Technical Annex: Setting Welsh carbon targets

The Committee's scenarios, which underpin the recommended targets for Wales, are not prescriptive. They provide an assessment of an achievable and cost-effective pathway, but there are other pathways to achieving an 80% reduction target.

This annex provides further detail of the sectoral scenarios. The sectors are power, buildings, industry, surface transport, aviation and shipping, agriculture, LULUCF, waste, and F-gases. The sectoral scenarios reflect feasible potential for emissions reduction at sector level:

- The sectoral 'Minimum' scenarios reflect Wales's contribution to the Central scenario for the UK and are consistent with the UK carbon budgets. The Minimum scenarios form the basis for our economy-wide "Wales Minimum scenario".
- The sectoral 'Maximum' scenarios are the basis for the economy-wide "Wales Maximum scenario" and reflect the Committee's assessment of the greatest feasible emissions reduction over the period to 2050.

The Committee's recommendations are based on a combination of the Minimum and Maximum sectoral scenarios to ensure an overall reduction of at least 80% by 2050.

In most sectors,[1] we have used baseline projections to establish a business-as-usual (BAU) scenario and then identified a set of abatement (i.e. emissions reduction) measures, one for the Minimum scenario and one for the Maximum scenario. Both scenarios are determined by subtracting the abatement from the BAU scenario, leaving residual emissions (i.e. the estimated emissions remaining after actions to reduce them).

This annex first presents our assumptions and sources for the baseline emissions projections and then the details of 'Minimum' and 'Maximum' scenarios, including abatement in 2030 and 2050. Residual emissions are also presented below.

Power sector

Emissions in the power sector in Wales were 13.1 $MtCO_2$ in 2015 across 33.5 TWh of electricity generation, representing a carbon intensity of generation of 395 gCO_2/kWh. This was slightly higher than the UK-wide carbon intensity of 378 gCO_2/kWh. Emissions in the Welsh power sector are driven by one large coal plant, Aberthaw, which emitted 7.3 $MtCO_2$ in 2015, and five gas CCGT plants (5.7 $MtCO_2$).

Electricity generation in Wales is part of the wider interconnected electricity system of Great Britain. In 2015, generation in Wales over the year was greater than consumption, with the surplus exported to the rest of Great Britain through the transmission network. However, at times, generation in Wales may be lower than consumption, with the deficit met by electricity produced elsewhere in Great Britain. The appropriate future distribution of generating assets between Wales and the rest of GB will depend on many factors including the future policy regime, changing patterns of electricity demand, fossil fuel prices, network charges, available energy technologies and their relative costs, or the role of carbon capture and utilisation and/or storage (CCUS) in the power sector and location of any CCUS clusters.

These factors are subject to considerable uncertainty, and it is difficult to make a judgment now on the appropriate scale or composition of the electricity system in Wales in the 2020s and beyond. We therefore present our scenarios for the power sector in Wales for illustration only.

[1] Exceptions are the Power sector and aviation and shipping

The scenarios are drawn from modelling by Imperial College, which provided the basis for our power sector scenarios to underpin our UK advice on the fifth carbon budget (see Box A.1). These scenarios cover the wider GB electricity system, including breaking out Wales as a separate part of the model's representation of the system. The model requires security of supply to be maintained at all times and the scenarios include extensive roll-out of demand-side response, interconnection and storage to support this, in line with our UK-wide 5th Carbon Budget scenarios.[2]

Imperial College modelled the Welsh power system within a GB system that reaches 100 gCO_2 per kWh in 2030, resulting in a range of emissions in Wales of 6-11 $MtCO_2$ (i.e. a decrease of 16-54% compared to 2015 levels). The emissions intensity in these Welsh scenarios is significantly higher than the UK average due to Wales's relatively higher share of fossil-fired capacity.

Our Welsh Minimum and Maximum scenarios draw on the results of this Imperial College modelling.

- The modelling produced by Imperial College underpins our Welsh power scenarios. However, given the uncertainty around levels of future gas generation in Wales, our scenarios cover a wider range of emissions in 2030, with emissions decreasing 46-75%.
- In the Minimum scenario, total power sector emissions in Wales decrease by 46%, from 13.1 $MtCO_2$ in 2015 to 7.1 Mt in 2030, due to the phase-out of unabated coal-fired generation, an increase in the share of low-carbon generation in the GB system to around 75% and a corresponding reduction in load factors of unabated gas-fired capacity. The emissions intensity of generation decreases by 65%, from 392 gCO_2/kWh in 2015 to around 138 g/kWh in 2030. This scenario is consistent with the UK-wide 'Central' scenario, which achieves an average emissions intensity of generation of 100 gCO_2/kWh. The percentage of Welsh consumption that is renewables increases from 29% in 2015 to 44% in 2030.
- In the Maximum scenario, total power sector emissions in Wales decrease by 75%, from 13.1 $MtCO_2$ in 2015 to 3.3 $MtCO_2$ in 2030, and the emissions intensity of generation decreases by 82%, from 392 gCO_2/kWh in 2015 to around 70 gCO_2/kWh in 2030. The Maximum scenario is consistent with the UK-wide 'Max' scenario, which achieves an average emissions intensity of generation of 50 gCO_2/kWh. Renewable generation in Wales increases to an equivalent of 75% of Welsh consumption by 2030, compared with 29% in 2015.
- In both scenarios continued deployment of renewables and a reduced role of gas generation continue to reduce emissions after 2030, consistent with a UK wide 20 gCO_2/kWh scenario. In the Minimum scenario emissions in 2050 are 1.4 $MtCO_2$, giving an average emissions intensity of 32 gCO_2/kWh. In the Maximum scenario emissions in 2050 are 0.7 Mt, giving an average emissions intensity of 13 g/kWh.
- The overall 'Wales 80%' economy-wide scenario follows the Minimum scenario for the period to 2030 and then transitions linearly to reach the emissions in 2050 under the Maximum scenario (Box A.2).

Emissions from power generation relate to unabated generation from fossil-fired capacity. Although deployment of low-carbon generation on the GB system is of great importance, from a system perspective it could equally be located in Wales or outside. The location of this low-carbon generation only reduces Welsh power generation emissions to the extent that it reduces

[2] See CCC (2015) *Power Sector Scenarios for the Fifth Carbon Budget*

load factor on the fossil-fired plants rather than simply leading to increased exports of electricity to the rest of the GB system.

While it is necessary for Welsh emissions targets, focusing on Welsh power generation emissions alone may not be the most appropriate measure of progress in the Welsh power sector, as this reflects fossil generation in Wales but not the contribution of zero-carbon generation to the wider GB system. The Welsh Government has recognised this, by setting a target on the penetration of Welsh renewable electricity generation as a percentage of Welsh electricity consumption (set at a level of 70% of Welsh consumption for 2030), rather than relying solely on carbon budgets.

The reduction in Welsh power generation emissions in our scenarios is due to the closure of coal capacity and reduction in gas generation:

- Coal generation, from the plant at Aberthaw, which emitted 7.3 Mt in 2015, is assumed to have lower running hours of 1,500 hours per year from the middle of 2020, due to the Industrial Emissions Directive. It is assumed to cease generating in 2025 consistent with UK Government commitments to end unabated coal generation by this date.
- In the Minimum scenario, unabated gas generation in Wales increases from 16 TWh in 2015 to 20 TWh in 2030 and subsequently falls to 4 TWh in 2050, a 76% decrease on 2015 levels. In the Maximum scenario gas generation falls to 10 TWh by 2030 and subsequently falls to 2 TWh in 2050, decrease of 88% on 2015 levels.
- Studies of potential storage locations for captured carbon emissions from Carbon Capture and Storage (CCS) in the UK suggest that deployment of CCS in Wales in unlikely,[3] therefore we did not consider any deployment of CCS on power generation within Wales in any of the scenarios.

[3] National Assembly for Wales Research Service (August 2017) *Research Briefing Low Carbon Electricity*.

Box A.1. Modelling of the Power sector

In support of our analysis for developing future Welsh power scenarios, we commissioned Imperial College London to model the GB and Welsh power systems on an hourly basis, in order to better understand the implications of our 5th Carbon Budget scenarios for the Welsh power system in 2030. After discussion with the Welsh Government, we modelled 10 scenarios around our Central 100 gCO_2/kWh scenarios for the GB electricity system in 2030, which allowed us to maintain compatibility with our advice to the UK and Scottish Governments. The key results are set out below:[4]

- Emissions are proportionately higher in Wales compared to the rest of GB due to more CCGT plant per level of demand. This is reflected in today's capacity mix: Wales has 5.6 GW of CCGT, 3.4 GW of which has been built over the last 10 years and is likely to remain online to 2030.
- The scenarios produced a range for Welsh emissions of 6-11 $MtCO_2$ in 2030, reflecting a variation in CCGT capacity and generation. Emissions could be lower, but require CCGT load factors lower than today's levels: scenarios with low emissions have CCGT at 60% load factors, similar to load factors in 2015 and 2016.
- Wales is a major exporter in all these scenarios, mostly because Wylfa power station alone could meet almost all of Welsh demand.
- There is sufficient transmission capacity already today to facilitate "cross-border" power flows (between Wales and England) observed in the model in 2030. The exceptions are the scenarios with Swansea and Cardiff tidal lagoons and with coal capacity replaced with CCGT. Both of these significantly increase the generation capacity installed in South Wales and therefore the transmission corridor between South Wales and South England can become constrained. However, the magnitude and duration of power flows exceeding these constraints is not very material: this happens in about 1% of the time across the year.

[4] Detailed results are published on our website.

Box A.2. Assumptions on gas-fired generation in the CCC scenarios for Wales

In 2015, 16% of Welsh power generation was from renewables, 12% was from nuclear, with 51% of Welsh power emissions and 24% of Welsh generation coming from the coal-fired plant at Aberthaw and the remainder of emissions and 48% of generation coming from gas-fired plants.

The key developments that affect emissions from the Welsh power sector relate to the operation of fossil-fired plants:

- Although low-carbon generation is important in decarbonising the overall GB system, from a system-wide perspective low-carbon generation could equally be in Wales, England or Scotland.
- It is unlikely that the level of low-carbon power generation in Wales will affect the load factors and therefore emissions of the Welsh fossil plants significantly.[5]

In developing scenarios for future Welsh power sector emissions, it is necessary to consider the type and size of operating fossil-fired capacity, together with the extent to which they will operate across the year:

- Emissions from the Aberthaw plant will cease by 2025 at the latest, under the UK Government's commitment to phase out unabated coal-fired generation by that date (see section 2).
- With the exception of Wales' newest CCGT plant (Pembroke), Welsh gas-fired plants currently operate at average load factors significantly below those for gas capacity across the rest of the GB system. In 2015, load factors for gas plant Wales were 14% (excluding Pembroke, which generated at 61%), compared with 33% for the GB-wide system.
- By 2030, our published scenarios at a UK level have a similar level of unabated gas-fired generation as in 2015, with the coal ultimately replaced by low-carbon generation.[6] However, it is expected that as a result of the coal phase-out gas generation will increase temporarily to compensate in the mid-2020s, while low-carbon capacity continues to ramp up.
- By the 2030s, it is likely that gas capacity will be broadly divided into plants with carbon capture and storage (CCS) that operate at relatively high load factors and unabated plants that operate at significantly lower load factors. Given the challenges relating to deploying CCS in South Wales, it is likely that the majority of any new gas capacity in Wales will be in the latter category.

Wales already has 5.5 GW of gas-fired capacity, which is high as a share of GB gas-fired capacity (around 18% of gas capacity compared with around 6% of electricity consumption). However, in terms of new-build capacity, it appears likely that the share will be considerably smaller as Wales has only 4% of proposed gas projects with planning permission:

- For GB as a whole, the capacity of gas-fired projects that have planning permission but have not commenced construction is 21 GW.[7]
- In Wales, there are only three small gas-fired projects that have planning permission but are not under construction, with a capacity totalling just under 900 MW. The capacity of each (299 MW) is just below the 300 MW threshold for new plants to be 'CCS ready'.[8]

[5] See modelling by Imperial College London published alongside this advice.
[6] CCC (2015) *Power sector scenarios for the fifth carbon budget*.
[7] Based on the National Infrastructure Planning Register of Applications (planninginspectorate.gov.uk) and the EMR Delivery Body Capacity Market Prequalification Database (emrdeliverybody.com).
[8] In 2009, Section 36 of the UK Electricity Act 1989 (licensing of power plants) was amended to implement the CCS Directive requirement that all new combustion power plants over 300MW must be constructed as CO2 Capture Ready.

Box A.2. Assumptions on gas-fired generation in the CCC scenarios for Wales

The requirement for new-build gas capacity by 2030 on the GB system will depend on the precise retirement dates of existing gas capacity, but is likely to be well below the 21 GW already with planning permission. However, it is uncertain which of those projects that already have planning permission, or any new projects, will actually be built.

Our assessment is therefore that it is reasonable to anticipate limited new build of gas-fired capacity in Wales, and that capacity added will operate at relatively low load factors in the longer term. Fossil-fired plants on the GB system derive revenue both from the electricity generated and from the provision of capacity. A lower load factor for a gas plant need not mean lesser profitability of that plant, as it will still be rewarded for providing capacity.

We have not assumed any deployment of CCS on power generation in Wales, given the constraints relating to access to CO_2 storage. To the extent that this is deployed on the UK system, we assume that it happens closer to likely CCS clusters (e.g. down the East coast).

In constructing our scenarios we have assumed:

- **Minimum scenario.**
  - To 2030, gas generation equivalent to the existing level of Welsh gas-fired capacity operating at load factors similar to those for unabated gas plants across the GB system as a whole and within a GB system that reaches 100 gCO_2/kWh by 2030. This could also be consistent with a situation in which some limited new gas capacity is built in the 2020s but where average load factors on gas plant remain below the GB average.
  - To 2050, we assume that Wales's share of gas capacity within the GB system remains at the 2030 level (around three times higher than the share of electricity consumption), within a system that reaches 20 gCO_2/kWh by 2050.
- **Maximum scenario.**
  - To 2030, gas generation equivalent to the existing level of Welsh gas-fired capacity operating at load factors similar to those for unabated gas plants across the GB system as a whole and within a GB system that reaches 50 gCO_2/kWh by 2030. This could also be consistent with a situation in which some limited new gas capacity is built in the 2020s but where average load factors on gas plant remain below the GB average.
  - To 2050, we assume that Wales's share of gas capacity within the GB system reduces from the 2030 level to half the level in the Minimum scenario (still around 50% higher than the share of electricity consumption), within a system that reaches 20 gCO_2/kWh by 2050.

For the purposes of the Wales 80% scenario we have assumed that the Minimum scenario occurs to 2030, with a linear transition to the Maximum scenario by 2050 given the need for extra emissions reductions to achieve an 80% reduction and the expected retirement of all currently existing gas plant by that date.

Buildings

Emissions from Welsh buildings were 4.4 $MtCO_2e$ in 2015 (not including F-gas emissions which are covered separately). This included 3.5 $MtCO_2e$ from residential and 0.8 $MtCO_2e$ from non-residential buildings.

Baseline emissions projections

Our baseline projection of emissions from residential buildings is based on analysis using the National Household Model and analysis for the UK's fifth carbon budget apportioned to Wales:

- The National Household Model was used to produce a new run to roll forward the existing stock. This is calibrated to 2015 emissions.
- A projection for emissions from new homes was derived from the fifth carbon budget analysis. The UK projection was developed at the time based on the DCLG household projections, and assuming that supply increases to match demand, stabilising by the mid-2020s. To derive a Welsh projection, we have calculated the Welsh share of supply based on the DCLG household projections. This share, i.e. 3%, is held constant from 2032.
- We have assumed that demand for water heating grows in line with population. ONS forecasts have been used for population projections.

The non-residential emissions baseline for commercial and public buildings used the devolved administration CO_2 projections produced by Cambridge Econometrics and previously used for the CCC's 2016 advice on Scottish targets. The projections have been used to derive a set of in-year Welsh scaling factors, which are applied to the latest UK EEP projections for services:

- The trend is then applied to temperature-adjusted 2015 emissions.
- The trend for non-CO_2 uses the public sector forecast, as the published projections do not split industrial combustion out from industry, and public non-CO_2 is deemed a better proxy for the services trend than services including industrial combustion.
- Post-2035, emissions are extrapolated using the trend from the CCC's services projection for the UK fifth carbon budget analysis.

Scenario analysis

We have developed a set of scenarios for Welsh buildings emissions, which brings together detailed model run outputs for Wales where available with further abatement derived by calculating a Welsh share of UK abatement where Welsh-level results were not feasible due to data limitations:

- We use Wales-specific modelling results where we can. This includes both the district heating scenarios developed by Element Energy for the fifth carbon budget advice,[9] and results from the scenario analysis on household low-carbon heat potential developed by the CCC using the National Household Model (NHM).[10] In the case of the NHM analysis, a set of runs were produced which included a better representation of heat networks uptake in Wales. The NHM results were calibrated using floor space estimates in the 2009 Living in Wales survey.

[9] https://www.theccc.org.uk/publication/element-energy-for-ccc-research-on-district-heating-and-local-approaches-to-heat-decarbonisation/

[10] See CCC (2015) *Sectoral scenarios for the fifth carbon budget*.

- Otherwise we apply a system of scalers according to a hierarchy:
  - For key insulation trajectories, we first scale down from UK to GB by excluding Northern Ireland via a scaling factor based on the number of households. We then get from GB to Wales using scaling factors based on remaining technical potential for installation of insulation measures. The Welsh and GB remaining technical potential estimates are derived from BEIS statistics[11] and NHM analysis of remaining potential at a regional level based on policy delivery to 2016.
  - Electricity demand for homes in Wales as a fraction of the UK total is used to scale electricity-led measures.
  - In all other instances, we have used projected in-year direct emissions to scale the UK abatement scenarios.
- Costs of measures to reduce emissions are assumed to be the same as equivalent measures at UK level in the absence of Wales-specific data.

Table A.2 outlines the main abatement measures and how much abatement the scenarios assume in 2030 and 2050.

Our Wales 80% scenario includes additional 0.12 $MtCO_2e$ of abatement in 2030 and 0.51 $MtCO_2e$ in 2050. This stems from including the following abatement measures from the Maximum scenario or at Maximum scenario uptake: further uptake of solid-wall insulation, high temperature waste heat from industry/power sector and further uptake of air source heat pumps. This will deliver around 20% of the additional abatement required to achieve a reduction of 80%.

[11] Household Energy Efficiency National Statistics data tables, Nov 2016 publication

Table A.1. Building sector abatement in 2030 and 2050 ($MtCO_2e$)				
	2030		**2050**	
Measure	**Minimum**	**Maximum**	**Minimum**	**Maximum**
Insulation	0.26	0.45	0.32	0.65
Heat pumps	0.20	2.33	0.30	2.49
District heating	0.17	0.70	0.23	0.99
Biomass boilers	0.14	0.04	0.16	0.02
Behavioural change	0.11	0.11	0.11	0.11
Heating controls	0.08	0.08	0.08	0.08
Hybrid heat pumps				0.36
Other	0.03	0.09	0.03	0.14
Residential abatement	0.65	0.83	3.05	4.12
Non-residential abatement	0.33	0.4	0.74	0.72
Residual buildings emissions	3.9	3.6	1.2	0.1

Source: NHM and CCC analysis.
Notes: Figures may not add up due to rounding.

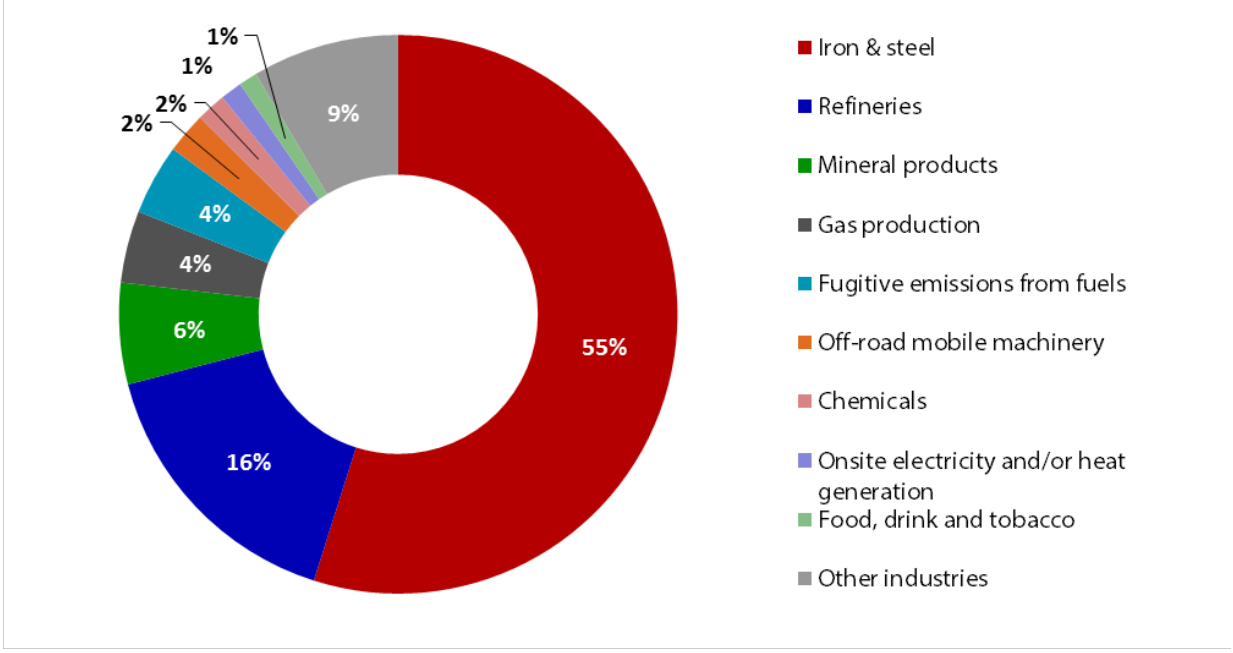
Industry

The industry sector includes manufacturing, construction, water and waste management, extraction and production of fossil fuels and fugitive emissions. F-gas emissions are covered separately.

Direct[12] emissions from industry accounted for around a third of Welsh greenhouse gas (GHG) emissions in 2015 (15 $MtCO_2e$), of which 55% came from the iron and steel sector and 16% from the refining sector (see Figure A.1). Between 1990 and 2015 Welsh industrial GHG emissions fell by 32%.

[12] Direct emissions exclude emissions from the generation of electricity supplied through the grid.

Figure A.1. Industry emissions by sector in 2015



Source: NAEI 2017.
Notes: Fugitive emissions are primarily comprised of methane leakage from closed coal mines and the gas distribution network, but also include iron and steel sector flaring and other smaller contributors.
Iron & steel includes coke production. Other Industries includes industries with <1% of emissions each, including paper and pulp, insulation, wood, mechanical/automotive/aerospace engineering, non-ferrous metals, water and waste management.

The scenarios for industry use a common baseline projection for industrial emissions. From this baseline projection we have created the Minimum and Maximum emissions scenarios, by deducting levels of emissions abatement aligned with effort levels set out in our UK fifth carbon budget Central and Max scenarios, respectively.[13]

In the Minimum scenario, industrial emissions fall by 72% over the period 1990 to 2050. In the Maximum scenario, industrial emissions fall a further 1.7 Mt by 2050, to 79% below the level in 1990. Over 95% of the abatement in both scenarios is of emissions covered by the EU Emissions Trading System (EU ETS).

A more detailed description of this methodology and results are outlined below.

Baseline emissions projections

Our baseline projections in the industry sectors do not assume deindustrialisation. The Welsh baseline emissions projection is based on a combination of data from the Welsh National Atmospheric Emissions Inventory (NAEI), the Government's Energy and Emissions Projections (EEP) and CCC-commissioned projections from Cambridge Econometrics.

The baseline is disaggregated by industry sub-sector and is taken to be in line with the Welsh NAEI estimate of emissions outturn. To create projections from 2015 to 2035, emissions were

[13] Sectoral scenarios for the fifth carbon budget, November 2015, https://www.theccc.org.uk/wp-content/uploads/2015/11/Sectoral-scenarios-for-the-fifth-carbon-budget-Committee-on-Climate-Change.pdf

assumed to change at the same rate as changes in UK CO_2 in the Government's EEP baseline projection,[14] for most sectors. The EEP projections reflect ongoing economic trends and the expected impact of EU, UK and Welsh policies introduced before July 2009. For the iron and steel sector the EEP projections assume roughly constant iron and steel output, and around a 10% fall in emissions.

Where there were gaps in UK EEP data for certain sub-sectors from 2015 to 2035, we assumed that emissions will change at the rates estimated in Cambridge Econometrics' Welsh projection work.[15] This work is based on Cambridge Econometrics' regional economic forecasts and estimated energy demand equations to determine the responsiveness of energy demand in Wales to key inputs (including prices, output and air temperature).

For baseline emissions projections beyond 2035, we have continue pre-2035 trends only where emissions are projected to rise:

- If the projected trend in emissions between 2030 and 2035 is downwards, we assumed that sub-sectoral emissions stay fixed at the 2035 level (i.e. ignoring the downward trend).
- If the projected trend in emissions between 2030 and 2035 is upwards, then baseline emissions are assumed to continue to increase linearly beyond 2035 at the same rate of change as between 2030-35.

Overall, in the baseline scenario, Welsh industrial emissions are projected to fall by 10% from 2015-2050, from 15.0 $MtCO_2e$ to 13.5 $MtCO_2e$.

Scenario analysis

The abatement measures identified in the Minimum and Maximum industry scenarios for Wales are based upon the set of cost-effective abatement measures identified in the Committee's UK fifth carbon budget advice. The amount of abatement from each of these measures was then calculated to equal the Welsh share of UK abatement, as set out by the Central and Max scenarios of the fifth carbon budget advice, respectively. Some of the abatement options in the scenarios were then tailored further, since Welsh Industry has many specific characteristics, for example, some industrial plants may have already installed certain abatement measures. The areas with further tailoring include abatement in the iron and steel sector, the refining sector and from the application of carbon capture utilisation and/or storage (CCUS) across sectors. These approaches are detailed below along with the subsequent abatement projections.

Welsh Abatement Based on Share of UK Abatement

Welsh abatement in the Minimum scenario has been calculated as a share of UK abatement on a sub-sectoral level (i.e. the share was calculated so that the abatement measure made up the same proportion of its sub-sector's baseline emissions as the same measure in the UK fifth carbon budget advice Central scenario). In the same way the Maximum scenario for Wales was derived from the UK Max scenario.

[14] EEP 2016, published in February 2017.

[15] The projections at devolved administration level were first used for advice on Scottish targets - see CCC (2016) Scottish Emissions Targets 2028-2032, page 28, https://www.theccc.org.uk/wp-content/uploads/2016/03/Scottish-Emissions-Targets-2028-2032.pdf

The majority (and size of) of the abatement in the UK scenarios reflects abatement outlined in the 'Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050', but also included a further assessment of the potential for low-carbon heat in industrial buildings.

Welsh Abatement with Further Tailoring

Abatement was further tailored to Wales for the iron and steel sector, the refining sector and for the application of carbon capture utilisation and/or storage (CCUS) in the iron and steel, refining, mineral products, chemicals and onsite combined heat and power sectors.

For the iron and steel sector we have tailored scenarios so that there are no mutually exclusive abatement options installed on a single installation. For the refining sector it is assumed that all fuel switching to gas has already been achieved in Wales. These assumptions were based upon consultation with industry stakeholders.

While acknowledging the possibility that challenges around geological sequestration of CO_2 may mean that some of the industrial CO_2 produced in South Wales goes to carbon capture and use (CCU), we have based our costs on deployment of carbon capture and storage (CCS). We assumed that CCUS would be more expensive in South Wales than better-suited parts of the UK, because of a lack of nearby potential CO_2 storage sites. The extra cost is assumed to be around £20/tonne, equal to the additional cost of shipping CO_2 to a storage facility. This pushes back the date by a few years at which we assess the technology to be cost-effective,[16] relative to CCUS in other UK locations.

Beyond this, our analysis assumes CCUS abatement consistent with effort in our UK fifth carbon budget. On this basis we have assumed in the Minimum scenario that CCUS is fitted in the iron and steel sector, the cement sector in North Wales and parts of the chemicals sector in the 2030s, and in the refining sector in the 2040s. In our Maximum scenario there is further CCUS in the chemicals sector in the 2030s, the cement sector and the onsite combined heat and power sector in South Wales in the 2040s, along with higher CCUS capture rates. As discussed in the main report, CCUS may be an alternative to CCS, but is not explicitly modelled in the scenarios because of very high uncertainty about its potential.

Abatement measures

Overall, in the Minimum scenario we have identified abatement of 1.0 $MtCO_2e$ in 2030 and 7.3 $MtCO_2e$ in 2050 (Table A.3). In the Maximum scenario we have identified potential abatement of 1.2 $MtCO_2e$ by 2030 and 8.9 $MtCO_2e$ by 2050. Measures in the scenarios include:

- **Energy efficiency.** Upgrades and replacements to existing processes and equipment to improve their energy efficiency.
  - **Energy and process management:** a range of improvements including energy management, utilities, improved process control, and maintenance.
  - **Best available and innovative technology:** improved equipment and insulation (e.g. motors, pumps, compressors, fans), and advanced technologies (e.g. innovative furnace designs).
  - **Waste heat recovery and use:** most of the available heat to recover is lower grade. To use it effectively requires either matched heat sinks nearby, or else the heat needs to be upgraded to higher grade heat or electricity. Low-grade industrial waste heat can be

[16] relative to BEIS carbon values for UK public policy appraisal.

used in district heating schemes, providing heat to local housing or non-domestic buildings.

  - **Material efficiency:** food waste and packaging reduction, reducing yield losses, scrap densification or shredding and reuse of steel, lighter bricks and reduced product weight (ceramics sector), and increased cullet use through recycling (glass sector).
  - **Clustering:** integration between industrial sites to optimise the use of energy and resources. For example, clustering could help co-locate industries that use lower grade heat (food and drink, semiconductor manufacturing).

- **Bioenergy used in space/process heat.** Switching away from direct combustion of fossil fuels to biogas/biomass. Biomethane injection into the gas grid is also accounted for in industry abatement.
- **Electrification of space/process heat.** Through electric kilns, boilers and melting of glass, in conjunction with the decarbonisation of the power sector or heat pumps in space heating.
- **Carbon Capture and Storage or Use (CCS/CCU).** Capture of waste CO_2 from large point sources, such as in cement, refining and chemicals sectors, transported to a storage site where it will not enter the atmosphere, or use in other industrial processes.

Table A.3 outlines the different levels of energy efficiency, bioenergy, electrification and CCUS in the Minimum and Maximum scenarios, which reaches 1.6MtCO_2e by 2050. Most of the extra abatement in the Maximum scenario (1 MtCO_2e) comes from incremental increases in the amount of abatement from the same abatement options. Some of the extra abatement in the Maximum scenario (0.6 MtCO_2e) is the result of extra technologies, including electrification of process heat, use of CCUS on CHP and the implementation of an advanced technology, such as Hlsarna, Corex or Finex, to improve energy efficiency in the iron and steel sector.

Our Wales 80% scenario for the Industry sector is equivalent to the Minimum scenario.

Table A.2. Industrial GHG emission abatement in 2030 and 2050 ($MtCO_2e$)				
	2030		**2050**	
Measure	**Minimum**	**Maximum**	**Minimum**	**Maximum**
Energy Efficiency	0.57	0.58	1.87	2.16
Bioenergy for space/process heat	0.32	0.32	0.37	0.44
Electrification of space/process heat	0.16	0.27	0.44	0.69
Carbon capture and use/storage			4.63	5.59
Total abatement	1.04	1.18	7.31	8.88
Residual industry emissions	12.8	12.7	6.20	4.62

Source: CCC analysis.
Notes: Figures may not add up due to rounding.

Surface transport

Emissions from surface transport in Wales were 5.8 $MtCO_2$ in 2015, representing 13% of Welsh emissions. Our analysis suggests that in the Minimum scenario, emissions could fall by 50% by 2030 through measures such as conventional vehicle efficiency, adoption of ultra-low emission vehicles (ULEVs), reducing demand for car travel and improving the efficiency of freight operations. Under the Maximum scenario, this could fall by 55% in 2030.

Baseline emissions projections

For our baseline emissions projection we use the run of the Department for Transport's National Transport Model (NTM) commissioned for our fifth carbon budget advice, which includes a separate projection for Wales.[17] The baseline emissions projection assumes no policies to mitigate climate change after 2010 and shows a 21% increase in total Welsh vehicle-km between 2010 and 2030.

There are some differences in the geographic distribution of the population in Wales compared to the UK as a whole which could affect travel behaviour. However, our analysis suggests that this is unlikely to have a significant impact on opportunities to reduce emissions (Box A.2).

Box A.3. Patterns of travel demand in Wales

Patterns of travel demand can influence the potential of emissions reduction measures, such as reducing demand for car travel and uptake and usage of electric vehicles (EVs). We have analysed the National Travel Survey (NTS), a survey of weekly travel patterns in Great Britain (GB). Overall travel patterns in Wales and GB are found to be very similar:

- Comparisons of the distribution of car trip distances for Wales and GB using the NTS data shows that the average car trip length in Wales is slightly longer than for the rest of GB at 8.9 miles (compared to 8.5 miles).
- As there a fewer shorter car trips in Wales (compared to the UK), which are more likely to switch to low emission modes, this indicates that the potential for reducing emissions through reducing demand for car travel is slightly lower in Wales compared to GB. Approximately 20% of trips could be switched to walking, cycling or public transport, leading to a reduction in car km travelled of 4%. In a Maximum scenario, this reduction could be increased to 8%.
- Opportunities to switch to EVs are broadly similar in Wales and in GB. For example, typical battery electric vehicle (BEV) cars will have sufficient range in 2020 to drive over 99.9% of trips in Wales without a need to charge. Typical plug-in hybrid EV (PHEV) cars have a battery allowing them to travel up to 30 km in electric mode. The NTS data for Wales shows that the percentage of daily distance under 30km travelled by car is around 49%, broadly in line with 50% for GB, meaning that PHEVs are expected to have a similar emissions reduction potential in Wales.

Source: NTS (2002-2012).

Scenario analysis

The Minimum scenario includes measures likely to reduce emissions more cheaply than the UK Government's projected carbon values (i.e. £78/tCO_2 in 2030), measures required by existing regulation and measures that at the UK level we identified as being required on the path to the legislated 2050 target. The Maximum scenario to 2030 includes more stretching options. These are not exhaustive of all possible measures:

- **New vehicle efficiency.** There is scope for cost-effective improvements to the efficiency of conventional new vehicles through measures such as aerodynamics, weight reduction and hybridisation. New evidence indicates that the gap between test-cycle and real-world emissions could persist to 2030 but could be reduced with an improved testing regime.
  - New conventional cars and vans could reach a test-cycle CO_2 intensity of 82 gCO_2/km and 127 gCO_2/km respectively by 2030.[18] This is equivalent to a test-cycle efficiency improvement of 41% for new cars and 37% for new vans between 2010 and 2030. These targets are consistent with our UK-wide recommendations.
  - Under testing procedures currently planned within the EU, real-world emissions for new conventional cars and vans could be 26% higher than test-cycle emissions. However, improved testing of cars and vans could help to reduce this gap to around 5% by 2030.[19]

[18] We assume these vehicles are tested using the Worldwide Harmonised light-duty vehicle Testing Procedure (WLTP).

[19] Element Energy and the ICCT (2015) *Quantifying the impact of real-world driving on total CO_2 emissions from UK cars and vans.*

  - In our Minimum and Maximum scenario for Wales (in line with the UK), real-world efficiency improves by 38% for new cars and 33% for new vans between 2010 and 2030.
  - The real-world efficiency of new HGVs could improve by 22% relative to 2010.
- **Electric vehicles.** Under the Minimum scenario, electric vehicles reach around 65% of new sales for cars and vans by 2030 (around 30% PHEV and 35% BEV). Under a Maximum scenario an additional 5% of new sales could be BEVs:
  - We have updated our modelling of how a high uptake of EVs could be achieved given capital and fuel cost projections, non-financial barriers and potential future incentives. We estimate that electric cars and vans could make up around 65% of new sales by 2030 if provided with a national network of rapid charging infrastructure and continued financial incentives whilst the market develops (this would not have to be an upfront grant and could include favourable Vehicle Excise Duty or Company Car Tax and provision of free access to low emissions zones or parking spaces).
  - Our modelling suggests that cost parity between EVs and conventional vehicles could be reached from a social perspective by 2025 and by 2028 when looking at total cost of ownership to the private consumer over a five year period.
  - Under our Maximum scenario, there is potential for a slightly higher sales share of 70% for electric cars and vans (30% PHEV and 40% BEV). This could be achieved if the Welsh Government is able to provide additional incentives for BEVs (again, not necessarily in the form of a grant) and/or if attitudes towards EV ownership are more advanced than in GB and non-financial barriers are addressed earlier or if battery costs fall more rapidly than under our central assumptions.[20]
  - Combined with efficiency improvements for conventional cars, this implies a test-cycle CO_2 intensity of around 39gCO_2/km for new cars and 52gCO_2/km for new vans under the Minimum Scenario and 31gCO_2/km for new cars and 43 gCO_2/km for new vans in 2030 under the Maximum scenario.
  - Electric small rigid HGVs reach 25% of sales (15% PHEV and 10% BEV). Electric buses reach 25% of sales. This level of uptake is included in both the Minimum and Maximum scenarios.
- **Hydrogen vehicles.** Hydrogen fuel cell buses make up 25% of new bus sales. Fuel cell vehicles may also have niche applications for other modes by 2030 but this is not explicitly included in the scenario. This level of uptake is included in both the Minimum and Maximum scenarios.
- **Biofuels.** The outcome of the recent Renewable Transport Fuels Obligation consultation is used to set levels of biofuels uptake to 2020. Through the 2020s, increasingly sustainable biofuels displace around 0.2 billion litres of petrol and diesel, constituting around 11% of liquid fuel by energy in 2030. This level of displacement is included in both the Minimum and Maximum scenarios.
- **Behaviour change.** The Maximum scenario includes further emissions reductions from behaviour change in passenger transport and improvements to freight operations. The measures included go beyond those in our Minimum scenario for the UK. Whilst stretching,

[20] CCC (2015) *Sectoral scenarios for the fifth carbon budget* https://www.theccc.org.uk/publication/sectoral-scenarios-for-the-fifth-carbon-budget-technical-report/

this level of behaviour change is potentially achievable given that Wales has devolved powers to influence travel behaviour.

- For cars, in our Minimum, we estimate that a 4% reduction in car-km relative to our baseline scenario could be achieved, a 2% fuel saving from the use of eco-driving technology and a further 2% fuel saving from enforcing the speed limit on motorways and dual carriageways. In our Maximum scenario, we estimate that an 8% reduction in car-km could be achieved and a reduction of the speed limit to 60mph on motorways and dual carriageways increases fuel savings to 7%.
- For HGVs we assume improved logistics provides a 16% reduction in HGV-km relative to our baseline scenario and a further 14% fuel saving from use of driver training and retrofitting fuel saving technologies, rising to 18% in our Maximum scenario.[21]

Some of these measures may be challenging to implement with powers currently devolved to the Welsh Government. This scenario is not intended to be prescriptive and if it is not possible to achieve the uptake of measures set out above, this could be offset with additional measures elsewhere insofar as those can be delivered.

Overall we expect these measures to reduce Wales' surface transport emissions in 2030 from 6.1 $MtCO_2$ in our baseline scenario to 3.0 $MtCO_2$ in our Minimum scenario by 2030. The abatement is primarily due to conventional vehicle efficiency (0.9 Mt) and uptake of electric and other ultra-low emission vehicles (1.5 Mt), with smaller reductions from biofuels (0.4 $MtCO_2$), behaviour change in passenger transport (0.1 Mt and improvements to freight operations (0.2 Mt).

In the Maximum scenario emissions would fall to 2.6 $MtCO_2e$ in 2030.

Our Wales 80% scenario for the Transport sector is equivalent to the Minimum scenario.

[21] CfSRF (2015) *An assessment of the potential for demand-side fuel savings in the HGV sector.*

Table A.3. Surface transport GHG emission abatement in 2030 and 2050 ($MtCO_2e$)				
	2030		**2050**	
Measure	**Minimum**	**Maximum**	**Minimum**	**Maximum**
New vehicle efficiency	0.94	1.01	1.01	0.03
Electric vehicles	1.55	1.65	1.65	6.99
Biofuels	0.35	0.33	0.33	0.00
Behavioural change	0.29	0.50	0.50	0.02
Other	0.04	0.04	0.07	0.08
Total abatement	3.17	3.52	6.67	7.12
Residual surface transport emissions	2.98	2.63	0.69	0.25

Source: National Transport Model and CCC analysis.
Notes: Figures may not add up due to rounding.

Aviation and Shipping

Aviation emissions scenarios

Aviation emissions in Wales are relatively small, at 0.1 $MtCO_2e$ from both international and domestic flights in 2015. This is less than 1% of UK-wide aviation emissions. While UK-wide aviation emissions have doubled since 1990, Welsh aviation emissions have not grown at all over that period.

The key drivers of future aviation emissions are demand for air travel and the carbon intensity of flying:

- **Demand for air travel.** The key drivers of demand will include future GDP growth, and fuel and carbon prices which feed through to ticket prices. Demand for air travel is particularly sensitive to changes in income rather than ticket prices, and will also be affected by the availability of alternatives to air travel (e.g. rail and potentially video conferencing).
- **Carbon intensity of flying.** There are a range of options available to reduce the carbon intensity of aviation. These include improving the fuel efficiency of aircraft through engine and airframe developments, through efficiency improvements in air traffic management and in airlines' operational practices, and through use of sustainable biofuels.

In the absence of measures, aviation emissions are likely to continue to increase. In our previous reports,[22] we set out analysis of the path for aviation emissions to 2050. This concluded that appropriate long-term assumptions for Government planning are for UK aviation emissions to be around 2005 levels in 2050 (i.e. 37.5 $MtCO_2$). Under our 'Likely' scenario this was achieved through a 0.8% annual improvement in fuel efficiency, 10% take-up of biofuels, and by constraining UK-wide demand growth to around 60% above 2005 levels in 2050.

Our scenarios for future Welsh aviation emission are consistent with our advice on the UK's fifth carbon budget. They take the emissions from Welsh airports within the scenarios:

- Minimum emissions scenario. In this scenario UK-wide emissions are capped at 37.5 $MtCO_2$ in 2050, in line with our planning assumption.
- Low emissions 'Maximum' scenario. In this scenario high abatement options are delivered.

Welsh aviation emissions are already at very low levels, and the emissions in 2050 in these scenarios do not differ significantly from current levels. In both scenarios total emissions from international and domestic aviation in Wales in 2050 are around 0.1 $MtCO_2e$.

Shipping emissions scenarios

Welsh shipping emissions in were 1.1 $MtCO_2e$ in 2015, around 10% of UK-wide shipping emissions. While UK-wide shipping emissions have fallen by 10% since 1990, Welsh shipping emissions have not grown at all over that period.

The key drivers of future shipping emissions are shipping demand and carbon intensity of ships:

- **Shipping demand.** This will be influenced in future by factors including GDP growth, fossil fuel and carbon prices, and consumption of fossil fuels and bioenergy. Our demand scenarios are consistent with our economy-wide analysis and reflect a reduction in UK demand for fossil fuels, in line with our trajectories for other sectors. They are scaled down from our fifth carbon budget scenarios, based on the historical Welsh share of demand by commodity group.
- **Carbon intensity of shipping.** The main options for reducing carbon intensity of ships include use of larger ships, technological and operational innovation to improve fuel efficiency, and use of alternative fuels. Together these could reduce average carbon intensity of ships by up to 65% by 2050.

Our emission scenarios are based on bunker fuel sales as reported in the Welsh emissions inventory, and are in line with our UK advice on the fifth carbon budget. Shipping is potentially at risk of carbon leakage if costly measures are adopted unilaterally. We therefore follow our approach at the UK level and develop scenarios in line with currently agreed international policy. These assume a modest level of efficiency improvement under the International Maritime Organisation's Energy Efficiency Design Index.

We use this as both our Minimum and Maximum scenarios for Welsh shipping emissions. Under this scenario Welsh shipping emissions, including domestic and international shipping, are around 0.9 $MtCO_2e$ in 2030 and 0.7 Mt in 2050.

[22] CCC (2012) Scope of carbon budgets – statutory advice on inclusion of international aviation and shipping

Table A.4. Aviation and Shipping GHG emission abatement in 2030 and 2050 ($MtCO_2e$)				
	2030		**2050**	
	Minimum	**Maximum**	**Minimum**	**Maximum**
Domestic aviation emissions	0.01	0.01	0.01	0.01
International aviation emissions	0.08	0.08	0.1	0.1
Total residual aviation emissions	0.09	0.1	0.1	0.1
Total residual shipping emissions	0.9	0.7	0.7	0.5
Source: CCC analysis.				

Agriculture

GHG emissions from agriculture in Wales reached 5.9 $MtCO_2e$ in 2015, 13% of total Welsh emissions. This is a higher share than at the UK level (10%) and in part reflects the importance of agriculture to the economy, compared to the UK as a whole.

Our analysis suggests that agriculture could deliver emissions savings of 0.7 $MtCO_2e$ by 2030 through a set of measures that improves crop and soil management, animal health and diets, waste management and on-farm energy efficiency measures.

Baseline emissions projections

We use BEIS' 'Updated energy and emissions projections: 2016' projections, published in March 2017,[23] for the baseline emissions projections in the agriculture sector. We include emissions in the 'Baseline policies' scenario. Since these projections are not disaggregated on a national level, we scaled them to estimate the Welsh share, by applying the rate of change for each gas in the UK projections to Wales' latest 2015 emissions.

The BAU scenario estimates a small decrease in agriculture emissions from 5.9 $MtCO_2e$ in 2015 to 5.6$MtCO_2e$ in 2030. Post 2030, we assume that emissions do not change and remain at 5.6Mt.

Scenario analysis

Our abatement scenarios comprise of abatement from existing uptake and future uptake of measures:

- **Existing uptake:** farmers are already implementing measures that reduce emissions, which are not accounted for in the emissions baseline projections. We estimate the level of cost-effective abatement for Wales in this 'baseline' to be 0.2 $MtCO_2e$ in 2030.
- **Future uptake:** estimated savings of 0.5 $MtCO_2e$ are based on a bottom-up assessment of cost-effective and feasible abatement potential largely taken from work the Committee commissioned from Scotland's Rural College (SRUC) and Ricardo Energy and the Environment[24] for our UK fifth carbon budget report.

Our estimates of future abatement potential are based on future uptake of a limited set of cost-effective measures. The measures were developed from a longer list and prioritised on the basis that they:

- Have the potential to deliver a high or medium level of abatement.
- Provide certainty of practical feasibility given current evidence and/or timelines required to test and deploy options.
- Are not deemed to be high-risk or have negative effects on other objectives (e.g. on animal welfare).

In total, our Minimum scenario delivers emissions savings of 0.7 $MtCO_2e$ by 2030 (Table A.2). This scenario would entail a move away from the current voluntary approach to reducing emissions in this sector, towards stronger Government policy. Our evidence suggests that there are a large number of small measures that could reduce emissions in this sector, therefore in practice, the

[23] https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2016
[24] Scotland's Rural College (SRUC) & Ricardo Energy & Environment (2015) Review and update of the UK agriculture MACC to assess the abatement potential for the fifth carbon budget period and to 2050.

same level of emission savings could be achieved with a slightly lower abatement from a wider mix of measures.

Combined with the latest baseline projection (5.6 $MtCO_2e$ by 2030) from BEIS, this implies residual agricultural emissions of 4.9 $MtCO_2e$ by 2030 in our Minimum scenario. This implies a 16% reduction in GHG emissions compared to 2015. Under a more ambitious Maximum scenario, which assumes a higher level of uptake of the same set of abatement measures, savings would reach 0.8 $MtCO_2e$ by 2030.

Beyond 2030, the agriculture sector is likely to represent an increasing share of total emissions as other sectors decarbonise more quickly. We have therefore estimated additional abatement potential to 2050 under both scenarios, which takes into account the Government's increasing value of greenhouse gas emissions savings over the period to 2050:

- **Minimum:** Savings reach 1 $MtCO_2e$ by 2050 based on increased uptake consistent with the Maximum scenario and the addition of three new abatement measures[25] covering waste management and soils that are now cost-effective with a higher carbon price by 2050.
- **Maximum:** The inclusion of demand-side measures (e.g. diet change and reduction in consumer food waste) combined with three additional measures that are cost-effective at the higher carbon price gives abatement of 1.2 $MtCO_2e$ by 2050.

These savings however, represent relatively modest increases. Deeper reductions will be needed which will require the development of future options and innovative solutions that go beyond those set out above. Given the roll-out of the new Smart Inventory, we will undertake a thorough assessment of the ambition and potential of the sector to deliver increased savings.

Our Wales 80% scenario includes additional 0.006 $MtCO_2e$ of abatement in 2030 and 0.25 $MtCO_2e$ in 2050. This stems from including the following abatement measures from the Maximum scenario or at Maximum scenario uptake: consumer food waste reduction and diet change. This will deliver around 10% of the additional abatement required to achieve a reduction of 80%.

[25] As identified by SRUC & Ricardo for the CCC fifth carbon budget work.

Table A.5. Agriculture GHG emission abatement in 2030 and 2050 ($MtCO_2e$)				
	2030		**2050**	
Measure	**Minimum**	**Maximum**	**Minimum**	**Maximum**
Crops & soil management Includes: – Precision farming for crops – Manure planning and application – Grass clover crops – Controlled-release fertilisers – GM crops with enhanced nitrogen use efficiency – Triticale – Loosening compacted soils	0.15	0.18	0.19	0.21
Livestock health measures Includes: – Improvements to cattle & sheep health	0.14	0.16	0.21	0.21
Livestock diets & breeding Includes – Improved nutrition – Probiotics & nitrate additives – Use of balanced breeding goals	0.10	0.11	0.15	0.15
Waste and manure management Includes – Anaerobic digestion – Slurry acidification	0.02	0.03	0.04	0.07
Fuel efficiency Includes – Improved housing, drying, glazing, irrigation etc.	0.10	0.11	0.11	0.11

Table A.5. Agriculture GHG emission abatement in 2030 and 2050 ($MtCO_2e$)				
	2030		**2050**	
Measure	**Minimum**	**Maximum**	**Minimum**	**Maximum**
Baseline abatement Includes – Measures already being taken up	0.22	0.22	0.22	0.22
Behavioural change Includes – Consumer food waste reduction – Diet change				0.25
Total abatement	0.74	0.81	1.02	1.23
Residual industry emissions	4.9	4.8	4.6	4.4

Source: CCC analysis.
Notes: Figures may not add up due to rounding.

Land use, land-use change and forestry (LULUCF)

The land use, land-use change and forestry sector in Wales was a small net carbon sink of 0.3 $MtCO_2e$ in 2015. While the net sink has increased year-on-year, it is projected to decline in the future, becoming a net source by the early 2020s. This is due to a 22% increase in net emissions from cropland, coupled with a 26% decline in the net carbon sink of forests due to the ageing profile of woodlands and the low level of new tree planting

Baseline emissions projections

For LULUCF baseline emissions projections, we use the National Atmospheric Emissions Inventory (NAEI) report 'Projections of emissions and removals from the LULUCF sector to 2050', published in March 2017. We use the scenario "Baseline 2" for our analysis.

We are aware that these projections differ significantly from the latest NAEI reported historic emissions for LULUCF. The latter reports emissions of -0.3 $MtCO_2e$ for 2015, whilst the projections estimate emissions of -0.8 $MtCO_2e$ in 2020. This gives the impression that we assume a significant increase in the LULUCF sink in the BAU scenario. This is not the case. Historic LULUCF emissions and LULUCF projections are published separately and therefore do not align, as the scientific methodologies to measure LULUCF emissions is constantly updated to reflect improvements in understanding. In addition, the emissions inventory published in June 2017 overestimated LULUCF emissions - we have been informed that this will be corrected in the inventory published in 2018.

Based on this, we decided to use the LULUCF projections without any alignment to historic emissions in 2015. Once the new inventory is published in June 2018 and updated projections are available (publication date unknown), the LULUCF baseline emissions projections can be reviewed.

Scenario analysis

Abatement options in this sector focus on increasing the sink by the planting of more trees. Our Minimum and Maximum scenarios includes two abatement measures, which deliver 0.4 $MtCO_2e$ and 0.8 $MtCO_2e$ respectively by 2030:

- **Afforestation:** Increasing the rate of tree-planting (above baseline rates, assumed to be zero planting) to around 2,000 hectares per year from 2020 to 2030 under the Minimum scenario could deliver 0.3 $MtCO_2e$ savings in 2030. The Maximum scenario of around 4,000 hectares a year (2020-2030) would double the level of savings to 0.6 $MtCO_2e$ by 2030. This level of afforestation is less than the current Welsh Government aspiration of 100,000 hectares between 2010 and 2030, which averages 5,000 hectares a year.
- **Agro-forestry:** The integration of trees and shrubs within arable and livestock systems can deliver GHG savings, such as increased soil carbon stocks and reduced nitrogen oxide emissions from fertiliser use. In addition, it can provide a range of non-GHG benefits (e.g. improvements in water quality and soil fertility). Financial and non-financial barriers would need to be addressed for emissions savings to be realised:
  - We assume savings of 0.07 $MtCO_2e$ and 0.1 $MtCO_2e$ can be delivered by 2030 under the Minimum and Maximum scenarios respectively. This is focused on CO_2 savings from carbon sequestration in trees and soil.
  - Our scenarios assumes a high level of government support, including finance to support farmers. However, barriers due to a lack of knowledge and awareness that currently exist among farmers about the potential benefits of agro-forestry systems are considerable and would also have to be addressed.

With baseline emissions projected to reach 0.4 $MtCO_2e$ by 2030, our range of abatement would imply that the LULUCF sector in Wales remains a small net carbon source of less than 0.1 $MtCO_2e$ by 2030 under the Minimum Scenario. Under the Maximum scenario it would become a net carbon sink of 0.4 $MtCO_2e$.

Beyond 2030, the rate of sequestration from trees planted by 2030 will increase rapidly as they start to reach maturity, thus offering higher abatement savings. Combined with continued new tree planting beyond 2030, we estimate that savings from afforestation could reach 1 $MtCO_2e$ and 2 $MtCO_2e$ by 2050 under the Minimum and Maximum scenarios.

Our Wales 80% scenario includes additional 0.33 $MtCO_2e$ of abatement in 2030 and 1.0 $MtCO_2e$ in 2050. This stems from including afforestation levels at Maximum scenario level. This will deliver around 40% of the additional abatement required to achieve a reduction of 80%.

Table A.4. LULUCF GHG emission abatement in 2030 and 2050 ($MtCO_2e$)				
	2030		**2050**	
Measure	**Minimum**	**Maximum**	**Minimum**	**Maximum**
Afforestation	0.32	0.65	0.95	1.95
Agro-forestry	0.07	0.13	0.10	0.13
Total Abatement	0.4	0.78	1.1	2.08
Residual LULUCF emissions	-0.94	-1.33	-0.98	-2.00

Source: CCC analysis.
Notes: Figures may not add up due to rounding.

Waste

Waste emissions accounted for 2% of Welsh greenhouse gas (GHG) emissions in 2015 (0.9 $MtCO_2e$), of which over 70% came from landfill. Landfill emissions are predominantly methane which arise due to the decomposition of biodegradable waste in landfill sites in the absence of oxygen. Waste water treatment accounts for a further 20% of the country's waste emissions, with biological treatment and incineration making up the remainder.

Between 1990 and 2015 total Welsh waste emissions declined by 72%. With regards to landfill, emissions fell by over 78% due to reductions in biodegradable waste going to landfill, investment in methane capture technology and improved management at landfill sites. The Landfill Tax has been the key driver to date by reducing the volume of waste sent to landfill.

Baseline emissions projections

We use BEIS' 'Updated energy and emissions projections: 2016' projections, published in March 2017,[26] for the baseline emissions projections in the Waste sector. We include emissions in the category 'waste management' in the 'Baseline policies' scenario. Since these projections are not disaggregated on a national level, we scaled them to estimate the Welsh share, by applying the rate of change for each gas in the UK projections to Wales' latest 2015 emissions. The BAU scenario estimates a decrease in emissions from 0.9 $MtCO_2e$ in 2015 to 0.6 $MtCO_2e$ in 2030. Post 2030, we do not assume any further decline in emissions in the BAU scenario and emissions remain at 0.6$MtCO_2e$.

Scenario analysis

Abatement estimated by the CCC for the fifth carbon budget work is based on measures that prevent or divert five biodegradable waste streams (food, paper/card, wood, textiles and garden

[26] https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2016

waste) from landfill across the UK by 2030, plus the specific waste measures of the devolved administrations.

Our analysis suggests that under the Minimum scenario, Wales could achieve 0.37 $MtCO_2e$ of savings by 2030. This abatement is split out at the national and UK level:

- Welsh specific measures to reduce waste emissions could contribute 0.21 $MtCO_2e$ in 2030. As part of its overall aim for circular economy approach to waste, it has an aspiration to have 70% of all waste recycled by 2025, and to reduce waste going to landfill to 5% over the same timeframe.
- Its share[27] of the UK wide ban on biodegradable waste to landfill by 2025 could deliver a further 0.16 $MtCO_2e$.

The latter element accounts for the additional 0.02 $MtCO_2e$ of savings estimated by 2030 for the Maximum scenario. The level of abatement from Welsh specific measures is the same as in the Minimum scenario.

With baseline emissions projected to decline by around a third to 0.6 $MtCO_2e$ between 2015 and 2030, these savings imply a reduction in waste emissions of 58% and 61% respectively under the Minimum and Maximum scenarios.

Our Wales 80% scenario for Wales is equivalent with the Minimum scenario.

Table A.6. Waste GHG emission abatement in 2030 and 2050 ($MtCO_2e$)

	2030		2050	
Measure	**Minimum**	**Maximum**	**Minimum**	**Maximum**
Welsh specific measures to reduce waste emissions	0.21	0.21	0.32	0.32
Welsh share of the UK wide ban on biodegradable	0.16	0.18	0.27	0.30
Total Abatement	0.37	0.39	0.59	0.62
Residual waste emissions	0.26	0.25	0.04	0.005

Source: CCC analysis.
Notes: Figures may not add up due to rounding.

[27] The share is 5% which is based on the share of UK waste emissions that occur in Wales.

F-Gases

Wales emitted around 0.67 $MtCO_2e$ of F-gases in 2015. Without policy it is likely that F-gas emissions would increase further. This is due to increasing use of products and appliances using F-gases, such as in refrigeration and air conditioning equipment or foams used for energy efficiency measures. However, new EU regulations are expected to significantly reduce F-gas emissions across the UK. We assume that Welsh F-gases change in line with our UK scenarios.

Baseline emissions projections

The 2006 EU F-gas Regulation and 2006 MAC Directive introduced restrictions on various uses of F-gases. However, BEIS's latest projections, without further policy (EU or domestic), show that UK emissions would stay broadly flat to 2030, with emissions from refrigeration and air conditioning accounting for 75% of the total.

Scenario Analysis

The 2015 EU F-gas Regulation introduced a series of measures, including a quota system, a series of bans and further leakage checks, which are expected to bring emissions down significantly by the early 2030s:

- It reduces the quantities of HFCs that producers and importers are allowed to place on the EU market. The allowed emissions are being reduced incrementally, which started with a 7% cut in 2016, stepping up to a 33% cut in 2018 and reaching a 79% cut by 2030.
- For new equipment, the regulation introduced a series of bans on the use of F-gases covering crosscutting areas.
- For existing equipment, there is a ban on using the most carbon-intensive HFCs (with a Global Warming Potential above 2,500) for the maintenance and servicing of existing refrigeration equipment from 2020.
- There is some strengthening of existing obligations related to leak checking and repairs, F-gases recovery and technician training.

We have estimated that if these policies are continued post-Brexit they will save around 0.5 $MtCO_2e$ by 2030, which is the basis for both our Minimum and Maximum scenarios in the F-gases sector.

Our Wales 80% scenario is equivalent to the Maximum scenario.

Table A.7. Waste GHG emission abatement in 2030 and 2050 ($MtCO_2e$)

	2030		2050	
	Minimum	**Maximum**	**Minimum**	**Maximum**
Total F-Gas abatement	0.48	0.48	0.61	0.68
Residual F-Gas emissions	0.21	0.21	0.17	0.09

Source: CCC analysis.
Notes: Figures may not add up due to rounding.