ZERO CARBON BRITAIN

RISING TO THE CLIMATE EMERGENCY

Centre for Alternative Technology
Canolfan y Dechnoleg Amgen

Zero Carbon Britain: Rising to the Climate Emergency

Zero Carbon Britain:
Rising to the Climate Emergency

https://www.cat.org.uk

We recognise this 2019 report builds on the Zero Carbon Britain research since 2007, and offer our thanks to all who have helped CAT to develop the project.

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Endorsements

"We're miles behind in the fight to slow climate change, and so the bold plans offered here are clearly necessary – the clarity of these goals should provide our marching orders as a society in the decades ahead."
Bill McKibben, 350.org

"Now that we finally have a target for zero carbon, it is high time we had a proper plan for how to get there. CAT have been ahead of the game and looking at this for years. This Zero Carbon Britain report fills in some of the much needed detail about what that carbon free future can look like."
Mike Berners-Lee, researcher and author of *There is No Planet B*

"I'm as impressed as ever. I love the fact that you literally encompass the whole of the economy, rather than going after the easy bits!"
Jonathon Porritt

"This new report is essential reading for politicians, business leaders and anyone interested in developing effective solutions to the climate emergency. Importantly, it comes at a time when grassroots pressure has opened up space for honest politicians to play their part in instigating a low-carbon revolution. With the CAT report as a guide, we can yet bequeath our children, future generations, and other species a sustainable and prosperous future."
Kevin Anderson, Professor of Energy and Climate Change

"The Centre for Alternative Technology understood the looming climate emergency, and the need for ambitious and rapid decarbonisation, well before this became an official target. CAT continues its trailblazing with this ambitious Zero Carbon Britain report, which is both pragmatic and visionary – exactly the kind of roadmap we need in these times. This should be read by policymakers, municipal councillors, business leaders, university and NHS site managers, indeed everyone who wants to understand what role they can play towards a new zero carbon world."
Julia Steinberger, Professor of Social Ecology and Ecological Economics

"A great new report on how the UK can be both 100% renewable energy and greenhouse gas neutral in healthy and pleasant ways. To manage the climate crisis and reduce emissions fast enough, we need such visionary thinking in all countries and local jurisdictions, together with brave politicians and concerned citizens."
Gunnar Boye Olesen, coordinator, International Network for Sustainable Energy

Acknowledgements

Many thanks to all those who are reacting to the climate emergency, you inspire us and have helped contribute in a great many ways to this project – we hope this new report will help support your good work.

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Responsibility for any errors, omissions or mistakes, however, lies solely with the Zero Carbon Britain project as part of the Centre for Alternative Technology.

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Last, but not least, we would like to thank those individuals and organisations who donated generously, enabling this project to go ahead. They are, in no particular order:

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Wild Ltd, in addition to a number of generous anonymous donors.

The Centre for Alternative Technology would like to dedicate this new 2019 report to the memory of our dear friends, Rebecca Sullivan and Godfrey Boyle, both of whom contributed deeply to this work.

Foreword

In so many respects, we are the pinnacle of 3.5 billion years of earthly evolution. We have an innovative and creative capacity for beauty, captured in Christopher Wren's soaring spires, Jocelyn Bell's scientific curiosity, Rosa Parks' courage, Steve Jobs' iPhone, the humble bicycle and the wonderful music of Simone and Bach. Sadly, this creative beauty has its dark side. From the plethora of devices for killing each other to the elaborate financial mechanisms of greed, we also demonstrate a capacity to lay bare and destroy. But perhaps our most unbalanced and dangerous traits are those around climate breakdown. Apathy, latent self-interest, fraudulent optimism, and acquiescence with the status quo all serve to support incremental destruction; to place us as the frog in the gradually warming pan.

Are we caught in a genetic cul-de-sac, destined to be little more than an anomaly in the fossil record – or do we yet possess the qualities needed for harmonious survival? Whilst most signs point towards the former, calls to avert the pending climate emergency point to a transformation from fear and 'politics as usual' to a future driven by our collective cogency, courage and beauty. But time is now very short…

To deliver on the 1.5 to 2°C commitments enshrined in the Paris Agreement, the UK requires a social and physical transformation reminiscent of the 1948 Marshall Plan. Recognising that Paris requires wealthier nations to lead on decarbonisation, work with University of Manchester and Uppsala colleagues concludes that the UK must achieve zero carbon emissions by the mid-2030s, and ideally earlier. This requires a programme of deep cuts in energy emissions rising rapidly to around 15% year-on-year – starting now.

Such a rate and timeframe are far more challenging than is typically stated in the mainstream media and indeed beyond what many academics and climate experts are prepared to acknowledge publicly. Rather than face the challenge with integrity, much of the burden is being passed onto future generations. With few exceptions, mitigation strategies and scenarios increasingly rely on planetary-scale and highly speculative negative emission technologies (NETs). These NETs are presumed, later in the century, to suck hundreds of billions of tonnes of carbon dioxide directly from the atmosphere. Remove this dangerous distraction, and a revolution in our energy system and land use infrastructure is required to avoid the chaos of unchecked climate change. Such a shift will need to embed equity at its core if it is to succeed mathematically and politically, as well as morally.

Since the launch of its first Zero Carbon Britain report in 2007, the Centre for Alternative Technology has been at the forefront of informed thinking on transitioning rapidly towards a fully decarbonised society. Its careful analysis demonstrates we have the necessary technologies and land use opportunities, but what we have thus far lacked have been political will, courage and foresight. This new report is essential reading for politicians, business leaders and anyone interested in developing effective solutions to the climate emergency. Importantly, it comes at a time when grassroots pressure has opened up space for honest politicians to play their part in instigating a low carbon revolution. With the CAT report as a guide, we can yet bequeath our children, future generations, and other species a sustainable and prosperous future.

Kevin Anderson
Professor of Energy and Climate Change
Tyndall Centre, University of Manchester (UK) and Uppsala (Sweden)

Preface

Wicked problems require wicked solutions!

There is no time to spare. In order to deliver the necessary solutions at the scale and speed required, we must fully understand the true nature of the climate problem. Back in 1973, design theorists Horst Rittel and Melvin Webber developed the term 'wicked problem' to help us recognise really complex, challenging problems, particularly those with many feedbacks and no single solution. The Centre for Alternative Technology (CAT) acknowledges the climate emergency as a wicked problem, and is launching a major programme of increasing action to help society develop the wicked solutions it so urgently demands.

The first reason to see climate change as a wicked problem is that it contains many feedbacks which make it non-linear. As the earth's climate systems break down, the resulting changes feed back on each other and drive further change. For example, loss of sea ice means the earth absorbs more of the sun's heat and warms faster, which causes more ice to melt. There are many others.

In addition, the root causes of climate breakdown are deeply intertwined, spanning many disciplines. All across our living systems humanity has become locked into high carbon ways of doing things; these exert a powerful influence, shaping the choices that define our lives. Despite the serious climate impacts being known, and despite the existence of cost-effective alternatives, the self-perpetuating inertia of high carbon energy, housing, transport, agriculture and economics creates persistent systemic forces that are highly resistant to change (Unruh, 2000). The reason we now face an 'emergency' is that, despite the climate problem being recognised by science for decades, governments and industries have not acted fast enough. A systemic bias against low carbon technologies and practices is a result of the historical development of the fossil fuel system (Perry, 2012). We could have – and should have – accelerated this shift to net zero carbon many years ago, avoiding many mistaken investments in fossil fuel assets that we simply cannot burn.

We have, at last, collectively acknowledged that the science tells us we must go to net zero. The UK government has now signed into law a new target to 'cut greenhouse gas emissions to net zero by 2050'. This was approved by both the Commons and Lords in June 2019, strengthening the target of the 2008 Climate Change Act. But many now believe that for a long-industrialised country, net zero by 2050 is not fast enough.

Thankfully, our human response embodies some 'wicked solutions' that can also accelerate change. For over 12 years, CAT's Zero Carbon Britain project has been demonstrating with increasing detail how we can connect up the currently available, well-proven technologies to achieve net zero greenhouse gas (GHG) emissions. What makes these zero carbon technology solutions wicked is, firstly, the fact they are also non-linear and contain an emerging array of feedbacks, which accelerate both the scale and speed of their deployment. Investment in research means production costs fall and the scale of deployment increases; this triggers further research and investments in manufacturing and costs fall even faster. For example, the falls in the cost of solar panels (solar photovoltaic, or solar PV) has been faster than even the experts predicted (Kavlaka, 2018; IRENA, 2018).

Secondly, when the shift to these new technologies is combined with a 'just transition' that offers a more socially just and equitable deal for workers, energy customers or citizens, the process begins to engage more and more people. That is the point of wicked systems thinking – not just looking at one feedback loop, but many.

Fortunately, yet another important wicked solution feedback is now emerging across many countries: new grassroots leadership is calling for climate emergency declarations, backed by action plans for town, city, regional and national levels. This is now feeding back, cross-fertilising again and again; as one town sees its neighbour declare, it then also joins the call. We are now witnessing a seismic shift in the collective action to prevent climate breakdown. It is becoming the new normal. And this shift is being documented: UK declarations are listed on the website climateemergency.uk and global declarations can be found on cedamia.org. Schoolchildren have gone on strike; many deeply committed people across the country have taken to their streets, towns, cities, and regions; even the UK parliament has declared a climate emergency. And there are many more declarations in the pipeline, so much so that this is now changing the national, political and cultural narratives in a deep way.

But perhaps the most powerful element of this 'wicked solution' is that delivering a zero carbon future also holds the potential to be one of the most exciting opportunities in human history, offering us the chance to simultaneously resolve many other problems (Jennings, 2019). Acting on climate breakdown with a multi-solving, interdisciplinary mindset can help us also deliver benefits across many sectors. The trick is to identify synergies between investments in the changes needed to reach net zero and investments to improve health and wellbeing, enhance biodiversity, create jobs, reduce poverty, stabilise our economy, and increase our resilience and ability to adapt to climate change. Maximising the benefits beyond carbon can help empower diverse constituencies, building the necessary engagement and a coalition of support across society. The Ashden Trust offer a co-benefits toolkit at https://www.ashden.org/programmes/co-benefits

CAT is now scaling up its ability to provide people with the knowledge, skills and resources needed to take action at the speed and scale required. We hope this new 2019 report will support the emerging 'climate emergency response team' of active citizens and local groups who are working hard to bring to life the wicked net zero solutions needed. And in the process, help us foster a stronger, more resilient society, united in a new sense of collective purpose!

Paul Allen B.Eng (Hons) FRSA
ZCB Project Coordinator

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Executive summary

Zero Carbon Britain: Rising to the Climate Emergency models a technically robust endpoint where we have achieved net zero greenhouse gas emissions – let's call this 'zero carbon'. Our work clearly demonstrates that we already have the tools and technology needed to efficiently power the UK with 100% renewable energy, to feed ourselves sustainably and so to play our part in leaving a safe and habitable climate for our children and future generations.

Addressing climate breakdown

People all over the world are feeling the effects of climate breakdown, from unprecedented heatwaves, droughts and massive wildfires to some of the most damaging floods and storms ever seen. The warnings from the scientific community are now becoming real life experiences.

The current UK greenhouse gas emissions target of net zero by 2050, though ambitious in comparison to some other countries, does not offer rapid enough reductions to provide a good chance of avoiding extremely dangerous climate breakdown. Neither does it adhere to what might be termed the UK's 'fair share' of the remaining global carbon budget.

Net zero starts now

Zero Carbon Britain: Rising to the Climate Emergency explores how we can do what we know is necessary, clearly demonstrating that we can achieve net zero emissions without relying on the promises of future technology.

By making changes to our buildings, transport systems, land use and behaviour, and by investing in a variety of renewable energy technologies, we can achieve a zero carbon transition while building in a wide range of additional benefits.

A blueprint for action

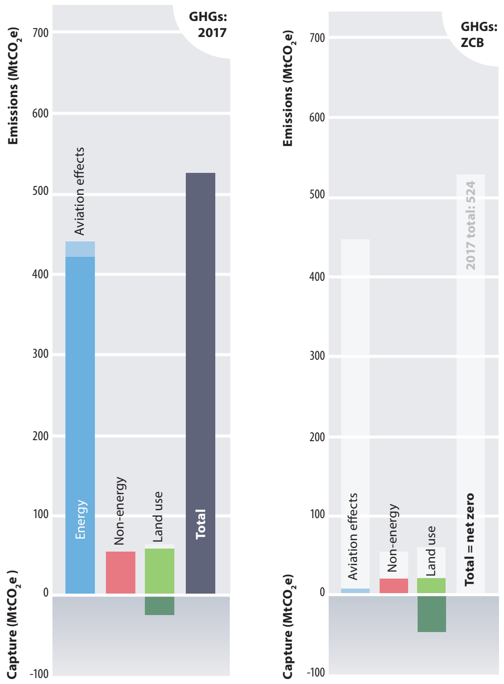
The report provides a blueprint to open new conversations around the scale and speed of change we need to deliver if we are to rise to the climate emergency.

It can be used as a template to help citizens and local and national policymakers develop and deliver zero carbon action plans.

By using energy more efficiently we can power down demand by 60%.

How can we reach net zero?

By using energy more efficiently we can power down demand by 60%. At the same time, we can power up the UK's renewable energy resources to replace fossil fuels. And by making changes to our



UK greenhouse gas emissions in 2017 (left) compared to our Zero Carbon Britain scenario (right), including carbon captured, international aviation and shipping, and the enhanced effect of emissions from aviation.

agricultural systems we could then balance out the remaining 8% of emissions from non-energy processes (such as cement production or methane from livestock) by removing greenhouse gases from the atmosphere through natural carbon capture from forests and restored peatlands. This would take us to net zero emissions overall.

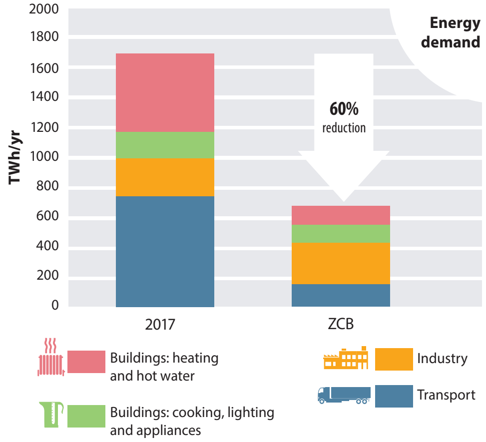
Powering down our energy demand

We can reduce energy demand for heating by around 50%.

Reducing how much we travel and changing our modes of travel could cut energy demand for transport by 78%.

Our current lifestyles use far more energy than we actually need. CAT's Zero Carbon Britain research shows that we could reduce our energy demand by around 60%, with particularly large savings in heating buildings and in transport.

- **Buildings**: having high 'Passivhaus' standards for new buildings, retrofitting all existing buildings, and improving internal temperature control would reduce energy demand for heating by around 50%.
- **Transport**: reducing how much we travel, and changing how we travel – with more use of public transport, walking, cycling, switching to efficient electric vehicles and two thirds less flying – would reduce energy demand for transport by 78%.



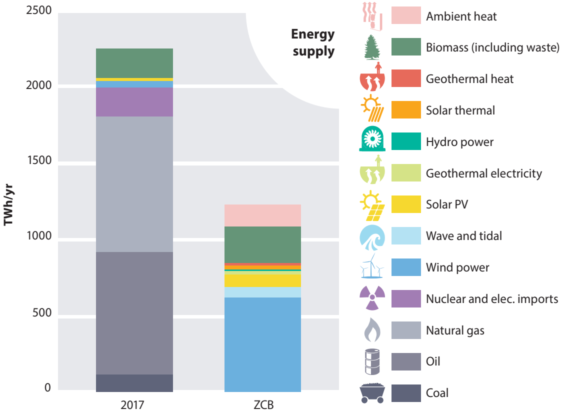
Total annual energy demand by sector in the UK in 2017 and in our scenario in terawatt-hours per year (TWh/yr)

We can supply 100% of the UK's 'powered-down' energy demand with renewable and carbon neutral energy sources.

Powering up renewable energy

It is possible to supply 100% of the UK's 'powered-down' energy demand with renewable and carbon neutral energy sources, without fossil fuels and without nuclear. In the Zero Carbon Britain energy scenario:

- Many different renewable energy sources suited to the UK – solar, geothermal, hydro, tidal and others – are used to produce electricity and heat.
- Wind energy – both offshore and onshore – plays a central role, providing around half of the energy supply.
- Most of the energy in this scenario (around 66%) is produced in the form of electricity.
- Carbon neutral synthetic fuels play an important role where it is not possible to use electricity – for example, in some areas of industry and transport, and as back up for our energy system.



Energy mix in our scenario – the amount of energy supplied by each renewable source.

Smart appliances and short- and long-term storage mean a 100% renewable energy system can provide power 24 hours a day, all year round.

The important question for a 100% renewable energy system is not if we can produce enough energy but whether we can produce enough energy at all times – even when the wind isn't blowing, the sun isn't shining and our energy demand is high.

Hourly modelling of the renewables mix in the Zero Carbon Britain scenario shows a surplus of energy 74% of the time. We ensure there is enough energy at other times by:

- Shifting energy demand using 'smart' appliances and using batteries, pumped storage, heat storage and hydrogen for short-term energy storage over hours or days.
- Using carbon neutral synthetic gas (which can be dispatched quickly into the electricity grid when we need it) for long-term energy storage over weeks or months.

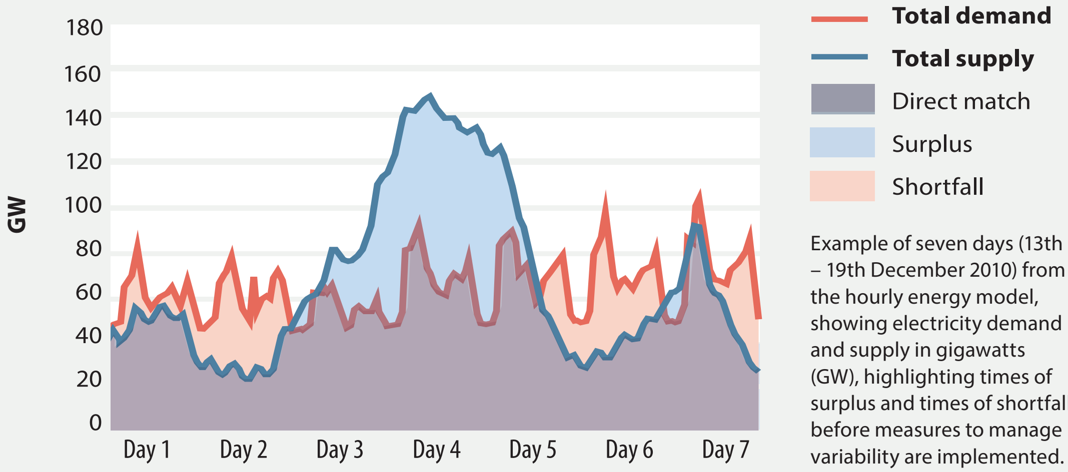
This research suggests 'baseload' power that provides a continuous supply of electricity but can only respond slowly (nuclear, for example) doesn't work well with a highly variable renewable energy system, as it leads to further overproduction when renewables already exceed demand.

Carbon neutral synthetic fuels

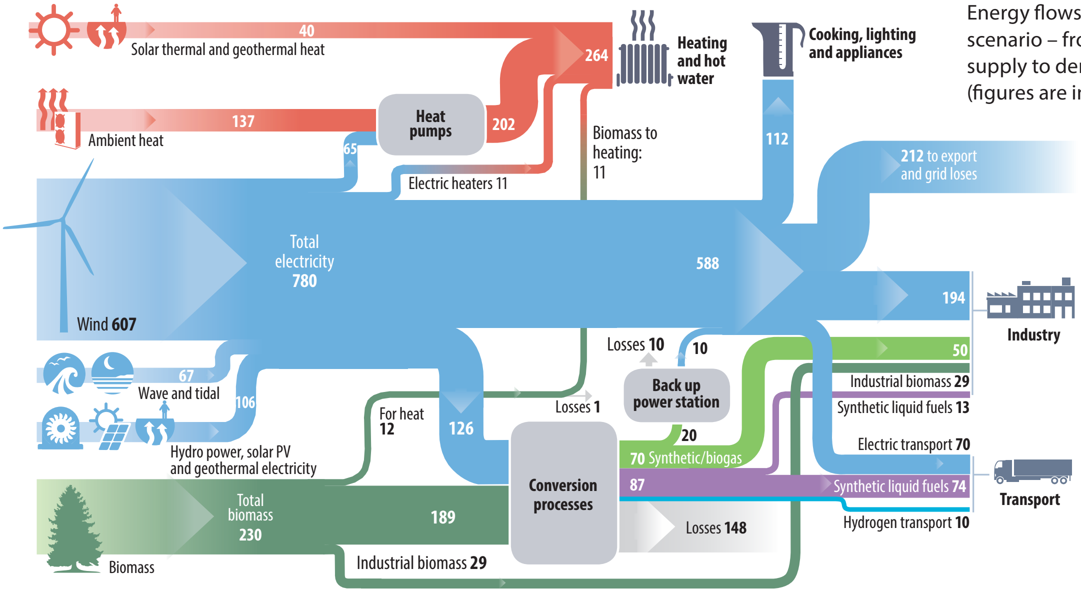
Synthetic fuels have the same chemical make up as fossil fuel oil and gas but can be created by combining hydrogen (produced by electrolysis using surplus renewable electricity) with carbon from sustainable UK grown biomass, making them carbon neutral.

Hourly energy model

The Zero Carbon Britain energy model is one of the most detailed studies to date on balancing demand and supply in a renewable energy system. It uses hourly weather data (sunlight, wind speeds, temperatures, etc.) from over the ten-year period of 2002 to the end of 2011 – a total of almost 88,000 hours – to test renewable energy mixes under real life conditions



Example of seven days (13th – 19th December 2010) from the hourly energy model, showing electricity demand and supply in gigawatts (GW), highlighting times of surplus and times of shortfall before measures to manage variability are implemented.



Energy flows in our scenario – from supply to demand (figures are in TWh/yr)

Land use

Through ‘powering down’ demand and ‘powering up’ renewable supply, the UK’s emissions can be significantly reduced save a few industrial and waste management processes that still emit residual greenhouse gases. However, there are also emissions associated with food production, land use changes and land management practices – this accounts for around 10% of current UK emissions.

Agricultural systems are threatened with reduced productivity due to a decline in the numbers and variety of plants and animals in farmland and the surrounding environment. This variety of life is necessary for efficient food production. Therefore, our land management practice must include restoring essential biodiversity.

Our model explores how we can achieve this whilst also reducing agricultural emissions, providing a healthier mix of foods, reducing unnecessary food imports, producing building materials, providing UK sourced biomass, and increasing natural carbon capture to ‘balance’ our residual emissions. In doing this, the UK will become more self-reliant and can clean up its own mess within its own territory. This is a vital piece in the net zero carbon jigsaw.

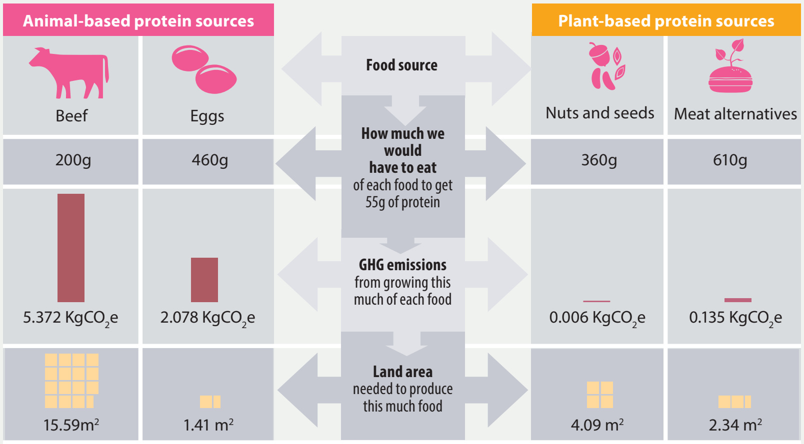
The use of land explored in the Zero Carbon Britain model will offer a healthier mix of food, plus backup energy supply, and will provide natural carbon capture, which allows the UK to be truly net zero carbon.

> *Through dietary change, food waste reduction and improved agricultural practices we could provide a healthy, sustainable diet for the whole UK population.*

A healthy low carbon diet

Through dietary change, food waste reduction and improved agricultural practices we could provide a healthy, sustainable diet for the whole UK population. These changes would mean that:

- Greenhouse gas emissions from agriculture would be reduced by 57% from 2017 levels. This represents only emissions produced ‘on the farm’, as food processing and distribution are taken into account in ‘powering down’ and ‘powering up’.
- The UK could become more self-reliant in food, reducing imports from 42% to 17%, and so



	Animal-based protein sources		Plant-based protein sources	
Food source	Beef	Eggs	Nuts and seeds	Meat alternatives
How much we would have to eat of each food to get 55g of protein	200g	460g	360g	610g
GHG emissions from growing this much of each food	5.372 $KgCO_2e$	2.078 $KgCO_2e$	0.006 $KgCO_2e$	0.135 $KgCO_2e$
Land area needed to produce this much food	15.59m^2	1.41 m^2	4.09 m^2	2.34 m^2

Food and diets model

The Zero Carbon Britain food and diets model combines data describing the nutritional qualities of the foods we eat, their land requirements and the greenhouse gases emitted in producing them. This model can then be used to assess the impacts of dietary change.

Comparison of four different high protein food sources: how much would need to be eaten to meet the recommended daily amount (RDA), the associated GHG emissions and land used.

reducing the impacts of food production for our consumption elsewhere in the world.

- Our health would be improved by eating a better and more balanced diet.
- 75% of the land currently used for grazing livestock could be repurposed, freeing up space for a range of other uses, which could also offer new income streams to farmers.

The modelled dietary change contains significantly less protein from meat and dairy (which have high emissions and use a lot of land) and more from plant-based sources like beans, nuts, cereals and vegetables.

We can double UK forest area and restore 50% of UK peatlands.

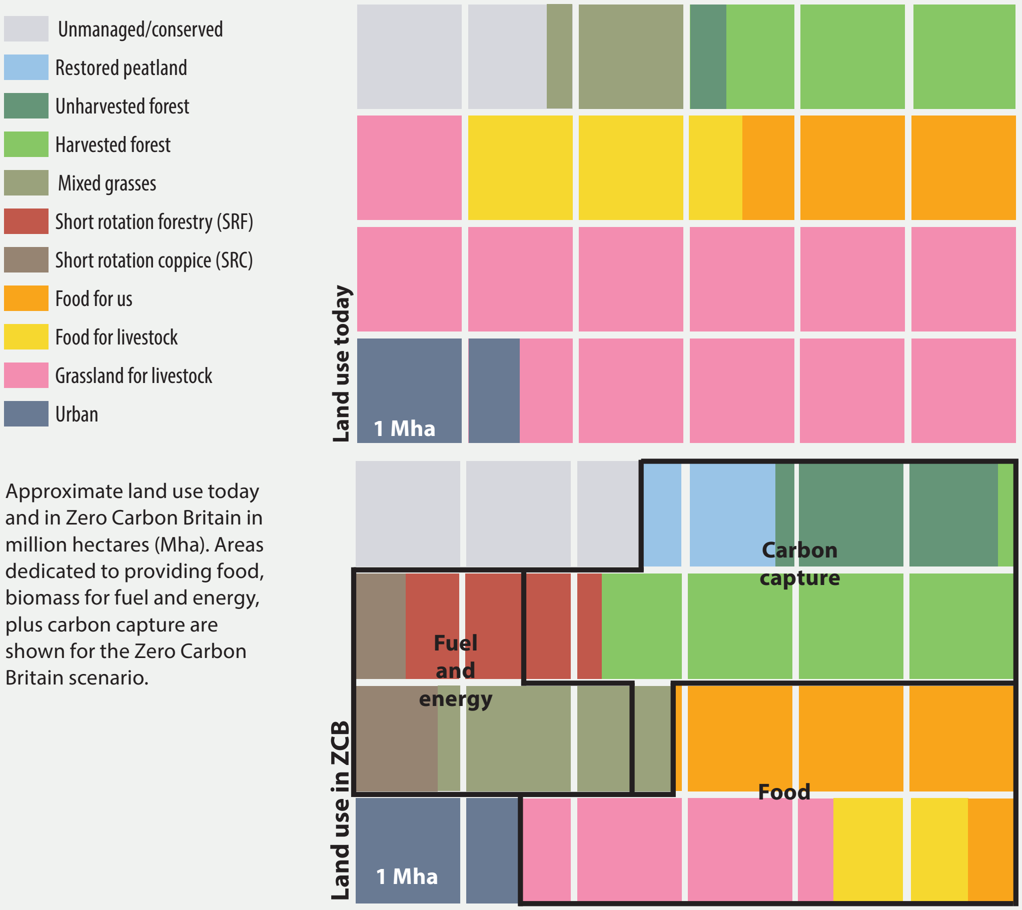
Diversifying our land use

Making these changes would mean that we have enough land in the UK not only for producing food but to offer new potential income streams:

As well as being used directly as a fuel, UK sourced biomass can be combined with hydrogen from surplus renewables to make carbon neutral synthetic gas and liquid fuels, which increases the amount of fuel produced per acre of land. These are ‘carbon neutral’ as the greenhouse gases they contain were initially captured by the biomass as it grew, resulting in no net increase in the atmosphere.

Forest area is doubled to 24% of the land area of the UK – roughly one third is unharvested and two-thirds harvested for timber. These forests, the wood products they produce and the restoration of 50% of UK peatlands, results in the capture of around 47 MtCO2e on average every year. This is required to balance the residual emissions in the scenario and so make the UK net zero carbon.

The changes would also provide more room for biodiversity in wild, restored, conserved or protected areas.



Approximate land use today and in Zero Carbon Britain in million hectares (Mha). Areas dedicated to providing food, biomass for fuel and energy, plus carbon capture are shown for the Zero Carbon Britain scenario.

Using Zero Carbon Britain

A great many people and organisations across the UK are working alongside their local governments to explore zero carbon transitions in transport, energy, buildings, food, land use and waste. Not only can we deliver this through collective action plans, we can also make the individual changes which directly reduce our own emissions, and so transform how we relate to climate breakdown personally.

How you use the report will depend on scale, location and circumstance, but here are some common approaches:

- Get informed and get skilled
- Get connected – join or start a local zero carbon group
- Map out key collaborators
- Make an action plan
- Minimise energy demand and rethink renewable supply
- Use the savings to help fund new projects
- Learn by doing
- Share your experiences

Image © ecosolarceo, pixabay.com

Join the change

While the impacts of individual changes are, of course, relatively small, as more and more of us scale these up they normalise emission reduction behaviours, empower people, help change social and political norms and so increase ambition for policy shifts.

Sharing Zero Carbon Britain can inform ambitious practical actions and policy shifts by clearly demonstrating:

- All the technologies needed to power down demand and power up clean energy are ready and waiting.
- Changes in land use, reduced food imports and healthier diets are a key part of the plan.
- Action on climate change can provide many additional benefits, including improved health and wellbeing, better housing and enhanced biodiversity.

Clearly, there is no single technology, policy or action that can prevent climate breakdown. It will require many people, from all walks of life, working together to bring about the change we need to see. So let's come together at individual, local, national and international levels – and collectively rise to the climate emergency!

Contents

Sometimes our work has revealed that there are multiple options, or a range of factors which require further investigation. To flag these up to the research community we have use the Ⓡ symbol to identify areas where we feel further investigation is required.

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ZERO
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Chapter 1

Introduction

1.1 A net zero scenario

Zero Carbon Britain: Rising to the Climate Emergency explores how we can achieve what is necessary. Our updated scenario describes one possible future end point in which the UK has actually risen to the challenges of the 21st century. We have acknowledged our historical responsibility as a long-industrialised nation and made our contribution to addressing climate change by rapidly reducing UK greenhouse gas emissions to net zero.

Building on the groundwork laid by the Zero Carbon Britain project over the last 12 years, we incorporate the very latest developments in science and technology, updating our detailed research in the key areas of balancing highly variable energy supply and demand, and the nutritional implications of a low carbon diet. It clearly demonstrates that we can do this using existing technology, without relying on unproven future developments.

Zero Carbon Britain: Rising to the Climate Emergency provides a positive and technically feasible future scenario that aims to stimulate debate, foster all-party political commitment and catalyse action across all parts of society.

Through this project, the Centre for Alternative Technology hopes to inspire, inform and enable contemporary society to embrace the changes required to rise to the climate emergency.

Practical advice on being part of the transition to a zero carbon Britain can be found at the end of this report.

1.2 History of the Centre for Alternative Technology (CAT)

"In the early 1970s I took a sabbatical and went to America. I talked to senior business and professional people and came to the conclusion that a lot of people realised there was a major problem, but were locked into what they were doing. I came back thinking what was needed was a project to show the nature of the problem and to indicate ways of going forward."
Gerard Morgan Grenville – CAT Founder

Forty years ago, catalysed by Gerard Morgan Grenville's vision, a small group of young visionaries adopted a long-derelict slate quarry in the village of Pantperthog, near Machynlleth in Mid Wales.

At the time, an important shift in the relationship between human beings and technology was happening. Until then, developments in technology were seen to bring progress and an ever-improving standard of living, and had been largely unquestioned as a result. However, as the industrial world began to collide with the limits of the planet's ecosystems, serious questions arose about the limits to material growth, damage to natural systems and the eventual depletion of resources.

This rethinking of the direction of science and technology gave rise to a key conference at which Peter Harper coined the phrase 'alternative technology' to describe a new role for technology, focusing on benefits to humans and nature as well as to economies. Alternative technology wasn't just about solar and wind power, but rather a shift in the philosophy of how a technology is applied and to what ends. Gerard took this concept as the basis for developing the Centre for Alternative Technology (CAT).

Society was just emerging from the swinging sixties, and few people were watching the problems, let alone looking for the solutions. This original community set out to test and develop, by a positive living example, new technologies that could provide practical solutions to problems now worrying the world's ecologists, economists and energy analysts. These early pioneers began trying out a wide range of low-impact, self-sufficient or self-reliant technologies, such as growing, cooking, nutrition, alternative medicine, clothing, buildings, smallholdings, transport, foundry skills, wildlife management and co-operative decision-making. This hands-on research would not only further the all round 'living lightly' message, it would feed, house, clothe, power and manage the community, independent of the mainstream.

Right from the outset, however, CAT recognised that building a genuinely sustainable future would

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need thousands of skilled professionals with a deep understanding of environmental technologies and practices.

Today, CAT offers residential courses, taught by experts with many years of practical experience, based in a 'living laboratory' with a new state of the art teaching facility. CAT's Graduate School of the Environment (GSE) offers research, training and hands-on skills up to postgraduate level, with core topics including low carbon building techniques, grid-linked and stand-alone renewable energy, solar water heating, ecological building, eco-renovation, sewage treatment, water supply, organic food production, composting, architecture, adaptation and solid waste disposal – each exploring the complex interaction between land use planning, food production, energy, buildings, transport, waste management and all aspects of human society.

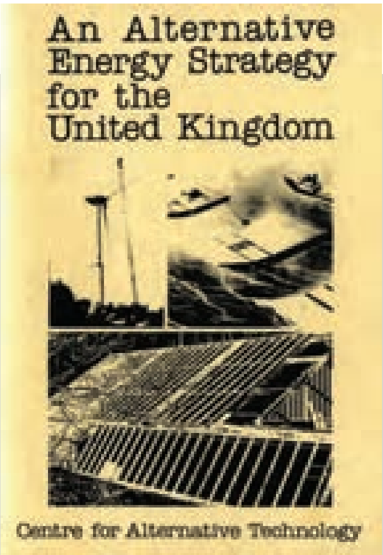
The Zero Carbon Britain project

1.3

The initial vision – An Alternative Energy Strategy for the UK (1977)

A key part of CAT founder Gerard Morgan Grenville's original vision was for the project team to assemble the findings of its research by the end of the first five years. These findings were to describe what the emerging alternative technologies could realistically offer. Experts from CAT initiated a process of collaboration, embracing leading thinkers from a number of key universities and industries. This led to the production of the very first *Alternative Energy Strategy for the UK*. Sixteen copies were delivered to Tony Benn's Ministry of Energy in 1977.

Not surprisingly, the reception from the energy mainstream varied from scorn to outright hostility.



An Alternative Energy Strategy for the United Kingdom

Centre for Alternative Technology

The strategy CAT suggested was poles apart from that of the official energy strategy of the time. Back in the early 1970s, the majority of mainstream energy planners expected UK demand to perpetually grow year-on-year as it had been doing since the end of the Second World War. This continued expansion in energy consumption was to be fuelled by the, as yet untapped, North Sea oil reserves and the promise of nuclear power, which was going to be "so cheap it wouldn't be worth metering". Renewable energy played a very small part in the national energy mix. Wind power and hydropower energy systems were associated with old-fashioned 'pre-national grid systems' used by remote rural villages in the 1920s and 1930s. The national grid, managed by the Central Electricity Generating Board, was not interested in buying power from any suppliers with a capacity below 10 megawatts (MW).

The oil price shocks of 1973 and 1979 gave a jolt to the mainstream, but they were portrayed as short-term political problems. They did, however, motivate the alternative movement – looking wider and further ahead than the mainstream. CAT's innovative initial report showed for the very first time that an alternative approach could head off resource depletion by reducing energy demand whilst radically increasing generation from clean renewable sources.

ZCB Begins: technical scenarios developed in 2007, 2010 and 2013

Throughout the last decades of the 20th century, evidence around climate change had been building. By the start of the 21st century, the importance of taking action had grown ever more urgent. However, efforts were still focused on communicating the problem. Research at that time showed that 60% of articles about climate change in UK national newspapers were negative and failed to mention possible solutions; only a quarter mentioned what could be done, or was already being done.

At that time, the UK official target (60% reduction in greenhouse gas (GHG) emissions by 2050) fell far short of what science was demanding. Furthermore, no other published work put forward decarbonisation scenarios that explored a fast enough transition from fossil fuel use to meet the challenge. Although a number of groups had developed scenarios around a decarbonised electricity grid for the UK, they did not cover GHG emissions from non-electrical energy demand – by far the largest part of UK energy demand. The challenges of climate change, fossil fuel depletion and global inequality had become increasingly familiar, but experts worked in isolation and their solutions were rarely considered in unison. Through a series of reports launched in 2007, 2010 and 2013, CAT sought to develop technical scenarios that could integrate solutions to all of these challenges in ever increasing detail.

It became clear that to be truly net zero carbon, all UK GHG emissions must be addressed – including those unrelated to energy. This proved a much harder challenge, with some emissions being impossible to reduce to zero. The 2010 and 2013 reports integrated emerging research exploring changes in the role of land in the UK. Land in the scenario became of crucial importance, providing food, energy, fuel and, in particular, carbon capture – integral to making the scenario reach net zero carbon emissions. What developed was a more robust framework that integrated detailed knowledge and cutting edge research in transport, food, energy, buildings and land use. Using 10 years of hourly data we address concerns around 'keeping the lights on' under a 100%

renewable energy supply, and 'feeding ourselves properly' on a low carbon diet. This work shows we can meet the scale and speed of decarbonisation required with positive effects on society, the environment and the economy.

People, Plate and Planet (2014)

The ZCB project increasingly recognised that we need to explore the role of integrating food and diets into climate solutions. This report was developed to detail the impact of various dietary choices – including high meat, meat reducing, vegan, and vegetarian – on health, GHG emissions and the land used.

Zero Carbon Britain: Making it Happen (2017)

Rather than an unresolved technical challenge, it is increasingly accepted that we must overcome a mix of political, cultural and psychological barriers. This report investigates how we can achieve this, linking up insights from research with examples and stories from individuals and organisations that are living the changes we need to see. Working within an interdisciplinary framework, this report brings together thinking from researchers working in psychology, sociology, political science, and economics, as well as faith and spiritual practice, arts and culture. Drawing on a wide range of peer reviewed articles, books and reports, as well as real life projects, it explores ways that we can overcome barriers in innovative ways.

zerocarbonbritain

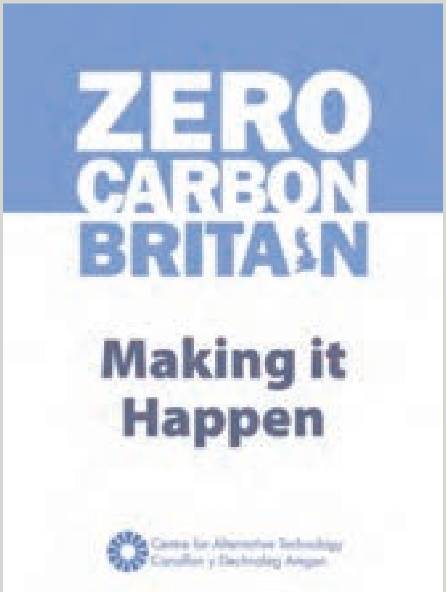
ZERO CARBON BRITAIN 2030

ZERO CARBON BRITAIN

Rethinking the Future

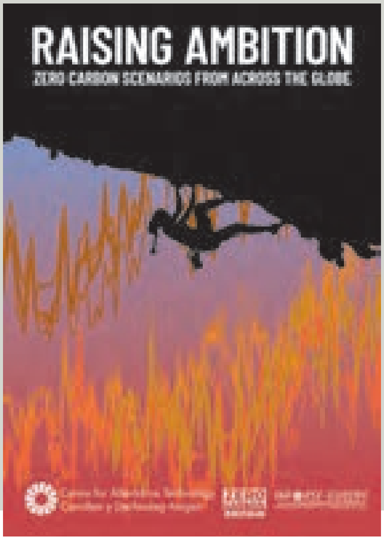
ZERO CARBON BRITAIN

People, Plate and Planet



ZERO CARBON BRITAIN

Making it Happen



Raising Ambition (2018)

Climate solutions research is not just emerging in the UK; it is now happening across the globe. CAT's Raising Ambition report brings together an international range of scenarios exploring climate stable futures at global, regional, national and sub-national scales. It offers an in-depth look at 18 case studies, drawn from 130 scenarios modelling net zero, deep decarbonisation, and up to 100% renewable energy, plus an analysis of key things we can learn from this breadth of work.

Support tools

All the above reports are free to download from https://www.cat.org.uk/info-resources/zero-carbon-britain/research-reports/

CAT regularly runs two-day ZCB specific training courses, plus a wide spectrum of other short courses and postgraduate qualifications that deliver the skills needed for action in key sectors such as energy, buildings and land use. See www.cat.org.uk

1.4 Why a new report?

A great deal has changed since CAT launched its previous technical scenario, *Rethinking the Future*, in 2013. We are now witnessing a seismic shift in the campaign to prevent climate breakdown. Schoolchildren have gone on strike; many deeply committed people up and down the country have taken to the streets; villages, towns, cities, regions and the UK, Welsh and Irish parliaments have declared a climate emergency. The UK Government has upgraded the Climate Change Act, so we have a legally binding net zero target.

We recognise that we now have very little time to ensure that we stay within 1.5°C of global temperature rise. The IPCC special report on 1.5°C was very clear: we must reach net zero greenhouse gas (GHG) emissions globally by 2050, with a 45% decrease on 2010 levels by 2030, if we are to avoid the destructive consequences of a world warmed by more than 1.5°C.

So, we have recognised that we are in an emergency. Now we must urgently turn the conversation to a climate emergency action plan to deliver the solutions. For over 12 years, CAT's Zero Carbon Britain project has demonstrated how we can get to net zero GHG emissions using technology available today – without relying on unproven future carbon capture technologies and without nuclear.

But as well as the shifts in how we humans recognise the urgent need to act on climate challenge, the past few years have also seen rapid shifts in the technologies this requires. Many technologies have fallen in cost faster than any of us imagined, offshore turbines are larger, and some can now float. Energy storage technologies have transformed, our understanding of land use shifts has developed, and there is powerful new research on how we can create more and better jobs in the process.

In response, we have now updated our core research, re-crunched the numbers on renewable energy, buildings, transport, diets and land use, and looked again at the social, cultural and economic changes that are needed to bring about this transformation.

CAT has launched a new Zero Carbon Britain Hub and Innovation Lab to help increase the confidence, competency and effectiveness of policymakers, communities and organisations in developing Zero Carbon Action Plans, whilst also increasing their resilience to climate change. We welcome any offers of collaboration.

The future is unwritten!

Overview of the new 2019 research

Energy

The period since the publication of Zero Carbon Britain: Rethinking the Future (2013) has seen significant changes in the UK energy system, impressive deployment and reductions in the cost of some technologies, and the emergence of new technologies as realistic possibilities. Therefore, in the energy sections we have:

- **Updated the baselines** in the report in order to reflect progress to date and to give an accurate picture of the challenge that remains.
- **Continued to refine the hourly modelling** that underpins the energy scenario. The scenario is developed with hourly modelling of the UK energy system using ten years of weather data to simulate our renewable electricity supply and the demand for electricity. The modelling also helps us understand how energy storage and demand management can allow us to balance energy supply and demand, and we have further developed our understanding in this area.
- **Incorporated the latest technological changes**. There have been technological developments since the previous report that we have included in the latest scenario. For example, the storage of electricity has become much more mainstream and is included to a greater extent in the new scenario. The electrification of large road vehicles and some shipping has also emerged as a realistic possibility and is included.

Land use

Since Zero Carbon Britain: Rethinking the Future we have seen the publication of the seminal report Food in the Anthropocene (Willett et al., 2019) in the leading scientific journal The Lancet. This strongly affirms how dietary changes, particularly a shift to low consumption of animal products, fulfils the need both for improved health and reduced greenhouse gas emissions.
In the land use chapter, we have:

- **Updated the baseline data**. Our understanding of greenhouse gas emissions from agriculture is continually evolving. We have included the latest UK government estimates for greenhouse gas emissions from land use and for carbon capture in soil.
- **Summarised the latest science on environmental farming practices**. We have updated the scenario to reflect the current science on agricultural practices. Some farming methods have been gaining increasing attention in social and other media for their environmental benefits, and we include the latest scientific thinking on their efficacy.
- **Greater emphasis on the necessity to protect and restore biodiversity**. The need to protect the diversity of life on our farms and in the wider environment is increasingly critical to our food security. We discuss the need for biodiversity restoration within a Zero Carbon Britain scenario.

1.5 The timeline to net zero

Zero Carbon Britain: Rising to the Climate Emergency describes an end point, where all UK emissions are net zero. So how soon can we get there? From installing clean energy to retrofitting buildings to transforming transport – how quickly can infrastructure be planned, financed, manufactured and installed?

When we launched our original scenario in 2007, we estimated that the net zero end point would take around 20 years to deliver, focusing on paths that minimised disruption. However, during the intervening 12 years the UK Government has been working to an underestimated '80% by 2050' target.

Without national-scale systemic transition in place, time is now very tight. 2030 remains a valid target from the perspective of climate science, but we must recognise that this is now becoming a hugely challenging delivery timeline.

Whilst a net zero date well in advance of 2050 is vital, the climate emergency arises from the total amount of carbon released rather than any particular end point. It is vital that we focus on ambitious, large-scale, near-term emission reductions, strengthening interim carbon budgets and bringing forward policies to get zero carbon solutions deployed at scale in the very near future.

Developing a UK zero carbon action plan to map out in detail how quickly we can achieve these reductions requires a cross-sectoral team with expertise in policy and financing frameworks as well as technology deployment timescales. Development of such a plan is an urgent task, and one which should be a key priority for UK and devolved governments. CAT would be happy to work with policymakers and industry associations to explore such timelines.

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Chapter 2

Context

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2.1 The global situation

We are in the midst of a global climate and biodiversity emergency. The natural ecosystems on which we all depend are being deeply affected. We have put our future at risk from the very serious, dangerous and real consequences of climate breakdown, mass extinction and global economic collapse.

Time is now of the essence, as succeeding slowly is actually failing. Unless we act immediately, over the coming decades, we will see natural systems irrevocably changing, with serious social and cultural implications. We are butting up against the environmental limits of our planet and cannot expect continual growth in a finite world.

An increasing number of countries publicly acknowledge this emergency situation. Humanity now needs to come together to develop and implement a global action plan capable of delivering the international target to limit warming to 1.5°C, restoring natural systems and maximising the many co-benefits of such a transition.

2.1.1 So you think this is normal?

In order to move forward we must understand the psychology of our current collective addiction to fossil fuels and how we were so gladly driven into the habit. On any historical or even geographical comparison, the amount of energy we now use in the developed West is highly abnormal, yet it has become normalised. A whole generation has grown up assuming the lights will come on, that there will be petrol in the pumps and stocked shelves in the supermarket. The challenge we face is not only for our technology, but also for our culture. Rising to this challenge requires us to consider the current relationship between human beings and energy in its wider historical context.

The story of human beings and energy began over 400 million years ago with the formation of fossil fuels. For millions upon million of years, plant life on planet Earth soaked up the sun's energy for photosynthesis, creating the largest, most concentrated and most convenient energy store we are ever likely to know.

Until relatively recently, we had no idea this energy store was under our feet. Our access to energy was limited to an annual ration of sunlight that reached the Earth's surface – providing the energy for plants to grow, making the wind blow and driving the water cycle. Access to land was vital – providing us with food to eat and fuel to keep warm. Over centuries we became more inventive, taking advantage of the trade winds to sail ships, and of wind and water to power windmills and waterwheels. All of this, however, still relied on the sun's annual energy ration.

The discovery of fossil fuels towards the beginning of the 19th century changed everything. With a powerful mix of the right skills and accessible stores, Britain burst into action with coal extraction, leading the world towards ways of making faster and larger withdrawals from a seemingly limitless account of ancient solar energy – fossil fuels. For the first time in human history, we had access to energy independent of land or season. Major changes in agriculture, manufacturing and transportation spread across Britain, Europe, North America and eventually the world. Oil soon displaced coal as the largest source of energy, being both easier to access and more transportable.

By the 1900s, the world was awash with abundant, cheap fossil fuels. Industrial and manufacturing processes were developed with little regard for the amount of energy they consumed. Continued expansion of access to fossil fuel energy gave rise to ever-growing industries. Our economic systems were built on the assumption that growth is the norm, and that it would be both perpetual and unrestricted.

Fossil fuel production was highly profitable, so much of our infrastructure was designed, quite literally, to use as much fossil fuel as possible. But at no time was this 'designed dependence' on fossil fuels as marked as with the arrival of the motorcar. Car production was to be the engine of post-Second World War economies; tramways were scrapped, rail links removed and newly sprawling towns and suburbs were deliberately developed in such a way that the car became not just a convenience but an absolute necessity.

Although the practice of having more than we need in order to highlight social standing in society is as old as civilisation itself, fossil fuels allowed this elite habit to become a mass culture. Conspicuous consumerism now exerts an irresistible pressure, making society reluctant to question the access to the energy supplies that underpins it.

Almost without realising it, we now depend on fossil fuels in nearly every aspect of our lives, while around the world they are linked to progress and betterment.

2.1.2 Climate change

When we burn fossil fuels to heat our homes and drive our cars, use chemical processes in industry, change how we use land and produce the food we eat, greenhouse gases (GHGs), such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and fluorocarbons, are emitted. The burning of fossil fuels contributes most to greenhouse gas emissions (Baumert et al., 2005).

Even though plants and oceans absorb much of the CO_2 that we emit (about 55%), the rest builds up in the atmosphere (Ballantyne et al., 2012). As a result, GHG levels in the atmosphere today are higher than they have been for at least the last 800,000 years (NRC, 2010), and are rising at a rate ten times faster than the last deglaciation (Shakun et al., 2012).

It has been known since 1861 that these GHGs trap heat from the sun (Tyndall, 1861). It is now certain that humans have changed the global climate by emitting GHGs (IPCC, 2014).

We are already seeing the effects, which include warmer average temperatures, hotter extremes, shifting seasons, reducing ice at the poles and changes in rainfall causing worse droughts and floods.

Climate today

Looking at our climate situation today reveals some interesting – and troubling – changes to current local and global climatic conditions.

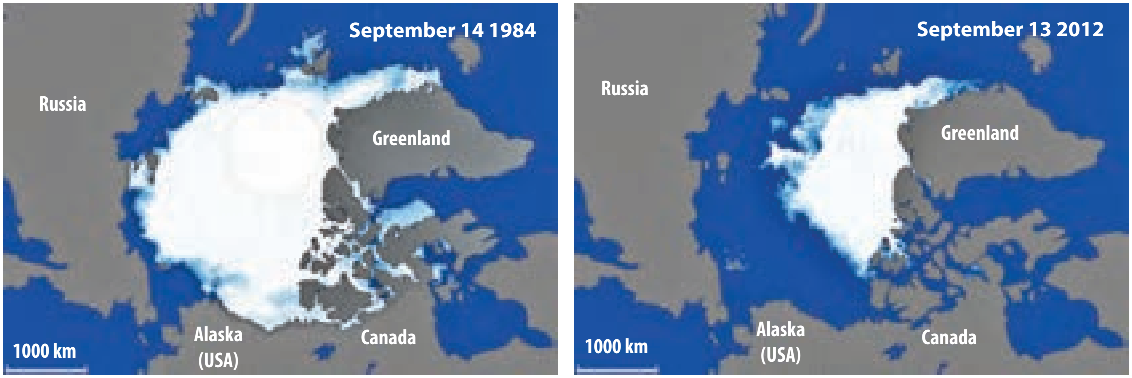

Figure 2.1: The difference in Arctic sea ice coverage during the 'summer minimum' between 1984 and 2012 (biggest ever recorded melt to date). Based on satellite data; adapted from NASA (2012).

New norms

Global average temperature has increased by about 1.0°C since pre-industrial times (IPCC, 2018). Each of the last three decades has been warmer than the previous one and warmer than any other on record since 1850. Eighteen of the 19 warmest years have all occurred since 2001, the other being 1998 (NASA, 2019). The seasons are changing – spring is coming earlier and autumn is appearing later (Richardson et al., 2013).

Oceans have been warming and becoming more acidic (as they absorb some of the CO_2 from the atmosphere). Sea levels are currently rising at about 3cm per decade, largely due to the fact that as water warms its volume increases (Church, 2011; NASA, 2019).

The Arctic is warming twice as fast as the rest of the globe (Lemos and Clausen, 2009). As a result, Arctic sea ice is melting more in summer (see figure 2.1). The twelve biggest sea ice melts occurred in the last 12 years (2007-18 inclusive) (NSIDC, 2019) - see figure 2.2. Greenland and Antarctica are losing ice, though less than in the Arctic and more slowly (NASA, 2019; World Bank, 2012). These changes are occurring faster than climate models had predicted (Allison et al., 2009).

New extremes

Heatwaves have been getting hotter and occurring more often. Local temperatures during heatwaves are much higher than extremes for these places over the last 510 years (Shearer and Rood, 2011). These weather extremes can be linked to climate change (IPCC, 2014). In late June 2019, much of Europe experienced 5-day average temperatures of 6-10°C above the long-term average (C3S, 2019) – see figure 2.3. This record-breaking heat wave was made five times more likely by climate change (Dunne, 2019).

The water cycle and weather systems are also changing. Warmer conditions mean more water evaporates and is held in the atmosphere (Coumou and Rahmstorf, 2012). Water in the atmosphere is the fuel of weather systems and thus intensifies weather patterns (Meehl et al., 2007). For instance, there have been longer, more intense droughts in some places (Dai, 2012; IPCC, 2014) and more intense downpours of rain in others (McMullen, 2009; IPCC, 2014).

Climate tomorrow

The global community is committed, through the Paris Agreement, to keeping the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursuing efforts to limit the temperature increase to 1.5°C (UNFCCC, 2016). Even a warming of 2°C would mean severe changes to the world in which we live. Many small island nations are calling for a limit of 1.5°C to be supported (World Bank, 2012), and evidence now suggests that 2°C is actually likely to be the threshold

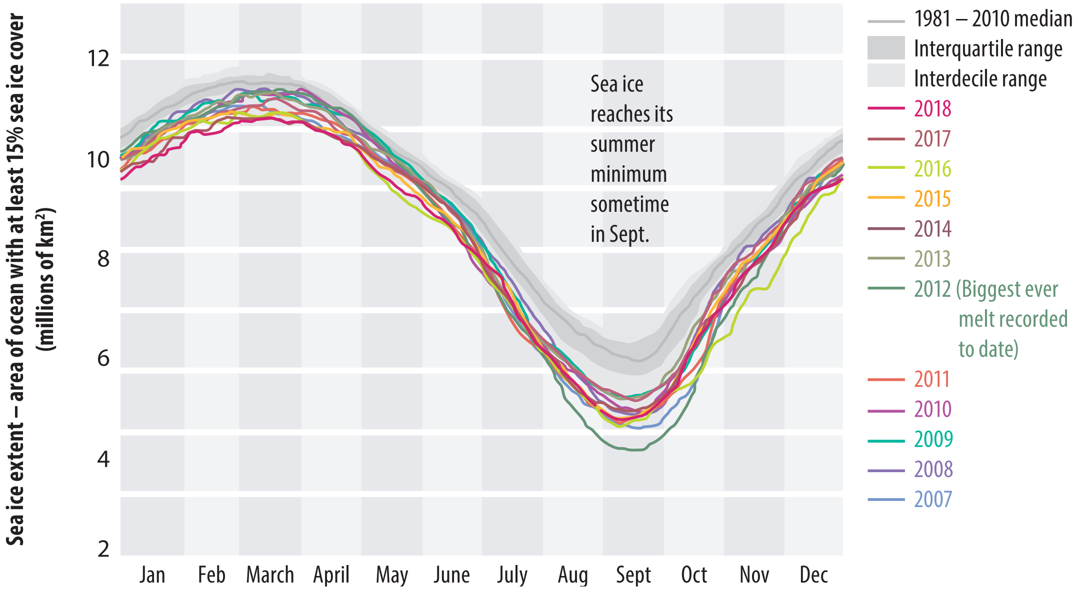

Figure 2.2: Artic sea ice melt. The twelve years with the biggest melts are shown relative to the average over 1981-2010 – what would usually be classified as 'normal' behaviour. Source: NSIDC (2019)

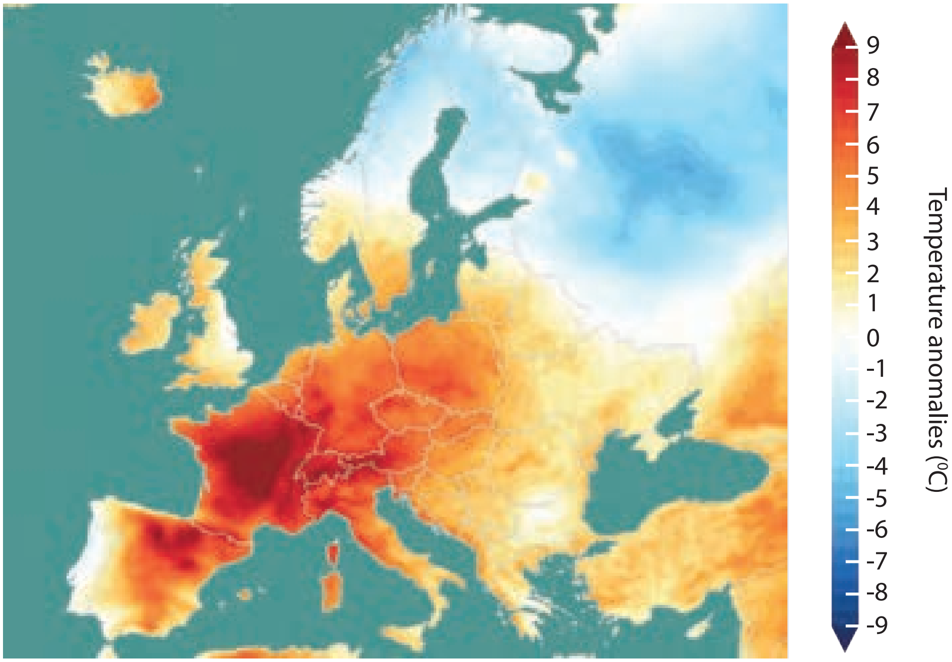

Figure 2.3: Map showing the anomalies in temperature (°C) for the 5-day period of 25-29 June 2019. Much of Western Europe experienced average temperatures 6-10°C above the 1981-2010 average (Adapted from: ECMWF, Copernicus Climate Change Service).

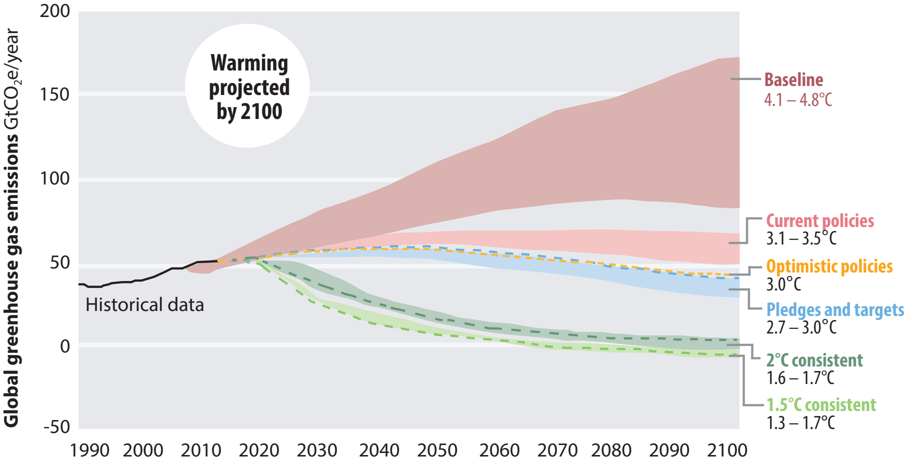

Figure 2.4: Temperature changes expected under different emissions scenarios. Source: CAT (2019).

between "dangerous and 'extremely dangerous' climate change" (Anderson and Bows, 2010).

Yet annual GHG emissions have continued to increase – about 1.7% per year on average since 2000 (CAT, 2019). Present emissions trends (even with current pledges to cut emissions) put the world on a course towards a temperature rise of 3°C by the end of the century (see figure 2.4). Without strong action, warming would result in a world more than 4°C hotter by 2100 (ibid).

According to the president of the World Bank (World Bank 2012):

"The 4°C scenarios are devastating: the inundation of coastal cities; increasing risks for food production potentially leading to higher malnutrition rates; many dry regions becoming dryer, wet regions wetter; unprecedented heat waves in many regions, especially in the tropics; substantially exacerbated water scarcity in many regions; increased frequency of high-intensity tropical cyclones; and irreversible loss of biodiversity, including coral reef systems."

It is unlikely we will be able to adapt to such a world:

"There is a widespread view that a 4°C future is incompatible with an organised global community, is likely to be beyond 'adaptation', is devastating to the majority of eco-systems and has a high probability of not being stable."

Kevin Anderson, former Director of the Tyndall Centre, UK (Anderson, 2012).

A sliding scale

Many impacts work on a sliding scale – as temperatures increase, the 'norms' and 'extremes' change, and the effects become worse. A 4°C warmer world would make it possible for oceans to acidify to the point of dissolving coral reefs (World Bank, 2012), and for sea levels to rise and flood over 150 million people each year (Met Office, 2011a). Very hot days (5-10°C hotter than the current hottest days) would be much more frequent. Droughts, floods and hurricanes would likely be much more commonplace. All this would have massive impacts on the basic necessities of food, clean water, health and shelter for many across the globe (ibid.). As temperatures increase, the severity of these impacts increases.

A bumpy ride?

Perhaps even more concerning is the possibility that long-term and cascading changes would occur, making climate change much worse, much faster:

- Melting permafrost as a result of warming would mean huge releases of methane (CH_4), a powerful greenhouse gas that would contribute to warming even further (Schuur et al., 2008).

- Acidification of the oceans and the death of parts or all of the Amazon rainforest because of warming would change these systems from those that capture CO_2 to those that emit CO_2, increasing the levels of GHGs in the atmosphere (die-back in the Amazon due to localised droughts in 2005 and 2010 – both 'one-in-a-hundred-year events' – released more CO_2 than the whole Amazon usually captures in a year (Lewis, 2011)).
- The melting of ice sheets in Antarctica and Greenland would mean over 10 metres of sea level rise, with New York, London and Taiwan under water (World Bank, 2012; McCandless, 2010).

As GHG emissions continue and the global average temperature rises, the risk that these events will occur increases.

In the world we are currently on course for, areas of the globe will almost certainly be completely uninhabitable, with huge ramifications on a global scale. There will be devastating worldwide impacts on the natural systems which support **all** of us. These changes will not be short-term, and would likely commit us to a worsening situation over the coming centuries.

Though there are many complex factors involved, we know that the major driver of these changes is our GHG emissions. This means that global reduction, and eventual elimination, of GHG increasing activities is necessary to change our course.

2.1.3 Planetary boundaries

The Earth provides many 'ecosystem functions and services'. Currently, we are exceeding the boundary of safe usage for several of them, making humanity's survival in the future highly uncertain.

The concept of 'planetary boundaries' recognises two things. Firstly, that the Earth must today be considered as an interconnected whole. Secondly, that human activities are pushing, and in some cases have already pushed, Earth's normal environmental balance beyond safe limits for the survival of human civilisation. Fig 2.5 shows the state of seven different thresholds that, if exceeded, are very likely to disrupt the stable environment that has facilitated human civilisation since the last ice age. We therefore need to find ways to live within these 'planetary boundaries'. Thresholds (elaborated in Table 2.1) represent examples of calculated human impacts for the point(s) where:

- Climate change – weather damage and changed ocean circulation (Lenton 2012) cause climate instability.
- Ozone depletion – ultraviolet light mutates DNA, causing widespread extinctions.

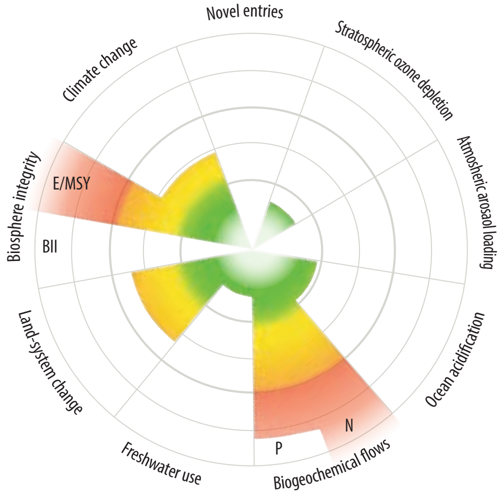

Figure 2.5: The state of global environmental degradation of seven calculated thresholds that, if surpassed, threaten global ecosystem resilience. Some 'boundaries' have already transgressed limits determined as 'safe' for human civilisation. E/MSY = extinctions per million species per year; BII = Biodiversity Intactness Index.
For description, see Table 2.1. Source: Steffen et al., 2015.

Environmental problem	Why it's important	Causes	Current situation and trends
Climate change	Climate determines temperature, land above sea level, vegetation, water availability, and species survival. See *2.1.2 Climate change.*	Greenhouse gases are emitted faster than assimilation rates, and build up in the atmosphere.	The 'safe' boundary of 350 parts per million (ppm) CO_2 is already exceeded and escalating, reaching 410 ppm in August 2019 compared to 387 ppm in August 2009 (NOAA, 2019).
Novel entities (e.g. new organisms and artificial chemicals in the environment)	Many manufactured chemicals cannot easily be broken down. New genetically-created organisms have unknown impacts and might not be controllable.	Industrial manufacture, release into the environment, and unquantified interactions with other chemicals and organisms.	Full effects are unknown and consequences unquantified.
Stratospheric ozone depletion	The ozone protects us from harmful radiation from the sun.	Chemicals such as halons and fluorocarbons are emitted into the atmosphere.	Within the boundary. CFCs are still decreasing. HFCs, SF6 and HCFCs increasing (WMO 2018).
Atmospheric aerosol loading	Interferes with climate balance, reducing insolation (exposure to the sun), and changing rainfall and monsoon patterns.	Release to atmosphere of black carbon (C), organic carbon (C), sulfates and nitrates from burning biomass and fossil fuel	Not yet fully quantified but thought to be in the zone of uncertainty (yellow in Fig. 2.5).
Ocean acidification	Oceans are vital for climate regulation, including absorption of CO_2, and are a globally important economic and biodiversity resource. The entire oceanic food web is jeopardised by acidification.	Greenhouse gases are emitted faster than assimilation rates, and build up in the atmosphere.	Approaching the boundary. Species balance and CO_2 absorption capacity is declining steadily.
Biogeochemical flows (focussing on phosphorous [P] and nitrogen [N])	Very high application of P and N (regionally and total global) causes major loss of biodiversity, 'dead zones', and risks ocean anoxia (insufficient, or absence of, oxygen).	Nearly all P and N come from fertiliser application, and enter water bodies when heavy rain washes them into rivers and the sea.	Dangerous concentrations of P and N contaminate the globe. The 'safe' boundary is greatly exceeded, in the 'high risk' category, and deteriorating.
Freshwater use	In many areas, water allocations for nature and the people depending on it are insufficient, leaving degraded and destroyed ecosystems, and increased poverty.	A supply and demand problem. Water needs for irrigation and industry are met, leaving insufficient for survival of ecosystems and people.	Many instances of ecosystem loss locally and regionally. Global total freshwater use is considered within the 'safe' boundary.
Land-system change	Sufficient forests have been destroyed to disrupt global climate, change rainfall patterns, and cause major genetic and species extinctions.	Forest clearance, especially in tropical, temperate and boreal biomes, mostly for timber, cattle grazing, and to grow soya and palm oil.	The safe boundary is exceeded and deteriorating. Now in the 'increasing risk' category. Nature is degraded and converted (to agriculture) in all biomes.
Biodiversity integrity: extinction rate and ecosystem integrity.	High biodiversity permits full ecosystem functioning, providing us with 'ecosystem services' such as feelings of connectedness, pollination, and oxygen.	Conversion of ecosystems to agriculture, overfishing, invasive species, pollution, and climate change.	We have entered Earth's sixth 'mass extinction'. The safe boundary is exceeded and deteriorating. Functional damage is not quantified.

Table 2.1: The nine 'planetary boundaries' identified as a 'safe operating space' for human civilisation to exist. They comprise global-scale environmental problems that threaten civilisation. The importance, causes and status of each is outlined. Sources: Rockström et al., 2009; Steffen et al., 2015.

- Ocean acidification – sufficient plankton and fish are killed to cause ecosystem collapse.
- Biogeochemical flows – eutrophication (artificial fertilisation) causes widespread extinctions.
- Freshwater use – not enough water is spared for natural systems to thrive.
- Land system change – wild nature is mostly eradicated.
- Biosphere integrity – extinction rates endanger most natural ecological functions.

Why the focus on ecosystem functions and services? This could be answered in many ways – for example, is it morally acceptable to harm the planet? – but one clear answer is that these services are what will enable human civilisation to survive into the future.

2.1.4 Future generations

Over recent years there has been a growing awareness that we must take the interests of future generations into account when discussing action on large-scale challenges like climate breakdown. As our descendants are not actually here to argue for their rights, we must build their rights into how we do things.

An early framework was set by the Brundtland Report of 1987, which proposed we 'provide for our own needs without compromising the needs of future generations'. This idea was enshrined in the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, setting out the case for global action on climate change.

We must cease to be 'future-blind'. Traditional economics assumes that the ability of future generations to solve environmental problems is best served simply by maximising economic growth in the present. Future costs are progressively 'discounted' at a rate of about 5% a year, so are assumed to diminish to almost nothing (Beckerman, 1995; Nordhaus, 2007).

Other economists, however, have urged that the interests of future generations should be treated as having the same value as our own, prompting a much more precautionary approach. For example, groundbreaking work by Stern (2009) estimates that an investment of 2% of UK gross domestic product (GDP) now could be sufficient to prevent future costs in the region of 20% of GDP. The argument is that if we make more realistic assumptions about what happens in the future, it is better to act earlier rather than later.

But our responsibility to future generations must extend beyond economics. It is unethical to treat fundamental needs in the future as equivalent to our lifestyle preferences today. The evidence for high risks of extremely grave outcomes cannot be ignored.

By making more realistic assumptions about the future now we can better support future generations.

Established in Wales in 2015, the groundbreaking **Well-being of Future Generations Act** not only gives the ambition and permission, but also makes it a legal obligation, for public bodies in Wales to think about the long-term impact of their decisions and how they affect future generations. The Act puts in place seven national wellbeing goals:

- A Prosperous Wales
- A Resilient Wales
- A More Equal Wales
- A Healthier Wales
- A Wales of Cohesive Communities
- A Wales of Vibrant Culture and Welsh Language
- A Globally Responsible Wales

The Act places a legal duty on public bodies to set objectives that contribute to achieving all of the goals, not just a token one or two, and to do this by following the five ways of working, which include long-term and preventive thinking. The Act also establishes a Future Generations Commissioner to be the guardian of future generations https://futuregenerations.wales

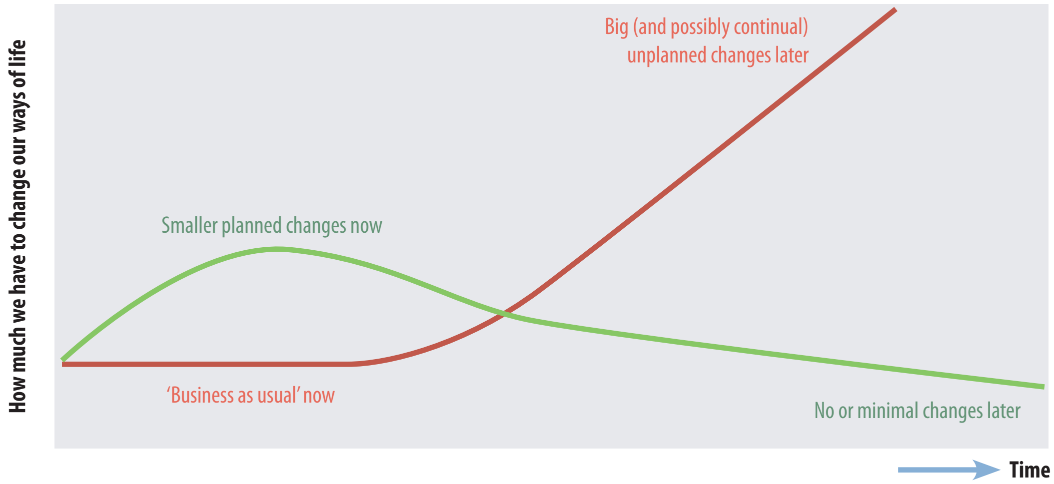

Figure 2.6: Illustration showing that choosing relatively small and planned changes now can avoid potentially much larger and unplanned changes to our ways of life later.

2.2 The situation in the long-industrialised West

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Though we have benefited hugely from industrialisation, the Western world has also created many problems for others as well as for ourselves in the process. In many cases, we have externalised the effects of our actions both economically and physically – by not counting the broader environmental impact of the actions we take, and by literally 'offloading' detrimental impacts elsewhere. In other cases, we have simply been looking in the wrong direction – favouring and fostering economic development over our happiness and wellbeing, for example.

As part of a global system, we rely on stable supplies of energy, goods and services from around the world to satisfy our 'needs' – meaning any global problem is also a local one. We fail to recognise that continual growth is not possible in a finite world, and are beginning to see the effects on our local energy supply, economy and our happiness as individuals and as societies.

2.2.1 Energy supplies

Climate change and environmental degradation are not the only drivers for a transition away from fossil fuels. Our fossil fuel based economies are being halted by the immovable facts of geology. For the first time in our history, and just as demand is exploding across the globe, humanity is close to no longer being able to increase annual energy production using fossil fuels. Despite the accelerating energy demand, global rates of 'conventional' oil and gas production are heading towards an inevitable plateau beyond which they must go into decline, with the remaining fossil resources being dirtier, harder and considerably more expensive to extract.

Consumption of oil has risen to nearly 33 billion barrels a year (some 90 million barrels per day) and the price has increased tenfold over the last century. This is mainly because sources of cheap, 'easy' oil are dwindling rapidly (Johnson et al., 2012). In the 1930s, burning oil produced about 100 times the energy used to extract it. But, as oil has become harder to get at, the amount of energy used to extract it has increased. By the 1970s, burning oil produced only 30 times the energy needed to extract it. Today, most new oil discoveries produce only ten times the energy we use to get it out of the ground (Morgan, 2013).

The peaking of global oil and gas supplies offers one clear reason to move beyond fossil fuel dependency: not because the supply will run out in the near future, but because the escalating prices will cause increasing turmoil in the economies (and societies) that still depend heavily on them.

Fracking: an answer for the UK?

Here in the UK, hydraulic fracturing (or 'fracking') is proving highly controversial. It involves inserting a mix of chemicals under high pressure into an area underground to release gas trapped in shale rock. It is unlikely to offer a lasting solution for our energy needs. Estimated yields from UK hydraulic fracturing fields are 150 billion cubic metres, equivalent to 1,470 TWh per year, or around a single year's primary energy production for the UK (Richards, 2012). Conventional gas fields decline relatively slowly whereas shale gas declines very rapidly, as pressure within the earth closes up the fissures being exploited. There is also concern over earthquakes, pollution of water supplies and the effects on wildlife.

The UK is now at a critical crossroads, as a significant amount of our current generation capacity is due for retirement within the next ten years. Strategic thinking is vital now to avoid panicked choices that will lock the UK into a problematic energy path for the future. Any investment in new generation plant infrastructure must take full account of the longevity of the fuel supply, the cost of extracting fuel and producing energy, as well as the potential fuel price rises that may occur during its design life.

In 2005, the UK became – once again – a net energy importer (DECC, 2009). Whilst increasing fossil fuel imports can substitute for falling domestic production in the immediate term, this is not a secure long-term solution due to global geological constraints. As supplies struggle to keep up with demand now, global oil and gas prices look set to rise, affecting our security of supply and damaging the UK's economy while potentially contributing to fuel poverty.

2.2.2 The economic crisis

Never before has there been such a time. We have experienced market crashes, we have endured resource scarcities, fought wars and witnessed the collapse of empires. But never have the stakes been so high. On numerous fronts, the consequences of the past 150 years of industrial civilisation are all simultaneously coming home to roost, and not least in our economy.

For over a decade, communities across the globe have been struggling to adjust to a new era of economic austerity. The spiralling energy prices and financial crash of 2007 not only revealed an enormous burden of hidden debt, but also led to the largest and deepest period of economic turmoil in generations. In 2019, the effects of this collapse still continue to roll on. Governments and communities urgently need a new approach to guide their economies through a process of resilience and regeneration.

Origins

Back in 1964, bank managers were renowned for being prudent – UK household debt was running at around 14% of GDP. However, following the deregulation of the 1980s and 1990s, it increased to 80% (Elliot and Atkinson, 2012). Cheap, deregulated finance not only enabled and encouraged UK consumers to live beyond our personal finances, but also beyond our fair share of global resources and beyond planetary boundaries – to provide for our 'wants' and deal with our wastes. Market rules were set well before we were concerned about climate change; consequently, they are carbon-blind.

As the manufacturing industry in the UK scaled down, debt-driven shopper spending increasingly became the engine powering a UK retail consumer economy. Initially, this appeared to be working – with a vibrant high street economy, Britain was once again a nation of shopkeepers, albeit mostly large corporate chain stores. But recent growth in lower cost online sales direct from overseas suppliers are now driving the high street chain store economy to very hard times.

Genuine recovery will require a new plan for going forward. In response to the 2007 financial collapse, a group of forward thinking organisations launched the Green New Deal, combining stabilisation in the short-term with longer-term restructuring of the financial, taxation and energy systems. This idea is now being developed internationally – the US Green New Deal brings ambitious action on climate and biodiversity together with a 'new jobs guarantee' and improved social support such as healthcare.

The science and technology needed to power an energy revolution are ready to go. By making visionary investments now, a Green New Deal approach can propel the latest advances into full-scale development and invest funds at ground level, getting Britain's labour force back to work, making our economy fairer and much more resilient.

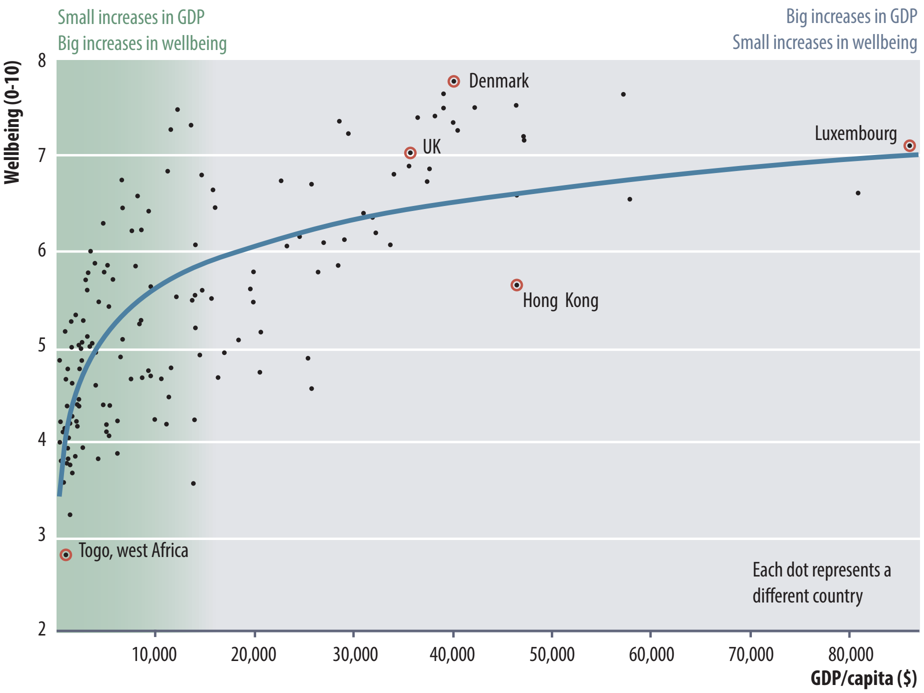
2.2.3 Wellbeing

Growth in fossil fuelled consumer culture isn't just wrecking the wellbeing of the planet – the tendency to base our identities on money, possessions or appearance is also seriously affecting our own health and happiness.

The practice of acquiring material possessions in excess of needs as a way of displaying status is as old as civilisation itself. However, the rise of abundant cheap fossil fuels has provided the means for this conspicuous consumption to be globally flaunted – a situation unique in human history.

Driven by powerful advertising and easy credit, we seek ever-higher levels of material consumption in the belief that this will lead to increased respect from our peers and a better, happier life. We are acquiring more than any human society has ever acquired

Figure 2.7: Wellbeing (as rated by individuals in a survey on life satisfaction) versus gross domestic product (GDP) per capita – consuming more doesn't necessarily lead to greater wellbeing past a certain point. Based on data from Abdallah et al. (2012).



before; shouldn't we be happier than ever before?

Clearly, below a crucial threshold we will be unhappy – when we don't have enough to eat or when we can't keep our children or ourselves warm, sheltered and clothed. But a growing body of research reveals that even far above this basic level, using or having extra energy or materials is not necessarily bringing higher levels of happiness or wellbeing (see figure 2.7). Significantly, only around 10% of the variation in subjective happiness observed in Western populations is attributable to differences in material circumstances such as energy use, income and possessions (Lyubormirsky et al., 2005).

People tend to adapt relatively quickly to increases in material consumption, soon returning to their prior levels of happiness (Abdallah et al., 2006 and 2009; Thompson et al., 2007). Even more surprisingly, the richer a nation gets (once it moves beyond 'enough'), the more unhappy and unhealthy its people can become – though some of this is due to the inequality in these situations, rather than absolute wealth.

Inequality contributes to a large number of social problems that influence the wellbeing of those at the 'top of the pile' as well as at the 'bottom' – poor health, higher levels of violence and drug abuse, and lack of trust amongst others (Wilkinson and Pickett, 2009). 'After becoming a much more equal nation post-war, UK inequality rose considerably in the 1980s, and reached a peak in the 1990s. Since 2010, it remains unchanged' (equalitytrust.org.uk, 2019), and the UK ranks among the most unequal countries in the world. From 1979 to 2012, only 10 per cent of overall income growth went to the bottom 50% of the income distribution, and the bottom third gained almost nothing; meanwhile, the richest 10% took almost 40% of the total (IPPR, 2018). Indeed, the share of incomes going to the 1% richest households has almost tripled in the last four decades (Joyce and Xu, 2019) and the median pay of a FTSE 100 CEO is 117 times that of the average UK full-time worker earning £29,574 (High Pay Centre, 2019).

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2.3 What does this mean for the UK?

Obviously, no single nation on its own can solve the climate problem. It has to be a collective effort. The United Nations Framework Convention on Climate Change (UNFCCC) was created in 1992 to address this problem, and it committed signatories to take steps to avoid 'dangerous climate change'. The Paris Agreement commits countries to holding the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursuing efforts to limit the temperature increase to 1.5°C (UNFCCC, 2016).

But what is the UK's appropriate contribution? By the standards of international climate diplomacy, the UK has been something of a leader. It has set a number of binding emissions targets relative to 1990 when GHG emissions were 794 million tonnes of carbon dioxide equivalent ($MtCO_2e$). The targets are:

- The 2012 Kyoto Protocol target of 12.5% reduction to 682 $MtCO_2e$ (UNFCCC, 1998).
- A series of carbon budgets, leading to a 57% reduction to 345 $MtCO_2e$ by 2030 (CCC, 2019).
- A long-term 2050 target of net zero emissions set out in the UK Climate Change Act.

These substantial reduction targets are backed by UK law. The Kyoto Protocol target was already achieved by 2006, and the general trend has been steadily downwards, broadly in line with the long-term target (see figure 2.8).

But is this consistent with global requirements? Science has moved on since 1992, and it has become clear that it is not the end point (or target) of emissions reduction that constrains global temperatures, but *the total quantity of emissions* along the way (Messner et al., 2010). Which begs the question, do current targets keep us within this new constraint?

Furthermore, as a long-industrialised nation we have contributed significantly to global emissions over the last 150 years or so, enabling progress and development and getting us to what we are today – a wealthy Western nation. Do current targets show that we are approaching the challenge of creating a sustainable future both fairly and equitably?

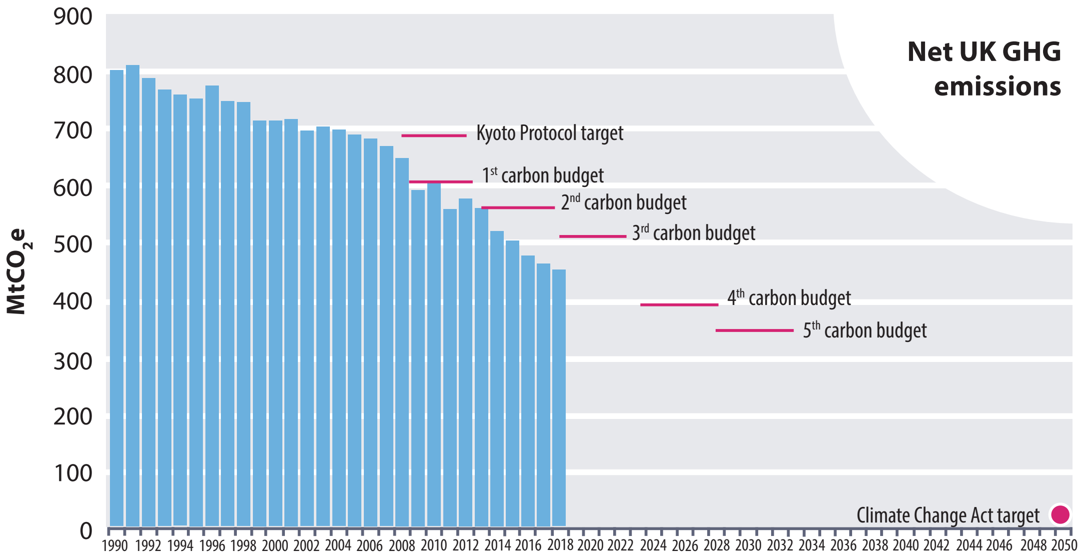

Figure 2.8: Annual production emissions of the UK (MtCO2e) from 1990 onwards (not including international aviation and shipping), showing progress alongside our internationally agreed emissions reductions targets. Targets are from references in text, emissions data from BEIS (2019a).

2.3.1 Our carbon budget

There is widespread acceptance that collective global policy should not permit an average temperature rise greater than 2°C and ought to pursue efforts to limit the temperature increase to 1.5°C. To achieve this, a cumulative ‘carbon budget’ for the world can be set – defining how much GHGs can be emitted in total. The world (mostly the Western world) has, of course, already ‘spent’ a large proportion of this budget. A global cumulative carbon budget measures ‘what is left’ at a particular date, and decreases every year we keep emitting GHGs.

There is, however, much uncertainty about what size a global carbon budget should be if it is to give us a good chance of avoiding a 1.5°C or 2°C global average temperature rise.

Indeed, what constitutes a ‘good chance’ is difficult to define.

One study (Meinshausen et al., 2009) calculates global cumulative GHG budgets, in terms of gigatonnes of carbon dioxide equivalent ($GtCO_2e$), between 2000 and 2050:

- 1,356 $GtCO_2e$ would give us an 80% chance of avoiding a 2°C global temperature rise.
- 1,500 $GtCO_2e$ would give us a 75% chance.
- 1,678 $GtCO_2e$ would give us a 67% chance.
- 2,000 $GtCO_2e$ would give us only a 50-50 chance.

Although there are developments in modelling methods and considerable uncertainties involved, these budgets remain broadly consistent with the CO_2 emission budgets and GHG emission pathways in the IPCC’s most recent reports (IPCC, 2018; IPCC 2014). Budgets for a two-thirds chance of avoiding 2°C of warming correspond to less than a one-third chance of limiting warming to 1.5°C. Therefore, a very high change of avoiding 2°C is necessary for a good chance of keeping below 1.5°C.

Global GHG emissions between 2000 and 2015 were ~720 $GtCO_2e$ (Gütschow et al, 2018), meaning we have already ‘spent’ a large proportion of what is available to us until 2050.

A defined remaining global carbon budget can then be ‘shared out’ between nations according to their population, meaning larger nations have a larger budget. A globally equitable per capita (per person) budget of this kind is the most likely basis for the necessary post-Kyoto Protocol treaty required for successful global decarbonisation (Messner et al., 2010).

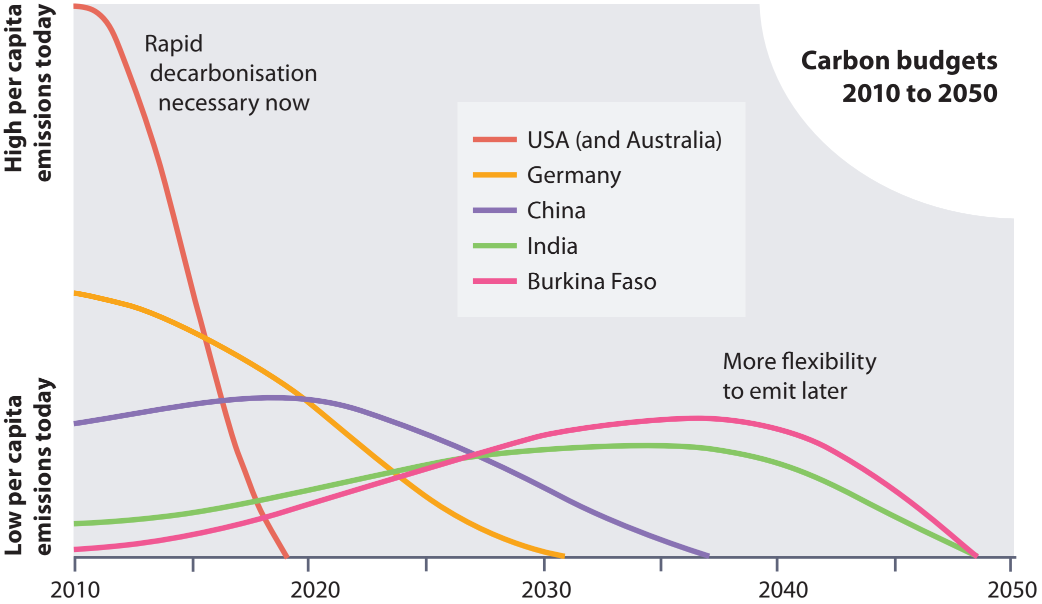

Figure 2.9: Examples of the difference that carbon budgets make to the decarbonisation trajectories of countries that currently have very high emissions and those which have low emissions. Adapted from Schellnhuber, 2009.

An important consequence of equal per capita budget allocation is that countries with high per capita emissions must reduce very quickly to stay within their budget, while those with low per capita emissions have greater flexibility, and are free even to increase their emissions if they consider it necessary. This is illustrated in figure 2.9.

Crucial to this is the year from which the remaining carbon budget is shared equally per capita. The earlier this date, the more that high emitting nations have already used most or all of their budget. The later this date, the more that lower emitting countries are constrained in their future emissions. Here we use 2010, a year by which the science of climate change was well established and nations such as the UK were formulating their long term goals.

Are we keeping within our budget?

Assuming an average global population of roughly 8.5 billion, and an average UK population of 70 million between now and 2050, the UK's share of the global budget between 2010 and 2050 would be about:

- 7,600 $MtCO_2e$ (80% chance of avoiding a 2°C global average temperature rise).
- 8,800 $MtCO_2e$ (75% chance).
- 10,300 $MtCO_2e$ (67% chance).
- 12,900 $MtCO_2e$ (50% chance).

This covers all that we could 'spend' (or emit) between 2010 and 2050.

As the UK government has already published a series of legally binding carbon budgets up to 2032, and further emissions reductions to 2050, we can calculate roughly how much carbon we will 'spend' if we meet all our targets.

Using data for UK GHG emissions from 2010-17 (BEIS, 2019) and a projection of GHG emissions in line with current policy targets, we find that the UK will emit over 14,600 $MtCO_2e$ (including emissions from international aviation and shipping) by 2050 – well over the amount for even a 50% chance of avoiding the 2°C limit.

Such a budget would not be acceptable in international negotiations, especially in view of the fact that most of the present atmospheric GHGs were generated by wealthy countries like the UK during their industrial development process. In some sense, such countries have already exhausted their 'moral budget' – having emitted far more than their 'fair share' over the years since the industrial revolution – and should perhaps shoulder this 'historical responsibility'.

From this perspective even 7,600 $MtCO_2e$ might be considered generous (Wei et al., 2012). For more discussion on what effect taking responsibility for our historical emissions has on the UK's 'fair share' of a global carbon budget, see *3.8.1 ZCB and the UK's carbon budget.*

2.3.2 The physics-politics gap

Physical problems have physical solutions and no amount of talking will make them go away. This is not to say that talking is not important; it is essential. But it is best to get the physics right first.

Virtually everybody agrees that rapid decarbonisation is the cornerstone of any solution to climate change, and we have adequate ways of measuring how much decarbonisation is required, plus how fast it is required.

However, if we analyse these physical requirements and work out a physically credible plan based on our scientific knowledge of the situation, we find it does not fit comfortably into the frame of normal politics and economics. On the other hand, if we work out a plan that does fit the politics, we find it does not meet the physical requirements. In fact, a huge gulf between what is physically demanded by science and what is seen as politically possible is revealed. This is reflected in the difference between our projected emissions 'spend' above (over 14,600 $MtCO_2e$) and the UK's portion of the global carbon budget in line with an 80% chance of avoiding a global temperature rise of 2°C (7,600 $MtCO_2e$). That's a difference of 7,000 $MtCO_2e$.

We can call this the 'physics-politics gap', as illustrated in figure 2.10.

Most current efforts attempt to build bridges from the now, working forwards within current political,

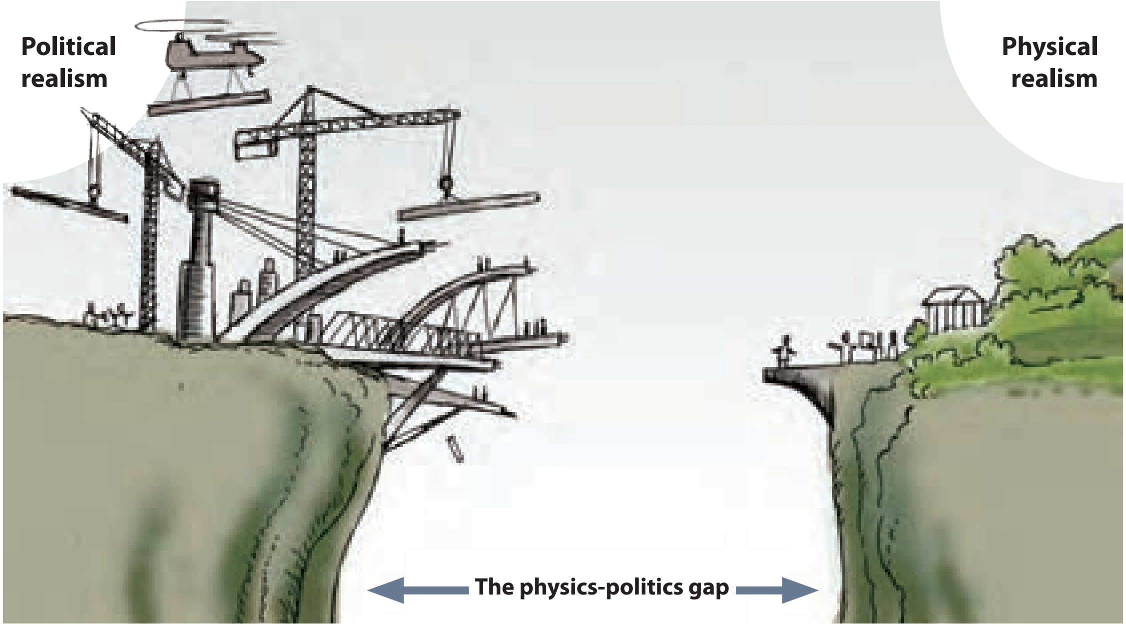

Figure 2.10: An illustration of the physics-politics gap and efforts to try to bridge it from the politically realistic side. A physically realistic perspective sits on the other side of the gap, denoting where we need to be to meet the physical requirements of the problem.

economic and social boundaries to try and meet the challenge of rapid decarbonisation. There are plenty of 'half bridges' built on foundations in the politically realistic perspective, none of which quite reach where we need to go from the physically realistic perspective.

Another approach is to instead ask, 'what is the end point?' A physically realistic perspective based on this line of question shows us where we need to get to in order to successfully meet the challenge of climate change. We can explore the possibilities for physically realistic worlds and consider what needs to change (from lifestyles, to infrastructure, to politics and economics) for us to get there, plus how fast we need to change, and the alternative routes that we can take.

Once we have worked out where we need to get to, we can work backwards to find out how we get there. Zero Carbon Britain focuses on the questions involved in this process and sets out such a physically realistic scenario – laying foundations on the 'right' side of the physics-politics gap.

ZERO
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Chapter 3

Our scenario: Rising to the Climate Emergency

3.1 About our scenario

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The great thing about the future is that anything can happen. Many radical changes throughout history have shown us that we are bold, innovative, creative and often surprising individuals and societies.

Trying to figure out 'where to go from here' can be restrictive, as it means operating within the systems and constraints we recognise and know. But figuring out 'where we want to end up' is both exciting and overwhelming in equal measure.

It is necessary here at the start then to reduce the very large – potentially infinite – range of future scenarios we could construct. We can do this by giving ourselves some aims to work towards and some rules by which to play. We must also state our assumptions – we're not modelling the entire world here, so we need to figure out on which basis we are setting our scene.

3.1.1 Aims

The first aim is obvious – to make our contribution to addressing climate change. To do this we must become 'net zero carbon', since any remaining emissions (no matter how small) that are not balanced with equivalent carbon capture methods will eventually add up, contributing to atmospheric greenhouse gases (GHGs). The transition must be rapid enough for us to maintain a carbon budget that gives a high probability of keeping the global average temperature rise below 2°C, and some chance of limiting the rise to 1.5°C. Our net zero carbon scenario is therefore set in 2030. Net zero must also be sustainable in the long-term.

We also want to make sure that decarbonising the UK in these ways does not mean living in a cave and eating bugs off the walls. Our wellbeing – physical and mental – and that of the local environment is important, and so we also need to:

- Keep the lights on and keep everyone warm, providing enough energy to meet demand at all times.
- Make sure we all eat enough, and eat well.
- Keep a decent standard of living, with the benefits of a modern society.
- Support biodiversity – making space for the natural world we rely on.
- Look at how to help adapt to a changing climate – building resilience into our systems to be able to respond to the foreseen and unforeseen effects of climate change.
- Weigh up the costs and benefits (not just monetarily) of our options.

Although living in the UK will be different in our scenario, we create a scenario that represents a positive future – one that inspires change.

3.1.2 Rules

Rules are born out of the values we hold as individuals and societies. They guide us when making decisions and make it easier for us to check that what we are doing is fair, and that we are meeting our aims. We have made the following list of rules to guide us in creating our scenario.

When counting GHG emissions we:

- Must include all the different GHGs as recorded by the United Nations Framework Convention on Climate Change (UNFCCC): carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and others. Since all of these GHG emissions contribute to climate change, we have to reduce them all. To make this easier, we measure them all in 'carbon-dioxide-equivalent' (CO_2e) – the equivalent impact in terms of CO_2 of each gas over the standard 100-year timeframe. For example, methane is 25 times more powerful as a GHG than CO_2, so 1 tonne (t) of methane equals 25 tCO_2e (IPCC, 2007). For the CO_2e of other GHGs, see *End notes*.
- Count carbon on a 'production' basis. This means we take into account all the GHGs emitted within the borders of the UK. We also include those from our share of international aviation and shipping (not currently included in UNFCCC totals). Counting carbon from a 'consumption' basis is discussed in *3.10.3 Carbon omissions*.
- Start with the UK GHG emissions in 2017 (BEIS, 2019). These emissions (UNFCCC and international aviation and shipping) come to a net total of about 503 $MtCO_2e$. We then calculate the additional impact of aviation, as GHGs emitted higher in the atmosphere may have a greater warming effect (Lee, 2010). This brings the net effect of the UK's actions in 2017 to about 524 $MtCO_2e$.

What do we mean when we talk about 'emissions' and 'zero carbon'?

In this report, we talk about both carbon emissions and carbon capture. These two things are usually combined in UK GHG emissions accounts.

In 2017, the UK actually *emitted* 532 $MtCO_2e$ including international aviation and shipping. But in the same year natural systems in the UK *captured* 29 $MtCO_2e$ of carbon, balancing out some of our emissions. These two figures combine to give the total **net emissions** of 503 $MtCO_2e$. On top of this, we add the additional effect of aviation, getting a total of 524 MtCO2e – this was the UK's estimated **net effect** or **net impact** in 2017.

When we talk about **emissions** in the report – for example, 'about 79% of our emissions come from energy use' – we are referring to the first figure here: the UK emissions totalling 532 $MtCO_2e$ in 2017.

When we talk about **net emissions** in the scenario, we are referring to emissions minus carbon capture – net emissions in 2017 were 503 $MtCO_2e$.

However, when we talk about becoming *zero carbon,* we are talking about the **net effect** on the climate, including the effects of flying – the UK's net effect was equivalent to 524 $MtCO_2e$ in 2017.

In creating our scenario we:

- Use only technology available now and currently in use, or technologies which have been demonstrated to work. This ensures that our scenario is realistic in technological terms – we don't rely on silver bullets (promises of future developments in technology). We need to act now on climate change, and so we must present solutions that could be implemented immediately.
- Propose changes that last – there is no point looking simply at the short-term. Any solutions we propose must have the capacity to last for the rest of this century, although hardware might need replacing and maintaining over this time, of course. Some short-term measures can, however, help during the transition to a zero carbon Britain (see *3.6.3 Capturing carbon*, and *3.8.1 ZCB and the UK's carbon budget*).
- Rely on well established research wherever possible. Some areas of scientific research are not well quantified, however. Where science currently doesn't have an answer, we should be cautious, and not overestimate the effect of an action.
- Supply our energy with 100% renewable technology, with no nuclear component. Even today, there is no plan for the waste from many of the UK's current nuclear power plants – it will have to be kept safe for thousands of years to come (DECC, 2011). Nuclear plants, and the hazardous waste produced, substantially increase the risk of very serious and lasting damage from natural disasters, climate-related events, or global political instabilities. Renewable energy systems do not have costly or difficult waste to manage, they don't require expensive and lengthy decommissioning processes, and they are at a much lower risk of very serious lasting damage from unpredictable future events.
- Rule out geoengineering options (see box on page 33) that are considered potentially dangerous, are only in early stages of development, or have not yet been proven to work. This leaves us with the following options:
  - Planting forests.
  - Producing biochar for soils.
  - Permanent burial of biochar or organic material ('silo storage').
  - Carbon Capture and Storage (CCS) at fossil fuel power stations or industrial plants.
  - Bio-energy Carbon Capture and Storage (BECCS) – carbon capture and storage at biomass-based power stations.
  - CO_2 air capture ('scrubbing') and storage – direct mechanical capture of CO_2 from the air.

Public support appears highest for planting forests and producing biochar, which were perceived as more 'natural' geoengineering methods (Ipsos Mori, 2010). For these reasons, the first three options are prioritised in our scenario. Fossil fuel power coupled with CCS does not provide a solution. Not all the GHG emissions are captured from the fossil fuel plant, and, as highlighted in *2.2.1 Energy supplies,* fossil fuels reserves are becoming dirtier, harder and considerably more expensive to extract. The storage suggested for carbon captured through CCS, BECCS and CO_2 capture from the air is usually old oil and gas fields (on land or under the sea), which must be monitored indefinitely to minimise leakage. This implies unknown costs and effective risk management long into the future, which cannot be guaranteed. Whilst abrupt leakage events might be seriously damaging to local systems (especially if the storage is underwater), diffuse leaks can be more difficult to stop and would, at least in part, reverse the mitigative effect of capturing the GHG emissions in the first place (IPCC, 2005). There are also limits to the CO_2 storage capacity of most methods, meaning that these options do not represent *alternatives* to decarbonisation, and in the long-term they would be phased out (Vaughan and Lenton, 2011).

- Do not rely on international or transitional credits. Funding the transition to zero carbon economies in less developed nations by paying so that we can emit more than our fair share of

GHGs, or paying them to capture equivalent carbon on our behalf, can be seen as a positive outcome of our inability to reduce emissions sufficiently in scale or speed. However, it is difficult to tell, without modelling the rest of the world, how many credits would be 'fair' (or indeed possible) to use, and lenient rules can lead to double counting, meaning global emissions reductions are eventually not met (UNEP, 2012). As such, we don't think there is anything inherently wrong with the purchase of international credits, if the scheme is implemented well, but choose not to rely on them in our scenario. International credits do not provide a long-term solution to GHG emissions, are not an alternative to decarbonisation and can delay the urgent need for action on climate change in long-industrialised nations (ibid.).

And finally, with reference specifically to our aims, we:

- Must make sure energy supply meets energy demand, at all times. This follows on from our aim to keep the lights on and to keep people warm.
- Only rely on renewable energy sources inside the UK (including UK offshore waters). Importing energy from other countries need not be a bad idea, but it is difficult to guarantee the reliability of energy imports or to ensure that we will only take our 'fair share'. As such, we choose only to use energy we can produce at home.
- Must ensure that the food we produce feeds the UK population sufficiently and healthily. We choose not to import livestock or feed for livestock, as this has detrimental impacts elsewhere in the world (Audsley et al., 2009).
- Must not increase the area of land managed by us – we must leave wild areas and room for conservation and habitat restoration or protection. At the very least, this will mean we do not further damage local environments. Other needs of the land (aside from carbon management) must be considered – including biodiversity and human enjoyment.
- Choose solutions that help us adapt to a changing climate, where possible. Despite efforts to mitigate climate change, there are some unavoidable impacts already 'in the pipeline' (Jenkins et al., 2009). We must therefore try to make sure our scenario provides flexibility to adapt to these changes.

Oh, and despite the project title, we don't just model Britain; we really mean the whole of the UK. Most data are provided for the UK rather than Britain. Climate change policy must be supported by central government, and our legally binding international targets on GHG emissions are for the UK, so it makes more sense to include us all.

What is geoengineering?

The term 'geoengineering' can cover many different technologies and techniques that aim to mitigate climate change or the effects of climate change – from planting forests to capture CO_2 from the air to deploying mirrors in space to reflect the sun's rays and cool the planet. These examples describe the two main types of geoengineering – those that directly reduce levels of CO_2 in the atmosphere, and those that reduce the warming effect of increased levels of CO_2 in the atmosphere. The latter type do not address all of the impacts of climate change, however – for example, ocean acidification would continue even if temperatures were prevented from further rising (Vaughan and Lenton, 2011). A report by the Royal Society, *Geoengineering the climate* (2009), assessed many geoengineering options on their effectiveness, their 'timeliness' (how close to being technically viable and how quick to work), their potential cost and their safety. Geoengineering options vary hugely in all these areas, and also have significant governance and policy implications.

3.1.3 Assumptions

About the UK in our scenario:

- The population of the UK increases as per projections. This means that in 2030 there are about 70.5 million people (ONS, 2017). Our scenario must cater for this population – from energy demand through to food provision.
- Official projections assume a decrease in household occupancy in the future (DCLG, 2016) but this is uncertain enough that we assume the average household stays roughly the same as it is now, about 2.35 people per household. Since larger households use energy more efficiently (Utley and Shorrock, 2008), we should aim to actually *increase* the number of occupants in a household over the long-term (though not indefinitely), meaning that fewer new builds are required and the energy use per capita continues to decrease.
- With respect to industrial energy demand, we assume the nature and size of UK industry will roughly stay as it is. In other words, we do not assume that energy intensive industries (such as manufacturing) will play a greater or smaller role than they do today. UK industry in our scenario is simply a more energy efficient version of industry today.
- We assume the average person would like the UK to stay just as it is. This means that, as far as possible, we keep daily life very similar to now. There are, however, some things we simply cannot keep the same. We try though to make reasonable compromises, or choose options we think will have other benefits.

About the rest of the world in which our scenario exists:

- The rest of the world decarbonises alongside the UK, though we do not state how – it makes no difference if each nation or group of nations decarbonises alone, or as part of an international agreement.
- We assume that decarbonisation happens under a fair division of responsibility. This doesn't mean that everyone decarbonises at the same rate, but does mean that each nation keeps within its carbon budget (see 2.3 *What does this mean for the UK?*). This means that GHG emissions associated with the production of goods that we import are accounted for globally, and the global carbon budget is still adhered to. A discussion related to the emissions associated with our imports can be found in *3.10.3 Carbon omissions*.
- The overall goal is a zero growth or steady state economy with a planned transition. Though we do not model global economics, we assume that the economy continuously becomes less energy (or carbon) intensive and that ultimately it is aiming to reach a steady state. Though this doesn't have much *explicit* impact on our scenario, we have known for a long time that economic growth, as it is currently generated, cannot continue while we live on a finite planet (Meadows, 1972).

About the transition to 2030:

- We do not explicitly model or make assumptions on *how we get there*. We do not assume a particular carbon price, emissions cap or suchlike. We create a scenario that technically achieves its aims – but it is not a road map of how to get there, which will likely depend on political persuasion and societal values. We can envisage a route that is either largely driven by market forces; by governmental regulation; by a voluntary large-scale change in aspiration by the UK population; or by widespread public demand for change in all sectors of society. We outline some of the options for policy frameworks in *3.8.2 Zero carbon policy*.
- We do, however, assume that the social and political priorities are different from those of today. We assume that over the course of the coming decades, the impacts of climate change will really start to bite, and that political and public motivation and action will become more aligned with what is physically necessary to rise to the challenge of climate change. Every sector

of society will have taken it seriously and will act accordingly. What is currently economically, socially or politically feasible takes second priority to what is physically necessary.

- We do not explicitly calculate the economic cost of our scenario or assume that there is a hard financial limit to our spending, though we do aim to avoid unnecessarily expensive solutions. Some technologies included are very expensive today because they are only used on a very limited scale. We assume that these will become a lot more financially viable when implemented on a large scale. We assume that if the need is there, the market will follow. We also assume that the cost of *not* acting is unacceptably high.

Who made the rules?

These aims, rules and assumptions were laid out by the research team involved in the creation of this scenario. They broadly reflect the values held by the group, the social and environmental responsibilities we felt to be important, and some compromises and limitations that were necessary for the operation of the project. They are not meant to be a universal set of guidelines, or to reflect the only way of doing things. In fact, there was much discussion amongst the group and different viewpoints were held on various topics, even amongst what was assumed to be a set of fairly like-minded individuals. We might have chosen different constraints within which to construct a future scenario. Some of these are discussed in *3.10 Other scenarios*.

Measuring up today 3.2

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Before we figure out where we end up, we should take stock of where we are now – what the size of the challenge is for the UK, and what components might help us to get to net zero emissions, or hinder us.

So, what is the UK like today? In our scenario, we look at the UK in terms of three principal metrics:

- Our greenhouse gas (GHG) emissions.
- Our supply and demand of energy.
- Our use of land.

The first one depends heavily on the second two. Figures 3.1-3.3 outline where we are today.

As stated above in 3.1 *About our scenario*, in 2017, we emitted roughly 532 $MtCO_2e$ including international aviation and shipping (BEIS, 2019). Additional effects from aviation emissions added the equivalent of roughly 21 MtCO2e. About 29 $MtCO_2e$ of carbon was also captured in the UK that year. Therefore the net effect on climate change was equivalent to 524 $MtCO_2e$.

In 2017, we used roughly 1,670 TWh of energy, which required a supply of about 2,235 TWh once losses in the system are taken into account (BEIS, 2018; BEIS 2018a). Our energy still mainly comes from two fossil fuels: oil and natural gas. Less is now coming from coal and more from biomass and renewables, such as wind power. Our total energy use creates about 80% of our GHG emissions, and is comprised of energy use in households, businesses and industry, and transport.

These sectors also cause emissions that are not related to energy, largely through industrial processes and the management of the waste we produce. These amount to about 9% of total annual emissions.

Just over 6% of our land is classified as 'urban' area, but as land is built on and grasslands and forests are cleared, more GHGs are emitted, contributing about 1% to our annual total emissions.

Over two-thirds of our land in the UK is dedicated to food production in some way, despite importing about 42% of what we eat. Almost 70% of agricultural land in the UK is used to graze livestock (sheep and cows) for meat and dairy products. Even half of our cropland is used for livestock production – to grow feed. The agricultural use of land, and land use changes associated with it, contribute the largest portion of our GHG emissions after energy – roughly 10%.

Only 12% of our land is currently covered in forest, with about 90% of it harvested for timber (wood used for building and carpentry). Just 8% of the UK's land is not managed or used productively in some way, which has significant implications for biodiversity and habitat protection – for example, over 80% of our peatland is damaged in some way due to our interventions, which further contributes to emissions. Forest (both harvested and unharvested) and some grassland are responsible for most of the carbon we currently capture in the UK.

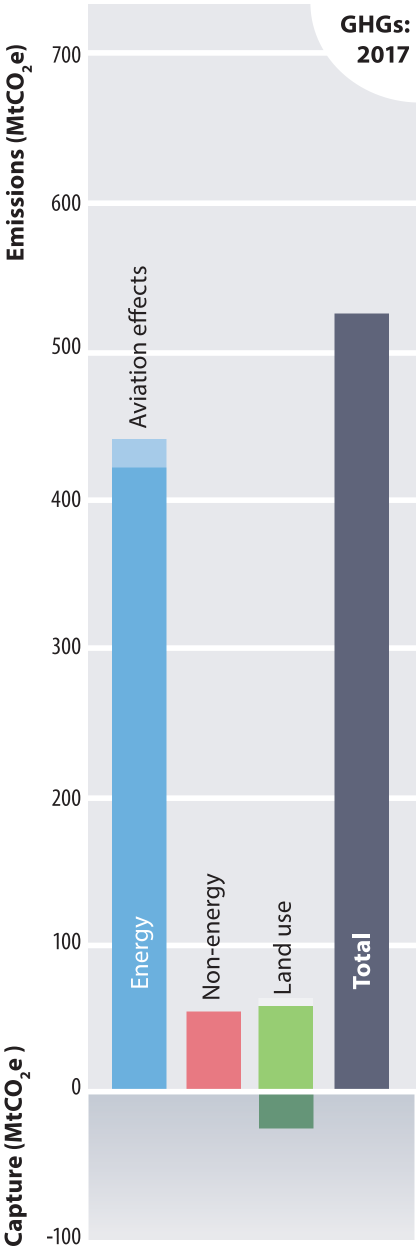

Figure 3.1: UK Greenhouse gas emissions in 2017, including international aviation and shipping, and the enhanced effect of emissions from aviation (BEIS, 2019).

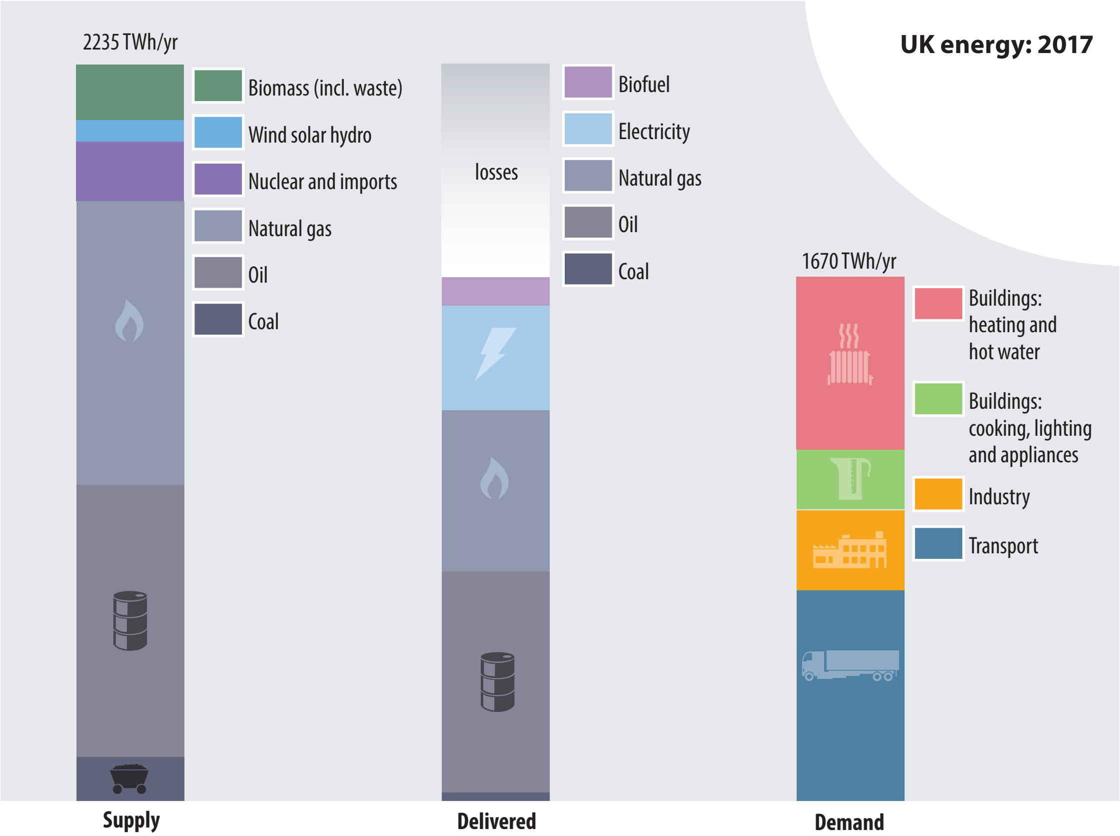

Figure 3.2: UK primary energy supply, delivered fuel mix and energy demand in 2017 (BEIS, 2018; BEIS, 2018a).

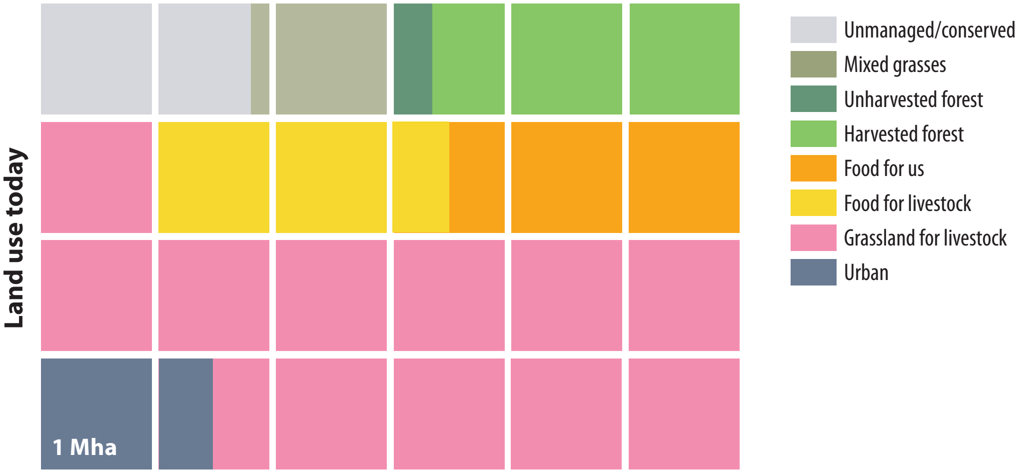

Figure 3.3: Approximate land use today (not including water courses and coastal areas). Based on data from Morton et al. (2008), Forestry Commission (2007), DEFRA (2012), NERC (2008), Bain et al. (2011) and Read et al. (2009).

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3.3 Power Down

Power Down is the reduction of our energy demand using efficient technology and making changes to the way we live. This is a vital part of the process of reducing GHG emissions from the energy system that powers our buildings, industry and transport. As outlined above, this energy demand – around 1,670 TWh in 2017 – accounts for roughly 80% of our current GHG emissions (BEIS, 2018; BEIS, 2019).

Power Down also makes it possible to fully meet our energy needs from renewable energy sources. As shown in sections *3.4 Power Up* and *3.6 Land use*, the UK could produce lots of electricity from renewables, such as wind power, but it has a limited amount of land available to grow biomass with which to make carbon neutral solid, liquid and gaseous fuels. The changes described in this section produce a 'fuel mix' that could be met by the UK's own renewable energy resources.

Power Down summary:

- Annual energy demand is reduced by about 60% from the current 1,670 TWh to around 680 TWh per year (see figure 3.4). An additional 135 TWh or so of ambient heat is used by heat pumps, making total energy use about 815 TWh per year (see figure 3.5 overleaf).
- A combination of efficient technology and behaviour changes can achieve large reductions in the energy used for heating and hot water, cooking, lighting and appliances, and transport.
- Industrial energy use is expected to remain similar to current levels – whilst industry will become more efficient, an increasing population and the need to build infrastructure will increase the demand for products.
- The 'fuel mix' resulting from Power Down means most energy is required as electricity (about 452 TWh per year), but some additional heat is required for buildings from geothermal and solar thermal generation – some 40 TWh every year.
- Buildings, industry and transport also require energy in solid, liquid and gaseous forms – 41 TWh of biomass for heat, 87 TWh of carbon neutral synthetic liquid fuel, 50 TWh of biogas or carbon neutral synthetic gas, and 10 TWh of hydrogen every year. Figure 3.5 shows this transition away from a fuel mix dominated by fossil fuels – oil and natural gas.

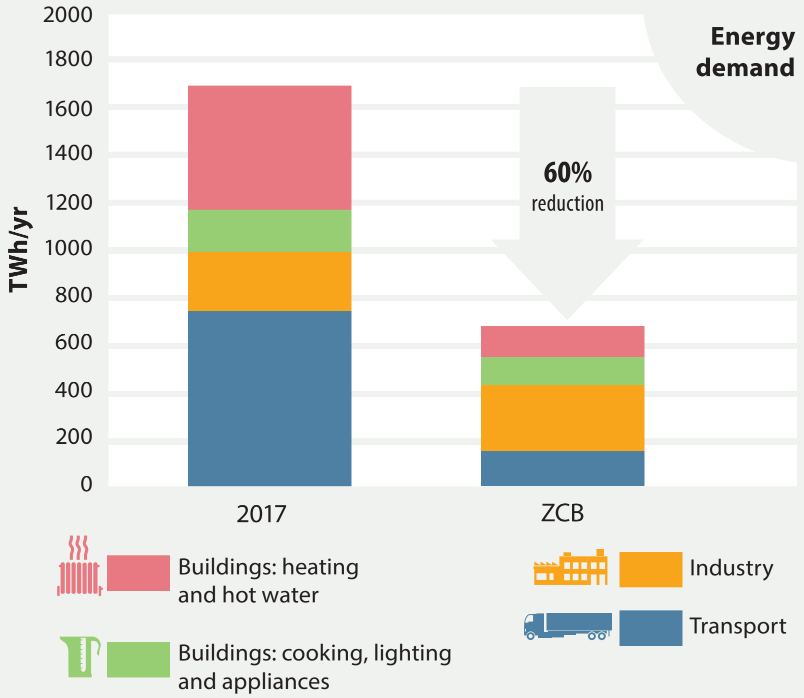

Figure 3.4: Total annual energy demand by sector in the UK in 2017 (BEIS, 2018) and in our scenario.

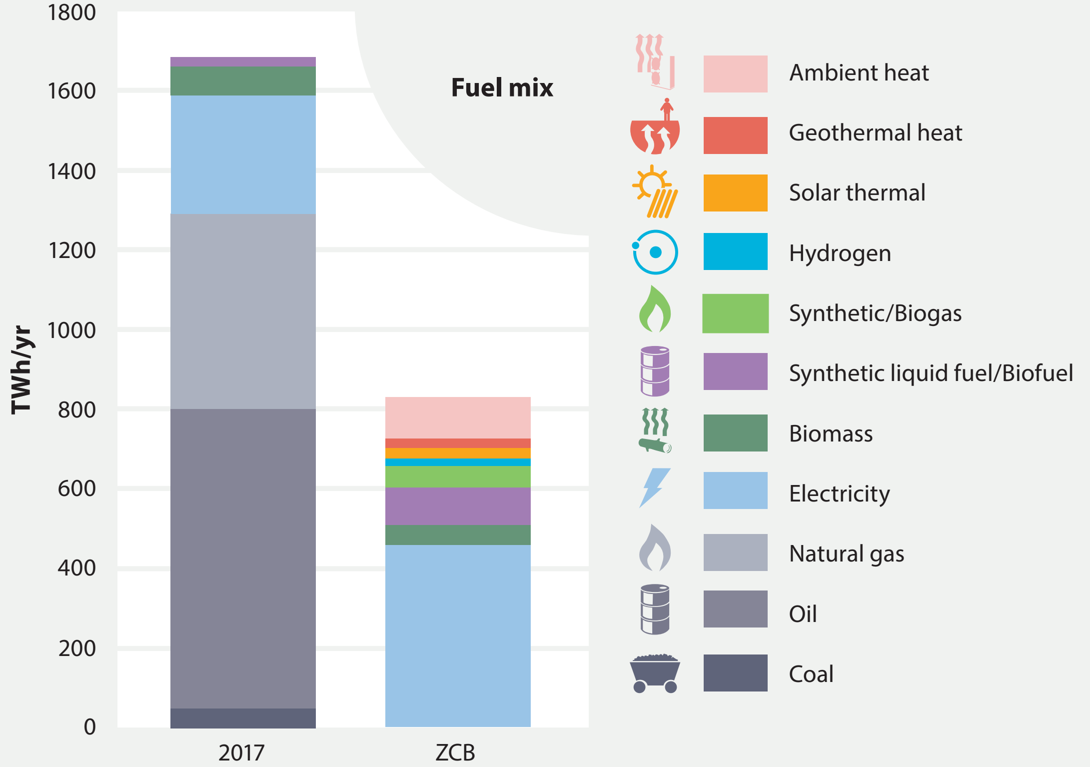

Figure 3.5: Annual energy use by fuel type in the UK in 2017 (BEIS, 2018) and in our scenario.

3.3.1 Buildings and industry

This section covers energy demand and GHG emissions from the UK's building stock and industry. It describes how we can reduce energy use in these sectors and how we can change the fuels used for energy to come from renewable sources.

Summary

- Energy use in buildings and industry accounted for 59% of UK energy use and 54% of GHG emissions in 2017.
- High standards for new buildings and the retrofit of all existing buildings can reduce energy demand for heating by around 50%.
- Efficiency improvements in cooking, lighting and electrical appliances can significantly reduce their energy demand.
- Industry can also be made more efficient, but a growing population and the need to build infrastructure mean industrial energy demand is expected to be similar to today.
- In total, buildings and industry energy demand is reduced from around 990 TWh in 2017 to 525 TWh per year in our scenario (660 TWh per year including ambient heat).
- Most heating and hot water, all appliances, and most of industry will be powered by electricity (382 TWh per year), but we also require some biomass for heating buildings (about 12 TWh per year), and some heat from geothermal and solar thermal sources (40 TWh per year).

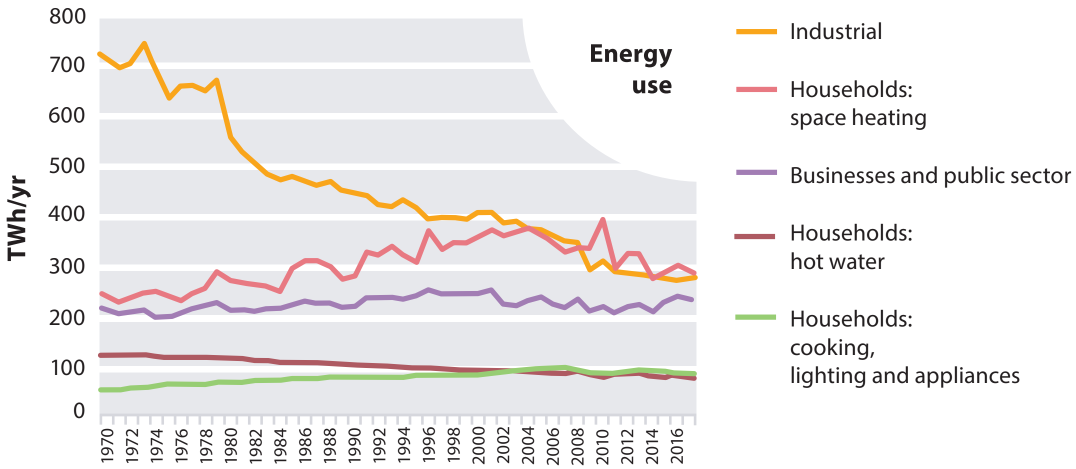

Figure 3.6: Annual energy use in UK buildings and industry over recent decades (BEIS, 2018).

- Industry is also expected to need carbon neutral solid, liquid and gaseous fuels – 29 TWh, 13 TWh and 50 TWh per year respectively.

What's the problem?

In 2017, 41% of the UK's energy use was in buildings – houses, offices, shops and public buildings (BEIS, 2018). This energy was used for heating, cooling and ventilation, hot water, cooking, lighting and electrical appliances.

The UK currently has an aged and poorly insulated building stock. Small improvements have been made to reduce heat loss from buildings, but we have also tended to heat our buildings to higher temperatures. This means that energy demand for heating has risen over recent decades, although it may be starting to decline (see figure 3.6). Energy demand for hot water however, *has* declined over recent decades, thanks to more efficient hot water systems. Together, heating and hot water accounted for 32% of total UK energy demand in 2017 (ibid.).

Energy demand for cooking, lighting and electrical appliances was 12% of total UK energy use in 2017. This has decreased slightly over recent decades, whilst combined energy demand for lighting and appliances has increased slightly over the same period. The efficiency of cooking, lighting and appliances has improved, but we're also using more appliances – resulting in higher energy demand overall (ibid.). The figure of 12% also includes energy for cooling and ventilation, responsible for 0.8% of UK energy demand in 2017.

Industry is the only sector in which energy demand has reduced significantly in recent decades. This is a result of changes to the mix of products manufactured in the UK and improvements in how efficiently products are made. It should be stressed that total UK industrial output has increased slightly in recent decades; however, the manufacture of some energy intensive products has decreased – for example, iron and steel production is now considerably less than 1970 levels. Large efficiency improvements have also been achieved in many parts of industry. Together, these changes have reduced the overall energy demand of industry (ibid.).

Industry was still responsible for 15% of the UK's energy use in 2017 (ibid.), and was responsible for a similar proportion of the UK's GHG emissions (BEIS, 2019) . The emissions are produced by burning fuel for energy, but are also emitted directly by some industrial processes, such as cement production (see *3.5 Non-energy emissions*).

Emissions from industry abroad

Although UK industrial output has only increased slightly over recent decades, our demand for products has increased significantly – we simply import more products from other countries. Emissions from manufacturing these products can be high, either because products are 'energy intensive' to make, or because they are made in countries that use high carbon energy sources.

These emissions are not included in UK 'production emissions', the figure most commonly used to represent total UK GHG emissions. Yet we still get the benefits of the goods we buy from abroad. Emissions associated with imported goods have risen around 28% since 1997 (DEFRA, 2019). When these emissions are included, total UK 'consumption' GHG emissions are shown to have decreased only slightly over the last decade. *3.10.3 Carbon omissions* explores how these 'consumption emissions' can be accounted for and how reducing these emissions, as required to tackle climate change, might affect what we buy from abroad and what we make in the UK.

What's the solution?

To make a zero carbon Britain a reality we will need to reduce the energy demand from our buildings and industry, and put in place systems that allow us to meet this reduced energy demand with renewable energy and carbon neutral fuels.

Reducing heating demand

To reduce the energy demand for heating we must improve our building stock. By reducing the heat our buildings lose we will reduce the energy needed to keep them warm. Heat loss from buildings can be reduced by:

- Improving insulation.
- Reducing draughtiness.
- Recovering heat from air leaving the building through ventilation.

New buildings can have very low heat loss if they are constructed with excellent insulation and air-tightness, and are fitted with heat recovery ventilation. Passivhaus standard buildings, for example, have very low heating demand – around 10% of an average existing building today.

Heat loss from existing buildings must also be reduced, since the vast majority of today's buildings will still be in use in 2030, and beyond. Retrofitting existing buildings can include: cavity wall or solid wall insulation; floor and loft insulation; improved glazing (all of which reduce the 'fabric heat loss' of a building); and draughtproofing (which reduces the 'ventilation heat loss' of a building) – see figure 3.7. A programme to retrofit all dwellings with the above measures, as required, could reduce the average heat loss of the UK's housing stock by 50% (DECC, 2010).

Improved heating controls could also reduce energy demand by only heating rooms to the temperature required and when they are in use. Also, a more widespread culture of putting on a jumper rather than turning up the thermostat would have an impact on heating demand and on our energy bills. With better heating controls and behavioural changes it could be possible to reduce average internal temperatures from the current average of 17.5°C to 16.7°C (ibid.). This would further reduce energy demand for heating. (Of course, reducing *average* internal temperatures will not stop us heating rooms to a higher temperature, such as 18-21°C, when we need to.)

Figure 3.7 shows how, in combination, the above measures can reduce space heating demand by around 50-60% per building on average.

Improved insulation can also help reduce the overheating of buildings in summer by keeping heat out rather than in. Adequate shading and ventilation are also needed though to prevent heat accumulating inside, and to allow the fabric of buildings to cool at night.

Zero carbon heating

Even with these changes we will still need to heat our buildings, and a bigger population will also lead to a similar level of hot water demand to today

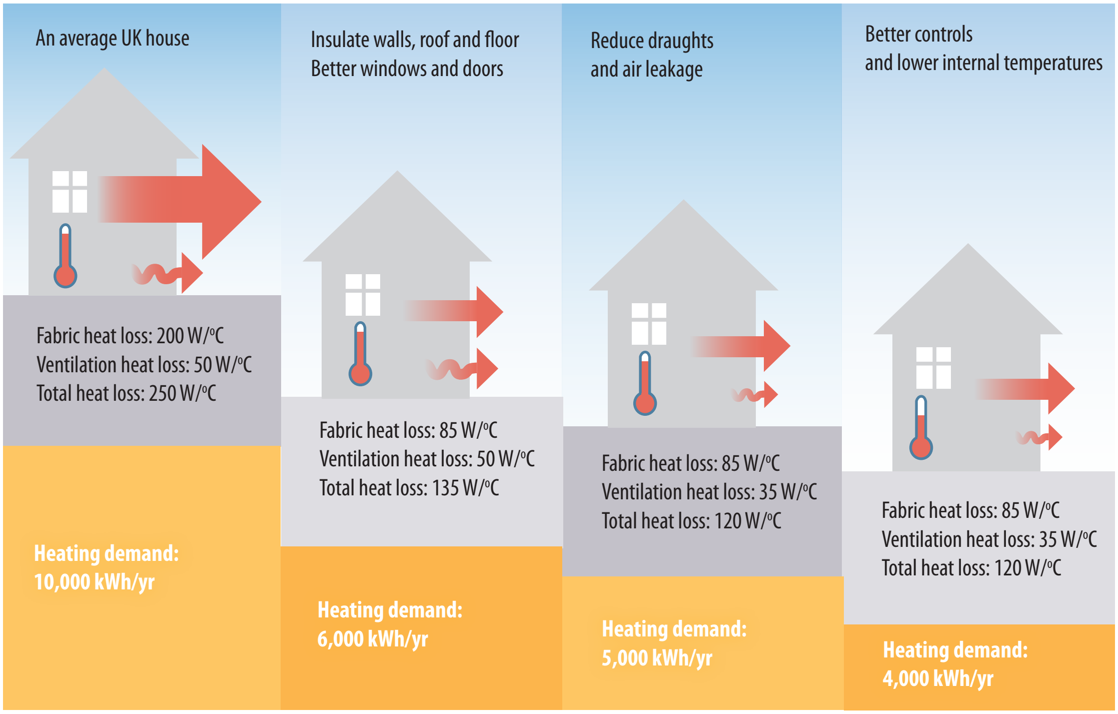

Figure 3.7: The impact of measures that reduce a building's heat loss and heating demand.

(for washing, cleaning, etc.). This heating and hot water energy demand must be met without GHG emissions.

Solar heated hot water and geothermal heat can meet some of this demand, but most will be met by heat pumps. Heat pumps take ambient heat in air, water or the ground and 'concentrate' it, usually in water, to the required temperature. To do this they must use energy, but for each unit of electricity consumed, heat pumps can typically deliver two to four units of heat – a very efficient way to generate heat from electricity. A mixture of biomass and direct electric heating systems can meet the remaining demand in situations where heat pumps are not practical, such as in buildings with large variations in energy demand, or which are not used regularly.

More efficient and smarter appliances

We can reduce the energy demand from lighting and electrical appliances significantly. Technological improvements can reduce 'in-use' power consumption, and better controls can minimise energy wasted by lights or appliances that are not being used. By maximising the currently available potential for efficiency, we can reduce lighting and appliance energy demand by around 60% per household, and by up to 30% in commercial and public sector buildings. Cooking can also be more efficient, using around 40% less energy per kitchen, and can be made fully electric. Systems used for cooling can be made around twice as efficient as today (ibid.).

As well as using more efficient appliances, it is possible to use smarter appliances. Such appliances are equipped with controls so that they can automatically reduce their energy demand to help balance the electricity grid. For example, at times of high demand, appliances such as fridges, freezers, washing machines and dishwashers would automatically use less energy over periods of just

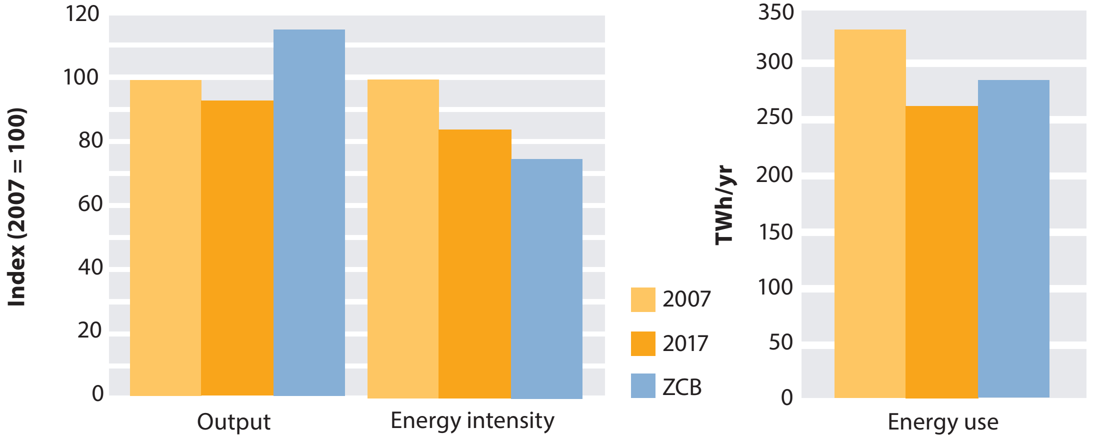

Figure 3.8: The amount of 'stuff' produced by UK industry (output), the energy used per unit of output (energy intensity), and the total UK industrial energy use for 2007 (representing pre-recession levels), 2017 (BEIS, 2018) and in our scenario.

a few seconds or minutes and up to a few hours. *3.4.2 Balancing supply and demand* further explains how this can help balance the supply and demand of electricity in a system incorporating lots of renewable energy.

Green industry

Energy use in industry depends on how much 'stuff' is produced (output) and on how much energy is needed to make each unit of 'stuff' (energy intensity) – see figure 3.8. These very much depend on:

- Changes in the demand for products.
- Shifts in what UK industry produces.
- Breakthroughs in efficiency.

An *overall* reduction in the demand for goods would decrease industrial output, and thus energy demand. Recycling, reusing and repairing items instead of throwing them away would likely lead to less demand for the production of goods. However, less demand for some goods can lead to more demand for others – known as the 'rebound effect'.

Changes to *what* UK industry produces could also reduce industrial energy demand. Reduced output of some energy intensive products, such as iron and steel, has already contributed to a reduction in emissions from UK industry. This trend could continue, for example if wood-based products were to substitute more conventional building materials (see *3.6.3 Capturing carbon*), further decreasing our 'production emissions'. Alternatively, to improve the economy and create jobs, we might actually want to *increase* the manufacture of some energy intensive products. For example, we might wish to manufacture a high proportion of our renewable energy systems in the UK.

Improvements in energy efficiency would mean we could produce the same amount of 'stuff' but using less energy – therefore reducing energy intensity. The UK has already reduced energy intensity in most industrial sectors over recent decades, and further energy intensity reductions of up to 25% are considered ambitious but feasible (ibid.).

Switching the type of energy we use

All energy used for heating, hot water, cooking, lighting and appliances could be supplied as electricity, rather than from sources like gas boilers or gas cooking hobs. *3.4 Power Up* describes how UK renewable energy sources could meet this electricity demand.

In industry, however, the form in which energy is supplied can be important. Whilst it is possible to increase the proportion of industry powered by electricity, it may not be possible to fully electrify all industrial processes. For example, it may not be practical to use electricity for some high temperature

Figure 3.9: Mix of fuel used annually by UK industry in 2017 (BEIS, 2018) and in our scenario.

What's 'carbon neutral'?

Synthetic gas, biogas, synthetic liquid fuel and biofuel can all be 'carbon neutral'. The CO_2 emitted by burning them was initially taken in by the biomass as it grew, and the electricity used to produce the hydrogen required (via electrolysis) can be renewably generated (see *3.4.2 Balancing supply and demand* and *3.4.3 Transport and industrial fuels*). Over the long-term there is no net increase in greenhouse gases in the atmosphere. The advantage of synthetic gas and liquid fuels over pure biogas and biofuel is that less biomass is required to produce the same amount of gaseous or liquid fuel.

processes, such as some iron, steel and ceramics manufacture.

It is estimated that roughly 50 TWh of the annual industrial fuel demand could be most feasibly met using carbon neutral synthetic gas (made by combining biomass and hydrogen – see 3.4.2 *Balancing supply and demand*) or made purely from biomass (NERA, 2010). Solid biomass can also efficiently provide heat for industry using Combined Heat and Power (CHP) systems, which also generate electricity. In addition, some industrial machinery may require liquid fuels equivalent to oil. Other 'high electrification' scenarios for industry also suggest some biomass, synthetic gas or biogas and synthetic liquid fuel (made in a similar manner as synthetic gas, combining biomass and hydrogen) or biofuel will be needed to meet future industrial energy demand (DECC, 2010).

Building in flexible demand

3.4 Power Up shows how renewables can meet the energy demand in our scenario. To make this easier, electricity demand should be made as flexible as possible, so that it can move up or down in response to the availability of electricity from renewables.

As discussed, smart appliances can help balance the grid by responding to signals and changing the times at which they draw power. The electricity demand for heating and hot water can also be made more flexible by having large heat stores (usually tanks of hot water), so that heat can be produced and stored at times when the electricity supply from renewables is high. Such heat stores could be inside buildings, or buildings could be connected to external heat stores supplying anything from a few houses to whole districts. Buildings themselves can also act as leaky but useful heat stores. If they only lose heat slowly, buildings can be heated when electricity is plentiful rather than exactly when heating timers are set.

Industrial electricity demand can also be made more flexible, with production decreasing at some times and increasing at others. This would help balance electricity supply and demand. This already occurs today but it could have a bigger role in the future, with industry adjusting its electricity demand both up and down, and more often. Fuel switching should also be viable in some industries, with electricity being used when it is abundant and low cost, and other fuels, such as synthetic gas/biogas, being used at other times.

The roles that heat stores and flexible energy demand from industry can play in a renewable energy system are discussed further in *3.4.2 Balancing supply and demand*.

Our scenario

In our scenario, energy demand for heating buildings is reduced by around 50% because:

- All new houses will be built to Passivhaus standard, or similar.
- A mass retrofit of all existing buildings (including offices, schools, etc.) will take place.
- Better heating controls and changes to behaviour will reduce average internal temperatures.

The trend in improved efficiency of hot water production continues, but a bigger population will lead to a slightly higher hot water demand – a 7% increase from 2017. Heating and hot water energy demand is about 264 TWh per year in total, though this will vary from year to year depending on outside temperatures. Heat pumps meet the majority of this demand (using about 65 TWh per year of electricity and 137 TWh per year of ambient heat); direct electric heating requires around 11 TWh per year of electricity; 11 TWh per year is provided directly with biomass; and the remaining heating demand (40 TWh per year) is met by solar thermal and

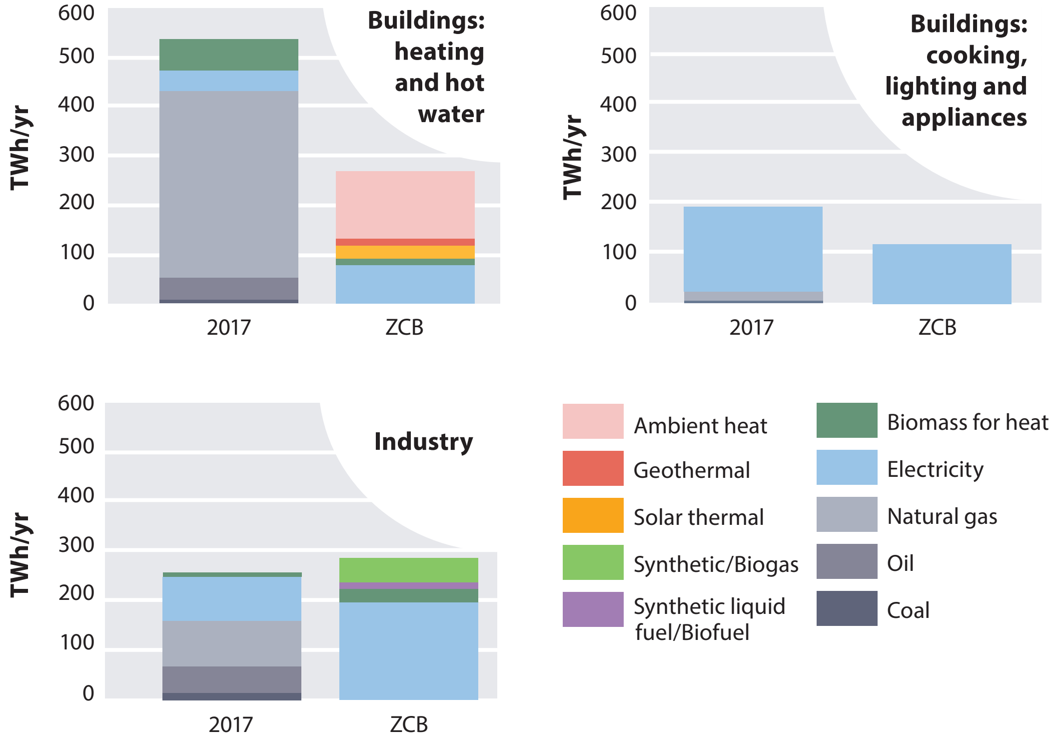

Figure 3.10: The change in energy demand for heating and hot water; cooking, lighting and appliances; and industry between 2017 (BEIS, 2018) and our scenario: by amount and type of fuel.

geothermal heating (see figure 3.10).

Despite potentially higher average temperatures due to climate change, better building insulation and well-designed shading and ventilation means that cooling demand remains at current levels. Since cooling systems become more efficient, energy demand for cooling and ventilation falls from 13 TWh per year in 2017 to 5 TWh per year.

Efficiency improvements reduce energy demand for cooking, lighting and electrical appliances by around 40% to 112 TWh per year.

We assume that UK industrial output per person returns to 2007 (that is, pre-recession) levels, although population growth means total output is 16% higher than in 2007. Exactly *what* will be produced is uncertain and may be very different from that produced in 2007. For example, the manufacture of renewable energy systems increases, but demand for other goods may also decrease if we replace some more conventional building materials with wood products (see *3.6.3 Capturing carbon*), if our society becomes less 'consumerist', and if we place greater emphasis on the longevity and reparability of products – recycling and reusing more. In our scenario, a strong push for further efficiency is assumed to reduce industrial energy intensity by 25% on average. Total industrial energy demand is 286 TWh per year (see figure 3.8).

Figure 3.10 shows the changes in energy use between 2017 and in our scenario, as well as the change in fuel type. Electricity supplies the majority of energy for heating, hot water, cooking, lighting and appliances. The proportion of industrial energy demand met by electricity also increases to 68% – to about 194 TWh per year (see figure 3.9). Other industrial processes require:

- Around 50 TWh of biogas or synthetic gas per year.
- Smaller amounts of biomass for heat (29 TWh) and synthetic liquid fuel (13 TWh) every year.

Energy demand is much more flexible than it is today with smart appliances, large heat stores inside or connected to buildings, and more flexible industrial electricity demand.

Overall, energy use in buildings and industry is reduced by about 47% to around 526 TWh per year (or 663 TWh per year if the ambient heat used by heat pumps is included) – 382 TWh per year (about 73%) of which is electricity demand.

3.3.2 Transport

This section covers energy use and emissions in the UK from transport, including international aviation and shipping. It describes how changes to our transport system can reduce energy demand and allow the energy to come from renewable sources.

Summary

- In 2017, 41% of UK energy demand and 37% of UK GHG emissions were from transport. Surface passenger transport accounted for about half of transport energy demand, aviation about a quarter, and freight around a quarter.
- Increased walking, cycling, and use of public transport can reduce our energy demand and GHG emissions, as well as making our urban environments more pleasant and making us healthier.
- We can switch most transport to very efficient electric vehicles. Hydrogen powered vehicles may also have a small role to play, but some road vehicles and ships, as well as aeroplanes, will continue to need liquid fuels.
- International aviation can be made more efficient, but its need for synthetic liquid fuel (which requires biomass), as well as additional climate impacts of GHGs emitted high in the atmosphere, mean we must reduce it to around a third of current levels.
- In our scenario, the need for freight transport is reduced as all of our energy and more of our food comes from the UK. Freight transport vehicles also become more efficient and 30% of road freight switches to rail.
- In total, UK domestic and international

transport energy demand is reduced from around 687 TWh in 2017 to 154 TWh per year in our scenario – a 78% reduction. 70 TWh of electricity is required per year, and energy demands in the form of synthetic liquid fuel and hydrogen are 74 TWh per year and 10 TWh per year respectively.

What's the problem?

In 2017, 41% of UK energy demand and 37% of UK GHG emissions were from transport (BEIS, 2019; BEIS, 2018). Energy for transport is overwhelmingly derived from petroleum products such as petrol, diesel and kerosene. Fuel use and GHG emissions from transport have increased over recent decades, peaking in 2007 and declining a little since. Road vehicles use most of this fuel (70%); aeroplanes are another large user, with trains and boats using smaller amounts (BEIS, 2018) (see figure 3.11).

On average, a British person travels around 6,500 miles a year by car or van. This figure declined slightly in recent years after increasing for many decades but is now increasing again (DfT, 2018). Efficiency improvements mean that, on average, the UK's cars are slowly using less energy and emitting less CO_2 per mile travelled – average CO_2 per mile is decreasing at about 1% a year (CCC, 2012). Nevertheless, cars and vans account for about 50% of all transport energy use (BEIS, 2018).

Around a further 1,450 miles is travelled on average per person per year by foot (200 miles), bicycle (50 miles), motorbike (50 miles), bus (370 miles), and train (780 miles). The amount of travel by these modes has been broadly stable over recent decades, except for train travel, which has doubled. Taken together, these forms of transport accounted for just 5% of all transport energy use in 2010. Interestingly, in the 1950s and '60s, travel by bicycle and bus were at much higher levels than today (ibid.).

In recent decades, people have also been flying more – passenger numbers, having declined a little after 2007, are now at record levels. The number of passenger arrivals and departures at UK airports has nearly tripled since 1990 to over 280 million in 2017 (DfT, 2018). Around 20% of flights are domestic and 80% international. Aviation accounts for about 23% of all transport energy use (BEIS, 2018). CO_2 emissions from burning aviation fuel contributed 7% to the UK's GHG emissions in 2017 (BEIS, 2019). However, other factors, such as aircraft contrails and emissions high in the atmosphere inducing cirrus clouds, multiply aviation's impact on climate change by a factor of 1.6 (this is subject to some uncertainty and even higher estimates exist) (Lee, 2010). In 2017, this would have had an additional impact equivalent to almost 21 $MtCO_2e$. Aviation also brings high noise pollution.

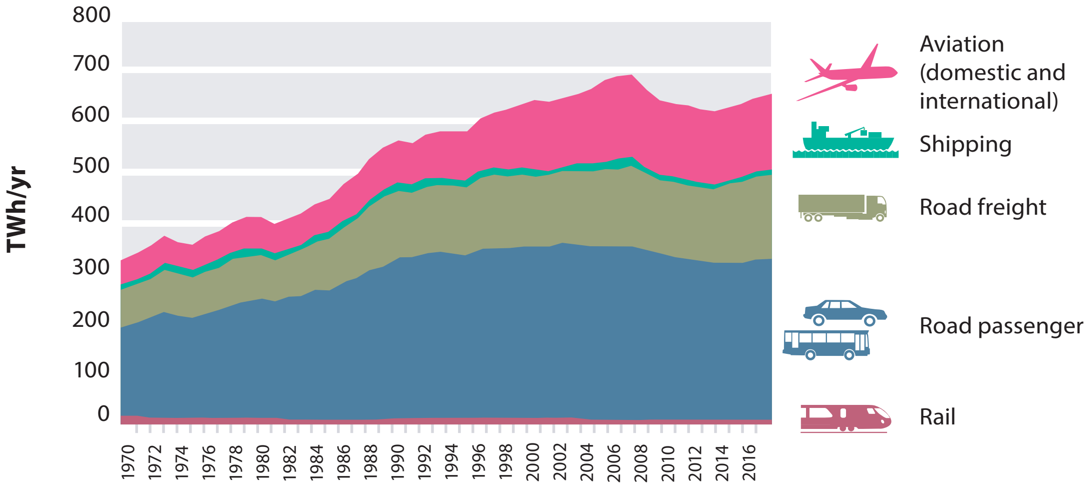

Figure 3.11: Energy demand for UK transport over recent decades (excludes international shipping (BEIS, 2018)).

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Fuel use by freight (Heavy Goods Vehicles (HGVs), trains, ships and planes transporting goods) has been increasing over recent decades. It decreased in the years after 2007 due to the recession but is now increasing once again (BEIS, 2018). The amount of goods transported, and the distance they are moved, follow a similar trend (DfT, 2018). In total, freight accounts for around 25% of our transport energy use (BEIS, 2018).

What's the solution?

Radical changes will be required to the amount and to the way we travel and move goods in a zero carbon Britain. This is essential to reduce energy demand. Changes are also needed to our transport system to make our urban environments more pleasant places to live and work, and to help us be healthier and more active.

How we travel, and how much

Improved communication technology (video conferencing, Skype, etc.) can make some journeys unnecessary. Living closer to where we work and play would also lead to less travel – and less time spent commuting.

Better infrastructure in towns and cities (cycle lanes and pedestrian areas, for example) can encourage people to walk and cycle shorter journeys. This has health as well as environmental benefits, and would decrease noise pollution in urban areas. Better public transport – bus, coach and rail – can also get people out of their cars, reducing road congestion, energy use and GHG emissions.

When we do use cars, we can make better use of them by increasing the number of occupants. By arranging car sharing, either informally or via car share schemes, the average occupancy of cars could improve from the current average of 1.6 people per vehicle (Dft, 2009a).

These changes will reduce energy demand from transport. Just as importantly, they could create more pleasant places in which to live, and could make us healthier.

Alternative fuels – biofuels, synthetic liquid fuels, hydrogen or electric vehicles?

Even if we travel less and more efficiently, we will still need lots of energy for transport. One possibility to reduce GHG emissions from transport is to use biofuels – fuels made from plant material ('biomass'), or carbon neutral synthetic liquid fuels – fuels made from biomass combined with hydrogen (see *3.4.3 Transport and industry fuels*).

European Union targets have seen biofuels mixed into the supply of petrol and diesel to around 2% of the mix (BEIS, 2018). Even at this low level, serious concerns have been raised about the effects of biofuel production on land use, and consequently food prices and biodiversity. It is clear that fuels made using biomass cannot replace all the petrol and diesel we use in cars, let alone meet all of our current transport energy needs. This would remain the case even after the changes to travel described above, and even if petrol or diesel vehicles were made more efficient. It is, therefore, necessary to change the *type* of fuel our vehicles use.

Electric cars and buses offer a solution. They are around three times as efficient as equivalent cars and buses that run on petrol and diesel – and they could be over five times as efficient as the average vehicle on the roads today (DECC, 2010). In addition, their batteries can be charged with electricity from renewables.

The distance that electric road vehicles can travel before they need recharging makes longer journeys more difficult. However, statistics show that around 90% of journeys made by cars are less than 100 miles long (DfT, 2009a). Improvements in battery technology mean all such journeys are achievable on one charge (current electric cars can travel around 80 to 200 miles per charge depending on the battery size). The scheduled recharging of buses and coaches would be straightforward, if planned into timetables. The development of an adequate electric vehicle charging infrastructure is essential, but this poses no technical challenges.

For some specialist vehicles – such as those used off-road and heavy commercial vehicles (such as HGVs, tractors and diggers) – or those requiring longer range, a mixture of fully electric, hybrid 'biofuel-electric', fully biofuel or synthetic liquid fuel powered vehicles could be used.

That said, a further reduction on even this small reliance on fuels derived from biomass is desirable and hydrogen fuel cell vehicles are a possibility. However, widespread use of hydrogen vehicles requires an entirely new infrastructure to distribute the hydrogen fuel. Since electric vehicles are a more efficient and simpler option for mass transport, a widespread hydrogen distribution network is unlikely to be developed. Therefore, hydrogen vehicles are likely to be used only on a small-scale.

Less aviation

Whilst small electric planes exist, no alternative to liquid fuel currently exists for large passenger planes. This is because aviation fuel must have a very high energy density by weight and volume. At current energy densities, a passenger plane carrying enough electric batteries to power its journey would be too heavy to fly, whilst one carrying enough hydrogen would be too large to fly at speed – although it could fly slowly, like an airship. It is hoped that electric or hydrogen passenger planes can be developed in the future. In the meantime, hybrid electric planes are being developed that could improve efficiency and reduce the use of liquid fuel (BBC, 2017).

In the shorter term, we can improve aircraft efficiency and manage flights better. This could improve aviation's fuel use per passenger by around 1% per year for the next few decades (DfT, 2009b). However, efficiency improvements will run into the physical limits that determine the energy required for flight. Therefore, to drastically reduce this sector's GHG emissions we must replace current petroleum-derived liquid fuel with sustainable biofuel from biomass, or synthetic liquid fuel made from biomass and hydrogen. As shown in *3.6 Land use* there are constraints on the land available to grow the biomass required for these fuels.

Another concern is that even a complete switch to biofuels or synthetic liquid fuels does not stop the additional impact on climate change of contrails or gases emitted high in the atmosphere. Therefore, the

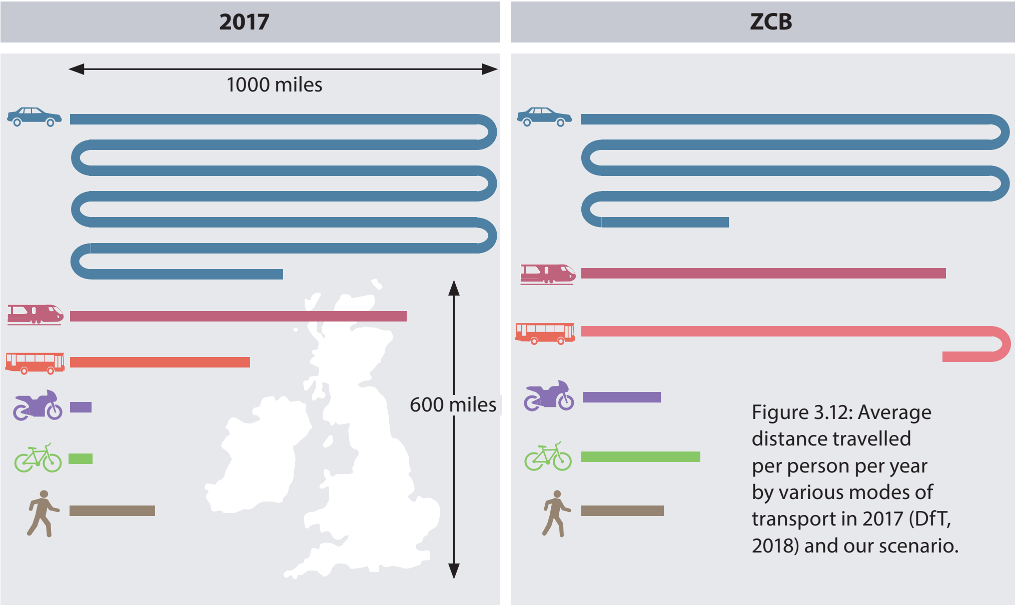

Figure 3.12: Average distance travelled per person per year by various modes of transport in 2017 (DfT, 2018) and our scenario.

only way to reduce the climatic impact from aviation is to fly less.

Rail or coach can replace journeys within the UK currently made by plane, as well as relatively local international flights. Eurostar connections provide an example of how European journeys currently made by plane could be made by high-speed rail instead. Nevertheless, a reduction in flying does challenge the strong social norm and perceived *right to fly* that has developed over recent decades.

Changing how we move 'stuff'

To reduce energy demand from transporting goods (freight) we can:

- Reduce the amount of goods we move.
- Reduce how far goods travel by sourcing them closer to home.
- Improve the efficiency of vehicles used.

Heavy Goods Vehicles (HGVs) will become more efficient in the future – with more efficient engines, better aerodynamics and more efficient operation. Electric HGVs are now in use and their range is improving. However, it is not certain if they can fully replace those running on liquid fuels. Given the limits on biomass for biofuel and synthetic liquid fuel supply, and to reduce road congestion, shifting more freight to railways makes sense. Increasing rail freight by 200% over 2010 levels is considered feasible (DECC, 2010).

Due to limitations on aviation, moving freight by air should be eliminated for all but essential items.

Similarly, electric powered ships are being developed, but some ships may continue to require similar liquid fuels – in the form of biofuel or synthetic liquid fuel. Fuel use in shipping can be reduced through more efficient engines and better management to reduce ships travelling only partially full or empty. Changes to the demand for some goods can also reduce the need for shipping.

Our scenario

In our scenario, the distance travelled per person decreases by around 13% from 2017 levels, as better communication tools reduce the need for some journeys and people live closer to where they work and socialise. People walk and cycle more often, and the use of public transport – buses, coaches and rail – increases from 14% to 28% of domestic travel. As a result of these changes, car travel is reduced from 81% to 62%. In addition, the average occupancy of

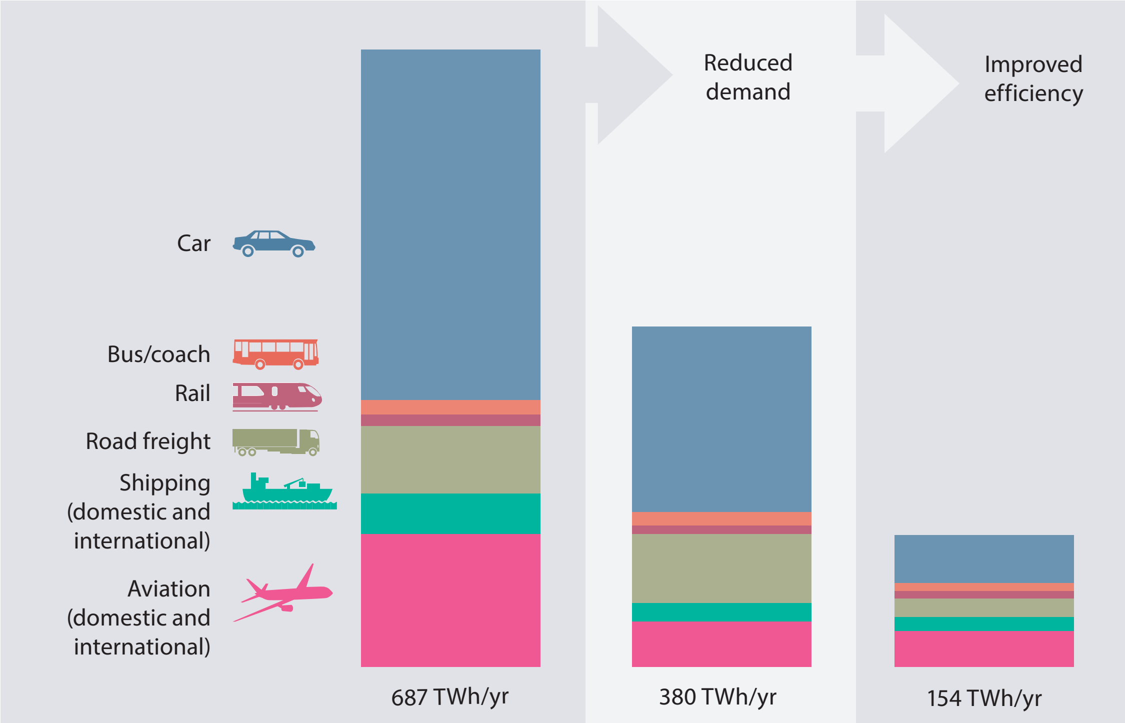

Figure 3.13: Reduction in energy demand for transport in our scenario, shown in two stages: firstly with only the impact of reduced distances travelled and higher occupancy levels; secondly, adding the impact of higher vehicle efficiencies (initial figures from BEIS, 2018; DfT, 2018).

cars increases from 1.6 to 2 people per vehicle. See figure 3.12 for a summary of these changes.

Around 90% of road passenger transport is electric vehicles – cars, vans, coaches and buses. The rail network is also close to fully electrified (95%).

Hydrogen powered vehicles are favoured to reduce the demand on land for biomass, but since a full infrastructure for hydrogen distribution is not envisaged, some synthetic liquid fuel powered vehicles are used. Carbon neutral synthetic liquid fuels and hydrogen power the remaining road passenger vehicles, such as those requiring longer range and heavy commercial vehicles.

Our scenario includes a small amount of domestic aviation, for example, for emergencies and access to remote areas and islands. However, most of the journeys currently made by domestic flights are now made by rail. The number of miles flown for international aviation falls by two-thirds. In combination with efficiency improvements, this reduces aviation liquid fuel demand by around 75%.

In our scenario, changes to our energy and food system eliminate the need to move some goods (such

Additional impact of flying in our scenario

Carbon neutral synthetic fuel is used to fuel planes in our scenario. It is 'carbon neutral' because the CO_2 emitted by burning it was initially taken in by the biomass as it grew, and the hydrogen used in its manufacture was produced using renewable electricity. Over the long-term, this means there is no net increase in GHG emissions in the atmosphere. However, contrails or gases emitted high in the atmosphere by flying may lead to an additional impact on climate change (Lee, 2010). Even with substantial reductions in flying in our scenario, there is a remaining impact that is equivalent to about 7.4 $MtCO_2e$.

as fossil fuels), but increase the need to move other goods (such as biomass). In general, since all of our energy and more of our food comes from the UK, we need less freight transport.

Total road and rail freight remains similar to today's levels, but rail freight more than doubles as around 30% of road freight switches to rail. HGVs and other heavy commercial vehicles (tractors and diggers, for example) are powered by a mixture of electricity (50%), carbon neutral synthetic liquid fuel (30%), and hydrogen (20%). Freight moved by air is all but eliminated, and changes to the type of goods that need moving means shipped freight decreases by over 50%. Ships are powered by a mixture of electricity and synthetic liquid fuels.

Overall, energy demand from transport falls by 78% from 2017 levels, to 154 TWh per year (see figure 3.13). With much of the transport system electrified, transport electricity demand rises to 70 TWh per year. Energy demand for synthetic liquid fuel is 74 TWh per year (34 TWh for heavy road vehicles, and 40 TWh for planes) and for hydrogen is 10 TWh per year. Figure 3.14 summarises this change.

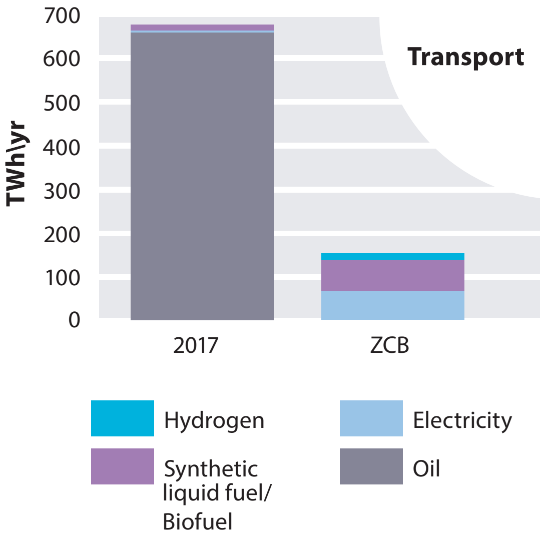

Figure 3.14: Change in total energy demand for transport and the types of fuel required in 2017 (BEIS, 2018) and our scenario.

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3.4 Power Up

The preceding section, *3.3 Power Down* outlined how we can reduce our energy demand (what we use), and this means we can reduce the amount of energy we produce, and thus the amount of greenhouse gases (GHGs) we emit. However, it is important not to underestimate how much energy is still required. In our scenario, the final energy demand – the amount of energy we use, including ambient heat, but excluding all exports and losses – is around 815 TWh per year. This is less than half of today's final energy demand, which is around 1,670 TWh per year (BEIS, 2018). However, it is still a large amount of energy compared to, for example, the amount of energy produced by wind turbines in the UK today (around 50 TWh in 2017 (BEIS, 2018a)).

This Power Up section outlines how renewable energy sources can meet 100% of this energy demand, reducing the GHG emissions from our energy production to zero.

In our scenario, the largest contribution will come from offshore wind turbines, which can produce around half of the energy we need. Figure 3.15 shows our final energy mix. However, this reliance on renewable energy from variable sources like wind power makes it challenging to ensure that energy supply always meets demand. A range of demand management methods and energy storage technologies play a role in solving this problem.

Biogas from biomass, and chemical processes for creating carbon neutral synthetic gas and carbon neutral synthetic liquid fuels from biomass and hydrogen (produced using surplus renewable electricity), allow us to balance energy flows and replace fossil fuels in systems that are difficult to electrify. Although there are significant losses in these processes, without them we would not be able to meet all demands.

Power Up summary:

Today, around 80% of our energy comes from fossil fuels. Together, Power Down and Power Up eliminate all emissions from our energy system. In our scenario:

- Renewable energy provides a primary energy supply before conversion losses of around 1,185 TWh per year, allowing us to meet 100% of a final energy demand of 815 TWh per year (680 TWh per year, not including ambient heat for use in heat pumps) using only renewable energy sources.
- Wind energy plays a central role, providing around half of the primary energy supply (607 TWh per year). The rest is generated using various renewable sources of energy. Figure 3.15 shows the change in energy mix between 2017 and in our scenario.
- Matching supply and demand in our scenario with a large share of energy from variable sources is technically challenging, but possible, incorporating chemical processes that create synthetic gas from biomass and hydrogen as backup. Only 20 TWh per year is required of this, but it plays a critical role when demand is high and supply from renewables is low (for example, when it is cold but not windy).
- Most of the energy in our scenario is produced in the form of electricity – about 66%, but there is also a significant amount of energy supplied in other forms – biogas is produced from biomass, and synthetic gas and liquid fuels are produced from surplus electricity and biomass. There are losses in the conversion processes, but demands from industry, transport and energy backup require these specific fuel types.

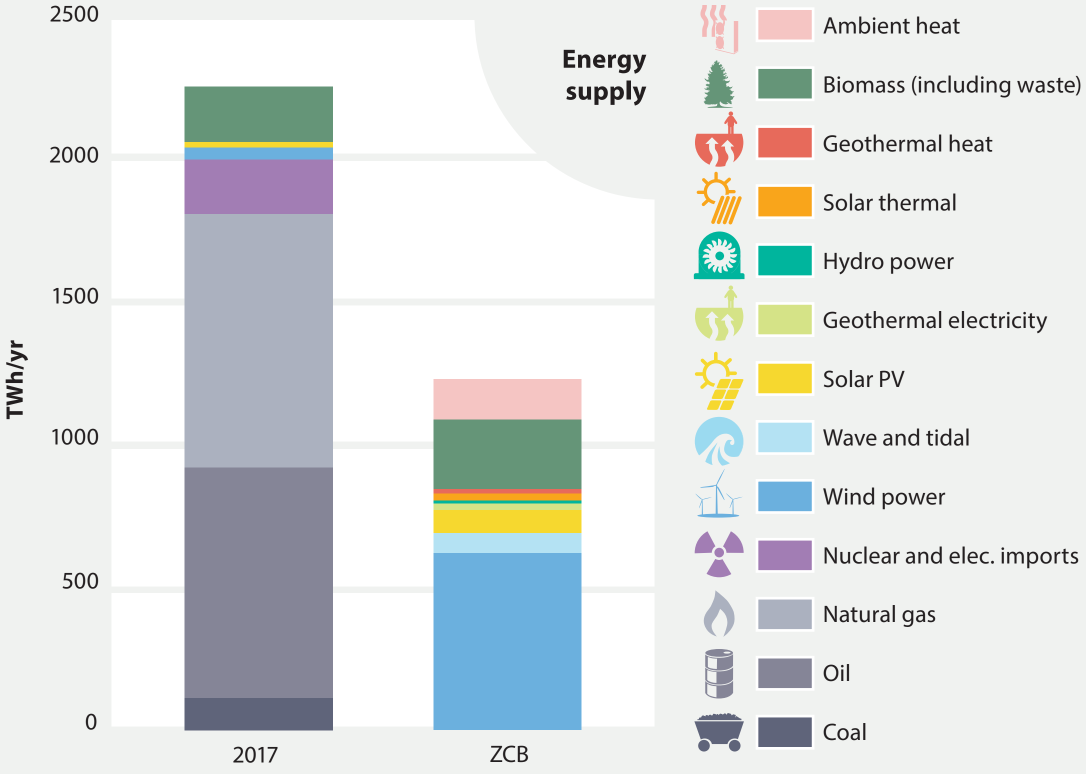

Figure 3.15: Energy supply in 2017 (BEIS, 2018a) and in our scenario.

3.4.1 Renewable energy supply

The section describes how we can Power Up the UK using renewable energy generation – providing all our energy supply from zero carbon technologies.

Summary

- Renewable energy only contributes a small but growing proportion to our total energy supply today.
- In our scenario, we produce about 1,185 TWh per year from renewable sources to meet 100% of the 815 TWh annual energy demand.
- Today, around 20% of our energy is in the form of electricity, but in our scenario most energy (780 TWh per year or 66%) is produced in the form of electricity, generated by a variety of renewable technologies.
- Offshore wind energy alone provides nearly half (530 TWh per year) of the total energy in our scenario.
- Biomass (230 TWh per year) and ambient heat (around 135 TWh per year, extracted from ground, water and air by heat pumps) also play major roles. Other contributions are made from solar thermal and geothermal heat (about 40 TWh per year).

What's the problem?

In 2017, around 80% of all of the UK's GHG emissions came from producing energy (BEIS, 2019). Burning coal, gas and oil emits carbon dioxide (CO_2). Together these fuels provided around 80% of the UK's primary energy supply, the 'raw' amount of energy supplied before conversion losses (BEIS, 2018a). This is illustrated in figure 3.16.

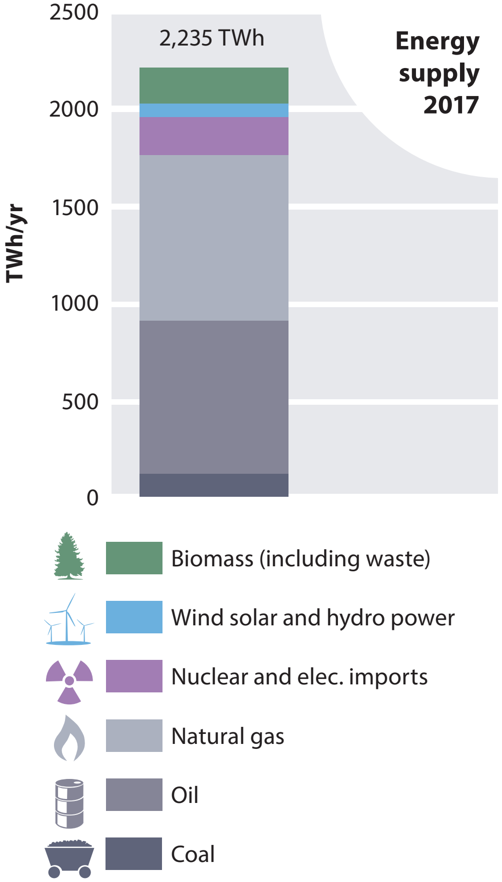

Figure 3.16: Energy supply in 2017 (BEIS, 2018a).

In 2016, renewable energy sources provided 25% of our electricity, and their share of our total energy consumption (heat, transport and electricity) was 9%. A year later, renewables produced 29% of the electricity and 10% of the total energy (BEIS, 2018a). This shows that, in relative terms, renewable energy, particularly renewable electricity generation, is growing rapidly in the UK. But in absolute terms, renewable energy still currently plays a minor role compared to fossil fuels. Also, a large proportion of renewable energy generation today comes from burning wood or biodegradable (plant- or animal-based) waste. There are limits to how much we can (or would want to) increase energy production from these sources. If we want to significantly increase the contribution of renewable energy, we need to dramatically increase the role of wind, marine (wave and tidal) and solar energy. In 2017, these sources only supplied around 3% of our total energy, but their contribution is rising sharply. The amount of energy we could theoretically produce from them is enormous.

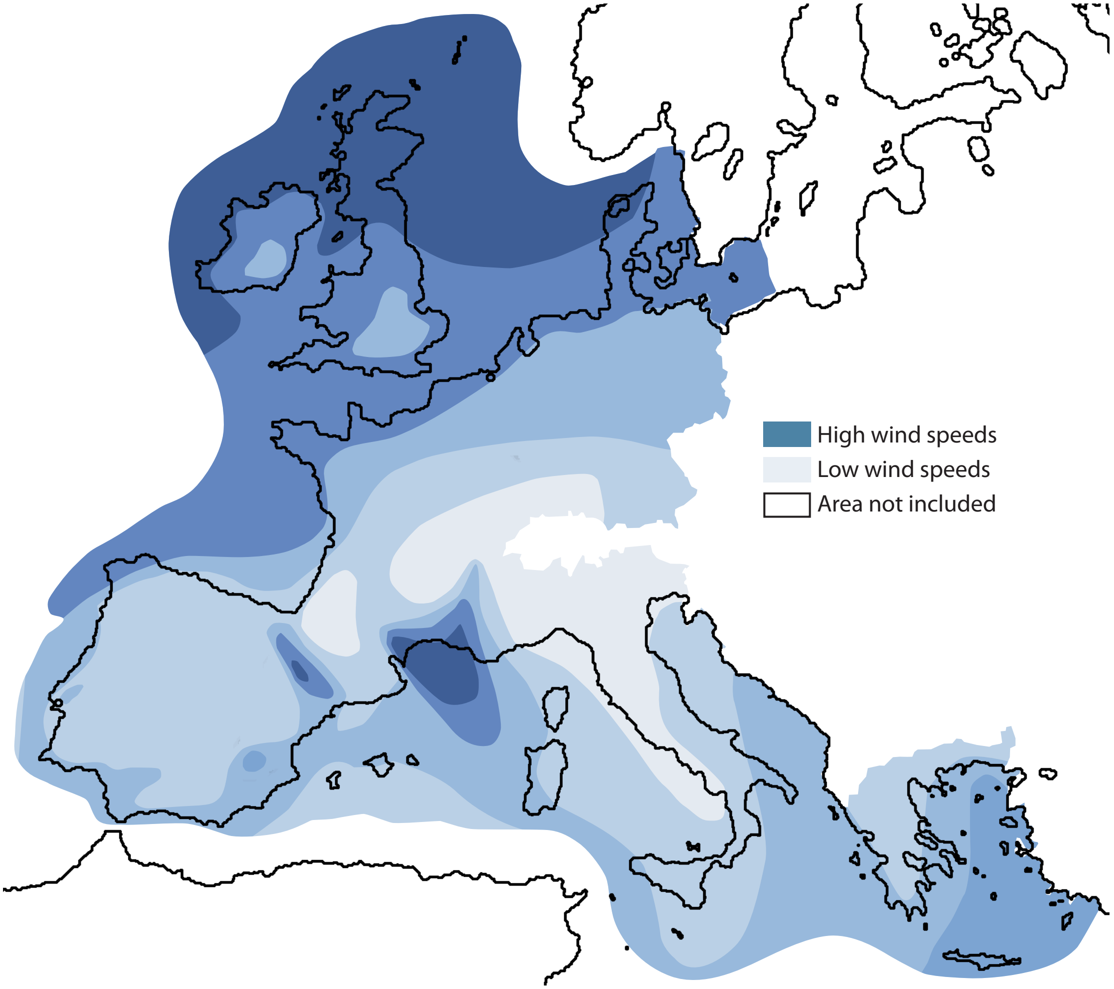

Figure 3.17: European wind speeds at 50 meters above ground level, ranging from the highest (dark blue), to the lowest (light blue). This represents sheltered and open areas, on hills and ridges, coastal areas, and in the open sea, though the highest wind speed and lowest wind speed will be different in each topographical area. Adapted from Troen and Petersen (1989).

What's the solution?

Energy supply from fossil fuels can be replaced with a variety of renewable energy sources that do not emit GHGs. These are:

Wind power

The position of the British Isles as Europe's 'wild and windy' western fringe (see figure 3.17) gives us one of the best wind power resources in the world. What's more, wind power also has the advantage that, statistically, wind speeds are stronger during the winter season when energy demand is highest. This does not mean that the wind always blows when we need energy, but it does show why wind power can help to meet a significant proportion of our energy demand. Currently, most UK wind turbines are installed on land (onshore), but the greatest potential is out at sea (offshore).

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Onshore wind: Turbines are easier to install, but as wind speeds are lower over land they produce less energy. The best locations for onshore wind are typically near the coast or on hills. It is estimated that by putting onshore wind turbines in all suitable places, we could produce more than 60 TWh per year, possibly up to 130 TWh per year (Pöyry, 2011; DECC, 2010). This is two to four-and-a-half times the energy produced from onshore wind turbines in 2017. If we want to make full use of onshore wind power, then we need to accept that wind turbines will become a prominent feature in large parts of the country, including some areas which many people would like to protect from industrial development.

Offshore wind: Out at sea wind speeds are higher. There are also fewer objections to putting very large wind turbines far away from where we live. A 10 MW wind turbine – the kind of size we can expect in a few years – will be as tall as the Gherkin building in London (180 m). A single turbine of this size can produce enough energy for thousands of households, and these machines will likely form the backbone of a future renewable energy system.

Where the sea is relatively shallow – the current limit is depths of 40-60 m – it is possible to build fixed turbines with foundations in the seabed. All existing commercial offshore wind farms are of this type. It has been estimated that the amount of energy we could produce from installing fixed offshore turbines is around 400 TWh per year (Offshore Valuation Group, 2010), more than the UK's current total electricity generation (336 TWh in 2017 (BEIS, 2018a)). This would require more than 10,000 large fixed offshore turbines. Most of these turbines would be in the North Sea, where very large shallow sandbanks, like the Dogger Bank, could accommodate huge wind farms.

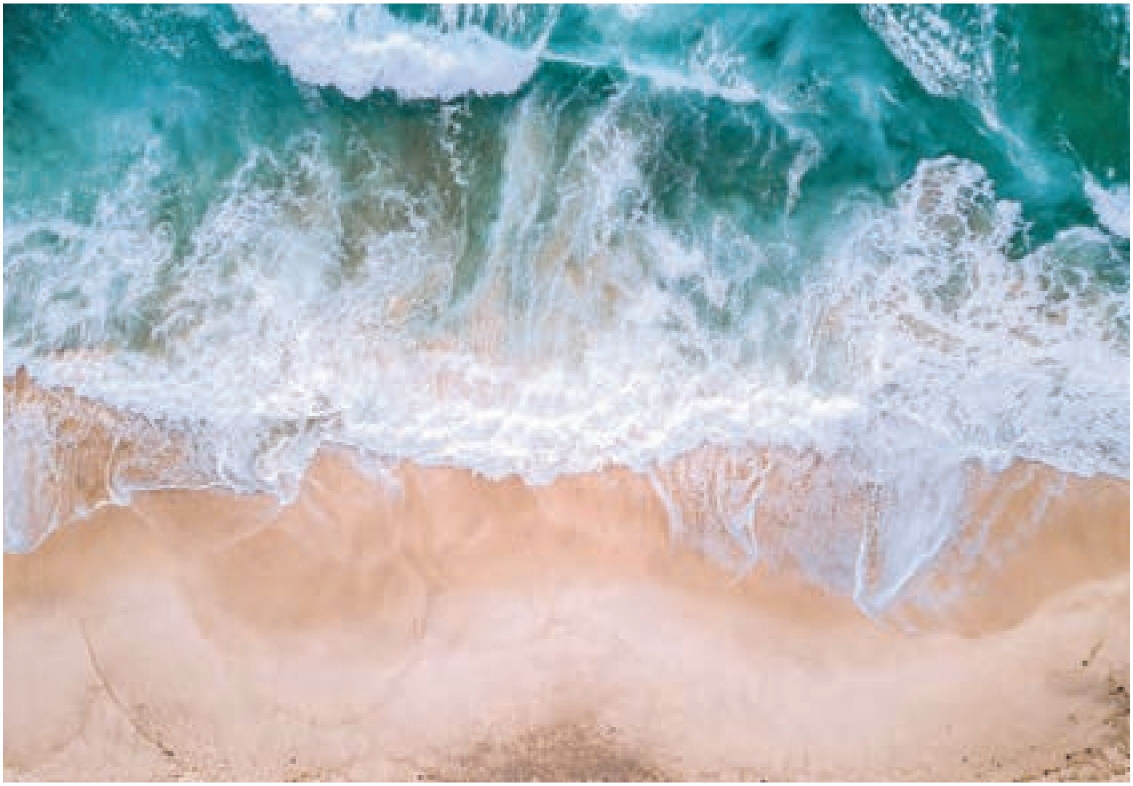
Where the sea is too deep for fixed foundations it is possible to use floating turbines that are anchored to the ocean floor by cables. Full-scale prototypes of this technology have successfully been tested for years. Since 2017, a 30 MW floating offshore wind farm (made up of five 6 MW wind turbines) has been operational, located 25 kilometres off the coast of Peterhead, in Scotland. Early indications are very promising with the turbines generating better than expected and exceeding fixed offshore wind turbines. The theoretical potential for rolling out this technology is massive, especially in the deeper waters of the Atlantic off the coast of Scotland and Cornwall. The Offshore Valuation Group (2010) report estimates that we could produce more than 1,500 TWh per year from floating wind turbines alone – this is close to the UK's energy demand in 2017 (1,670 TWh (BEIS, 2018)).

Wave and tidal power

Compared to wind power, wave and tidal power generation is still at a very early stage of development. Tidal stream systems resemble 'underwater wind turbines' and produce electricity from natural underwater currents in places such as the Pentland Firth between Scotland and the Orkney islands. Wave power systems produce electricity from waves on the surface of the ocean. According to the Offshore Valuation Group (2010) report, the UK could produce 40 TWh per year from wave power and 116 TWh per year from tidal stream. However, existing wave and tidal stream power projects are still at the prototype stage, and current estimates of their full potential vary greatly. Tidal range projects use barrages or artificial lagoons to produce energy from rising and falling tides. The Offshore Valuation (2010) report estimates that we could produce 36 TWh per year from this technology, with a large contribution (16 TWh per year) from a scheme in the Severn estuary. However, depending on the choice of technology, the local environmental impact of such schemes (for example, reducing tidal range) can be very significant.

Hydropower

Hydropower – generating electricity from water flowing downhill – has a long history in the UK. In fact, the world's first public electricity supply was from a generator driven by a water wheel in



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Godalming, Surrey, in 1881. Today, the UK produces around 6 TWh per year from hydropower (BEIS, 2018a). Most of this is from large power stations, and there is limited scope for building more of these. However, Arup (2011) assume that significant growth in smaller 'micro' hydropower schemes could bring the total production to 8 TWh per year.

Solar photovoltaics (PV) and solar thermal

Solar panels can be used to produce electricity (solar PV) or heat (solar thermal, or 'solar hot water'). South facing roofs are ideal but east or west facing roofs can also be suitable for either technology. The total potential for energy generation is large if all roof areas in the UK are considered; it has been estimated that solar panels on UK roofs could produce 140 TWh of electricity and 116 TWh of hot water every year (DECC (2010) 2050 pathways, level 4). Solar farms in fields could theoretically produce even more energy, but they could compete with other land uses, such as food production. Both solar PV and solar thermal produce much more energy in summer than in winter.

Geothermal electricity and heat

In some parts of the UK, including Cornwall and East Yorkshire, hot rock layers can be accessed by drilling to a depth of several kilometres. The heat can be used to produce electricity in Combined Heat and Power (CHP) stations and to deliver heat to district heating systems that supply hundreds or thousands of households through well insulated heat pipelines. Just how much energy we could produce from geothermal heat in the UK is still debated, with figures of up to 35 TWh per year of electricity (ibid.).

Ambient heat for heat pumps

A heat pump can be seen as a kind of 'heat concentrator' because it takes relatively 'dilute' (low temperature) 'ambient' heat energy from the air, the ground or from (sea or fresh) water, and delivers it as more 'concentrated' (higher temperature) heat. For example, an air source heat pump (ASHP) extracts heat energy from a large amount of cold outside air and uses it to produce a much smaller amount of hot water, which can then be used to heat our homes. Heat pumps need electricity to run but for every unit of electricity input they can deliver two to four units of heat. Today, the overall benefits of heat pumps are often limited, as the electricity they consume is mostly produced in inefficient fossil fuel power stations. But in a future powered by a large amount of wind power, heat pumps are a great way to turn renewable electricity into heat.

Biomass

Plants store energy from the sun in their branches, trunks, leaves and roots. This 'biomass' can then be burned in boilers and power stations to produce heat and electricity. It can also be used to produce biogas and biofuels, or combined with hydrogen to create synthetic liquid and gaseous fuels, as discussed in *3.4.2 Balancing supply and demand* and *3.4.3 Transport and industrial fuels* below. Burning biomass is 'carbon neutral' – no GHGs are emitted overall since the same amount of CO_2 has been absorbed during the plant's growth as is subsequently released during burning. As such, there is no net increase in CO_2 in the atmosphere if a new plant is grown for every plant burned.

The burning of solid biomass in the form of wood has been used to produce energy in the form of heat for millennia. However, there are many competing uses for land in the UK (as discussed in *3.6 Land use*) and this puts a limit on how much we can use for 'growing energy'.

Our scenario

In our scenario, we use a variety of different renewable energy technologies. The energy mix is shown in table 3.1, and relies most heavily on offshore wind power.

The energy flow diagram (figure 3.18) illustrates the production and use of energy in our scenario. It illustrates the central role of electricity – more than 60% of all energy is supplied in this form, compared to less than 20% today. This is in part due to the central role of wind turbines that produce electricity on the supply side, and also to the electrification of heating and transport on the demand side. Biomass

Renewable electricity	**Energy (TWh per year)**	**Details**
Offshore wind	530	140 GW maximum power, 14,000 turbines rated 10 MW
Onshore wind	77	30 GW maximum power, 15,000 turbines rated 2 MW
Wave power	25	10 GW maximum power
Tidal (range and stream)	42	20 GW maximum power
Solar PV	74	90 GW maximum power, Covering 15-20% of UK roof area
Geothermal electricity	24	3 GW maximum power
Hydropower	8	3 GW maximum power
Total electricity	**780**	
Renewable heat	**Energy (TWh per year)**	**Details**
Solar thermal	25	Covering around 3% of UK roof area
Geothermal heat	15	
Ambient heat	135	Extracted from air, ground and water by heat pumps
Total heat	**175**	
Biomass	**Energy (TWh per year)**	**Details**
For biogas and carbon neutral synthetic gas	74	From waste (36 TWh) and grasses for anaerobic digestion (AD) (38 TWh)
For carbon neutral synthetic fuel	115	From Miscanthus and Short Rotation Coppice (SRC)
For heat	41	From Short Rotation Coppice (SRC) and Short Rotation Forestry (SRF)
Total biomass	**230**	
TOTAL RENEWABLES	**1,185**	

Table 3.1: Energy mix in our scenario.

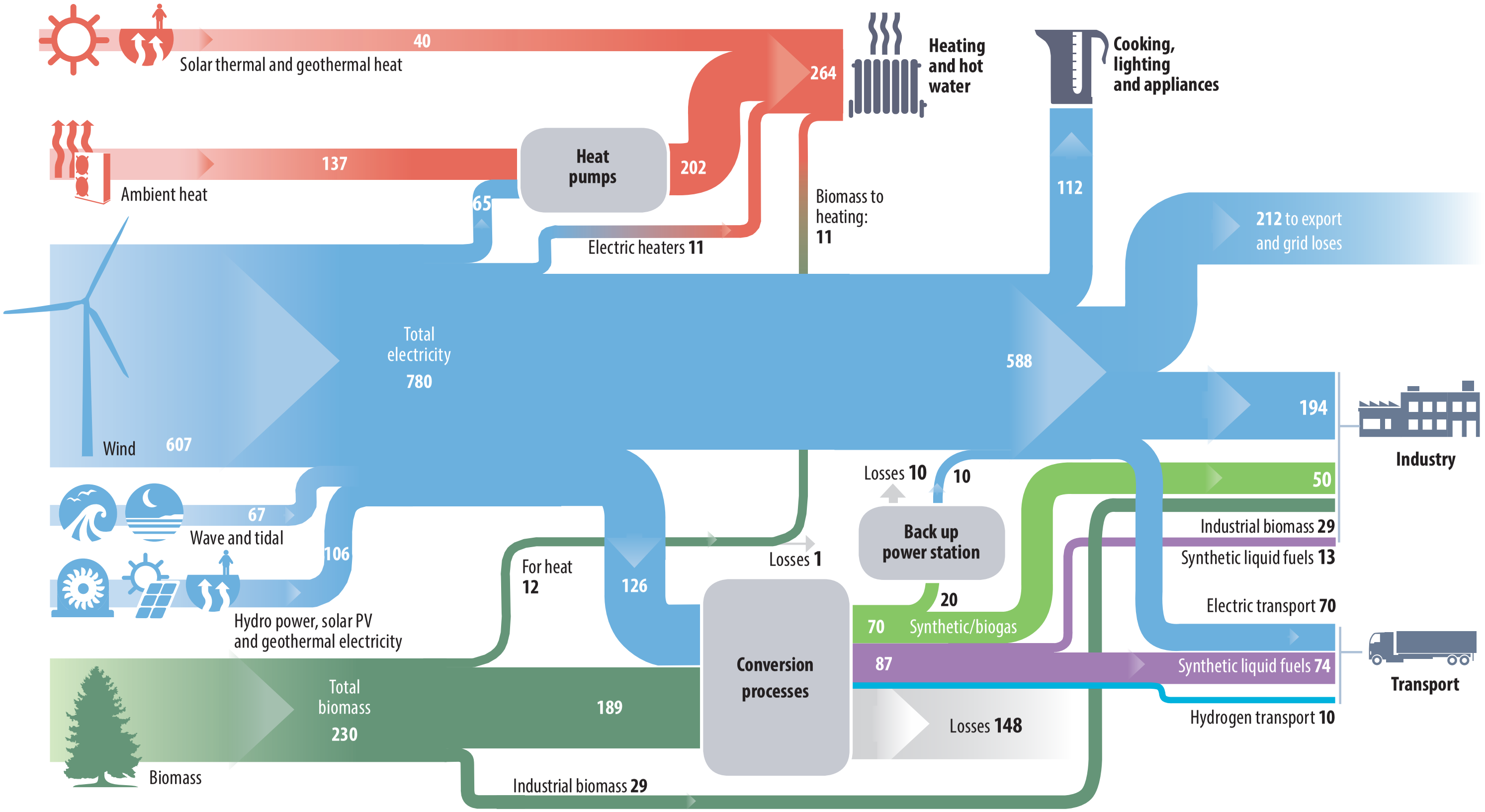

Figure 3.18: Energy flows in our scenario – from supply to demand. Numbers used here are rounded up or down to the nearest TWh and so inputs and outputs may not add up exactly.

also plays a big role in our scenario. As discussed in *3.6.2 Growing energy and fuel*, this has important implications on land use in our scenario.

3.4.2 Balancing supply and demand

The section describes how we can balance fluctuating energy demand and supply by managing our demand, and creating a back up system with carbon neutral synthetic gas.

Summary

- As most of the energy in our scenario is from variable (fluctuating) sources, there is often a mismatch between supply and demand, with both large surpluses and shortfalls.
- Adding more electricity generating capacity (for example, more wind turbines) would increase surplus electricity production without significantly reducing the problem of shortfalls.
- Shifting certain energy demands to times of high energy supply and combining different renewable sources of energy helps, but it doesn't completely solve the problem.
- Our scenario combines various short-term energy storage mechanisms (hours to days) with the capacity to store up to 80 TWh of carbon neutral synthetic gas for months or years.
- On average, we would be producing 20 TWh of synthetic gas every year, which would be used only as and when required.
- Although overall synthetic gas covers only a very small percentage of our total energy supply, it plays a critical role at times when demand is high and supply from variable renewable sources is low – for example in the cold, windless December of 2010.

What's the problem?

The previous section explains how in our scenario the total amount of renewable energy produced in an average year (about 1,185 TWh) is more than enough to meet the demand (about 815 TWh per year on average). However, as both demand and supply of energy in our scenario are variable (fluctuating) it is still a challenge to make sure that the supply always meets the demand.

Energy demand is variable

The amount of energy we use changes all the time. Currently, our electricity consumption increases rapidly between 5 a.m. and 9 a.m. on a weekday; it reaches its peak in the evening when we come home from work and switch on lights, cookers and televisions. Electricity demand can rise sharply when thousands of kettles are switched on during a TV advertising break or when clouds move over the skies of a big city and lots of people switch on the lights. Also, our demand for heating increases sharply when it gets colder. The distribution infrastructure for gas and liquid fuels has a number of built-in buffers – petrol stations and refineries have large fuel tanks and the gas grid has various stores, including the pipelines themselves. In contrast, the electricity system has much less built-in buffer capacity, hence the supply of electricity always needs to closely match demand. If in the future electricity plays a larger role in heating (heat pumps) and transport (electric cars) then dealing with demand variability will become more challenging.

Renewable energy supply is variable

The energy supply (or 'output') from most forms of renewables is variable. Whereas a nuclear power station might produce the same amount of energy whatever the weather, renewables produce different amounts of energy depending on how fast the wind is blowing, or how much sunshine there is – factors that are beyond our control. With wind power, the changes in energy output can be very sudden. Even with thousands of wind turbines spread around the whole of the UK, it is possible that energy production can near its maximum on one day and be close to zero the next. Moreover, we cannot change these things according to our needs.

This does not mean that renewable energy supply is unpredictable. We can predict the tides centuries ahead, and even predict wind speeds reasonably well a few days in advance. Combining a diverse mix of different renewable energy sources can help 'smooth

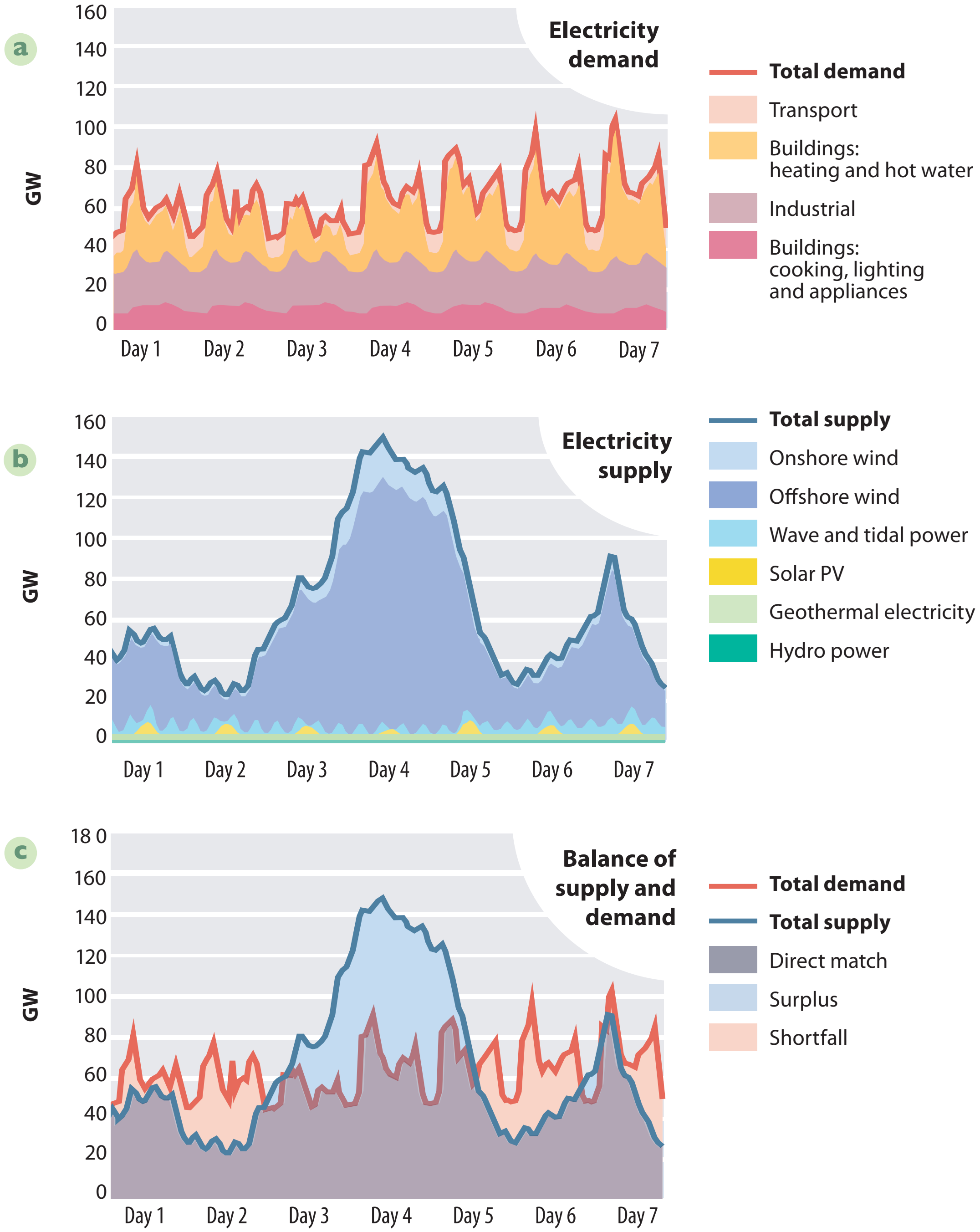

Figure 3.19 a, b, and c: An example of 168 hours (7 days from the 13th – 19th December 2010) of (a) electricity demand, (b) electricity supply, and (c) the balance between them. Supply and demand are modelled using ten years worth of hourly UK weather and electricity demand data. The marked increase in electricity demand for heating during the last four days in (a) reflects colder UK temperatures. Figure (c) shows that at times there may not be enough supply to meet demand (red areas = shortfall), or at other times there may be a greater supply than is needed (blue areas = surplus).

out' energy supply. However, our research shows that even when we combine all the renewable energy sources available in the UK, the energy supply will fluctuate significantly, for example, between a windy, sunny day (lots of energy) and a calm, dark night (little energy). And just adding more generating capacity, for example building more wind turbines or solar panels, is not enough to solve the issue, either. Our calculations suggest that, beyond a certain point, adding more generating capacity will primarily increase the amount of energy that is surplus to requirements without making much difference at times of low renewable energy supply.

Supply does not match demand

Unfortunately, our variable energy demand and variable energy supply don't necessarily 'match-up' – they don't go up and down in step. Figures 3.19a and 3.19b illustrate a typical pattern of electricity supply and demand in winter. A few days of strong winds and waves (lots of energy) are followed by days of calm (little energy). Energy demand also fluctuates – it is typically higher during the daytime, and higher still on cold days because of the demand for heating.

Sometimes renewables supply much more electricity than there is demand for, but at other times wind, waves, tides and solar combined do not produce enough to supply the energy required (see figure 3.19c). Our research shows that there are significant differences over hours, days and even years. For example, 2010 was a year with very cold winters at each end (high heat demand) and unusually low wind speeds (low renewable electricity supply), whereas 2011 was a warmer year with stronger winds. Finding ways to deal with these fluctuations is one of the biggest challenges in powering the UK on 100% renewable energy. We need to ensure our lights stay on and our houses stay warm even during a dark windless night, or during a year with low wind speeds and cold winter months.

What's the solution?

The infrastructure of a renewable energy supply must incorporate some way of 'balancing out' this potential mismatch in supply and demand that is flexible and responsive to fast-changing weather. There are two main methods that can work in conjunction.

Shifting demand to match supply (demand management)

One way to balance supply and demand is to change our energy consumption patterns so that we consume more energy when supply is plentiful, and need less when it is scarce. Industry and some households already pay less for energy during the night when demand is low. It is not difficult to imagine a future in which electricity will be cheaper when it is windy and demand is low, and more expensive when it is calm and demand is high. This could provide an incentive to consume more energy at times when supply exceeds demand and to reduce consumption when energy is in short supply.

'Smart' appliances (such as washing machines and freezers, as well as industrial processes) will automatically run more when electricity is cheap – at times of high supply and low demand – in order to minimise energy consumption when electricity is expensive and in short supply.

'Smart' car charging of millions of electric vehicles could play an important role. Their very large electricity demand can easily be 'shifted' to times when there is a surplus in the supply of electricity, for example at night or during windy periods.

Storing energy

There are a number of options for storing energy during times of surplus supply so as to make it available at times when more energy is needed. Different types of storage can perform different roles. Sometimes we only need to store energy for short periods – hours or days. At other times, over a very cold and calm winter period for example, we need to be able to build up energy stores for longer periods in advance, in order to make sure we have enough energy to last.

What is crucial for any energy storage solution working with a variable renewable energy supply, is that the 'building up' or the 'emptying' of a store is flexible and, if necessary, relatively quick. We need a dispatchable energy store that can be called upon whenever demand requires it.

For hours or days: There are a number of energy storage options that can help balance out supply and demand over timeframes of a few hours or days.

- **Pumped storage** is used today to store electricity by pumping water uphill into a reservoir at times of surplus energy supply and then letting the water flow downhill through a hydropower turbine when energy is needed. This form of energy storage can be activated very rapidly, but the total amount of energy that can be stored is small. The UK consumes far more than 1,000 GWh of energy on a single cold winter day. The UK's largest pumped storage station, Dinorwig in North Wales, can only store around 10 GWh of electricity.
- **Batteries** in electric vehicles can help shift some electricity demand (as described above). With today's battery technology, dedicated battery storage – batteries installed exclusively for the purpose of storing surplus electricity – is becoming an increasingly cost-effective way of storing energy.
- **Heat storage** offers an attractive solution in the UK where a large proportion of electricity would be used for heating. Heat can be stored over a few hours or days without significant losses in well insulated hot water tanks (those required, for example, in solar thermal systems). Two hundred litres of storage per household – either individual hot water cylinders, or large external heat stores connected to district heating systems – can store around 200 GWh of heat. This allows heat pumps to play an important role in demand side management as they can be run at times when electricity supply exceeds demand.
- **Hydrogen** can be made by the electrolysis of water – splitting H_2O into hydrogen (H) and oxygen (O) using electricity. Electrolysers can use electricity at times when there is abundant surplus of electricity, to create hydrogen gas for storage. In principle, hydrogen can be stored and then used directly to produce electricity using gas turbines or fuel cells. However, hydrogen is a very light gas that needs to be highly compressed for storage. It is also quite explosive and can even corrode metal. It is possible to store relatively large amounts of hydrogen (a few 100 GWh) over long periods of time, for example in salt caverns. However, compared to natural gas (primarily methane), hydrogen is difficult to store and transport and there is almost no existing infrastructure suitable for it.

What's the difference between *baseload* and *dispatchable* generation?

It is sometimes said that to balance an energy system with a large amount of variable renewable energy you need *baseload* power stations – power stations that produce energy at a constant rate, day and night, such as nuclear power stations. However, constant power output is actually not very useful as it leads to overproduction at times when output from variable renewables is already enough to meet all demand. Instead, our research indicates that there is a requirement for *dispatchable power* – power from generators which can very flexibly increase or decrease output, or even switch off completely, as and when we need them and depending on whether or not there is enough power from variable renewables. Gas power stations, running on either fossil or renewable gas, can be used for this purpose, though of course burning fossil fuel gas emits GHGs.

For weeks or months: Storing enough renewable energy for, say, a cold, dark winter week with low wind speeds is technically very challenging. Realistically, solid, liquid or gaseous fuels are the best option to store the very large amounts of energy required (a few 10,000 GWh). Their high energy densities mean that vast amounts of energy can be stored in relatively small spaces over long periods of time.

Biogas and synthetic gas are both produced from renewable sources. Biogas, a mixture of methane and carbon dioxide, can be produced by anaerobic digestion (AD) – the decomposition of biomass (for example, grass, animal manure or food waste) in an oxygen-free environment. Carbon neutral synthetic gas is made via the Sabatier process. Here, hydrogen

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(made by electrolysis) and carbon dioxide (from burning biomass, or from biogas) are combined to produce methane. Methane is easier to store than hydrogen. The Sabatier process can be seen as 'upgrading' hydrogen to a gas that is easier to handle. The process of using electricity to produce gaseous fuel is sometimes referred to as 'power to gas' (GridGas, 2012).

Methane gas is also the primary component of today's fossil fuel natural gas. The methane in biogas and synthetic gas can be stored in very large quantities just as natural gas is currently. The UK has a highly developed gas infrastructure, including storage facilities with a capacity totalling around 17,000 GWh. The Rough gas store off the coast of Yorkshire, recently closed for economic and safety reasons, had a capacity of 35,000 GWh. Methane is a powerful greenhouse gas, so it is very important that any escaping from pipelines or storage is kept to a minimum.

Biogas and synthetic gas, once stored, can be burned in power stations (again, like natural gas today) to provide energy when electricity supply from renewable sources is insufficient to meet demand. Gas power stations burning biogas or synthetic gas can be flexible – we can turn them on or off quickly. We can use them as 'back up' generation to meet demand when electricity supplies from variable renewables fall short. They can also supply industry for very energy intensive processes which would be difficult to run on electricity (see *3.3.1 Buildings and industry*).

Importing and exporting energy

When planning our scenario we decided to meet all of our energy needs from zero carbon, renewable sources located within the UK, including UK offshore waters. It is important to stress that this is not because we think importing renewable energy from other countries is necessarily a bad idea. It is perfectly possible that solar power from southern Europe or even northern Africa could complement UK wind energy. This is often discussed in the context of a European high voltage 'super grid' which would enable the distribution of large amounts of electricity over long distances with low losses.

However, when designing an energy scenario that allows imports, it is difficult to decide what would be our 'fair share' of foreign renewable energy sources.

Crucially, this is true even in a scenario where the UK is a *net exporter* of energy, that is, a country that sometimes has to buy energy but overall sells more energy than it buys. The problem is that other European countries are likely to be in a very similar position to the UK, with low electricity supply when wind speeds are low over the North Sea, and high electricity demand on cold, dark winter days. Therefore, if the UK were to rely on imports for days when its own renewable sources did not produce enough, it would likely find itself competing with these other countries over resources, such as solar electricity from the Mediterranean region.

Without detailed modelling of energy flows for all of Europe we cannot simply assume that our neighbours will want, or be able, to sell us energy whenever we need it. Conversely, it is possible that at times when we produce more energy than we need, our neighbours will also have more than enough energy and would not be willing to pay a high price for our surplus. Therefore, while in our scenario a fairly large amount of surplus electricity (around 145 TWh per year) is exported, this does not necessarily mean large income from electricity sales.

All this is not to say that energy imports and exports should not play a role in zero carbon energy scenarios. The benefits from exchanging renewable energy with our neighbours could significantly reduce the cost of storage and back up. We are looking forward to working together with researchers from other countries to model energy flows in a 'zero carbon Europe'.

It is important to remember that burning methane is only carbon neutral when it is produced using biomass and/or renewable electricity. When methane gas is produced from biomass, the amount of CO_2 released by burning it is reabsorbed when new biomass plants are grown, resulting in no net increase of GHGs in the atmosphere. Synthetic gas is carbon neutral when the hydrogen used is produced using renewable electricity, and the CO_2 used is from non-fossil fuel sources (like biomass).

The processes involved in creating a significant biogas and synthetic gas back up system have many losses associated with them. As energy is converted between forms (electricity and biomass to gas, and back to electricity), we lose energy in the process – about 50%. However, the ability to store energy in this way forms an integral part of an energy system powered by renewables, and is a good way of using electricity which would otherwise be surplus to requirements.

Our scenario

In developing our scenario, we used real hourly weather data (solar radiation, wind speeds, temperatures, etc.) for the last ten years – a total of 87,648 hours – to simulate patterns of supply and demand. In other words, we looked at how well the technical solutions we propose for a zero carbon future would have fared hour-by-hour under the weather conditions observed in the past decade.

In our scenario:

- **74% of the time**, the supply of renewable electricity exceeds the direct demand for electricity (including electricity for heating and transport) required at any one moment. Due to the very large number of wind turbines and other renewable electricity producers, over a third of the total electricity produced (about 300 TWh per year) is surplus to what is directly required at the time of production. However, 26% of the time, electricity supply does not fully meet demand.
- **Short-term storage** mechanisms, such as pumped storage and battery storage (200 GWh

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storage capacity), 'shiftable' demand from smart appliances and electric car charging (over 500 GWh storage capacity in total but only part of this capacity is ever available), and heat storage (200 GWh heat) reduce the proportion of time during which electricity supply does not meet demand from 26% to 11%. This reduces the amount of surplus electricity to about 270 TWh per year. Crucially, by 'capping the peaks' of unmet demand, these mechanisms significantly reduce the backup power station capacity required (see below). So short-term storage reduces not only the number of hours during which back up is needed, but also the number of gas power stations required.

- **Electrolysis** units, with a maximum power consumption of 25 GW, use around half (125 TWh per year) of the surplus electricity (the rest is exported). The hydrogen produced (around 100 TWh) is stored mostly in large underground caverns with a capacity to store 20,000 GWh of gas. A small proportion of this hydrogen is used as fuel for hydrogen vehicles (10%) but most of it is used to produce carbon neutral synthetic gas (35%) or synthetic liquid fuels (55%), as explained below.
- **Biogas and carbon neutral synthetic gas** are burned in gas power stations to supply electricity during the 11% of the time when electricity demand would otherwise exceed supply. In our scenario, we need to produce on average 20 TWh of biogas or synthetic gas as back up every year, to be used as and when required, which in turn produces an average of 10 TWh of electricity per year. We incorporate a large number of (renewable) gas power stations (45 – 70 GW maximum output, comparable to the capacity of all gas power stations we have today), but these power stations are inactive most of the time, turned on only when electricity demand would

otherwise exceed supply. Overall, these gas power stations only produce 2% of the electricity in our scenario. But our simulation shows that in weather conditions such as those experienced in December 2010, with very low temperatures and very little wind, such back up power stations would play a critical role, supplying more than half of all electricity on some days. To store enough biogas and synthetic gas for these periods, our scenario includes 80,000 GWh of methane gas storage. Today the UK has gas storage facilities with a total capacity of around 17,000 GWh.

3.4.3 Transport and industrial fuels

In this section, we describe how we can provide carbon neutral synthetic liquid fuel to meet transport and industrial energy demands.

Summary

- In our scenario most energy (452 TWh per year) is used in the form of electricity but planes and some large vehicles work better with liquid fuels. Even with reduced amounts of travel, they require a total of 74 TWh of liquid fuel and 10 TWh of hydrogen per year.
- There is also a demand for liquid fuel (13 TWh per year) from industry. And gas is required for industry and for long-term energy storage and back up – 50 TWh and 20 TWh per year respectively.
- We use processes that produce carbon neutral synthetic liquid fuels and synthetic gas by combining biomass and hydrogen.
- For these processes, a total of 100 TWh of hydrogen is produced using surplus electricity every year. 10 TWh of this is used directly in transport. 55 TWh of hydrogen is combined with 115 TWh of energy in the form of 'woody' biomass to make the required 87 TWh of carbon neutral synthetic liquid fuels for transport and industry. The remaining 35 TWh of hydrogen, with an additional 74 TWh of biomass, provides the required 70 TWh of carbon neutral synthetic gas and biogas required as back up and for industry.
- There are significant losses in these conversion processes (about 50%), which mean more energy must be put in than we get out. However, it is the form of the fuel and our ability to use surplus electricity that is important here.

What's the problem?

As described in *3.3.2 Transport*, although much of our transport can be electrified, there are some transport needs that can't be met by electricity. Liquid fuels, such as the kerosene, diesel and petrol we use today, offer a much higher energy density – smaller and lighter ways to store energy – than even the best batteries available today. If we want planes, ships and heavy commercial vehicles (such as Heavy Goods Vehicles (HGVs)) in a zero carbon future, we need to find ways to provide transport fuels with similar energy densities that are carbon neutral and can be produced from renewable energy.

There are also industrial processes that currently use natural gas or liquid fossil fuels, and these processes, too, will require carbon neutral, renewable alternatives.

What's the solution?

There are processes which allow us to produce liquid or gaseous fuels from renewable sources, replicating the fuels we use today but without the associated GHG emissions.

Hydrogen

Hydrogen (produced through electrolysis as described in *3.4.2 Balancing supply and demand*) can also be used to power hydrogen cars. However, the problems that apply to hydrogen storage also apply to using it to power vehicles: hydrogen is difficult to store and transport and, in practice, it would be difficult to use it as the main source of transport fuel. Doing so would require us to develop a whole new infrastructure.

Biofuels

Biomass can be used to produce liquid fuels very similar to today's fossil fuels. **First generation biofuels** are liquid fuels such as 'corn ethanol' or 'rapeseed oil biodiesel' that are produced from biomass in wheat, corn, sugar crops and vegetable oil. They have come under much criticism because their production can require a lot of energy, pesticides and fertiliser. They also grow best on cropland that is often in short supply, and so can compete with food production, or can contribute to land use change and deforestation, mainly overseas. **Second generation biofuels** allow the production of fuels from biomass in more 'woody' plants, such as fast-growing trees and grasses (3.6.2 *Growing energy and fuels*). These can be grown using less fertiliser and on lower quality land not usually used for food crops. However, there are still many competing uses for land in the UK (as discussed in 3.6 *Land use*) and this puts a limit on how much we can use for fuel production.

Carbon neutral synthetic liquid fuel

Similar to the production of synthetic gas, it is possible to produce synthetic liquid fuels by combining carbon, produced from biomass, with hydrogen, produced through electrolysis. The Fischer-Tropsch (FT) process is a collection of chemical reactions that can be used to combine carbon monoxide (which can easily be produced from 'woody' biomass) with hydrogen to form carbon neutral synthetic fuels for heavy commercial vehicles and planes. This combines the advantages of hydrogen (use of surplus electricity) and second generation biofuels (high density liquid fuels from 'woody' biomass).

Just as with synthetic gas, the resulting fuels are carbon neutral: the CO_2 emitted by burning them was initially taken in by the biomass as it grew, and the electricity used is renewably produced. Over the long-term there is no net increase in greenhouse gases in the atmosphere.

From an energy perspective, the conversion of surplus electricity (via hydrogen) and biomass into liquid fuels is not very efficient, as more than half of the energy is lost in the process. However, it is the *form* of energy that is important here – liquid fuels allow us to do things (fly planes, drive heavy commercial vehicles) that would otherwise not be possible.

Areas for further research

Ⓡ There is a great deal of interest from local councils and other local groups in developing zero carbon energy plans for their region. How best the research and modelling conducted for Zero Carbon Britain can be adapted for use at different scales and geographic regions is a key area for future work.

Ⓡ The role for hydrogen in the heating of buildings, in industry and as a backup fuel for electricity generation should be explored. It may be possible for its role to be larger than in the scenario presented here.

Ⓡ The electrification of large vehicles such as lorries, ships and even aeroplanes has emerged as a possibility. Some electrification of these vehicles is included in our scenario but further investigation is needed into the feasibility and energy system implications of even higher levels of electrification as an alternative to liquid fuels.

Ⓡ Industrial energy use is dealt with here at a high level and a cautious approach is taken to energy demand reductions. More research is needed to further explore how changes to what is manufactured, the materials used and processes involved could impact on industrial energy use and emissions.

Ⓡ The manufacture of synthetic gas and liquid fuels using biomass and hydrogen (made with surplus electricity from renewables) is a key part of our scenario. Developments in this area mean that the cost and efficiencies of these processes, as well as the potential to use CO_2 captured directly from the air as the source of carbon, should be monitored

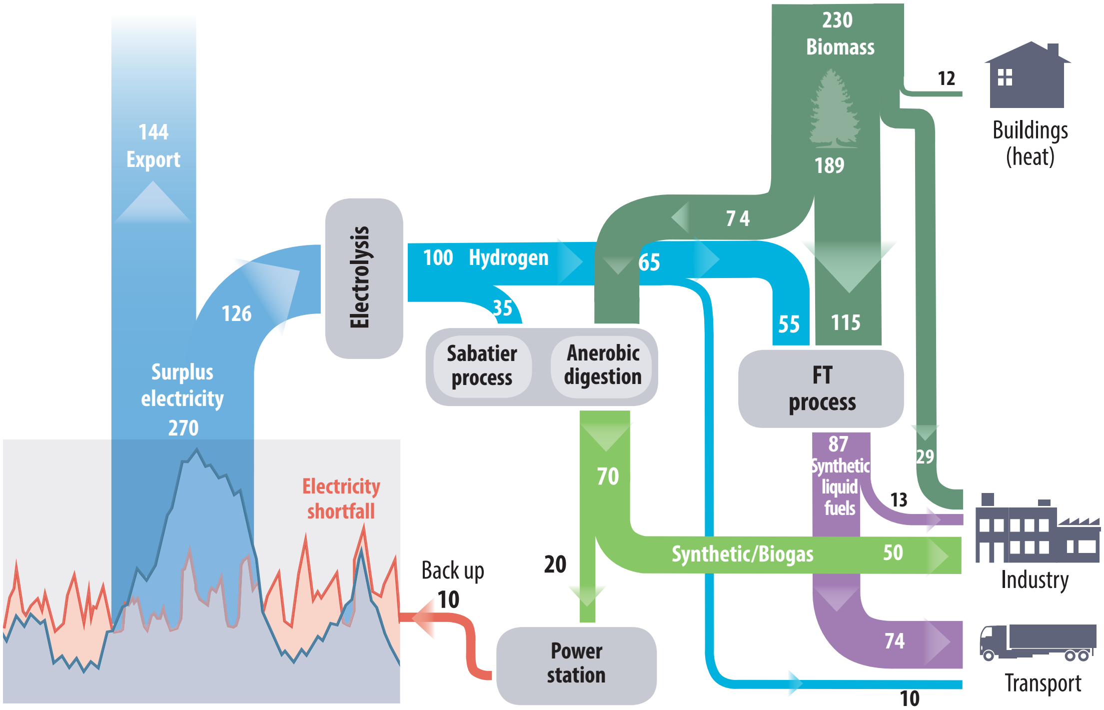

Figure 3.20: From surplus electricity and biomass to synthetic fuels for industry, transport and energy system back up. Losses are not shown in this figure.

Our scenario

In our scenario, every year, 125 TWh of surplus electricity is used to produce 100 TWh of hydrogen through electrolysis. 10 TWh of this hydrogen is supplied directly for hydrogen vehicles every year. 55 TWh of the hydrogen and 115 TWh of energy in the form of 'woody' biomass (see 3.6.2 *Growing energy and fuel*) are combined in the FT process to deliver 87 TWh of carbon neutral synthetic liquid fuels, which are used in aviation (40 TWh), vehicles (mostly ships and HGVs) (34 TWh) and industry (13 TWh). The remaining 35 TWh of hydrogen, together with 74 TWh of biomass (38 TWh from grasses and 36 TWh from waste, see 3.5.2 *Waste*) provide 70 TWh of biogas and synthetic methane. 50 TWh of this is used by industry, and 20 TWh (as described in *3.4.2 Balancing supply and demand*) is used as backup to balance supply and demand.

Figure 3.20 summarises these processes of producing synthetic fuels for industry, transport and energy system backup.

The large amount of biomass, and therefore land, required is the main limiting factor in the production of synthetic liquid fuels (and hence the amount we can fly, or supply fuel for vehicles – see 3.3.2 *Transport*). 'Boosting' fuel production by adding hydrogen from surplus electricity reduces the amount of biomass required. However, even with the use of hydrogen, the amount of land needed to meet today's liquid fuel demand from carbon neutral sources that rely on biomass is likely to exceed the land area of the UK.

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Non-energy emissions 3.5

There are some GHG emissions that are not caused by the combustion of fuels for energy. Instead, they occur from the expansion of urban areas, chemical reactions in industrial processes, the leakage of GHGs in industry, businesses and households, and from waste management.

By changing industrial processes and substituting gases and/or products with less polluting alternatives, we can reduce the emissions from businesses, industry and households fairly significantly, but not entirely.

Furthermore, with some changes to the way we deal with waste, it is possible to turn waste processing from a net GHG emitter to a method of capturing carbon. Additional benefits from doing this include energy generation and use of certain wastes for better fertilisation of soils.

Non-energy emissions summary:

- Emissions from non-energy sources accounted for just over 10% of UK GHG emissions in 2017 – 54 $MtCO_2e$. These came from urban expansion, industrial processes, leakage of some GHGs in industry, businesses and households (for example in gas pipelines), and from waste management – mainly landfills.
- These emissions are reduced to about 20 $MtCO_2e$ in our scenario – a 63% reduction. However, using technologies available today, it is not possible to completely eliminate these emissions.

3.5.1 Industry, businesses and households

In this section, we describe ways of reducing non-energy emissions from industry, households and business.

Summary

- Non-energy emissions from industry, businesses and households together accounted for just under 6% of total UK GHG emissions in 2017 – 34 $MtCO_2e$.
- In our scenario, these emissions are reduced to just under 15 MtCO2e – by changing industrial processes and substituting gases and/or products with less polluting alternatives.
- There is potential for the complete elimination of emissions from iron and steel production but the methods are as yet unproven.

What's the problem?

In addition to the GHG emissions from burning fossil fuels for energy, GHGs are emitted by chemical reactions in industrial processes. GHGs can also leak directly into the atmosphere from products containing them, or when they are moved around, and there are some emissions associated with the expansion of urban areas. In total, the non-energy emissions from industry, businesses and households accounted for 6% of total UK GHG emissions in 2017 (BEIS, 2019).

Non-energy emissions specifically from industry, businesses and households can be divided into six categories:

1. Iron and steel production: CO_2 emissions are incurred in iron and steel manufacture when carbon is used to reduce iron oxides.
2. Cement production: CO_2 emissions are incurred in the production of clinker, a component of cement, when limestone ($CaCO_3$) is converted to lime (CaO).
3. Emissions from making fertiliser and synthetic materials: emissions occur from the chemical reactions involved in making these products.
4. Leakage of 'super greenhouse gases': around 3% of UK GHG emissions are super greenhouse gases (super GHGs) (BEIS, 2019). They are released from refrigeration and aerosols, and during foam manufacture. Although only released in tiny quantities, they are very powerful (between 150 and 23,900 times as powerful as CO_2 (ONS, 2012)) and so make a significant contribution to UK GHG emissions.
5. Leakage of methane (CH_4): this occurs from the current gas network and from disused coal mines.
6. Urban expansion: this causes GHG emissions from soils and plants as they are cleared for development and was responsible for emitting roughly 7 $MtCO_2e$ in 2017.

What's the solution?

There are various ways these emissions can be reduced or eliminated completely:

1. Total UK emissions from iron and steel production (including energy and process emissions) could be brought down by around 80% by 2030 (AEA, 2010). This could be achieved by: reusing and recycling more steel; powering more iron and steel production with electric arc furnaces; using biomass, biogas and carbon neutral synthetic gas for heat; and using 'top gas recycling' to recirculate gases so that more carbon is fully oxidised. However, this still leaves some emissions from the reduction of iron oxide using carbon. There may be ways to completely eliminate these emissions (see box on page 75), but they are as yet unproven, so our scenario assumes that process emissions remain at current levels.
2. The substitution of up to 40% of clinker with non-emitting alternatives in cement production is considered feasible, and would achieve an equivalent reduction in emissions (ibid.).
3. Nitrous oxide emissions from producing adipic and nitric acid (used in nylon and fertiliser manufacture, respectively) can be virtually eliminated by changes to how they are made.

4. In most cases, it is possible to substitute super GHGs with gases that have low or no greenhouse effect – this could achieve emission reductions of up to 80-90% by 2050 (Lucas et al., 2007). Reductions of 75% should be feasible by 2030.
5. Using less methane and improving network maintenance can reduce methane leakage from the gas network.
6. Halting or slowing urban expansion could decrease emissions – redeveloping, renovating and retrofitting old unused buildings and developing under-occupied areas in urban landscapes offer alternatives.

Our scenario

Table 3.2 below shows the extent to which non-energy emissions are reduced in our scenario given the measures detailed above. In deriving these figures we also consider changes in demand for the products causing the emissions. The following

An end to emissions from iron and steel manufacture?

- Iron and steel manufacture could use electrolysis, not carbon, to reduce iron oxide. This would completely avoid CO_2 emissions. In electrolysis, iron ore is dissolved at high temperatures. When electricity is passed through the solution, oxygen and liquid iron are produced. This process has been shown to work on a small scale (ULCOS, 2010b).
- Another possible carbon neutral way to reduce iron oxide is to use charcoal derived from biomass. It is under investigation whether this could provide a suitable alternative (ULCOS, 2010a).

Whilst these alternatives are promising, neither is sufficiently well proven to be included in our scenario. In addition, Carbon Capture and Storage (CCS) could be used to prevent the release of emissions from iron and steel production into the atmosphere. However, as with CCS in electricity generation, we do not consider it for our scenario (see *3.1 About our scenario*).

Source	**2017**	**Our scenario**	
	$MtCO_2e$	% of 2017	$MtCO_2e$
Iron and steel production	2.5	100%	2.5
Cement production	4.4	84%	3.7
Super GHGs	15.0	23%	3.5
Other process emissions (from aluminium, lime, soda ash, fletton brick and the production of other chemicals)	4.0	49%	2.0
Leakage of methane from gas network	0.6	17%	0.1
Emissions from disused coal mines	0.5	100%	0.5
Conversion to urban land	7.0	36%	2.5
Total	**34.0**	**43%**	**14.8**

Table 3.2: Summary of non-energy emissions from industry, businesses and households in 2017 (BEIS, 2019), and in our scenario.

additional assumptions are made:

- Using a greater proportion of plant-based building materials, for example wood (see 3.6.3 *Capturing carbon*), means demand for steel and cement in building construction decreases. However, demand will also *increase* to build wind farms and other infrastructure. Therefore, it is assumed that UK iron and steel and cement production remains at similar levels to today.
- The demand for some products that currently use, and potentially leak, super GHGs will increase. For example, the number of heat pumps, which use refrigerant gases, will increase. However, these products can be switched to gases with a much lower greenhouse effect, so in total a 75% reduction of super GHGs is still considered achievable in our scenario.
- Methane leakage from the gas network is assumed to remain at the same percentage of total gas used as in 2017. However, the synthetic gas used in our scenario is much less than current natural gas use. Methane leakage from coal mines is assumed to continue at the 2017 level.
- Emissions from the expansion of urban areas is reduced by renovating existing buildings and developing under-occupied urban areas.

3.5.2 Waste

This section covers non-energy emissions from waste management processes and describes ways in which they can be reduced.

Summary

- Emissions from waste management contributed about 4% to UK GHG emissions in 2017. These mainly come from landfill, but also from waste incineration and wastewater processing.
- Landfill emissions are, however, decreasing due to concerted efforts to divert waste elsewhere (for example, recycling and composting) and increased efforts to capture methane emissions for the production of energy.
- The best way to reduce emissions from waste is to produce less. Consuming less, reusing, recycling and recovering materials and energy are all preferable to putting materials in landfill.

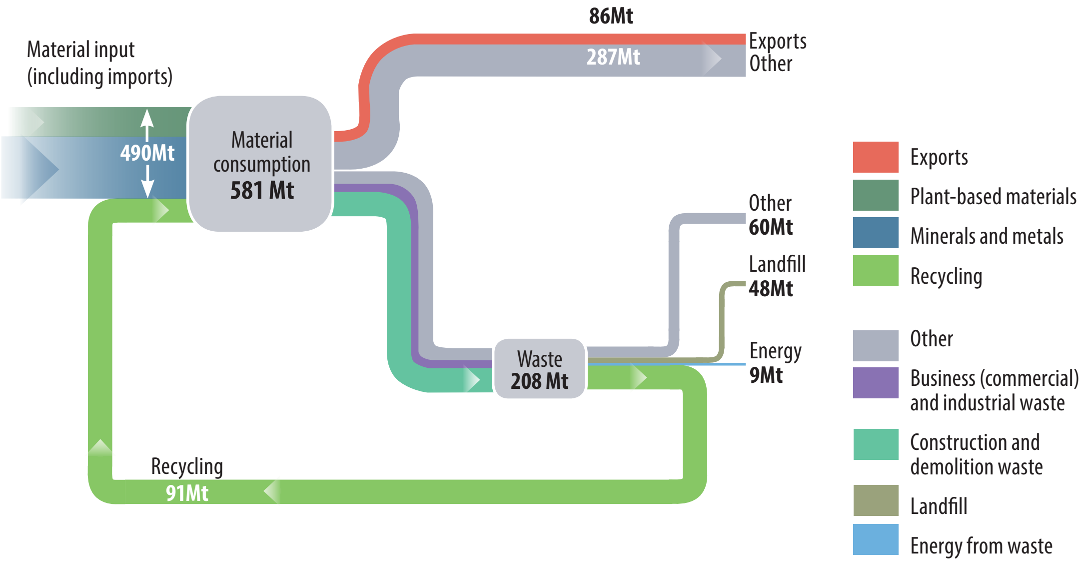

Figure 3.21: Where our waste currently goes in the UK. Adapted from DEFRA (2019).

- Landfill can be converted into 'silo storage' units or bioreactors, and wastewater processing plants can be fitted with anaerobic digesters – both of which reduce emissions and produce energy.
- Overall, emissions from waste management in the UK can be reduced by 75%, to just over 5 $MtCO_2e$.

What's the problem?

In 2017, according to UK statistics, waste management was responsible for 16.5 $MtCO_2e$ (4% of the UK's total GHG emissions). The majority of this, 14.7 $MtCO_2e$, came directly from landfill. Wastewater processing (the cleaning of wastewater before it is pumped into rivers and seas) contributed 4 $MtCO_2e$. The remainder came from waste incineration, composting, anaerobic digestion and mechanical treatment (BEIS, 2019).

Only about 18% of the 495 million tonnes (Mt) of products and materials that we consume in the UK every year is recycled (DEFRA, 2018), though this is increasing (DEFRA, 2019). About 48 Mt is landfilled every year (see figure 3.21), and this figure is decreasing (DEFRA, 2019). We currently waste about 25% - 30% of all the food we produce (FAO, 2011, DEFRA 2018).

There are substantial gaps in our knowledge about waste because not all of it is regulated or recorded (Fawcett et al., 2002). Figure 3.22 shows the proportions of waste from some sectors in the UK. In general, whilst recycling rates are improving the total amount of waste produced in the UK is increasing (DEFRA, 2019).

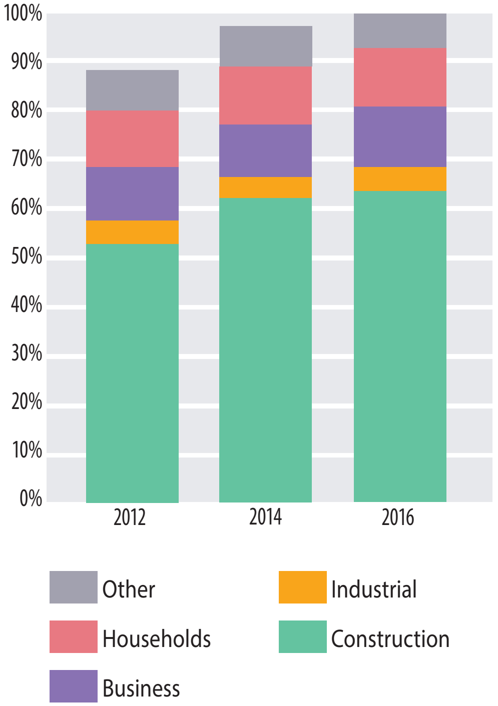

Figure 3.22: Estimated percentage of waste generated by each sector, and demonstration of the increase in waste generation in recent years. Adapted from DEFRA (2019).

Many products have an environmental impact simply from the process of manufacture – in other words, in the extraction of the basic materials, plus GHG emissions from processing and manufacturing. Products can also contain materials which are in relatively short supply globally. By not reusing or recycling these materials we rapidly use up remaining resources.

Any plant-based materials (wood, paper and food, for example) that end up in landfill emit GHGs as they decompose. Since there is very little, or no, oxygen in landfill, these materials don't decompose completely. Some carbon stays in the materials almost indefinitely, whilst some is released as methane (CH_4), which is a much more powerful GHG than the CO_2 that these plants originally captured. Less 'woody' plant-based materials – food waste, grasses, agricultural and crop residues, decompose relatively quickly and more completely, releasing lots of CH_4, and storing relatively little carbon. More 'woody' materials (timber) decompose less, meaning less CH_4 emissions and more carbon stored per tonne landfilled (UNEP, 2010).

Methane from landfill can be captured and used to produce energy. GHG emissions from landfill have decreased significantly over recent years because of methane capture, and because we are diverting wastes from landfill. GHG emissions from landfill fell 77% between 1990 and 2017 (BEIS 2019).

What's the solution?

The waste hierarchy

Current government policy and recommendations by the United Nations Environmental Programme (UNEP) for reducing the environmental impact of waste are shown in figure 3.23. Preventing waste should be the first and foremost measure taken (UNEP, 2010).

Benefits from preventing waste, reusing materials and recycling are much greater than those from any waste treatment, even if energy is recovered in that process (ibid.). Wasting less would mean consuming less, also resulting in less manufacturing. In turn this reduces the environmental impact (and GHG emissions) from production and manufacturing processes, and from waste treatment; to change only what we do with waste once it is generated has no impact at all on the emissions in the production and manufacturing stages.

Recycling 70% of household waste could save 4.4 MtCO$_2$e per year, for example (Fawcett et al., 2002), and there are many, many more opportunities to recycle in business and industry. As many things should be reused or recycled as possible (Michaud et al., 2010), though burning some materials, like medical wastes, may be the only way to prevent potentially dangerous contamination.

One important precondition for reducing emissions from waste is to sort it into different types, so that it can be treated appropriately. This applies to non-plant-based materials (plastics, metals, etc.) though these are not the major contributors to emissions from landfill. Plant-based biodegradable materials that decompose, contributing to landfill emissions, could be sorted as follows:

- Food and agricultural waste (high GHG emissions in landfill, low carbon storage potential) should not be landfilled. There are better purposes for food waste, if we are careful – for example, feeding livestock, or creating compost for soils. Agricultural waste (manure from livestock, agricultural or crop residues, animal industry wastes) can be used to produce energy through anaerobic digestion (AD). The residue from AD still contains all the nutrients in the original material and so can be reapplied to soils as compost or fertiliser (UNEP, 2010).
- More 'woody' waste (off-cuts from forestry, branches, bark and sawdust), could either be used to make biochar via pyrolysis or as biomass for energy production (ibid.) (see *3.4 Power Up* and *3.6.3 Capturing carbon*).

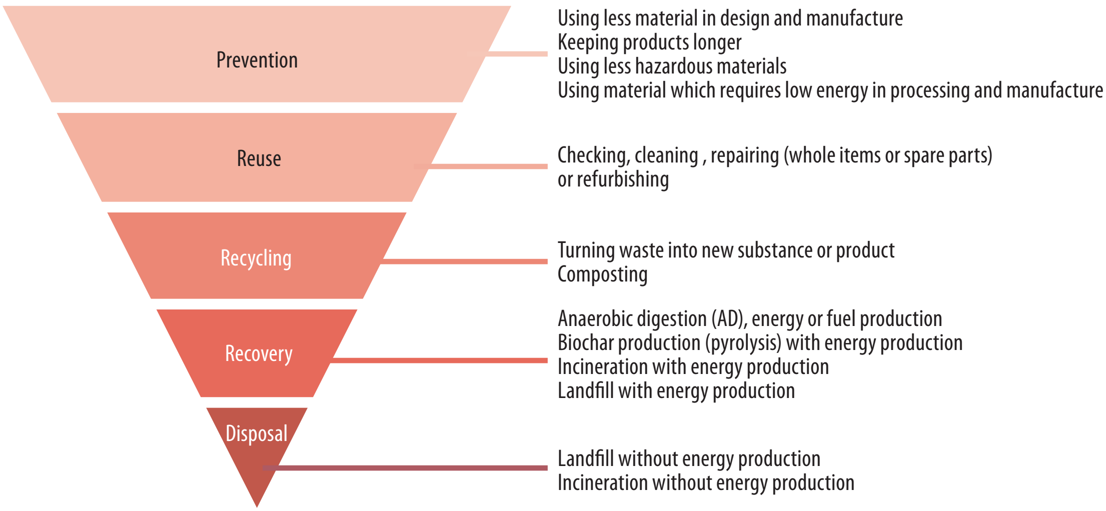

Figure 3.23: The waste hierarchy. Measures at the top of the triangle are best. Adapted from DEFRA (2011b).

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- There are many opportunities for reducing, reusing and recycling plant-based construction and demolition materials (up to 90% of all waste from construction and demolition is recycled in some countries (Symonds, 1999)). However, eventually waste will occur (for example, if wood products become partially rotten or are damaged beyond reuse or repair). This waste can also be converted into biochar (*3.6.3 Capturing carbon*), but if it contains materials that have been heavily treated with chemicals, or if it is likely to produce harmful residues when burned, landfill perhaps remains the only option.

Better design and protection of landfill sites – for example, covering waste within a few months to stop decomposition – can create 'storage silos' that capture carbon (UNEP, 2010; Hogg et al., 2011). Alternatively, promoting decomposition by adding air or water can create 'bioreactors' that produce energy. In both cases there is the potential to eliminate nearly 100% of the methane emissions from landfill (ibid.).

Wastewater processing

All sewage and wastewater treatment plants could be fitted with anaerobic digesters (ADs), using the gases to produce energy (biogas), while enclosing tanks and adding waste gas scrubbing mechanisms could further reduce emissions (AEA Technology Environment, 1998b).

Our scenario

Most of the plant-based waste streams in our scenario are diverted from landfill to other uses:

- Food waste is halved and we assume the remaining portion feeds livestock (pigs) or is composted.
- All biodegradable agricultural waste (straw from cereals, for example), waste from sewage systems, poultry waste and manure from livestock is used to produce energy through anaerobic digestion (AD) of the biomass. The residue is used as compost or fertiliser on agricultural land and land used to grow energy crops.

- The amount of 'woody' construction and demolition waste increases in this scenario due to planting new forests and using more plant-based materials in buildings (see 3.6.3 *Capturing carbon*). It is assumed that about two-thirds of all construction and demolition waste (once it has been reused and recycled) will not be safe to turn into biochar, and will be landfilled. New landfills are built as 'storage silos' meaning a negligible amount of methane is released, and methane capture from existing landfills is improved.

What about non-plant-based materials?

Most manufacturing processes, and hence waste streams, are not explicitly modelled in our scenario. Reuse or recycling of any non-plant-based materials (like metal, plastics and glass) are assumed to contribute to energy demand reductions from industry if they are produced in the UK (see *3.3.1 Buildings and industry*).

Therefore:

- There is a 75% reduction in emissions from landfills (91% reduction from 1990 levels are assumed feasible by AEA Technology Environment (1998a)).
- Emissions from burning waste are assumed to remain the same.
- Methane emissions from wastewater processing are used to produce energy, and N_2O emissions are reduced by 25%.

Together, these measures mean the waste sector in 2030 emits 5.1 $MtCO_2e$ – just over a quarter of 2017 emissions.

Biogas from anaerobic digestion of some biodegradable waste and wastewater processing, and a small amount of methane from remaining landfills, help meet some of our energy demands in our scenario. Together, they produce the equivalent of 36 TWh of biomass for biogas production (see 3.4 *Power Up* and 3.6.2 *Growing energy and fuel*).


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Land use 3.6

The previous sections – *3.3 Power Down, 3.4 Power Up* and *3.5 Non-energy emissions* – show that most of the UK's greenhouse gas (GHG) emissions (about 90%) can be reduced significantly – almost to zero, save a few industrial and waste management processes that still emit GHGs. The remaining impact on climate change from these areas is about 27 $MtCO_2e$ per year in our scenario – 14.8 $MtCO_2e$ from non-energy emissions from industry, businesses and households, 5.1 $MtCO_2e$ from waste management, and 7.4 $MtCO_2e$ from the effects of aviation (see 3.3.2 Transport).

However, there are still emissions associated with agricultural food production, and those from land use changes and land management practices – about 10% of current UK emissions. We will see how we can reduce some of these emissions in this section.

That said, since our target is net zero for all emissions, this is still not quite enough.

In addition, our agricultural systems are threatened with reduced productivity due to a decline in the numbers and variety of plants and animals in the agricultural and surrounding environment. This variety of life is necessary for efficient food production (UN FAO 2019)(See box on page 95).

Therefore, our land must be managed to preserve essential diversity of life and provide food (and building materials) as well as two more demands.

One is the need for biomass – to fuel some parts of our transport system, and to provide backup for our energy system. The other is to 'balance' the impact of our remaining emissions by capturing carbon – removing CO_2 from the atmosphere every year in equal measure to this impact. In doing this, the UK will essentially be cleaning up its own mess within its own territory.

This is the last piece in the jigsaw. Our use of land in the UK will provide food, energy resources and carbon capture, which allows the UK to be truly net zero carbon.

Land use summary:

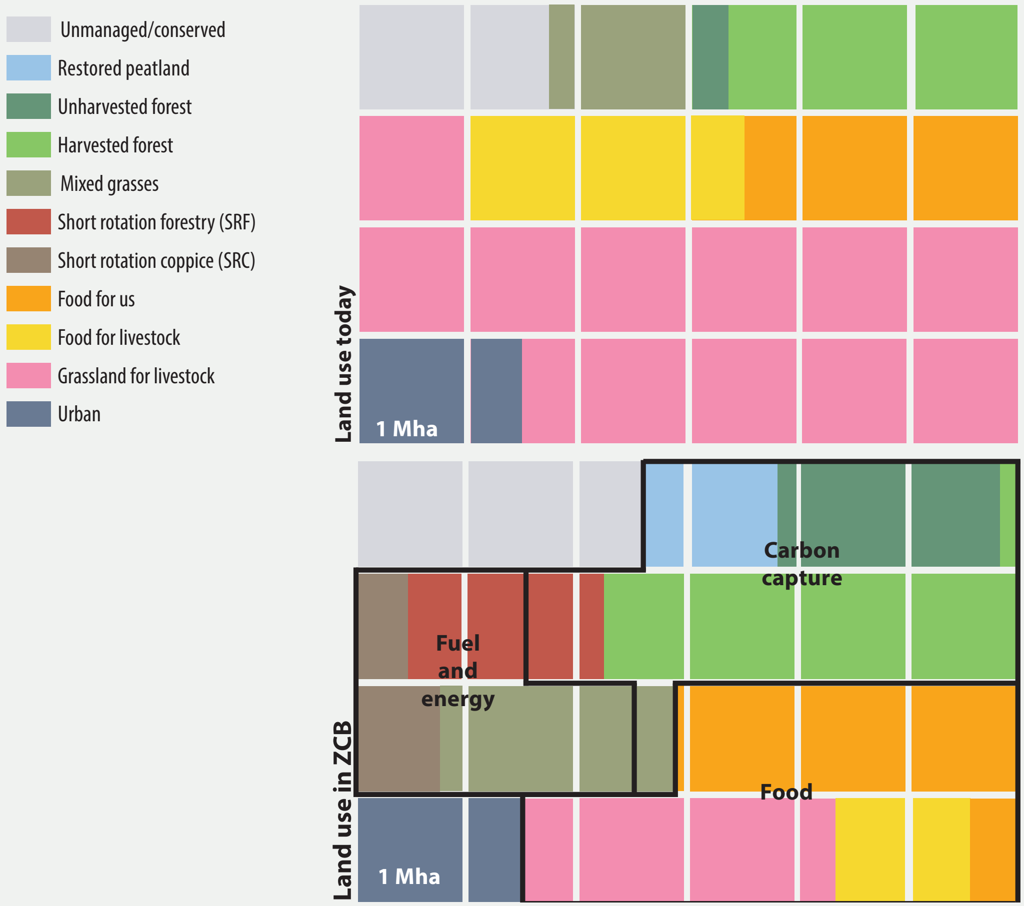


Figure 3.24: Change in land use between today (based on data from Morton et al. (2008), Forestry Commission (2007), DEFRA (2012), NERC (2008), Bain et al. (2011) and Read et al. (2009)) and our scenario. Approximate areas dedicated to providing food, fuel and energy, and carbon capture are shown in our scenario.

- Agricultural GHG emissions are reduced from 45.6 MtCO2e to about 19.7 MtCO$_2$e per year via a combination of dietary changes, waste reduction, elimination of conversion of land to agricultural use and improved land management practices.
- There is much less protein in the diet from meat and dairy sources, and more from plant sources like beans, legumes, cereals and vegetables.
- This results in a healthier and more balanced average diet for the UK population.
- The amount of land required to grow grass for livestock is only a quarter of the area used today (2.8 million hectares (Mha). The same amount of cropland is used, though more of it is used to grow food for people, rather than feed for livestock.
- Whilst re-purposing this land to cater for other needs in our scenario, it is important not to plough up grassland as this can release carbon dioxide, so grassland is converted to use for biomass and wood production and habitat restoration.

- Roughly 4.2 Mha of land (most of which was previously used for grass for livestock) is used to produce energy by growing various grasses, Short Rotation Forestry and coppice. In total, about 230 TWh of biomass energy is produced, including 36 TWh of biomass from waste (see *3.5.2 Waste*).
- Forest area is doubled to 24% of the land area of the UK – roughly one third of which is unharvested, and two-thirds is harvested for timber. These forests, the wood products produced and the restoration of 50% of UK peatlands, results in the capture of about 47 $MtCO_2e$ on average every year – this is required to balance the remaining emissions in the scenario and make the UK net zero carbon.
- Overall, there is more room for biodiversity in wild, conservation or protected areas as well as its integration into functional landscapes.

A note on land use in our scenario

We don't break down the types of land that are used for agriculture any further than 'cropland' and 'grassland' (of three different types – temporary, intensively grazed and semi-natural grasslands). In reality, these include a wide variety of types of soil, topography (whether an area is flat or mountainous) and climate (the north of Scotland compared to southern England). For example, grassland varies greatly in the number of animals it can feed, the wildlife it sustains and the amount of carbon stored in the soil. All this needs to be taken into account when allocating which is to be retained or converted to other uses.

More analysis would show which farming and production practices would be most appropriate for each area, and whether higher or lower yields could be expected. It would also give us the opportunity to research and incorporate local knowledge, and ecological farming practices. See *Alternative Farming Techniques* on P94.

3.6.1 Agriculture, food and diets

This section covers emissions associated with growing food. We can reduce these emissions whilst improving the average UK diet. It has implications for how we use land, and for global agricultural systems.

Summary

- Agricultural food production is responsible for just under 10% of total UK GHG emissions – about 45.6 $MtCO_2e$ in 2017 (BEIS 2019).
- The UK's agricultural GHG emissions can be dramatically reduced by changing the mix of foods in our diet: less meat, more fruit and vegetables, pulses and starchy foods (such as pasta, bread and potatoes). These proposed dietary changes would have positive health outcomes: reducing levels of obesity and diet-related diseases.
- Reducing how much beef, lamb and dairy we eat not only reduces GHG emissions significantly, but also frees up large amounts of both grassland and cropland.
- Reducing the amount of food wasted on the farm, throughout the supply chain and at home would greatly reduce food production burdens, and hence GHG emissions.
- The UK could become more self-sufficient in food, reducing imports and the impact of food production for our consumption elsewhere in the world.
- In our scenario, emissions from food production ('on the farm') are reduced to 19.7 $MtCO_2e$ per year – about 43% of what they were in 2017. Imports are reduced from 42% to 17%. Land used for food production is reduced from about 78% of total UK land to about a third, freeing up space – all grassland – for other uses.

What's the problem?

The balance of foods in our diet (meat, dairy, starchy foods, fruits and vegetables) affects the GHGs emitted, the amount of land needed to grow food, the health of UK wildlife populations and our own health.

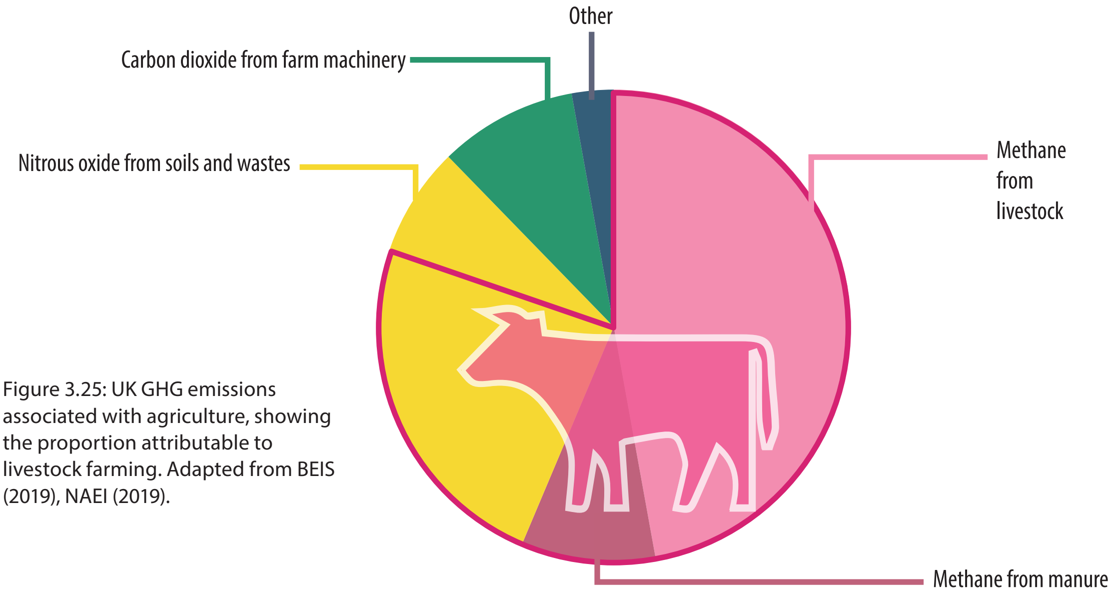


Figure 3.25: UK GHG emissions associated with agriculture, showing the proportion attributable to livestock farming. Adapted from BEIS (2019), NAEI (2019).

Greenhouse gas emissions

Figure 3.25 shows a breakdown of all emissions associated with agriculture.

Currently in the UK, about 56% of GHG emissions relating to the agricultural sector come from methane (CH_4), and 31% from nitrous oxide (N_2O). Both methane and nitrous oxide are much more powerful GHGs than carbon dioxide (CO_2) (BEIS, 2019). The proportion of non-CO_2 emissions in agriculture is unusually high when compared to other sectors. And they can be harder to reduce, as they originate mainly from biological rather than technological sources.

Some of the CO_2 from agriculture is emitted from fossil fuel powered agricultural machinery (for example, tractors and combine harvesters) and fertiliser manufacture. In the UK, this currently makes up about 9% of our agricultural emissions (ibid.). CO_2 is also emitted in other areas of the food supply chain (for example, in processing, packaging, distribution). In our scenario, all of these emissions are minimised or negated: for example, fertiliser can be produced using hydrogen from electrolysis. These are included in the energy and non-energy emissions from business, industry and transport (see *3.3 Power Down* and *3.5 Non-energy emissions*) and are therefore not discussed further here.

Other agricultural GHG emissions come from the following:

Converting land for food production: There are two main types of land used to produce food:

- Grassland, including intensively grazed pasture and semi-natural grassland, as well as land cropped for hay and silage.
- Arable land for crops such as wheat, vegetables and sugar beet to feed people and livestock.

Globally, the majority (47%) of emissions from agriculture come from converting natural habitats to farms (Millstone and Lang, 2008). The vast majority (78%) of UK land has already been cleared for agriculture. Some emissions remain from converting land to cropland (about 6.2 $MtCO_2e$ per year). Foods produced outside of the UK (the foods we import) also result in significant land use changes and are responsible for GHG emissions overseas (see box).

Meat and dairy: Cows and sheep release methane from their mouths as they digest grass. This process ('enteric fermentation') accounts for 14% of global agricultural emissions (Millstone and Lang, 2008), but a greater 56% of the UK's agricultural emissions (BEIS, 2019). UK methane emissions are higher than the global average as much more of our agricultural land is grassland (61%) for meat and dairy production (DEFRA, 2011).

Other animals, like pigs and chickens, emit very little methane through enteric fermentation. They do, however, require food, which is grown on cropland. In this way, they contribute to emissions from fertiliser use (see below) and can also contribute to emissions from land use change. The manure they produce is also responsible for a small amount of methane emissions (about 0.8 MtCO2e per year – 1.3% of total UK agricultural emissions in 2010 (DECC, 2012).

Rice: Methane is also released during paddy rice production, where rice is grown in fields that are flooded or irrigated. This generates about 5% of global agricultural emissions (Millstone and Lang, 2008). No methane emissions from rice production occur in the UK, however, as we do not grow rice here.

Nitrogen fertilisers: The nitrogen present in fertilisers is not taken up entirely by the crops on which they are used. Bacteria and other microbes in the soil convert fertiliser nitrogen to other compounds including nitrous oxide (N_2O) a powerful GHG (Butterbach-Bahl et al., 2013). N_2O emissions from soils occur both on land used to produce crops (for us and to feed livestock), and on land that is used for grass production for cows and sheep.

What we eat

Our diets supply us with the materials needed for growth and repair as well as the energy we require for daily activities and basic metabolic processes.

GHG emissions from land use change abroad

In some accounts, GHG emissions from land use change abroad attributable to food consumption in the UK amounts to as much as 100 MtCO$_2$e per year, though our knowledge about the extent of this issue is incomplete. However, a major contributor is tropical forests cleared to make way for palm oil and soya plantations and for grazing of cattle (Pendrill et al. 2019). This causes very high losses of carbon and loss of valuable plant and animal species. Plants and soils store a lot of carbon, and converting land for food production releases both CO_2 and CH_4 (De Stephano & Jacobson, 2018). See *3.10.3 Carbon omissions* for further discussion on this point.

The food we eat also provides essential amino acids (from protein), vitamins and minerals, essential fatty acids (such as omega 3) and antioxidants that help prevent disease. Eating an unhealthy diet for a long time can lead to many diet-related diseases like heart disease and diabetes (Friel et al., 2009).

In the UK, on average (individuals differ), we currently eat:

Too much food: Eating too much makes people overweight or obese, and at greater risk of specific diet-related diseases, such as heart and circulatory problems, strokes, Type 2 diabetes, and certain cancers (ibid.). In the UK today, 64% of adults are overweight or obese (Bates et al., 2011), and 71% of all deaths in the UK in 2010 were from the types of diseases mentioned here (WHO, 2013). Physical activity levels are also decreasing. Increased car use, office jobs and more television lead to less exercise and a rise in sedentary lifestyles (Poskitt, 2009).

One of the biggest problems is that a lot of food is wasted. This occurs at every stage from farm to plate, but on average four portions of fruit and vegetables are thrown away in the home per week (Quested, 2011). Over 30% of all food produced in Europe is wasted (FAO, 2011). Added to overconsumption, far more food is produced than is needed.

An unhealthy balance of foods: Many developed countries are eating diets that are becoming less and less 'balanced' – too much of some foods and not enough of others. Sweets, crisps, kebabs and pizzas provide us with lots of energy (measured in kilocalories (kcal)) but very few essential nutrients. Fruits and vegetables, on the other hand, are high in beneficial nutrients and relatively low in energy (Monsivais and Drewnowski, 2007).

An average UK citizen today eats 2,630 kcal in energy, and 80 grams (g) of protein per day. Both are too high – about 2,250 kcal and 55g respectively are recommended daily amounts (RDA) (COMA, 1991; FSA, 2007). The average UK person also doesn't eat the recommended minimum of five portions a day of fruit and vegetables or enough cereal and fibre. Our average diet contains too many foods that are high in fat (particularly saturated fat), salt and sugar (known as 'high in fat, salt and sugar (HFSS)' foods), and too much red and processed meat. This shows that there is a problem with the current mix of foods within our diet as well as with overall calorie consumption (ibid.).

What's the solution?

Many solutions reduce GHG emissions and address health issues together. For example, for us in the UK, eating less red meat should be recommended from both a GHG emissions perspective and a health perspective. Figure 3.25 highlights the high proportion of total agricultural GHG emissions in the UK, and globally, attributed to all livestock (cows, sheep, pigs, chickens, etc.). These changes would also reduce habitat loss and emissions overseas (McMichael et al., 2007).

In 2019, the *Food in the Anthropocene* report was published by the leading medical journal The Lancet. The report came to the same conclusions globally as this (and previous) ZCB reports have done for the UK – that consuming less animal and more plant protein will have huge benefits to both our health and the sustainability of our agricultural systems (Willett et al., 2019). The diet recommended in the report contains a majority of protein from plants, with a recommended intake of meat of around 43 g per day (ibid.), a little less than in our scenario.

Greenhouse gas emissions

There are many ways we can reduce emissions from food production:

Minimising land for food production, and managing it better: Reducing CO_2 emissions from agricultural land use, both at home and overseas could be achieved by minimising the amount of land converted to agricultural production, or stopping agricultural expansion completely (especially into forests, peatland and less intensively managed, or semi-natural landscapes). Soil management techniques can promote carbon capture on agricultural land (see *3.6.3 Capturing carbon*). We could use even less land to produce food and restore some of it to more natural landscapes – adding carbon to soils in some cases, rather than releasing it (again, see *3.6.3 Capturing carbon*). There are a number of ways of doing this:

- **Product switch:** Change the mix of foods we eat, reducing land intensive foods, such as beef, lamb and dairy, and replacing them with foods that require less land – see figure 3.26.
- **Intensify production:** In developed countries we might be able to grow more food on less land, leaving more for carbon capture and wildlife. Whereas low input farming (for example, organic) tends to increase biodiversity on the farm over conventional agriculture (Tuck et al., 2014, Miraglia et al., 2009) it takes up more land, therefore leaving less for nature elsewhere.

Agricultural emissions overseas

Emissions from the UK food chain amount to 115 $MtCO_2e$ (this includes transportation and processing of goods – energy emissions included in *3.3 Power Down* and *3.4 Power Up*). Because we import 42% of all the food we eat, it is likely we are responsible for a great deal more emissions globally – at least a further 59 $MtCO_2e$, not including land use change (Holding et al., 2011). Emissions relating to imports are not included in the 'production' GHG emissions accounting system as these emissions do not occur on UK territory. If a consumption based accounting system is used instead, however, overseas emissions relating to imports would be included (see *3.10.3 Carbon omissions*).

These two approaches are sometimes referred to as 'land-sparing' (intensive) and 'land sharing' (low input). Current evidence indicates that land sparing is probably better environmentally than land sharing as long as the spare land is used for natural landscapes and not more farmland (Balmford et al., 2018). However, healthy biodiversity on the farm is essential for food production. Therefore, methods to intensify production while increasing on-farm biodiversity are needed. See Box on page 95. We could also use glasshouses for food production, meaning higher yields. Renewable energies and waste heat, or geothermal heat, could be used to increase heat and light (Sinclair Knight Merz, 2012). Food production can sometimes be combined with other land uses, such as grazing animals on wind farms.

- **Increase imports:** Importing more food from abroad would mean we use less land in the UK. Although this might be good for our GHG emissions, it would also mean increasing reliance and stress on land elsewhere, and potentially increasing emissions from land use change and agriculture overseas (see boxes on pages 85 and 86).

The power of methane

Methane is usually considered to be 25 times more powerful a GHG than CO_2. However, methane is broken down in the atmosphere relatively quickly, after about 10 years. So, whereas a tonne of CO_2, emitted now will continue to cause climate change in 100 years, the effect of methane does not last this long (Lynch 2019). This can be used as an argument to regulate agricultural methane emissions to a level that results in no net climate impact and not reduce livestock agriculture beyond this point. However, in the short term, reducing methane emissions has a larger effect than reducing CO_2 emissions. Therefore, if we reduce methane emissions now, this will reduce temperature increases in the near future making it less likely we will reach dangerous tipping points.

What about 'GM' crops?

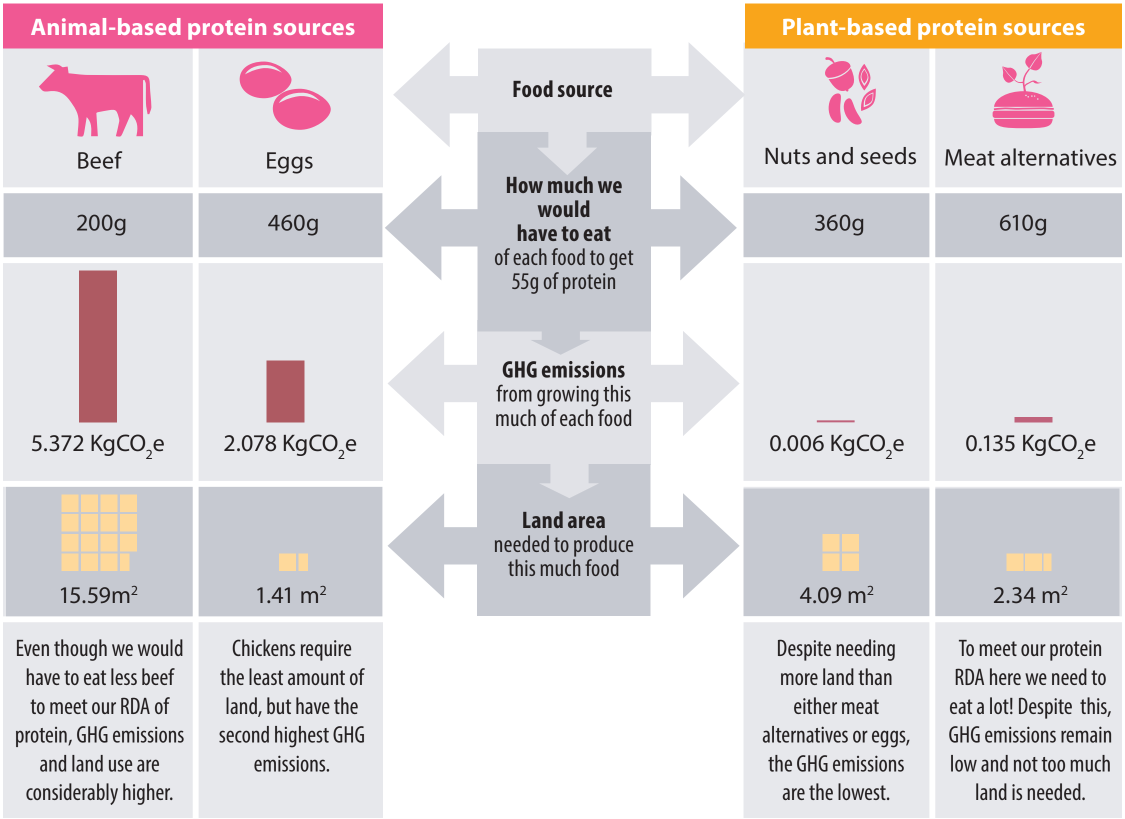
Crops can be genetically modified (GM) to have characteristics enabling the production of more food using less land. Whether to grow GM crops is currently hotly debated. In Europe the use of GM crops is restricted, but in America they are already grown widely (Devos et al., 2009). Some people believe that the use of GM crops is necessary to feed a growing population (Godfray et al., 2010). However, changing the mix of types of food in the diet has a much greater effect on our ability to provide enough food than use of GM crops could.

There are concerns over the long term sustainability of GM crops and the rights of small-scale farmers to access varieties of seed (Catacora-Vargas et al., 2018; War on Want, 2012). Therefore, GM crops are not used in this scenario. However, if they were proved to be beneficial and managed correctly, higher yields could be useful for the UK

Less meat (particularly red meat) and dairy: Technical 'fixes' for reducing methane emissions from cows and sheep are not proving to be effective. See the box opposite. Currently, the only feasible way of reducing methane emissions from livestock is to reduce the number of cows and sheep. Since over 11 Mha of grassland is currently used to feed livestock in the UK, reducing the number of grass-fed livestock also has the advantage of freeing up substantial portions of land for other uses (DEFRA, 2011).

Are there other ways of reducing methane emissions from grazing livestock?

Researchers are investigating potential methods to reduce methane from ruminants which include breeding new strains of livestock (Hayes et al., 2013), and use of vaccinations, antibiotics and pro-biotics (Broucek, 2018). Much research is being conducted into diet and supplements, for example increasing fatty acid intake, and additions such as seaweed products (Molina-Alcaide et al., 2017; Jafari et al., 2019; Salami et al., 2019). Though these methods may prove useful in the future, they are not yet proven to be safe, sustainable and effective (Broucek, 2018; Huws et al., 2018).



	Animal-based protein sources		Plant-based protein sources	
Food source	Beef	Eggs	Nuts and seeds	Meat alternatives
How much we would have to eat of each food to get 55g of protein	200g	460g	360g	610g
GHG emissions from growing this much of each food	$5.372\ \mathrm{KgCO_2e}$	$2.078\ \mathrm{KgCO_2e}$	$0.006\ \mathrm{KgCO_2e}$	$0.135\ \mathrm{KgCO_2e}$
Land area needed to produce this much food	$15.59\mathrm{m}^2$	$1.41\ \mathrm{m}^2$	$4.09\ \mathrm{m}^2$	$2.34\ \mathrm{m}^2$
	Even though we would have to eat less beef to meet our RDA of protein, GHG emissions and land use are considerably higher.	Chickens require the least amount of land, but have the second highest GHG emissions.	Despite needing more land than either meat alternatives or eggs, the GHG emissions are the lowest.	To meet our protein RDA here we need to eat a lot! Despite this, GHG emissions remain low and not too much land is needed.

Fig 3.26: Comparison of four different high protein food sources: how much would need to be eaten to meet the recommended daily amount (RDA), the associated GHG emissions and land used.

Can grasslands be managed to sequester carbon?

Much has been written recently on the potential to increase soil carbon through grassland management. Creating new grassland can certainly sequester carbon into soil and plants (Ostle et al., 2009) if the starting levels of soil organic carbon are low. However, all soils have a maximum carrying capacity, and once this is reached, further additions of carbon are of no benefit (Smith, 2014; Carolan and Fornara, 2016).

One technique which has received much attention is the practice of Intensive Rotational Grazing (IRG) or Holistic Planned Grazing (HPG), popularly known as 'mob grazing'. This is where animals are intensively grazed on one area, which is then left to allow plants to grow tall. A diversity of plant life is encouraged, and the technique is thought to increase soil carbon by the trampling of tall plants into the soil, the transfer of carbon from dying roots, and substances exuded from roots into the soil (Zaralis, 2015). Whilst this has been demonstrated to yield short-term benefits when introduced on land that was previously low in soil organic carbon, there is little evidence that grassland can be managed to continue sequestering additional carbon in the long-term (Garnett, 2017; Ward et al., 2016).

Ongoing research to maximise the benefits of grassland systems for animal and ecological health is important, but the surest way to increase carbon stocks is to plant new woodland. It is important that soil carbon in existing natural and semi-natural grassland is not lost, therefore the Zero Carbon Britain scenario does not allow any ploughing of grasslands for conversion to arable crops.

What about replacing meat with ‘cultured meat’?

The benefits of this type of meat production would be incredibly low land and water usage, and a significant reduction in GHG emissions (Tuomisto and de Mattos, 2010). Two techniques are currently being trialled:

Lab produced meat from stem cells. It is possible to grow basic muscle and fat tissue (the main parts of an animal that we eat) in this way, but the process doesn’t successfully mimic the taste and texture of meat (Post, 2012). The different types of tissue have to be grown individually, so what is grown is only suitable for ground meat, which is used in burgers, for example (Datar and Betti, 2009).

Organ printing. This technique is being developed within medical research to make human organs for transplants. Live cells are sprayed onto gels in layers to make 3D structures. It could provide more realistic taste and texture, and even produce individual cuts of meat (such as a steak or lamb chop) (Mironov et al., 2009).

Both of these technologies are still at the research stage and not currently viable for mass production (Bhat and Bhat, 2011), but could offer an opportunity for the future.

Plant-based sources of protein require much less land and emit far fewer GHGs than animal-based proteins, even if larger amounts (by weight) need to be eaten to get recommended amounts of protein. Figure 3.26 shows four high protein food sources and compares the land needed to produce the amounts required to satisfy a recommended daily allowance (RDA) of protein. Changing the mix of high protein foods in the diet – from animal-based to plant-based sources – can result in land use reductions and lower GHG emissions, while maintaining a healthy diet. Protein deficiency in most cases is not associated with a lack of meat but with not enough, or a poor variety of, other foods (Gonzalez et al., 2011).

The recent rise in veganism, which is estimated to have quadrupled in the UK between 2014 and 2018 (The Vegan Society 2019), has resulted in a much wider variety of meat alternatives being available. This makes it easier for anyone to increase the proportion of plant-based foods in their diet, and 34% of British meat eaters are reported to have reduced their meat consumption in 2018 (Petter 2019).

Different rice: We can reduce methane emissions from rice production by importing more of our rice from rice crops not grown in paddy fields. This can reduce field GHG emissions from rice production by up to 50% (Blengini and Busto, 2009).

Managing soil nitrogen: Close monitoring of crop nutrient needs with well-timed fertiliser application, along with the use of slow release fertilisers can reduce build-up of nitrogen compounds in the soil, which reduces nitrous oxide (N_2O) emissions (Elliot et al., 2014; Thapa et al., 2016). There is uncertainty over the estimations of N_2O from UK soils, many of which are being revised downwards. However, emissions depend highly on the type of fertiliser used and soil conditions (Bell et al., 2015; NAEI, 2019). It is estimated that with appropriate measures UK nitrous oxide emissions could be reduced by 19% (Thapa et al., 2016).

Nitrification inhibitors (NIs) NIs are chemicals which can be mixed into fertilisers – they slow the conversion of ammonium nitrogen to nitrate nitrogen, which has been shown to reduce nitrous oxide emissions (Ruser and Schulz, 2015; Thapa et al., 2016). There are currently some safety concerns over NIs as traces have been found in cows’ milk, which has led to a voluntary ban in New Zealand (Dairy Reporter, 2013). However, with further research, this is a potential technique for use in the UK.

What we should eat

On average (again, these rules don’t apply to each individual!) for a healthy diet, we in the UK could:

Eat less food: We (as a nation) need to rebalance our energy levels (eat the right amount of kilocalories each day). We can do this by eating less or becoming more physically active, or (most effectively) a combination of both. This will help lower the incidence of diet-related diseases in the UK (Lang and Rayner, 2007). Becoming more physically active can result from efforts to reduce GHG emissions from transport, like walking and cycling more (see *3.3.2 Transport*).

A better balance of foods: No food need be completely off limits, but foods do vary significantly in their nutritional qualities. The government offers advice on the right proportions of different types of foods in the form of an 'Eatwell Guide'. Based on these guidelines, we developed a number of criteria to assess a diet, including both 'essential' and 'ideal'. The essential criteria relate to things that have been proven to promote health and lower disease risk (see WHO, 2003 and Pan et al., 2012 for two examples). The ideal criteria are simply recommended for a healthy diet (Public Health England, 2016).

Essential criteria:

- A minimum of five portions of fruit and vegetables per day.
- About a third of the diet made up of starchy foods (for example, pasta, rice, bread and potatoes (not fried)).
- Very little intake of unhealthy foods high in fats, sugar and salt (HFSS).
- No more than 70g of red and processed meats eaten per day.

Ideal criteria:

- Wholegrain cereals (such as brown rice and bread) chosen where possible.
- More plant-based protein, such as pulses (lentils, chickpeas and baked beans). These are much lower in saturated fats than animal-based protein.
- More 'good fats' from foods like oily fish, nuts, seeds and vegetable oils, rather than 'bad fats' from foods like butter, cheese, crisps, sweets, biscuits, cakes and chocolate.
- Less battered and fried chicken than other forms of chicken.
- Skimmed and semi-skimmed milk chosen over whole milk.

Our scenario

It is completely feasible for the UK population to have an average diet that is both lower in GHG emissions and healthier. In fact, dietary changes required to make us healthier as a nation also reduce GHG emissions.

In our scenario we become more self-sufficient, importing only 17% of our food products rather than the current 42%. Most importantly, we do not import livestock products or feed for livestock (see *3.1 About our scenario*). This has the additional benefit of reducing demand for land in other countries, thus helping to prevent emissions from agricultural land use change overseas (though it can be difficult to exactly quantify the effect – see *3.10.3 Carbon omissions*).

Furthermore, in our scenario the UK can provide a healthy diet for a growing population not only without converting new land to agriculture but while actually reducing the amount of agricultural land needed in the UK. This has positive consequences for energy and fuel production, and for the protection and conservation of natural landscapes, as well as for GHG emission reductions (see *3.6.2 Growing energy and food* and *3.6.3 Capturing carbon*).

What does this average diet look like?

Again, it is important to remember that the average diet does not need to be followed exactly by everyone. Averages do not reflect the differences between recommendations for men and women, or between those of different age groups. Neither do they reflect the wide range of personal preferences or cultural choices. An average diet does, however, provide an idea of what might change in the consumption patterns of a population.

In our scenario, on average every person eats (in energy terms) about 2,280 kcal per day. Most of the energy we need comes from starchy foods like pasta and potatoes. We still allow up to 10% of the diet to be made up of HFSS foods, which is much less than in today's diet. However, this should be reduced to near zero for optimum health.

On average, each person's daily protein needs come from a weekly combination of:

- One large portion of red meat per week (a steak, pork or lamb chop, a portion of liver or a chicken fillet).

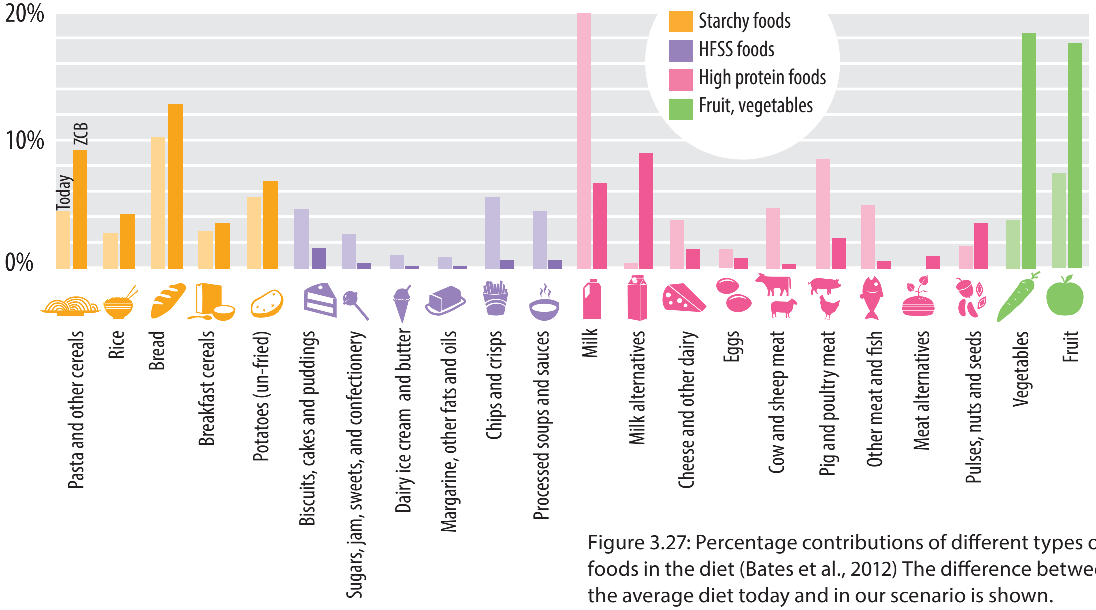


Figure 3.27: Percentage contributions of different types of foods in the diet (Bates et al., 2012) The difference between the average diet today and in our scenario is shown.

- Two further smaller portions of pig or chicken per week (for example, two rashers of bacon or a few slices of chicken).
- A fillet of fish.
- One portion of meat alternatives, such as tofu.
- Four portions of pulses (such as lentils, chickpeas and baked beans).
- Two eggs.
- Enough milk to cover breakfast cereal and cups of tea and coffee (with additional milk coming from alternatives, such as soya).
- A small portion of cheese and yoghurt.

The amount of protein this combination supplies (along with proteins in other foods, such as cereals and vegetables) provides an average intake of 72g, which is still higher than the RDA of 55g. The fact that our modelled values for protein still exceed the RDA demonstrates that, on average, protein insufficiency is unlikely to occur in our scenario.

There are almost four portions of vegetables per day (one portion is 80g) and three portions of fruit – four times more than we eat today. Figures 3.27 and 3.28 show how much of our diet is made up by each of the different food types and categories compared to the average UK diet now. This diet would greatly improve the nation's health, yet still allow some 'treats' such as cakes and alcoholic drinks.

What impact does this have on GHG emissions?

Agricultural emissions from food production in our scenario are reduced to 19.7 $MtCO_2e$ per year – a 43% reduction. This represents only agricultural emissions produced 'on the farm'. Emissions from food processing and distribution are energy related emissions and so are taken into account in *3.3 Power Down* and *3.4 Power Up*. The emissions reductions come from:

- Increasing nitrogen use efficiency to reduce field N_2O emissions by 19%.
- Reducing total food production, even though the population is expected to increase. The amount of food produced for each person over a year is reduced from 1.1 tonnes to 0.9 tonnes per person per year. This is mainly because half the current level of food waste is assumed, and each person eats only the amount of food that is recommended, thus reducing how much food we need to produce.

What about specific dietary needs?

Although our modelling looks at the broad nutritional adequacy of diets, nutrition is a very complex area of research. To get a better picture we would need to look at the provision of the whole range of nutritional needs, for example micronutrients (especially vitamin B12 and iron). It would also be good to look at the individual needs of various population sub-groups – we know that the elderly and children have different dietary requirements, for instance. Our scenario greatly improves the 'healthiness' of the average UK diet, and it is likely that individual needs could be catered for within the range available, but we have not specifically tested for this.

- Reducing the amount of beef and lamb products in our diet by 92%.
- Pig and chicken products (including eggs) are reduced by 58%.
- Dairy consumption is also reduced; products such as milk, cheese and yoghurt are reduced by 59%.

It is also worth noting here that agricultural GHG emissions from sugar are some of the lowest amongst all crops grown in the UK. If we only consider GHG emissions, we could eat a lot more sugar crops. Restrictions on these products in our scenario are for health and land use reasons.

What about removing meat from the diet altogether?

It is important to note that by far the easiest possible way of reducing emissions from food production would be for the entire population to eat no red meat and no dairy, and for optimum health almost no HFSS foods should be eaten. In the design of a new average UK diet, however, we attempt to balance nutritional requirements, land use restrictions and GHG emissions reductions with current taste preferences and so allow, on average, a lower amount of meat and some HFSS foods so that everyone can choose a diet they can enjoy.

What impact does it have on land use?

Figure 3.28 shows how the land we use for food production changes from the current UK situation to that in our scenario. In our scenario about 7.4 Mha of UK land is used for food production. The area of cropland required (4.6 Mha) is about the same as today. The demand for animal feed is reduced in our scenario; only about a quarter of our cropland is now used to grow feed. The rest of the cropland (74%) is used to grow food for us to eat. Of this:

- 1.6 Mha is used to grow starchy foods (cereals).
- 1.3 Mha is used to grow fruit and vegetables. Fruit and vegetable production increases fourfold. This is because we import less and produce more at home, and because how much we eat increases. The number of hectares used for glasshouses also doubles. This enables us to grow more salad vegetables (such as tomatoes, cucumbers and peppers).
- 0.6 Mha is used to grow pulses (such as lentils and kidney beans), soya and nuts to supply protein.
- 0.2 Mha for HFSS foods. As we eat less HFSS foods, the total amount of land dedicated to sugar and oils is reduced dramatically. As we can grow oil crops and sugar beet in the UK, however, all sugar and oil production is brought home, meaning that UK land dedicated to these products actually increases slightly.

The remaining imports are grown on cropland overseas – an estimated 1.2 Mha abroad is used to grow cocoa beans, rice and tropical fruits – things we cannot grow in the UK.

The amount of grassland required for livestock is only a quarter of the area used today (2.8 Mha) – some of which is intensively grazed, or cut for hay/ silage, and some of which remains as semi-natural grassland. The amount of grassland for meat production is reduced by 82% and the amount of land for dairy cows is reduced by 65%.

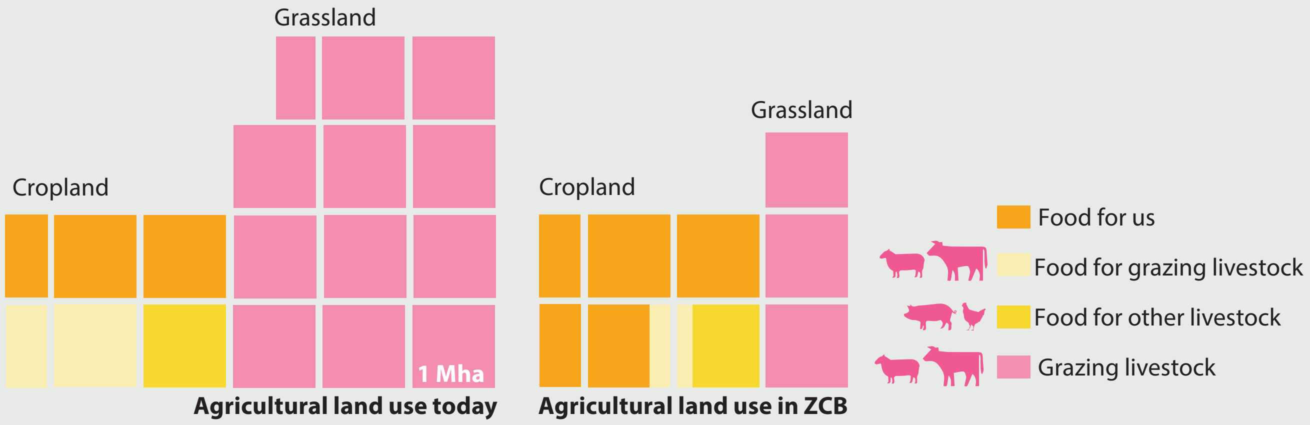


Figure 3.28: The area of cropland and grassland used for agriculture today (DEFRA, 2012) and in our scenario.

What impact does this have on the UK's health?

Since our proposed average diet is specifically designed to have a positive impact on the UK's health, this question is easy to answer: the suggested average diet in our scenario both satisfies health recommendations and meets nutritional requirements, and is based on government recommendations for a healthy food balance (see figure 3.29).

The dietary changes in our scenario are in line with nutritional recommendations for lowering levels of obesity and diet-related diseases, and so also improve the health of the UK population in this way.

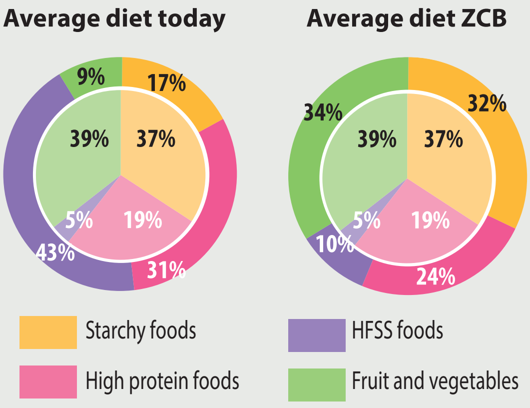


Fig 3.29: Government recommendations for a healthy balanced diet. Both today's average diet and the average diet in our scenario are shown (outside circle) relative to the Eatwell guide recommendations (central circle).

3.6.2 Growing energy and fuel

This section shows how we can grow various energy crops in the UK to provide biomass to cover energy demands that cannot be met with electricity.

Summary

- In our scenario, industry and transport require biomass for heat, and synthetic liquid and gas. Back up for our renewable energy supply also requires synthetic gas. This energy demand comes to 198 TWh per year (see *3.3 Power Down*).
- Around 230 TWh of biomass is required every year to meet these demands (see *3.4 Power Up*). 36 TWh of this biomass comes from waste (see *3.5.2 Waste*). The remaining 194 TWh comes from specifically grown energy crops.
- 4.2 Mha of land is converted to growing energy crops, most of which is currently used for grass for livestock.
- Second generation energy crops grown on this land with low inputs and without significant release of carbon from soils are Short Rotation Forestry (SRF), Short Rotation Coppice (SRC), Miscanthus (also known as 'elephant grass') and other mixed grasses.

- The yields of Short Rotation Coppice, Miscanthus and other grasses are expected to increase in the future, which helps produce more biomass from less land.

What's the problem?

Sections 3.3 *Power Down* and 3.4 *Power Up* show that some energy demands cannot be met by electricity. Some demands require fuels with high energy densities by weight and by volume – ones that are easily stored and transported because they are small and light. Fossil fuels are currently particularly useful in these cases. Alternatives that do not emit GHGs are required to provide all our energy requirements with zero carbon emissions.

In total, some 198 TWh per year of this type of energy is required in our scenario. These energy demands are:

- **Buildings and industry**: (section *3.3.1*) 41 TWh of biomass for heat per year (12 TWh for buildings, and 29 TWh for some industrial processes); 50 TWh of biogas or synthetic gas and 13 TWh of synthetic liquid fuels, also for industrial processes.
- **Transport**: (section *3.3.2*) 74 TWh per year of synthetic liquid fuel (40 TWh for aviation, 34 TWh mainly for heavy commercial vehicles and ships).
- **Balancing supply and demand**: (section *3.4.2*) about 20 TWh per year of biogas or synthetic gas as a back up fuel for our electricity supply.

This means we need to produce 87 TWh of synthetic liquid fuel, 41 TWh of biomass for heat, and 70 TWh of synthetic gas or biogas, but without emitting GHGs.

What's the solution?

Carbon neutral fuel replacements

Biomass from energy crops can be used to make fuels with identical (or sufficiently similar) characteristics to fossil fuels. However, we cannot solve the entire energy problem by growing biomass – there

Alternative farming techniques

There is a range of approaches to ecological farming. Permaculture and 'regenerative agriculture', for example, use an overlapping range of methods, such as no-till, high biodiversity, supply of nutrients by organic matter, use of nitrogen-fixing plants, inclusion of trees and shrubs, and involvement of local people as growers and consumers (Hathaway, 2016; Rhodes, 2017).

These methods of production have the potential to provide large benefits to local communities, increase the diversity of life on the farm, and optimise carbon storage in soils (known as 'sequestration') (Hathaway, 2016; Rhodes, 2017; Lacanne and Lundgren, 2018). In many cases though, more research is needed. For example, provision of food by perennial (long-lived) plants can increase carbon sequestration in non-ploughed soil and in the biomass of trees (Lorenz and Lal, 2014). However, these plants, such as nut trees, perennial grains and beans have received little attention from breeders compared to our staple annual crops (Crews and Cattani, 2018; Molnar et al., 2013).

A cornerstone of many of these methods is the addition of nutrient-rich organic material to the soil, in preference to the use of manufactured fertilisers. Providing nutrients in organic matter can improve soil structure and functioning while feeding crops, as well as sequestering carbon, though careful control of the rates and quantity of nitrogen application are required in order to minimise runoff, leaching and nitrous oxide emissions.

Availability of organic matter is a key limitation of these methods (Poulton et al., 2018). Whilst many regenerative agricultural systems include grazing livestock and make good use of the resulting manure, the benefits of doing this will not necessarily negate the methane emissions from livestock in the system. An alternative source of organic matter is green manure, but this requires a significant land area to grow. Application of organic matter as fertiliser is more complex than the use of manufactured fertiliser (Powlson et al., 2011; Poulton et al., 2018), and more research, improved methods of measuring soil nutrient levels and guidance on application rates is required in order for the full benefits of using organic matter to be realised (Carter et al., 2014).

is simply not enough land. In fact, to provide enough biomass to satisfy all our energy demands today we would need an area at least twice the size of Britain.

That said, the use of some biomass is essential because it provides storable energy, and can provide gaseous and liquid fuels through various chemical processes. Though biofuel and biogas can be created from biomass directly, *3.4.2 Balancing supply and demand* and *3.4.3 Transport and industrial fuels* show that biomass can be combined with hydrogen to produce synthetic gas and liquid fuels, which increases the amount of fuel produced per unit of land. Though there are significant losses in these processes, the hydrogen required can be made using surplus electricity (at times of high supply and low demand), meaning we do not have to have additional infrastructure to produce it. These chemical processes are called the Fischer-Tropsch (FT) process (which produces synthetic liquid fuels), and the Sabatier process (which produces synthetic gas).

These synthetic gas and liquid fuels are 'carbon neutral' (see section *3.4.2 Balancing supply and demand*). The CO_2 emitted by burning them was initially taken in by the biomass as it grew, and the electricity used is produced from renewables. Over the long-term there is no net increase of GHG emissions in the atmosphere.

Energy crops in the UK

Various types of energy crops are suitable for growing in the UK. They vary in how much biomass they produce (the 'yield'), and how suitable they are for various land types. Some energy crops need very good quality cropland to grow on, which is limited and usually already used for growing food. For example, **first generation biofuels** are made from wheat, corn, sugar crops and vegetable oil – all of which could alternatively be eaten. **Second generation biofuels**, in contrast, are from 'woody' plant material and non-food grasses, which can be grown on grassland that is currently used to grow grass for livestock.

Why agriculture needs biodiversity

Biodiversity describes all the genes, species and populations of plants, animals, fungi, bacteria and other organisms in any given area. So the more species and genetic diversity, the higher the biodiversity. We often don't notice the work that ecosystems do until they are weakened or gone, but they provide many 'services' to human society. These include providing air to breathe, pollinating our crops, cleaning water, cleaning air, making it rain, reducing flooding, providing wood and, of course, food (Cardinale et al., 2012). Without biodiverse ecosystems, human civilisations would not last. The threats to agriculture from climate change and biodiversity loss are intertwined. For example, a changing climate threatens the survival of species (Bellard et al., 2012), and loss of biodiversity reduces resilience to soil erosion and soil carbon loss (Wiesmeier et al., 2019). A wide range of plants and animals, including invertebrates and soil microbes, is essential for the functioning of agriculture (Mcbratney et al., 2014; FAO, 2019). The following are two examples of this:

Predators of pests

The organisms we think of as pests are a normal part of the ecosystem that have increased in number in response to a food source (crops) and a lack of predators. A diversity of predators ensures that if one is scarce, another will be available. Without this, it is harder to protect our crops from attack. Use of pesticides can supplement the everyday control of pests by predators, but this can be counterproductive, as pesticides can wipe out the predators as well as pests (Ndakidem et al., 2016).

Ecological soil functioning

Soil biodiversity enables processes such as nutrient cycling and erosion prevention. For example, fungi and invertebrates process plant and animal remains, creating a healthy soil structure; fungi also improve nutrient and water uptake in plants; and microbes convert nitrogen into plant available forms (Whalen and Sampedro, 2010).

To protect our agricultural production, we urgently need to preserve and increase biodiversity. Most proposed land use changes in the Zero Carbon Britain scenario create more biodiversity, for example, converting intensive grassland to woodland. However, great care is needed to ensure biodiversity is not lost from highly biodiverse land uses, such as semi-natural grasslands.

Yields of some energy crops are expected to increase in the future due to plant breeding, but this requires immediate high investment in research (Clifton-Brown et al., 2019; Searle and Malins, 2014). In addition, the stocks of high yielding plants need to be increased to allow for planting on a large scale, and methods of production must be efficient in order to achieve high yields with low fertiliser and water inputs (Clifton-Brown et al., 2019; Alexander et al., 2014; Sims, 2006).

The main **second generation** energy crops are as follows (Biomass Energy Centre, 2011):

Short Rotation Forestry: Short Rotation Forestry (SRF) is the closest energy crop to conventional forestry and uses fast-growing native tree species, such as birch, alder and sycamore. These species grow well on many different qualities of land. These trees grow much faster than many conventional timber producing species – SRF is usually cut back after 2-4 years, or felled after 8-20 years of growth, and then replanted. However, this is a much slower 'turnaround' than many other energy crops, and yields generally aren't as high.

The biomass produced from SRF can be burned directly to produce heat, or in Combined Heat and Power (CHP) systems.

Short Rotation Coppice: Short Rotation Coppice (SRC) is usually made up of willows and poplars, which are 'coppiced' after a few years. The main woody material of these plants is harvested, but the tree stumps and roots remain and regrow. The whole coppice needs replanting only every 30 years or so. SRC grows well on various different qualities of land, and yields are expected to increase in the future.

Biomass from SRC is very flexible in its use – it can be burned directly for heat, used to make biofuel or biogas directly, or to produce synthetic biogas or synthetic liquid fuels.

Miscanthus: Miscanthus is a tall grass – sometimes known as 'elephant grass' – that is harvested every year to grow back from the roots the following year. As a dedicated energy crop, Miscanthus has high yields, which are expected to increase substantially in the future.

Miscanthus can also be burned to provide heat, can be used to make biogas or biofuel directly, or to produce synthetic gas or liquid fuels.

Other grasses: Other grasses can also be used for energy production. They are harvested 'green' (with a high moisture content) and are best used to produce biogas through anaerobic digestion (AD). They can be grown on various different land types, and the most suitable species can be chosen depending on local conditions. Growing mixed species can help improve the biodiversity of the area.

Our scenario

In our scenario we try to match the needs of our energy system with the needs of our land – that is, we try to match the energy crops to the most suitable types of land that are 'freed up' when we reduce the amount of grass grown for livestock. This helps minimise carbon lost from soils, which can occur when we change the way we use our land (see *3.6.3 Capturing carbon*), but also limits the amount of land we can use to grow energy and fuel.

Some land currently used as temporary agricultural grassland (around 1.2 Mha) continues as such, but some is used for mixed grasses grown as an energy crop. Most of the land made available to grow energy crops is currently intensive grassland (about 2.5 Mha). This good quality grassland is used to obtain high yields of Miscanthus and SRC. Some of this land is also used to grow SRF, together with a small amount of semi-natural grassland (around 0.5 Mha), which also becomes available because it is no longer grazed.

We assume that yields of grasses, Miscanthus and SRC increase so that top yields today become more commonplace in the future. SRF is expected to produce similar yields to those today.

Figure 3.30 summarises the area required for these different crops, how much biomass is produced and what this biomass is used for in our scenario. Biomass from mixed grasses is used to produce carbon neutral synthetic gas and biogas by anaerobic digestion; biomass from Miscanthus and some SRC is used to produce carbon neutral synthetic liquid fuel; and the remaining biomass from SRC and SRF biomass is used for heat in buildings and industry.

Losses in the conversion processes from biomass to synthetic gas and liquid fuels mean that a total supply of 230 TWh per year is required to meet the 198 TWh of demand (see *3.3 Power Down*). The annual yield of all the energy crops in our scenario is about 194 TWh per year. In addition, the equivalent of 36 TWh of biomass is produced every year from sewage, manure, and agricultural and crop residues – straw from cereals, for example (see *3.5.2 Waste*). This is used to produce biogas through anaerobic digestion (AD). The residue from AD is reapplied to soils to recycle the nutrients and decrease the amount of fertiliser required.

In total, the biomass produced (from energy crops and waste) is used to supply energy in the following forms, to cover the various demands:

- 115 TWh per year of biomass for the production of synthetic liquid fuels.
- 74 TWh per year of biomass for the production of biogas and synthetic gas.
- 41 TWh per year of biomass for heat.

3.6.3 Capturing carbon

This section describes how we can use and manage land to reduce associated emissions, and increase the amount of carbon we capture. It shows that the total potential is limited, but that we can balance the remaining GHG emissions in our scenario

Summary

- In our scenario, the remaining effect we have on climate change is equivalent to about 47 $MtCO_2e$ per year, despite emissions reductions of about 91% from 2017.
- By doubling the forested area of the UK, harvesting more timber to use in buildings and infrastructure, restoring 50% of our peatlands, and converting waste wood either into biochar or leaving it in 'silo stores', we capture the required 47.8 $MtCO_2e$ per year (on average), making our scenario net zero carbon.
- It is possible that planting more forest, or restoring more peatland could capture more carbon, though the land available means there are limits to this. We must be careful not to release carbon from soils in the process of land use change.
- These methods should last long enough (about 100 years) for us to develop new technologies or ways of doing things that replace the activities in our scenario that still emit GHGs.

What are the effects of growing energy crops?

Energy crops require very little fertiliser. This is partly due to their being made up of a high level of energy dense material, and very little protein. In addition, most are perennials (live for many years), so retain their root systems overwinter. In autumn, nutrients are drawn down into the roots and stored for the following year's growth. The ability to grow on poorer quality land less suited to food production is a specific breeding target for energy crops, so that food and fuel are not in competition for land use (Sims, 2006).

A crop harvest can also be timed so that nutrients in the plants return to the soil and, in the main, only plant material containing carbohydrate is removed. By-products from burning biomass and the residue left after producing biogas by anaerobic digestion can also be returned to the soil to recycle the nutrients, further decreasing fertiliser requirements. However, more research on the cycling of nutrients such as potassium and phosphorus will increase the sustainability of these systems.

It is important that proposed changes to land use are assessed for their impact on wildlife. Miscanthus and Short Rotation Coppice can provide good habitats for wildlife in comparison with cropland (Haughton, 2009). However, land used for growing energy crops must be managed responsibly in order to promote biodiversity and regulate water use.

What's the problem?

Despite GHG emissions reductions of about 91%, our scenario still has an impact on climate change equivalent to 47 $MtCO_2e$ per year – emissions of 14.8 $MtCO_2e$ from the non-energy emissions from industry, businesses and households; 5.1 $MtCO_2e$ from waste management; 19.7 $MtCO_2e$ from agriculture; plus the additional impact of flying equivalent to 7.4 $MtCO_2e$.

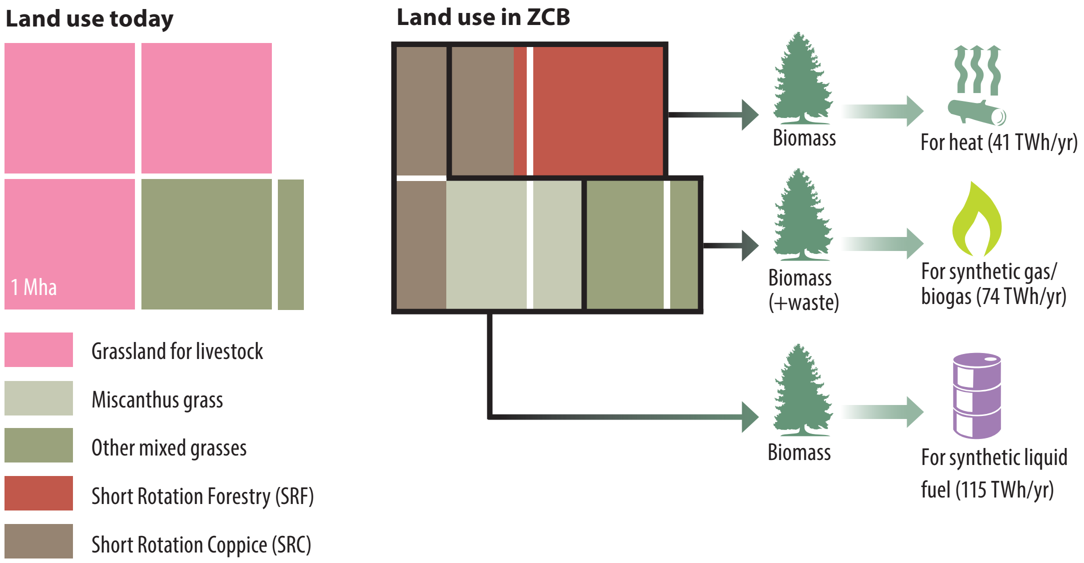


Figure 3.30: Area of land used today (DEFRA, 2012) that is used for energy crops in our scenario, the types of crop grown, and the amount and use of the biomass produced.

To become net zero carbon, we must balance this impact by capturing carbon every year.

Capturing carbon today

Carbon is being captured in the UK already:

1. New forests and grasslands take carbon into soils, trees and grass as they grow (Sedjo and Sohngen, 2012).
2. Existing forests in the UK cover about 2.9 Mha (12%) of UK land. They were capturing over 10 $MtCO_2e$ per year in 2010 (Read et al., 2009).
3. Harvested wood (timber) stores carbon when used in construction – for example, in timber-frame buildings (ibid.).

In 2017, a total of 29.4 $MtCO_2e$ was captured (see figure 3.31), according to UK GHG accounts (BEIS, 2019). However, this is less than 6% of the UK's total GHG emissions, and the current carbon capture processes will not last forever:

1. Relatively little new forest has been planted over recent decades (Atkinson and Townsend, 2011).
2. As existing forests mature, they will capture less carbon year-on-year – these carbon 'stores' will eventually fill up (Smith, 2010). By 2020, only about 4.6 $MtCO_2e$ will be captured each year (Read et al., 2009).
3. The majority of British conifer forests are due for felling in the next 10-20 years (ibid.). UK timber supplies, which store carbon in wood products, are projected to decrease (Forestry Commission, 2010).

Furthermore, 18.7 $MtCO_2e$ was emitted from parts of the UK landscape in 2017. Therefore, only 10.7 $MtCO_2e$ was captured on balance (BEIS, 2019) – see figure 3.31. Our management of the UK landscape is contributing to the problem and will continue to do so without changes:

- CO_2 was emitted from soils and plants by urban expansion into forest and grassland environments (BEIS, 2019). These emissions are discussed in 3.5 *Non-energy emissions*.
- Conversion of forest and grassland to cropland, and the management of all agricultural land

(both cropland and grassland) also contributed to GHG emissions (discussed in *3.6.1 Agriculture, food and diets*).

- UK peatlands, including (though not exclusively) 'wetlands' in figure 3.31 (some peatlands form part of cropland and grassland habitats) are currently estimated to emit almost 3.7 $MtCO_2e$ per year (Worrall et al., 2011). This is because they are drained for agriculture or forestry – peat is removed to be used as fuel or fertiliser; they are burned, over-grazed, eroded or wasted (ibid.; Bain et al., 2011). Less than 20% of UK peatlands are currently undamaged (Littlewood et al., 2010).

Balancing GHG emissions today

It is not possible to balance all our GHG emissions today simply by capturing the same amount of carbon as we emit. There are limits to how much carbon can be captured every year. The Intergovernmental Panel on Climate Change (IPCC) notes that 'only a fraction of the reduction [in emissions] can be achieved through sinks [that capture carbon]' (IPCC, 2007).

We would need a forest at least double the size of the UK to balance all our current GHG emissions (Broadmeadow and Matthews, 2003). We have to reduce emissions alongside capturing carbon.

Furthermore, even this forest would not capture carbon forever – the store would eventually 'fill up'. Most methods of capturing carbon do not last forever and are therefore simply 'buying us time' to replace activities which emit GHGs with alternatives that do not (Smith, 2008).

What's the solution?

The carbon cycle naturally contains a number of carbon 'flows' and 'stores'. Flows occur when carbon is added or removed from a store; stores can be built up or emptied in this way – the aim of carbon capture methods is to build up stores.

Some stores can, however, get 'full up'. How much carbon these can ultimately hold varies between different stores. Figure 3.32 shows a comparison of different UK carbon stores, though they are not necessarily 'full' yet. How fast carbon can flow into and out of stores also varies.

As a general rule, it is much easier (and quicker!) to empty a store than to build it up. The fossil fuels we are currently burning are stores of carbon that have taken hundreds of millions of years to build up (Smith, 2008). We are 'emptying' them over just a few hundred years (Le Quéré et al., 2016).

Figure 3.33 shows various stores and flows of carbon. The aim here is to build up stores of carbon, or promote continuous flows to long-term carbon

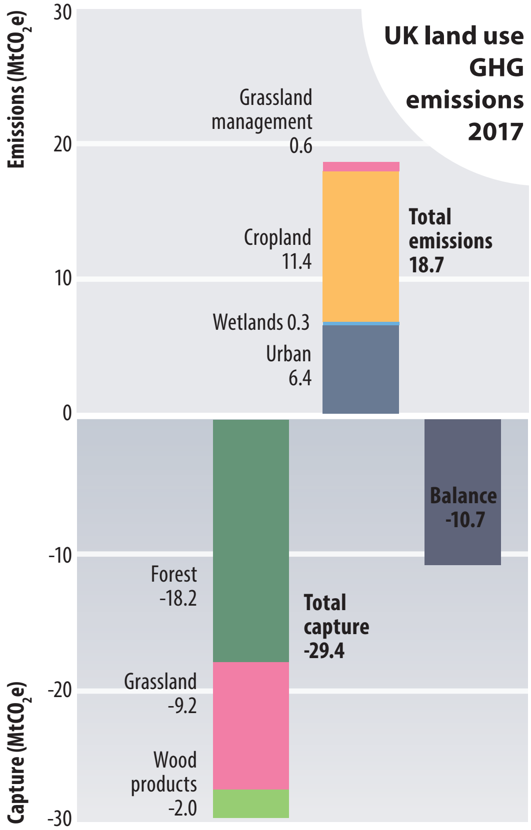


Figure 3.31: UK GHG emissions (due to land management and land use change) and carbon capture in the UK in 2017 (BEIS, 2019). Emissions due to the conversion of land to cropland and urban areas are discussed in *3.6.1 Agriculture, food and diets* and *3.5 Non-energy emissions*.

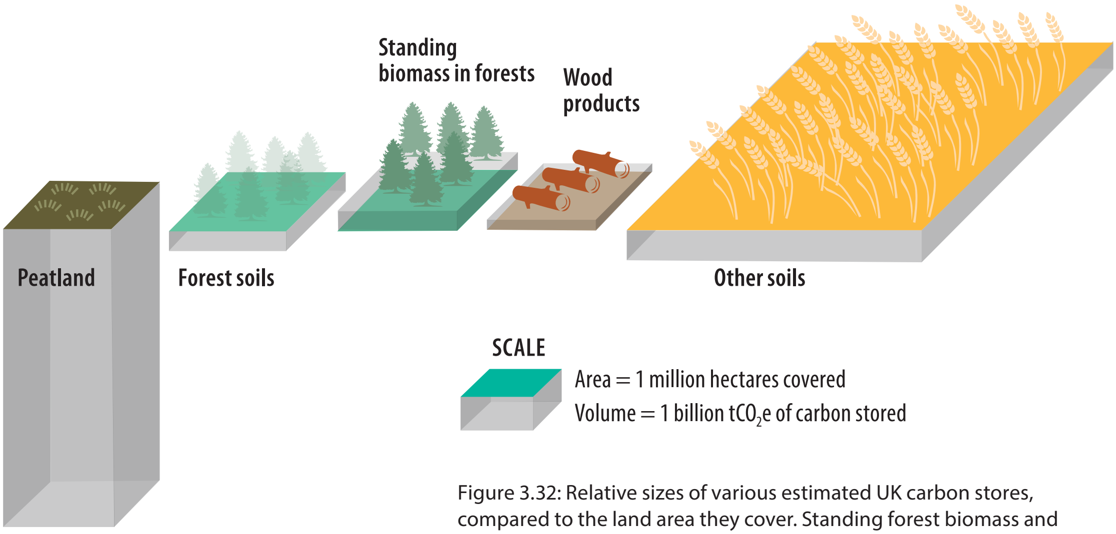


Figure 3.32: Relative sizes of various estimated UK carbon stores, compared to the land area they cover. Standing forest biomass and wood products show the carbon store above the ground level.

stores. This can be done in a number of ways that offer:

- **One-off opportunities** where the store may become full.
- **Long-term opportunities** where carbon can continuously flow into a store.

Interestingly, the long-term opportunities usually include the very first stage (of the incredibly long process) involved in creating fossil fuels – oil, coal and gas all originated from plant and animal material. Most carbon capture processes tend to be slow, or need to be implemented on large scales to have substantial year-on-year carbon capture potential.

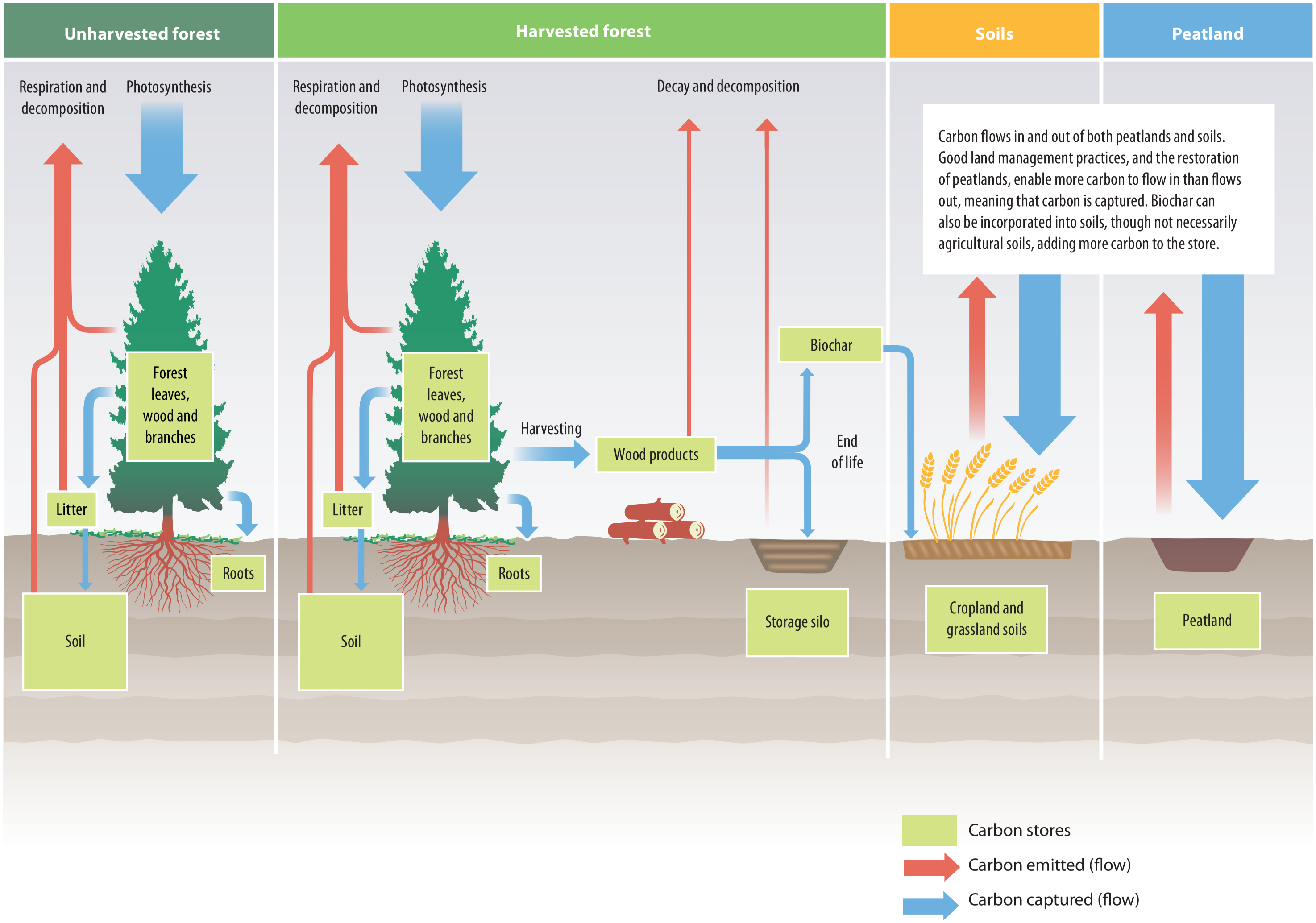
One-off opportunities

Different techniques of capturing carbon can last for different amounts of time before a 'store' becomes full – from a few decades to a hundred or so years. These are:

Planting forests: Forests capture carbon by taking in CO_2 during photosynthesis and releasing carbon naturally through respiration (Broadmeadow and Matthews, 2003). As a new forest grows, more carbon is captured than is released every year – it is stored in the leaves, roots, wood and branches. Some of this is released as parts of the tree die, but some remains in the tree trunk, roots and branches ('standing biomass'), or is transferred to the soils – another carbon store (ibid.). Eventually, when the forest is mature, the carbon captured every year is roughly equal to the carbon emitted over the same period, and thus the forest carbon store is full.

Planting new forest increases carbon stores over a period of 50-150 years depending on tree type. An unharvested forest can hold (or store) significant amounts of carbon once mature – up to about 1,400 tCO_2e per hectare in standing biomass (Morison et al., 2012). Planting forests can also help increase biodiversity, improve flood management (Atkinson and Townsend, 2011) and give us more natural spaces to enjoy.

Harvesting and using wood: When wood in a forest is harvested (clear-felled, or thinned) it makes space for new trees to grow and more carbon to be captured (Broadmeadow and Matthews, 2003). However, for this to happen the forest must be sustainably managed (replanted when felled, protected from damage to soil or water, and subject to good forest management). Harvesting wood from non-sustainable forests simply empties their carbon



Carbon flows in and out of both peatlands and soils. Good land management practices, and the restoration of peatlands, enable more carbon to flow in than flows out, meaning that carbon is captured. Biochar can also be incorporated into soils, though not necessarily agricultural soils, adding more carbon to the store.

Figure 3.33: Carbon stores and flows. Adapted from Dewar and Cannell (1991) and Morison et al. (2012).

stores, which emits GHGs into the atmosphere (Read et al., 2009).

Carbon is stored in both the standing biomass (tree trunks, roots and branches) and in the harvested wood. Once the forest is established, up to an average of 460 tCO_2e per hectare is held (or stored) in standing biomass, and 150 tCO_2e per harvested hectare when converted to wood products (Morison et al., 2012). How much is in each category depends on how quickly the trees grow and how regularly they are harvested – the balance between the two stores can be different at different points in time. It generally takes between 50-100 years to accumulate the carbon – less time than unharvested forests, which are left longer to mature.

The ultimate size of the carbon store in harvested wood products depends on how many things can be made out of these materials and how long they last. Currently about 80 $MtCO_2e$ is estimated to be stored in wood products in buildings and infrastructure in the UK (Read et al., 2009). However, as a net importer of timber, the UK demand for wood products is much larger than our present homegrown supply (Broadmeadow and Matthews, 2003). This affects how much of these wood products count as 'capturing carbon' in UK GHG emissions accounts (see lower box on page 103).

UK demand for wood products, regardless of the source, could be much higher than it is today. We can use much more wood and other plant-based materials such as hemp and straw in construction and retrofitting. These kinds of buildings are currently unconventional, but timber-frame buildings are becoming more widespread – 15-28% of new builds in the UK are currently timber-framed (CCC, 2019) compared to only 7% in 1997 (Read et al., 2009). At present over 1 $MtCO_2e$ is stored in building materials per year (CCC, 2019). However, if as well as timber-frame building we use plant-based materials such as hemp and straw as much as possible, employing what are currently considered unconventional building methods, it is estimated that a massive 22 $MtCO_2e$ (net total of 'materials in' minus 'materials out') could be added to buildings and infrastructure in the UK every year (Sadler and Robson, 2013). This would mean big changes to the construction industry, and to the types of buildings we are used to seeing (see box below).

Replacing conventional building materials like steel with plant-based materials, such as wood, will sometimes mean more material is required to give the same strength. However, this is still likely to mean lower GHG emissions in the production of the material (see *3.2.1 Buildings and industry*).

Changing land use and agricultural management of soils: Soils currently store huge amounts of carbon in the UK – about 18,000 $MtCO_2e$; much more than forests, but spread over a much wider area – see figure 3.32 (Ostle et al., 2009). Good land management can increase the amount of carbon in soils (West and Six, 2007), but most 'fill up', too. How much carbon soil can hold depends on what it is used for, and what the climate is (Ostle et al., 2009). This means that climate change poses real risks for soil carbon stores in the UK (ibid.).

It also means that changing land use can involve a trade-off. For example, if we were to plant forest or energy crops on some semi-natural grasslands, carbon would be captured by the trees as they grew but some would be lost from soil stores (Bell et al., 2011). Generally, semi-natural grassland soils hold more carbon than forest soils, while forest soils can hold more carbon than intensively grazed or fertilised grassland and cropland soils (Ostle et al., 2009). Therefore, converting semi-natural grassland or forest to cropland or to intensively grazed or fertilised grassland should be avoided, while conversion to less intensively managed or semi-natural landscapes should be encouraged.

Whether an agricultural soil is actively capturing or releasing carbon largely depends on how it is managed (ibid.) and what the state of the soil is to begin with (Groenigen et al., 2011). However, we can do many things to encourage soil carbon capture in agricultural soils (and those that produce energy crops):

- On some grasslands we can grow a wider variety

of plant species, which improves soil functioning and animal health (Gregorini et al., 2017). Better management of fertiliser use and grazing can result in up to 0.9 tCO_2e per hectare captured every year (Bellarby et al., 2013; Dawson and Smith, 2007).
- On some cropland we can reduce or stop ploughing, apply manure, slurry, sewage sludge, straw or compost, and better manage fertiliser and water use, resulting in up to 3.12 tCO_2e per hectare captured every year (Smith et al., 2000; Smith et al., 2008).

It is important that these practices are maintained, as otherwise soils start releasing carbon again.

Long-term opportunities

Peatland: UK peatlands vary from raised bogs and upland blanket bogs to lowland peat-rich soils, and currently store a huge 19,300 $MtCO_2e$ (Ostle et al., 2009) – more than all the carbon stored in all other soils in the UK together.

When lowland peats are used for arable cropping, they emit CO_2, and peatland in England is thought to be the UK's largest source of CO_2 from the land sector (Evans, 2016) with emissions of 39 tCO_2e per hectare per year (CCC, 2019). Raising of the water table to within 0 to 10 cm of the soil surface can reduce emissions to net zero (Evans, 2016). Rewetting, however, can cause increased methane and nitrous oxide emissions, so care needs to be taken when rewetting peatlands to ensure that other GHGs do not counteract the reduced CO_2 emissions (Evans, 2016).

There are about 2.3 Mha of blanket and raised bog in the UK. Peat bogs don't behave like other types of soil. They do not get 'full up' for a very long time. Under the right (waterlogged) conditions, they get deeper, and so continue to grow for many metres. In the UK, some peatlands have been capturing carbon for over 10,000 years (Bain et al., 2011). This store can only be maintained, and increased, if we look after peatland. Healthy peatbogs can capture roughly 1.1-2.6 tCO2e per hectare every year (Bain et al.,

How can we use more plant-based materials in buildings and infrastructure?

Although fairly conventional building techniques (timber-frames and cladding, for example) across the building stock of the UK would increase our store of carbon substantially, plant-based materials can be used a lot more in construction in other ways. Hemp and lime offer good alternatives to conventional plaster and render, and can also be used for floors or insulation. Straw can be used in construction, too. If we use more of these materials, however, they must be sustainably sourced and made into biochar or put in silo stores at the end of their lives so that carbon is not re-released into the atmosphere.

What's important about importing wood?

About 85% of the timber we use in the UK is currently imported (Broadmeadow and Matthews, 2003). Using 'production' GHG emissions accounting, we do not take responsibility for carbon emissions *produced* on our behalf elsewhere in the world (for the 'stuff' we import), and so we cannot claim the benefit of carbon *captured* on our behalf either – trees grown to produce the timber and wood products we import. If we were to look at our 'consumption' emissions, however (see *3.10.3 Carbon omissions*), this imported timber would count towards our capacity to capture carbon. We estimate that current imported timber would constitute roughly an additional 22 $MtCO_2e$ captured per year, as long as the wood products came from sustainably managed sources.

Similarly, when looking at the 'end-of-life' of wood products, only those originally from timber grown in the UK 'count'. Again, if we were to look at consumption emissions, we could count captured carbon in imported products that were eventually made into biochar or put in 'silo storage', too – potentially another 20 or so $MtCO_2e$ of carbon captured every year.

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2011), but damaged peatland must be rehabilitated in order for it to capture this amount of carbon. This might involve changing livestock grazing, burning practices, or blocking ditches to 're-wet' drained peatland, though must be carefully managed. Small-scale restoration can have an effect in as little as five years, whereas much larger interventions can take between 20-50 years to take full effect (ibid.).

Recent research is showing that carbon losses from UK peatlands are higher than previously thought. By 2020/2021 new government statistics are likely to show losses from UK peatland of up to 18.5 $MtCO_2e$ per year (CCC, 2019). However, using current data, if we restored all of our peatland, we could avoid emitting 3.7 $MtCO_2e$ every year, and instead capture roughly 4.2 $MtCO_2e$ every year (Bain et al., 2011). This would also improve biodiversity and water quality (ibid.).

Biochar: Biochar is essentially charcoal made under carefully controlled conditions. By burning carbon-rich compounds in the absence of air (pyrolysis), the volatile and non-carbon components are burnt off, leaving much of the carbon behind as a solid 'char'.

This has particular properties that make it valuable as a means of storing carbon, especially in the soil. It has been found in stable condition after thousands of years (Hammond et al., 2011), making biochar a potentially useful tool in carbon sequestration and storage. Conversion of biomass to biochar for agriculture can be regarded as carbon-negative (Smith, 2016), i.e. the process takes more carbon from the atmosphere than is emitted in manufacture, though the capacity of biochar to sequester carbon globally might be modest (Schlesinger and Amundson, 2019).

Biochar can be made from any readily available carbon source, e.g. wood and agricultural residues such as rice husks, nut shells and beet tops, and the quality of this source material (feedstock) partly determines the properties of the biochar. For example, if the feedstock is nutrient-rich, so will be the char. By-products of pyrolysis include a biogas and a tar, both of which have useful applications.

Can rewilding help store carbon?

The habitat restoration and land use changes indicated in this chapter will result in significantly increased stores of soil carbon. It has been argued that restoration of certain habitats including megafauna (rewilding) would lead to additional soil carbon benefits, (Rewilding Britain 2019), via impacts on plant diversity, frequency of fires, the redistribution and cycling of nutrients and effect on soil microbes (Cromsigt et al., 2018; Bakker and Svenning, 2018), Whilst this may be proved to be true for certain types of habitat, this cannot be taken to mean that specific species reintroduction will have similar impacts in UK habitats.

Carbon accumulation in soils – how much and by when?

In theory the potential to capture carbon in soil is enormous. The global '4 per 1000: Soils for Food Security and Climate' initiative proposes that if soil carbon capture increased to 0.4% per year globally it could offset two thirds of annual anthropegenic emissions, (4p1000 2018; Chabbi et al., 2017).

For the UK, this makes restoration of peatland a high priority. Other soil types are more limited than peat in their ability to accumulate carbon, which varies according to the soil type and how much carbon it already contains. However, by using soil maps we can maximise carbon storage by treating soils in different locations according to their capacity to accumulate carbon. Some practical problems need addressing such as a lack of straw or compost for addition (Poulton et al., 2018). However, good agricultural practice, such as preventing soil erosion (and therefore carbon loss) should be adopted on all farms. To be on the safe side we don't include any long-term soil carbon capture, but there may be substantial opportunity here in the future.

Applied to agricultural soil, biochar has been found to increase water retention in dry soils and bind to both of the major nutrients, phosphorus and nitrogen, making them available to crops in an increased soil microbial biomass, increasing yields (Abid et al., 2017; Liu et al., 2016; Pandey et al., 2016).

Converting landfill to silo storage: Presuming every effort is made to capture GHGs from landfill, and that landfill sites are converted to 'storage silos' (see 3.5.2 *Waste* for details), a proportion of all wood products in landfill remains for thousands of years (Zeng, 2008; IPCC, 2000). This proportion, therefore, represents captured carbon (Augenstein, 2001).

One estimate states that UK grown wood products that are currently landfilled capture roughly 3.6 MtCO$_2$e of carbon every year (Fawcett, 2002). This does not include any imported timber that might also end up in landfill (see lower box on page 103). If we grow more of our own timber and use more in construction, it is likely that more will end up in storage silos – even if it were reused or recycled first – again meaning more captured carbon.

Our scenario

The ways in which we capture carbon in our scenario last for about 100 years – long enough, we think, to be able to develop other solutions for the remaining GHG emissions in the UK. The captured carbon represents an average over this time, though it may change from year to year. In future we should also aim to export as much food as we import, (see *3.10.3 Carbon omissions*), so that on net balance we are taking responsibility for all our emissions.

The land use changes in the scenario will improve UK biodiversity. However, the threat to our food security and human wellbeing due to biodiversity loss will need addressing further with implementation of land management best practices.

In our scenario we keep land use the same as far as is possible – particularly not converting further land to cropland and losing less land to urban areas, as this is currently where the majority of GHG emissions in land use change occur (see 3.5 *Non-energy emissions* and *3.6.1 Agriculture, food and diets*).

Although we do not count any long-term carbon captured by soils (see box on page 105), we do look at what happens in the short-term – carbon captured or released by planting woodlands and energy crops (see *3.6.2 Growing energy and fuel*) and by improved management of agricultural land. It is important that we do not lose carbon here, even in the short-term. Overall, about 260 MtCO$_2$e is captured in soils due to land use changes (carbon is lost in some areas, but more is captured in others) and better management, plus by improved management of agricultural land practices (about 13 MtCO$_2$e per year for 20 years). Whilst this is no trivial amount it will not continue in the long-term – after (approximately) 20 years the soils become pretty 'full' and only very small amounts of carbon will be captured. These measures can, however, help a small amount in our transition to a zero carbon Britain (see *3.8.1 ZCB and the UK's*

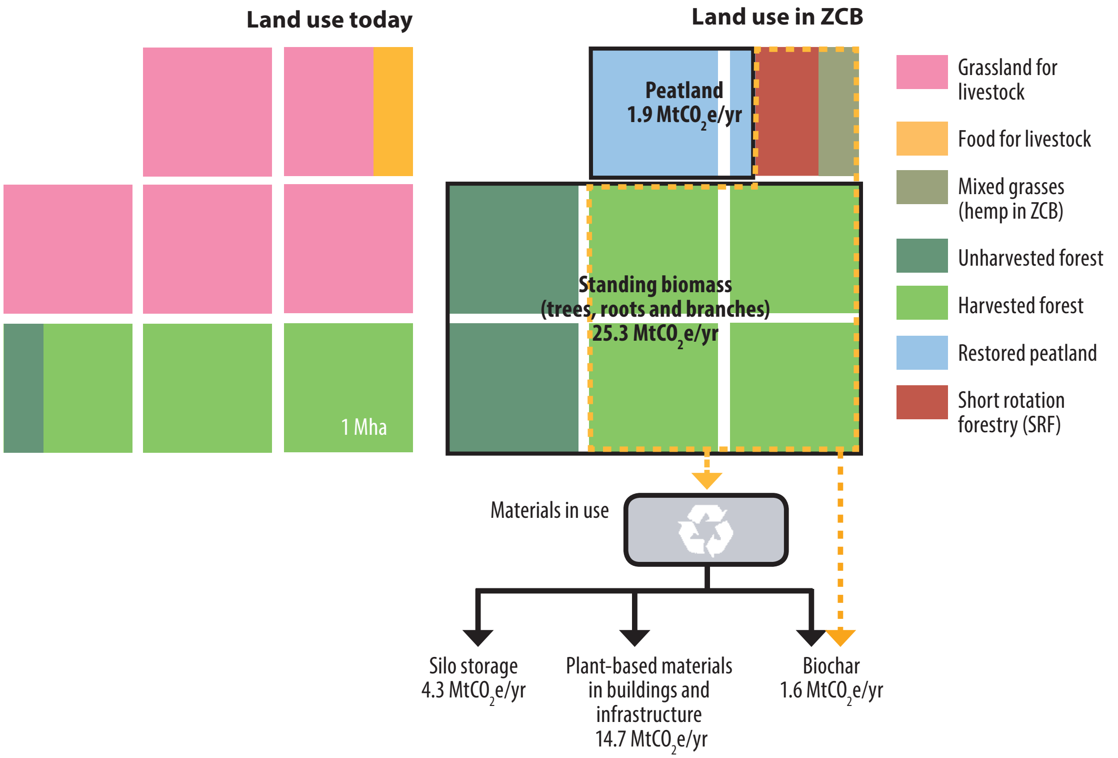

Figure 3.34: Area of land used for capturing carbon in our scenario, the methods, and how much carbon is captured as a result.

carbon budget). They are also likely to have benefits for the quality and productivity of soil.

To capture the carbon equivalent to our remaining impact on climate change (about 47 MtCO$_2$e per year) we:

- Keep all of the forests that we have currently (about 2.6 Mha of harvested forestry and 0.3 Mha of unharvested forest), and manage them sustainably – replanting trees, and looking after ancient woodlands.
- Use some intensive grassland and semi-natural grasslands 'freed up' by reduced levels of livestock to:
  - Plant an additional 3.1 Mha of forest (doubling the forest area in the UK). 1.7 Mha of this is unharvested – simply there for us to enjoy and to enhance biodiversity, and 1.4 Mha is harvested for wood. This makes a total of 24% of the UK land forest, closer to the EU average of 37% (Atkinson and Townsend, 2011).
  - Plant about 0.7 Mha of Short Rotation Forestry (SRF) to be harvested for wood for materials.
- Plant hemp on 0.3 Mha of land previously used for fodder crops for use in buildings and infrastructure.
- Do not further degrade any of the UK's peatland, but instead restore about 50% (about 1.15 Mha).

A small fraction of wood (5%) goes to making biochar. Most of the wood products, however, go into construction, and hemp is also used in buildings and infrastructure. Because of the additional use of UK grown timber, there is additional construction and demolition wood waste in the UK's system. About a third of all this construction and demolition waste is made into biochar, and the remaining two-thirds goes into silo storage.

How all of these measures fit together is shown in figure 3.34. Carbon is captured as follows:

- 25.3 MtCO$_2$e on average per year in standing biomass in newly planted forests (harvested and unharvested).
- About 14.7 MtCO$_2$e on average per year in plant-based products harvested and used in buildings and infrastructure.
- 4.3 MtCO$_2$e per year in silo storage.
- A net capture of 1.9 MtCO$_2$e per year in peatlands (although some peatland is restored, the rest will still emit an amount of GHGs).
- 1.6 MtCO$_2$e per year in biochar, added to about 0.8 Mha of non-agricultural soils.

This adds up to 47.8 MtCO$_2$e – sufficient to balance our remaining impact on climate change in our scenario.

Our scenario is now net zero carbon.

Areas for further research

Ⓡ **How best to monitor our soil?** Farmers need practical methods to monitor a crop's nutrient needs throughout the season. Adding exactly the right amount of fertiliser prevents pollution by run-off to rivers and reduces nitrous oxide emissions.

Ⓡ **How best to manage nitrogen in soil?** We need to create the right conditions in soil for nitrogen to be processed by microbes so that as little as possible becomes nitrous oxide. We know a lot already, but research must continue for agricultural soil and other landscapes, such as wetlands.

Ⓡ **We often don't eat the things we know we should!** Today's life pressures, temptation from shops and adverts, as well as low incomes and busy lives for many, don't make it easy. How can we change society to help us eat what is good for us and our environment?

Ⓡ **Could we 'grow' fertiliser as trees and shrubs?** Using tree leaves and some woody growth such as 'Ramial wood' – chipped and composted wood from thin branches – can improve soil health and supply nutrients. This could reduce our need for manufactured fertiliser, or nitrogen supplied by clover 'leys' which take up valuable farmland. However, little is known about the effect on carbon sequestration and on soil greenhouse gas emissions.

Ⓡ **Breed better varieties of perennial (long lived) plants** such as chestnut trees, perennial grains and beans. Perennials are more efficient than short-lived plants, they need less fertiliser and the soil is left undisturbed, helping to store carbon.

Ⓡ **Breed more new strains of biomass crops to increase yields**. The higher the yields of biomass crops, the more carbon neutral fuel we have, and the more land available to capture carbon and the preservation of essential diversity of wild species.

Ⓡ **What should we grow on lowland peatlands?** What types of farming could co-exist with a raised water table, and how can it be managed for maximum carbon capture and lowest greenhouse gas emissions?

Ⓡ **How to increase carbon capture in soil?** We need long term experiments (10 years or more) on soil organic carbon. Which farming practices help carbon storage and how much carbon can be stored? What are the best types of organic matter to add? Where can we get it from, considering we also need carbon-rich materials for biofuels, and carbon capture in buildings?

Ⓡ What is needed socially and economically to enable farmers, industry, researchers and consumers to **work together** to ensure our land is managed for a zero carbon future?

Ⓡ **Pet Food.** Our dogs and cats eat a lot of food too, and horses graze some of our grassland. What are the most carbon efficient ways to feed our companion animals? Should we consider whether we have too many of some types of pet?

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3.7 Measuring up 2030

Having described the UK in our Zero Carbon Britain (ZCB) scenario, we can now see that many things have changed by 2030. One important implication of the changes is that we have now completely integrated our three principal metrics:

- Greenhouse gas (GHG) emissions.
- Energy supply and demand.
- Land use.

Figures 3.35-3.37 summarise our scenario for the UK.

Most importantly, our GHG emissions have decreased from 532 $MtCO_2e$ to just 40 $MtCO_2e$ – a reduction of 92%. Our remaining effect on climate change is equivalent to 47 $MtCO_2e$ in total (this includes additional effects from aviation emissions).

Relatively small reductions in GHG emissions have been made in non-energy emissions from households, business and industry and from waste management, largely through changes to industrial processes, diversion of waste from landfill and the conversion of landfill sites to storage silos. These emissions together are reduced by just over 64%.

The largest contribution to the reduction in GHG emissions is due to changes in our energy system – how much energy we use (demand) has been reduced by about 60% from 1,670 TWh per year today to 680 TWh per year, on average, through a number of energy saving measures, and also through changing the way and the amount we travel and move goods. We produce an average of 1,185 TWh per year of energy to supply our needs, covering losses in the system, requirements for synthetic gas and liquid fuels and back up to balance supply and demand. This is produced completely using renewable energy and carbon neutral energy sources, meaning that

GHG emissions from energy use are zero.

This system also has implications for land – in total, about 17% of our land is used to produce energy in some way, either fuel for transport and industry or as back up for our electricity system. More of our landscape is used to grow Short Rotation Forest, Coppice and various grasses for energy production – a significant change to the grazed fields we are used to.

GHG emissions from agriculture have decreased substantially – by roughly 73%. This is largely due to changes in our diet, including significant decreases in the amount of meat and dairy we eat, plus changes in management practices and the elimination of the need to use ever-more land for agricultural purposes. In total, we now only use a third of our land to feed ourselves (compared to 70% today), despite importing less food from abroad (about 17% of the food we eat is imported, compared to about 42% today). Over half of our agricultural land is still dedicated to livestock (sheep and cows) in some way – either grazing grassland or growing feed.

Another significant change to our landscape is a doubling of the area of forest. A larger proportion of this – 32% – is unharvested, meaning there is more space for biodiversity. A larger proportion of land in the UK (almost 15% compared to only 8% in present day UK) is not used productively, increasing the space for wild, conserved or protected areas, including restored peatlands – all of which are very important habitats for biodiversity, not just for carbon management.

Alltogether, these changes to the way we use land, the increased area of forest, the restoration of 50% of our peatlands, and the use of more plant-based products made mainly from harvest wood, allow us to capture about 47 $MtCO_2e$ every year.

This balances out the emissions left in our scenario, meaning that we capture the amount of GHGs equivalent to our remaining impact every year – we are net zero carbon.

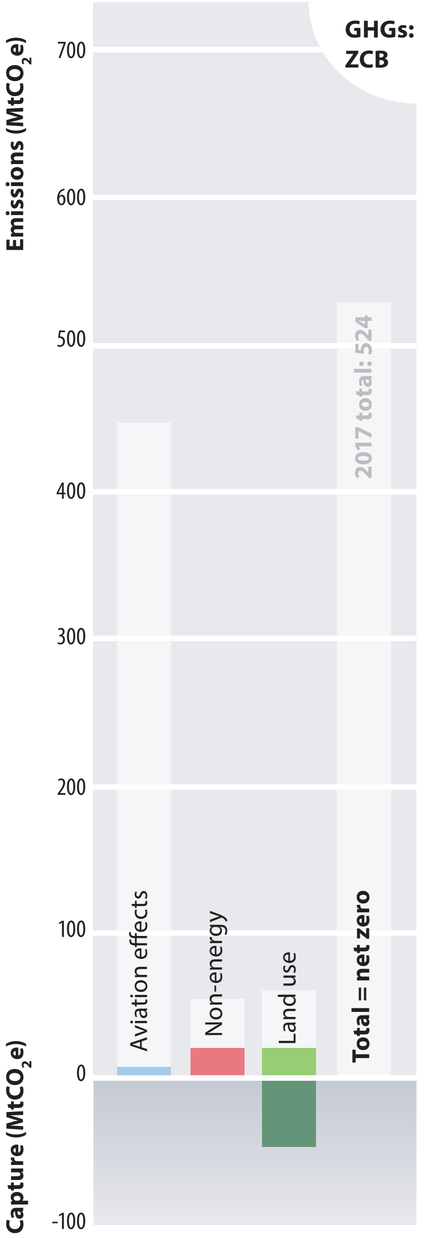

Figure 3.35: Carbon captured and greenhouse gas emissions for the UK in our scenario relative to 2017, including international aviation and shipping and the enhanced effect of emissions from aviation. Total emissions sum to net zero.

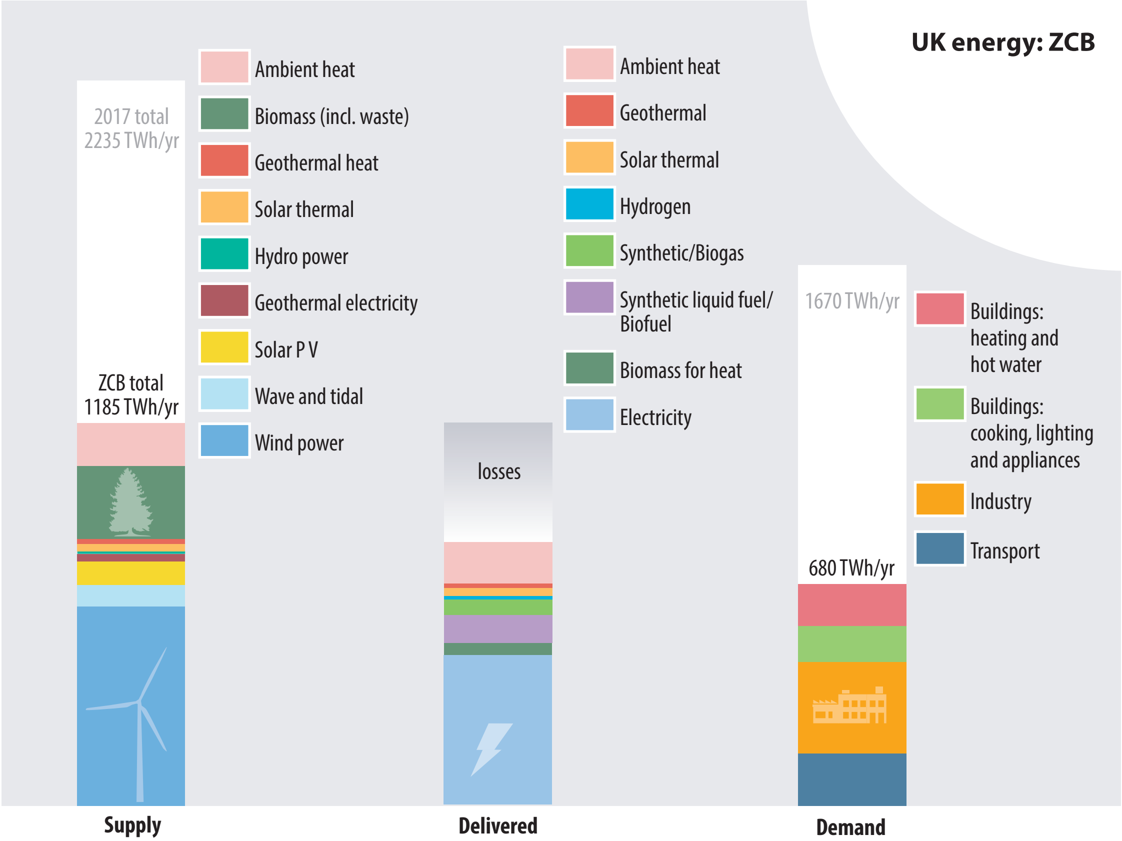

Figure 3.36: Primary energy supply, delivered fuel mix, and final energy demand for the UK in our scenario, relative to 2017.

Figure 3.37: Approximate land use in our scenario (not including water courses and coastal areas). 'Mixed grasses' includes hemp, Miscanthus and other energy grass crops.

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How we get there 3.8

3.8.1 ZCB and the UK's carbon budget

In *2.3.1 Our carbon budget*, we estimated the UK share of the 2010-2050 global carbon budget as:

- 7,600 MtCO2e (corresponding to an 80% chance of avoiding a 2°C global average temperature rise).
- 8,800 MtCO2e (75% chance).
- 10,300 MtCO2e (67% chance).
- 12,900 MtCO2e (50% chance).

Using data on UK GHG emissions from 2010 to 2017 (BEIS, 2019; BEIS, 2019a) we then assume our emissions decrease linearly until they reach zero in 2030. Our emissions remain at net zero after 2030. Figure 3.38 shows how this transition compares to current UK policy emissions reductions targets.

Adding up our emissions year-on-year, and then deducting carbon captured in short-term measures, such as improved land management techniques (roughly 240 $MtCO_2e$ – see *3.6.3 Capturing Carbon*), tells us how much carbon we 'spend' over the period 2010 to 2050.

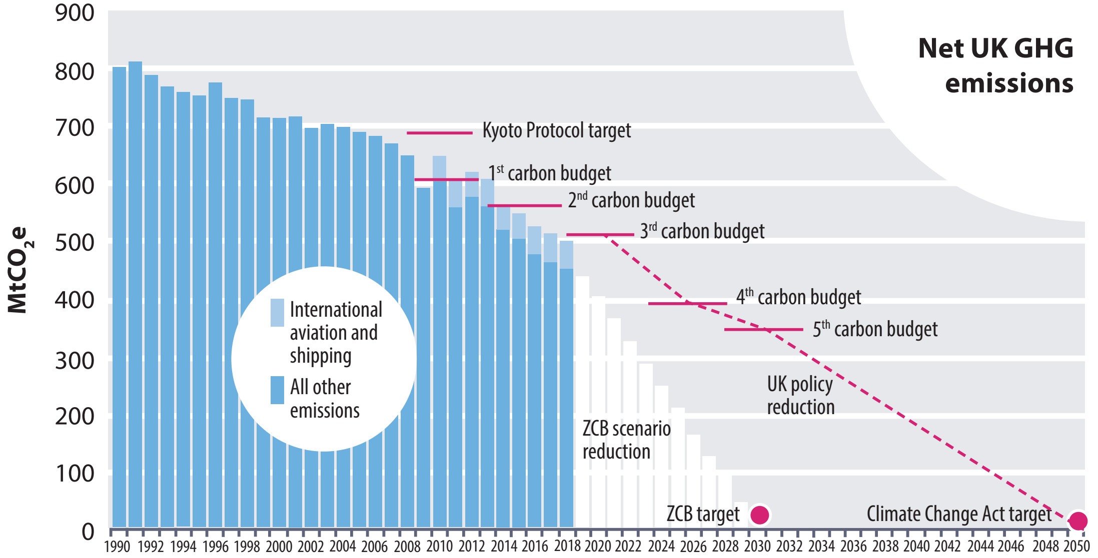

Figure 3.38: Transition used to estimate the total carbon 'spent' in transition to our ZCB scenario, modelled for our scenario relative to current UK policy. Targets are from references in text, emissions data from BEIS (2019a).

This comes to about 8,050 $MtCO_2e$ including emissions from international aviation and shipping (currently not counted under the UNFCCC Kyoto Protocol).

This very simple estimation implies that the Zero Carbon Britain scenario comes in 'under budget' for the UK share of a global carbon budget corresponding to a 75% chance of avoiding a 2°C temperature rise, when current UK policy fails to meet the criteria even for a 50% chance (*2.3.1 Our carbon budget*).

Whilst the target of net zero by 2030 is now very challenging, this represents the need for deep reductions in global emissions in the short-term and accepts the responsibility of wealthy nations to deliver deep reductions soonest. As the Paris Equity

What about emissions resulting from changes to UK infrastructure?

What we may not have accurately represented in our simple linear decarbonisation is the additional carbon we might 'spend' (or emit) in building the infrastructure in the scenario. Materials for those offshore wind farms and insulation for our houses all have to be manufactured and transported, and until they are in place the energy we use to do this will cause GHG emissions.

This might make the shape of the transition quite different. For example, there could even be an increase in emissions at the beginning (as we get busy building), followed by a sharp decrease in emissions once the majority of our energy supply becomes 'zero carbon'. This is an important avenue for further research.Ⓡ

What about our historical responsibility?

How much 'historical responsibility' we take for GHGs we have emitted in the past is an important and difficult moral issue that requires substantial attention from international policymakers. Since most GHG emissions persist for hundreds of years, a substantial amount of what is now in the atmosphere is 'ours'. In some sense, we may have already exhausted our 'moral budget' – having emitted far more than our 'fair share' over the years since the industrial revolution. For example, a large proportion of the 430 $GtCO_2e$ of GHGs emitted globally between 2000 and 2009 (Gütschow et al, 2018) were from industrialised nations like the UK – far more than our 'fair' per capita share. The division of a global carbon budget on a per capita basis from an earlier date therefore means that we take responsibility for the fact that we have emitted more than our 'fair share' of global emissions *in the past*, as well as continuing to do so today. Between 2000 and 2009, UK GHG emissions came to about 7,145 $MtCO_2e$ in total (almost double our 'fair' per capita share of the GHGs emitted globally), meaning we have already 'spent' a larger proportion of what is available to us through to 2050. Under this frame of historical responsibility, between 2010 and 2050 the UK's remaining budget is:

- 4,000 $MtCO_2e$ (corresponding to an 80% chance of avoiding a 2°C global average temperature rise).
- 5,200 $MtCO_2e$ (75% chance).
- 6,700 $MtCO_2e$ (67% chance).
- 9,300 $MtCO_2e$ (50% chance).

Comparing this again to the 8,050 $MtCO_2e$ 'spent' between 2010 and 2050 in the transition to our scenario, we now find that we only come in 'under budget' for the UK share of a global carbon budget corresponding to a 50% chance of avoiding a 2°C temperature rise – we have 'overspent' budgets with better chances. This is still far better than current UK policy, but is a one in two chance of what is now defined as 'extremely dangerous' climate change too high? There is also the question, what *is* 'fair' – how far back should our emissions be counted?

The longer the frame of historical responsibility we take (the further back we go), the harder it is for the UK – and other long-industrialised nations – to keep to a budget that gives any reasonable chance of avoiding a 2°C temperature rise. However, there are some options open to us in these cases:

- **Faster decarbonisation**. This means we tighten our purses and 'spend' less carbon. For example, for an 80% chance in the above example, the UK would have to fully decarbonise before 2020.
- **More carbon capture**. This means we rein in our 'overspending' by 'earning' more. It would be beneficial to maximise techniques that capture carbon – those that work in both the short-term and long-term are beneficial here (*3.6.3 Capturing carbon*). Other geoengineering options to remove CO_2 from the atmosphere may also be considered (*3.1 About our scenario*) should these methods be exhausted.
- **International credits**. This means we pay others to cover our 'overspend'. Paying for our remaining emissions and funding the transition to zero carbon economies in less developed nations has been recognised as an important aspect of global decarbonisation (Chichilnisky, 1994).

The latter two options do not provide alternatives to rapid decarbonisation, but are complementary – they 'settle up' historic contributions to the problem and 'buy us more time' for the process of decarbonisation. There are limits to how fast we can decarbonise, but also to how much carbon can be stored, and to how many credits it would be possible to purchase in an equitable and effective scheme (UNEP, 2012). We cannot rely on any of the above options individually. What is clear is that as a long-industrialised nation, we have a responsibility to cut our emissions to net zero as quickly as possible.

In all cases, rapid decarbonisation is necessary, but it may not always be sufficient. Historical responsibility is an important question that can only be addressed at an international level, and will play an important part in future climate negotiations.

Check tool shows, when the 'development rights' of poorer nations are considered, wealthy countries must achieve net zero emissions by the early to mid-2030s (Robiou du Pont, 2017).

Global cumulative carbon budgets do not represent 'hard limits', but a sliding scale of risk. Essentially, the sooner we decarbonise, the smaller our contribution to the problem and the better our chances of avoiding what is now defined as 'extremely dangerous' climate change (Anderson and Bows, 2010). Acknowledging our historical responsibility as a long-industrialised nation only further emphasises the necessity to decarbonise rapidly, to help international negotiations and catalyse global action on climate change.

3.8.2 Zero carbon policy

The climate emergency requires strong policies capable of reducing emissions to net zero, both quickly and equitably. Such transitions are becoming part of mainstream thinking, but are not yet reflected in UK government policy frameworks.

Current policy frameworks and mechanisms

The historic 2015 UNFCCC Paris Agreement and the recent IPCC 1.5°C report make clear the urgent need for ambitious policies. In July 2019, the Committee on Climate Change (CCC), an independent statutory body established to advise and monitor progress, called for the UK Government to show it is serious about its legal obligations to reach net zero emissions by 2050. They point out that UK action to curb emissions is lagging far behind what is needed, to meet even previous, less stringent targets.

Time is tight. There now needs to be an urgent and systemic shift in policy. Here we explore and compare a range of leading potential policy mechanisms.

Cap schemes can be implemented either 'upstream' or 'downstream'. Upstream systems target suppliers of fossil fuels and energy services directly; downstream systems seek to change individual behaviours, such as home energy use, driving and flying. In essence, they both treat GHG emissions as a tradable commodity ('carbon trading'). Companies or individuals who emit less than their share (as defined in various ways) can sell their surplus to those who have emitted more than their share.

Upstream systems are currently more common, but downstream systems are also being explored by policy makers. Table 3.3 outlines the advantages and disadvantages of various policy mechanisms that could help reduce the UK's GHG emissions.

Which policy framework is best for the UK?

It is unlikely that any one single policy mechanism can deliver the radical emissions reductions we now require. We will need a policy framework combining effective mechanisms designed to work well with a range of sectors, including energy production, industry, housing, business, transport, land use and agriculture. Working national and local policies together in this way has been shown to be effective in reducing emissions (UNEP, 2012). Closing the gap between what is physically necessary to address climate change and what current UK emissions reduction targets are projected to achieve (see *2.3.1 Our carbon budget*) will require high-level all-party political commitment, cross-sectoral collaboration and public engagement at every level.

The next section, *3.8.3 Economic transition*, describes how some of these policy mechanisms can be used to decrease emissions on a national level, and what effects they may have for the UK economy.

Some of the mechanisms that operate on an international level are subject to 'carbon leakage' – moving production abroad to areas where carbon trading has not yet been implemented, or where carbon taxes are lower. Some mechanisms can even provide a disincentive to decarbonise, especially in the short-term, delaying decisions and leading to infrastructure 'lock-in' that commits to higher energy use or emissions over the following decades. If policy mechanisms are to be effective on a global

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level, they must be designed to avoid or manage these issues (ibid.). Potential solutions could be delivered through trade agreements like those organised by the World Trade Organisation (WTO), or by using border taxes to level out costs (Carbon Trust, 2010). This issue is associated with the need for us to take account of emissions arising from the production of goods that we import, and not just those from goods produced at home, which is currently the case in international agreements under the UNFCCC (*3.10.3 Carbon omissions*). Taking full account of emissions arising from internationally traded goods is a vital area for future policy research.

	Mechanism	Description	Advantages
UPSTREAM	Emissions Trading Scheme (ETS)	The government sets a soft cap on carbon emissions. Allowances or permits are distributed among industry and businesses. They must have sufficient permits to cover the emissions they produce, either through the initial allocation, or auction, or by trading with others.	• The emitter can emit only limited GHGs, which reduces over time. • It provides incentives for industry and businesses to develop low carbon technologies to keep their emissions within defined limits.
UPSTREAM	Cap and share	A hard cap is placed on GHGs emitted by fossil fuel suppliers. Emissions permits are distributed equally among adult citizens. Each citizen, or group of citizens, can choose to sell the permits to fossil fuel suppliers. The money raised by the sale of permits can be shared between citizens.	• The cap is enforced by requiring the fossil fuel supplier to pay for a fixed amount of emissions permits. • The money raised can compensate for a potential rise in energy (or fuel) prices.
DOWNSTREAM	Tradable Energy Quotas (TEQs)	A hard cap is set on emissions and an annual carbon budget is set based on the speed of emissions reduction required. The proportion of emissions associated with households is distributed equally to every adult citizen for free. The remaining permits are sold by tender to all non-household energy users. All fuels would carry carbon ratings. A consumer 'pays' in carbon permits to cover the rating of their purchase (Fleming and Chamberlin, 2011).	• There is equal entitlement to fuel use among all citizens. All other energy users are also included. • It provides large incentives to all sectors of society to reduce their carbon emissions. • All emissions from energy use can be measured simply and efficiently by assigning a rating based on the quantity of GHGs generated by their production and use. This avoids the need for complicated lifecycle emissions calculations. • It can help deal equitably with restricted energy use as well as emissions reduction.
DOWNSTREAM	Personal Carbon Allowances (PCAs)	Emissions allowances are allocated equally to adult citizens (half an allowance is proposed for children) and can be 'spent' as required on GHG emitting activities, such as paying a gas bill. Those who keep to budget will have spare quota to sell, whilst those who don't will have to buy allowances to cover their excess.	• Individuals can either maintain existing behaviours and buy allowances, or change their behaviour and reduce their emissions, potentially profiting by doing so. • There is the potential to constrain emissions in 'an economically efficient, fiscally progressive, and morally egalitarian manner' according to some (Roberts and Thumin, 2006).
TAXATION	Carbon tax	A tax is imposed on the release of GHG emissions from industry and businesses, providing an incentive to reduce GHG emissions if doing so costs less than paying the tax.	• Simple to design and implement. • Raises the cost of using fossil fuels and encourages innovation and investment in developing renewable technologies and more energy efficient processes.

Table 3.3: A comparison of different policy mechanisms.

Disadvantages	Recent developments
• The 'carbon price' (the cost of each permit) can fail to reflect the real cost of environmental damage in the long-term. • It can be cheaper to buy permits from other businesses, rather than reducing emissions – especially in the initial stages of the scheme. • Can be subject to 'carbon leakage'.	• The European Union (EU) ETS is the world's largest carbon market and is now in its third phase (2013-2020). • National or sub-national systems are being operated in Australia, Japan, New Zealand and the USA, and are planned in Canada, China, South Korea and Switzerland.
• Administrative and commercial systems, such as banks or post offices, are needed to support the operation of the scheme. • The ability of the citizen to make money out of the scheme may reduce the motivation to achieve emissions reductions. • Can be subject to 'carbon leakage'.	• 'Cap and Dividend' is a similar mechanism and has gained political popularity in the USA.
• Administrative systems are required for the registration of permits and all transactions. • Can be subject to 'carbon leakage'.	• The TEQ concept has been embraced in France, and the Resource Cap Coalition is assigned to carry the idea across Europe. • It has won support from the main political parties in the UK. A policy framework for peak oil and climate change was published in 2011 with support from all parties.
• The mechanism applies to individuals and may have limited impact on the economy as a whole. • Administrative systems are required for the registration of allowance quotas and all transactions. • There is potential for unequal effects on individuals – a recent study suggested households in rural areas, detached houses, or those that use oil and electricity for heating, retired people or single dwellers without children, are more likely to experience a deficit of PCAs (White et al., 2013).	• This mechanism is only in the research phase.
• There is potential for unequal effects on individuals – increased production costs caused by the carbon tax may be passed on to consumers, having a larger impact on low-income households. This could be addressed through subsidies. • There is no guarantee that the tax would keep emissions within the carbon budget. • Setting the 'right' carbon price that would change behaviour sufficiently to avoid emissions is difficult.	• The EU plans to phase out all subsidies for fossil and nuclear energy and introduce an EU-wide carbon tax by 2050 (EREC, 2010). • The Climate Change Levy (CCL) is the carbon tax currently in use in the UK. It only applies to energy used for lighting, heating and energy in non-domestic sectors. • The Carbon Price Floor (CPF) has recently come into force as a tax on fossil fuels used in parts of the energy sector in the UK.

3.8.3 The economics of climate action

We now have a chance to change everything, because everything must be changed. Reducing national debt was the reason given for ‘austerity’ policies that constrained public investment over the last decade. But, as many economists warned, it has proved an ineffective – or worse, counterproductive – singular strategy for a nation challenged to invest in the rapid transition to zero carbon. It defies precedent too. Not only was Britain far more indebted, for example, when it found the resources to build bold new national infrastructure after the Second World War, but schemes were quickly devised to bail out the banks that caused the 2007-2008 financial crisis. However these schemes were focused on a return to ‘business as usual’. In this mindset perpetual growth is still the goal and many of the true costs of burning fossil fuels, such as public subsidies, medical care costs arising from poor air quality, or future adaptation costs, are still ‘externalised’ and so not paid by either producers or consumers. To move forward we need to understand the need and opportunities of investing in a rapid transition, and embrace a full accounting approach for all our economic choices.

It would be bad economics to see Climate Emergency Actions in terms of costs. They offer an investment now which delivers immediate returns in jobs, activates the multiplier effect from spending and avoids very large, unknowable later costs from the impact of climate breakdown. Action now is an investment in our future that offers tangible economic returns across multiple sectors, such as cost savings in healthcare or reduced bills from increased energy efficiency in buildings, or income from renewable energy generation schemes. To fully account for this, the economics we use needs to break through current budgetary silos. The approach we take has to account for all the benefits of resource allocation; for example, when an investment made in one sector, such as investment in clean transport, accrues benefits mostly in a different sector, such as a fall in public health costs. By making visionary but absolutely necessary investments at ground level, we not only create employment and stimulate the economy, but we also ‘future-proof the UK’ to be ready for the challenges of the 21st Century.

Britain is currently still too reliant on volatile financial services and a retail consumer economy. We need to rethink the economy, based on harvesting our renewable assets and working with our ecosystems. So, rather than powering Britain from a peaking pipeline of imported fossil fuels, an energy smart British economy can be driven by its own renewable energy supply chain. By their very nature, these renewable reserves will not expire. The major part of any investment in renewables is made upfront, to install the generators, after which the fuel – wind, tides or sunshine – is delivered free, leaving only maintenance costs to consider and making the returns much more predictable and quantifiable.

The hard economic lessons of the past decade should refocus the ingenuity of the finance sector on the actual challenges at hand. As economist Simon Wren-Lewis writes: “No one in 100 years’ time who suffers the catastrophic and irreversible impact of climate change is going to console themselves that at least they did not increase the national debt. Humanity will not come to an end if we double debt to GDP ratios, but it could if we fail to combat climate change.” A new kind of energy-smart, decarbonised economy can be stable in the long term, locally resilient, globally active, rich in quality jobs, reliant on indigenous, inexhaustible energy and have a strong sense of purpose. This is an important area for future research Ⓡ.

The Green New Deal

Taking inspiration from Franklin D. Roosevelt's original New Deal, which drove the recovery from the 1929 economic crash, the Green New Deal outlines an integrated response to our current challenges through a dual approach:

- Firstly, it entails sorting out the rules by which the economy works, so the problems will not reoccur. This means re-regulating finance and taxation so finance will return to its role as servant and not master of the economy. This means dealing prudently with people's savings and providing regular capital for productive and sustainable investment.
- Secondly, it supports a climate emergency action plan using a mix of public and private investment to rethink the economy in a way that will rapidly decarbonise it, and also create employment by tapping into the UK's massive renewable energy asset base.

To tackle the problems facing us with the urgency required we need the equivalent of an 'environmental war effort' – the Green New Deal offers a path to re-engineer the economy at a scale and speed typically only seen during wartime (Green New Deal Group, 2008). This approach will deliver huge increases in investment in energy infrastructure and the retrofitting of the UK's estimated 30 million buildings (mostly domestic homes) backed by a new legislative framework offering price signals adequate to accelerate the shift away from a fossil fuel based economy. These signals should include rising carbon taxes and a price for traded carbon that is high enough to cause a rapid drop in carbon emissions (ibid.).

Once the market becomes alert to the economic role of carbon, the most economically effective option automatically becomes that with the lowest embodied emissions, and the economy itself becomes an engine for rapid change – effectively, a race away from carbon. Economic market pressure for ever lower carbon options then accelerates the development and implementation of new kinds of technologies (ibid.).

The 2013 Green New Deal report outlines an interlinked package of measures including an investment in green infrastructure of at least £50 billion a year, which will benefit every community and constituency in Britain, providing skilled jobs, eradicating fuel poverty, making homes comfortable in summer and winter, and keeping energy costs down. Money is not the problem.

This Green New Deal could be funded through a wide range of measures including:

- Linking tax relief on pension funds and other savings to minimum levels of investment by funds into Green New Deal initiatives.
- Switching subsidies that currently go to fossil fuels to renewable energy and energy efficiency measures.
- Direct spending by government which can borrow at very cheap interest rates.
- Resources raised from tackling tax evasion and avoidance.
- A programme of Green Quantitative Easing (QE), where the Bank of England 'creates' money in a targeted fashion to fund a Green New Deal, generating jobs, new productive assets and economic activity that also transforms the economy for the future. This is very different from any previous round of QE.
- Controls to ensure that banks that were bailed out by the taxpayer also invest in such a programme at low, sustainable rates of interest.
- Buying out the private finance initiative (PFI) debt using Green QE and redirecting some of the otherwise huge repayments into funding green infrastructure.

This Green New Deal would create employment. It would generate wages, salaries, profits and tax revenues – from both the public and private sectors. Tax revenues could then be used eventually to finance the economic deficit and pay down the national debt. More than that, insulating every home and building in the UK, transforming our transport system for a low carbon future and ensuring maximum efficiency in the use and reuse of raw materials would create jobs for a reskilled 'carbon army' of workers across the country (Green New Deal, 2013).

In the USA in 2019, congresswoman Alexandria Ocasio-Cortez, along with Senator Ed Markey, and significant numbers of Democrats, put forward a resolution on a Green New Deal. Their plan is to shift the US to zero carbon through a far-reaching package of government support for investment and jobs, aiming for a transition that is socially just as well as delivering on climate.

Multiple groups in the UK and Europe are now promoting policies that prioritise decarbonisation, community and employee-led transition from high-carbon to low and zero-carbon industry.

3.9 Multi-solving – maximising the benefits beyond carbon

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Delivering a zero carbon future holds the potential to be one of the most exciting opportunities in human history, offering us the chance to simultaneously resolve a number of other interrelated challenges. So it's important not to have tunnel vision, and avoid focusing on the climate emergency in isolation – if we get to zero carbon in a smart way, there are huge multi-solving opportunities.

Adopting a multi-solving mindset can help us deliver improvements across many sectors – but it requires a cross-disciplinary approach. The trick is to identify synergies between the global or national changes needed to reach net zero and the changes which can also improve our health and wellbeing, enhance biodiversity, create jobs, stabilise our economy, and increase our resilience and ability to adapt to climate change. Maximising the benefits beyond carbon can also help empower diverse constituencies, building the necessary engagement and coalition of support across society.

Building on the work of Climate Interactive, we suggest the shifts in approach needed to multi-solve include:

- A national, cross-sector climate emergency action plan to link it all up.
- Interdisciplinary skills, so experts in one field can access the knowledge to optimise additional gains across a range of different fields. For example, well-designed solar farms can create space for biodiversity and increase local income streams.
- Break through the budgetary silos to reveal

all the benefits – for example, if a clean air or mobility investment comes from the Department of Transport, the benefits may well appear mostly in NHS budget savings.

- Link up the different levels of authority, so collaboration happens between different organisations operating at different scales or sectors.
- Long-term thinking, to avoid focusing on short-term thinking alone (such as quarterly or annual targets), because significant benefits may be realised over much longer periods.

Through a multi-solving approach, a climate emergency action plan for the UK can help create new and more meaningful employment; make us happier, healthier, and increase our wellbeing; and help foster a stronger, more resilient society with a new sense of collective purpose.

Useful tools and research are available from https://www.climateinteractive.org/programs/multisolving/

3.9.1 Adaptation to Climate Change

The climate is changing. The IPCC 1.5°C 2018 report shows that we are being forced to adapt to a certain level of climate breakdown. We can limit CO_2 but we cannot mitigate its effects entirely. Over the coming decades change will be uneven, regionally unique, non-linear.

International co-operation and transboundary agreements will be essential to help humanity adapt to social and economic disruption caused by climate change. National and regional adaptation plans will need to deal in, or with, uncertainty and deploy long-term scenario planning.

The UK: adaptation at a national level

The UK's Department for Environment, Food and Rural Affairs (DEFRA), under the overall framework of the Climate Change Act 2007 and their National Adaptation Programme, produces the current guide to 'making the country resilient to a changing climate' (see table for risks and opportunities, based on the DEFRA strategy 2018).

Some of the particular vulnerabilities and risks facing the UK include a long coastline, some of which is at risk, even now, to rising sea levels; an agricultural industry that will require significant changes in terms of its land use; and a historical reliance on high emissions for our economic growth, including large amounts of investment in fossil fuels from the City of London. The challenges to our future economy are significant as part of our adaptation of climate change, and arguably receive too little attention from the UK government.

Within the UK, cities and devolved areas with unique challenges, like London and Wales, are developing adaptation plans (For example, 1.5C Compatible Climate Action Plan, Mayor of London, 2019, or the Climate Change Adaptation Plan for Wales.)

We can expect greater coastal erosion, warmer winters, more frequent and severe summer heatwaves, and more severe and unexpected flooding. We can also build adaptive capacity into some of our methods of reaching net zero, so that some adaptation measures can have the co-benefit of helping us reach zero emissions (see 3.9 Multi-solving). For instance, reforestation in rural areas and tree planting in urban areas can help to mitigate flooding from rivers or control higher temperatures in urban areas. At the same time, it acts as carbon sequestration, contributing to getting to net zero. Similarly, more localised food production results in fewer food miles, which contributes towards our net zero target. Moreover, shorter supply chains are more resilient to climate change impacts.

The expectation from the United Nations Framework Convention on Climate Change is that states will develop their own adaptation plans based around their unique vulnerabilities to climate change. The Flexible Workplan of the Adaptation Committee 2019-2021 is the framework for helping countries to develop their own solutions, using data systems for planning and implementing action. On a practical level, this might be recording changing rainfall patterns and installing green urban infrastructure to help deal with flash floods, or it could be predicting urban population growth and adjusting sustainable transport links accordingly.

Risks, opportunities, and management in the UK

In the table opposite, the 'Risks' are taken from *DEFRA's National Adaptation programme, the Third Strategy for Climate Adaptation Reporting 2018* and the *UK Climate Change Risk Assessment 2017.* The 'Management and opportunities' are also taken from these documents, plus additional research from the Centre for Alternative Technology's Sustainability and Adaptation MSc programme and Zero Carbon Britain work.

Green and blue infrastructure vs grey – an example of a multi-solving adaptation tool

'Green' infrastructure is plant-based, like trees and grass roofs. 'Blue' infrastructure is water-based, like ponds and swathes. Some might be both, like reed beds.

Traditional 'grey' infrastructure like the drains and pipes that we are used to in urban areas tend to draw water (such as rainfall) to rivers as fast as possible. This has two effects: sudden rainfall overwhelms sewers (and sometimes streets) creating either flash floods or overspill from rivers and sewers, which kills fish and wildlife. Also, paving and tarmac are reducing our porous surfaces and reducing plant growth, both of which contribute to heating (even in rural areas!).

Green Infrastructure Adaptation	**Reduce flooding and need for super sewers**	**Co-benefit Biodiversity**	**Urban cooling**	**Connect to nature/ homes for nature**
Raingardens	✓ Main reason	✓	✓	✓
Trees	✓	✓	✓	✓
Green roofs	✓	✓	✓	✓
Porous paving	✓			

Green and blue infrastructure is a multi-solving tool with co-benefits. It's a key adaptation tool, to address flooding and heatwaves. It helps preserve and create new biodiversity, promotes nature connection for people, acts as carbon sequestration, muffles noise and reduces localised air pollution.

Sector	Risks	Management and 0pportunitiess
Natural environment	Change to ecosystems causing shifts in distribution and abundance of freshwater marine life, habitat loss, diseases and invasive non-native species of plant and animal. Loss of resilience of ecosystems due to inability to adjust and adapt to the speed of change. Peatland restoration put under pressure by temperature increase. Rivers over-extracted for water, reduction in biodiversity and bank stability, vicious cycle.	Large-scale tree planting, forest management, rewilding to help capture carbon. Creation of wildlife corridors. Restoration of peatlands.
Infrastructure and the built environment	Flooding, particularly in coastal areas, but also inland risks from flash floods. Intensity of urban heat in cities and built up areas. Transport issues from heat, flooding and unpredictable weather.	Increase sea defences where possible. Managed relocation for affected communities in coastal areas when sea defences won't work. Green and blue infrastructure, which is a way of slowing down water flow in flood prone areas. Green is usually plant and soil additions, and blue is usually water-based additions to the architecture of the building or area. Examples include swathes, ponds, sustainable drainage systems, reed beds, and green roofs. Knowledge of the regional variants based on gathering local learning will help. Trees, green roofs, green walls, ponds, and urban gardens to help with heat management.
Land use and agriculture	Risks of flooding, water shortages, and unpredictable weather. Disruption to food supplies. Unintended consequences of land use change, such as bioenergy causing displacement of food crops, or import of crops that displace forests.	Reforestation. Changes to farming and land use to reduce waste, build resilience, increase local food production and build further international co-operation to help with food supply fluctuations. Accounting for unintended land use change consequences through international carbon balance sheets.
Health and wellbeing	Heat related deaths could double by 2050. Risk to human life and wildlife. Possible compounding factors of air particulates and ozone. Disruptions to health and social care services.	Car reduction in cities, more cycling-friendly infrastructure. Green and blue infrastructure in cities can reduce localised pollution and increase nature connection. Changes to land use may influence diet in positive ways, with overall reduction in meat and dairy consumption.

Table 3.4: Opportunities within our scenario for adaptation to a changed climate; the risks a changed climate might pose for our scenario; and some management options which may help decrease the risks. Much of the information is taken from the Climate Change Risk Assessment (HM Government, 2012).

Further reading

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3.9.2 Planetary boundaries

Pressures on the 'planetary boundaries' are driven by a combination of population growth, increased consumption and environmentally damaging production systems (Rockström and Klum, 2012). There is probably little that can be done to modify the trajectory of population growth, now slowing and projected to stabilise globally at around 9 billion in 2050 (Lutz et al., 2004).

With respect to increased consumption, it is important that economic growth is concentrated where it is needed most – in developing countries. The already wealthy regions (largely the Western world) need to plan for low growth and a transition to steady state economies (Victor, 2008).

With these changes as a background, our scenario proposes a wide range of technological shifts in production methods, as well as changes in consumption patterns. Although the planetary boundaries are measured globally, some of the issues depend on local conditions. For others, there are obvious links between local actions and global effects – for example, adhering to a nation's carbon budget plays a part in global efforts to tackle climate change. Whilst the UK can play its part in helping local and global conditions progress in the right directions, many of the trends ultimately depend on co-ordinated global action.

Zero Carbon Britain is focused on the **climate**

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change boundary. It tries to demonstrate an adequate national contribution to the planetary problem through complying with the proposed global budget for accumulated GHG emissions to 2050 (*3.8.1 ZCB and the UK's carbon budget*).

Ocean acidification is directly connected with climate change (see figure 3.39), as oceans acidify through the uptake of CO_2 from the atmosphere – the more CO_2 there is in the atmosphere, the more the oceans acidify. There are some geoengineering proposals for dealing with climate change that would leave the acidification problem unchanged – for example, shielding the Earth from the sun's heat to keep temperatures down (Williamson and Turley, 2012). Reducing GHG emissions (and thus levels of CO_2 in the atmosphere), as in the Zero Carbon

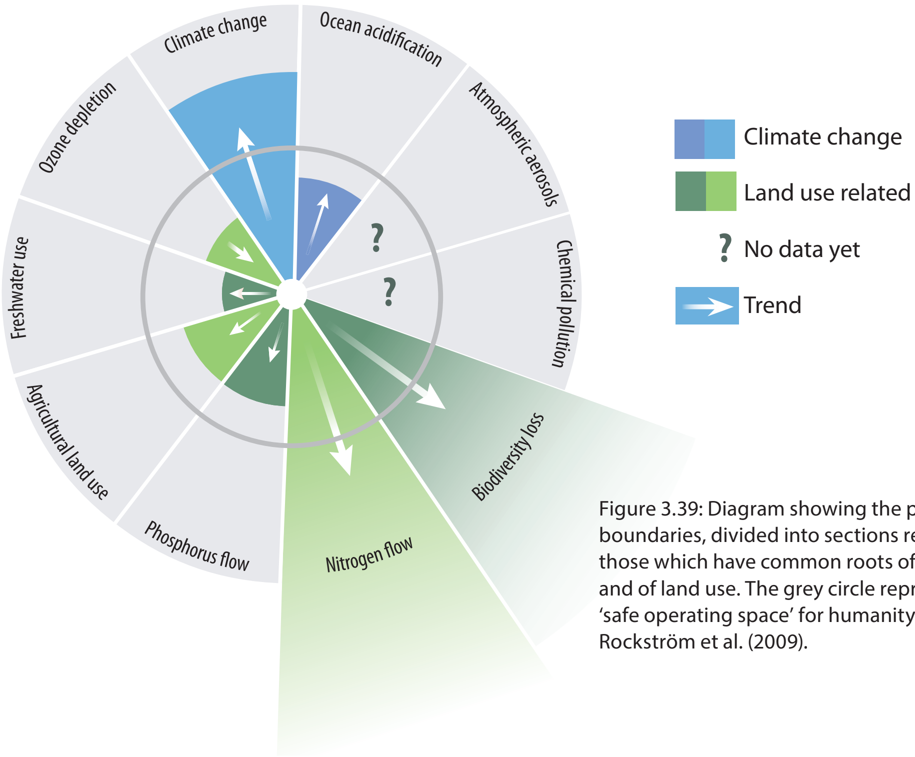

Figure 3.39: Diagram showing the planetary boundaries, divided into sections representing those which have common roots of climate change and of land use. The grey circle represents the 'safe operating space' for humanity. Adapted from Rockström et al. (2009).

Britain scenario, targets both climate change and ocean acidification simultaneously.

The pressures on the other planetary boundaries (not including ozone depletion, which is already improving (UNEP, 2012), plus those not quantified yet) are broadly proportional to how much land we use (see figure 3.39), and how intensively we use that land. There can be little doubt that the largest driver of unsustainable trends has been increasing consumption of grazing livestock products (largely beef, lamb and dairy), which require much more land than crops (Nelleman, 2009; Pelletier and Tyedmers, 2010; Foley et al., 2011; Greenpeace International, 2012).

Therefore, the simplest way to help change these trends is to reduce livestock production and consumption (Elferink et al., 2008). This is largely what our scenario does, particularly by reducing grazing livestock significantly and banning the import of livestock products and livestock feed.

Looking at each of the boundaries in slightly more detail, **biodiversity loss** is principally a result of changing land use away from more natural systems to managed systems and agriculture – the clearing of forests, for example. Overfishing also contributes to the problem in the oceans, and invasive species are a major cause of biodiversity loss in both land and sea ecosystems. Globally, land use change is driven disproportionately by the growth of grazing livestock production, and to a lesser extent by first generation biofuels. Our scenario does not use these first generation biofuels at all. Rather, it generates a large quantity of biomass crops that offer richer habitat possibilities than typical cropland (Haughton et al., 2009) while increasing forest area and maintaining, or in some cases restoring, habitats of ecological importance – peatlands, for example.

Water consumption becomes a global issue in terms of 'embodied' water in goods and food (Hoekstra, 2013). Our scenario at least partly addresses this question with a reduction of food imports and zero imports of water intensive livestock products (Mekonnen and Hoekstra, 2012).

The problems of **nitrogen and phosphorus** excess are also connected with grazing livestock production, since more nitrogen and other fertilisers are required to produce animal rather than plant protein – simply because of the quantity of land used (Lilywhite and Rahn, 2005). Although in our scenario we do not explicitly model fertiliser application, reducing the amount of land used to produce foodstuffs is likely to decrease the amount of fertiliser used to some degree (Sutton et al., 2013).

Although it has not been possible to investigate in detail the interaction of the Zero Carbon Britain scenario with these proposed planetary boundaries, the requirements have consistently been kept in mind. The technical choices made in our scenario aim at genuine sustainability, not merely a reduction in impact.

3.9.3 Employment

By its very scale, the transition outlined in this new ZCB report holds the potential to be a powerful employment generator: not only in rapidly growing industries such as offshore wind, but also in existing technology and manufacturing sectors like construction and transport. There are also significant new employment potentials in land-based industries, such as growing energy and fuel crops, power-to-gas and natural carbon capture processes. Denmark and Germany have already set an example by decarbonising rapidly, and by manufacturing in-country, so creating employment on a large scale.

Although some jobs will inevitably be lost in coal, oil and gas, there will be more new jobs in renewable energy, construction, transport and agriculture. There will be a net gain in jobs overall, though the new jobs will be different and may not emerge in the same locations. Many will involve similar skills: for instance, offshore wind development will need many of the same skills as offshore oil. Such jobs will rejuvenate rural, coastal and ex-industrial areas. Plus, with a clear transition strategy, skills of existing workers and existing manufacturing bases could be transitioned to create the infrastructure for a zero carbon Britain. Employment will be created in powering down energy demand through a massive national programme of retrofitting public, domestic and commercial buildings, energy efficiency improvements and a large expansion in public transport. Powering up the UK's renewable energy assets also offers significant employment, particularly if the generation equipment can be manufactured here. Further employment opportunities would be found in sustainable forestry management, the conservation sector and in the growing fields of biomass for carbon neutral fuels.

There is a clear need for further more detailed research to map out the skills transition and resulting employment potential. Ⓡ

Many studies cite a variety of estimates, based on widely differing assumptions, which makes it difficult for an accurate analysis of the effect of our scenario on employment. However, three useful pieces of work have recently emerged:

1) Unlocking the Job Potential of Zero Carbon (December 2018)

https://gef.eu/wp-content/uploads/2018/12/GEF_ClimateJobs-brochure-main.pdf

In 2018, the think tank Green House led a project which estimated the number of jobs that would be created by a transition to a zero carbon economy where we reduce emissions of GHG in line with the aspiration to limit global warming to 1.5°C. Using a detailed methodology, this work embraces a local jobs-rich green investment strategy in local authority areas in the UK. It also offers parallel analysis for each region of Hungary and the Republic of Ireland.

Their results for the UK indicate that at least 980,000 new jobs would be created during the transition phase to 2030 and 710,000 in the longer term through the changes suggested. They do make it clear their estimates are conservative. For example, they did not estimate the jobs created in the wider economy by the spending of those in the new jobs. Also, they did not include jobs in the supply chain, such as those involved in making wind turbine blades and generators. These are likely to replace existing UK manufacturing jobs.

2) Sea Change: Climate emergency, jobs and managing the phase-out of UK oil and gas extraction (May 2019)

http://priceofoil.org/2019/05/15/sea-change-report/

This report underlines that the UK and Scottish governments face a choice between two pathways that stay within the Paris climate limits:

1. **Deferred collapse**: continue to pursue maximum extraction by subsidising companies and encouraging them to shed workers until worsening climate impacts force rapid action to cut emissions globally; the UK oil industry collapses, pushing many workers out of work in a short space of time.
2. **Managed transition**: stop approving and licensing new oil and gas projects, and begin a phase-out of extraction and a just transition for workers and communities, negotiated with trade unions and local leaders, and in line with climate change goals, while building quality jobs in a clean energy economy.

Given the tightness of remaining carbon budgets, each new license, permit or tax break for oil and gas pushes the UK further towards the deferred collapse path. This report instead recommends the second course; it shows that energy transformation can meet UK climate commitments while protecting livelihoods and economic wellbeing, if the right policies are adopted. Local manufacturing and workforce participation therefore need to guide new approaches to economic development, industrial policy and ownership, together with stronger trade union rights for workers affected by energy transitions.

This report shows that with the right policies, job creation in clean energy industries will exceed affected oil and gas jobs by more than threefold. Such an energy transformation can meet UK climate commitments while protecting livelihoods and economic wellbeing, if suitable policies are adopted, guided by affected workers, trade unions and local communities.

3) One Million Climate Jobs: Tackling the Environmental and Economic Crises (2014)

https://gef.eu/wp-content/uploads/2018/12/GEF_ClimateJobs-brochure-main.pdf

A group of trade unionists, environmental activists and various experts have been working under the umbrella of the Campaign against Climate Change Trade Union Group to show the changes demanded by climate breakdown can offer a million direct jobs, and a further half million in the supply chain. Their work is built around the recognition that rapidly reducing GHG emissions must be at the heart of any UK jobs and training strategy. Their report developed the concept of a 'national climate service' programme, which recognises that – just as during times of emergency in our past – it is government, not the private sector, that can deliver a response on a scale and speed needed to tackle the challenge. (See also *5.2 ZCB and One Million Climate Jobs*)

Conclusions

The research described in these reports makes it clear that a transition to a zero carbon economy is possible, has immense employment benefits and is going to keep us very busy, which will offer many millions of jobs across Europe.

But how do we maximise benefits for people in the UK? The Grantham Institute Briefing Paper 'Co-benefits of climate change mitigation in the UK' (Jennings, Fecht and de Matteis, 2019) explores this. The UK manufactures 20% of the electric vehicles driven in Europe. Our offshore wind sector has created 10,000 jobs – with the highest installed capacity of offshore wind of any country. (6,836MW in 2017 compared to 5,355MW in Germany, the second highest country). Employment in the offshore wind industry has been created in UK regions, such as the Humber and Solent, which need the jobs. The global recognition of the need to move towards net-zero means that the UK is in a good position to further develop expertise and benefit from economic growth and job creation.

Increasingly the trade union movements recognise this and are calling for a 'just transition' that ensures the new jobs offer similar or better wages and conditions, and that workers in industries associated with causing climate breakdown receive relevant training and are able to take up new socially useful jobs. Many believe that diversifying ownership, such as employee, municipal or national ownership models, can help deliver a just and rapid transition.

Maximising the UK's employment and economic co-benefits in all aspects of a zero carbon transition from energy to transport, from land use to buildings, is an important topic, where much more research is urgently required if we are to make the best choices.

3.9.4 Wellbeing – measuring what matters

Wellbeing can be understood as a measure of how people feel, how they function on a personal and a social level, and how they evaluate their lives as a whole (New Economics Foundation, 2012). It is more closely associated with 'quality of life' than 'standard of living' and is influenced by personal and external conditions. For example, physical health (Edmunds, 2013), social connection (House, 1988), satisfying employment (Bryson, 2014), levels of equality/inequality (the Equality Trust reviews the evidence of how inequality affects economies, social mobility and education, health, crime, and trust, participation, attitudes and happiness – see www.equalitytrust.org.uk), and what might be called 'spiritual' factors, such as a sense of meaning and purpose (Steptoe, 2014), gratitude (Macy and Johnstone, 2012) and connection with the natural world (Capaldi, 2014).

In order to understand how wellbeing changes over time we need to measure what matters. As we explore a scenario for moving away from fossil fuel dependency while also preparing for the climate impacts already in the system, we must adopt these new indicators to chart how this influences our wellbeing – both in our personal lives and collectively as a society.

Measures of collective wellbeing

Traditional collective measures, such as Gross Domestic Product (GDP), do not offer a reliable measure of our wellbeing. For example, traffic jams may increase GDP as a result of the increased use of petrol, but obviously not the quality of life. Moreover, if citizens are concerned about the quality of air, and air pollution is increasing, then statistical measures which ignore air pollution will provide an inaccurate estimate of what is happening to citizens' wellbeing (Stiglitz, 2009).

Since the 1970s, the UK's GDP has doubled, but our perceived 'satisfaction with life' has hardly changed (Aked and Thompson, 2011). Such measures not only fail to register the damage we do, they also fail to actually tell us how well we are doing. The New Economics Foundation's (NEF) Happy Planet Index (HPI) is an example of a global measure of sustainable wellbeing (Abdallah et al., 2012). It tells us how well nations are doing in terms of supporting their inhabitants to live good lives now, whilst ensuring that others can do the same in the future. On a more local level, the Happy City project (Happy City, 2016) has synthesised a number of domains to provide better insights into what really matters to local communities in the UK. The resulting 'Thriving Places Index' allows individuals and organisations to look at the strengths and challenges of where they live.

Measures of individual wellbeing

Behind many recent innovations in measuring wellbeing is the New Economics Foundation's 'Five Ways to Wellbeing' report (Aked and Thompson, 2011) which identified a set of five evidence-based actions that individuals can use to improve wellbeing:

- Connect with your friends, colleagues or local community.
- Be active, walk or run, step outside, cycle, play a game, garden or dance; enhanced if this exercise is 'meaningful', e.g. horticulture (Stevens, 2010).
- Take notice, be curious, catch sight of the beautiful and remark on the unusual.
- Keep learning, try something new, set a challenge you will enjoy achieving.
- Give, do something for a friend or a stranger, thank someone, volunteer.

Measuring wellbeing at an individual level is a valuable additional way to evaluate local low carbon projects and compare them over time. The New Economics Foundation has practical advice for community groups, with links to standard and bespoke measures (New Economics Foundation, 2018).

Zero Carbon Britain and wellbeing

Any climate emergency action plan will, of course, require a new approach to many of our current lifestyle choices. The trick is to find synergies between the changes required to reduce our emissions and the changes that can increase our wellbeing. Whilst measuring the impact of our Zero Carbon Britain scenario is challenging, we can use it to begin to explore how a decarbonised society might affect our wellbeing. Ⓡ

For example, our scenario includes challenging consumerism and thereby increasing resilience – both of our environment and our society – by changing our diet, increasing levels of physical activity, and reprioritising how we spend our time. There will be more room for natural spaces around us, more people working closer to nature, and perhaps closer to home. All of these hold the potential to deliver direct benefits to our wellbeing (Stevens, 2010).

By pursuing real needs over induced wants, and through finding ways of defining ourselves and our relationships independent of an excessive focus on material possessions (e.g. via the Five Ways to Wellbeing, for example), we can face up to our fossil fuel addiction and decarbonise our diet, buildings, energy, travel, water, work, clothing, heating and holidays. Rising to this challenge may offer us an additional benefit by way of a rich sense of individual meaning and collective purpose that is perhaps lacking in today's society.

3.10 Other scenarios

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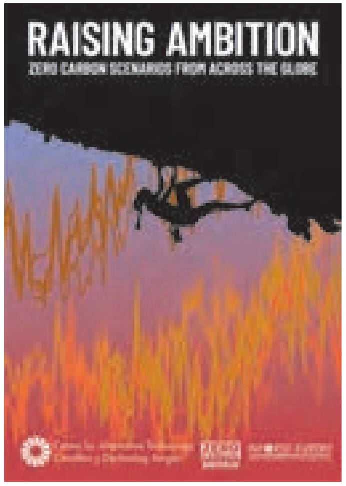
To offer an international perspective, CAT's 2018 report *Raising Ambition* brings together action plans for other parts of the world. From Tanzania to Los Angeles, South Asia to the Baltic, it offers 18 case studies drawn from 130 scenarios that model the levels of ambition needed.

This new 2019 scenario describes a technically feasible climate emergency transition for the UK that could be implemented immediately in response to local and national declarations. It doesn't depend on unproven techno-fixes and illustrates that we can provide our own energy and nutritional needs, whilst fulfilling our role in a global shift to a safer world.

Along the way, however, we have to make some big changes. Mostly we think the changes we propose would have multiple benefits (see *3.9 Multi-solving - benefits beyond carbon*). But there are some things that may be less palatable to some people – eating much less meat and flying much less frequently, for example. However, there are many other potential zero carbon pathways. Here we explore a few of the alternative options. We have not modelled these explicitly and so can't be certain of exactly how (or if) they reach net zero, but we felt it useful to open conversations around what other kinds of futures they could create.



RAISING AMBITION
ZERO CARBON SCENARIOS FROM ACROSS THE GLOBE

3.10.1 Scenario variations using ZCB rules

Even within the rules we set ourselves to create our scenario (see *3.1 About our scenario*), there were options and we had some choices to make. Here we discuss what alternative choices could be like.

Different ways of eliminating emissions from energy

Most scenarios concentrate on energy because it makes the largest contribution to our GHG emissions (around 82% in 2010 (DECC, 2013)). There are very many ways to reduce emissions from the energy sector – David Mackay provides examples in *Sustainable Energy Without The Hot Air* (Mackay, 2009).

In a similar manner we can construct widely different energy mixes that equally serve to deliver a zero carbon supply, and then explain the various choices.

Virtually all analysts agree that a standard mix of renewables will be viable by 2050, if not well beforehand (since we, and many other countries are already generating power using renewables). Any scenario is likely to include biomass of various kinds, hydropower, solar, wave, tidal and ambient heat for heat pumps (these are examples of what might be included in 'other UK generated renewables' in figure 3.40), and a generous wind component (both onshore and offshore). Equally, any scenario would need a reorganised electricity grid. These are common factors in almost all scenarios (Wiseman and Edwards, 2012).

Beyond this there can be substantial differences. In figure 3.40, **Scenario 1** illustrates a kind of mix that features in many conventional zero carbon energy scenarios. Similar to our energy system today, the focus is on supply rather than demand (small amounts of demand reduction meaning a large energy supply is still required), including a fairly high proportion of baseload sources. It relies heavily

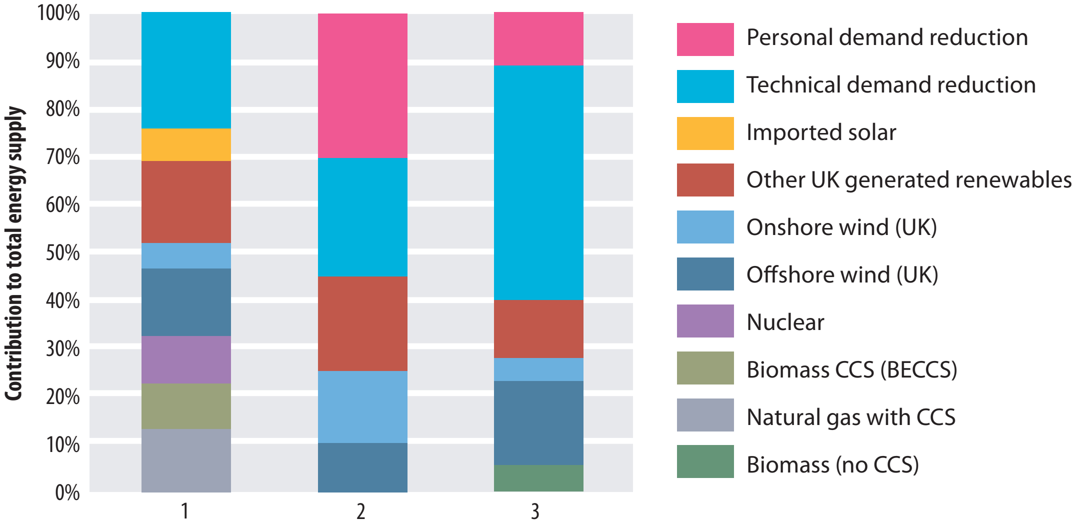


Figure 3.40: Illustrative examples of three different zero carbon energy scenarios. Note these are not calculated, but are illustrations of a concept – the specific percentage contributions of various measures to the energy supply may be different to those presented here.

https://pixabay.com

on nuclear power and biomass energy, plus imports, perhaps via a European super grid. Bending our rules slightly, it uses natural gas with carbon capture and storage (CCS), but because this is not strictly carbon neutral (there are still some emissions from burning the fossil fuel that are not captured (DECC, 2012)), it requires a proportion of biomass with CCS (Bio-energy with Carbon Capture and Storage – BECCS) to provide carbon capture of the remainder of emissions from gas power production.

In complete contrast is **Scenario 2**, which emphasises demand management rather than supply, relying partly on consumers to reduce energy consumption through lifestyle changes – 'personal demand reduction'. It uses only renewables to provide energy, with a particularly large onshore wind component (though again, this energy mix could be vastly different). Within this scenario there could also be a substantial micro-generation element, and possibly decentralised management (community wind turbines or solar farms, for example), resulting in big differences in the types of energy generation in different parts of the country. Occasional shortages and fluctuations in supply might be accepted as a reasonable exchange for low cost and minimal environmental impact.

Scenario 3 is most similar to our ZCB scenario energy mix, with a high level of attention to 'technical demand reduction' (measures like insulating homes and using efficient appliances) and therefore fewer requirements for lifestyle changes. The energy inputs are again all renewable, but provide generous amounts of back up, and an important role for hydrogen (with biomass) in balancing supply and demand (for details on this, see *3.4.2 Balancing supply and demand*). It would be a high-tech and centrally managed system much as we have today, but with more emphasis on demand-side management (see *3.3 Power Down*).

Different ways of reducing other emissions

Any of these alternative mixes would mean emissions associated with energy production would be reduced to zero. But there would still be about 18% of emissions remaining in the scenario (DECC, 2013).

To get to zero, a typical approach reduces these non-energy emissions as far as possible, then balances what remains using a variety of processes that capture carbon. Both these steps can be done in a variety of ways, giving rise to many possible scenarios.

The ZCB approach is to apply technical measures wherever practical. These apply mainly to non-energy industrial, household and business emissions, as well as to those from waste (see 3.5 *Non-energy emissions*).

A major question regarding emission sources that do not have convenient 'techno-fixes' is: to what extent are we willing to change our lifestyles? It is more difficult to decarbonise without social and personal choices and trade-offs. For example, as mentioned in *3.6.1 Agriculture, food and diets*, the best way of reducing emissions from agriculture would be to eliminate meat and dairy products entirely from our diets. Since GHG emissions from flying have an amplified effect higher in the atmosphere, not flying at all would eliminate this component. If we want to eat a bit of meat or dairy, or we want to fly a bit, we have to capture the exact carbon equivalent to achieve net zero emissions.

Fuelling transport (aeroplanes and heavy commercial vehicles, for example) using fuels derived from biomass; feeding ourselves adequately; providing a portion of energy for heating, industrial processes and back up; and capturing any carbon that is still emitted by any of these non-energy processes, all require land, which is limited.

The limitation arises from the need to respect the global context: to minimise claims on overseas land that others might need for their own decarbonisation process.

Unfortunately, there is not enough land in the UK to do everything we are used to doing and still meet the carbon budget. Almost 80% of land in the UK is currently dedicated to food production (the majority of which is used to graze livestock), and only 8% is not currently managed or productive in some way. This 8% likely contains some conservation areas and particular habitats that are rare or protected in some way. In short, there is little space for growing aviation fuel, and not nearly enough space to balance out the current emissions associated with agriculture and/or flying using processes which capture carbon – planting new forests or restoring peatland, for example (see *3.6.3 Capturing carbon* for more detail).

Therefore, an unavoidable change is to relinquish some of the grassland currently used for grazing for other uses. There are trade-offs to be made, for example, between flying and eating meat and/or dairy products – both of which contribute to climate change and take up land. Generally, we find that more of one means less of the other.

To remain zero carbon, each component of land use that still ultimately leads to GHGs emissions (growing biomass for aviation fuel, or grazing livestock) must have a complementary area dedicated to capturing the carbon it emits. We must also be careful not to release carbon from soils and plants when changing how we use land – we have to match our demands on land with the type of land available. In these ways, there are limits on how much of certain activities any scenario can contain and still remain zero carbon. In short, we have to make compromises, and perhaps prioritise lifestyle choices.

In our scenario we provide a balanced, abundant diet for the UK population (but with much less beef, lamb and dairy products); sufficient energy for heating and energy system back up; and sufficient fuel for most of today's transport needs aside from aviation, where we only have enough land to provide for a third of today's international flights. We also double the forested area in the UK and restore peatlands to capture carbon with the added benefits of increased biodiversity and more 'natural spaces' to enjoy.

3.10.2 Breaking the ZCB rules

There are, of course, many other scenarios that could be constructed, by changing the rules by which we play the game. We could, for example, include more technical fixes currently in research or early developmental stages, which would in many cases reduce those last few emissions further and would alleviate some of the demands on land. We've highlighted some promising technologies throughout the report, but have not included them in our scenario.

Furthermore, we could depend on international connections for energy provision – either balancing supply and demand via importing renewable electricity from Europe, or importing fossil fuels and coupling them with CCS and BECCS technologies. This would also reduce demand on land. With these types of changes, it might be possible to keep levels of meat consumption or flying closer to what they are today.

To balance the extra emissions, we could use various forms of geoengineering currently in research and development, such as air capture of CO_2 ('scrubbing'), or store the gas in old, now empty, gas or oil fields. Or we could buy international credits to pay for our remaining emissions – funding the transition to zero carbon economies in less developed nations by paying so that we can emit more than our 'fair share' of GHGs, or paying them to capture equivalent carbon on our behalf.

Overall, however, most of these scenarios involve more speculative technical measures, which may not deliver on time; or they rely on resources elsewhere, of which we could easily take more than our 'fair share.'

3.10.3 Carbon omissions

It is widely assumed that decarbonisation is basically an energy problem. From a world perspective it is true that GHG emissions arise principally from burning fossil fuels but, from a national point of view, direct energy emissions might account for little more than half the total depending on what we define as 'our emissions' – meaning those we are responsible for. Table 3.5 shows the effects on the total GHG emissions of the UK in 2016 by adopting various 'frames' of responsibility.

2016 UK emissions ($MtCO_2e$)	**Frame**
383	Emissions from direct UK energy use.
473	All GHG emissions arising from UK territory, less carbon captured by soils and plants. Often called a 'production account' it is the basis of current international agreements on climate change (the UNFCCC's Kyoto Protocol) and official emissions targets and carbon budgets.
515	***All production GHG emissions, plus those from international aviation and shipping.***
784	Emissions associated with all goods and services consumed, including imports, minus exports. Often called a 'consumption account' or our 'carbon footprint.'
(up to) 884	All consumption emissions plus emissions associated with land use change abroad attributable to UK food consumption, sometimes referred to as 'indirect land use change'.

Table 3.5: UK GHG emissions associated with various frames, and details of what the frames include.
The frame used for our scenario is highlighted in italics. Data is taken from BEIS (2019) and Audsley et al. (2009).

Which are the real UK emissions? There are good and bad reasons for choosing any of these frames but, broadly speaking, decarbonisation gets harder, and more expensive, as you move down the list. That is one reason why governments and most research institutions try to stick to the 'easy end' and assume that the rest will somehow be dealt with elsewhere. But these emissions do occur, and the responsibility has to be picked up somewhere. They are in fact 'carbon omissions' that need to be accounted for if we are to take the mitigation process seriously.

In our scenario we have adopted a compromise frame, incorporating traditional 'production accounts' and international aviation and shipping, but not imports of goods and materials, or land use change abroad that would be attributed to our food consumption.

Land use change abroad

In some accounts, land use change abroad that is attributable to food consumption in the UK amounts to as much as 100 $MtCO_2e$ per year, though our knowledge about the extent of this issue is incomplete. It is a very complex issue, but it is estimated that the problem arises largely from consumption of livestock products within a globalised market – for example, clearing forests to rear cattle that we import and eat, or to grow feed for UK livestock (Audsley et al., 2009).

For this reason, the dietary changes and food importing rules in our scenario – no imports of livestock or feed – can be considered to reduce indirect land use change effects to a negligible level.

The 'stuff' we import

In the ZCB scenario, carbon emissions from imported goods are considered only by stating that our scenario must be part of a concerted global effort to reduce GHG emissions – the UK alone cannot 'solve' climate change. Other nations also have to decarbonise at rates and along trajectories coherent with their fair share of the global carbon budget (see *2.3.1 Our carbon budget*). This means that GHG emissions associated with the production of goods that we import are accounted for globally.

However, it has been widely argued that allocation of responsibility for GHG emissions should not be on the basis of production, but *consumption* (Helm et al., 2007; Druckman and Jackson, 2009). In other words, the emissions from all goods and services should be allocated according to *who consumes them* and not from where they are produced. This is bad news for wealthy countries like us that import a great deal of goods and commodities, but good news for countries that export large amounts, like China.

Of course, whatever the accounting conventions, the total world emissions remain the same – the national totals would just be allocated differently. It could be asked then, if production accounts are good enough for current international agreements regarding emissions reduction, like the Kyoto Protocol, why quibble? The argument, however, is that accounting based on production seems somehow unfair, open to abuse, and leaves a distinct impression of accounting fraud.

For example, on a consumption basis, taking net imports into account, we find that the UK has much higher emissions. Unlike production emissions, which have declined considerably from 818 $MtCO_2e$ in 1990 to 503 $MtCO_2e$ in 2017, consumption emissions have actually increased from 862 $MtCO_2e$ in 1997 to 996 $MtCO_2e$ in 2007 before declining in recent years to 784 $MtCO_2e$ in 2016 (DEFRA, 2019).

Since fairness is likely to be a key component of any international decarbonisation process, consumption as well as production emissions are important when considering nations' contributions to tackling climate change (Wei et al., 2012).

Although we have not modelled it in our scenario, we can make some general suggestions about what we could do to decrease these emissions if we were to include our responsibility for imported goods and still aim for zero carbon. For instance, the emissions associated with the import of food could be reduced from a potential 59 $MtCO_2e$ (Holding et al., 2011) to less than 1 $MtCO_2e$ (assuming a decarbonised energy and transport system), which shows what can be done through a combination of reduction in demand, altered product choice, and increased domestic production (*3.6.1 Agriculture, food and diets*).

Based on this example, a number of additional things could help us decrease the consumption emissions from the 'stuff' we import:

- Reducing how much we buy (or consume), whether it is produced at home or abroad.
- Encouraging long-life products, product-service systems, and much higher levels of reuse and repair. This would also reduce the demand for goods.
- Importing items with lower or zero GHG emissions, including alternative low or zero carbon materials – for example, bioplastics and composites.
- Increasing imports that would constitute additional 'carbon capture' – for example, the import and use of wood products. According to our rough calculations, current use of imported timber and wood products results in an additional 42 $MtCO_2e$ captured per year (see *3.6.3 Capturing carbon*). With more use of plant-based products in buildings and infrastructure, this could go part way to 'balancing out' additional emissions from imports.
- Producing more in the UK – domestic production of which the UK is entirely capable, but has systematically off-shored because production is cheaper elsewhere, could be reclaimed and increased once again. This might mean higher industrial energy demand, and perhaps more non-energy emissions. We might need to install more energy infrastructure and capture more carbon as a result. Fewer imports would, however, decrease fuel demand for aviation, shipping and UK distribution even further.

Having said this, with a somewhat de-industrialised economy deeply dependent on imports for finished goods and raw materials, rapidly increasing domestic production may be problematic for the UK. Furthermore, with higher emissions at the start of the decarbonisation process, we might fail to keep to a carbon budget that would give a reasonable chance of avoiding a 2°C global average temperature rise. The purchase of international credits might be necessary to aid the transition, or a re-assessment of geoengineering options to remove CO_2 from the atmosphere may indeed have to be considered. Neither of these options, however, provide an alternative to decarbonisation – they would simply 'buy us time'.

Using consumption accounting methods would almost certainly make it more challenging to get to net zero, but some of the changes mentioned here might be beneficial to the UK – for example, we might create more jobs by producing more at home.

There are many unanswered questions, and unlike the rest of our scenario, we have not quantified any of these effects or explored the possibilities. How much more energy infrastructure would we need? What are the options for low or zero carbon materials currently? Do we have enough land to capture sufficient carbon? How much might demand for goods reduce?

These are areas we would love to look into in more depth, and will form important subjects for further research.

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ZERO
CARBON
BRITAIN

Chapter 4

Using ZCB

Now that you've read our Zero Carbon Britain scenario, you've begun to get to grips with the scale and speed of the transition required. This is an important first step! Hard though it may be, recognising the magnitude of the climate emergency actions we need to take forms the cornerstone of our response. However, there are many ways to take the next step – joining the 'growing movement calling for change' and 'being the change' ourselves.

Recognising the emergency and acting on it gives us a strong, clear sense of purpose. It makes us feel alive, engaged, expanding who we are and enlarging how we think about ourselves and our relationships with the communities around us. There are many things that need to be done at national and international levels, but if you feel like starting at home, that's OK too – we need both. Together, we will deliver real action!

4.1 Changing how we think about human beings and energy

https://pixabay.com

Humanity's relationship with the incredible amount of ancient sunlight energy stored and concentrated as fossil fuels has brought us into spectacular times.

On the one hand, we have seen incredible advances in technology, medicine, art, science, education and entertainment. In the developed world, life expectancy has increased dramatically and many new medicines are tackling killer diseases. If you have the means, you can have most of the things you could ever want. You can listen to a perfect digital reproduction of traditional Tibetan flute music, whilst watching widescreen 3D images of the beauties of the lower Nile, and eating authentic Chilean cuisine with fresh New Zealand kiwi fruit to follow. If you wish, you can even go there and experience it all first-hand. It is a feast that we all, to a greater or lesser degree, participate in.

On the other hand, the incredible power of fossil fuels has allowed us to manipulate the world as never before. From one day to the next, we must live with, or bury, the psychological and emotional pain of the destruction, corruption, exploitation, globalisation and capitalisation of our ecosphere. Many carry this sadness in quiet solitude, often unconsciously, through life. But as the eyes and ears of the media reach out, we experience the destruction of our planetary life support systems as it happens – a spectacle we all, to a greater or lesser degree, also participate in.

Living with, and trying to reconcile, this paradox is a real problem, leaving many paralysed and confused. The destruction of our life support system is one of the most pervasive sources of anxiety of our time. Environmental groups initially assumed that we don't change our ways because we simply lack information to make sensible decisions and change our behaviour. Experience suggests, however, that most of our numbness and apathy does not stem from ignorance of the facts, or even indifference. We are held fast, sleepwalking through the shopping malls, paralysed and overloaded from the continuous barrage of information we receive. It is estimated that the average American is exposed to more than 3,000 marketing messages every day (Futerra, 2005).

As our understanding of the global climate and biodiversity emergency spreads, we find we have become trapped by our dependence on the systems that are causing it and so are inevitably obliged to conform. Although humanity's present day fossil fuel driven frenzy of production and consumption is affecting us deeply, society has created taboos against the public expression of the associated emotion and anguish. Although most of us are only too aware of the destruction of the ecosystem, it's just too easy to put it in that 'locker' just out of our conscious thought – that place where smokers might keep the knowledge about lung cancer or where heavy drinkers might keep their awareness of liver disease.

We see the crisis, we have the solutions – but the reason it has become an emergency is that collectively society has been far too slow in taking the actions that could avert it, making it increasingly obvious that our entire culture, indeed our entire civilization, has been locked into denial. Denial is the primary psychological symptom of addiction. It is both automatic and unconscious. In psychological terms, denial is a 'defence mechanism'. It defends the individual or collective consciousness from some truth that they cannot afford to acknowledge because it would expose overwhelming feelings of fear, shame or confusion. As long as we remain in denial about climate and biodiversity emergency or the exploitation of the majority world, we are free from the associated pain and can lose ourselves in our day-to-day lives. Yet if we do not deal with these feelings they will manifest as problems in our physical or mental condition. Over the past couple of decades, these collective fears have transformed the way we tell stories about our future: from stories of an exciting new world of progress, to a dark, dystopian world of ecological collapse.

Fortunately, the way we think about humans and energy is changing again – and fast! The climate genie is now out of the bottle: everyone sees the fossil fuel emperor has no clothes. The emergency is now clear, and rising to it is rapidly becoming the new normal. Our relationship with energy is very powerful, shaping how we see ourselves and how we relate to the world around us. As we now begin to rethink this relationship, we can transform our fears into empowerment.

By demonstrating we have all the tools and technologies we need, Zero Carbon Britain aims to open a new chapter in the story of human beings and energy, one in which we may once again talk excitedly about the future…

4.2 Taking action in our homes, communities and places of work

Many of us have now recognised the changes demanded by the climate emergency and wish to bring them to life in the way we live our lives. Not only can we call for action from our local and city government, we can make changes which directly reduce our own greenhouse gas (GHG) emissions, and so transform how we relate to climate action personally. By living the changes that we want to see in the world, we demonstrate that we have both the will for change and the technology for change, which can strengthen our calls to government and industry for a radical and rapid shift in policy. Better policies, in turn, should make it easier to scale up and roll out similar lifestyle shifts across society. We must actively explore how our practical, real life changes can synergise with policy actions at local, national or international levels, to accelerate an evolution in our relationship with energy, transport, buildings and land use. But mostly, we just need to get on and do it…

As we set out to pioneer a path to a zero carbon Britain in our homes, communities and places of work, it is useful to explore how to 'do the numbers' – in other words, to work out where we are starting from so we can assess our progress in cutting our carbon emissions. To help you do this, the Centre for Alternative Technology (CAT) offers a wide range of training from short courses to postgraduate qualifications. Exploring your best way forward will depend on your individual location and circumstance, but there are some common approaches:

- Get informed.
- Get connected – join or start a group.
- Get skilled.
- Learn by doing.
- Make a plan.
- Minimise demand.
- Rethink supply.
- Recycle the savings to help fund your next action.
- Share your experiences openly and honestly with others.

A good way to begin is to map your energy use. Get your hands on your household data and begin to understand how you use different types of energy. You can begin with a list of the types of energy (gas, electricity, petrol, etc.) that you use in a typical week, month and year, and for what purpose you use it. How have costs increased? Be brave; try out your ideas – get rid of your old lamps and fit new LEDs, then compare your past and present electricity bills. You'll be surprised how much energy and money you can save. You can do this as a group, family or on your own.

It has been shown that simply becoming aware of our energy consumption generally means we use less. It is also worth doing a quick 'energy resilience' check for your current lifestyle. What would happen to your personal choices if any of the forms of energy you currently use became very much more expensive, or even intermittent? Assembling this picture is the first step to getting rid of that subconscious, outdated 1950s approach to 'limitless' energy use, equipping you for the process of rationalising your energy demand and addressing your GHG emissions. As well as changing your energy use, our research has identified a range of actions that you can take to reduce your GHG emissions.

As general guidelines, ZCB recommends the following:

- Significantly reduce or even eliminate air flights – take the train, use Skype and holiday more locally.
- Walk or cycle when possible, and avoid taking the car, especially for short journeys.

- Use public transport when you can. Share lifts or join a car share scheme. Invest in an electric car.
- Eat less meat and dairy, and avoid palm oil; this will leasd to huge savings on GHG emissions and biodiversity loss. Going vegan is better still.
- Switch to a green tariff provider for your electricity.
- Invest in insulating your home to the highest level. Use natural building materials and buy wooden furniture. Ensure all the products you use are sustainably sourced.
- Buy things which last, or things made from recycled materials. Reuse, reclaim, recover or mend any items or materials that you can. Think before throwing things away and try to reduce your waste as much as possible.
- Compost your food waste and recycle as much as you can.
- Buy peat-free compost – or even better, make your own.
- Ask yourself whether you really need that puppy or kitten? They are very high consumers of meat.
- Be an active citizen and campaign for the changes you want to see.
- Learn more about the natural world, and spend more time outdoors – it's pretty amazing once you start thinking about what it does for us just by being there.

Some of these actions will be challenging, and there are restrictions to how much we can change as individuals. This is where joining with others can help – both with the practical changes to how we live, and collectively by using ZCB as a way of 'influencing policy' as described in the next chapter. Individual actions on their own are not enough to change the world, but they do play a crucial part.

Humanity now recognises the climate emergency, locally, nationally and internationally. In pioneering real change in our own lives and in sharing our collective achievements, we play a vital role in breaking the dangerous deadlock of 'politics as usual'. While the impacts of individual changes are, of course, relatively small, as more and more of us take them up, they normalise emission reduction behaviours, empower people, help change political norms and so increase the range of policy options.

Influencing policy 4.3

We must develop policies which can transform the way we live within a generation. The evidence base is now crystal clear. Released in October 2018, the Intergovernmental Panel on Climate Change (IPCC) 1.5°C report shows that global science now fully acknowledges a climate emergency situation. In June 2019, an amendment to the Climate Change Act legislated for the UK to reach net zero emissions by 2050, although many fear this is not fast enough.

Since 2007, CAT's Zero Carbon Britain project has offered an evolving set of net zero scenarios to open the new policy conversations required for the transitions ahead. Our work to date has generated significant interest in the UK and overseas. We have presented the findings at several United Nations Climate Conferences, in the UK, Welsh and Scottish Parliaments, and in person to key policymakers.

This new 2019 ZCB report backs up the evidence that we *must* get to zero, by providing the vital evidence that we *can* get to zero. CAT offers this work to support active citizens, innovative businesses, forward-thinking policymakers, creative arts and cultural industries. It is a prototype of a climate emergency response, which can inform the necessary policy innovation across many sectors by clearly demonstrating:

- All the technologies needed to power down demand and power up supply to achieve net zero emissions are ready and waiting.
- Land use, food and diets must be a fully integrated part of our plan.
- Thinking across silos reveals a great many multi-solving co-benefits.

This is backed up by our 2017 *Making it Happen* report which explores the key delivery barriers in politics, economics, psychology and culture – revealing ways we can work together to overcome them.

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The big shift

Over recent months, there has been a massive social and political recognition of the urgency of our collective situation. This has arisen not only from the science, but from the powerful voices of youth school strikes, from the actions of brave citizens taking to the streets across the globe, and from bold elected officials, councils and parliaments declaring a climate emergency.

At the time of writing (September 2019), 330 local and national government bodies have declared across Britain since November 2018: in Wales, the Welsh Parliament and 21 local councils; 261 in England; 10 in Scotland; 2 in Northern Ireland; 2 in Jersey; and the Parliaments of the Isle of Man, Jersey and and Gibraltar. The current global count is 1009 jurisdictions in 19 countries – https://www.cedamia.org/global.

There is now a massive social demand for the detailed sectoral policies which can drive the rapid actions needed to reach net zero. If policy frameworks are to be truly compliant with this evidence base, existing policies must rapidly be reviewed and new policies developed.

Development of new policies must not be limited by a 'business as usual' mindset, as succeeding too slowly is just the same as failing. The scale and speed required challenges the very nature of a capitalist democracy. To have any chance of staying under 1.5°C of warming, no new fossil fuel projects should go ahead. We must recognise the challenge this places on our current system. Policy must demand that all institutions immediately withdraw their support from the fossil fuel industry – be that investments, sponsorships, subsidies or permits. Many are now urging restoration of the corporation's original purpose, to serve the public interest, which requires us to re-establish democratic control over these institutions.

Clean energy technologies have fallen in price faster than anyone expected, but if Britain is to reap their benefits we need bold, innovative policy. We need to build the new skills, new manufacturing and new installation capacity to deliver the deployment rates necessary to meet the emergency goals. Climate emergency action also requires policies that drive specific and well-focused technical research, backed by a national network of innovation incubators. And to maximise multi-solving, cross disciplinary engagement is essential.

To drive this process, policies that under-invest in environmental measures must now end and be replaced with the investment required to support a just transition, ensuring local councils can access the resources they need to deliver on time. If plans and policies do not emerge rapidly, public confidence in our politicians and policymakers will fall. Greater use of deliberative processes, such as citizens' assemblies, could allow politicians, the public and experts to meet on equal terms, assess evidence and agree how targets could be met in ways that improve social and economic outcomes.

Clearly, there is no magic policy bullet or a single policy action which can solve the climate challenge. It will require a wide array of people, from all walks of life, working together to bring about the changes we need to see in the time we have left. Gathering enough momentum to cross the tipping point requires collective action from a wide range of people and organisations. So let's all work together for one big solutions push, and engage with our elected policymakers at all levels – local, national and international – and make a plan for a Zero Carbon Britain!

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4.4

Zero carbon education

The Zero Carbon Britain project provides the framework for the education offered at CAT for all ages. The main themes explored by the Zero Carbon Britain reports – energy, building, transport, nature and green living – are developed through age-appropriate workshops. One example of this is the sustainable building workshop: this can be delivered to everyone from postgraduates to Foundation Stage children with the materials and activities appropriately differentiated. All ages explore sustainable materials and investigate their use. We include a practical, 'hands-on' aspect to all our workshops and have received the Learning Outside the Classroom (LOtC) award accrediting our work.

The message and themes delivered through our workshops are one of positivity – imagining a better zero carbon future and developing the skills to make this a reality. Communicating the issues surrounding climate change and offering a solutions-based approach, with a clear and realistic scientific and mathematical basis, is key to a positive future. Our aim is to encourage understanding and behaviour change.

An essential aspect is also the development of understanding and awareness of biodiversity and the link to climate change; we offer a range of workshops on nature connection as well as enabling learning through citizen science and environmental monitoring projects on site, such as the new Living Wales project.

Teaching Zero Carbon Britain

Elements of the Zero Carbon Britain project and scenario are included in most of the workshops and tours that we deliver. The Zero Carbon Workshop has been developed specifically to communicate and explore the ZCB scenario, and is delivered here on our site as well as a part of our outreach programme to any group of learners from secondary school age upwards; we are currently developing a climate change workshop for younger age groups.

The Zero Carbon Workshop

Scene setting: Students are given information about climate change and other global challenges we face. They are provided with the 'context' of these challenges and of current political targets to reduce greenhouse gas emissions in the UK. This is as topical and up to date as possible. A large map of the British Isles is provided to prompt thinking about available land resources.

Group work: Students divide into groups representing various bodies – for example, agriculture, energy, buildings and transport – and are tasked with developing a zero carbon plan for their sector. They decide how to present their ideas to the rest of the group – through models, drawings, props, etc. Each group has a pack of relevant background information – for example, maps showing the average wind speed over various parts of the UK (onshore and offshore), potential locations suitable for tidal power, UK car use, or the impacts of the food we eat.

Sharing plans: Groups take turns to present their plans to their peers. Debate ensues and groups can adapt their plans to accommodate new ideas or challenges that have arisen.

Summing up: We draw out the main points and conclusions brought up, highlighting common ground and challenges. The group discusses whether their own vision for a zero carbon Britain is technically possible and desirable.

The principles of the ZCB workshop are:

- It allows learners to understand and come to terms with the reality of climate change, our relationship with energy, and the consequent impacts on economy, environment and society.
- It allows learners to develop future scenarios of their own, using discussion and practical resources.
- It provides accurate information on which learners can base their decisions.
- It demonstrates connections between our own actions and the environment and societies around the world.
- It considers quality of life.
- It is a practical activity, including debate, humour and creativity.

This workshop enables us to understand what students know and feel about issues like climate change. It also helps us to work with what they already know and do to identify future potential solutions. And it helps us to encourage them in what they can do as individuals.

The solutions that students develop as part of the workshop are often very similar to the ZCB scenario – the message of both is that we have all the technology and skills that we need; the next step is for us to use it effectively to create a zero carbon future.

Developing your local climate emergency action plan

4.5

A great many people and organisations across the UK are calling for climate emergency action plans for their local areas. They are working with local governments to explore net zero transformations in transport, energy, housing, food, waste, buildings and land use. Many local governments, often at the front line of dealing with climate impacts such as flooding, fires, and storm damage, have now made climate emergency declarations – and are working on climate emergency action plans. This process is happening on many different scales – in urban cities such as Edinburgh or Bristol, in large devolved areas such as Manchester or London Metro regions, in rural market towns such as Machynlleth, or in villages like Wedmore.

But how on earth do local groups and councils kick-start such projects?

Developing your Action Plan

Key elements of the process include:

1. **Declare an emergency**: Work with a wide range of independent local groups, backed by a citizen's petition calling on your council to make a climate emergency declaration, which includes a commitment to planning and delivering the necessary actions with a clear timeline to a net zero end point. Some communities have called for a combined climate and biodiversity emergency declaration. Once successful, this council declaration offers civic ownership of the climate emergency planning process, so widening its engagement, resources and influence.
2. **Clear and open process**: Establish a steering group and relevant working groups by identifying examples of good practice, e.g. potential governance models. The process by which the council's plan is then developed should be as inclusive as possible, as local citizens, businesses, and community groups will better engage in the required actions if their voices have been fully heard from the outset. An open process means getting everyone on board and this will not be done if it's just the usual suspects. The team must think about getting those who aren't interested or motivated on board too and not alienate them in the process. Ensure all minutes can be shared, including to those who don't go online, by placing copies in the local library, for example.
3. **Make it public:** Make a clear civic announcement of the climate emergency declaration and launch the action planning process and timeline, calling for input from citizens, funders, experts and other key players. By using local and social media and through presentations to universities, community groups, campaigners and policymakers, it is possible to create a significant level of public engagement in building the plan.
4. **Mapping**: Identify and engage relevant collaborators – e.g. local universities, industry, experts, non-governmental organisations, funders, young farmers, think tanks and of course citizen expertise. You may wish to seek someone with stakeholder mapping, engagement and facilitation expertise to help map out and inform interactions with processes such as local transport or food waste.
5. **Connect local**: The framing of any process should reflect what is unique or is already happening in the area. It should respect local needs, traditions and culture, linking to important local opportunities such as agriculture, health or local businesses. This helps by embedding any research around the key issues and language which are relevant to your locality.
6. **Boundaries**: Be clear on what areas your action plan has responsibility for, working out who has control of what, and at which level. Making effective action plans means being clear on what the village council, town council or local government has exclusive control over, and where the complex and diffuse boundaries of responsibility lie.
7. **Cross-fertilise**: Identify and build links with relevant research already underway. Are other similar towns or villages further ahead with their action planning process? Are there already existing plans from the councils above or below your level?
8. **Multi-solve**: Think strategically across disciplines and across your local mapping. Don't just think about projects, but consider which projects would bring about the most change (for least cost?) and could leverage co-funding from other areas of public activity. Encourage cross-sector collaborative working, since the changes needed to get to net zero can also create: healthier, more resilient local communities; locally generated renewable energy; affordable public transport; cleaner air; more efficient and easy-to-heat housing stock; greater employment; stronger local supply chains; reduced poverty and fuel poverty; healthier food and land systems with more space for biodiversity. A climate emergency action plan can help inform new

development pathways, offering economically viable and resilient futures for your area.

9. **Tools**: There are now many councils out there making and delivering action plans, and many organisations are helping them with such work. For example, you may want to explore support tools in energy modelling, or social engagement and visioning (e.g. Open Source Energy Monitor – https://github.com/zerocarbonbritain/hourlymodel or Three Horizons – https://www.iffpraxis.com/three-horizons).
10. **Resources**: Developing plans will involve a great deal of detailed work, so it may be worth seeking initial kick-start funding for your 'project team' from key funding organisations, individuals and agencies. But even if there is little initial funding, the current wave of citizen commitment can unleash a great deal of expert volunteer time for your various groups. It is also good to recognise that the delivery of the necessary actions must be publically reflected in the council's annual budget.
11. **Zero Carbon 'expert seminars'**: Expert seminars can bring together a selection of leaders relevant to a working group. It is useful to have a high profile partner organisation to make the invitations, plus an independent facilitator.
12. **Keep up the momentum**: Agree a timeline, including consultations and make key milestones public so everyone knows what's happening.
13. **Celebrate**: Come together as a community to recognise key milestones and celebrate achievements.

How can plans deliver action?

Councils can make change happen simultaneously in several key ways. Here we build a UK perspective on the four key roles suggested by the Australian group CACE (Council Action in the Climate Emergency) https://www.caceonline.org.

Upwards: Once they have declared a climate emergency, local councils can collectively lobby district or county councils for actions beyond their own jurisdiction and to make available the resources needed to enable actions in their areas. They can also advocate for action from national government, including the funding and commitment needed to implement a UK climate emergency action plan.

Downwards: Councils can undertake policy and budgetary development to drive action within their own jurisdiction; for example in the transport systems it runs, its food purchasing contracts for schools or hospitals, the land it controls, the education system it manages, its libraries, arts and cultural venues. To increase resilience and local benefits, a council can also make it clear when any subcontracted tenders are coming up for renewal and encourage bids from social enterprises and local supply chains, as Preston Council has done. Councils also need to support the bodies they have responsibility over – for a district council, this could include the development of 'climate emergency action packs' to support the parish councils within its area.

Sideways: Leading by example encourages others to act. Councils can share both their declaration, plan and actions achieved to date – openly communicating on what works and what doesn't. This can include councils nearby, councils they work with, those they are twinned with and council networks such as Local Government Association.

Inwards: Councils need to educate their own staff about the climate emergency, its causes, the potential actions and the role the council can play in driving a broader climate emergency response. This could include Carbon Literacy training within the council, developing a new approach to decision-making, from the CEO downward. The council can also take strong and immediate action on its own infrastructure, including the energy it buys, the buildings it uses, the roof space potentials for PV, and divestment of its own assets.

Councils will not be able to reverse global warming by themselves, but by working in these four directions they can help deliver meaningful practical actions and put pressure on national government to act. For every aspect there are real life case studies which show what can be achieved. Researching and sharing relevant case studies can demonstrate locally that change is achievable, and can help scale up plans, avoid mistakes and highlight co-benefits, such as jobs, cost savings, health benefits or community cohesion. It is worth considering quick wins – changes that can be achieved rapidly and offer significant emissions reductions.

More information and resources can be found on the CAT website, including training courses, conferences, and our free information service. Please do get in touch if you have any questions and we'll do our best to help. Good luck!

http://www.cat.org.uk

Useful links include:

https://climateemergency.uk

http://www.caceonline.org

https://static1.squarespace.com/static/5a8b2f10017db29af12740d5/t/5c5105ac4ae23755fa8e3739/1548813761390/Darebin_Climate_Emergency_Plan_lo-res_-_web-ready_June_1_2018.pdf

https://policy.friendsoftheearth.uk/insight/33-actions-local-authorities-can-take-climate-change

https://policy.friendsoftheearth.uk/insight/policy-changes-needed-enable-local-authorities-england-deliver-climate-change

https://climateoutreach.org/resources/report-are-the-public-ready-for-net-zero/

https://www.local.gov.uk/councillor-workbook-acting-climate-change

https://www.tcpa.org.uk/planning-for-climate-change

https://www.greatermanchester-ca.gov.uk/media/1986/5-year-plan-branded_3.pdf

http://unlockingsustainablecities.org/A%20Civic%20Plan%20for%20a%20Climate%20Emergency.pdf

http://www.green-innovations.asn.au/RSTI/Local=first-implementation_local-govt.pdf

4.6 Developing a zero carbon model for your area

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The development of a zero carbon scenario for your local area can help optimise your climate emergency action plan. Bringing together findings from all aspects of the research, the model allows the team to explore a range of paths to net zero by varying constraints, assumptions, demand patterns, energy inputs and land use options. This will eventually result in an emerging 'favoured scenario'. To help verify the model it may prove effective to begin by using it to represent the existing system.

The model can be developed in sections that reflect the findings of the different working groups: for example, transport, food, land use and energy supply. This model works best on an annual timescale (looking, for example, at GHG emissions per head of the population, per year), but as the project progresses you might find it useful to model smaller time frames – see 'Dealing with variability' below.

Key elements could include:

- Wide and detailed investigation into models used by other councils, relevant reports, previous research, industry and academic journals.
- Ensuring all data is robust, verifiable, compatible and reliable.
- Full citation of original sources and references.
- Clarity about the assumptions underlying your scenario.

Choosing the software for your model is dependent upon the scale and scope of your research and the skills and funding available. In its simplest form, the model is an accountancy tool, constraining the scenario to a defined carbon budget over the chosen transition period, and enabling a balancing of the books for the supply and demand of energy. Though energy modelling software is available commercially or from research institutions, local carbon models specifically designed for this type of project are hard to come by. This makes it likely that your research team will actually create the best one, encompassing your approach to the problem and based on the data you have available to you. This isn't as daunting as it sounds!

Accessing data

To ensure the model is robust and its results verifiable, input data must be carefully selected. There are benefits to scaling up data from real life renewable projects or measured energy use. However, where necessary you can use theoretical data, or scale down from local authority or national level data. Good data sources include government, industry, energy think tanks and academia (some of this may be sensitive due to it being 'commercial in confidence'). A number of input sources are now being used that were not available only a few years ago. In the UK, for example, the current national breakdown of energy consumption is derived from the government's 'Digest of UK Energy Statistics' (DUKES).

Dealing with variability

Nobody seriously questions the fact that renewable sources like offshore wind can produce a huge amount of energy. However, if we are serious about proposing scenarios where most or all of our energy needs are met by renewables, then we need to be able to explain with confidence how supply and demand are matched at any given moment. To provide a perspective on dealing with variability in your local area, your research could model hourly supply and demand patterns using national weather data and also identify storage options in your chosen area.

Resources

At CAT we are keen to develop more resources to help local groups deliver zero carbon and climate emergency action plans. In addition to our Zero Carbon Britain reports, materials and courses, and the help available from our information service, we want to develop specific tools to assist local groups with the process of producing local plans.

In collaboration with Open Energy monitor, we have begun to explore the process of scaling the Zero Carbon Britain scenario to the local level. Initial examples of this work are available on the Open Energy Monitor website https://learn.openenergymonitor.org/sustainable-energy/energy/scenarios.

Reclaim the future: engaging with arts and creative practice

4.7

Communicating the Zero Carbon Britain scenario includes helping people visualise what it could be like to live in a future where we have actually risen to the challenges of the 21st century. Although hard data is a vital cornerstone, stories are often what works best to change hearts and minds. To offer a context to this, we looked at the stories our society currently uses to portray the future, and how they have changed over time. We quickly became aware that there are actually very few stories being told of a positive 21st century future. Dystopia and ecological collapse almost always abound when contemporary culture looks even 10 or 20 years ahead. Be it a novel, a film, a TV series or the gaming world, the setting is dark. From *Children of Men*, *The Road*, and *28 Days Later* to *The Survivors* – the list seems endless.

Yet back in the 50s, 60s and 70s, the way we projected the future felt very different. The likes of *Dan Dare*, *Thunderbirds* and *Star Trek* were going to take us away to exciting places with transporters, hover bikes and jet packs. As the 70s rolled into the 80s and 90s, the wonders of science and technology were seen to be smashing into the limits of the planet's ecosystems. Alarm signals from the green movement, along with Bhopal, Chernobyl and a wide range of other major catastrophes, led us into a different way of seeing our future. In film, a tipping point was perhaps *Blade Runner*, where the future became much darker. Of course, setting any human drama in a tragic famine situation would not make palatable viewing, so a number of clever tricks are deployed. Either 98% of the population dies from 'the

Image © Culture Declares

virus' before the film begins and the story is based around those relearning to plough with oxen in a deserted Somerset mansion, or 98% of the population are converted to zombies so that if you have to shoot a few dozen of them as you escape the city with the medicine for the sick child, no one thinks any the worse of you. Despite the fact that a great many of us would like to explore the drama of human interaction set against a backdrop in which we are rising to our 21^{st} century challenges, the artists, novelists, filmmakers and playwrights usually choose to paint it black.

But if society is unable to imagine a positive future, then we won't create it. There is, therefore, a need to forge direct links between your local zero carbon work and those working in the arts and sustainability to create a community of practice to catalyse big shifts in how we think. In tackling issues of race, gender and class, the arts and creative practice have demonstrated they can reveal our blind spots and help us see our prejudices; they can break through denial and catalyse a transformation of attitudes and behaviours. The arts offer a much-needed mirror that can help individuals and societies reflect on where we really are, and help us to explore positive stories. The Culture Declares movement is a growing community of creative practitioners and organisations keen to engage with solutions to the climate emergency – https://www.culturedeclares.org/

Although science based reports such as ZCB can show a way forward, when the arts and science work together we can begin to visualise what it might actually be like to live and love in a world where we are rising to the demands of the 21^{st} century, and so begin to reclaim the future.

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End notes, glossary and references

To find out more

Urgent action is needed if we are to avoid dangerous climate breakdown. The Centre for Alternative Technology (CAT) is committed to offering practical solutions and hands-on learning to help create a zero carbon world. A wide variety of useful resources can be found on the Zero Carbon Britain page of the CAT website – these include:

ZCB training sessions: short courses at CAT and other locations.

'ZCB and…': short papers written by a variety of individuals and organisations to explore the zero carbon transition in all aspects of life.

Methodology papers: how we constructed this scenario.

News and updates: news on our research and outreach work.

Other ZCB reports, including:

- *Zero Carbon Britain: Making it Happen*. Rather than an unresolved technical challenge, it is increasingly accepted that we must overcome a mix of political, cultural and psychological barriers. This report investigates what these barriers are and how we can overcome them.
- *Raising Ambition: Zero Carbon Scenarios from Across the Globe*. This report brings together an international range of scenarios exploring climate-stable futures at global, regional, national and sub-national scales.

Getting the skills we need to make change happen

The CAT website links to ways we offer the practical skills and training required:

- Postgraduate qualifications from CAT's Graduate School of the Environment, including Masters courses on energy, buildings, architecture, behaviour change, ecology, food and more.
- Zero Carbon Britain Hub and Innovation Lab to help communities, local authorities and policymakers to create Zero Carbon Action Plans, and support the development of innovative solutions.
- Short residential courses covering a range of skills needed for a zero carbon future, including renewable energy and environmentally friendly building techniques, as well as specialist courses for educators and trade professionals.
- Educational tours, workshops, outreach activities, day visits and residential visits for school groups, universities and educators.

We also offer an impartial, free information service, and our online shop offers a wide range of books on relevant issues. To receive our quarterly magazine Clean Slate, why not become a CAT member and help support our work?

Find out more about any of the above at www.cat.org.uk

Notes

Units

Here is a list of common units we use in this report and what they mean.

°C	degrees Celsius; temperature measurement.
g	gram; unit of weight.
ha	hectare; unit of area of land.
kcal	kilocalorie; energy contained in food.
m	metre; unit of distance.
mph	miles per hour; speed – how fast something is travelling.
MW	megawatt; unit of power; the rate at which energy is produced or used.
MWh	megawatt-hour; unit of energy.
tCO$_2$e	tonne of carbon dioxide equivalent; a measure of greenhouse gas (GHG) impact relative to carbon dioxide (CO$_2$). For example: • Carbon dioxide (CO$_2$) = 1 x CO$_2$ • Methane (CH$_4$) = 25 x CO$_2$ • Nitrous oxide (N$_2$O) = 298 x CO$_2$ • Super GHGs = 124 to 22,800 x CO$_2$ as per the IPCC's Fourth Assessment Report (AR4). However, since the research for the land use model was conducted prior to this update, this uses CO$_2$ equivalence figures from the IPCC's Second Assessment Report (SAR).

Units we use

Ever wondered what we mean by a TWh? Yes, it's a million megawatt-hours, but what does that actually *mean*? Here are some examples to help you get a feel for the units used.

Greenhouse gases (GHGs)

tCO_2e – one tonne of CO_2e. About 1.2 tCO_2e of GHGs are emitted per passenger during a return flight from London to New York; or, about 2 tCO_2e are emitted in the annual commute of one person travelling alone by car from the outskirts of London to the city centre.

$ktCO_2e$ – one thousand tCO_2e. Almost one $ktCO_2e$ would be emitted if we flew the entire UK Olympic squad (541 athletes) around the world once.

$MtCO_2e$ – one million tCO_2e. The city of Oxford was responsible for just under 1 $MtCO_2e$ of emissions in 2003. It is estimated that about 13.1 $MtCO_2e$ is emitted during a year's worth of commuting in the UK.

$GtCO_2e$ – one thousand million tCO_2e. In 2005, global GHG emissions totalled about 45 $GtCO_2e$.

Energy

MWh – one megawatt-hour. A typical UK household consumes around 4 MWh of electricity per year.

GWh – one thousand megawatt-hours. The total energy consumption of Cornwall in 2007 was 12,026 GWh; one supermarket uses about 2.5 GWh of electricity per year.

TWh – one million megawatt-hours. The UK's daily electricity consumption is a bit less than 1 TWh.

Land area

ha – 100 metres by 100 metres. Trafalgar Square in London is about 1.2 ha; a football pitch is about 0.7 ha.

kha – one thousand hectares. The area of Manchester is about 11.5 kha while that of Norwich is only about 3.9 kha.

Mha – one million hectares. The area of Belgium is about 3 Mha. The UK's area, including coasts, rivers and lakes, is about 24.7 Mha.

Acronyms

AD	Anaerobic digestion
BECCS	Bio-energy carbon capture and storage
CCS	Carbon capture and storage
CHP	Combined heat and power
DECC	Department for Energy and Climate Change
FAO	Food and Agriculture Organization
GDP	Gross domestic product
GHG	Greenhouse gas
GM	Genetically modified
HFSS	High fat, salt and sugar
HGV	Heavy goods vehicle
HPI	Happy Planet Index
IPCC	Intergovernmental Panel on Climate Change
NDNS	National Diet and Nutrition Survey
NI	Nitrogen inhibitors
NPS	Nutritional profile scores
PCA	Personal Carbon Allowance
PV	Photovoltaic
REA	Renewable Energy Association
RUK	RenewableUK
TEQs	Tradable energy quotas
UK	United Kingdom
UKCIP	UK Climate Impacts Programme
UNFCCC	United Nations Framework Convention on Climate Change

Glossary

Adaptation – changes that we make to natural or human systems (infrastructure, political systems) to minimise, adjust to, or take advantage of the effects of climate change.
Ambient energy – low temperature heat energy in the air, the ground and water. Can be extracted and 'concentrated' to higher temperatures by *heat pumps*.
Anaerobic digestion (AD) – breakdown of plant material, food wastes and manure by bacteria which produces *biogas* that contains *methane* (CH_4).
Atmosphere – layer of gases around the Earth that protects us by absorbing solar radiation, warms by keeping heat in (via the *greenhouse effect*), and reduces temperature extremes between day and night.

Back up generation – form of electricity generation used when not enough energy is available, usually a form of *dispatchable generation*.
Biochar – virtually pure carbon derived from *biomass* through the process of *pyrolysis*. A portion of the carbon remains stable (not *biodegradable*) for hundreds to thousands of years.
Biodegradable – compostable, material that decomposes or breaks down back to basic elements.
Biodiversity – from biological-diversity; variety in the natural world, including variations within and between species, *ecosystems* and *habitats*.
Biofuel – liquid fuel made from *biomass*.
Biofuel, first generation: biofuel produced from crops such as wheat, corn, sugar crops or vegetable oil.
Biofuel, second generation: biofuel produced from woody material, such as fast-growing trees and grasses.
Biogas – gas containing *methane* (CH_4), the carbon in which originates from recently grown *biomass*. Biogas can also contain impurities such as CO_2, which when removed leave pure or near pure methane. The *methane* in biogas produces energy when burned (like fossil fuel gas).
Biomass – plant and animal material.
Bioreactor – manufactured, engineered or controlled environment designed to encourage decomposition of plant material, usually by adding air or liquid. The gases produced can be captured and used to produce energy.

Cap and Share – *downstream emissions reduction scheme* where a '*hard cap*' is placed on emissions produced by energy suppliers. Emissions permits are shared equally per capita among the adult population.
Carbon budget – or **cumulative carbon budget**; an amount of carbon dioxide (CO_2) or *greenhouse gas* that can be emitted over a budget period. Carbon budgets are used to define the maximum emissions that can occur before there will be a particular risk of various degrees of *climate change*.
Carbon capture – the taking in of carbon (usually CO_2) by natural systems, usually (though not always) through *photosynthesis*. (In this report, the opposite to carbon *emission*).
Carbon capture and storage (CSS) – process of capturing CO_2 emitted as waste (from fossil fuel power plants, for example) and storing it, normally underground or underwater (in old oil or gas fields, for example) to prevent it being released into the *atmosphere*.
Carbon cycle – movement of carbon through the land, oceans and atmosphere in various different forms (for example, CO_2, or carbon in plants).
Carbon dioxide (CO_2) – the primary *greenhouse gas* emitted by human activities. It is the largest contributor to climate change.
Carbon flow – movement of carbon around the *carbon cycle*, for example, *carbon capture* of *carbon dioxide* by plants during *photosynthesis*.
Carbon intensity – amount of carbon emitted to produce a unit of output.
Carbon neutral – GHG emissions are balanced by *carbon capture* such that the net emissions are zero, or neutral.
Carbon neutral synthetic liquid fuel – man-made fuel from the combination of hydrogen and carbon using the *Fischer Tropsch process*. Hydrogen is obtained by *electrolysis* using electricity from a renewable source, and the carbon comes from *biomass*, making the *fuel carbon neutral*.
Carbon neutral synthetic gas – man-made fuel from the combination of hydrogen and carbon using the *Sabatier process*, where the hydrogen is obtained by *electrolysis* using electricity from a renewable source, and the carbon comes from *biomass*, making the gas carbon neutral.
Carbon store – a place where carbon can be kept out of the *atmosphere* for a significant period of time (for example, carbon in the plant matter of trees, or in soils).
Carbon tax – an *emissions reduction scheme* where a tax is

paid on activities that cause *greenhouse gas* emissions.

Climate – defines what the 'normal' and 'extremes' of weather are in a region. Climate is usually defined as 'an average of weather' over about 30 years. Though different places have different climates, the globe as a whole has a defined climate, averaged over all locations.

Climate change – change in global *climate* as a result of increased levels of *greenhouse gases* in the atmosphere (largely from burning *fossil fuels*) that enhance the *greenhouse effect,* causing warming and other impacts.

Combined heat and power (CHP) – systems in which the combustion of fuels generates usable electricity and also heat. Common in industry and for community heating schemes.

Compost – decomposed organic (plant derived) material used as *fertiliser* for soil.

Consumption emissions – *greenhouse gas* emissions from the production of all goods and services consumed by a nation. Includes *greenhouse gas* emissions from goods and services produced for, but not within, a nation (imports). Excludes the *greenhouse gas* emissions from the production of goods and services that are exported.

Contrails – long thin artificial clouds that sometimes form behind aircraft.

Cumulative carbon emissions – sum of *greenhouse gases* emitted year-on-year, creating a total that represents all GHG emissions over a period of time.

Decarbonise – to remove the GHG emissions from a product, service or system by changing the way it is produced or operates.

Demand management – shifting energy demand from times when energy supply is low to times when energy supply is in excess.

Denitrification – the release of nitrous oxide produced when microbes act on nitrogen deposited in the soil by fertilisers.

Dispatchable generation – a form of electricity generation that can be called upon to operate as and when required, for example, as *back up generation*. Ideally, power stations that provide dispatchable generation can increase or decrease output quickly and without efficiency losses.

Downstream – a system whereby the focus is on individuals to change their behaviours (driving, flying, etc.) to reduce GHG emissions.

Ecosystem – a system formed by the interaction of a community of organisms (plants, animals, etc.) and their environment (for example, a chemical system like the water or *carbon cycle*).

Electricity grid ('the grid') – a system of wires and equipment that transports electricity from generators to consumers. The grid must be 'balanced' so that electricity supply matches demand.

Electrolysis – the process of 'splitting' water (H_2O) into hydrogen (H) and oxygen (O) using electricity.

Emissions allowance – emissions permitted by an individual, organisation or nation as designated by an international agreement or *emissions reduction scheme*.

Emissions pledge – amount by which a nation has promised (sometimes set in law) to reduce its emissions relative to a particular year, usually by a certain date (an emissions reduction target).

Emissions reduction scheme – a policy framework designed to reduce *greenhouse gas* emissions.

Emissions cap – total permitted *greenhouse gas* emissions as set by international agreement, government or organisation, usually on an annual basis, resulting in year-on-year reductions.

Emissions trading scheme – a *'soft cap' upstream emissions reduction scheme* where permits to emit *greenhouse gases* are distributed to emitters – mainly industry and businesses. Permits can be traded.

Energy intensity – amount of energy required to produce one unit of output.

Energy crop – crop grown and harvested specifically for the production of energy.

Energy demand – or **final energy demand**; the amount of energy required/consumed, excluding conversion and distribution losses. In this report, this is the same as *final energy demand.*

Energy supply – or **primary energy supply**; the 'raw' energy input before any losses from conversion or transmission processes.

Energy use – refers to energy used by a final user. This excludes conversion and distribution losses, but includes end use inefficiency losses (for example, energy lost as heat by electrical appliances).

Enteric fermentation – occurs during the digestion of food by a cow or sheep (or other ruminant). Methane is one of the by-products of this process.

Fertiliser – provides the necessary nutrients required for plant growth (in addition to sunlight and rain) when applied to the soil. The most common nutrients are *nitrogen*, potassium and *phosphorous*.
Fossil fuel – material made over the course of hundreds of millions of years from plant and animal material that has been heated and compressed by various natural geological processes. The burning of fossil fuels emits additional *carbon dioxide* into the *atmosphere* and contributes to *climate change*.
Fischer-Tropsch process – a chemical process that uses carbon monoxide (CO) and hydrogen (H) to form synthetic liquid fuels.
Fixed offshore wind turbine – offshore wind turbines with foundations embedded in the seabed, in contrast to *floating offshore wind turbines*.
Floating offshore wind turbine – offshore wind turbines floating in the water and connected to the seabed using anchor cables. Can be used in deeper water than *fixed offshore wind turbines.*
Fracking – or 'hydraulic fracturing': the unconventional extraction of oil which involves inserting a mix of chemicals under high pressure into an area underground to release the fossil fuel gas trapped in shale.
Fuel mix – the types and quantity of fuel required by *energy demand.*

Global average temperature – the average temperature of the earth's surface, as measured combining thousands of temperature measurements on land and on sea.
Greenhouse effect – the warming of the earth's surface due to the absorption and reflection of heat leaving the Earth by *greenhouse gases* in the *atmosphere*.
Greenhouse gas – a gas in the *atmosphere* that absorbs heat from the earth and emits it in all directions.

Habitat – a particular area or environment inhabited by a species, plant or animal.
'Hard cap' – emissions are not allowed to exceed an agreed/designated limit (the 'cap').
Heat pump – a technology that extracts and 'concentrates' *ambient heat* from a low temperature source (the air, water or the ground) and delivers it as useful heat at a higher temperature.
Heat recovery ventilation – a type of ventilation in which the heat from exhaust air is transferred to incoming fresh air without the two air sources combining. This reduces both heat lost by ventilation and space heating demand.
Heat store – electricity is used to warm a tank of water, for example (the'heat store'), so that heat is available for later use.
Heat stress – the detrimental impact felt by plants and animals (including humans) when temperatures are too high, or they remain high for long periods of time.
Historical responsibility – the responsibility taken on for GHG emissions in the past when calculating *cumulative carbon emissions* measured against a nation's *carbon budget*.
Hydropower – generating electricity from water flowing downhill.

Industrial emissions – emissions of *greenhouse gases* that are produced by industrial processes (but not related to energy production), usually as a result of chemical processes.
Industrial output – the amount of products produced by industry. It can be measured in monetary value by weight or volume – tonnes of steel, for example.
Infrastructure – physical and social structures that make our society work (for example, roads and electricity grid, or governmental systems)
Insulation – material used in the fabric of buildings to reduce heat loss.
Intensively grazed grassland – grassland that is managed intensively to graze livestock (usually sheep and cows), which is often fertilised.

Kyoto Protocol – international agreement to reduce *greenhouse gas* emissions under the UNFCCC in 1997.

Livestock – animals kept to produce meat or dairy products (usually cows, sheep, pigs and chickens).

Methane – flammable gas with the chemical formula CH_4. It is the chief component of the fossil fuel 'natural gas' but is also produced from biological material in *anaerobic digestion* and other processes (see *biomethane*).
Miscanthus – also known as 'elephant grass', a tall grass harvested usually every year as an *energy crop* with a high *yield.* Used as biomass for producing *biogas*, *biofuel* or *synthetic fuels.*
Mitigation (of climate change) – actions to limit the impact, or rate of, long-term climate change; usually involves

the reduction of *greenhouse gas* emissions.
Monoculture – single plant species (an area that is planted with a monoculture is low in *biodiversity*).

Net energy importer – where more energy is imported than exported.
Nitrogen – a chemical element needed for plant and animal growth. Found in *fertilisers*.
Nitrogen inhibitors – chemicals that block the conversion of nitrogen to nitrous oxide in soils, thereby reducing nitrous oxide emissions.
Nitrous oxide – a *greenhouse gas* with a greenhouse effect roughly 298 times that of *carbon dioxide*.
Non-CO_2 emissions – *greenhouse gas* emissions that are not in the form of carbon dioxide (CO_2). For example, *methane* (CH_4), *nitrous oxide* (N_2O) and *super greenhouse gases.*
Nutrients – substances that provide essential components required for life. These can be minerals for plants, or vitamins required for humans.

Ocean acidification – the process of ocean water becoming more acidic (usually through CO_2).
Offshore wind – electricity production from either *fixed* or *floating offshore wind turbines* situated out at sea.
Onshore wind – electricity production from wind turbines on land.

Passivhaus – a building certified as complying with the Passivhaus standard requires buildings to have a very low heating demand (15 kWh per metre square of floor area per year, or less).
Peak oil – the point at which maximum extraction of oil is reached, and conventional supply sources go into decline.
Peat – type of soil that contains a high level of dead organic matter (plant material) that has accumulated over thousands of years.
Peatland – area of land where *peat* is found.
Permafrost – soil at or below freezing point (0°C) for two or more years.
Personal carbon allowances – a *downstream emissions reduction scheme* where *emissions allowances* are allocated equally per capita within a given population.
Phosphorus – chemical element that is essential for life; low levels can limit growth.
Photosynthesis – the conversion of sunlight into energy by plants. A plant takes in carbon dioxide and uses the carbon to grow new plant material.
Power to gas technology – technology that uses electricity to produce gas. For example, (surplus) renewable electricity can be used to produce hydrogen and, in a subsequent step using the *Sabatier reaction*, methane gas.
Pre-industrial – usually cited as before c. 1750 when the industrial revolution began.
Production emissions – includes *greenhouse gas* emissions from all activities occurring in a territory but excludes emissions from goods and services produced outside the territory but which are consumed within the territory (imports).
Projection (of climate change) – indication from climate modelling of what is likely to happen in the future with respect to global (or regional) climate.
Pyrolysis – the heating of biomass at high temperatures in the absence of air to produce *biochar* and *biogas*.

Renewables – technologies that use renewable sources of energy – that is, those which are continually replenished, such as sunlight, wind, rain, tides, waves and geothermal heat.
Retrofitting – the improvement of existing buildings with energy efficiency measures, such as insulation, better windows and doors, draughtproofing and *heat recovery ventilation*.

Sabatier process – a chemical process that uses hydrogen (H) and carbon dioxide (CO_2) to produce methane gas (CH_4) and water (H_2O).
Semi-natural grassland – grassland that is managed to some extent, though not intensively. Covers a wide variety of *habitats* and is a good *carbon store*. Currently, a large proportion of semi-natural grassland is grazed by *livestock*.
Short Rotation Coppice (SRC) – usually made up of willow and poplar species which are 'coppiced' (cut back) after a few years and which regrow. Coppiced *biomass* can be used to produce heat, for producing *biogas, biofuel* or *synthetic fuel*.
Short Rotation Forestry (SRF) – usually made up of fast-growing species of trees, such as birch, alder and sycamore which are planted and harvested regularly, usually for use as *biomass* for heat.
Smart appliances – electrical appliances with controls that

allow them to alter the pattern of operation and thereby assist the balance of the *electricity grid*.
'Soft cap'– emissions above an agreed/designated limit (the 'cap') are allowed, but prices discourage behaviours that may cause this to happen.
Soil carbon – carbon stored in soils. Can be taken in by soils directly, or transferred through the carbon in litter from plants (dead leaves, branches, etc.).
Solar photovoltaic (PV) – technology producing electricity from the energy in sunlight.
Solar thermal – technology producing heat from the energy in sunlight.
Storage silo – landfill sites can be converted into storage silos so that decomposition of materials is almost entirely stopped, thereby preventing the emission of *greenhouse gases*.
Sustainability – the potential for long-term maintenance of *wellbeing*, dependent on the surrounding environment, economics, politics and culture.
Sustainably managed woodland/forest – woodland or forest that is harvested for timber to produce wood products and is replanted after felling, maintaining *biodiversity*.
Super greenhouse gas – *greenhouse gas* that has a much stronger warming effect than CO_2.
Synthetic fuel/gas – man-made fuel from the combination of hydrogen and carbon: in contrast to fuels with a fossil base (for example, petrol) or *biomass* base (for example, oil seed crops).

Temporary grassland – grassland that is usually harvested on an annual basis; can form part of a crop rotation.
Tradable Energy Quotas (TEQs) – *downstream* '*hard cap*' scheme for limiting *greenhouse gas* emissions. Government sets the cap and a proportion of emissions are allocated to adult household members. The rest of the emissions permits are sold to non-household energy users.
Tidal stream energy – energy created from marine currents caused by changing tides, typically harnessed using underwater turbines.
Tidal range energy – energy created from the difference between high and low tides, typically harnessed by turbines in the walls of structures (barrages or artificial lagoons, for example) that hold back tidal water.

Unconventional oil – oil accessed by unconventional means (for example, '*fracking*'), as opposed to from an oilfield or oil well.
Upstream system – a system whereby the focus is on energy suppliers and fossil fuel users to decrease GHG emissions.

Waste emissions – emissions that are a by-product of a process or system.
Weather – short-term (day-to-day) changes in temperature, rainfall and humidity.
Weather systems – atmospheric dynamics (like pressure and temperature) that typically bring certain types of *weather.*
Wellbeing – social, economic, psychological, spiritual or medical welfare of an individual or group.
Wildlife corridor – an area of habitat (woodland, grassland, etc.) connecting wildlife populations that have been separated by human developments (roads, trainlines, etc.).

Yield – output (for example, energy, biomass or food crop) produced per unit of land.

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Preface

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Chapter 2. Context

2.1.2 Climate change

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Chapter 3. Our scenario: Rising to the Climate Emergency

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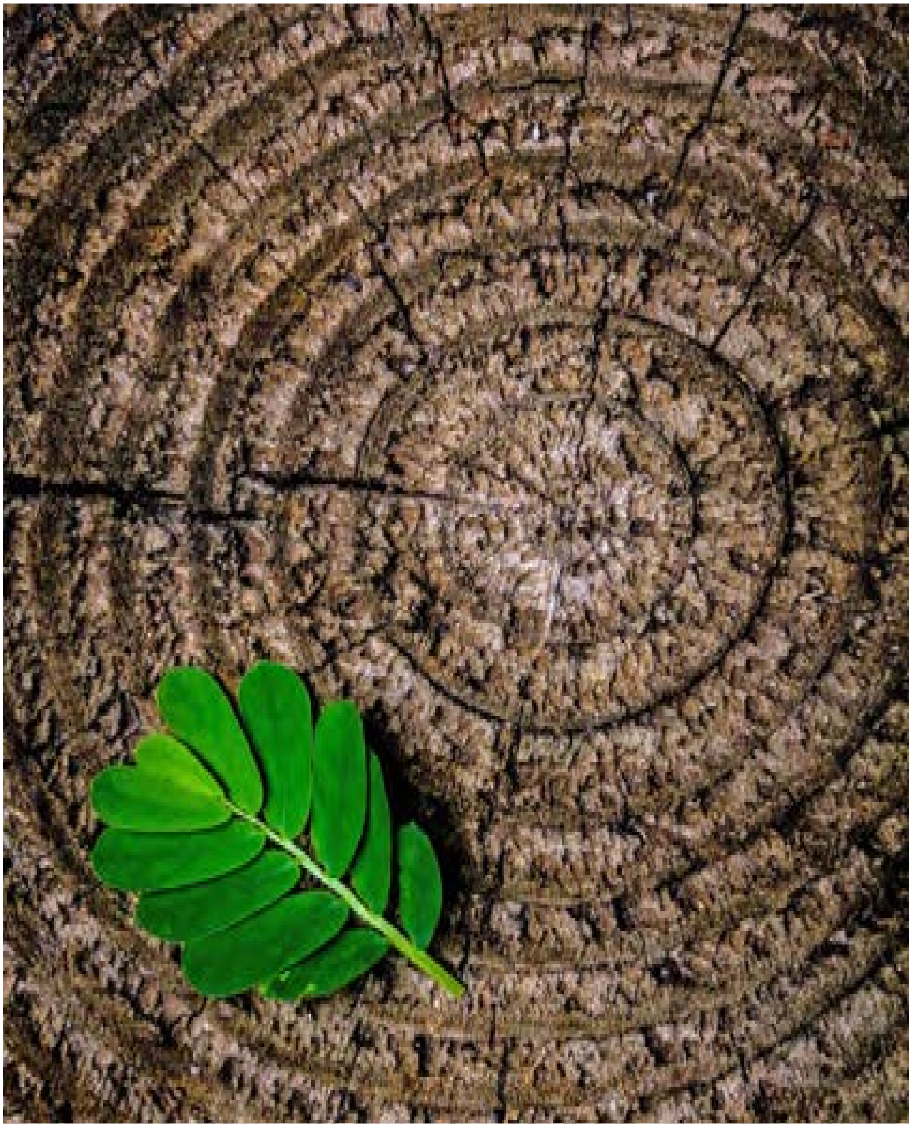

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