

2050 Pathways Analysis

July 2010

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Foreword



We are committed to reducing greenhouse gas emissions in the UK by at least 80% by 2050, relative to 1990 levels. When we take into account the expected levels of population growth over the period, that means that each person in the UK will need to have a carbon footprint that is about one fifth the size of their current footprint. DECC and other departments have been working hard with stakeholders to work out what this means for the country, for the energy sector and other major emitting sectors, and for individuals.

When we look ahead as far as 2050 there are inevitably major uncertainties. For example, it is not possible to accurately predict which low carbon technologies will flourish and which will fail, what the mix of our low carbon electricity generation will look like, or exactly how behaviours and infrastructure will have changed or will need to change over the intervening period. This challenge is not restricted to the UK – right across the world people will be going through a low carbon revolution and the direction that other nations take will affect the opportunities, technologies, fuels, skills and supply chains available to the UK.

Yet despite the difficulties in looking so far ahead, a successful shift to a low carbon economy requires a clear direction and early action: investors and consumers require confidence to act; large building and infrastructure projects require long term planning; new technology takes time to reach commercial deployment; and behaviours change gradually. Power stations typically have a lifespan of around 40 years, and a passenger aeroplane can be in service for over 30 years. We need to make sure that we understand the long term implications of today's investment decisions.

The analysis in this 2050 Pathways Analysis report presents a framework through which to consider some of the choices and trade-offs which we will have to make over the next forty years. It shows that it is possible for us to meet the 80% emissions reduction target domestically in a range of ways, and the online 2050 Pathways Calculator allows people to explore the combinations of effort which meet the emissions target while matching energy supply and demand. The route to 2050 will not be easy: we know that very substantial changes will be required across a wide range of sectors and across many aspects of our lives, even though we do not yet know the precise detail of these changes.

This report presents a range of different pathways to 2050. None of these is a preferred route and the exercise is not about choosing a pathway out to 2050 today – such a task would not be feasible as there are too many unknowns. It would be like asking someone in 1970 to predict the impact of mobile telephones and the internet. But the illustrative pathways facilitate a discussion about the long term options available. They also point to a set of long term 'good bet' actions which appear to be common to a number of the possible pathways. Although the rationale for moving to a low carbon pathway is not to reduce energy costs, the analysis indicates that low carbon energy generation can actually be less expensive than conventional energy generation under the highest fossil fuel price scenarios. Given the inherent uncertainty in predicting the likely price

of fossil fuels over forty years, it is significant that the low carbon pathways reduce our exposure to the risk of high fossil fuel prices.

Creating a low carbon economy will require the consent and participation of citizens. The publication of this Call for Evidence and the launch of the online 2050 Pathways Calculator allows the public to engage in the debate about how we achieve our goals and ensure that our efforts add up to what is required.

A handwritten signature in black ink, appearing to read 'Chris Huhne', with a stylized flourish at the end.

Chris Huhne
Secretary of State for Energy and Climate Change

Executive summary

Rationale

The UK faces major choices about how to move to a secure, low carbon economy over the period to 2050. Should we do more to cut demand, or rely more on increasing and decarbonising the energy supply? How will we produce our electricity? Which technologies will we adopt?

Approach

2050 pathways is a tool to help policymakers, the energy industry and the public understand these choices. For each sector of the economy, four trajectories have been developed, ranging from little or no effort to reduce emissions or save energy (level 1) to extremely ambitious changes that push towards the physical or technical limits of what can be achieved (level 4).

Pathways

The 2050 Pathways Calculator – available on the DECC website - allows users to develop their own combination of levels of change to achieve an 80% reduction in greenhouse gas emissions by 2050, while ensuring that energy supply meets demand.

This report describes six different illustrative pathways to show the varied routes to 2050, ranging from a pathway that requires significant effort across all sectors to pathways with only a minimal contribution from particular sectors, such as renewables, bioenergy, nuclear or carbon capture and storage, and a pathway with less action on energy efficiency. None of them represents a preferred option.

Uncertainties and common themes

The pathways differ substantially. They also illustrate uncertainties and trade-offs. For example, the availability of sustainable bioenergy resources and the degree of global competition for them is hard to predict; and we cannot know which new and unproven technologies will succeed. However, there are several common messages emerging from the pathways:

- 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.
- A substantial level of electrification of heating, transport and industry is needed.
- Electricity supply may need to double, and will need to be decarbonised.
- A growing level of variable renewable generation increases the challenge of balancing the electricity grid.

- Sustainable bioenergy is a vital part of the low carbon energy system in sectors where electrification is unlikely to be practical, such as long haul freight transport and aviation and some industrial high-grade heating processes.
- The pathways also show 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.
- Emissions from agriculture, waste, industrial processes and international transport make up a small proportion of emissions today, but by 2050, if no action were taken, emissions from these sectors alone would exceed the maximum level of emissions for the whole economy.

Next steps: call for evidence

Creating a low carbon economy will require the consent and participation of citizens given the scale and pace of change required. Government can play a leadership role, but transforming our economy will require a coalition of citizens, business, and the energy industry. That is why over the next 10 weeks we will be gathering evidence to test and refine the model, before engaging the public more widely in the 2050 work.

This work is not about choosing a pathway to 2050 today – such a task would not be feasible given the major unknowns and timeframe involved. However, this analysis enables us to better manage some significant long term uncertainties, and helps us to avoid making long term decisions that are incompatible with meeting our 2050 emissions target.

Part 1

Introduction and overview

1. Background and approach to 2050 analysis

Why the analysis was done

Climate change is a major threat to our common future. The UK has a commitment to reduce its greenhouse gas emissions by at least 80% by 2050 relative to 1990 levels and carbon budgets have been set down in law to make sure the UK stays on track.¹ 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 while ensuring that the UK is able to take up the economic opportunities presented by global decarbonisation.

The analysis in this report presents a framework with which to explore a range of potential pathways from today to 2050 and to consider some of the difficult choices and trade-offs which we will have to make. This report is published as a Call for Evidence; alongside this, the detailed model – the 2050 Pathways Calculator – which underlies the analysis, has been published on the DECC website, as well as a user-friendly version of the model.² This Call for Evidence marks the start of a period of discussion and we welcome suggestions on how to refine the analysis and the approach. Around a hundred stakeholders have already been involved in the development of the sectoral trajectories which underpin this analysis. The responses to this Call for Evidence will feed in to a refinement of our analysis and the publication of an updated 2050 Pathways Calculator in the autumn. The 2050 analysis will be one source of information used in determining the UK's fourth carbon budget.

By 2008, the UK had already reduced greenhouse gas emissions by 22% from 1990 levels. We have five-year carbon budgets set out to 2022 – the first beginning in 2008 – which set us on a trajectory to our longer term target, and by summer 2011 the UK is required to set the level of the fourth carbon budget (2023–2027).³ However beyond 2020 there are many uncertainties about the shape of the emissions reduction trajectory, the relative contribution of different sectors, the potential for energy imports and the use of international carbon credits.⁴ The further ahead we look, the more difficult it becomes to predict the technologies that might facilitate decarbonisation, the amount of energy we will need to produce, the costs and benefits of taking any particular action and the availability of resources both here and abroad.

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). Not all sectors are necessarily required to reduce emissions by 80% and emissions cuts within the *UK energy* system may have to be greater than 80% if emissions from other sectors, such as agriculture and industrial processes, are harder to achieve.

2 http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/2050/2050.aspx.

3 The requirement is in the Climate Change Act.

4 International emissions credits are a mechanism by which developed countries such as the UK can pay for emissions reductions to take place in developing countries, and count these against domestic targets. This relies on the fact that greenhouse gases have the same impact regardless of where in the world they are emitted, but abatement in developing countries can be cheaper than in developed countries.

Despite the difficulties in looking so far ahead, a successful low carbon transition requires a clear direction and early action: investors and consumers require confidence to act. Large building and infrastructure projects require long term planning; new technology takes time to reach commercial deployment; and behaviours change gradually. But time is short and the pace of change must be rapid. The analysis shows that we can meet the 80% emissions reduction target and that there are a range of different routes. To achieve the ambitious 2050 targets and minimise cumulative emissions along the way, the UK will have to step up the rate of decarbonisation over the following decades.

Furthermore, energy infrastructure is long lasting. For example, many of the power stations built in the 1960s and 1970s are still powering the country today. Decisions made in the next decade about the replacement of energy infrastructure will, similarly, have consequences for the next 40 years or more. Choices must therefore be based on an understanding of the long-term challenges that the UK faces in decarbonising and maintaining energy resilience. Exploring now the ways in which a 2050 energy system might be configured will help us to understand the options available and to limit the risk of making costly mistakes.

Ongoing work is already looking in detail at the investment and strategic decisions which will be necessary in putting us on the right path to 2050. The Annual Energy Statement, made alongside this 2050 report, fulfils the commitment in the Government's Coalition Document to present an annual statement to Parliament to set strategic energy policy and guide investment. And the Government's Electricity Market Reform Project is conducting a detailed appraisal of the way the electricity market should be designed; recognising the need to decarbonise the electricity sector and the need to secure billions of pounds of new generating capacity, transmission and distribution infrastructure. This depends on developers having confidence in the investment environment. The Electricity Market Reform Project will involve engagement with industry, investors and other groups as well as detailed analysis and economic modelling.

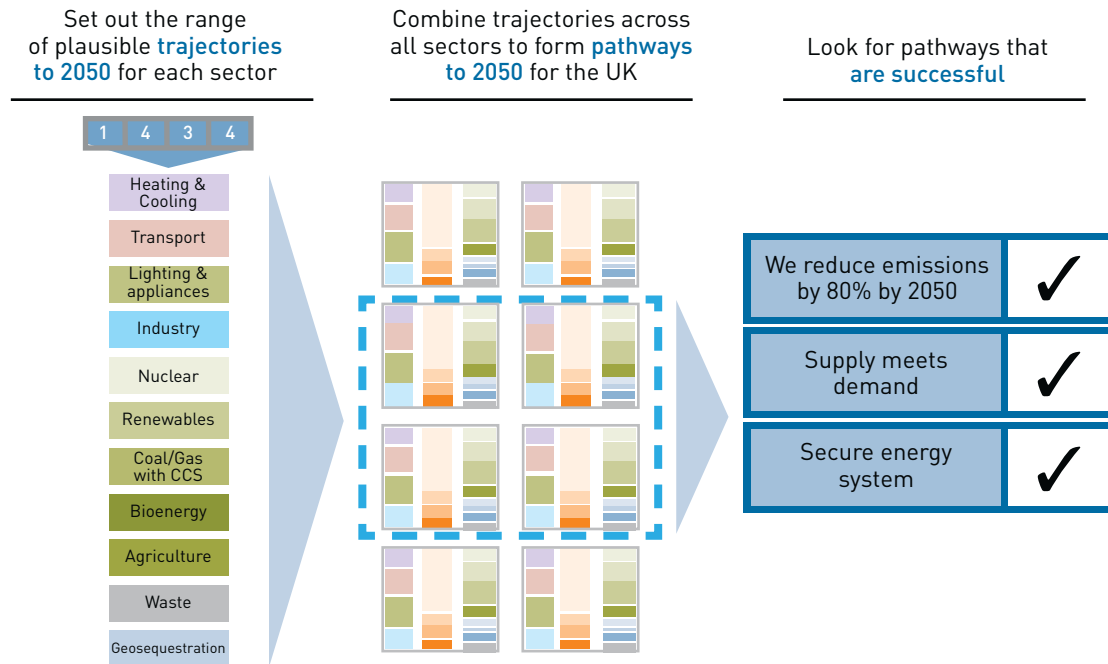
The analytical approach

Given the uncertainties when considering a very long timeframe, a scenario approach has been used in this 2050 Pathways work to illustrate potential outcomes under alternative assumptions. The approach taken to explore potential pathways to 2050 was kept simple to make the assumptions and choices transparent, and to allow the 2050 Pathways Calculator model to be as flexible as possible.

A sector by sector approach has been used to understand what levels and types of change are physically possible in each area of the emissions and energy system. For each sector a range of four different future trajectories are set out, and these aim to span the full range of potential futures in that sector.

Having understood the range of trajectories in each individual sector, a computer model was developed (the 2050 Pathways Calculator) which makes it possible to combine the sectoral trajectories together in different ways to construct possible pathways to 2050. The approach looks not just at 2050 as an end point, but at the sequence of changes that would need to occur over the next 40 years.

The schematic below describes the process undertaken.



Developing the sectoral trajectories

The first step was to build a picture of the range of changes which might be possible in the different energy supply and energy demand sectors. In addition, sources of non-energy-related emissions (for example agriculture) were also explored. Emissions from the non-energy sectors are important as these can be particularly hard to reduce. In addition, as the energy system decarbonises, these emissions will take up a far larger share of total emissions.

The sectors examined were as follows.

Energy supply sectors

- bioenergy
- nuclear
- fossil fuels with carbon capture and storage (CCS)⁵
- onshore wind
- offshore wind
- tidal range
- wave and tidal stream
- micro-generation
- geothermal
- hydroelectric power

5 The work considers CCS being applied to both gas and coal. However in the Calculator itself, in order to simplify the modelling, coal is mainly used. This can give the impression that gas is not expected to be used, but this is not a conclusion of the analysis. We will be looking to refine this aspect of the Calculator over the coming months, and welcome views on how the relative roles of coal and gas out to 2050 may vary from those shown in this analysis.

The detailed analysis focuses on low carbon energy supply sectors, but the implications for coal, gas and oil use are also explored. We do not set out a range of trajectories for these fossil fuels, as they are assumed in this model to be available from domestic and global sources in the quantities required. The model uses these fuels after having used all the low carbon energy available in each pathway.

Energy demand sectors

- lighting and appliances
- transport
- industry
- heating and cooling

Non-energy sectors

- waste
- agriculture (noting that there is some energy demand from agriculture)
- industrial processes
- land use, land use change and forestry
- negative emissions⁶

In each sector, up to four trajectories were developed for the types of changes that might be seen.⁷ These are designed to cover a broad range of possibilities and to test the boundaries of what might be possible. They are intended to reflect the whole range of potential futures that might be experienced in that sector. They are illustrative and are not based on assumptions about future policy and its impacts, and should not be interpreted as such.

The trajectories developed have drawn on existing work as well as input from a large number of experts in businesses, NGOs, technical fields, and academics, through workshops and other discussions. Several hundred stakeholders have so far been involved in the analysis, and about 100 of those experts took part in detailed discussions about the trajectories. A diverse range of views and expertise has been included and we are grateful for the input we have so far received. This is only the start of the conversation and we hope that this Call for Evidence will provide even more detailed input into the analysis. The list of questions and the instructions for how to participate in the Call for Evidence can be found on page 44. We are keen to refine this analysis in the light of new evidence.

The section below describes how the trajectories were defined and developed. The work aimed to achieve a level of consistency across the different sectors in terms of 'level of change', so that a 'level 2' effort in one sector would be broadly comparable to a 'level 2' effort elsewhere. Although by necessity this is something of a subjective judgement – particularly when comparing very different sectors, for example offshore wind power and thermal comfort levels in buildings. Part 2 below gives a full explanation of how each trajectory was developed and what assumptions were made in shaping them in each sector.

⁶ Negative emissions technologies aim to remove carbon dioxide directly from the atmosphere, for example via burning biomass in CCS power stations.

⁷ In some sectors, additional choices can be made about technologies or conversion processes. For international shipping, only one trajectory is available.

The energy supply sectors

The energy supply trajectories examine different energy generation sectors. These trajectories have been presented as four levels of potential roll-out of energy supply infrastructure (levels 1–4), representing increasing levels of effort. The levels depend on the lead time and build rate of new energy infrastructure, and different assumptions about how quickly and on what scale the infrastructure can be rolled out. The higher levels also depend on improvements in technology, such as floating wind turbines and carbon capture and storage. The build rates will in practice depend not only on the physical possibilities, but also on investment decisions by the companies involved, as well as wider international developments and public acceptance.

- **Level 1:** assumes little or no attempt to decarbonise or change or only short run 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 the build rate 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 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 observer. This level pushes towards the physical or technical limits of what can be achieved.

It should be recognised that even at level 2, the consequences of pursuing this effort across several different sectors in parallel will place a high demand on supply chains and skills, especially given that other countries are likely to be undertaking concurrent infrastructure changes.

In addition to the domestic supply sectors, the analysis also sets out some international dimensions, including four levels of potential bioenergy imports and four levels of electricity imports.

The energy demand and non-energy sectors

The demand sectors explore several different drivers of change. The primary drivers of change are summarised below. Where these factors can be considered as changing levels of effort or ambition, these are described in the analysis as levels 1–4 on a similar basis to the supply side sectors. Where the changes described reflect a choice rather than a scale (for example choices of fuel or technology), they are described as trajectories A, B, C, D; these choices cannot be compared between sectors.

The demand trajectories have been developed to be consistent with two key input assumptions: 0.5% per year growth in population, based on the central scenario of the Office of National Statistics; and 2.5% growth in the UK GDP to reflect HM Treasury's assumption for long term growth. Different actual rates of population and GDP growth would have potentially significant impacts on the level of effort required to reach 80% emissions reductions.

In determining the trajectories, several factors are considered:

- **Levels of behavioural and lifestyle change:** reductions in energy demand and emissions through changes such as wasting less food; accepting lower average room temperatures in winter; and transport mode shifts, such as from private to public transport.
- **Levels of technological improvement and change:** the development and penetration of less carbon intensive technologies, such as LED lighting or ground source heat pumps; technological advance such as new industrial processes; and improvements in the efficiency of existing technologies. More ambitious trajectories may be dependent on the successful deployment of technologies still in development.
- **Different technological or fuel choices:** technological and fuel choices that are not directly related to ambition levels; examples include choices between district heating or ground source heat pumps, or between fuel cells and batteries for cars.
- **Structural change:** reflects possible changes in the structure of the economy, for example a decline or resurgence in manufacturing.

The sectoral trajectories as defined above have been entered into a computer model – the 2050 Pathways Calculator – which then allows users of the model to combine the sectoral trajectories in different ways. For the given trajectory choices, the Calculator displays how that combination compares against the emissions target and energy supply needs. The 2050 Pathways Calculator has been published on the DECC website alongside this report, as well as a user-friendly version of the model – the 2050 online tool.⁸

The 2050 Pathways Calculator has been used to explore a range of pathways that meet our aims on energy and climate change. Six purely illustrative pathways plus a high carbon reference case are described below. There are a large number of potential pathways – just a small number of these are set out below to illustrate some key themes.

How the analysis can be used

While this analysis helps us look ahead, there are some limitations to the approach. It is not possible to predict the future and none of the pathways that this analysis produces or describes is an optimal or preferred route. In particular, the pathways contained in this document do not prejudge the decision on the level of the fourth carbon budget (2023–2027) that has to be made by summer 2011. The aim of this 2050 pathways analysis is to demonstrate the scale of the changes that will be required, and the choices and trade-offs which are likely to be available to us as a society.

It is a model based on physical limits, not cost optimisation

Unlike some other approaches, this 2050 Pathways analysis does not adopt a cost optimisation approach – ie, the Pathways Calculator does not identify the least costly way of meeting the 2050 target. The aim instead is to look at what might be practically and physically deliverable in each sector over the next 40 years under different assumptions. The Calculator then allows users of the tool to explore their own choices.

8 http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/2050/2050.aspx.

Cost is of course one critical dimension when making such a choice, and the cost implications for large scale electricity generation in different pathways are described below as an illustration. Other criteria such as public acceptability, land use impacts, wider environmental impacts, practical deliverability, technological risk, international dependency, business investment behaviour, and fiscal, competitive and socio-economic and welfare impacts would also be important in understanding which of the potential pathways to 2050 is most desirable and most deliverable.

In exploring pathways, it is important to bear in mind that the 'level 4' sectoral trajectories represent heroic levels of effort or change, and as a result it might be expected that the trade-offs associated with a pathway containing level 4 ambition in one or more sectors would be particularly difficult.

Understanding the role of the economy in the pathways

The level of GDP growth is a fixed input assumption in the model (2.5% per annum). Meaning that, in those sectors where the level of change is understood to be influenced by GDP, such as transport demand, the trajectories were developed to reflect that assumption. The model does not capture potential positive and negative feedback impacts on the economy from the levels of effort implied by the pathways.

There could be benefits to a low carbon transition beyond helping to mitigate climate change. Across the world, governments and industries are looking for the technologies that can help them to decarbonise. There are valuable opportunities for British businesses to develop and manufacture these products and associated services, for both domestic and international consumption. The low carbon and environmental goods and services sector was worth £3.2 trillion in 2008–09 and employed approximately 910,000 people in the UK.⁹ The sector is the world's sixth largest by turnover value. However, other countries are also investing in order to take up the global opportunities on offer in the light of increasing efforts to reduce emissions in order to tackle climate change. To capitalise on these opportunities, the UK will need to act fast and effectively to secure competitive advantage in emerging low carbon technologies and markets. Although there are opportunities in the transition, there would also be costs on business, and it is not clear to what extent low carbon jobs will be additional to existing jobs.

The model has a UK focus

The model looks specifically at the UK. It also includes trajectories for potential international imports of bioenergy and electricity. The international context will have a strong steer on what happens in the UK in terms of the development, supply and price of new technologies, skills and fuels. This work does not attempt to assess what shape these international developments will take.

This 2050 analysis does not consider the role that international emissions credits might play in helping the UK to achieve emissions cuts cost-effectively.¹⁰ However, the Pathways Calculator tool is flexible and users of the model could in theory aim for a higher or lower emissions target than the one the UK is committed to achieving.

⁹ BIS (2009) *Low Carbon and Environmental Goods and Services: an industry analysis update for 2008–09*. www.bis.gov.uk

¹⁰ International emissions credits are a mechanism by which developed countries such as the UK can pay for emissions reductions to take place in developing countries, and count these against domestic targets. This relies on the fact that greenhouse gases have the same impact regardless of where in the world they are emitted, but abatement in developing countries can be cheaper than in developed countries.

The pathways presented in this report achieve the full 80% cuts within the UK. The model includes emissions from international aviation and shipping assigned to the UK even though these are emissions not currently part of the 2050 target.

The model does not take account of the emissions from growing biofuels abroad, from electricity generated in other countries or from the overseas manufacture of products which the UK imports, as our 2050 emissions target excludes these emissions. If the UK were to rely increasingly on imports of food, fuel, and products, it would become even more important to consider the potential global emissions impacts.

The interactions between sectors

Given the need to ensure that the functioning and content of the model is manageable, it has been necessary to keep it as simple as possible. Therefore, the 2050 Pathways Calculator model does not itself make 'intelligent' judgments about which trajectories in different sectors can sensibly be combined together: the users of the model must themselves make these judgements. A few examples of combinations unlikely to be plausible include:

- very high levels of both solar PV and solar thermal at the same time – because in practice these technologies may be competing for the same roof space;
- a thriving manufacturing industry and high levels of additional construction at the same time as a reducing demand for freight transport;
- generating electricity through non-thermal processes, while at the same time rolling out use of district heating.¹¹

Similarly, the model does not account for all possible feedbacks between trajectory levels in different sectors. Changes in one sector might be expected to have a knock-on effect in another sector, and not all of these are reflected in the Pathways Calculator.

Understanding energy security through the model

As well as aiming for the 80% emissions target, the model allows users to explore implications for managing energy supply and demand. For example, the electricity system must be continually balanced to match supply and demand. The model tests the ability of the system to meet increased demands for electricity during a five-day period of light winds and low temperatures, which can occur typically during settled periods of weather in winter. Large areas of Europe can be affected by these 'anticyclonic blocking events'.

In order to simplify the modelling process, the Calculator assumes that any new, unabated generation is provided by gas fired power stations, and all the CCS-fitted generation is assumed to be coal fired. Because of this assumption, pathways with significant CCS plant will show high coal consumption and low gas consumption in later years. The balance between coal and gas for these pathways is determined by the simplified modelling assumption, and is not a conclusion of the analysis. In reality, it may become possible to fit CCS to gas fired plant.

¹¹ This would then require heat to be generated by heat-only boilers, eliminating the efficiencies obtained from technologies such as Combined Heat and Power; the Calculator does not capture this detail.

The trajectories are not projections based on policy decisions

Although this analysis takes a detailed look at what might be possible to achieve over the next 40 years, it does not set out what policy decisions would be required to deliver such a future. A detailed policy roadmap covering such a long timeframe would be neither possible nor plausible. Instead we have described the shape of trajectories as they might be experienced on the ground under the assumptions of the associated levels.

The Climate Change Act 2008, which sets our 2050 target, introduced the concept of 'carbon budgets'. A carbon budget is the total quantity of emissions that can be emitted by the UK over a five-year period. The first three carbon budgets (2008–2012, 2013–2017, 2018–2022) were set in 2009 and require emissions in these budget periods to be reduced by 22%, 28% and 34% respectively, below 1990 levels. Carbon budgets need to be set three carbon budget periods in advance, to give long term certainty and to set an appropriate pathway to our 2050 target. The fourth carbon budget, running from 2023 to 2027, needs to be set by the middle of 2011, and the independent Committee on Climate Change will be giving its advice on the level of the budget by the end of this year.

The timeframe of the transition and the role of different groups

This model is primarily focused on the 2050 timeframe. However it also provides a picture of the transition during the interim years. It is worth noting that this transition will need to happen over a long timeframe with key decision points along the way. Although it is not necessary or indeed possible to make all these changes immediately, it is also the case that large scale infrastructure takes many years to plan, design and build, and that behaviour change is usually a gradual process, and so the UK should take the opportunity to consider options sooner rather than later.

All sections of society will need to play a part in creating a low carbon economy. In the Coalition Agreement the Government committed to a radical redistribution of power away from Westminster and Whitehall to individuals, neighbourhoods, communities, local institutions and local government across the nation. So that, wherever possible, people take control of the decisions that affect their lives. This commitment means that developing and implementing local approaches to climate change and energy policy design and development is important. Consequently, a major consideration is what individuals, neighbourhoods and communities can do to tackle climate change and energy needs by themselves if the right incentives are in place and bureaucracy removed. Climate change is a good example where individuals, communities and neighbourhoods that come together to develop innovative solutions can make a difference. There is clearly a role for central government in major projects but climate change also needs to be tackled from the bottom up, by individuals acting together in their diverse communities to solve problems. Government needs to enable people to act by putting in place the right incentives and enabling the creative power of people to solve problems. This Call for Evidence is an early move towards building a consensus across society about the potential options for a way forward and considering the roles that different parts of society will play in the transition.

This work is not about Government or the public choosing a pathway to 2050 today. Such a task would not be feasible – there is too much which is not yet known about the future. But this work starts to give us a better understanding of where the 'good bet' actions might lie, and it can be used to help us to understand the timing of future decision points. While this analysis does not set out a single roadmap to 2050, it better enables us to manage some significant uncertainties.

2. Illustrative pathways

Six purely illustrative pathways showing different potential directions of travel are described below. They combine different types and levels of change across sectors, to achieve an 80% reduction in greenhouse gas emissions by 2050, while ensuring that energy supply meets demand. These are just some of the range of plausible pathways to 2050 that can be explored with this analysis.

It is not possible to predict the future and none of the pathways that this analysis illustrates is a preferred route. By taking into account realistic constraints and considering different plausible contributions from all the different sectors that contribute to the UK's greenhouse gas emissions, the pathways illustrate some of the ways in which it is possible to allocate effort across sectors, such that the UK as a whole achieves its goals.

The pathways take into account emissions from the supply and use of energy, as well as emissions from agriculture, waste, industrial processes, carbon capture technologies, land use, land use change and forestry.¹² The 2050 analysis takes into account the possible drivers and constraints that affect different sectors, such as economic growth, population growth, technical potential, roll-out rates, land availability and ecological sensitivity.

'Successful' pathways are those that achieve an 80% reduction in greenhouse gas emissions by 2050, while ensuring that energy supply meets demand and energy is secure. Pathways would also need to ensure that cumulative emissions remain within the level likely to be allowed by future carbon budgets and this 2050 analysis does not prejudge future decisions on the level of carbon budgets, such as the fourth carbon budget.

This 2050 Pathways Analysis focuses on pathways that meet the key emissions and energy supply objectives, but before setting a long term course, further detailed analysis of the wider impacts and implications would be needed, for example, cost-effectiveness, public acceptability, and environmental sustainability.

A selection of pathways

The six pathways presented here show some different perspectives on how the target could be met. While the level of ambition in each sector varies between pathways, they aim to minimise extreme ambition in any one sector and the associated trade-offs. They all achieve an 80% emissions target while ensuring that energy supply meets demand.

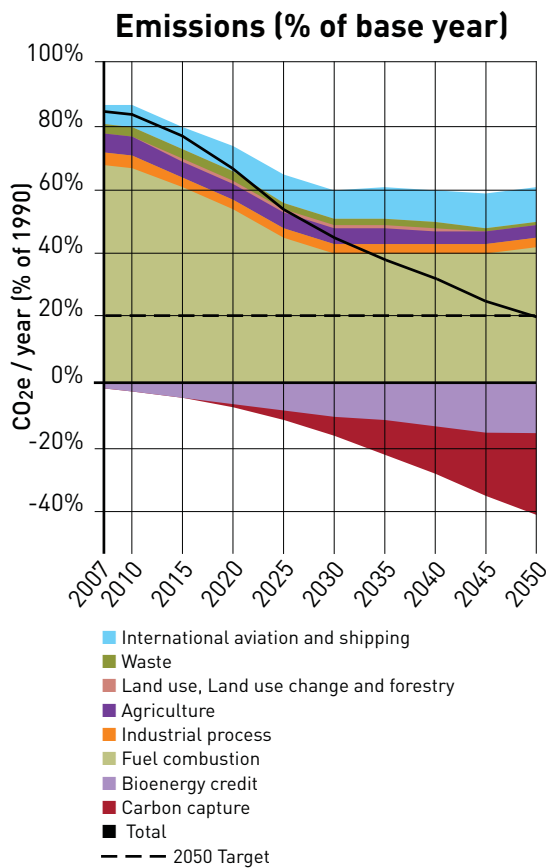
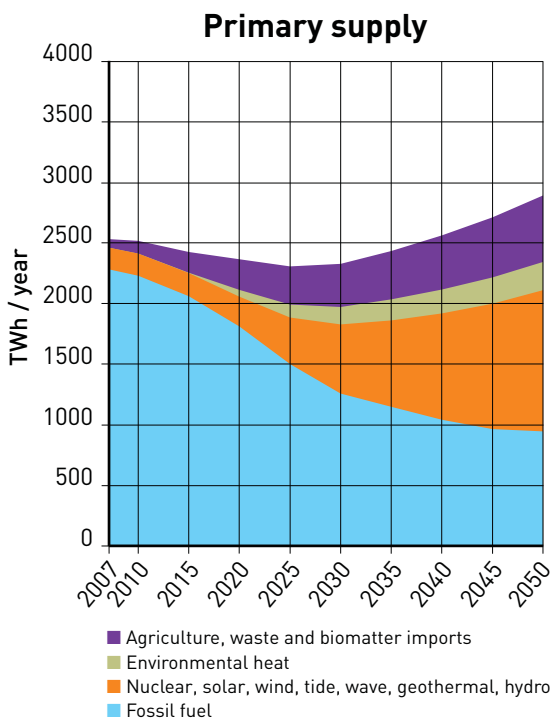
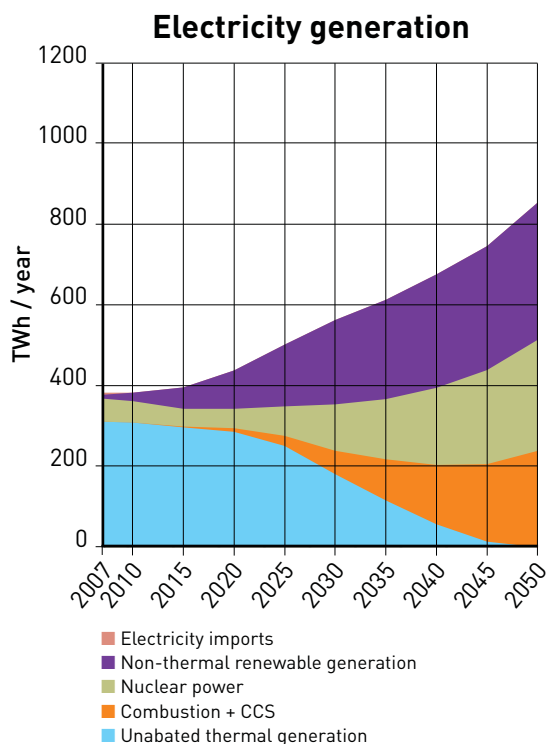
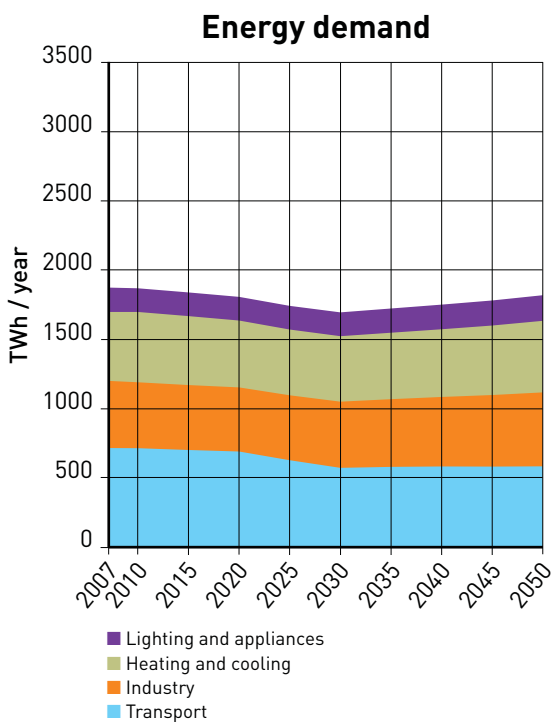
¹² For illustrative purposes, emissions from international aviation and shipping have been included in the pathways presented. However, only domestic transport is currently included in the UK's carbon budgets, because there is no internationally agreed framework for allocating international aviation and shipping emissions to nations. Aviation emissions are however bound into the 2020 EU level targets through the sector's participation in the EU Emissions Trading System. 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.

- **Pathway Alpha** illustrates a pathway with largely balanced effort across all sectors, based on physical and technical ambition. In this pathway, there would be a concerted effort to reduce overall energy demand; an equivalent level of effort from three large scale sources of low carbon electricity (renewables, nuclear, and fossil-fuel power stations with carbon capture and storage); and a concerted effort to produce and import sustainable bioenergy.
- **Pathway Beta** looks at what could happen if we were not able to generate electricity using carbon capture and storage technology.
- **Pathway Gamma** looks at what could happen if no new nuclear plant were built.
- **Pathway Delta** looks at what could happen if only minimal new renewable electricity capacity were built.
- **Pathway Epsilon** looks at what could happen if supplies of bioenergy were limited.
- **Pathway Zeta** looks at what could happen if there were little behaviour change on the part of consumers and businesses.
- **The reference case:** this pathway assumes that there is little or no attempt to decarbonise, and that new technologies do not materialise. This pathway does not meet the emissions targets and would not ensure that a reliable and diverse source of energy was available to meet demand – it would leave us very vulnerable to energy security of supply shocks.

The pathways are chosen to show a range of illustrative futures. Pathways Beta to Zeta show what *could* happen, not what *would* happen, if a key technology or lever were to be unavailable. The pathways below try to illustrate this wide range of futures, while at the same time minimising the need for extreme effort in any one sector (the level 4s), while aiming to avoid incompatible combinations of trajectories, and while taking account of the balancing requirements of the electricity grid. Many other pathway combinations are possible. These pathways do not reflect policy decisions and are not projections.

Pathway Alpha

This pathway reflects effort spread across all sectors.



In this pathway, all sectors would help make the transition to a low carbon economy.

This would require increasing and sustained investment in low carbon electricity generation. Among other distributed generation technologies, three main low carbon generation options (renewables, nuclear and fossil fuels with CCS) would be rolled out between now and 2050.

Despite a slight reduction in overall energy demand, demand for electricity would double by 2050, as a result of electrification of much of industry, heating and transport. Decarbonisation of generation would mean that all of the UK's electricity would come from low carbon sources by the 2040s, making significant use of the UK's wind resources, onshore and offshore, while keeping wind deployment well within the estimated limits that account for land use, sea use, ecological sensitivity and proximity constraints. It also assumes that we build new nuclear plant at a rate of 1.2 GW a year, and that carbon capture and storage on fossil fuel plants is successful and rolled out at a rate of 1.5 GW a year after 2030.

This pathway would also make use of the UK's available bioenergy resources. Against the backdrop of growing demand for food and the need to increase food production sustainably through improving productivity and competitiveness in the UK, EU and beyond, and without impacting on areas of outstanding natural beauty, we would make use of 10% of UK land for energy crops. The UK would also import an amount of bioenergy equivalent to half of the UK's projected market share of global bioenergy by 2050, based on IEA figures. The majority of this bioenergy would be co-fired in CCS power stations.

The pathway encompasses a thriving UK industrial sector, in which industry would make use of low carbon technologies that significantly reduce emissions and improve efficiency.

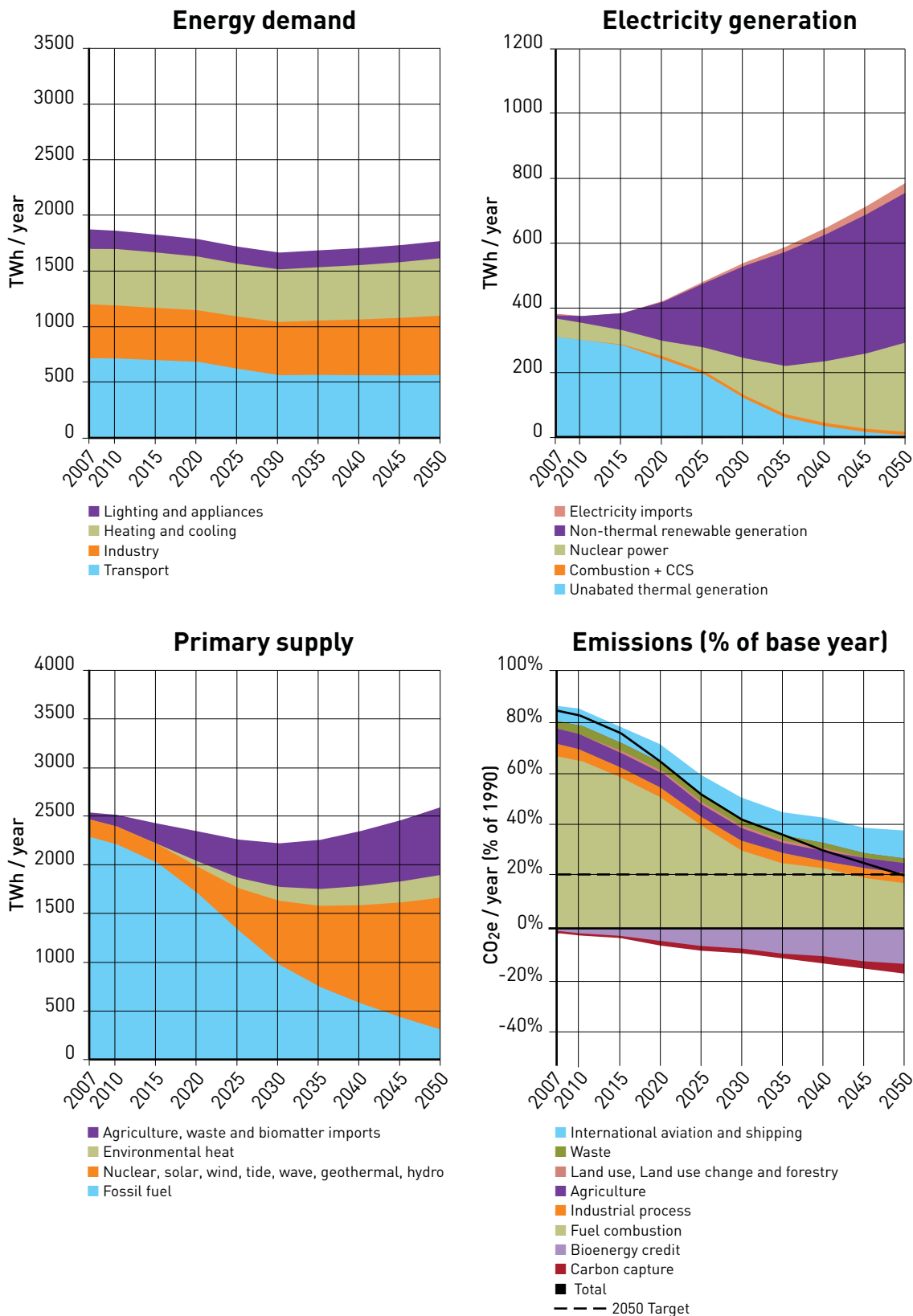
People would use the more energy-efficient lighting and appliances that are available today. Homes and buildings that are currently standing would be better insulated, with insulation measures being installed at a steady pace until 2050. New homes and buildings would be built to a very high standard to better maintain comfortable indoor temperatures, requiring less fuel for heating, and average internal temperatures would rise by just 0.5 degrees by 2050. By 2050, up to 30–60% of domestic heat demand would be met by electric technologies and most of the remainder would come from district heating connected to large power stations.

The pathway assumes that vehicles would continue to become more efficient out to 2050, and there would be breakthroughs in battery technology facilitating the introduction of significant numbers of electric and plug-in hybrid electric vehicles, such that by 2050, 60% of mileage was covered in electric and plug-in hybrid vehicles. It also assumes that there are substantial numbers of fuel cell vehicles, covering about 20% of mileage by 2050. More rail would be electrified and we would see modal shifts of freight to rail and water where these are viable options, with the share of freight travelling by road decreasing on today's levels.

Energy supply would meet energy demand overall and come from diverse sources. For the occasional cold periods when there is little wind, back-up would be through an increase in storage, interconnection with the continent and flexible demand together with 2 GW of fossil-fuel-fired back-up generation which would be inactive for most of the year.

Pathway Beta

This pathway illustrates what other sectors might do in order for the UK to achieve its objectives by 2050 if carbon capture and storage were not deployed at scale.



In this pathway, it is assumed that carbon capture and storage demonstration plants are implemented before 2018, but that no further CCS plants are built.

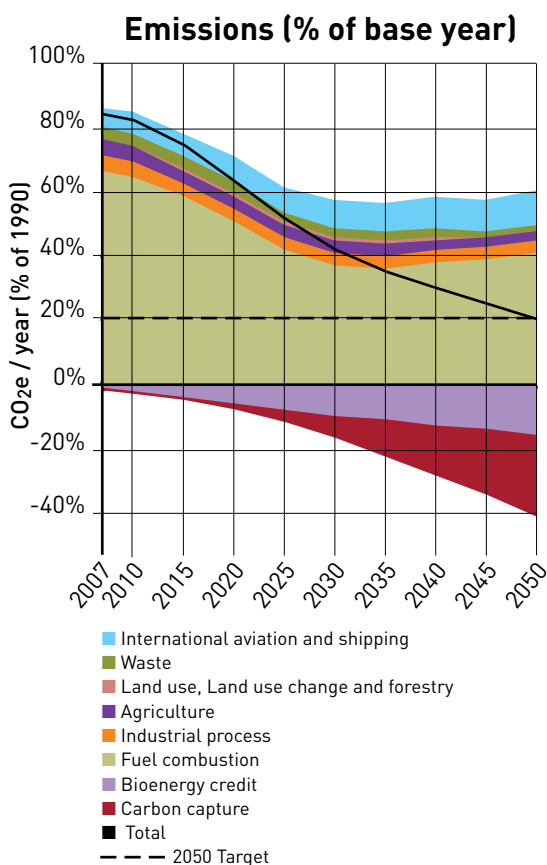
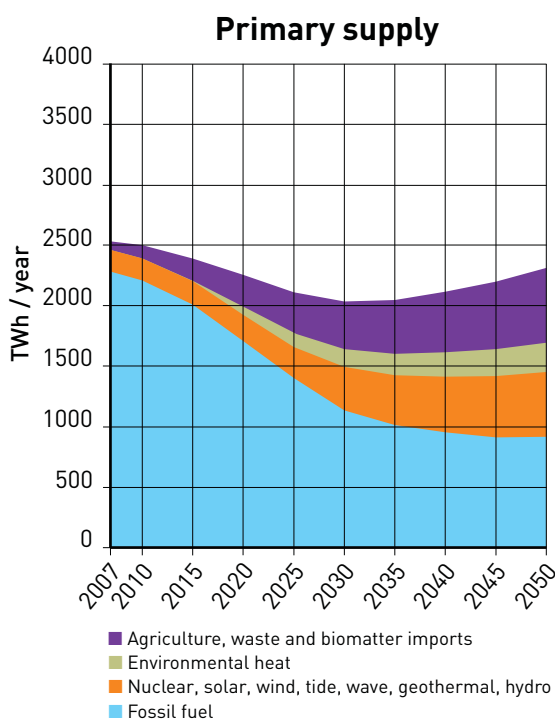
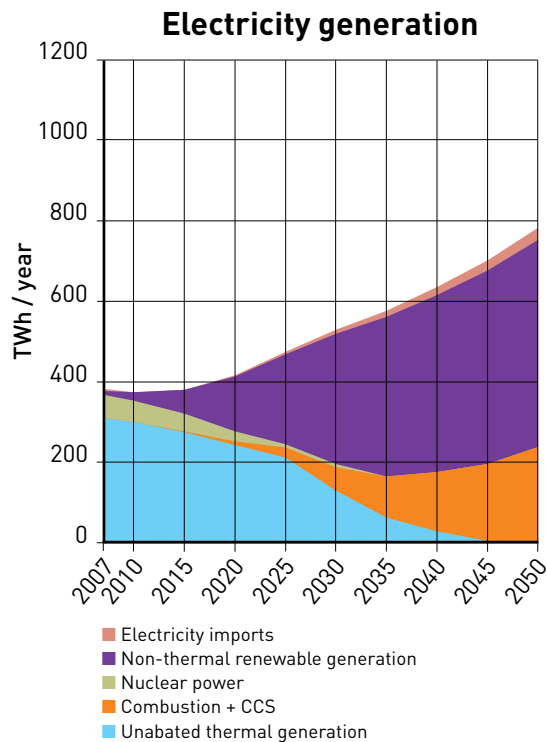
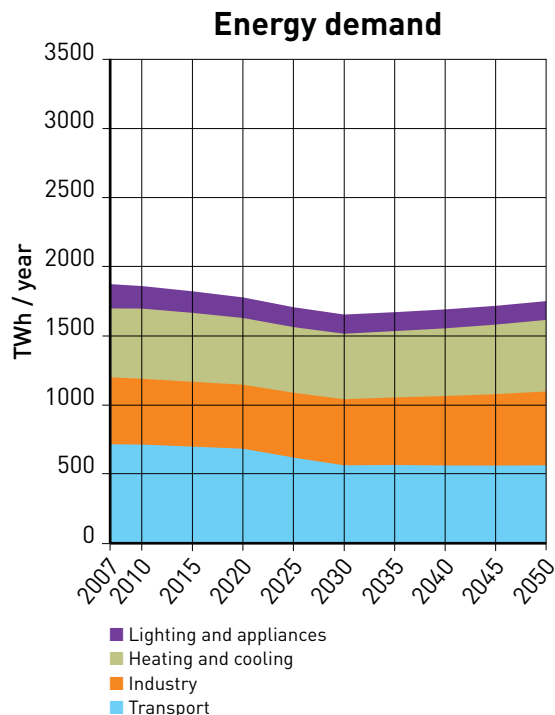
In order to meet electricity needs without CCS, it is assumed we very significantly increase effort in offshore wind. We also significantly increase bioenergy imports, such that the UK would import an amount of bioenergy equivalent to its entire projected market share by 2050, based on IEA figures. This bioenergy would mostly be used as liquid biofuels.

Under this pathway, we increase effort on reducing energy demand from domestic lighting, appliances and cooking, for example, by replacing all lights with LEDs, and using more efficient appliances. There would be greater efficiencies in the aviation sector.

Because of the large amount of renewables in this pathway, the challenges of balancing the electricity grid in the event of a five-day peak in heating and a drop in wind are more substantial. We would need a very significant increase in energy storage capacity, demand shifting and interconnection, together with 5 GW of fossil-fuel-powered stand-by generation that would be inactive for most of the year.

Pathway Gamma

This pathway addresses what might be done in other sectors if new nuclear plant were not built in Britain.



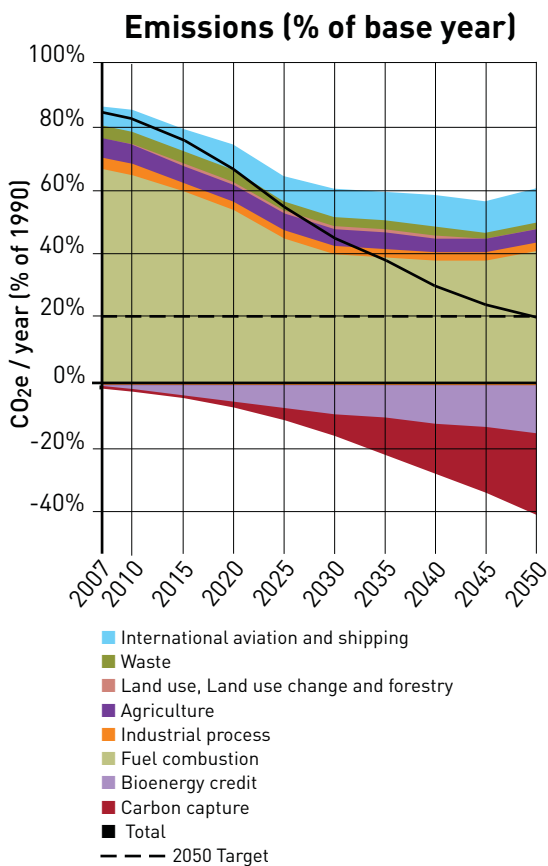
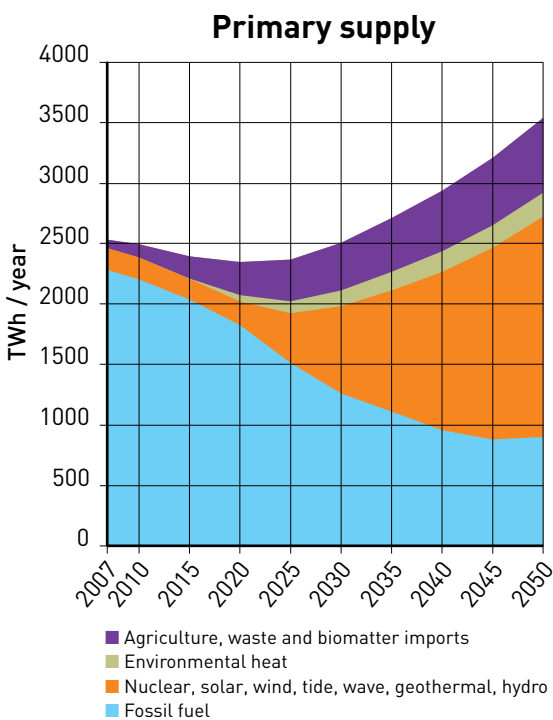
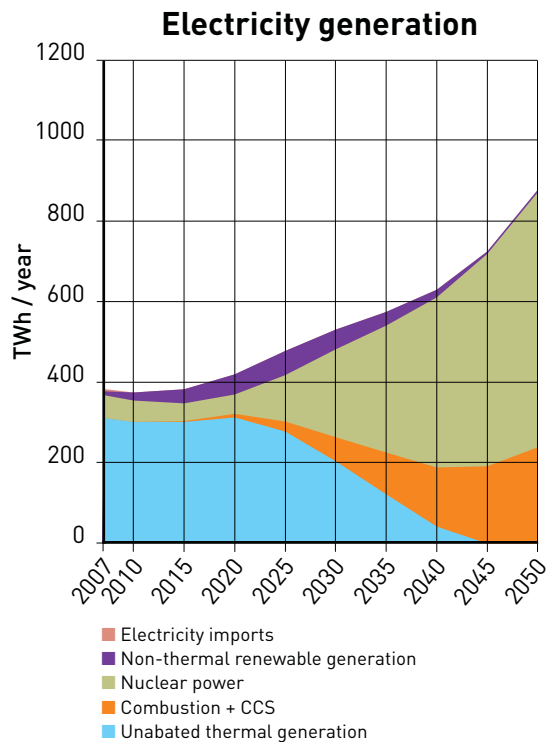
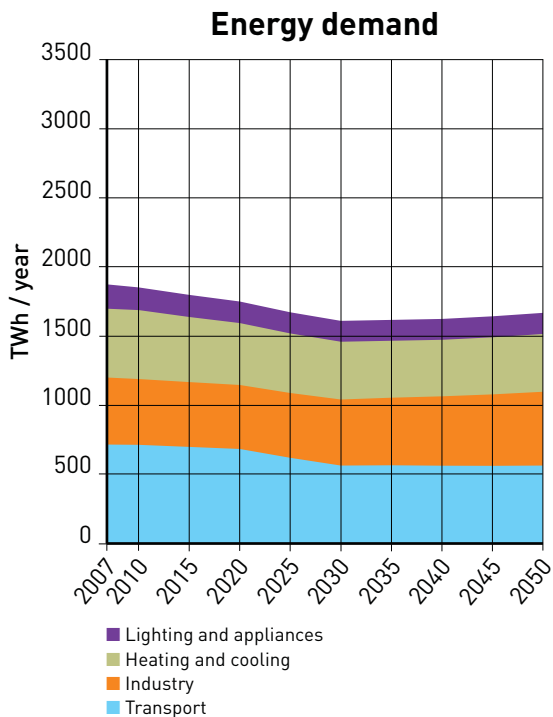
In this pathway, it is assumed that no new nuclear plants are built.

In order to meet electricity needs without new nuclear, it is assumed that compared to Pathway Alpha, we significantly increase effort from onshore and offshore wind and from distributed solar PV (the equivalent of 5.4 square metres of panels per person by 2050). Imports of bioenergy are significantly increased compared to Pathway Alpha, such that the UK would import an amount of bioenergy equivalent to its entire projected market share by 2050, based on IEA figures. Energy demand is reduced in both the domestic and commercial sectors from lighting, appliances and cooking. As in Pathway Beta, efficiencies are seen in the aviation sector.

Even more than in Pathway Beta, the challenges of balancing the electricity grid are very substantial: we would need an extremely substantial increase in storage, demand shifting and interconnection.

Pathway Delta

This pathway addresses what might be done in other sectors if we did not continue to build new renewable electricity generation.



In this pathway, it is assumed that no new renewables are built.

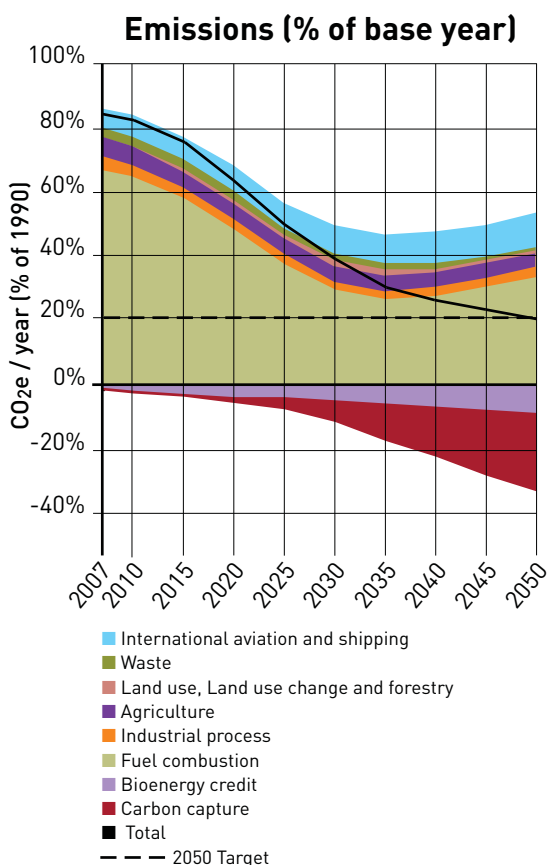
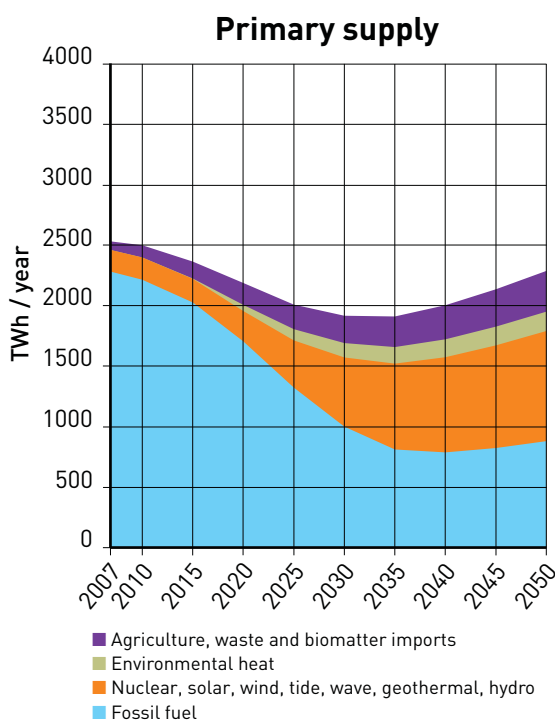
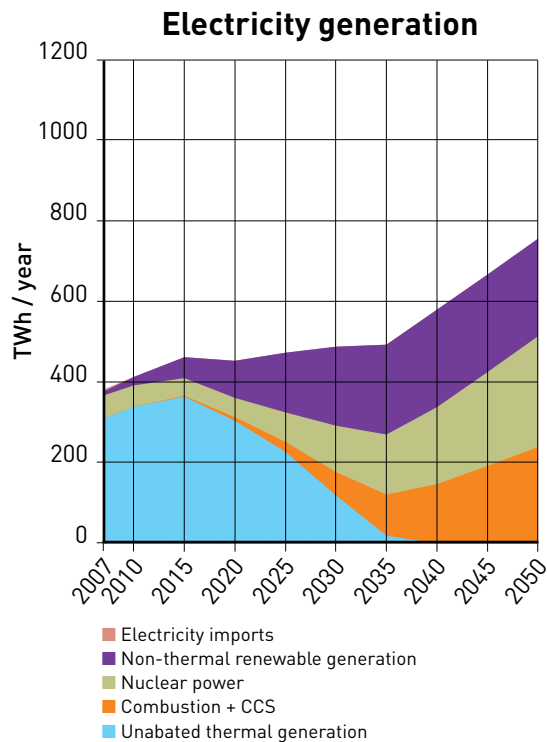
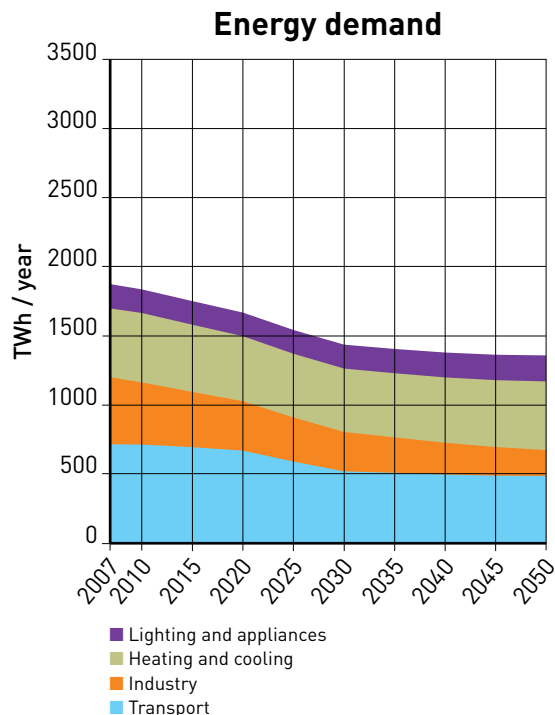
In order to meet electricity needs without renewables, it is assumed that we significantly increase effort in nuclear generation (from 57 TWh of electricity in 2007 to 633 TWh of electricity in 2050). Imports of bioenergy are significantly increased compared to Pathway Alpha, such that the UK would import an amount of bioenergy equivalent to its entire projected market share by 2050, based on IEA figures projecting future growth of bioenergy production.

Energy demand is reduced significantly across more sectors: in homes, the average temperature decreases by 0.5 degrees centigrade from the 2007 winter average, using smarter room heating controls; and insulation would be much more comprehensive: for example, 70% of appropriate dwellings would install solid wall insulation. This pathway also assumes that the UK sequesters 1 MtCO₂ per year, through for example biochar, chalk or bio cement. As in the previous pathways, efficiencies are seen in the aviation sector and demand reductions from domestic lighting, appliances and cooking.

Without renewables in the system, it is easier to balance the electricity grid and no additional back-up capacity beyond what exists today is required.

Pathway Epsilon

This pathway addresses what might be done in other sectors if only small levels of bioenergy were available.



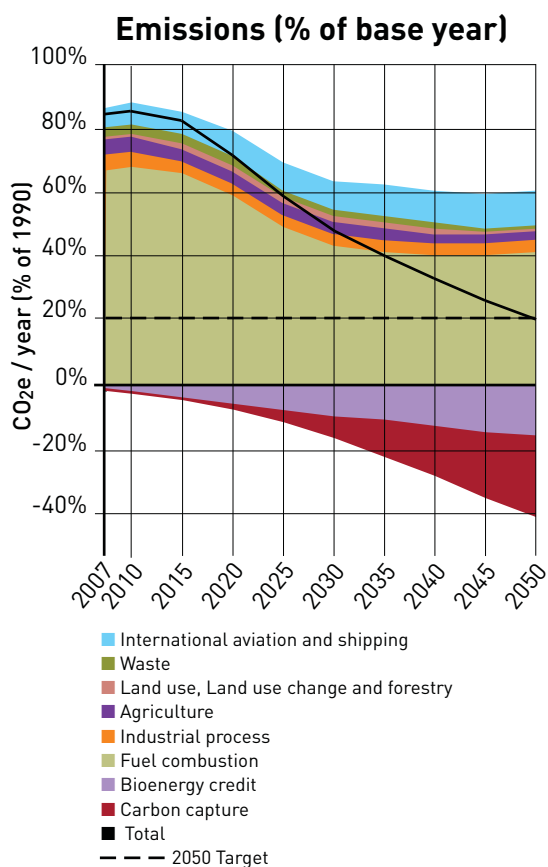
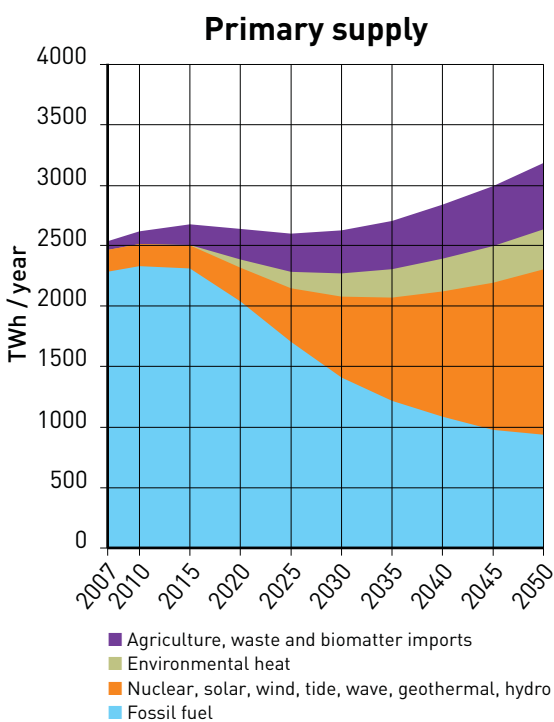
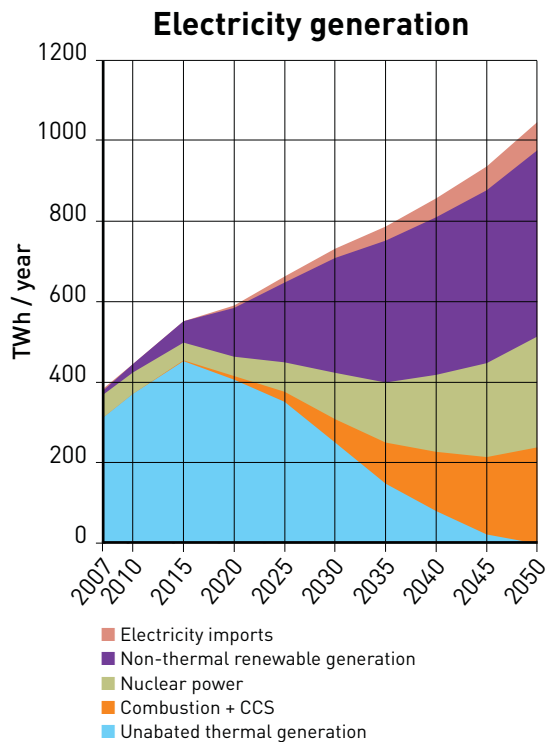
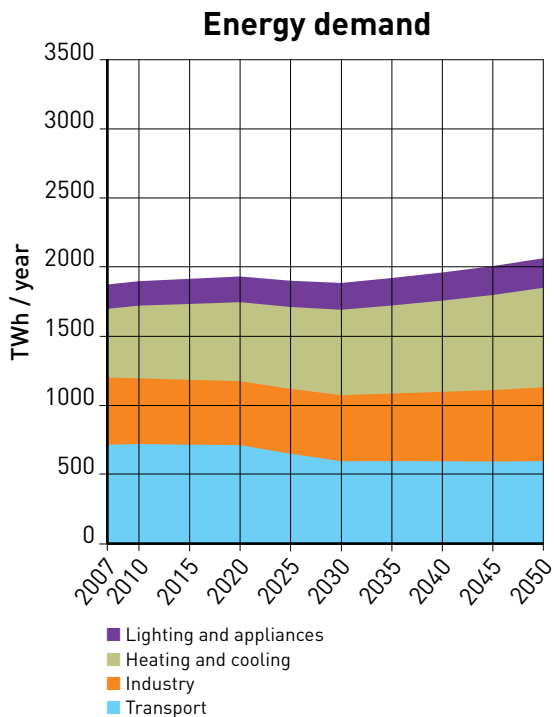
In this pathway, it is assumed that current trends and drivers in domestic agricultural production continue, such that 5% of land in the UK is used for biocrops. It assumes that we access half of UK projected market share of global bioenergy by 2050. According to the 2050 Pathways Calculator, it is not possible to meet our targets and energy needs with *no* bioenergy available.

With such low levels of bioenergy available, our energy needs are met by significantly increasing solar thermal energy provision compared to Pathway Alpha, such that all suitable buildings get approximately 30% of their hot water from solar thermal installations. In order to reduce our total energy need, extremely high levels of electrification of heating and transport are assumed: all car and van travel is powered by electricity by 2050; and all heating may need to be provided through electric heating technologies. The demand side changes are similar to Pathway Alpha in domestic and commercial appliances; and domestic and commercial heating, hot water and cooling.

The balancing challenge is also similar to that in Pathway Alpha.

Pathway Zeta

This pathway addresses what might be done in other sectors if there was minimal behavioural change.

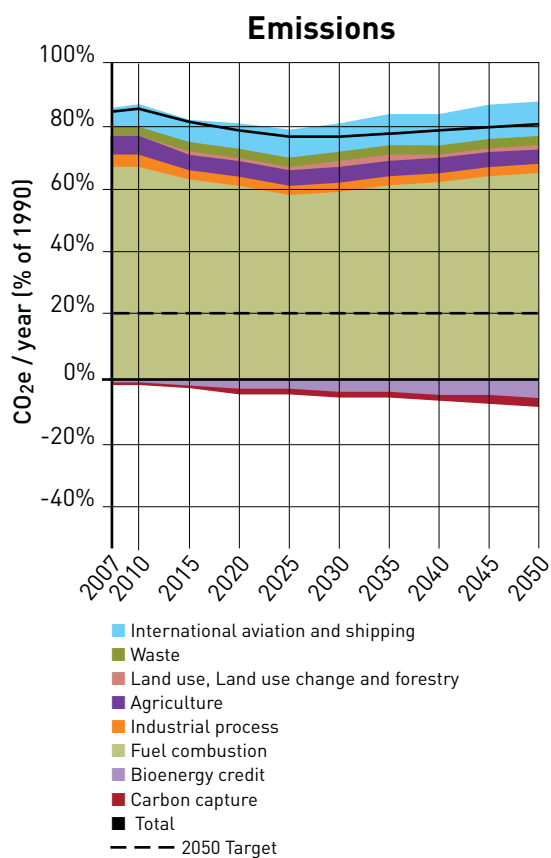
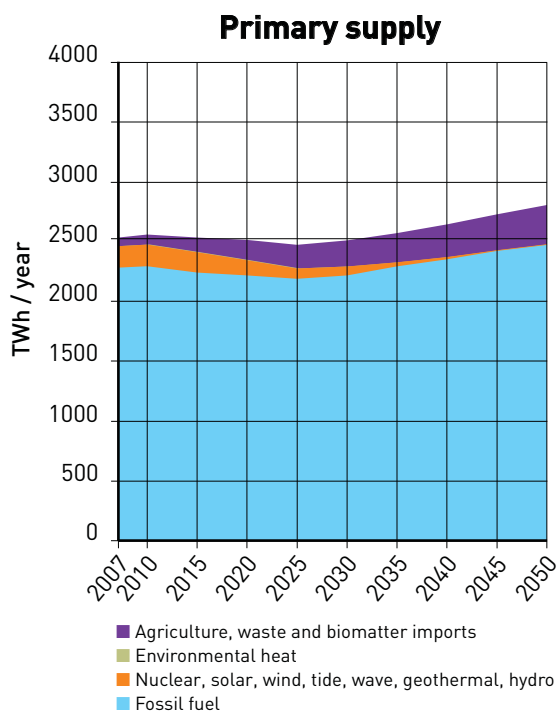
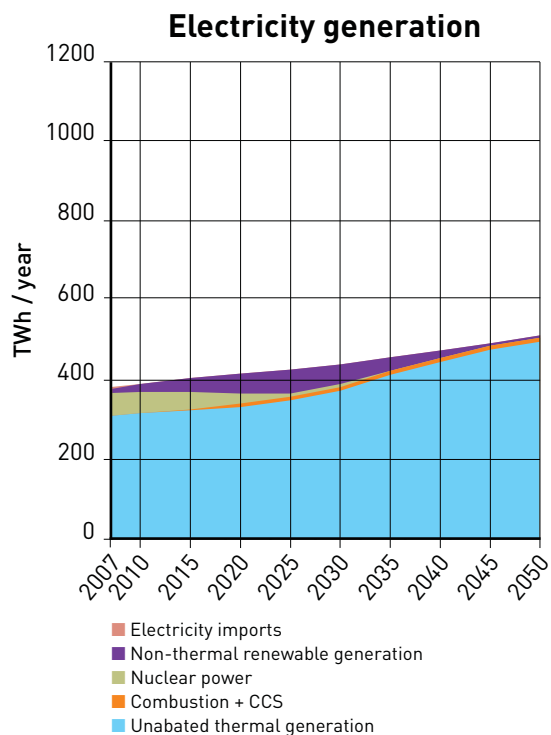
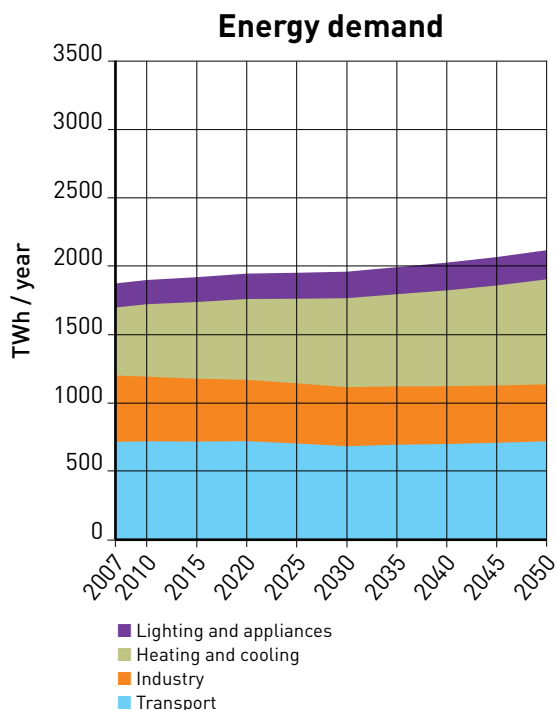


In this pathway, it is assumed that no effort is made to adapt behaviours in response to the threat of climate change and energy security concerns. This means that no efforts are made to change heating and cooling comfort levels or thermal efficiency and insulation levels in either domestic or commercial buildings. This pathway also assumes that no effort is made to reduce demand or improve the efficiency of appliances, lighting and cooking. Transport demand is assumed to rise, as in all pathways, but here private car transport continues to significantly dominate travel choices with relatively little mode shift to cycling or public transport, and the freight and aviation sectors undergo little change.

The targets are met through extremely high levels of electrification of heating, transport, industry and appliances. In order to generate enough electricity to meet needs, all generation technologies need to play a part, and offshore wind is significantly increased relative to Pathway Alpha. Electricity imports are significantly higher (70 TWh compared to 5.2 TWh net imports in 2007). We would also need to use some bioenergy, and we would make use of 10% of UK land for energy crops, and import an amount of bioenergy equivalent to half of the UK's projected market share of global bioenergy by 2050.

The balancing challenge is similar to Pathway Beta.

The reference case pathway



The above successful pathways all require a degree of effort in different sectors. For comparison we present a baseline pathway, where there would be little or no attempt to decarbonise, and where no significant new technologies are deployed at scale. Under such a scenario, with no policy effort, total emissions would only fall by around 16% from 1990 levels, far short of the 2050 target.

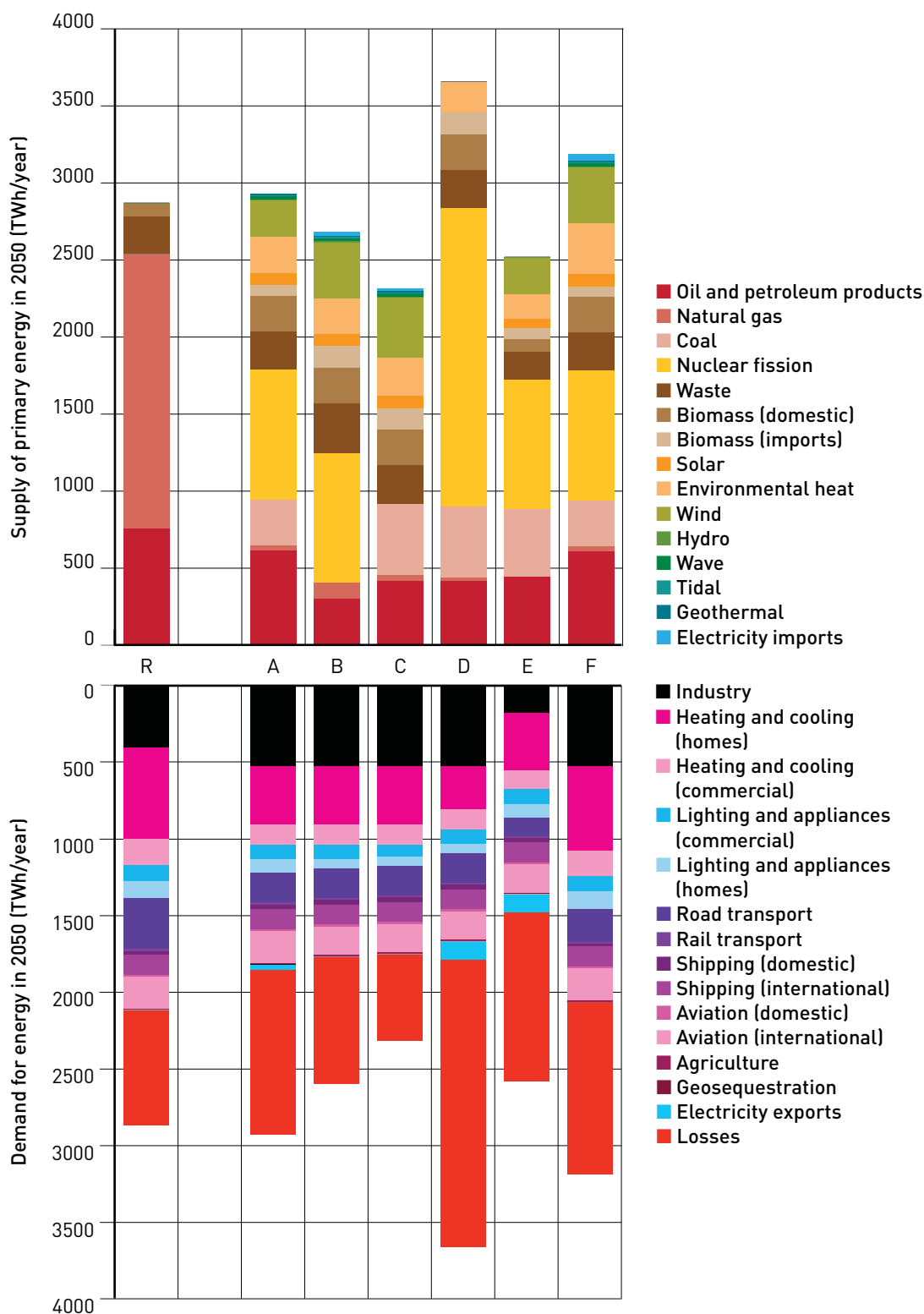
Despite the lack of effort to decarbonise, emissions are still lower than in 1990 because of the emissions reductions that had already been made between 1990 and 2010.

Summary of the selection of levels and trajectories for the different pathways

| | Alpha: cross-sector effort | Beta: low CCS | Gamma: low nuclear | Delta: low renewables | Epsilon: low bioenergy | Zeta: low behaviour change | Reference case: high carbon |
|--|----------------------------|---------------|--------------------|-----------------------|------------------------|----------------------------|-----------------------------|
| Combustion + CCS | 2 | 1 | 2 | 2 | 2 | 2 | 1 |
| Nuclear power | 2 | 2 | 1 | 3 | 2 | 2 | 1 |
| Onshore wind | 2 | 2 | 3 | 1 | 2 | 2 | 1 |
| Offshore wind | 2 | 3 | 3 | 1 | 2 | 3 | 1 |
| Hydroelectric | 2 | 2 | 2 | 1 | 1 | 2 | 1 |
| Marine | 2 | 2 | 2 | 1 | 1 | 2 | 1 |
| Geothermal | 2 | 2 | 2 | 1 | 1 | 2 | 1 |
| Distributed solar PV | 2 | 2 | 3 | 1 | 1 | 2 | 1 |
| Distributed solar thermal | 2 | 2 | 1 | 1 | 3 | 2 | 1 |
| Micro wind | 2 | 2 | 2 | 1 | 1 | 2 | 1 |
| Biomatter to fuel conversion | B | C | A | A | B | B | A |
| Bioenergy imports | 2 | 3 | 3 | 3 | 2 | 2 | 1 |
| Agriculture | C | C | C | C | A | C | A |
| Waste arising | C | B | C | C | C | C | A |
| Marine algae | 2 | 2 | 2 | 2 | 1 | 2 | 1 |
| Electricity imports / exports | 1 | 2 | 2 | 1 | 1 | 3 | 1 |
| Storage, demand shifting, backup | 2 | 3 | 4 | 1 | 2 | 3 | 1 |
| Domestic space heating and hot water | | | | | | | |
| <i>(i) Heating/cooling comfort level</i> | 2 | 2 | 2 | 3 | 2 | 1 | 1 |
| <i>(ii) Housing thermal efficiency</i> | 2 | 2 | 2 | 3 | 2 | 1 | 1 |
| <i>(iii) Electrification level</i> | C | C | C | C | D | D | A |
| <i>(iv) Non-electric fuel direction</i> | C | C | C | C | D | C | A |

| | Alpha: cross-sector effort | Beta: low CCS | Gamma: low nuclear | Delta: low renewables | Epsilon: low bioenergy | Zeta: low behaviour change | Reference case: high carbon |
|---|-----------------------------------|----------------------|---------------------------|------------------------------|-------------------------------|-----------------------------------|------------------------------------|
| Commercial heating and cooling | | | | | | | |
| <i>(i) Heat/cooling demand</i> | 2 | 2 | 2 | 2 | 2 | 1 | 1 |
| <i>(ii) Electrification level</i> | C | C | C | C | D | D | A |
| <i>(iii) Non-electric fuel direction</i> | C | C | C | C | D | C | A |
| Domestic lighting, appliances, and cooking | | | | | | | |
| <i>i) Demand/Efficiency</i> | 2 | 3 | 3 | 3 | 2 | 1 | 1 |
| <i>(ii) Technology pathway</i> | B | B | B | B | B | B | A |
| Commercial lighting, appliances, and catering | | | | | | | |
| <i>(i) Demand/Efficiency</i> | 2 | 2 | 3 | 2 | 2 | 1 | 1 |
| <i>(ii) Technology pathway</i> | B | B | B | B | B | B | A |
| Industrial processes | C | C | C | C | D | C | A |
| Domestic passenger transport | | | | | | | |
| <i>(i) Behaviour</i> | 2 | 2 | 2 | 2 | 2 | 1 | 1 |
| <i>(ii) Electrification</i> | C | C | C | C | D | D | A |
| Domestic freight | 2 | 2 | 2 | 2 | 3 | 1 | 1 |
| International aviation | 1 | 2 | 2 | 2 | 2 | 1 | 1 |
| International shipping | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Geosequestration | 1 | 1 | 1 | 2 | 2 | 1 | 1 |

Figure 1: A summary of energy supply and energy demand in 2050 across the illustrative pathways



There are of course other pathways that achieve the UK’s emissions target. We are keen for others to explore the alternative plausible pathways, using the 2050 online calculator tool.

We have explored some common messages from the pathways illustrated above.

Common messages from the pathways

Through exploring some of the different possible ways to achieve an 80% emissions reduction, this work has drawn out some common elements of the plausible pathways and explored the implications and uncertainties associated with different choices. It reveals the scale and pace of change that is required and some of the key decisions that will be faced. Below, some of the implications of the illustrative pathways are set out.

Ambitious per capita energy demand reduction is needed. In these illustrative pathways, total energy demand in 2050 ranges from 10% above to 45% below 2007 levels, even though over the 40 year period the population grows by 25%, the number of households by 50% and GDP by almost 200%. The greater the constraints on supplies of low carbon energy, the greater the ambition on demand reduction through energy saving and efficiency will need to be. Only one of the pathways presented in this report sees an increase in total energy demand, Pathway Zeta. As a result of failing to reduce demand for energy in this pathway, the UK would need to see very significant ambition in all supply sectors to generate enough electricity.

A substantial level of electrification of heating, transport and industry is needed. Decarbonised electricity can be used for a wide range of activities, often with high efficiency compared to other fuels, and can be scaled up to meet demand. It therefore makes sense to switch to electricity where this is practical, despite the major technological and engineering challenges involved. For heating, other technologies (for example, using heat from power stations, and solar thermal technologies) may also be required. In road transport, biofuels may play a role and fuel cells may also be a long-term contributor, particularly for sectors that are hard to electrify. However, some degree of electrification appears to be critical—analysis of alternative pathways shows that failing to at least partially electrify heating and transport would make the emissions target undeliverable unless very substantial demand reductions and technological breakthroughs were made and extremely large amounts of bioenergy were available.

Electricity supply needs to be decarbonised, while supply may need to double. The use of electricity for significant parts of the industry, heating and transport sectors would mean that demand for electricity would be likely to rise, even as overall energy use declines.

- This would require substantial, sustained investment in low carbon electricity generation technologies, beyond current levels.
- The transmission grid would need to become bigger and more sophisticated. It would draw in electricity from a wider range of providers, likely to include offshore wind turbines and electricity imports. A greater number of interconnections to neighbouring countries may be of mutual benefit in smoothing variable renewable supplies and increasing access to competitively priced sources of electricity.
- Electrification of industry, transport and heating systems may potentially double overall electricity demand. The distribution network would need to become bigger and smarter to enable this.

A growing level of variable renewable generation increases the challenge of balancing the electricity grid. Potential growth of peak loads, combined with the expansion of inflexible or variable low carbon generation sources, such as wind power, would present challenges for the management of electricity networks. Demand-side flexibility could help by providing consumers with new incentives to shift demand to

better match electricity generation. But either significant storage, interconnection and other balancing technologies are likely to be required, or we would need to rely on extra back-up capacity.

Sustainable bioenergy is a vital part of a low carbon energy system. There are energy demands – such as industrial high grade heating processes, long-haul road freight journeys and aviation – where electrification is unlikely to be practical. However, it is not feasible to continue using solely fossil fuels in all of these sectors and achieve an 80% emissions cut, without using international credits. In these sectors sustainable bioenergy currently offers the only plausible option for domestic action. Working towards establishing sustainable bioenergy supply chains will be an important activity in the coming years. In all practical pathways explored through the analysis, some level of sustainable bioenergy is required to reach the 2050 target. In some pathways the use of bioenergy with carbon capture and storage (BECCS) is important. This is where bioenergy is burnt to produce electricity and the carbon dioxide released is captured and stored, which can lead to a net reduction in carbon dioxide in the atmosphere. This has a potentially large greenhouse gas benefit, but is dependent on the ability to use CCS with biomass – which has not yet been proven at scale.

Reduction in emissions from agriculture, waste, industrial processes and international transport will be necessary by 2050. In addition to emissions from the energy sector, greenhouse gases are emitted by livestock, waste, soils and industrial processes. If no action were taken to reduce emissions from agriculture, waste, and industrial processes, as well as those from international aviation and shipping (which are not currently included in the 2050 target, but are included in the 2050 Pathways Calculator), then these sectors alone would exceed the maximum level of emissions allowable for the whole economy under an 80% cut.

Fossil fuels continue to play a role. The pathways show an ongoing need for fossil fuels in our energy mix, although the precise long term role of oil, coal and gas will depend on a range of issues, such as development of CCS.

Uncertainties and trade-offs presented by the pathways

As well as a set of common conclusions, the pathways analysis also identifies some areas of uncertainty, where it is not yet clear what developments will take place, or what the optimal choice would be. Key areas of uncertainty are described below.

The shape of future energy infrastructures. Different low carbon pathways present different implications for the infrastructures required. In order to facilitate a low carbon pathway there will be important decisions to make in the coming years on creating, extending or upgrading the electricity networks, electricity interconnectors, transport infrastructures, the gas grid, oil and petroleum infrastructures, CCS pipelines, bioenergy infrastructure and heating infrastructures. In particular:

- Upgrades in electricity transmission and distribution networks need to plan to allow for growth in electricity demand.
- The long term future of the gas distribution network is uncertain, and the network could have diminishing use if a decline in the use of fossil gas is not offset by use of biogas. The long term future of this asset during the transition to a low carbon UK needs to be better understood.

The precise 2050 electricity generation mix. A range of electricity-generating technologies could contribute to the 2050 supply mix:

- The highest potential contributions come from wind, nuclear and fossil fuels with CCS. Smaller but potentially important contributions could be made from other renewable sources.
- There remain some technological uncertainties around many low carbon electricity generating technologies, which emphasises the need for a portfolio approach.
- As described above, a growing level of variable renewable generation would place greater emphasis on sources of supply and demand flexibility and storage. The level of need and balance of solutions will be influenced by market arrangements, incentives and technological development, but are likely to include:
 - higher levels of interconnection with neighbouring countries to allow fluctuations in demand and supply to be smoothed across a number of countries;
 - new storage technologies, such as large scale batteries; and
 - smart or flexible demand, such as off-peak charging of electric vehicles.

Availability of sustainable bioenergy. Some bioenergy will be important to achieving the UK's emissions target, but the extent of sustainable bioenergy resources, and the potential for their expansion, are uncertain. There is likely to be competition for bioenergy resources globally and from a number of sectors.¹³ The utilisation of both domestically produced and imported bioenergy will require careful monitoring of the associated emissions arising from its cultivation and transportation, and the impacts of direct and indirect land use change, the potential air quality and health impacts of production processes and usage, the effects on local livelihoods and natural ecosystems of large scale bioenergy cultivation, and impacts on global food prices. 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. Also, when considering infrastructure that would use sustainable bioenergy, the UK should continue to assess the risk of locking-in a sub-optimal use of limited bioenergy resources.

International dynamics. The direction that other nations take will affect fuel and resource demand, availability and price, supply chains for key technologies, and technological development. UK decisions need to respond to shifting global priorities and events, to be resilient to developments and to maximise UK business opportunities. As well as in the area of low carbon technologies, international developments will be particularly influential in four fuel sectors:

- **Sustainable bioenergy:** availability will depend increasingly on technological and supply chain development, and global sustainability criteria, as well as demand from other countries.
- **Oil:** production and use will decline substantially in our energy mix by 2050, but use of oil is likely to remain an important fuel for some sectors, and an important feedstock for manufacturing. Indeed the decline in UK oil production is such that under some scenarios our need for oil imports may be higher in 2050 than today.

¹³ There may also be competing demands for biomass resources for non-energy uses such as construction and chemical feedstocks.

- **Gas:** will remain an important fuel for many years to come, but its precise long term role will depend on developments such as the viability of CCS at scale.
- **Coal:** use of coal will decline substantially in our energy mix by 2050, and its use in the transition will also depend on CCS developments

To deal with this, the UK will need to build on its range of policies to promote the development and deployment of energy efficiency policies and low carbon technologies internationally, promote price stability via efficient and transparent markets and encourage investment in essential fossil fuels production. The UK will also need to continue working with its partners in Europe to ensure that further progress is made on the functioning and integration of EU energy markets, the diversity of the routes and sources of the EU's energy supplies, and the move to a low carbon economy.

The availability, cost and public acceptability of international credits will influence the level of abatement needed in the UK. Purchase of credits reduces the level of action needed in the UK, by paying for equivalent emissions reductions abroad.

Technological uncertainties. Each of the pathways is reliant upon the development and innovation of a range of technologies. Some of these technologies have been demonstrated but require scaling up; other technologies are more speculative and to some extent unproven. It is not possible to predict exactly how this range of technologies will develop over the next 40 years and surprises will occur – both successes and failures. Some of the most critical areas of technological uncertainty include:

- low carbon heating technologies—several technologies have potential but few have so far been deployed on a wide-scale in the UK;
- low carbon road vehicles, with breakthroughs anticipated in both battery and fuel cell technologies;
- 'second generation' biofuels processes, which require development and scaling up;
- CCS, which is yet to be demonstrated at a commercial scale on a power station. The full extent of geological CO₂ storage is still to be proven;
- hydrogen,¹⁴ which may have potential in the long term to offer flexibility to the power sector and provide a low carbon fuel to segments of transport demand;
- negative emissions technologies are currently highly uncertain.

Environmental impacts. Cutting greenhouse gas emissions is a key part of protecting our local and global environment. However, the deployment of low carbon energy on the scale needed presents some tensions with other environmental objectives. For example:

- offshore wind turbines might affect the marine environment and onshore turbines may be at odds with landscape character;
- wave and tidal power could affect sensitive marine and coastal habitats; and
- the production of bioenergy can have implications for biodiversity domestically and internationally and food supplies and its use can affect air quality.

¹⁴ Hydrogen does however need to be generated using low carbon energy (such as low carbon electricity) and its generation involves efficiency losses.

A successful pathway for decarbonising our economy will need to involve an acceptable balance between those tensions and, where feasible, solutions which bring multiple environmental benefits.

Understanding the cost implications

The 2050 Pathways Analysis explores the physical and technical limits of what can be delivered within each sector over the next 40 years. But in evaluating different pathways, there are a range of implications which are important to understand. One critical implication is the cost of each pathway.

Providing a comprehensive estimate of the costs of decarbonisation out to 2050 is very challenging. First, it is impossible to predict accurately how fuel and technology costs will develop over such a long period. Costs will necessarily depend on the assumptions on fuel prices, technology development and the paths taken by other countries. And in some sectors the technological solutions required to allow the necessary emissions reductions are not yet known. Second, many of the wider impacts of the move to a low carbon economy are very difficult to quantify, for example those on security of supply, the wider environment and people's behaviours.

Cost estimates from other studies

Other published studies have attempted to cost decarbonisation. The studies are not directly comparable to this 2050 Pathways Analysis, but they provide a high level picture of the magnitude of costs which people are anticipating over the long term. These studies suggest that the costs of decarbonising are manageable, though they are sensitive to assumptions about the future costs of technologies and fossil fuel prices, and also the underlying structures of the models.

A recent Ofgem study suggested that around £200 billion of investment in the UK's energy infrastructure is necessary over the coming decade to 2020.¹⁵ Looking beyond 2020, the uncertainties surrounding the cost projections increase. Nonetheless, Lord Stern's review suggested a macro-economic cost of around 1% of global GDP by 2050 to stabilise global emissions: less than the costs of the environmental impacts of failing to act.¹⁶ Previous DECC analysis has reached similar conclusions, for example analysis published in 2009¹⁷ found that an 80% 2050 UK emissions target meant that UK GDP is 0.85% lower in 2050 than in the baseline. A joint study by some leading organisations has recently costed 2050 pathways for the European Union.¹⁸ This concluded that under a series of assumptions, for the EU as a whole, the cost of electricity and overall economic growth in the decarbonised pathways would be comparable to the baseline over the period 2010–2050.¹⁹

15 Ofgem (2009) *Project Discovery*, 2009. This figures excludes investment in UK Continental Shelf oil and gas production.

16 Stern, N (2006) *The Economics of Climate Change*.

17 DECC (2009) *The UK Low Carbon Transition Plan: National strategy for climate change and energy*

18 McKinsey & Company, KEMA, Imperial College London, Oxford Economics and the European Climate Foundation. <http://www.roadmap2050.eu/>

19 The assumptions included: industry consensus learning rates for those technologies; increased emission reduction efforts in the rest of the world; market demand for low carbon investments; IEA projections for fossil fuel prices; a significant expansion of grid interconnection between and across regions in Europe; and an average carbon price of at least € 20–30 per tCO₂e over 40 years.

Costs in the large scale power generation sector

The large scale power generation sector is one of the areas where some of the biggest changes are required, and we have carried out some initial costs analysis to explore the implications of the illustrative pathways for costs in this sector. *The analysis which follows is necessarily partial. It is not attempting to provide a full picture of the trade-offs between different pathways.* Given inherent uncertainties around future costs of technologies and fuels, and the limitations of the approach, these cost estimates cannot claim to be accurate projections of what actual costs would be. It is particularly difficult to assess the likely future cost of technologies still in early stages of development. The analysis does not attempt to cost the choices made in other sectors beyond the large scale generation sector. However, it is possible to draw some preliminary and tentative high level conclusions for the electricity sector from this analysis.

Approach

Drawing on published cost estimates for different generation technologies and fossil fuel price assumptions,²⁰ the physical resource costs to society of building and operating the required power generation and the associated infrastructure costs have been estimated for each 2050 Pathway. All costs are expressed in 2009 prices.²¹

This analysis includes the following costs:

- physical capital (build) costs;
- fixed and variable operating costs;
- fuel costs;
- nuclear decommissioning and waste costs; and
- infrastructure costs (the electricity transmission and distribution network, interconnectors and storage).

It does not include:

- **Financing costs:** capital intensive technology is often financed from debt and/or equity, incurring a financing cost (such as interest payments on debt). These costs are excluded from this analysis because of the difficulty of estimating the future financing costs and the required rate of return of each technology. Low carbon technologies tend to be more capital-intensive than fossil fuel technologies, meaning their costs of finance are higher; this means that relative costs of the low carbon pathways would be higher if finance costs were included.
- The **costs of carbon** (for example EU ETS allowances) have been excluded at this stage to enable a clear comparison between the reference pathway where little effort is made to reduce emissions and the low carbon pathways. Including the costs of carbon would mean that the reference pathway would be higher cost.

²⁰ These assumptions are set out in the annex.

²¹ Where costs are presented in Present Value terms, they have been discounted back to 2010 using standard Green Book discount rates to reflect the increased value society attaches to present, as opposed to future, consumption.

- **The costs of imported electricity:** some pathways involve importing electricity. It is unclear how much this electricity will cost and for this reason the costs have been excluded from the analysis. Including them would increase the relative costs of those pathways which include significant amounts of electricity imports.
- **Research and development (R&D) costs:** the rates of technology deployment imply that significant investment is needed in R&D. However, these costs are very difficult to estimate. Many low carbon technologies are less mature technologically than fossil fuel technologies, such that higher levels of R&D spending will be required to make them more competitive. This means that the relative costs for the low carbon technology pathways would likely be higher if these costs were included.
- **Behavioural change costs:** the direct costs of changing people's behaviour (for example, through information campaigns to encourage people to use less electricity) have not been estimated, or the welfare costs implied by changes in behaviour (for example, through changes in patterns of electricity use). Moving to a low carbon economy will require more behavioural change than if we make little effort to decarbonise, meaning that the relative costs of the low carbon pathways would be higher if these costs were included.
- **Macro-economic costs:** we have not quantified what the pathways mean for adjustments in the wider macro economy, or for its resilience to shocks such as oil and gas price spikes, that have in the past caused recessions, business failures and job losses.

Moreover, the analysis does not take into account potential benefits from particular technologies – for example, in relation to security of supply, innovation or wider economic benefits. Therefore a focus purely on physical resource costs does not truly reflect the trade-offs involved with different technological choices.

Technology costs are apportioned over time broadly according to when they are incurred by society. For example, the costs of building a power plant are spread over the years of construction and the operating costs over the years of operation. This differs from those studies which apply a levelised cost approach and thereby effectively spread the costs of construction over the years of operation. Although a levelised cost approach more accurately reflects when the generator would actually pay back the costs of construction (ie, through selling the energy produced to consumers), the method used here more accurately reflects when resources are actually used, providing a better picture of the size of resources the economy needs to make available and when.

The findings

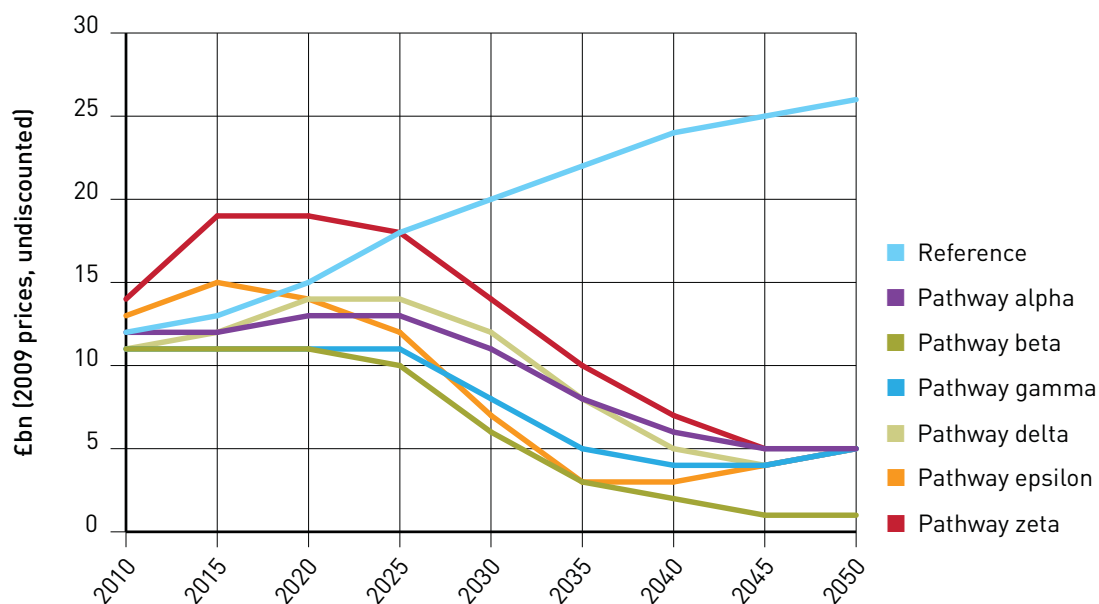
Shift from expenditure on fuel to expenditure on capital

One key feature of the low carbon pathways is their costs profile. Most low carbon generation technologies involve greater upfront capital costs but much lower operating (particularly fuel) costs than conventional power plants such as gas. Therefore, compared to the reference case, each of the illustrative pathways involves a shift from expenditure on fuel (primarily gas) to upfront expenditure on capital (building low carbon power plants).

Fuel costs

As shown in Figure 2, fuel costs in the low carbon illustrative pathways are lower in 2050 than they are today, although in some pathways fuel costs increase towards the end of the period due to CCS deployment. Compared with the reference pathway, annual undiscounted fuel costs are £5–13 billion lower in the low carbon pathways by 2030.

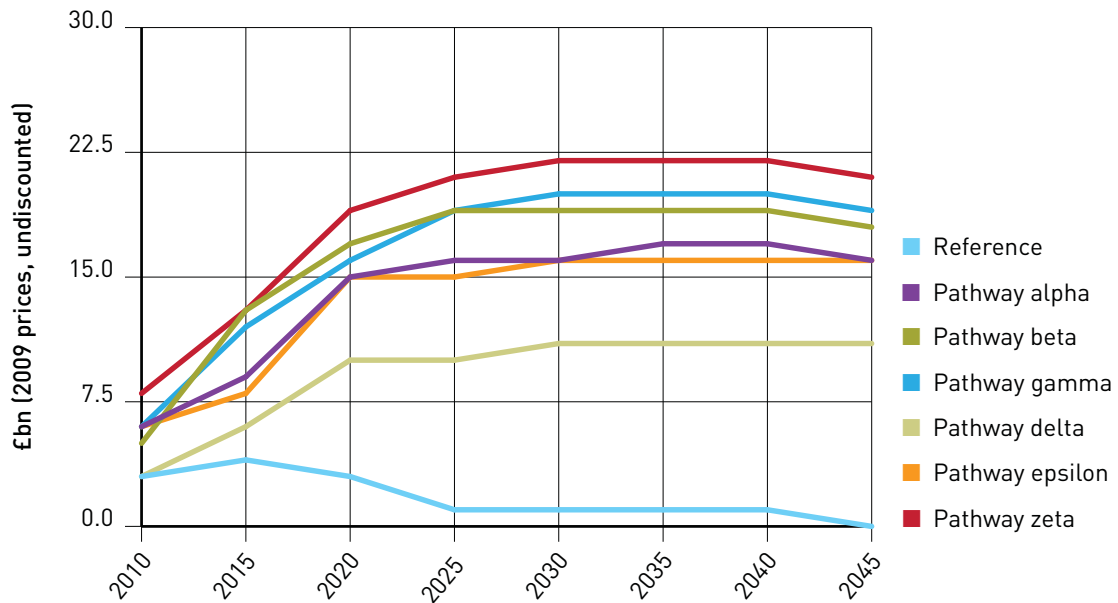
Figure 2: Annual fuel costs for large scale electricity generation to 2050



Capital costs

As Ofgem’s ‘Project Discovery’ has indicated, significant investment will be required over the coming decade to facilitate the move to a low carbon economy. In the period to 2020, total capital and infrastructure costs for the large scale power sector in our low carbon illustrative pathways are estimated at over £100 billion. As shown in Figure 3, annual capital expenditure will need to rise from around £6 billion per year today to £10–19 billion per year by 2020 in the low-carbon pathways, compared to £3 billion per year in the reference pathway.

Figure 3: Annual capital costs for large scale electricity generation to 2050



Costs projections depend very heavily on fossil fuel price assumptions

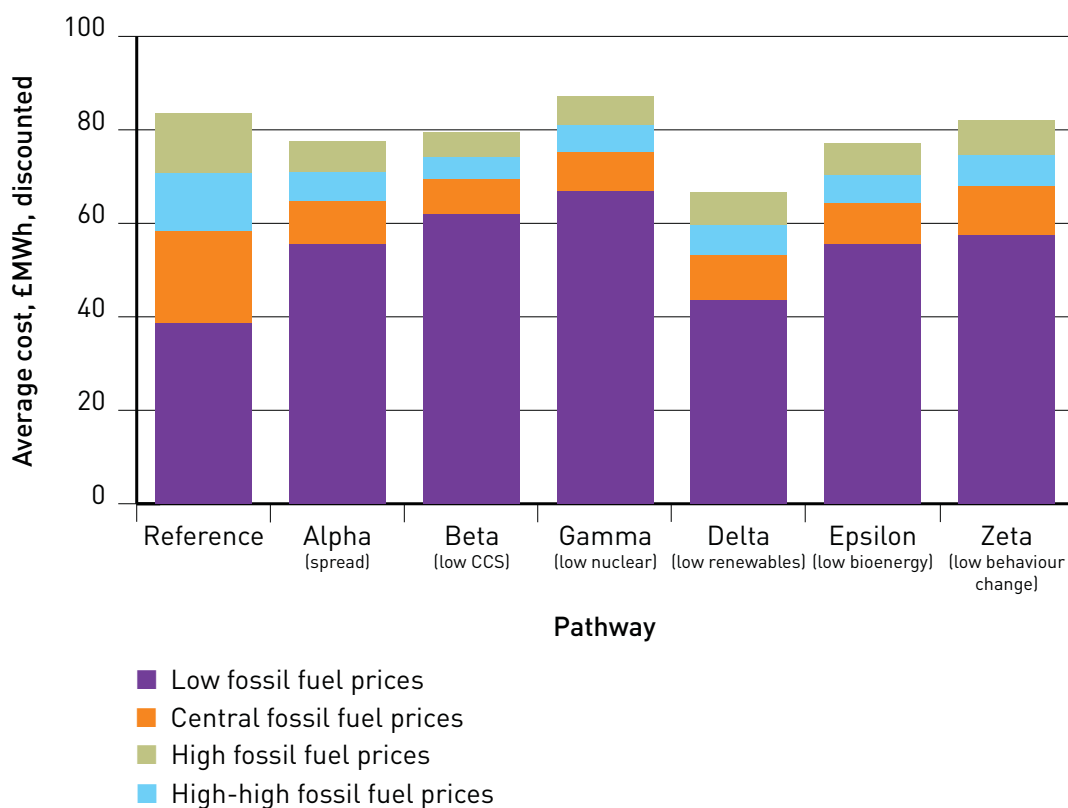
The relative costs of the high and low carbon pathways depend very heavily on the assumptions made about fossil fuel prices. Figure 4 presents the costs on a per MWh basis under different fossil fuel price assumptions. In the reference case for example, the average cost per MWh under low fossil fuel prices is just under £40/MWh. This rises to nearly £60/MWh under central fossil fuel prices, over £70/MWh under high fossil fuel prices, and just under £85/MWh in a world of high-high fossil fuel prices.

The chart shows that most of the low carbon pathways are less costly than the reference pathway under high-high fossil fuel price assumptions; similar costs to the reference pathway under high fossil fuel price assumptions; around £6–11/MWh more expensive than the reference pathway under central fossil fuel price assumptions; and around £20/MWh more expensive than the reference pathway under low fossil fuel price assumptions. Although the rationale for moving to a low carbon pathway is not to reduce energy costs, the analysis indicates that low carbon energy generation can actually be less expensive than conventional energy generation under the highest fossil fuel price scenarios. Given the inherent uncertainty in predicting the likely price of fossil fuels over 40 years, it is significant that the low carbon pathways reduce our exposure to the risk of high fossil fuel prices.

The figures used represent the total (discounted²²) gross physical costs (ie, excluding benefits) to 2050 divided by the total (discounted) amount of electricity generated and cannot therefore be taken as indications of what electricity prices would be in each of the pathways. As explained previously, these numbers do not include any wider benefits. Electricity prices will depend on the market framework in place and will also include a number of costs not covered here, including carbon prices, financing costs, and taxes.

22 Discounted using standard HMT Green Book social discount rates.

Figure 4: Average gross cost per megawatt-hour of the illustrative pathways in 2050



Differences between the pathways

It should be noted that the pathways are illustrative – we have shown ways of meeting the target and balancing energy supply and demand under different assumptions, but these pathways are not the only way, or the cheapest way, of doing so. When constructing pathways, we have made choices across a wide range of sectors and technologies. For example, in Pathway Beta we have restricted CCS and filled the gap by increasing offshore and onshore wind. It is important to note that other options would also be available – the choices in each pathway are illustrative only.

Next steps for understanding the cost implications

This initial costs analysis begins to explore the implications of the illustrative pathways for costs in the large scale power generation sector. Since the power generation sector is only one part of the total costs picture, these costs do not tell us whether one pathway costs more or less than another in total. But over the coming months, we will explore the implications of the illustrative pathways for costs in other sectors, in order to build up a fuller picture of the cost implications of alternative pathways.

3. Call for evidence questions

List of questions

When responding to questions, please provide all appropriate evidence to support statements and assumptions. The questions which follow refer to: the assumptions made for each sector set out in detail in the sectoral chapters in Part 2 of the report; the Excel model 'the 2050 Pathways Calculator'; or the findings as set out in Part 1 above.

1. Scope of model:

- (a) Are there any low carbon technologies or processes or major demand-side options which are not currently included within the scope of the model but that you consider should be in future?

2. Scope of sectors:

- (a) Does the range of alternative levels of ambition presented for each sector cover the full range of credible futures? If not, what evidence suggests that the range of scenarios should be broader than those presented?
- (b) Do the intermediate levels of ambition (levels 2 and 3) provided for each sector illustrate a useful set of choices, or should they be moved up or down?
- (c) The 2050 Pathways Calculator currently describes alternative directions of travel rather than different levels for some sectors where changes reflect a choice rather than a scale. Is this a suitable approach and clear to users?

3. Input assumptions and methodologies:

- (a) For each sector, are the input assumptions and the methodologies applied to those input assumptions reasonable?

As regards specific sectors:

- (b) Are the bioenergy conversion routes used in the model accurate, or are there more efficient routes for converting raw biomass into fuels?
- (c) Can the model's assumptions on wave resource be improved, for example regarding the length of wave farms, their distance from shore, the efficiency of devices, constraints from other ocean users, and other assumptions?
- (d) Can the model's assumptions on tidal stream resource be improved, for example regarding the method for assessing the resource at specific locations, and the scaling up of individual devices into an array?
- (e) Is there any evidence that would help build an understanding of the potential impact of long term spatial development on transport demand, and how could this be accounted for in the model?

- (f) Due to uncertainties in the evidence base on energy demand and associated emissions, the model currently sets out only one level of ambition for the future UK share of international shipping. Is there any evidence you could contribute to help build a greater understanding of the potential shipping trajectories?
- (g) Could the relative roles of coal and gas out to 2050 vary from the assumptions shown in this work, and if so, how?

4. Common implications and uncertainties:

- (a) The introduction to the report sets out some of the implications and uncertainties common to the illustrative pathways. Does this list cover the key commonalities? If not, please identify other common implications and uncertainties and provide evidence as to why these are key conclusions from the analysis.

5. Impact of pathways:

- (a) What criteria should be taken into account in understanding the impact and relative attractiveness of pathways?

6. Cost analysis:

- (a) Can you suggest a methodology by which the wider cost implications of choosing one pathway over another could be accurately reflected, and any relevant findings from such an approach?

7. Future improvements to model:

- (a) Do you have any further suggestions for refining the 2050 Pathways Calculator?
- (b) Could the 2050 Pathways Calculator be improved to reflect the fact that the level of ambition for some sectors will depend on local preferences? Could the Pathways Calculator be improved such that the inherent degree of individual and local choice in a chosen pathway were clear?

How to respond to the call for evidence

The Department of Energy and Climate Change (DECC) invites comments on the issues set out in this Call for Evidence covering the whole of the UK. Representations from all interested parties are invited and a list of questions is set out above. **Respondents are requested to clearly label all responses with the relevant number(s) of the question(s) which they aim to address.** The deadline for responses to the Call for Evidence is **5 October 2010**. Responses should be submitted online at the following location http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/2050/2050.aspx.

Other versions of this document in Braille, other languages or audio-cassette can be made available on request. This includes a Welsh version.

It is intended that responses will be made public. If you do not wish all or part of your response (including your identity) to be made public, please state in your response which parts you wish us to keep confidential. However, information provided in response to this consultation, including personal information, may be subject to publication or disclosure in accordance with the access to information regimes (these are primarily the Freedom of Information Act 2000 (FOIA), the Data Protection Act 1998 (DPA) and the Environmental Information Regulations 2004). If you want information that you provide to be treated as confidential, please be aware that, under the FOIA,

there is a statutory Code of Practice with which public authorities must comply and which deals, amongst other things, with obligations of confidence.

In view of this it would be helpful if you could explain to us why you regard the information you have provided as confidential. If we receive a request for disclosure of the information we will take full account of your explanation, but we cannot give an assurance that confidentiality can be maintained in all circumstances. An automatic confidentiality disclaimer generated by your IT system will not, of itself, be regarded as binding on the Department. The Department will process your personal data in accordance with the DPA and in the majority of circumstances this will mean that your personal data will not be disclosed to third parties.

Enquiries to: 2050 Pathways Call for Evidence Coordinator
Department of Energy and Climate Change
3 Whitehall Place, London SW1A 2AW
Email: 2050pathways@decc.gsi.gov.uk

Issued on: 27 July 2010

Respond by: 5 October 2010

Next steps

The Government intends to use the responses to help refine the analysis underpinning the 2050 Pathways Calculator. An updated version of the Calculator will be made available in autumn 2010. This will help inform discussions of the long term decisions faced by the UK. The analysis will also be one source of evidence used by the Government in determining the UK's fourth carbon budget, for the period 2023–2027.

This work is not about Government or the public choosing a pathway to 2050 today. Such a task would not be feasible – there is too much which is not yet known about the future, for example: which technologies will develop and which will fail, the relative future costs of different options, the international developments which could steer the choice. However, this work does start to give us a good understanding of where the 'good bet' actions might lie, insofar as some requirements appear to be common to most of the plausible pathways to 2050. The analysis can be used to understand how decisions today might be closing off options in the future and it will allow us to understand the timing of future decision points. For example, understanding when we will have a good idea about whether a specific technology is viable and what that implies for the pathway options still available. Although this analysis does not set out a single roadmap to 2050, it better enables us to manage some significant uncertainties and helps us as a society to explore the choices likely to be available.