United Kingdom Chapter

pathways to

deep decarbonization

2014 report

IDDRI
SciencesPo.

SUSTAINABLE DEVELOPMENT
SOLUTIONS NETWORK
A GLOBAL INITIATIVE FOR THE UNITED NATIONS

Published by Sustainable Development Solutions Network (SDSN)
and Institute for Sustainable Development and International Relations (IDDRI),
september 2014

The full report is available at deepdecarbonization.org.

IDDRI

The Institute for Sustainable Development and International Relations (IDDRI) is a non-profit policy research institute based in Paris. Its objective is to determine and share the keys for analyzing and understanding strategic issues linked to sustainable development from a global perspective. IDDRI helps stakeholders in deliberating on global governance of the major issues of common interest: action to attenuate climate change, to protect biodiversity, to enhance food security and to manage urbanization, and also takes part in efforts to reframe development pathways.

SDSN

Sustainable Development Solutions Network (SDSN) mobilizes scientific and technical expertise from academia, civil society, and the private sector in support of sustainable development problem solving at local, national, and global scales. SDSN aims to accelerate joint learning and help to overcome the compartmentalization of technical and policy work by promoting integrated approaches to the interconnected economic, social, and environmental challenges confronting the world.

Disclaimer

The 2014 DDPP report was written by a group of independent experts acting in their personal capacities and who have not been nominated by their respective governments. Any views expressed in this report do not necessarily reflect the views of any government or organization, agency or programme of the United Nations.

Publishers : Jeffrey Sachs, Laurence Tubiana
Managing editors : Emmanuel Guérin, Carl Mas, Henri Waisman
Editing & copy editing : Claire Bulger, Elana Sulakshana, Kathy Zhang
Editorial support : Pierre Barthélemy, Léna Spinazzé
Layout and figures : Ivan Pharabod

Preface

The Deep Decarbonization Pathways Project (DDPP) is a collaborative initiative, convened under the auspices of the Sustainable Development Solutions Network (SDSN) and the Institute for Sustainable Development and International Relations (IDDRI), to understand and show how individual countries can transition to a low-carbon economy and how the world can meet the internationally agreed target of limiting the increase in global mean surface temperature to less than 2 degrees Celsius (°C). Achieving the 2°C limit will require that global net emissions of greenhouse gases (GHG) approach zero by the second half of the century. This will require a profound transformation of energy systems by mid-century through steep declines in carbon intensity in all sectors of the economy, a transition we call "deep decarbonization."

Currently, the DDPP comprises 15 Country Research Partners composed of leading researchers and research institutions from countries representing 70% of global GHG emissions and different stages of development. Each Country Research Partner has developed pathway analysis for deep decarbonization, taking into account national socio-economic conditions, development aspirations, infrastructure stocks, resource endowments, and other relevant factors. The pathways developed by Country Research Partners formed the basis of the DDPP 2014 report: Pathways to Deep Decarbonization, which was developed for the UN Secretary-General Ban Ki-moon in support of the Climate Leaders' Summit at the United Nations on September 23, 2014. The report can be viewed at deepdecarbonization.org along with all of the country-specific chapters.

This chapter provides a detailed look at a single Country Research Partner's pathway analysis. The focus of this analysis has been to identify technically feasible pathways that are consistent with the objective of limiting the rise in global temperatures below 2°C. In a second—later—stage the Country Research Partner will refine the analysis of the technical potential, and also take a broader perspective by quantifying costs and benefits, estimating national and international finance requirements, mapping out domestic and global policy frameworks, and considering in more detail how the twin objectives of development and deep decarbonization can be met. This comprehensive analysis will form the basis of a report that will be completed in the first half of 2015 and submitted to the French Government, host of the 21st Conference of the Parties (COP-21) of the United Nations Framework Convention on Climate Change (UNFCCC).

We hope that the analysis outlined in this report chapter, and the ongoing analytical work conducted by the Country Research Team, will support national discussions on how to achieve deep decarbonization. Above all, we hope that the findings will be helpful to the Parties of the UNFCCC as they craft a strong agreement on climate change mitigation at the COP-21 in Paris in December 2015.

Contents

United Kingdom

Steve Pye, *UCL Energy Institute*

Gabrial Anandarajah, *UCL Energy Institute*

1 Country profile

1.1 The national context for deep decarbonization and sustainable development

Part of the G20 group of nations, the UK is an advanced economy with trade focused in services, and a declining manufacturing base over recent decades. Once a large producer of oil and gas, declining reserves have increased import dependency in recent years. A large energy infrastructure exists due to the historical reliance on gas for heating and high level of electrification. The changing economy and energy system have led to three key energy policy issues emerging over the last 10 years: energy security, affordability, and system decarbonization.

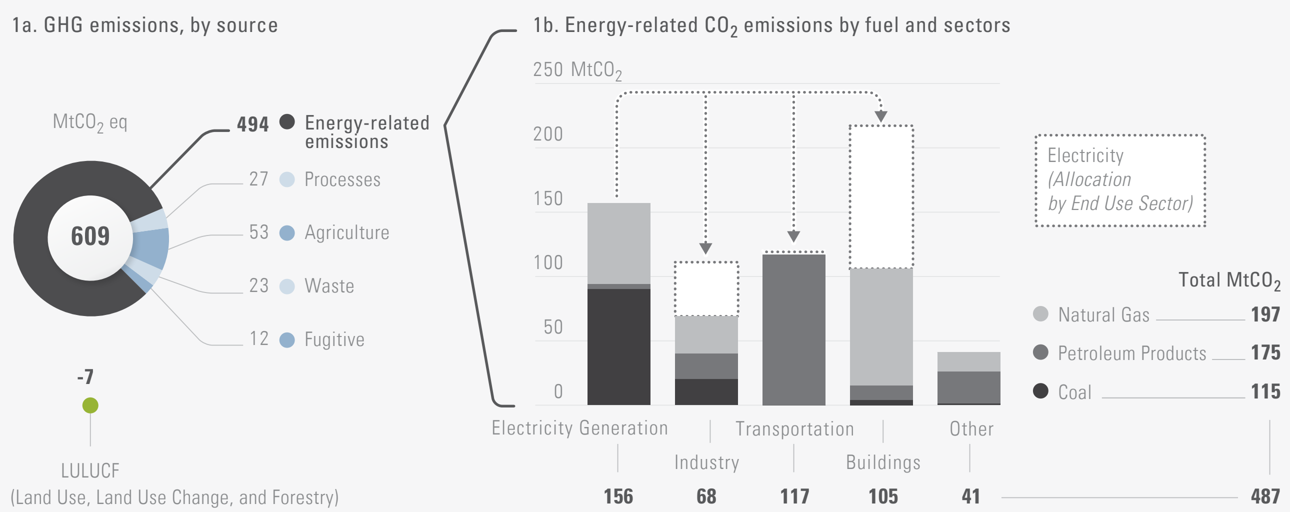
The case for deep decarbonization of the UK energy system was first made in a landmark report by the Royal Commission on Environmental Pollution in 2000,[1] which proposed a voluntary 60% reduction in CO_2 emissions by 2050, recognizing the serious challenge of climate change. Over the decade that followed, the Government undertook a number of strategic analyses, notably in 2003 and 2007,[2] which further assessed

1 RCEP (2000). Energy - The Changing Climate. 22nd report of the Royal Commission on Environmental Pollution. London. TSO.

2 DTI (2003). Our energy future – creating a low carbon economy. Energy White Paper. Department for Trade and Industry. London; DTI (2007). Energy White Paper: Meeting the Energy Challenge. Department of Trade and Industry. London

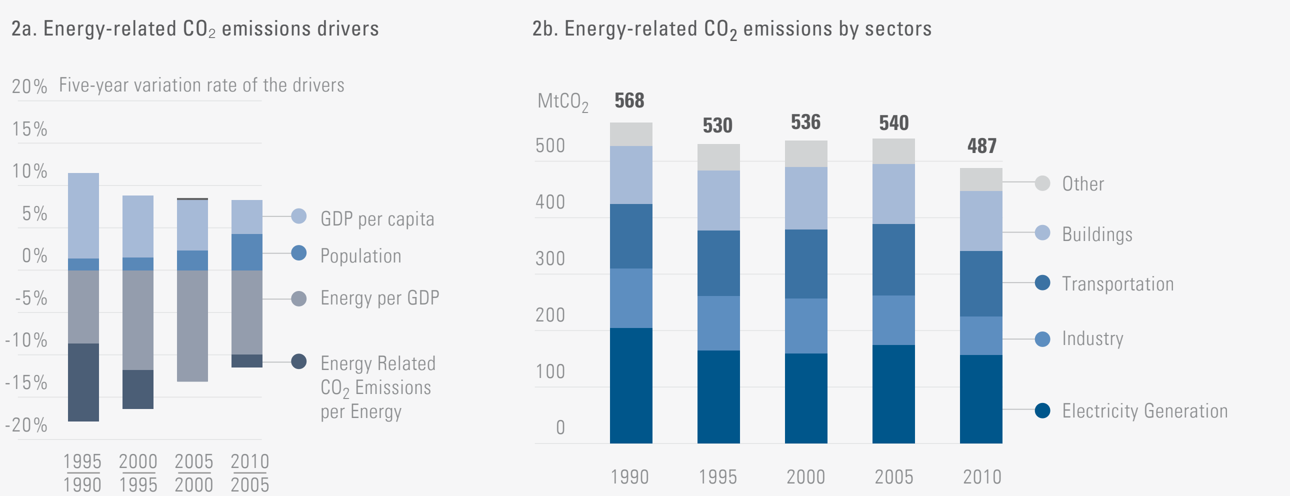
the techno-economic implications of deep decarbonization. These strategies, and supporting modelling,[3] laid the foundation, in 2008, for the UK to be the first G20 economy to legislate a long-term emission reduction target. Under the Climate Change Act 2008,[4] a GHG reduction target of 80% is to be achieved by 2050 (relative to 1990 levels), with a set of 5-year carbon budgets

Figure 1. Decomposition of GHG and Energy CO_2 Emissions in 2010



Source: UK Greenhouse Gas Inventory, 1990 to 2012. Annual Report for Submission under the Framework Convention on Climate Change. April 2014. https://www.gov.uk/government/publications/uk-greenhouse-gas-inventory

Figure 2. Decomposition of historical energy-related CO_2 Emissions, 1990 to 2010



Source: Strachan, N., Kannan, R., & Pye, S. (2007). Final report on DTI-DEFRA scenarios and sensitivities using the UK MARKAL and MARKAL-macro energy system models. Policy Studies Institute / UK Energy Research Centre.

independently proposed and monitored by the Committee on Climate Change (CCC).

The Illustrative Deep Decarbonization Pathway scenario described in this chapter reflects both government-led and independent analysis undertaken over the past five years, assessing a range of transition pathways. Its core focus is on timely emission reductions to ensure that the longer-term target objective is not undermined, and on delivery of these reductions in the most cost-effective way. The scenario also assumes domestic action only, with no explicit use of international offsets.

1.2 GHG emissions: current levels, drivers, and past trends

The level of UK GHG emissions in 2010 was 602 $MtCO_2e$ (excluding international aviation and shipping), 82% of which were CO_2 emissions related to fuel combustion. The three sectors that constitute the largest sources of emissions include power generation, transport, and buildings, accounting for 77% of total CO_2 emissions. In per capita terms, GHG emissions are 9.6 tCO_2e/capita, and 7.9 tCO_2/capita for CO_2 emissions only. Since 1990, GHG emissions have been falling, and in 2010 were 22% below 1990 levels. Over half of this reduction (56%) can be attributed to CO_2 emissions, with the remainder from non-CO_2 emissions. A key driver of the reduction in CO_2 emissions has been the large-scale take-up of gas for power generation (the so-called 'dash for gas'), reducing the UK's historical reliance on coal (Figure 2). The other key driver has been economic restructuring, with large reductions in emissions from industrial energy use (including in the iron and steel sector) over the period and a general shift to a lower energy-intensive economy. Efficiency gains in end-use sectors (buildings, transport) have led to either no growth or small decreases in emissions, relative to 1990, despite rising incomes and population growth. For non-CO_2 gases, the main reductions have been in CH4 emissions from the agriculture sector, and N2O emissions from specific industrial processes.

2 National deep decarbonization pathways

2.1 Illustrative deep decarbonization pathway

2.1.1 High-level characterization

Current government forecasts suggest that the UK economy will continue to grow at around 2.5% over the long term (between 2022 and 2050) and 2.2% in the near term[5] and that population will increase to 70.8 million by 2030 and 76.6 million by 2050,[6] from the current population in 2012 of 63.7 million. These underlying drivers make emission reductions challenging.

3 Strachan, N., Kannan, R., & Pye, S. (2007). Final report on DTI-DEFRA scenarios and sensitivities using the UK MARKAL and MARKAL-macro energy system models. Policy Studies Institute / UK Energy Research Centre. http://www.ukerc.ac.uk/support/tiki-download_file.php?fileId=205

4 Climate Change Act, 2008. Climate Change Act. Available at: http://www.opsi.gov.uk/acts/acts2008/ukpga_20080027_en_1S

5 OBR (2013). Fiscal sustainability report. http://cdn.budgetresponsibility.independent.gov.uk/2013-FSR_OBR_web.pdf

6 ONS population projections, http://www.ons.gov.uk/ons/rel/npp/national-population-projections/2010-based-projections/index.html

This illustrative UK decarbonization pathway has a strong focus on early decarbonization of the power sector by 2030, with low-carbon electricity becoming an enabling route for emission reductions in end-use sectors over the 2030-2050 period, replacing gas use in buildings and use of liquids fuels in transport (see Figure 3). In combination with fuel switching through electrification, robust

Table 1. Aggregate indicators under UK illustrative scenario

Scenario indicators	Unit	2010	2050
Population	Millions	63	77
GDP/capita	US $/capita	35600	75800

Figure 3. Energy Pathways, by source

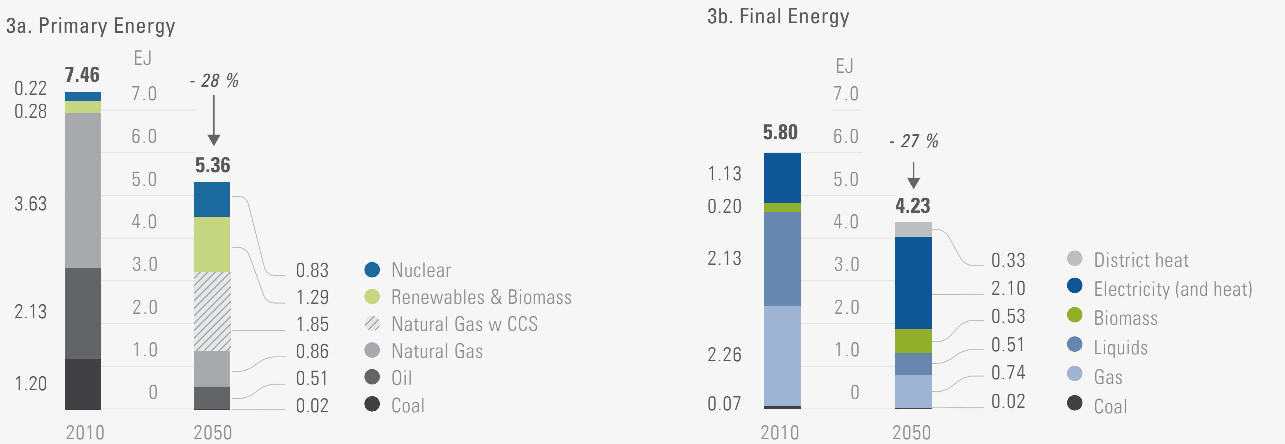
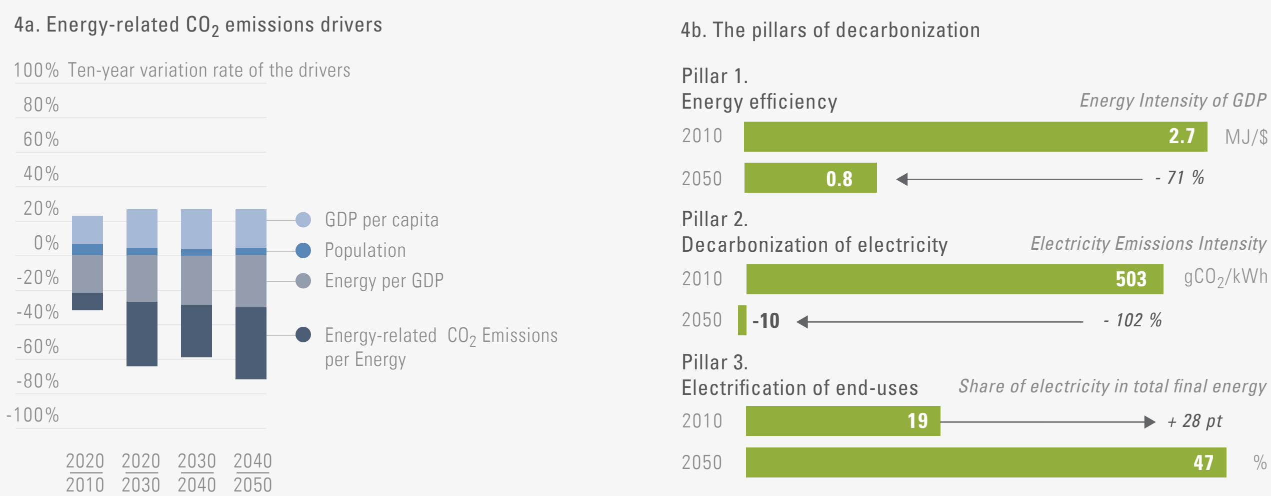


Figure 4. Energy-related CO_2 Emissions Drivers, 2010 to 2050



efficiency and technology retrofit by 2030 in the transport and buildings sectors are also envisaged, with more radical technological and infrastructure change through to 2050, as the energy system further decarbonizes.

The role of biomass is also critical in the decarbonization of the energy system, with a supply of over 230 TWh by 2050, from current levels of around 40 TWh. Use is focused in power generation and district heating, but also in industry and buildings. Biofuel use in the transport sector does not increase by 2050 in absolute terms due to the large-scale reduction in use of oil products, which fall from 46 to 11 Mtoe by 2050. Gas, while only playing a small role in end-use sectors (as shown above), remains important for power generation in CCS plants, and by 2050, the sector uses over 30% more than current levels. Overall, gas use decreases by 23% due to its reduced role in heating buildings and industrial production.

System changes result in energy-related CO_2 reductions being 40% below 2010 levels by 2030 and 68% lower by 2050 (relative to 1990 levels, this is a 57% and 86% reduction respectively). This equates to a reduction in per capita CO_2 levels from 7.9 tonnes in 2010 to 3.6 tonnes in 2030 and to 1.1 tonne in 2050.

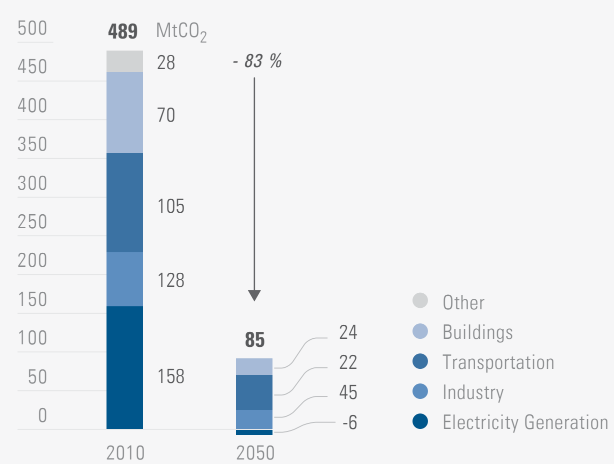
Figure 4 highlights the key drivers of emissions and the impact of pillars of decarbonization. The switch to lower-carbon fuels is a key pillar, with carbon intensity of final energy consumption (FEC) falling 78% by 2050. This reflects increasing electrification of end-use energy services, a shift away from gas use in buildings (-69%), and increasing uptake of bioenergy. Abatement action in power generation plays a critical role in the decarbonization of energy supply; by 2050, the carbon intensity of generation is less than zero. Energy efficiency gains are illustrated by a 21% reduction in FEC and a 71% reduction in energy intensity of GDP. This reflects significant uptake of increasingly efficient technologies, particularly in the transport and building sectors, by 2050. As shown in Figure 4, all of these drivers are decreasing at a rate much greater than growing emission drivers, including population and GDP per capita (Table 1).

Finally, structural and behavioral change play important roles in reducing FEC. In addition to efficiency gains, the reduction in energy intensity of industrial consumption also reflects structural changes in the economy, with growth in high value, less energy-intensive sectors, and a reduction in energy-intensive industries, in part due to global competitiveness impacts. Price-induced behavioral change further reduces energy service demand in passenger transport and building by 7.5% and 10% in 2050, saving an additional 4% of CO_2 emissions.

2.1.2 Sectoral characterization

The change in energy-related CO_2 emission levels highlight the efforts required across all sectors (Figure 5). The power generation sector sees dramatic reductions in both absolute and relative terms. Buildings and transport sectors also see large absolute reductions although re-

Figure 5. Energy-related CO_2 Emissions Pathway, by Sector, 2010 to 2050

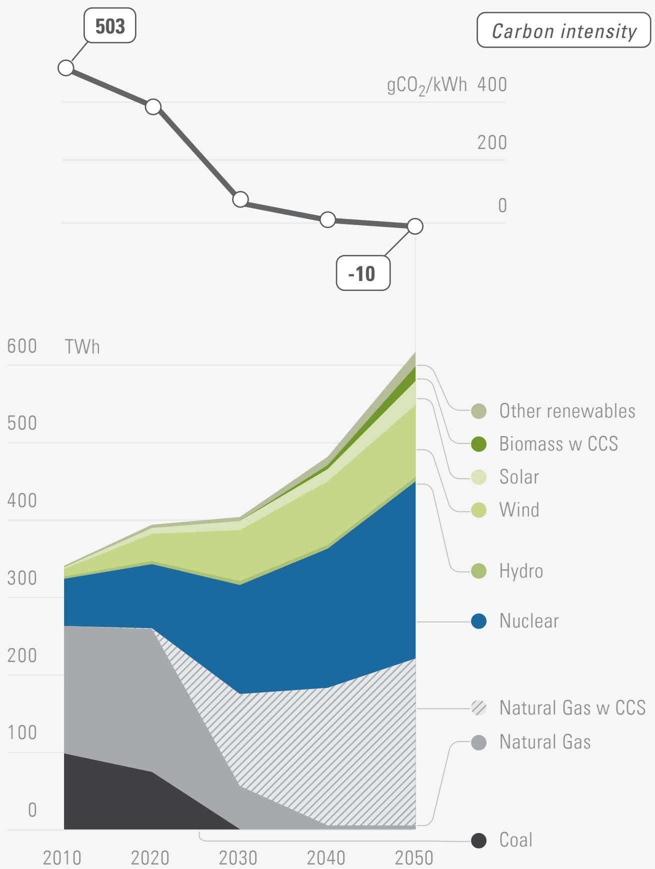


tain similar shares of overall emissions. Overall, energy-related CO_2 emissions decrease by 83%. Lower reductions in non-CO_2 emissions of 57% mean that their share of total emissions in 2050 nearly doubles, to around 35%.

Power generation

This scenario is characterized by early decarbonization of the power sector and a large expansion in capacity to enable electrification of end use sectors. To achieve this, investment in 30-40 GW of low-carbon capacity in the 2020s is required, reducing carbon intensity of generation from a current level of 500 gCO_2/kWh to well below 100 gCO_2/kWh by 2030. By 2050, a large expansion in nuclear and gas with CCS and wind is envisaged (Figure 6), all well within the estimated UK wind and CO_2 storage resource potential. The overall capacity of the system is expected to increase to more than 140 GW, from the 2010 level of 88 GW. The intensity of carbon generation falls to below zero, due to the generation of electricity from biomass with CCS, which saves an estimated 19 $MtCO_2$. With over 50 GW of intermittent capacity on the system in 2050, there is a continued role for open cycle gas turbine (OCGT) plant as backup and other grid-based and end-use sector storage technologies.

Figure 6. Energy Supply Pathway for Electricity Generation, by Source



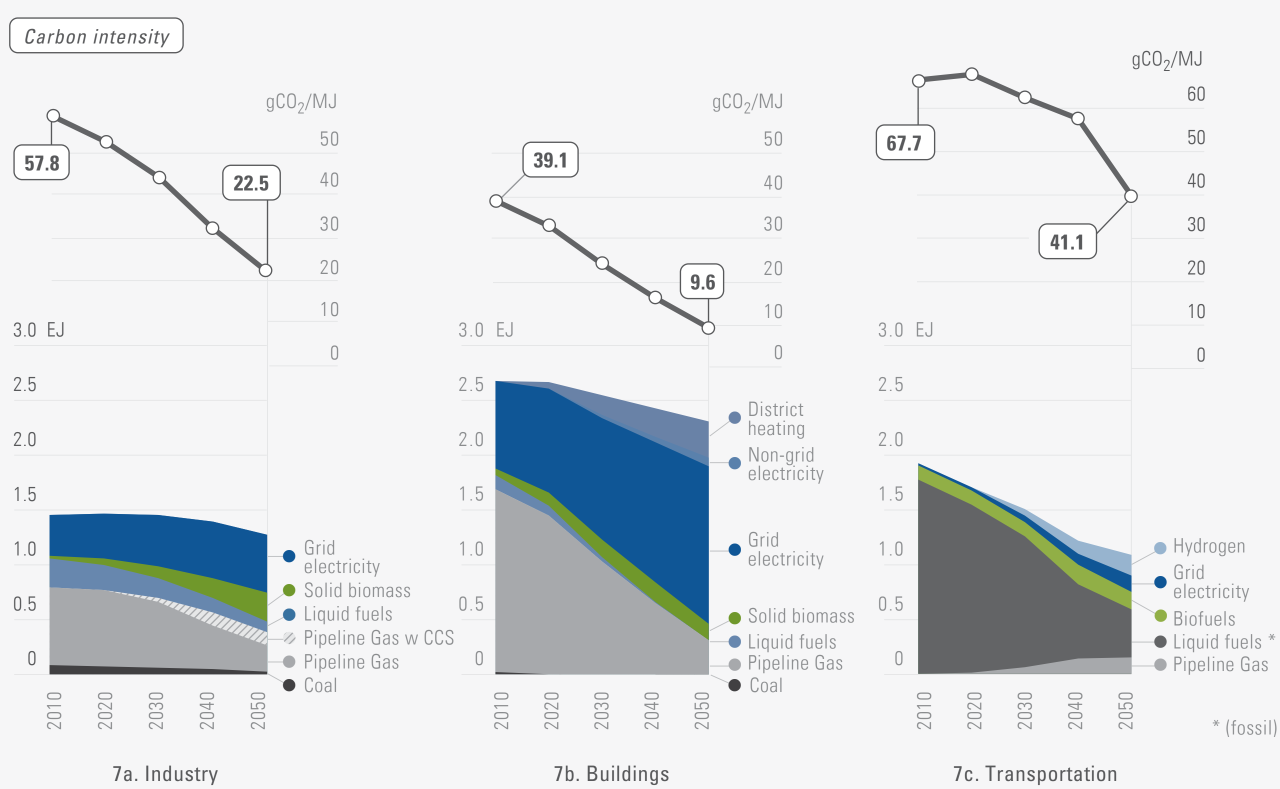
End use sectors

Strong growth in passenger and freight transport demands to 2050 make deep emission reductions especially challenging. Passenger demand is driven by population growth, and an 8% increase in per capita demand for passenger travel along with a 45% increase in freight transport demand reflecting a growing economy and increasing per capita consumption. As a result, the transport sector accounts for around 50% of energy-related emissions in 2050 (Figure 7). In the car vehicle stock, action to reduce emissions is first through a strong transition to hybrid vehicles in the 2020s and then to plug-in hybrid/battery electric vehicles (EVs) in the 2030s and beyond. By 2050, 65% of car passenger travel is met by EVs. Limited penetration of a hydrogen network in specific regions sees hydrogen provide only 20% of demand. Overall, efficiency of road passenger travel increases significantly, with a 40% reduction in FEC despite growing demand. Transport road freight sees a move towards hydrogen and dual gas fueled vehicles. Diesel still accounts for 30% of road freight demand but with a higher share of biodiesel than observed for lighter duty vehicles.

Energy demand in residential buildings is based on projected growth in dwellings of 34% between 2010 and 2050, rising from 26.6 to 35.5 million. While constituting a much smaller share of total energy use, commercial sector floor space is also projected to grow from 0.55 to 0.86 billion m^2. The key mitigation actions in this sector include retrofitting of the existing build stock using a range of different energy efficiency measures (near- to mid-term) and decarbonization of heat through electrification (heat pumps/resistive electric heaters) and district heating (mid- to longer-term). District heating is primarily supplied via waste heat recovery, biomass, and gas. The scenario suggests a pathway that radically reduces the role of gas for heating in buildings, with supply reducing from 44 to 7 BCM by 2050.

Industrial sector emissions fall in part due to a reduction in energy intensity of production, which decreases from 62 to 35 toes/£m. This is both due to efficiency gains and ongoing industrial restructuring, with a move to higher value production sectors (for example, in chemicals) and shrinking energy intensive production capacity (including iron and steel and non-ferrous metals). The decrease in the carbon intensity of FEC (Table 2) reflects fuel switching to electricity and biomass, accounting for about 70% of total FEC in 2050, and industrial CCS on industrial plants which continue to use gas.

Figure 7. Energy Use Pathways for Each Sector, by Fuel, 2010 – 2050



Note: Carbon intensity shown in Figure 7 for each sector includes only direct end-use emissions and excludes indirect emissions related to electricity or hydrogen production

2.2 Assumptions

The decarbonization pathway described relies on a large-scale shift to low-carbon power generation, based on a portfolio of options including nuclear, CCS, and renewables, particularly wind. Nuclear capacity is 32 GW in 2050, implying a build rate of 1 GW/year from 2020, the date when the first 3rd generation plant is planned to have been built. Higher annual build rates for gas CCS capacity of 1.5 GW will be needed, which will be challenging given the technological and CCS infrastructure novelty. Once demonstrated, the UK is well placed to benefit from this emerging technology, with significant storage capacity for captured CO_2, particularly in the North Sea. The technical capacity of the UK (including continental shelf) is estimated to be in the region of 70 billion tonnes, sufficient to store a 100 years' worth of current emissions from the energy sector.[7] Wind generation also plays a strong role in this scenario, providing almost 100 TWh in 2050, based on capacity levels of 35 GW, which is well within the practical resource potential available of over 400 TWh for UK.[8] Implied build rates of under 1 GW are similar to those being currently observed in the UK.

The building sector offers strong potential for retrofit to reduce energy use through fabric upgrade. In 2030, the CCC estimate annual savings of 7 $MtCO_2$ (sector emissions are approx. 40 $MtCO_2$).[9] Key measures include solid and cavity wall insulation, loft insulation, improved controls, and behavioral measures. However, there is also an important heat replacement effect due to more efficient appliances, which increases heating requirement (and reduces savings). Rapid switching to heat pumps and establishment of large numbers of district heating schemes see the gas distribution grid redundant by 2050. In household terms, this equates to 20 million homes switching to these systems from gas by 2050, or an average of 500,000 per year over the period.

The electrification of passenger road transport is assumed to take place at scale in the 2030s. This assumes EVs will be cost-competitive, the required manufacturing capacity is in place to meet demand, and a level of charging infrastructure is in place that provides confidence for uptake. This scenario assumes around 25 million EVs are on the road by 2050. Penetration in the market place during 2020s of 20-25% of new cars sales (on average) could establish a fleet of 5 million EVs by 2030. Post-2030, stronger growth would be required, with EVs accounting for 50-60% of new car sales.

Biomass plays an increasingly important role in the energy system transition. The bioenergy levels used in the UK scenario are in the center of the range of resource potential considered in recent UK analysis, taking account of the share of global resources.[10] Modelling for this analysis suggested optimal use in power generation with CCS, if this option was available. This is reflected in the UK scenario described in this chapter, alongside a strong role in buildings (including district heating provision) and industry.

7 DECC (2012). CCS Roadmap: Supporting deployment of Carbon Capture and Storage in the UK. Department of Energy & Climate Change. April 2012. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48317/4899-the-ccs-roadmap.pdf

8 CCC (2011). The Renewable Energy Review. Committee on Climate Change, May 2011. http://www.theccc.org.uk/

9 CCC (2013). Fourth Carbon Budget Review – part 2: The cost-effective path to the 2050 target. Committee on Climate Change. December 2013. http://www.theccc.org.uk/

10 CCC (2011b). Bioenergy review. Committee on Climate Change. December 2011. http://www.theccc.org.uk/

2.3 Alternative pathways and pathway robustness

The pathway described for the UK is challenging and requires a substantial diffusion of a wide range of mitigation options. However, it is important to highlight that many other decarbonization pathways are technically feasible and could be delivered under the right conditions. A recent UK synthesis study draws out commonality across modelling studies, but also highlights the different options that could achieve deep emission reductions, particularly in the power sector.[11] Uncertainty analysis published by the CCC highlights differences in deployment of renewable technologies. Even when both nuclear and CCS are available, shares of renewable generation ranged from 30% to 94%, with most solutions in the range of 40% to 70%.[12] This highlights the uncertainties even where all options are available and that the illustrative pathway presented here is one of many plausible futures.

Further analysis is being undertaken in the UK to explore other uncertainties in energy system decarbonization, and what that means for different pathways.[13] What is evident from such analyses is that reductions, particularly in the power sector, can be achieved by a range of different technologies. However, the non-availability of key technologies such as nuclear and/or CCS increases costs substantially, and tends to both increase the role of renewables and reduce the role of electrification in the energy system.

In the transport sector, under an alternate pathway, hydrogen-fuelled vehicles can play an important role as a dominant vehicle technology especially for passenger cars. This depends on the cost assumptions of the relative fuel production systems, the technology and infrastructure costs, and the system-wide role for electrification. For road freight, there is less flexibility, due to the limited role for electrification. Switching to natural gas and hydrogen-based vehicles is therefore critical. There could also be a stronger role for biofuels across the transport system, the penetration of which has been limited in this scenario.

Electrification of heating in buildings has been a strong feature of most modelling analyses undertaken in the UK, as gas use rapidly decreases out to 2050. Alternatives to electricity-based heating (through heat pumps) include increasing use of bioenergy, solar thermal, and district heating, which is a key element of this scenario. In summary, a significant role for electricity is required in the UK for decarbonization, although the extent of its role can be balanced against other options.

Further systematic assessment of robustness of different pathways is needed, to better understand what are the key technologies and associated uncertainties that impact deep decarbonization. From a UK perspective, key issues around pathway robustness include ensuring security of electricity supply given higher peak demand and a more intermittent supply, maintaining bioenergy supply, and delivering demand-side reduction. Recent analysis assessing the impacts of key uncertainties on delivery of decarbonization pathways analysis points to critical assumptions concerning the availability of biomass (due to its use for delivering negative emissions in 2050), and the price of gas and

11 Ekins, P., Keppo I., Skea J., Strachan N., Usher W., Anandarajah G. (2013). The UK Energy System in 2050: Comparing Low-Carbon, Resilient Scenarios. (UKERC Report UKERC/RR/ESY/2013/001). UK Energy Research Centre: London, UK. http://www.ukerc.ac.uk/

12 CCC (2011). The Renewable Energy Review. Committee on Climate Change, May 2011. http://www.theccc.org.uk/

13 Trutnevyte, E., & Strachan, N. (2013). Nearly perfect and poles apart: investment strategies into the UK power system until 2050. International Energy Workshop 2013.

cost of nuclear in determining the generation mix.[14] The prospective role played by demand reduction and other behavioral change measures is also highly uncertain but critical in the mix of demand and supply-side responses needed for meeting stringent targets.[15]

2.4 Additional measures and deeper pathways

Additional reductions beyond those considered in the illustrative pathway significantly increase abatement costs and stretch credibility of technology deployment rates. Modelling studies have considered more stringent decarbonization levels,[16] using scenarios to explore CO_2 reductions of 90-95% below 1990 levels (95% is equivalent to ~0.4 tCO_2/capita). These scenarios are by nature exploratory but do provide some interesting insights. In the power sector, CCS becomes a less relevant technology, due to the residual emissions, resulting in larger nuclear and renewable capacities. The exception is biomass CCS (in one analysis), which provides important negative emission credits. In the transport sector, the share of biofuels increases while all hydrogen production is fully decarbonized. In a number of scenarios, it is only the increased role of price-induced demand response that allows the model to meet the stringent reduction levels.

The feasibility of this level of reduction is questionable, both from a techno-economic and political perspective. Most of these analyses suggest marginal costs of abatement of over \$US 1,200/tCO_2 or higher by 2050. The question is whether this level of mitigation could be incentivized and whether political will could be sustained. However, it is also worth noting that most modelling studies do not account for radical social change resulting in changing behavior. For example, there are a range of measures in the transport sector that could lead to radical demand reductions e.g. modal shift, including a move to non-motorized transport, changes in patterns of living/work aided by urban planning, and increased uptake of telecommunications as an alternative.[17]

2.5 Challenges, opportunities, and enabling conditions

Transforming the energy system requires strong and maintained policy interventions in technology development, leveraging capital investment, removal of market barriers, and enabling behavioral change. In the power sector, a key challenge is the scale of investment required in low-carbon technologies. For strong decarbonization of the sector by 2030, estimates of total cumulative investment range from £200bn to over £300bn. Based on recent analysis, this means an average investment requirement of £6.1bn/year (3.4 GW per year of new capacity) to 2020, increasing to £12.3bn (5.7 GW) to 2030 due to the increased construction of capital-intensive low-carbon plant, and greater levels

14 Pye, S., Sabio, N. & Strachan, N. (2014). An integrated systematic analysis of uncertainties in UK transition pathways. UKERC Working Paper. London, UK: UK Energy Research Centre (UKERC).

15 Pye, S., Usher, W. & Strachan, N. (2014). The uncertain but critical role of demand reduction in meeting long-term energy decarbonisation targets, Energy Policy (Accepted).

16 i) AEA (2011). Pathways to 2050 – Key Results. A Report to the Department of Energy and Climate Change. May 2011. AEA, London. ii) AEA (2008). MARKAL-MED model runs of long term carbon reduction targets in the UK, Phase 1. Authored by Pye, S., N. Hill, T. Palmer, and N. Ozkan. On behalf of the Committee on Climate Change. November 2008. iii) Usher, W. and Strachan, N. (2010). Examining Decarbonisation Pathways in the 2020s on the Way to Meeting the 2050 Emissions Target. On behalf of the Committee on Climate Change. November 2010.

17 For example, see Anable, J., Brand, C., Tran, M., & Eyre, N. (2012). Modelling transport energy demand: A socio-technical approach. Energy Policy, 41, 125-138.

of plant retirement.[18] Mitigating investment risks is critical; the Electricity Market Reforms (EMR) introduced by the UK Government seeks to incentivize large-scale investment in less mature low-carbon generation.[19]

Notable uncertainties remain about the viability of CCS, since it has not yet been sufficiently demonstrated at scale. A strong focus now on CCS by the UK and other countries could see its wide-scale deployment in the late 2020s. Strong capacity in the offshore industry means the UK would be in a good position to benefit from this technology (as is the case for offshore wind). Demonstrating cost-effective deployment of the first new nuclear reactor in the UK in 20 years (at Hinkley Point C) will be critical to increase acceptability on cost grounds, as well as broader public acceptability. An increased role for renewables, particularly wind, could lead to increased technical operational challenges due to the higher share of intermittency. However, analysis suggests that high shares need not materially impact the security of supply given a range of options to address intermittency, such as demand response, storage, and interconnection.[20] Finally an additional challenge is high infrastructure costs. For wind, other renewables, and CO_2 storage, much of the resource is offshore and often located in remote areas, such as Northern Scotland.

Decarbonization of heat in buildings will require a radical shift away from piped natural gas (and potential decommissioning of the gas distribution system) to electrification via heat pumps and/or introduction of district heating systems. Large-scale uptake of heat pumps will require householder incentives for switching and a supply chain capacity to be in place. There may also need to be significant reinforcement of the electricity distribution system, especially with smart metering and two-way flows of electricity. District heating systems will require a financing mechanism, perhaps via local authorities, and could run up against public acceptability issues.

Electrification of road passenger cars (especially for the 70% of travel demand that is made up of trips of less than 50 miles) is a key mitigation option. A major challenge concerns large-scale uptake which will be dependent on some level of charging infrastructure, and the necessary incentives to get around the higher costs associated with the battery technology.[21] In a recent study, three key uncertainties were highlighted to large-scale uptake, as envisaged under this scenario: 1) long-term certainty across different incentives, 2) lack of an integrated payment mechanism for EV charging, and 3) more robust methodologies for the estimation of the environmental performance, costs, and range limitations to ensure confidence.[22] Points 1) and 3) are also relevant for other low-emission vehicles, such as hydrogen.

For the industry sector, limited modelling on economic structural change, the role of CCS, and potential for fuel switching make the uncertainties considerable. Capturing the impact of global de-

18 Blyth, W., McCarthy, R. & Gross, R. (2014). Financing the power sector: is the money available? UKERC Working Paper. UK Energy Research Centre. London, UK.

19 DECC (2013). Electricity Market Reform Delivery Plan. Department of Energy and Climate Change. December 2013. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/268221/181213_2013_EMR_Delivery_Plan_FINAL.pdf

20 Poyry (2010). Options for low-carbon power sector flexibility to 2050. Report to Committee on Climate Change. October 2010. http://www.theccc.org.uk/

21 Element Energy (2013). Pathways to high penetration of electric vehicles. December 2013. http://www.theccc.org.uk/wp-content/uploads/2013/12/CCC-EV-pathways_FINAL-REPORT_17-12-13-Final.pdf

22 Morton, C., Anable, J. & Brand, C. (2014) Perceived Uncertainty in the Demand for Electric Vehicles: A qualitative assessment. UKERC Working Paper. London, UK: UK Energy Research Centre (UKERC).

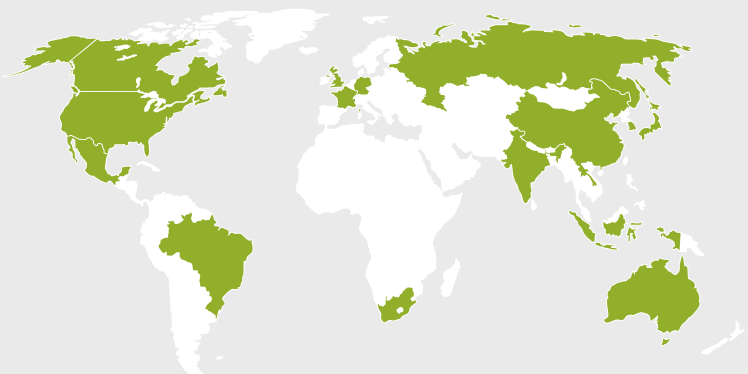
carbonization on UK industry is also challenging. In terms of burden on different industrial groups and regions, government action will be needed to mitigate such distributional impacts.

2.6 Near-term priorities

Whilst challenging, and with large inherent uncertainties, a transition to a low-carbon economy is an opportunity for significant investment in R&D and infrastructure. This could have major benefits for economic growth due to the emergence of new industries and investment, whilst replacing and developing new energy infrastructure. A move towards a lower-carbon technology and resource base could also strengthen energy security.

It is clear that the Government has a strong role to play in creating the right investment environment for the transition. Key actions, many of which have or are in the process of being developed, include:

- Maintaining the political will to enact the independently set 5-yearly carbon budgets with a corresponding set of implementation policies that are backed across government.
- Through electricity market reforms, incentivizing investment in low-carbon generation that is capital intensive, less mature, possibly more intermittent, and requires significant payback periods.
- Focusing R&D on technologies that the UK can develop economic benefits from, including offshore renewables but also in automotive industries and other energy technology manufacturers.



COUNTRY RESEARCH PARTNERS. Australia. Climate Works Australia; Crawford School of Public Policy, Australian National University (ANU); Commonwealth Scientific and Industrial Research Organization (CSIRO); Centre of Policy Studies, Victoria University. Brazil. COPPE, Federal University, Rio de Janeiro. Canada. Carbon Management Canada; Navius Research; Simon Fraser University; Sharp. China. Institute of Energy, Environment, Economy, Tsinghua University; National Center for Climate Change Strategy and International Cooperation (NCSC). France. Université Grenoble Alpes, CNRS, EDDEN, PACTE; Centre International de Recherche sur l'Environnement et le Développement (CIRED), CNRS. Germany. Dialogik. India. The Energy and Resource Institute (TERI). Indonesia. Center for Research on Energy Policy-Bandung Institute of Technology, CRE-ITB; Centre for Climate Risk and Opportunity Management-Bogor Agriculture University (CCROM-IPB). Japan. National Institute for Environmental Studies (NIES); Mizuho Information and Research Institute (MIRI). Mexico. Instituto Nacional de Ecología y Cambio Climático (INECC). Russia. Russian Presidential Academy of National Economy and Public Administration (RANEPA); High School of Economics, Moscow. South Africa. The Energy Research Centre (ERC) University of Cape Town (UCT). South Korea. School of Public Policy and Management, Korea Development Institute (KDI); Korea Energy Economics Institute (KEEI); Korea Institute of Energy Research (KIER); Korea Environment Institute (KEI). United Kingdom. University College London (UCL) Energy Institute. United States of America. Energy + Environmental Economics (E3).

DDPP PARTNERS ORGANIZATIONS. German Development Institute (GDI); International Energy Agency (IEA); International Institute for Applied Systems Analysis (IIASA); World Business Council on Sustainable Development (WBCSD).