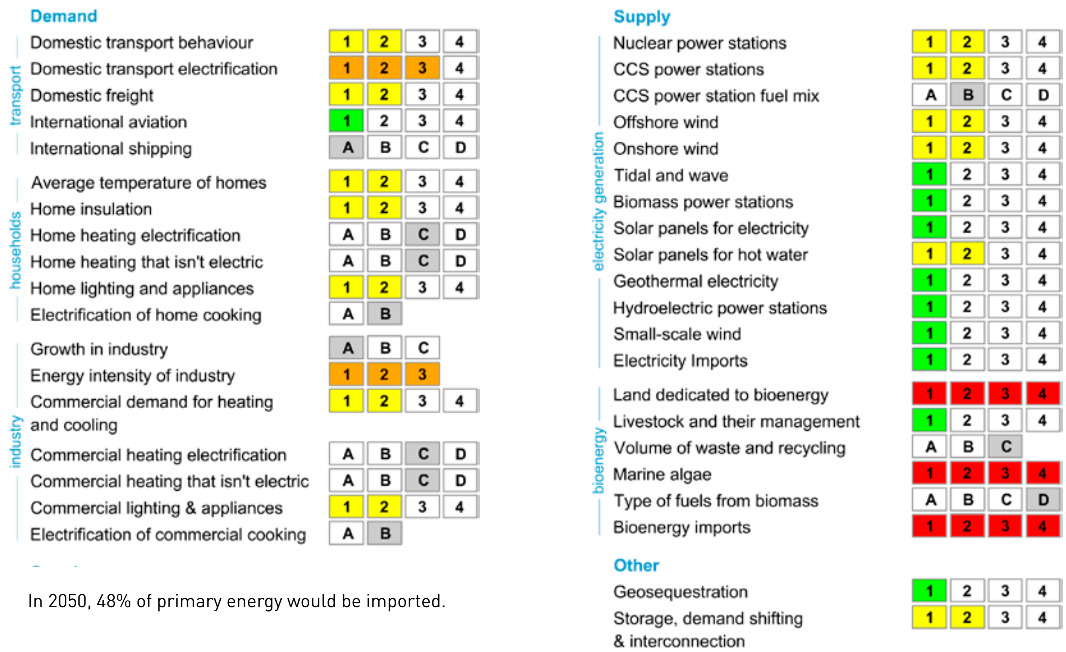
Under this scenario, our dependence on imports of oil would be significantly lower than in some other illustrative pathways. We would need to import 170 TWh of oil by 2050, which is less than half of what would be needed if biomass were predominantly converted to solid fuels. For reference, in 2009 the UK imported 89 TWh of oil (net).[13]

13 In 2009 the UK consumed 822 TWh of crude oil, importing 548 TWh of oil, and exporting 459 TWh (DUKES 2009).

Pathway 10 – Bioenergy used primarily for gaseous fuel

See this pathway in the online web tool at www.decc.gov.uk/2050pathways/10





In 2050, 48% of primary energy would be imported.

Focus

In Pathway 10 we assume that bioenergy is converted into gaseous fuels. Biogas would mostly be used in CCS power plants, heating and industry, potentially using the existing gas grid infrastructure. The pathway maximises supply of bioenergy from UK land production, marine algae and imports.

Impact

The conversion of bioenergy to gas is the least productive in terms of generating substitutes for fossil fuels.[14] However, a focus on gaseous bioenergy produces less than half the emissions gains that would be possible with conversion to solid biofuel.

14 When compared with the same baseline as Pathways 8 and 9. There are some pathways where gaseous conversion is a better option, e.g. when large amounts of gas CCS are deployed.

Making the pathway successful

A pathway with conversion to biogas only just makes the 80% target when supply of domestic and imported bioenergy is set to maximum, alongside the same balanced energy supply and demand levels used in Pathways 8 and 9, as shown in the screenshot above.

This presents a potential advantage against the other conversion routes: whereas in the other scenarios we are reliant on extensive gas imports to support demand in sectors like industry and heating, in this pathway we produce sufficient amounts of biogas by 2050 to export the energy equivalent of around 100 TWh per year.

- **Sustainable bioenergy is a vital part of a low carbon energy system.**
- **The extent of sustainable bioenergy resources, and the potential for their expansion both in the UK and abroad, remains uncertain.**

Pathways 11–16: Electricity generation

An important question in 2050 is how to generate the electricity we need. There are a series of key characteristics required of our energy and electricity supplies in 2050, of which two stand out as being particularly important. First, our supply must be decarbonised. Electricity generation is currently the largest emitting sector, and making progress in decarbonising electricity generation is not only important of itself, but also in determining the success of key demand side measures, such as electrification of demand sectors like transport and heating.

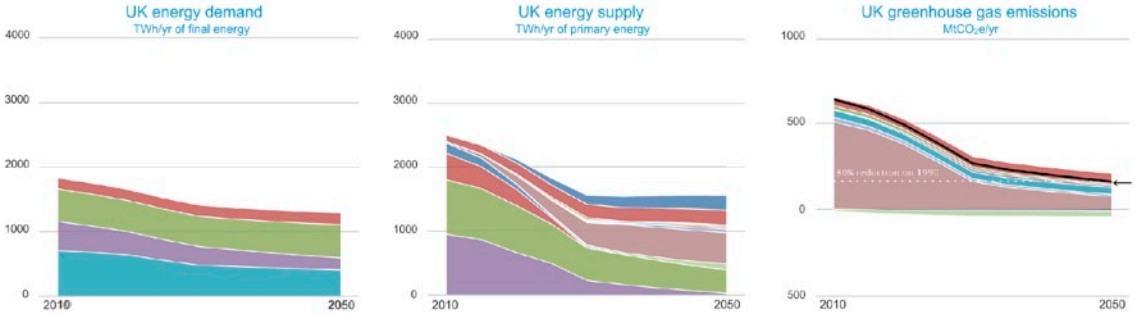
A second key point is that our supply of energy must remain secure and safe in all conditions. That means having the flexibility to cope with the inherent intermittency of some renewable technologies, whether that is provided by storage, demand shifting, interconnection or backup plant capacity; and considering to what extent we rely on imports of energy.

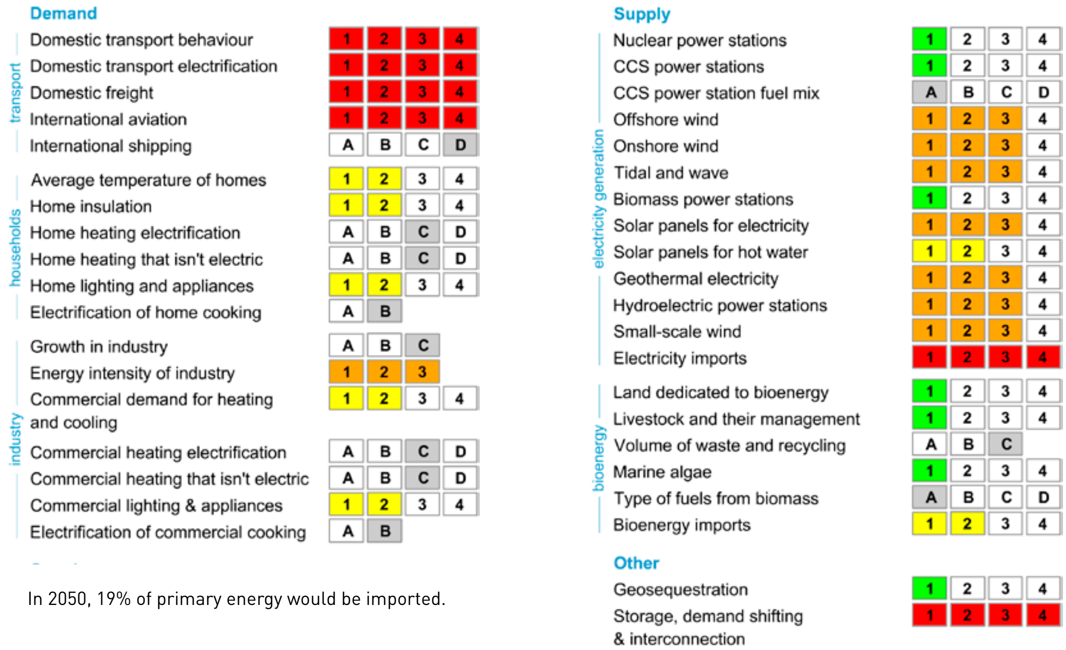
There are several supply-side technologies which can be used to generate electricity (nuclear, fossil fuels, renewables, biomass power, etc). Each of these technologies might be expected to present different levels of delivery challenge, for example in terms of technological uncertainty, costs, impacts on the environment and landscape, reliability of performance, the need for imports and so on. The following pathways examine the consequences of focusing strongly on a particular form of generation, looking at what actions might be needed beyond that to achieve the 80% target.

- Strong emphasis on renewable generation (Pathway 11),
- Strong emphasis on offshore renewable generation (Pathway 12),
- Strong emphasis on nuclear (Pathway 13),
- Strong emphasis on carbon capture and storage (Pathway 14),
- Strong emphasis on gas generation (Pathway 15),
- Strong emphasis on microgeneration (Pathway 16).

Pathway 11 – Strong emphasis on renewable generation

See this pathway in the online web tool at www.decc.gov.uk/2050pathways/11





In 2050, 19% of primary energy would be imported.

Focus

Pathway 11 assumes that all renewable generation technologies are deployed to a very ambitious (though not maximum) degree, with no nuclear or CCS technology installed. This would mean for example, that we have: about 17,000 offshore wind turbines and about 13,000 onshore wind turbines in 2050; as well as about 600 km of wave farms, 4,700 tidal stream turbines; and four tidal range schemes; and 5.4 metres squared of photovoltaic panels per person.

Impact

Alongside a balanced demand-side effort, this would leave the system 16% short of meeting the 80% target, owing to significant remaining emissions from transport, agriculture and industry.[15]

Making the pathway successful

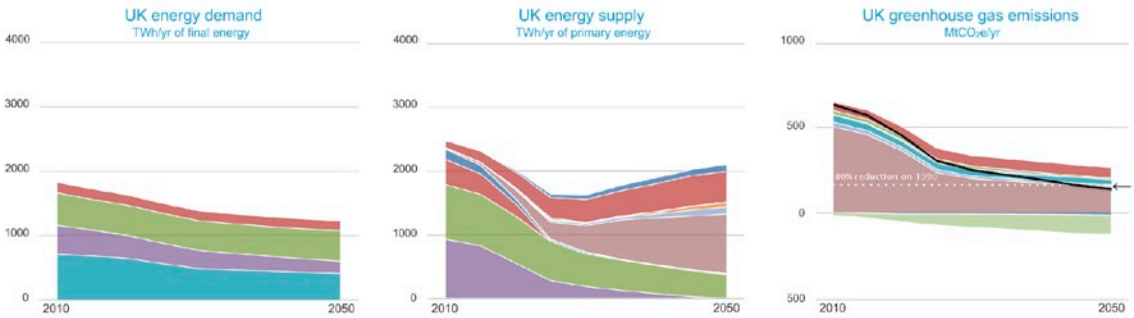
To make up for the shortfall would need a big shift in how we treat at least one demand side sector. The screenshot above shows that heroic across-the-board efforts on all transport levers plus a low-output industrial sector would ensure this pathway hits the target.

Pursuing a highly ambitious build rate of renewable electricity technologies might be expected to have most impact on the appearance of the natural landscape but fewer wider environmental impacts. The UK would be less reliant on imports than in most other pathways, with the UK a net exporter of electricity, coal and gas. While oil imports increase, they are still less than half of those needed in Pathway 1. Balancing is the key challenge – even with storage set to maximum, 26 GW of spare capacity is needed on the system by 2050.

15 This illustrates the wider point that electricity generation is unable to provide the full answer on reducing emissions, a point that holds true for all of the pathways in this section (11-16).

Pathway 12 – Strong emphasis on offshore renewable generation

See this pathway in the online web tool at www.decc.gov.uk/2050pathways/12



Demand

transport	Domestic transport behaviour	1	2	3	4
	Domestic transport electrification	1	2	3	4
	Domestic freight	1	2	3	4
	International aviation	1	2	3	4
	International shipping	A	B	C	D
households	Average temperature of homes	1	2	3	4
	Home insulation	1	2	3	4
	Home heating electrification	A	B	C	D
	Home heating that isn't electric	A	B	C	D
	Home lighting and appliances	1	2	3	4
	Electrification of home cooking	A	B		
industry	Growth in industry	A	B	C	
	Energy intensity of industry	1	2	3	
	Commercial demand for heating and cooling	1	2	3	4
	Commercial heating electrification	A	B	C	D
	Commercial heating that isn't electric	A	B	C	D
	Commercial lighting & appliances	1	2	3	4
	Electrification of commercial cooking	A	B		

Supply

	Nuclear power stations	1	2	3	4
	CCS power stations	1	2	3	4
	CCS power station fuel mix	A	B	C	D
electricity generation	Offshore wind	1	2	3	4
	Onshore wind	1	2	3	4
	Tidal and wave	1	2	3	4
	Biomass power stations	1	2	3	4
	Solar panels for electricity	1	2	3	4
	Solar panels for hot water	1	2	3	4
	Geothermal electricity	1	2	3	4
	Hydroelectric power stations	1	2	3	4
	Small-scale wind	1	2	3	4
	Electricity imports	1	2	3	4
bioenergy	Land dedicated to bioenergy	1	2	3	4
	Livestock and their management	1	2	3	4
	Volume of waste and recycling	A	B	C	
	Marine algae	1	2	3	4
	Type of fuels from biomass	A	B	C	D
	Bioenergy imports	1	2	3	4

Other

Geosequestration	1	2	3	4
Storage, demand shifting & interconnection	1	2	3	4

In 2050, 21% of primary energy would be imported.

Focus

Given concerns surrounding the impact of new energy infrastructure on the visual landscape, some people have suggested that we should prioritise harnessing the energy of the sea and offshore wind to reduce the need for new power installations on land. Pathway 12 pushes as hard as possible on marine renewables - offshore wind, tidal range, tidal stream and wave energy. This would entail: about 40,000 offshore wind turbines in 2050; about 900 km of wave farms; 10,600 tidal stream turbines and eight tidal range schemes.

Impact

In this pathway, all land-based renewables are omitted.[16] CCS and nuclear power stations, two of the biggest potential generators, are not used either. This would lead to an emissions drop of 64%, requiring a further 16% of cuts to meet the 2050 target. Supply of electricity meanwhile would drop dramatically to around half of 2007 levels.

Making the pathway successful

As shown in the screenshot above, in this pathway the 80% target is achieved by reducing demand for electricity: i.e. by setting maximum effort on all transport levers, adopting a low output industrial sector and making greater efforts in increasing domestic heating efficiency. Increases in UK bioenergy production help compensate for the loss of district heating as an option.[17]

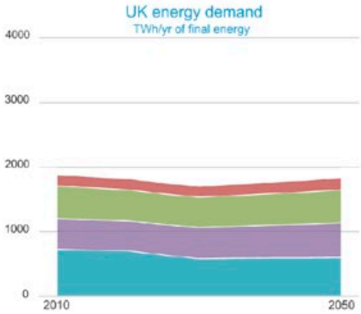
Without taking specific measures to reduce the risk, this pathway would have very significant balancing requirements due to its dependency on intermittent generation. The effects of this are reduced by making heroic efforts on electricity storage, as well as electrifying transport and following a low output industry growth trajectory. At the same time, Pathway 12 has the equal highest level of gas exports of any pathway, with just over 100 TWh of gas exports (net) in 2050.

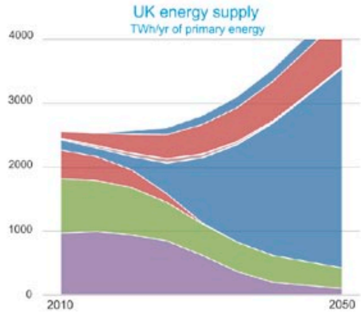
16 Such as onshore wind, hydropower and microgeneration options.

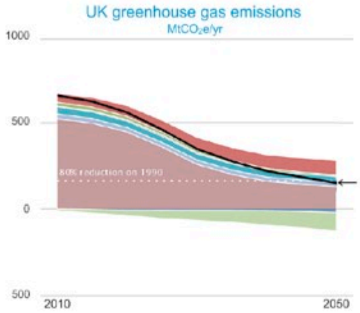
17 Thermal generation plants are required to provide district heating capacity.

Pathway 13 – Strong emphasis on nuclear generation

See this pathway in the online web tool at www.decc.gov.uk/2050pathways/13







Demand

Sector	Lever				
transport	Domestic transport behaviour	1	2	3	4
transport	Domestic transport electrification	1	2	3	4
transport	Domestic freight	1	2	3	4
transport	International aviation	1	2	3	4
transport	International shipping	A	B	C	D
households	Average temperature of homes	1	2	3	4
households	Home insulation	1	2	3	4
households	Home heating electrification	A	B	C	D
households	Home heating that isn't electric	A	B	C	D
households	Home lighting and appliances	1	2	3	4
households	Electrification of home cooking	A	B		
industry	Growth in industry	A	B	C	
industry	Energy intensity of industry	1	2	3	
industry	Commercial demand for heating and cooling	1	2	3	4
industry	Commercial heating electrification	A	B	C	D
industry	Commercial heating that isn't electric	A	B	C	D
industry	Commercial lighting & appliances	1	2	3	4
industry	Electrification of commercial cooking	A	B		

In 2050, 80% of primary energy would be imported.

Supply

Sector	Lever				
	Nuclear power stations	1	2	3	4
electricity generation	CCS power stations	1	2	3	4
electricity generation	CCS power station fuel mix	A	B	C	D
electricity generation	Offshore wind	1	2	3	4
electricity generation	Onshore wind	1	2	3	4
electricity generation	Tidal and wave	1	2	3	4
electricity generation	Biomass power stations	1	2	3	4
electricity generation	Solar panels for electricity	1	2	3	4
electricity generation	Solar panels for hot water	1	2	3	4
electricity generation	Geothermal electricity	1	2	3	4
electricity generation	Hydroelectric power stations	1	2	3	4
electricity generation	Small-scale wind	1	2	3	4
electricity generation	Electricity imports	1	2	3	4
bioenergy	Land dedicated to bioenergy	1	2	3	4
bioenergy	Livestock and their management	1	2	3	4
bioenergy	Volume of waste and recycling	A	B	C	
bioenergy	Marine algae	1	2	3	4
bioenergy	Type of fuels from biomass	A	B	C	D
bioenergy	Bioenergy imports	1	2	3	4

Other

Lever				
Geosequestration	1	2	3	4
Storage, demand shifting & interconnection	1	2	3	4

Focus

Pathway 13 maximises the contribution from nuclear power. This would involve about 50 nuclear power stations of 3 GW each, delivering about 1030 TWh of electricity per year.

Impact

If no further efforts were made on the supply or demand side, this pathway would fall 16% short of achieving the 80% target. However, even with this single source of electricity generation, energy demand would comfortably be met, reducing the need for efforts on demand reduction: primary supply increases by almost 50% from 2007 levels in 2050.

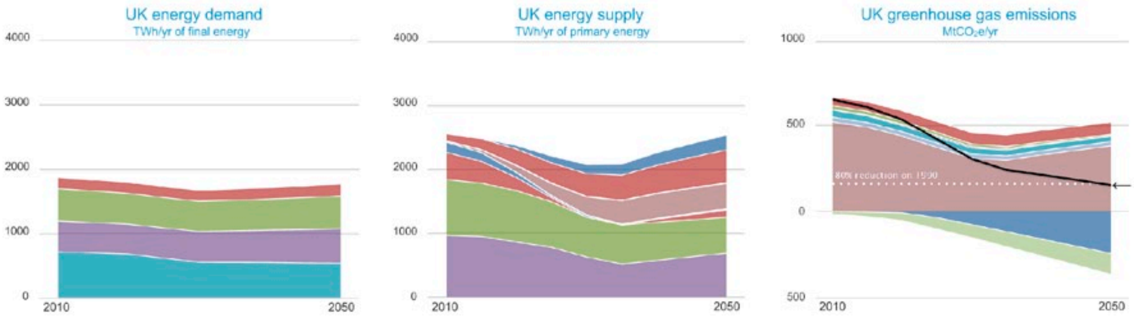
Making the pathway successful

As the screenshot above shows, one route to hitting the target from this point is to change the conversion route of biomass from solid to liquid biofuels (because transport remains the largest contributor to the remaining emissions total).

Balancing the electricity grid would present no significant difficulties in 2050. However, the quantities of nuclear waste to be dealt with would be higher in this pathway.

Pathway 14 – Strong emphasis on carbon capture and storage (CCS) generation

See this pathway in the online web tool at www.decc.gov.uk/2050pathways/14



Demand

transport	Domestic transport behaviour	1	2	3	4
	Domestic transport electrification	1	2	3	4
	Domestic freight	1	2	3	4
	International aviation	1	2	3	4
	International shipping	A	B	C	D
households	Average temperature of homes	1	2	3	4
	Home insulation	1	2	3	4
	Home heating electrification	A	B	C	D
	Home heating that isn't electric	A	B	C	D
	Home lighting and appliances	1	2	3	4
	Electrification of home cooking	A	B		
industry	Growth in industry	A	B	C	
	Energy intensity of industry	1	2	3	
	Commercial demand for heating and cooling	1	2	3	4
	Commercial heating electrification	A	B	C	D
	Commercial heating that isn't electric	A	B	C	D
	Commercial lighting & appliances	1	2	3	4
	Electrification of commercial cooking	A	B		

In 2050, 46% of primary energy would be imported.

Supply

electricity generation	Nuclear power stations	1	2	3	4
	CCS power stations	1	2	3	4
	CCS power station fuel mix	A	B	C	D
	Offshore wind	1	2	3	4
	Onshore wind	1	2	3	4
	Tidal and wave	1	2	3	4
	Biomass power stations	1	2	3	4
	Solar panels for electricity	1	2	3	4
	Solar panels for hot water	1	2	3	4
	Geothermal electricity	1	2	3	4
	Hydroelectric power stations	1	2	3	4
	Small-scale wind	1	2	3	4
	Electricity imports	1	2	3	4
bioenergy	Land dedicated to bioenergy	1	2	3	4
	Livestock and their management	1	2	3	4
	Volume of waste and recycling	A	B	C	
	Marine algae	1	2	3	4
	Type of fuels from biomass	A	B	C	D
	Bioenergy imports	1	2	3	4

Other

Geosequestration	1	2	3	4
Storage, demand shifting & interconnection	1	2	3	4

Focus

CCS is an unproven technology at commercial scale in the electricity sector, but would have the potential (if rolled out to its physical limits) to cover our entire electricity demand. This would mean about 510 TWh of electricity a year from 50-90 CCS power stations; implying a build rate similar to that of gas plants in the 1990s.

Impact

Pathway 14 shows that even using the most emissions-friendly fuel mix (two-thirds gas fuel, one-third solid[18]) CCS alone cannot be relied upon for electricity generation, if we are to hit the emissions target. This is because the emissions capture rate of CCS technology is assumed to be around 90%, resulting in residual emissions from the electricity generation sector. This, on top of 'hard-to-reach' sectors, means that reaching the 80% target is impossible without some other form of low-carbon generation on the grid.

Making the pathway successful

Choosing either nuclear generation or offshore wind alongside a substantial CCS roll out could make a significant contribution towards helping make up the shortfall. The screenshot above shows that opting for offshore wind means that the remaining gap can made up for by a big effort on one or two demand side measures – allowing others more scope for variation. In this pathway industry grows on a high output trajectory to 2050.

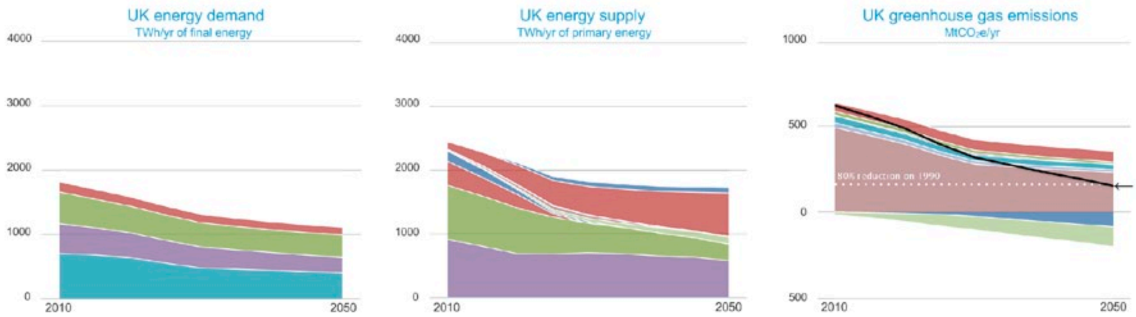
Under Pathway 14, the UK becomes a net importer of coal, oil and gas. It has the highest level of gas imports in any illustrative pathway with over 580 TWh[19] per year, four times the level imported in 2007. This occurs as our total gas consumption falls from 972 TWh in 2007 to 684 TWh in 2050.

18 Including solid bioenergy.

19 580 TWh is approximately equal to 52.7 bcm of gas.

Pathway 15 – Strong emphasis on gas generation

See this pathway in the online web tool at www.decc.gov.uk/2050pathways/15



Demand

transport	Domestic transport behaviour	1	2	3	4
	Domestic transport electrification	1	2	3	4
	Domestic freight	1	2	3	4
	International aviation	1	2	3	4
	International shipping	A	B	C	D
households	Average temperature of homes	1	2	3	4
	Home insulation	1	2	3	4
	Home heating electrification	A	B	C	D
	Home heating that isn't electric	A	B	C	D
	Home lighting and appliances	1	2	3	4
	Electrification of home cooking	A	B		
industry	Growth in industry	A	B	C	
	Energy intensity of industry	1	2	3	
	Commercial demand for heating and cooling	1	2	3	4
	Commercial heating electrification	A	B	C	D
	Commercial heating that isn't electric	A	B	C	D
	Commercial lighting & appliances	1	2	3	4
	Electrification of commercial cooking	A	B		

In 2050, 45% of primary energy would be imported.

Supply

electricity generation	Nuclear power stations	1	2	3	4
	CCS power stations	1	2	3	4
	CCS power station fuel mix	A	B	C	D
	Offshore wind	1	2	3	4
	Onshore wind	1	2	3	4
	Tidal and wave	1	2	3	4
	Biomass power stations	1	2	3	4
	Solar panels for electricity	1	2	3	4
	Solar panels for hot water	1	2	3	4
	Geothermal electricity	1	2	3	4
	Hydroelectric power stations	1	2	3	4
	Small-scale wind	1	2	3	4
	Electricity imports	1	2	3	4
bioenergy	Land dedicated to bioenergy	1	2	3	4
	Livestock and their management	1	2	3	4
	Volume of waste and recycling	A	B	C	
	Marine algae	1	2	3	4
	Type of fuels from biomass	A	B	C	D
	Bioenergy imports	1	2	3	4

Other

Geosequestration	1	2	3	4
Storage, demand shifting & interconnection	1	2	3	4

Focus

Pathway 15 was constructed to see whether it was possible to hit the 80% target using a large number of gas power plants for electricity and, if so, what demands it would place on other sectors.

Impact

The analysis shows that such a route is possible, and that it becomes a more plausible option if gas is used with CCS technology to abate emissions, as shown in the screenshot above.

An entirely *unabated* gas pathway would only possible with heroic efforts in both reducing our demand for energy and producing bioenergy, and with some renewables on the system.

Making the pathway successful

In a scenario where gas CCS is successful, we would be able to meet our target while also reducing our requirement for bioenergy (both in terms UK production and imports) relative to what would be required in a successful unabated gas pathway.

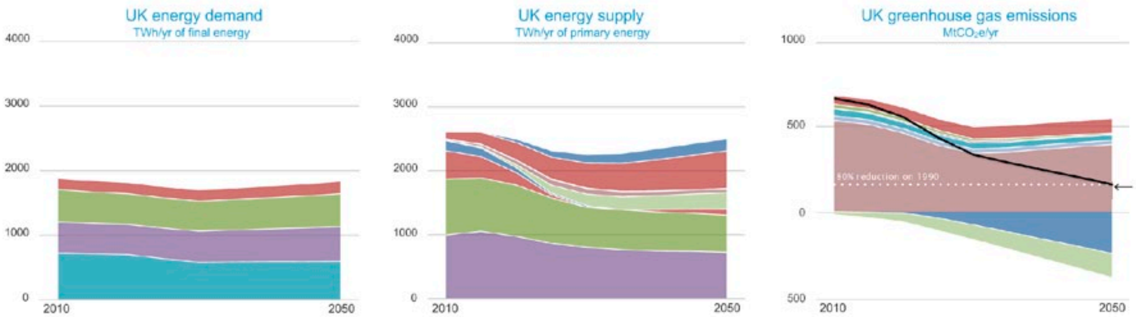
In a high-gas pathway, there would be no balancing issue in 2050. The need for the UK to import gas is significantly increased, moving from 2007 net levels of 134 TWh per year to 471 TWh per year.[20] This pathway shows that fossil fuels can continue to play a significant role out to 2050, and that this becomes more feasible in the presence of an abated gas option through CCS.

If we were to follow an unabated gas pathway, we would potentially have to import at least 400 TWh of gas per year by 2050.

20 471 TWh is approximately equal to 42.8 bcm of gas.

Pathway 16 – Strong emphasis on microgeneration

See this pathway in the online web tool at www.decc.gov.uk/2050pathways/16



Demand

	Lever				
transport	Domestic transport behaviour	1	2	3	4
transport	Domestic transport electrification	1	2	3	4
transport	Domestic freight	1	2	3	4
transport	International aviation	1	2	3	4
transport	International shipping	A	B	C	D
households	Average temperature of homes	1	2	3	4
households	Home insulation	1	2	3	4
households	Home heating electrification	A	B	C	D
households	Home heating that isn't electric	A	B	C	D
households	Home lighting and appliances	1	2	3	4
households	Electrification of home cooking	A	B		
industry	Growth in industry	A	B	C	
industry	Energy intensity of industry	1	2	3	
industry	Commercial demand for heating and cooling	1	2	3	4
industry	Commercial heating electrification	A	B	C	D
industry	Commercial heating that isn't electric	A	B	C	D
industry	Commercial lighting & appliances	1	2	3	4
industry	Electrification of commercial cooking	A	B		

In 2050, 48% of primary energy would be imported.

Supply

	Lever				
	Nuclear power stations	1	2	3	4
	CCS power stations	1	2	3	4
	CCS power station fuel mix	A	B	C	D
electricity generation	Offshore wind	1	2	3	4
electricity generation	Onshore wind	1	2	3	4
electricity generation	Tidal and wave	1	2	3	4
electricity generation	Biomass power stations	1	2	3	4
electricity generation	Solar panels for electricity	1	2	3	4
electricity generation	Solar panels for hot water	1	2	3	4
electricity generation	Geothermal electricity	1	2	3	4
electricity generation	Hydroelectric power stations	1	2	3	4
electricity generation	Small-scale wind	1	2	3	4
electricity generation	Electricity imports	1	2	3	4
bioenergy	Land dedicated to bioenergy	1	2	3	4
bioenergy	Livestock and their management	1	2	3	4
bioenergy	Volume of waste and recycling	A	B	C	
bioenergy	Marine algae	1	2	3	4
bioenergy	Type of fuels from biomass	A	B	C	D
bioenergy	Bioenergy imports	1	2	3	4

Other

Lever				
Geosequestration	1	2	3	4
Storage, demand shifting & interconnection	1	2	3	4

Focus

Pathway 16 maximises the input from microgeneration technologies. For example: the equivalent of all suitable roof and facade space would be used for solar panels (9.5 metre squared of photovoltaic panels per person); all suitable buildings would get about 60% of their hot water from solar thermal equipment; small-scale wind turbines would be installed in all suitable domestic and non-domestic sites; and about 80-100% of home heating would be supplied using electricity, predominantly through air source heat pumps.

Impact

Pathway 16 indicates that microgeneration alone would not be sufficient to meet our electricity generation needs – turning off all supply side technologies other than micro wind and solar PV would leave us a full 46% short of meeting the target. That said, microgeneration does make significant in-roads into reducing emissions from heating.

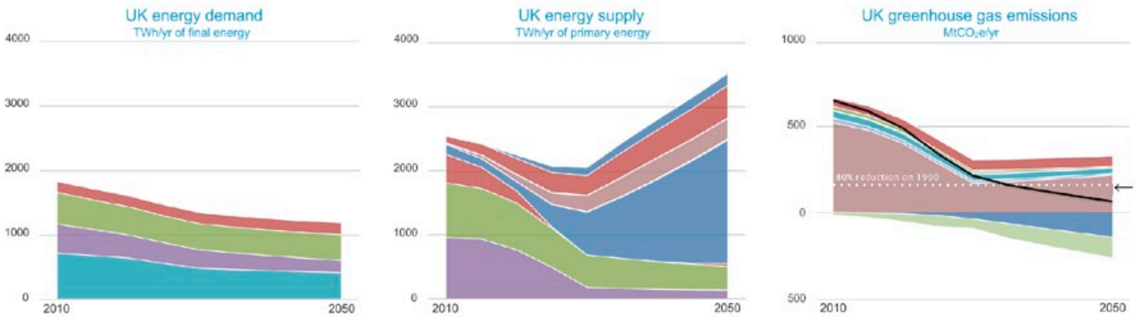
Making the pathway successful

Further analysis shows that we are significantly constrained in our ability to pick just one other low-carbon electricity generation technology to make up the shortfall – only Level 4 nuclear would be sufficient. As the screenshot above shows, this pathway uses CCS, onshore wind and a big step up in bioenergy imports to cover the energy supply gap.

- **A growing level of variable renewable generation increases the challenge of balancing the electricity grid and increases our dependence on storage and interconnection options.**
- **The shape of future energy infrastructures and commercial success of some electricity generation technologies remain significant sources of uncertainty.**
- **Fossil fuels continue to play a role – it is physically possible to reach the 80% target using unabated gas generation if heroic efforts are made across many other sectors of the economy.**
- **Import prices and international fuel markets will still impact on the UK in 2050.**

Pathway 17: Hedging Strategy

See this pathway in the online web tool at www.decc.gov.uk/2050pathways/17



Demand

transport	Domestic transport behaviour	1	2	3	4
	Domestic transport electrification	1	2	3	4
	Domestic freight	1	2	3	4
	International aviation	1	2	3	4
	International shipping	A	B	C	D
households	Average temperature of homes	1	2	3	4
	Home insulation	1	2	3	4
	Home heating electrification	A	B	C	D
	Home heating that isn't electric	A	B	C	D
	Home lighting and appliances	1	2	3	4
	Electrification of home cooking	A	B		
industry	Growth in industry	A	B	C	
	Energy intensity of industry	1	2	3	
	Commercial demand for heating and cooling	1	2	3	4
	Commercial heating electrification	A	B	C	D
	Commercial heating that isn't electric	A	B	C	D
	Commercial lighting & appliances	1	2	3	4
	Electrification of commercial cooking	A	B		

In 2050, 45% of primary energy would be imported.

Supply

electricity generation	Nuclear power stations	1	2	3	4
	CCS power stations	1	2	3	4
	CCS power station fuel mix	A	B	C	D
	Offshore wind	1	2	3	4
	Onshore wind	1	2	3	4
	Tidal and wave	1	2	3	4
	Biomass power stations	1	2	3	4
	Solar panels for electricity	1	2	3	4
	Solar panels for hot water	1	2	3	4
	Geothermal electricity	1	2	3	4
	Hydroelectric power stations	1	2	3	4
	Small-scale wind	1	2	3	4
	Electricity imports	1	2	3	4
bioenergy	Land dedicated to bioenergy	1	2	3	4
	Livestock and their management	1	2	3	4
	Volume of waste and recycling	A	B	C	
	Marine algae	1	2	3	4
	Type of fuels from biomass	A	B	C	D
	Bioenergy imports	1	2	3	4

Other

Geosequestration	1	2	3	4
Storage, demand shifting & interconnection	1	2	3	4

Focus

There are risks associated with the delivery of all of the illustrative pathways, because they rely to differing degrees on factors such as: unproven technologies; very fast build-up of possibly expensive infrastructure; imports of energy, skills and capital; or significant changes in people's lifestyle and behaviours. These delivery risks have led some people to argue that we should be aiming beyond our target across a broad range of sectors, so that in the event that some sectors fail to deliver, the modified pathway will still deliver the emissions reduction and energy security required.

This 'hedging strategy' assumes, for example, heroic changes in energy demand and electrification of transport and heating. It assumes the UK pushes very hard on some of the more established low carbon electricity generation sectors like nuclear and onshore wind. It also assumes ambitious UK production of bioenergy, while reducing reliance on bioenergy imports.

Impact

This hedging strategy would attain a cut in emissions of more than 90% from 1990 levels.

Making the pathway successful

Pathway 17 shows a possible hedging strategy which is robust to failures in several sectors.

This pathway would still meet the emissions target even if one of the following sectors failed to deliver change: carbon capture and storage, offshore wind, onshore wind, nuclear power, international aviation and shipping, the efficiency of industry, or the electrification of heat.

- **It is possible to achieve 90% (and higher) emission reductions according to the physical and technical limits of effort.**
- **Hedging strategies require high or maximum levels effort across a large number of sectors, including agriculture, waste, industry and transport.**

Messages from the pathways

Although these illustrative pathways might not be considered the most plausible pathways, insofar as they tend to push to heroic levels of ambition in different sectors, they nevertheless help to highlight some of the common messages and uncertainties posed by the choices and trade-offs.

- Ambitious per capita demand reduction is an essential part of a successful pathway to 2050. These reductions need to be made across the economy – efforts from just individuals or just businesses will not be sufficient as some significant emissions sources would be left unaddressed.
- A substantial level of electrification across the major sectors is needed. Alongside this, electricity supply needs to be decarbonised and supply will need to increase, possibly as much as a doubling in capacity. The electrification of heating should be considered as a high priority given its significant impact on total emissions, but this will only reduce emissions once the grid is extensively decarbonised.
- Sustainable bioenergy is a vital part of a low carbon energy system. The extent of sustainable bioenergy resources, and the potential for their expansion both domestically and abroad, remains uncertain.
- A growing level of variable renewable generation increases the challenge of balancing the electricity grid and increases our dependence on storage and interconnection options. The more stringent balancing test has profound implications for the system.
- The shape of future energy infrastructures and commercial success of some electricity generation technologies remain significant sources of uncertainty.
- Fossil fuels continue to play a role - it is physically possible to reach the 80% target using unabated gas generation if heroic efforts are made across many other sectors of the economy.
- Import prices and international fuel markets will still impact on the UK in 2050.
- It is possible to achieve 90% (and higher) emission reductions according to the physical and technical limits of effort. Hedging strategies require high or maximum levels effort across a large number of sectors, including agriculture, waste, industry and transport.

Part 1B. Engagement about 2050 pathways

The illustrative pathways presented in the previous section (Part 1A) are an effort to highlight some of the key themes emerging from the 2050 analysis. They draw out some of the major choices and trade-offs in the dialogue about the merits of different pathways to 2050. In particular, how far might the UK reduce its demand for energy? How far might the UK attempt to electrify demand for energy, and in which sectors? How much bioenergy might the UK attempt to source, and in which sectors might it be used? How might we generate the electricity required? What is the future role for fossil fuels?

We believe the 2050 Pathways tools can be useful in helping to raise public awareness and understanding of the energy and climate change challenge. The tools can help in stimulating an energy-literate debate about the options available to the UK over the next forty years as we transition to a low-carbon economy. And they are useful ways to facilitate public and stakeholder feedback about the relative merits of different pathways to 2050.

We strongly encourage readers to come up with their own pathway, and see whether it is possible to create a world in which you would be happy to live in forty years' time. And we are offering means by which stakeholders and the public can engage in a dialogue these important issues.

The 2050 Pathways debate

Building on the discussion about pathways that we have presented in this report, we have invited experts to host a debate about pathways to 2050. If you look at our website (http://decc.gov.uk/2050) you can see the pathways that these experts prefer and their explanations of why they chose them.

On Thursday 3rd and Friday 4th March 2011 these experts will be debating the merits of the pathways they have presented, exploring the choices and trade-offs they have made, and the criteria they used when choosing their pathways. On Monday 7th and Tuesday 8th March you can have your say, asking questions of the experts, sharing your own preferred pathway to 2050 or offering your thoughts on the choices and trade-offs. Finally on Wednesday 9th March the experts will respond, possibly amending their own preferred pathways, possibly defending their initial position, certainly responding to many of your questions and suggestions.

This debate will launch a month of dialogue on DECC's blog, running until the end of March 2011. We would encourage stakeholders and the public to contribute their preferred pathways to 2050 and engage in dialogue about the merits of different pathways.

My2050

BIS (through Sciencewise-ERC) has co-funded development of My2050.[21] This simulation takes the data underpinning the updated 2050 Calculator and makes it more accessible to a wider audience. This can be explored at http://decc.gov.uk/my2050.

My2050 enables users to develop their '2050 world', finding their preferred way of meeting the 80% emissions reduction target while keeping the lights on. It visualises the changes this may imply for our homes, our cities and our countryside. It has a function for users to share and compare their 2050 world with those of others. It also has a feedback function so that users can share their 2050 world with DECC, providing us with their opinions on the best way to meet the target. Ipsos MORI will be analysing initial feedback gathered from My2050 to understand what can be learnt from input via this tool.

The DECC Youth Panel has been involved in testing and improving this new and visually attractive version of the 2050 model and we are very grateful for their input. We aim to distribute My2050 widely: we hope that other young people will be keen to play My2050 and that in the process they will learn about the energy and climate change challenge and the options available to the UK in meeting its long term energy and climate change goals. We also hope it will stimulate young people, the next generation, to investigate the more detailed 2050 Pathways Analysis after completing My2050.

2050 local deliberative dialogues

We believe the 2050 Calculator is a strong vehicle for initiating dialogue among local decision-makers about the long-term choices available to the UK. We hope that it has potential to strengthen and inform public participation in the debate about energy and climate change, and to help government understand the range of views in local communities. Co-funded by BIS (through Sciencewise-ERC) and working with Ipsos MORI and Involve, we are piloting a model of '2050 Local Deliberative Dialogues' in three local communities around the UK. If these prove to be successful we will explore the opportunity for extending them further. We are also working with Involve and Think Global to develop a trial toolkit to support continuation of such conversations with local community leaders and in schools.

21 Sciencewise-ERC is the UK's national centre for public dialogue in policy making involving science and technology issues: http://www.sciencewise-erc.org.uk

Part 1C. Future work

This publication does not mark the end of the 2050 analysis. DECC is committed to further developing the model, further engaging with the public, and applying the analysis on an ongoing basis.

1. Continuing to improve the analytical credibility of the 2050 Calculator

Engagement with expert stakeholders during the development of the 2050 Calculator, and feedback from stakeholders through the Call for Evidence have enabled us to improve the 2050 Calculator and ensure it is robust. However, there are inevitably major uncertainties in looking so far ahead. As technologies develop, so what is physically and technically possible changes, and our knowledge and understanding of this potential is improving all the time. In addition, the Calculator currently uses 2007 data as its empirical baseline in most sectors – this too will need updating as more recent empirical data becomes available. We intend to update the Calculator on an annual basis, incorporating the latest evidence about what is possible in each sector.

We are also keen to develop our analytical understanding of the implications of different pathways to 2050. To that end, we have added to the 2050 Calculator (both the Excel Calculator and the updated web tool) analysis of the land use impacts of different choices within the Calculator. Our next update to the Calculator, planned for summer 2011, will begin to integrate an analysis of the costs and some of the environmental impacts associated with choices into the 2050 model.

Costs

Of the 116 responses we received to the Call for Evidence, over 30 responded directly to our question about the costs analysis, including E.ON, Exxon Mobil, the National Grid and ETI. The majority of respondents highlighted the importance of the further development of the costs analysis. The response of RWE nPower is typical of those in favour of adding costs to the model: "Cost implications of various pathways will be important in assessing overall implications of pathways and is essential for the model to be able to provide any input into policy decisions".

We agree that costs should be added as a priority, and have begun the process of developing cost estimates for integration into the Calculator in summer 2011. Future costs are uncertain, so we propose to provide cost ranges, rather than absolute figures. The inclusion of costs in the Calculator will be the first step on a long-term process in improving awareness of the financial commitment needed to meet our 2050 target. The initial work will start to illuminate some of the key trade-offs in cost-effectiveness for both energy supply and demand, and thereby allow the public and policy makers to have an increasingly informed debate as to which 2050 pathways are realistic, palatable and affordable.

The initial phase of the work will draw upon existing data. In some areas the ranges may be wide to reflect different opinions as to what future costs might be, and in some areas costs may be partial or incomplete. Where there is good data, we will make separate assessments of capital expenditure, operating expenditure and fuel costs, giving high and low scenarios for each. System costs, such as those associated with transmission, distribution and back-up generation, will also be considered as part of this exercise. In keeping with the Calculator's current methodology for examining technical and physical constraints, we will clearly state our assumptions and methodology for generating the costs outputs associated with each sector trajectory in the Excel model, and wherever possible provide full details on the evidence source.

We are not complacent about the demands of this exercise and recognise that the ranges produced will not, like the illustrative pathways, be 'right answers'. However, we believe making this information available and transparent is an important step in the interests of starting vital conversations about what we do with our energy in the short-, medium- and long-term. As the 2050 Calculator develops over time, we will need to regularly review the costs data as estimates improve and technologies change. Part of this process will be requesting feedback from Calculator users on our initial analysis, which we hope to release in the summer.

Environmental impacts

Given the Calculator's focus on greenhouse gas emissions and technical constraints, legitimate questions have been raised about how the Calculator can best account for the broader impacts such measures will have on the environment. Many of the available options have implications of real consequence for the wider environment – how we generate electricity, how we use transport, how we heat our homes, the composition of our economy – and recognising these impacts will play an important part in the public debate over what a sustainable pathway should look like.

To begin addressing these questions, the web tool now includes the facility to see the land use impact of different choices. We have also started analysis looking at the impact on air pollutant emissions of user choices in the Calculator. We are conducting work with a view to providing an air quality metric for pathways. This will give a sense of the relative environmental impact a pathway will have. It may also show which user choices have bigger impacts on air quality – be they positive or negative.

We hope to tie this metric to outcomes that people can truly identify with – impacts on health for example – and by doing so to help increase awareness of how energy choices impact on all aspects of our lifestyles. Work on producing a robust dataset forming the foundation of this work has begun, and we are aiming to include the air quality metric alongside costs in an updated Calculator later this year. Over time, we intend to extend this sort of approach to other environmental impacts such as water quality and biodiversity.

2. Further public engagement using the 2050 Pathways Analysis

We are keen to use the 2050 tools to engage the public in conversations about the energy and climate change challenge. We have set out our initial plans for doing this in the previous section (part 1B).

The Office for Public Management will independently evaluate the success of these measures in generating effective public dialogue about the energy and climate change challenge and the choices and trade-offs we face in the course of a transition to a low-carbon economy. Following this evaluation, we will review our future plans for public engagement.

We are keen to exploit the value of the 2050 Pathways Analysis in helping to educate people about the energy and climate change challenge and give them a channel through which to express their views. Co-funded by BIS (Sciencewise-ERC), we are currently working with Involve, specialists in public participation, to develop a 2050 Toolkit. This would provide support to local community leaders and teachers (of 14-18 year olds) to encourage dialogue about the transition to a low-carbon economy.

3. Using the 2050 analysis to support policy development

The updated version of the 2050 Calculator is useful in informing discussions of the long-term challenges faced by the UK as we transition to a low-carbon economy.

Common messages from the pathways

We will continue to develop the 2050 Pathways Analysis. In particular, we will continue to explore the features that are common to most successful pathways to 2050. We have set out our current understanding of these common themes in part 1A of this report, and we will continue to develop our understanding of where 'good bet' actions lie. Already, the common themes that we have identified have supported the development of work programmes within DECC.

For example, one of our common messages is about the need for ambitious per-capita energy demand reduction. The Energy Bill introduced into Parliament on 8th December 2010 includes provision for a new 'Green Deal', which we believe will revolutionise the energy efficiency of British properties. The Government is establishing a framework to enable private firms to offer consumers energy efficiency improvements to their homes, community spaces and businesses at no upfront cost, and recoup payments through a charge in instalments on the energy bill. This will enable the energy demand reduction seen as essential by the 2050 Pathways work.

Another of our key messages is about the need for electricity supply to be decarbonised, while supply may need to double. In his Annual Energy Statement to Parliament on the same day as the 2050 Pathways Analysis was published, the Secretary of State for Energy and Climate Change announced that Government would publish a consultation document on electricity market reform to examine the reforms necessary to achieve the Government's objectives on decarbonisation, renewable energy, security of supply and affordability. On 16th December 2010, the Government launched its consultation on a package of options for reforming the electricity market. The proposals are designed to strike a balance between the best possible deal for consumers and giving existing players and new entrants in the energy sector the certainty they need to raise investment. Specifically, they are designed to ensure that low-carbon technologies become a more attractive choice for investors, and adequately to reward back-up capacity to ensure the lights stay on.

Another of our key messages is about the fact that a growing level of variable renewable generation increases the challenge of balancing the electricity grid. The technical and market requirements to ensure the electricity system balances at all times will change as new sources of demand and supply are added. The Government recognises that the 2050 balancing analysis will need to be both deepened and broadened. DECC will continue to carry out analysis on the physical need for balancing technologies (including back-up, storage, demand response and interconnection), and work to ensure that the market structure reflects these physical requirements. In particular, the Electricity Market Reform White Paper to be published later in 2011 will set out how the market will enable new technologies, including demand response, to enter the market effectively. And it will set out the role of a smarter grid in balancing the electricity system.

Developing our understanding of plausible pathways

The Climate Change Act 2008 requires the UK government to set the level of the UK's fourth carbon budget, for the period 2023-27, in June 2011. Carbon Budgets are a requirement under the Act and provide a trajectory to deliver the 80% emissions reduction target by 2050.

We will use the input from the further analysis set out above (including the costs analysis and the input from the engagement opportunities we have outlined in Part 1B), to feed into our understanding of plausible pathways to 2050. The analysis of plausible pathways to 2050 will be one source of evidence that DECC will consider in understanding possible mechanisms and trade-offs to deliver the fourth carbon budget.

Department of Energy and Climate Change

www.decc.gov.uk

First published March 2011.

URN 11D/0024