Wales Centre for Public Policy
Canolfan Polisi Cyhoeddus Cymru

Net zero 2035: Overview of emissions trends and pathways

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Executive summary

Our analysis of current and historical emissions trends for Wales and key overall sources of abatement in the UK Climate Change Committee's (CCC's) balanced pathway highlights some key patterns.

GHG emissions are falling in Wales and have, so far, kept pace with intermediary targets to achieve net zero by 2050. However, in recent years the majority of emissions reductions in Wales have been driven by progress in the electricity generation sector, offsetting very limited progress in some other key emissions sectors such as agriculture and surface transport. Continuing to meet existing targets for emissions reduction will depend on achieving faster and deeper cuts to emissions in sectors which have historically proved difficult to decarbonize.

Compared to the UK as a whole, sectors such as agriculture and manufacturing and construction contribute a much higher proportion of Wales' total emissions. This means that the success or failure of actions to drive emissions reduction in those sectors will have a proportionately higher impact on Wales' emissions trajectories.

The CCC's balanced pathway scenario for Wales sees emissions falling 69% from the baseline by 2035 and a further 26% by 2050. The fall in emissions is not uniform across sectors, with the pathway relying on steep reductions in electricity generation, surface transport and manufacturing and construction over the next decade. Two thirds of the emissions reduction in the balanced pathway occurs before 2035, with the fastest pace of decarbonization in the early 2030s.

Over 70% of emissions savings in the balanced pathway are driven by technological solutions for decarbonizing electricity generation, industrial processes, surface transport and the heating of buildings; compared to 16% from reducing demand for emissions-intensive activity and efficiency improvements. Remaining emissions savings come from significant changes to land use, as the size of Wales' natural carbon sink more than doubles by 2050 to 4.2 $MtCO_2e$.

The pathway assumes considerable progress in the take up of low carbon technologies across sectors between now and 2035, as fossil fuel technologies are phased out almost completely from the late 2020s and early 2030s. This is reliant on a combination of technological innovation and upgrades and development of infrastructure happening on a substantial scale, including investment in commercial trials of newer technologies. It also highlights the need to address skills gaps to support the transition.

The balanced pathway's proportionately higher reliance on technological solutions partly reflects the CCC's assumptions about how much societal and behaviour change is plausible (and, to an extent, desirable) in the timeframe. This may indicate the potential to accelerate emissions reductions in some areas, through greater ambition on policies to reduce demand for emissions-intensive activity and to deliver efficiency improvements. It is also worth noting that there is considerable debate in climate policy research about the extent to which policymakers should prioritise technological solutions over societal and behaviour changes, given that many of the proposed technologies are still emergent and yet to be proven at scale.

In this paper we provide a more detailed analysis of emissions trends and sources of abatement described in the balanced pathway for six key emissions sectors: electricity generation, manufacturing and construction, residential buildings, agriculture, land use, land use change and forestry (LULUCF), and surface transport. These are a combination of the sectors which either contribute the majority of Wales' current emissions, are regarded as 'difficult to mitigate', or have the highest levels of residual emissions in the balanced pathway in 2035 (plus the LULUCF sector which we include to reflect the importance of its potential role in removing emissions). For each sector, this analysis highlights implications of seeking to accelerate progress in emissions reduction, summarised below:

Electricity generation

- Emissions from this sector fall to almost zero by 2035 in the balanced pathway, with reductions heavily dependent on the phasing out of unabated gas generation by this date. However, this transition is likely to prove more difficult than the transition away from coal, as some low carbon alternatives to gas are yet to be fully commercialized and deployed at scale.
- The pathway assumes a significant upscaling of renewable energy: accelerating emissions reduction will rely on this happening sooner. However, costs for both installing and running some technologies remain uncertain. Policy support could help decrease levelized costs, encouraging private investment; clear signposting of policy goals and implementation plans could also help ensure that the right products and skills are available at the right time.
- While the decarbonisation of electricity generation drives around a third of emissions savings in the balanced pathway for Wales, many of the relevant policy levers are reserved to the UK Government, meaning that commitment and collaboration will be required to accelerate emissions reduction in this sector in Wales, both within the UK and, to a lesser extent, with Europe.

Manufacturing and construction

- In the balanced pathway, manufacturing and construction emissions fall by 85% from the baseline to near zero by 2035. Almost two thirds of these emissions savings come from a switch away from fossil fuels in all manufacturing processes and off-road mobile machinery, with carbon capture and storage deployed for processes where this is the only cost-feasible option. However, many of the technologies involved – both for fuel-switching for industrial processes and carbon capture and storage – are unproven at scale, with considerable uncertainty about what mix of options will prove to be feasible and cost-effective.
- A handful of industrial sites are responsible for most of Wales' manufacturing and construction emissions. Ensuring these businesses are committed to investing in the switch to low carbon fuel sources is critical to both achieving net zero by 2050 and any ambitions to accelerate emissions reductions. At a minimum, this relies on ensuring that the right incentives are in place and that these do not result in emissions being displaced across the globe through offshoring.
- The balanced pathway also assumes some reductions in end-user demand leading to reductions in industrial output. This could have significant socio-economic impacts, including the closure of some industrial sites and job losses – highlighting the importance of a 'just transition' approach which strengthens those communities most impacted by the shift to an emissions neutral economy.

Residential buildings

- The balanced pathway for Wales sees residential buildings emissions falling by 45% from the baseline by 2035 and a further 55% by 2050. About 70% of these emissions savings result from the phase out of fossil-fuels (mainly gas-powered boilers) for heating Wales' homes, with the remaining 30% coming from reductions in domestic energy demand, driven by a combination of behaviour change and energy efficiency measures.
- Reductions in domestic energy demand in the balanced pathway rely on large-scale deployment of retrofit installations, with almost 400,000 of Wales' existing homes receiving roof or wall insulation by 2035. The scenario assumes that several regulatory levers are deployed in the 2020s to drive uptake across different tenure types, some of which are reserved to Westminster; the current housing turnover rate in Wales means that additional incentives will still be needed to ensure a high uptake of retrofit measures among homeowners and private landlords.

- The balanced pathway for Wales assumes the phase out of fossil fuel boiler installations in homes by 2033 at the earliest, with the need to scale up new markets and supply chains from current low levels constraining potential for earlier large-scale deployment, alongside current skills gaps and the need for retrofit measures to prepare Wales' housing stock for the transition to low carbon heating.
- However, lifetime emissions for gas boilers means that any delay in the transition to low carbon heat puts the sector's pathway to net zero in jeopardy, if new gas boilers continue to be installed in homes in Wales after 2033. It is instructive to recognise the scale of the challenge – with just 700 heat pumps installed in Wales in 2019, compared to the 68,000 annual installations by 2035 in the balanced pathway.

Agriculture

- In the balanced pathway the agriculture sector in Wales does not reach net zero, with agricultural emissions falling 25% from the baseline by 2035 and a further 8% by 2050. The majority of these emissions savings are driven by measures to release farmed land for other uses, including productivity improvements, dietary change, and reductions in food waste. The remaining 35% of reductions comes from uptake of a range of low carbon farming practices and improved energy use on farms.
- The pathway assumes a 35% reduction in meat and dairy consumption by 2050, resulting in falls in livestock numbers and the amount of farmland used for grazing, with an assumption this land is shifted to crops where possible. It is important to consider the potential impact of these changes on Welsh farmers and farming communities, given that livestock accounts for 81% of Wales' gross agricultural output, and the most common farm type in Wales (25%) relies on cattle and sheep grazing on land designated as Less Favoured Areas; just 2% of all current farms in Wales are dedicated to crops and horticulture.
- While some land release measures in the pathway involve increases in agricultural productivity, including increases in wheat yields, there is considerable uncertainty about how these might be affected by future changes in the climate. When exploring options to accelerate emissions reduction, it remains vital to consider potential impacts of a changing climate on Welsh farming and food systems.
- The balanced pathway assumes uptake of between 50% and 70% for different low carbon farming practices. In the CCC's exploratory modelling, scenarios which involve higher levels of innovation achieve similar levels of abatement

as scenarios which are more reliant on measures involving behaviour change for farmers. This suggests that behavioural measures can deliver emissions reduction at a lower cost and with less reliance on technological development, potentially allowing for easier and earlier policy intervention.

LULUCF

- In the balanced pathway the LULUCF sector becomes a net carbon sink from 2024 onwards, removing 4.2 MtCO2e of emissions in 2050. The majority of these emissions savings come from afforestation measures, with a smaller reliance on peatland restoration, measures relating to energy crops and agroforestry.
- Other potential natural sources of removals, including marine and coastal ecosystems, are not included in the pathway modelling because limitations in the data mean it is not currently possible to present a carbon budget for Welsh waters. Areas with the highest potential sequestration benefits, such as kelp and marine sediments, remain poorly understood and are harder to quantify in the context of abatement.
- While Wales is making strong progress on peatland restoration, these measures are likely to make a less significant contribution to emissions savings in Wales (reflecting Wales' relatively low amount of degraded peatland compared to the rest of the UK). In consequence, afforestation measures are likely to have a greater proportional impact, but progress remains well behind both the Welsh Government's existing targets and the annual level of tree planting assumed in the balanced pathway, which reaches 7,500 hectares a year by 2035.
- The energy crops, agroforestry and hedgerow measures in the balanced pathway involve changes to farming practices. While these measures can have additional environmental co-benefits alongside sequestering emissions, the planting of energy crops can have negative impacts on biodiversity, soil health and water quality. This highlights the importance of ensuring farmers possess the necessary skills and expertise to implement measures in a way that maximizes the benefits and mitigates risks. A package of support for farmers in this area may be necessary to accelerate emissions reduction; the new Sustainable Farming Scheme could present an opportunity for this.

Surface transport

- Emissions from surface transport have seen relatively little progress since 1990, largely as a result of continuous growth in the volume of road traffic in Wales up to 2019 offsetting improvements in other areas (the volume of both

road traffic and surface transport emissions fell significantly for the first time in 2020 as a result of pandemic restrictions).

- In the balanced pathway, surface transport emissions fall 75% from the baseline by 2035 and a further 25% to near zero in 2050. Almost three quarters of the fall in emissions by 2035 results from uptake of low emissions vehicles, with fully electric cars making up close to 100% of new sales by 2030 (compared to 7% in Wales in 2021). This relies on considerable levels of ambition on the pace of the infrastructure roll out to support the transition to electric vehicles, including installation of up to 55,000 public charge points for electric cars across Wales by 2030 and rapid upgrades to the electricity network to meet the substantial demand added to the grid by electric vehicle charging.
- Cuts to surface transport emissions in the balanced pathway are proportionally less reliant on reducing demand for travel, with the pathway assuming a maximum 16% reduction by 2035. However, options may exist to go further and faster than the balanced pathway in accelerating modal shift and reducing demand through societal changes (such as increased homeworking). Indeed, many experts advocate a greater emphasis on interventions to reduce demand for travel, cautioning that widespread electrification of surface transport is likely to prove too slow to meet climate mitigation targets.

Introduction

At the first meeting of the Net Zero 2035 Challenge Group on 10th January 2023 the Wales Centre for Public Policy (WCPP) presented an overview of existing emissions trends in Wales and emissions pathways for Wales modelled by the UK Climate Change Committee (CCC), addressing the following research questions:

1. What is Wales' current progress towards its emissions targets?
2. What are the key sources of abatement described in the CCC's 'balanced pathway' for Wales, both up to 2035 and 2050?
3. What are the potential implications of seeking to accelerate these?

This paper expands on the presentation and sets out the policy background and current and historical emissions trends, before providing an overview of the CCC's balanced pathway scenario for Wales and then going into a more detailed analysis of the pathway and emissions trends for six key emissions sectors. Throughout, we follow the sector definitions used by the CCC, which differ slightly from those used by the Welsh Government.

This paper was written to support the Net Zero 2035 Challenge Group and therefore the analysis and conclusions are the authors' own and do not represent the views or positions of the Group.

Context

Welsh policymaking and the climate emergency

With less than ten years until climate system breakdown at current emissions rates, the need for rapid and drastic reductions in greenhouse gas emissions has never been more urgent – and cannot be achieved without widespread societal and industrial transitions and ambitious action at all scales (IPCC, 2019). Emissions are still rising globally, and current trends are inconsistent with meeting the long-term objective of the Paris Agreement to limit global warming to well below 2 degrees Celsius compared to pre-industrial levels, with every fraction of a degree of further rises expected to compound the accelerating effects (IPCC, 2022). In this context, in every nation, every year and every choice matters.

The Environment (Wales) Act 2016 marked an escalation in Wales' efforts to tackle climate change, in tandem with the Well-being of Future Generations (Wales) Act 2015 (WFG Act). The latter piece of legislation places duties on all public bodies, including the Welsh Government, to act in accordance with the sustainable development principle and work towards seven wellbeing goals for current and future generations. The Environment Act placed new duties on the Welsh Government to ensure emissions reduce, and introduced a carbon budgeting method to measure progress towards the target of an 80% reduction in emissions by 2050. Based on advice from the CCC (UK CCC, 2017), the first two carbon budgets were set in late 2018, followed by the publication of a low carbon delivery plan setting out how Wales aimed to meet the first carbon budget (2016-2020) (Welsh Government, 2019a) In 2019, the Welsh Government declared a climate emergency in response to the latest evidence from the Intergovernmental Panel on Climate Change (IPCC). Shortly after, it amended its existing target for reducing emissions based on updated advice from the CCC, and in early 2021 laid regulations to set a legally binding target of net zero emissions by 2050, as well as setting the third carbon budget (2026-2030), Table 1. The plan for delivering the second carbon budget, reflecting the amended net zero target, was published in November 2021. It draws substantially on the CCC modelling, and in particular the 'balanced pathway' emissions reduction scenario described in their advice report (UK CCC, 2020a), while setting out policy ambitions and actions which depart from this in some areas to better reflect the geography, culture and economy of Wales (Welsh Government, 2021a). The Net Zero Wales delivery plan for carbon budget 2 was accompanied by an independently commissioned sustainability appraisal, to better understand the collective well-being impacts of the plan, evidencing how it meets the requirements of the WFG Act (Welsh Government, 2021b). A delivery plan for the third carbon budget is required to be published in 2026, the first year of the next Senedd term.

Table 1: Targets and carbon budgets approved by the Senedd in March 2021

Carbon budget 2 (2021-2025)	Average 37% reduction
Carbon budget 3 (2026-2030)	Average 58% reduction
2030 target	63% reduction
2040 target	89% reduction
2050 target	At least 100% reduction (net zero)

Source: Welsh Government, 2021c

Following Senedd elections in May 2021, a Cooperation Agreement between the Welsh Government and Plaid Cymru commenced in December that year, containing

a range of policy areas on which the Welsh Government and Plaid Cymru will cooperate for a period of three years as well as an agreement for Plaid Cymru to facilitate the passing of Welsh Government budgets during this period. On Wales' ambitions for reducing emissions, the Cooperation Agreement includes the following commitment:

> **Working together, we will [commission] independent advice to examine potential pathways to net zero by 2035 […]. This will look at the impact on society and sectors of our economy and how any adverse effects may be mitigated, including how the costs and benefits are shared fairly. We support devolution of further powers and resources Wales needs to respond most effectively to reach net zero, specifically the management of the Crown Estate and its assets in Wales.** (Welsh Government, 2021d: 5)

In August 2022, the Minister for Climate Change announced that while the approach to fulfilling this commitment was still being developed, it was expected to involve both analysis of research and data and involvement of a wide range of stakeholders, and would be chaired by Jane Davidson (Welsh Government, 2022a). In response to this, a Net Zero 2035 Challenge Group was established and met for the first time in January 2023, with an intention to meet monthly for the remaining 18 months of the co-operation agreement. This paper expands on the presentation of existing emissions trends and pathway modelling given by WCPP at the January meeting of this group.

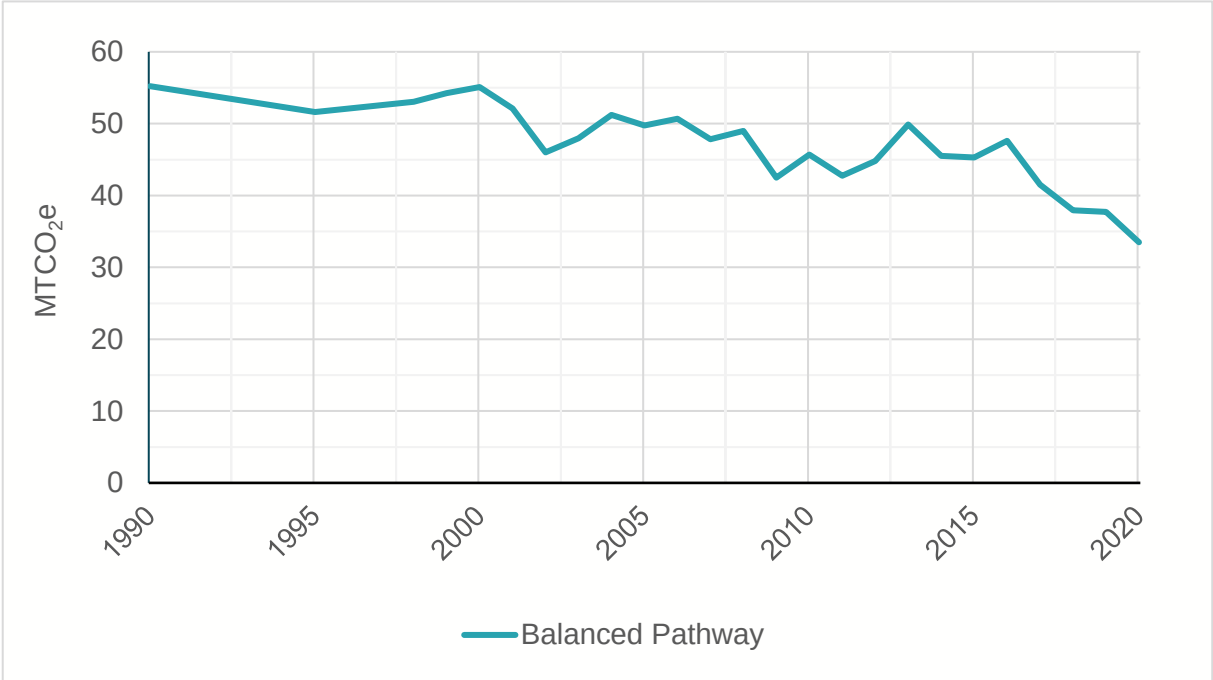
Overview of emissions trends in Wales, 1990-2020

Emissions of greenhouse gases in Wales have fallen by 31% since 1990, from 51.2 $MtCO_2e$ to 33.6 $MtCO_2e$ in 2020, with emissions reductions accelerating from 2016. Between 2016 and 2018, greenhouse gas emissions reduced by close to 20% and fell a further 12% in 2020, exceeding the target for carbon budget 1 (a 23% average reduction) by around 6.7 $MtCO_2e$.

This downward trend has not been uniform across emissions sectors, with slower or stalled reductions in some sectors offset by faster and greater gains in others. In recent years emissions reductions in Wales have been dominated by the electricity generation sector, which was responsible for 85% of total reductions between 2016 and 2018 – indeed, the slowdown and closure of Aberthaw coal-fired power station alone contributed over half of the total fall in emissions between 2016 and 2020 (Corbyn, 2021). Emissions from manufacturing and construction (-9%) and fuel

supply (-7%) have also seen encouraging recent declines – but emissions in all other sectors fell by an average of just 1% between 2016 and 2018, with sectors such as agriculture seeing only marginal reductions between 1990 and 2018, and emissions from surface transport higher in 2018 than they were in 1990.

Figure 2: GHG emissions in Wales in $MtCO_2e$, 1990-2020



Emissions data for Wales is available until 2020, but the long-term trend is difficult to interpret because of the impacts of the Covid-19 pandemic which saw dramatic changes to Wales' economy and society that year. In 2019, greenhouse gas emissions fell by just 1% whereas in 2020 they dropped by 12%. Three quarters of the fall in emissions in 2020 came from two sectors, surface transport (-22%) and electricity generation (-26%), while other sectors remained relatively flat (and residential buildings emissions increased) (NAEI, 2021, WCPP analysis). While emissions data for Wales are not available for 2021, indications are that emissions rose as the economy began to recover from the pandemic but remain lower than they were in 2019 (UK CCC, 2022a). In the remaining sections of this presentation, we discuss emissions trends to 2019 unless otherwise stated, because 2020 was such an exceptional year and 2021 emissions data are not yet available.

Overview of the balanced pathway

Wales' existing emissions reduction targets reflect advice from the CCC, based on a range of detailed exploratory scenarios modelling pathways to net zero by 2050. Each of the CCC's scenarios use the same central assumptions, but explore

pathways involving different levels of success in the extent and pace of technological and behaviour change:

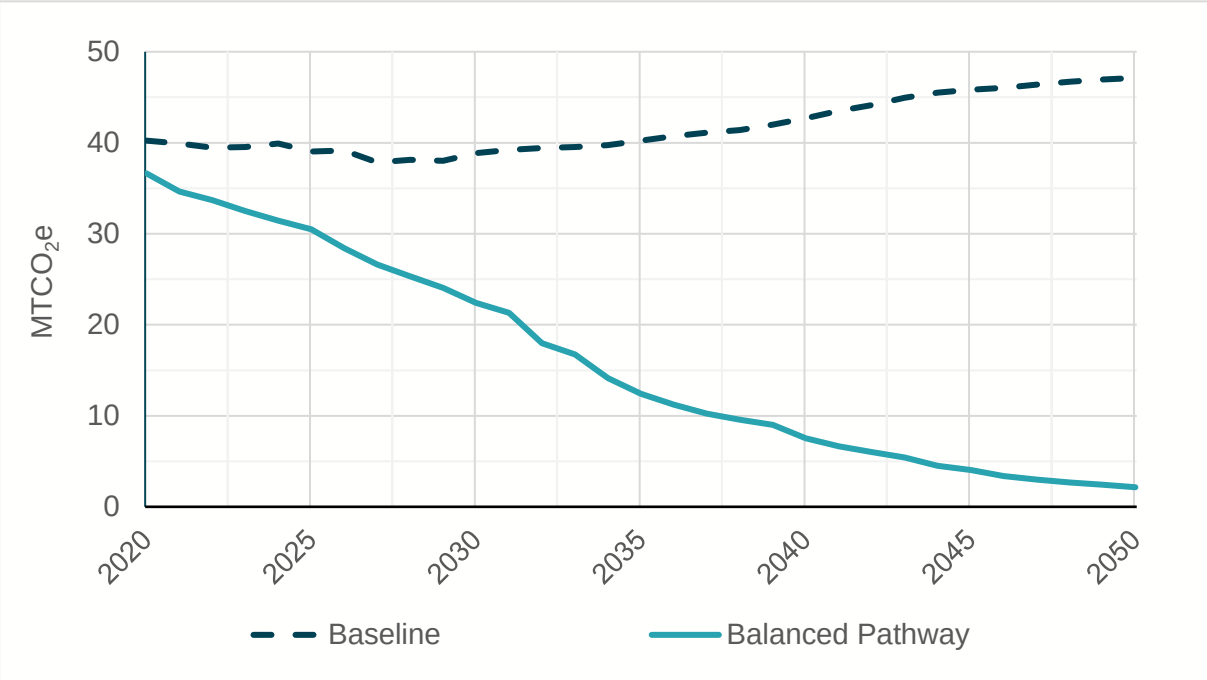
- A ‘widespread engagement’ scenario, assuming higher levels of behaviour change;
- A ‘widespread innovation’ scenario, assuming greater success in reducing costs of low-carbon technologies, more widespread electrification, improvements to resource and energy efficiency and more cost-effective carbon removal technologies;
- A ‘headwinds’ scenario, in which policies have a limited influence on behaviour change and widespread innovation is also limited (this scenario is more reliant on the use of hydrogen and Carbon Capture and Storage (CCS) to reach net zero); and
- A ‘tailwinds’ scenario, which assumes considerable success on both fronts – regarded by the CCC as stretching feasibility in some areas and going beyond current evidence in others.

The balanced pathway is the basis of the CCC’s emissions target advice to the Welsh Government. This draws on the range of solutions across the different exploratory scenarios described above, with an emphasis on known and existing technologies and behaviours, aiming for the flexibility to be adapted as these develop in the coming decades and more evidence emerges about the most effective ways to cut emissions (UK CCC, 2020a). Importantly, the scenario is not intended to be prescriptive, but rather *illustrative* of what the CCC regards as a broadly sensible path based on moderate assumptions, with the scope to mix and match between the different scenarios and make faster progress wherever possible – either to accelerate overall emissions reduction or compensate for slower than anticipated progress in other areas. In terms of timeline, the pathway involves a scaling up of solutions in this decade and full delivery and implementation in the 2030s and 2040s, with two thirds of emissions reduction occurring before 2035 and the fastest rate of decarbonisation happening in the early 2030s (Figure 3). This would mean Wales achieving the majority of its emissions reductions by the end of the next Senedd term.

For Wales, the balanced pathway scenario involves four principal drivers of emissions reduction. The bulk of emissions savings between now and 2050 come from *take up of low carbon solutions* by people and businesses as high carbon options are phased out, with all new cars and vans and all boiler replacements in homes and other buildings low carbon by the early 2030s, and the South Wales industrial cluster switching away from fossil fuels and/or installing CCS at scale from mid-2030s. About a third of Wales’ emissions reduction is driven by the *expansion of low carbon energy supplies* as the low-carbon share of generation in Wales increases from 27% today to 100% by 2035, cutting energy supply emissions by more than 95%. 16% of emissions savings in the pathway arise from a combination

of *reduced demand for carbon-intensive activities and efficiency improvements*. On the demand reduction side, reduced demand for travel, a shift away from meat and dairy consumption, and reductions in waste are particularly important sources of abatement. Better insulation of buildings, vehicle efficiency and efficiency improvements in industry are all key to driving emissions reduction via increased efficiency. The final driver of emissions reduction in the pathway involves very substantial changes in the use of Wales' land including changes to agriculture and food systems, which we expand on in the sections on agriculture and land use below.

Figure 3: GHG emissions in Wales in $MtCO_2e$, baseline and balanced pathway scenarios



It is also important to highlight the extent to which the CCC's modelling and advice to the Welsh Government recognises the specificities of the Welsh context. Multiple features of Wales' geography mean that the pace, scale, and key drivers of emissions reduction in the balanced pathway are different for Wales compared to the UK as a whole. For one thing, Wales has a distinctive emissions profile, with sectors like agriculture and manufacturing and construction contributing much more proportionally than they do to UK emissions as a whole. This means that the success or failure of actions to drive emissions reduction in those sectors has a disproportionate impact on Wales' emissions trajectories. Reflecting this, the pace, scale and contribution of emissions reduction is not uniform across sectors in the balanced pathway for Wales, relying on some quite steep reductions in the coming decade for manufacturing and construction, surface transport and electricity supply,

while other sectors decarbonise slower – and agriculture becomes far and away the highest sector by 2035 (see Annex).

The final sections of this paper provide further detail on emissions trends and pathways for six emissions sectors: electricity generation, manufacturing and construction, buildings, agriculture, LULUCF (land use, land use change and forestry), and surface transport. These are a combination of the sectors which contribute most to Wales' emissions currently and those with the highest levels of residual emissions in the balanced pathway in 2035 (with the exception of LULUCF which we have included for its potential role as a carbon sink).

Sectoral pathways

Electricity generation

Current and historic emissions trends

In 2019, electricity generation was Wales' second largest source of emissions, contributing to 19% of the total. Emissions in this sector come from the burning of fossil fuels to generate electricity, as only 27% of Wales electricity generation in 2019 came from renewable sources (Welsh Government, 2020a). Much of the non-renewable generation in 2019 came from gas fuelled power stations, with coal and diesel playing a much smaller role. Emissions reductions in the electricity generation sector has been responsible for 85% of the total fall in emissions in Wales since 2016.

Significant progress has already been made to decarbonise this sector, with emissions falling by around 33% since 1990. In 2019, emissions from the electricity generation sector fell by 8%, which can partly be attributed to the commissioning of 145MW of new renewable energy capacity (Welsh Government, 2020a). Wales was a net exporter of electricity to the rest of the UK grid in 2019, generating 28 TWh of electricity in 2019, while consuming approximately 15 TWh.

Wales remained a net exporter of electricity to the rest of the UK grid in 2020, however there were reductions in both the amount of electricity generated and consumed. 23 TWh of electricity were produced in 2020, a 17% reduction on the previous year, while there was also a 6% reduction in the amount of electricity consumed (Welsh Government 2022b). Reductions in consumption can largely be

attributed to the impacts of the COVID-19 pandemic, whereas reductions in generation came from Calon Energy, operator of two gas power plants, entering administration, as well as the closure of Aberthaw coal-fired power station (Welsh Government, 2022b).

Aberthaw was Wales' last remaining coal-fired power station, and its closure in 2020 means that there is now no electricity generated from coal-fired sources in Wales: in comparison, coal-fired sources generated 21.5% of Wales' total electricity generation in 2015 (Department for Business, Energy and Industrial Strategy, 2017). Reductions in fossil fuel generation, reflected in the closure of Aberthaw reflect continued focus and commitment in decarbonising the sector. This is illustrated in the Welsh Government's target of meeting 100% of Wales' electricity demand from Welsh renewable sources by 2035 (Welsh Government, 2023).

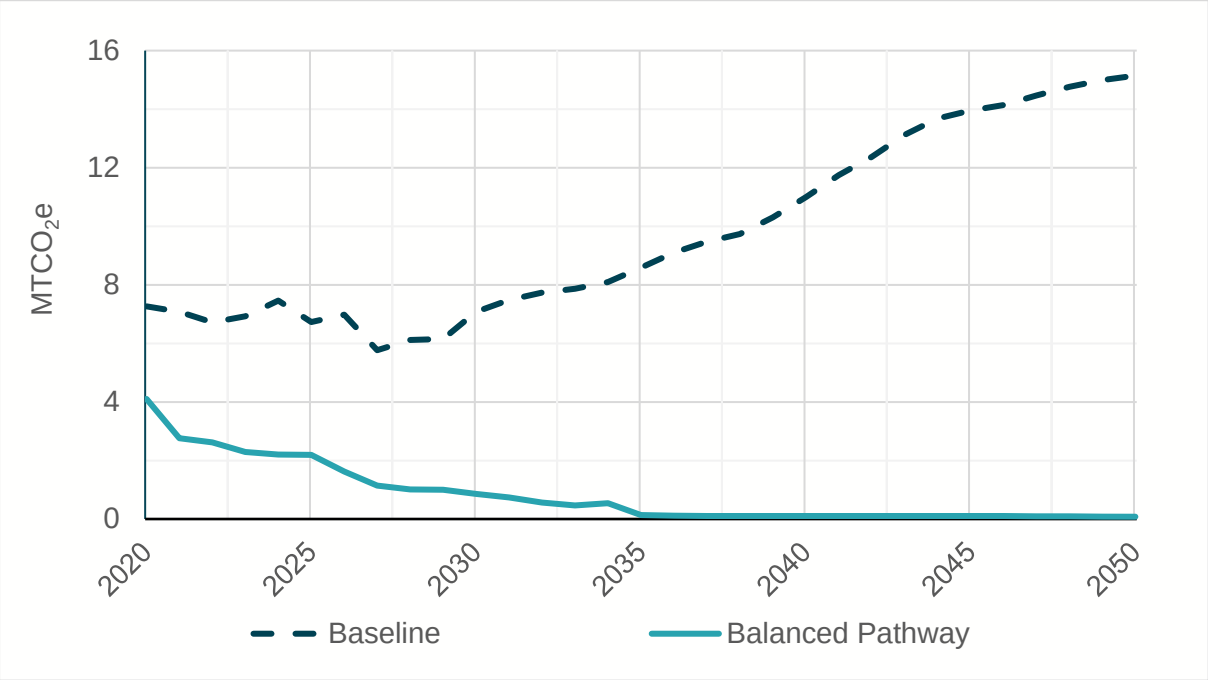
Significant progress has been made in decarbonising the sector in recent years, both in terms of decreasing consumption and increasing renewable generation, with electricity consumption in Wales decreasing by 16% since 2005, and renewable electricity generation increasing by more than 500% since the same date (Welsh Government, 2020a). However, progress has slowed in recent years, with the rate of renewable electricity installation falling every year since 2015, and a simultaneous slowing of the decline in electricity consumption (Welsh Government, 2020a).

Electricity generation emissions in the balanced pathway

The balanced pathway sees emissions from the Welsh electricity generation sector fall 99% from the baseline by 2035, reducing to near zero by 2050. Largely, the path to decarbonising the sector involves continuing recent efforts to both reduce consumption and increase the proportion of renewable energy, with the balanced pathway modelling a scenario where energy efficiency measures mitigate increased demand for electricity, and where the electricity generated is increasingly low or zero carbon. Given the reliance on variable renewable generation methods in this scenario, it also features measures to build a more flexible energy system.

The path to decarbonisation in several other sectors, such as buildings, manufacturing, and surface transport, is likely to include electrification as a key low-carbon option. This has the effect of increasing demand for electricity, which, in the balanced pathway scenario, rises to 37TWh in 2050, more than double Wales' electricity consumption in 2019 (15TWh). While improvements in efficiency for products such as heat pumps, lightbulbs, appliances, and electric motors can help to mitigate increases in demand, the scope for further improvements will decrease over time as uptake of efficient options increases.

Figure 4: Wales manufacturing and construction emissions, baseline and balanced pathway



The balanced pathway scenario also assumes that burning of gas for electricity generation (without the application of carbon capture and storage) ceases from 2035, meaning that electricity generation in Wales is 100% low carbon from that date, rising from around 28% in 2021. Wind power is the predominant source of generation, with the majority of this generated offshore; there is also increased deployment of solar energy. The balanced pathway scenario also includes use of gas power stations fitted with carbon capture and storage to provide dispatchable generation, although these are converted to hydrogen when that option becomes feasible at scale. Bioenergy generation is also deployed, providing it is also fitted with carbon capture and storage. Despite retirements of some existing nuclear power plants, the model assumes that new projects, such as those outlined in the UK Government's Ten Point Plan for a Green Industrial Revolution, also provide low carbon electricity (Department for Business, Energy, and Industrial Strategy, 2020a).

The balanced pathway for electricity generation in Wales also includes measures to mitigate the variability in the electricity supply generated by renewable sources, providing flexibility in both demand and supply. Electrified technologies, such as smart charging and pre-heating are used to allow for flexibility in demand, and surplus electricity is stored in batteries for in-day flexibility. Hydrogen can be used as a method of medium-term storage, at around the same cost as pumped hydroelectric storage, which is also used to provide low carbon electricity when it is most in need. In addition, surplus energy is also used to produce hydrogen for a variety of uses at a

low cost through electrolysers: 25% of UK hydrogen supply originates from electrolysis by 2035, with this figure rising to 45% by 2050. Lastly, increased interconnection capacity allows the purchase and sale of energy from neighbouring countries, with capacity for this tripling by 2050.

Implications for accelerating emissions reduction

Emissions reduction for this sector in the balanced pathway relies heavily on the phasing out of unabated gas generation by 2035. However, this transition is likely to prove more difficult than the transition away from coal, as low carbon alternatives to gas, including hydrogen, are yet to be fully commercialised and deployed at scale (UK CCC, 2020b). Costs in both installing and running different technologies remain uncertain, and while offshore wind has become cheaper, it is unclear whether the reductions will be sustained (UK CCC, 2020b), or replicated for other renewable technologies. A significant upscaling of renewable energy is a key assumption in the balanced pathway and accelerating emission reductions will rely on this happening faster. Policy support could help decrease levelised costs[1], encouraging private investment; moreover, clear signposting of policy goals and steps to achieving them can help ensure that the right products and skills are available at the right time.

As well as solar and wind energy, the future mix of electricity generated in Wales could include other sources such as tidal or wave energy if they prove to be cost-effective. Ultimately, the precise mix of sources used to generate electricity in Wales in the future will depend on the cost-effectiveness of different options, meaning it is impractical to determine the precise amount of electricity generated by different sources in the future. Wales forms part of the National Grid, along with England and Scotland, and is currently a net exporter of electricity to the rest of the UK. Depending on where is best suited to the relevant renewable energy sources, this may change in the future; however, Wales has significant potential for off-shore wind, which is assumed in the balanced pathway to be the primary source of renewable generation.

Even if the British electricity network is decarbonised, there is the potential to import residual emissions through interconnection, as there may be uncertainty surrounding the carbon intensity of electricity imported from other countries. CCC analysis (2020b) notes that these potential residual emissions can be minimised by ensuring electricity supply exceeds peak demand, making the UK a net exporter of electricity. In addition, ensuring there is flexibility in the domestic energy system to manage

[1] Levelised cost is the ratio of the total costs of building and operating an energy plant, compared to the total revenue expected to be generated over the plant's lifetime (Department for Business, Energy and Industrial Strategy, 2020b).

variability in supply and demand can reduce the need to import energy in times of peak demand. Decarbonising this sector requires an effort to both reduce the carbon intensity of generation, but also to embed flexibility within the energy network. However, many of the relevant policy levers are reserved to the UK Government, meaning that commitment and collaboration will be required to accelerate emissions reduction in this sector in Wales both within the UK and, to a lesser extent, with Europe.

Manufacturing and construction

Current and historic emissions trends

In 2019, emissions from the manufacturing and construction sector accounted for 28% of emissions in Wales. Emissions in the sector include those from both the business and industrial processes emissions inventory categories, with emissions from iron and steel production having a significant impact on the Welsh total (Department for Business, Energy, and Industrial Strategy, 2022). Emissions in the sector have fallen by around 36% compared to 1990 levels, driven largely by changes in operating practices, switching to less carbon-intensive fuels, and efficiency improvements (Welsh Government, 2021a). However, other underlying factors may also explain the fall in emissions from the sector, as the period from 1990 to 2019 also coincided with a significant reduction in the iron and steel output in Wales (StatsWales, 2022).

Emissions in the sector are susceptible to significant year-on-year variability, as they are strongly influenced by the output of industrial sites, for example, there was a 5% increase in sectoral emissions in 2019 compared to 2018, driven by a significant increase in emissions from the iron and steel sector (Welsh Government, 2021a).

Around 77% of UK emissions in this sector come from the combustion of fuel (for a variety of purposes), 13% were process emissions, arising from a range of chemical reactions. The remaining 10% of emissions come from the combustion of diesel as a fuel in off-road mobile machinery. Emissions in the sector are largely comprised of carbon dioxide (93% of the UK sectoral total), with smaller amounts of methane (0.6%) and nitrous oxide (0.8%).

A significant number of people in Wales are employed in the manufacturing and construction sector, with around 25,000 people employed in the iron and steel industry, and around 100,000 people employed in the construction industry in 2019 (CITB Wales, 2021; StatsWales, 2022). It will be crucial to support this workforce as the sector decarbonises; moreover, if decarbonisation of the sector results in reduced

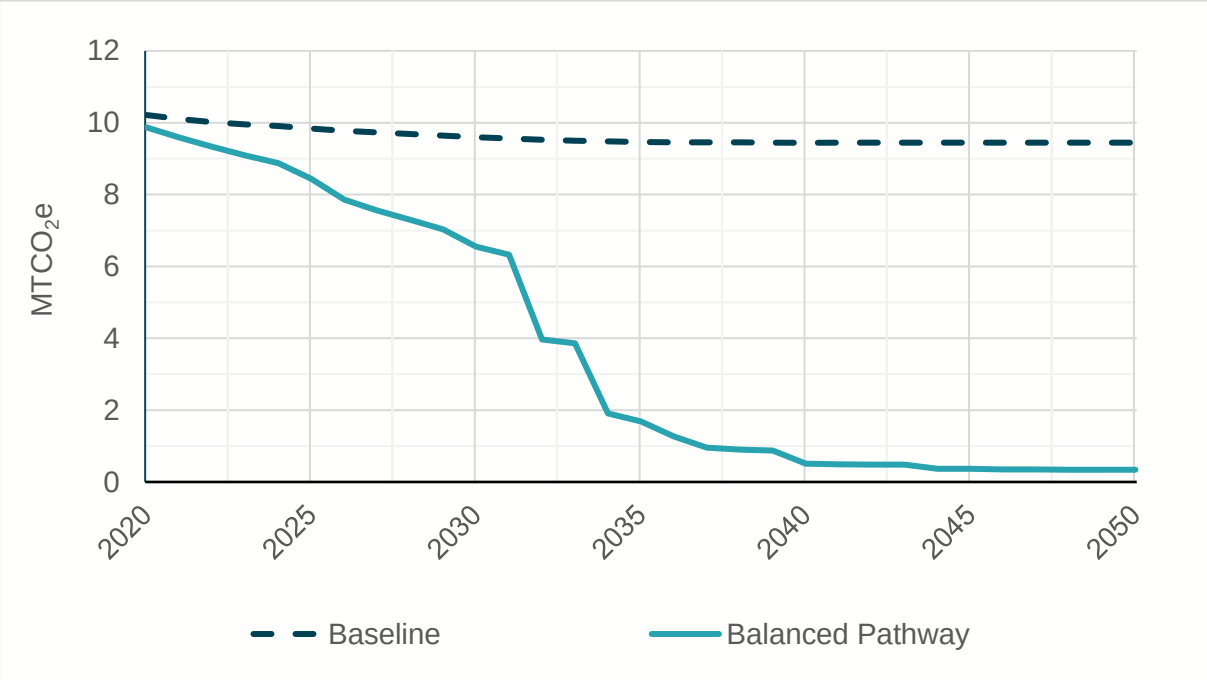
industrial output, it will be important to ensure that emissions are not offshored elsewhere.

Manufacturing and construction emissions in the balanced pathway

The balanced pathway models a scenario for decarbonising the manufacturing and construction sector in a way which keeps options open, while assuming that low regret actions to progress to net zero are undertaken. Under the balanced pathway scenario, there is an 85% reduction in emissions in the sector by 2035, with the sector reaching near net zero by 2035. This is as a result of both short-term efficiency improvements and medium-to-long-term deployment of fuel switching options.

In the balanced pathway scenario, around 32% of emissions reductions for the sector by 2035 are driven by short-term efficiency improvements: these measures account for the vast majority of emissions reductions before 2030. This includes measures to improve the efficiency of resource use, improving energy efficiency in industrial processes, and substitution towards low-carbon materials in subsectors such as cement production and construction.

Figure 5: Wales manufacturing and construction emissions, baseline and balanced pathway



The remaining 64% of emissions reductions for the sector by 2035 are driven by medium-to-long term fuel switching options. Fuel switching occurs in all manufacturing processes and in all off-road mobile machinery (e.g., generators and forklifts), and a mix of options are deployed in the 2020s due to uncertainty over which options will be the most cost-effective. The model deployed in assessing business decarbonisation options (Element Energy, 2020) assumes that cost-effectiveness drives the adoption and deployment of fuel switching technologies, with electrification and hydrogen being the primary measures selected. Carbon capture and storage (CCS) is deployed as a lower cost measure in around half of the UK's steelworks capacity, and in other processes where it is the only cost-feasible option. It is assumed in the balanced pathway model that carbon capture and storage is rolled out across the South Wales Industrial Cluster during the early 2030s, accounting for significant emissions reductions for the sector between 2030 and 2035. It is also assumed that bioenergy is deployed in sectors that already use it, fitted with carbon capture and storage.

Implications for accelerating emissions reduction

Large-scale emissions savings in the manufacturing and construction sector could be achieved by the decarbonisation of relatively few industrial sites, because large industrial sites such as the Port Talbot steelworks are responsible for a significant proportion of Wales' emissions from manufacturing and construction. Ensuring that these businesses are committed to the goal of decarbonisation will be critical to both achieving net zero by 2050 and any ambitions to accelerate emissions reduction pathways. The CCC's more ambitious tailwinds scenario sees faster progress towards decarbonising the sector, reliant on businesses going further than simply responding to government incentives to decarbonise (UK CCC, 2020c). It is therefore critical that at a minimum the right incentives are put in place and that these do not result in emissions being displaced across the globe through offshoring.

As stated above, measures which aim to improve industrial efficiency include those which reduce end-user demand for goods, such as increased reuse and recycling, increased product longevity, and increased product sharing. Within the CCC's model, it is assumed that reducing the consumption of resources will result in lower industrial demand. If this is not offset by baseline increases in demand for goods (for example due to population growth), it is assumed that some industrial sites reduce their output or close completely. This would likely have significant socio-economic impacts on local communities in Wales, including job losses. Moreover, effectively implementing the measures required to decarbonise Welsh industry will require an updated skills base. It is important that the transition to a net zero manufacturing and construction sector incorporates lessons from previous industrial transitions in order to mitigate

socio-economic consequences, taking a collaborative approach that strengthens the communities most impacted by the transition to net zero (Silva et al, 2022).

Wales is significantly more reliant on carbon capture and storage for emissions reductions than the UK as a whole, given that emissions from this sector are significantly higher in Wales than in other parts of the UK, and given the assumption within the balanced pathway model that CCS is the method of decarbonisation for around half of all steelworks. However, there is no option in South Wales to store captured carbon locally, meaning that captured CO_2 would have to be transported from the South Wales industrial cluster to other clusters to be stored offshore (Element Energy, 2020). While pipeline transportation is well-established, the most viable option is for captured carbon from South Wales to be transported by ship, however this practice is currently limited to small volumes and there are concerns over operating costs (High, 2022). Any deployment of carbon capture and storage to decarbonise industry in Wales would therefore likely happen after other industrial clusters in the UK, requiring additional lead time to develop the infrastructure to transport captured carbon. Despite this, analysis suggests that the infrastructure for the transport and shipment of captured carbon could be available in the South Wales industrial cluster by 2030 (Element Energy, 2020).

Residential buildings

Current and historic emissions trends

In 2019, direct emissions from residential buildings (mainly from the use of gas for heating, hot water, and cooking) accounted for 10% of Wales' greenhouse gas emissions – this proportion increases to over 15% when including indirect emissions from electricity use in homes (mainly from lighting and appliances) (NAEI, 2020, WCPP analysis).

Between 1990 and 2014 direct emissions from residential buildings in Wales fell by almost a third, with some year-on-year fluctuation due to economic and temperature effects. The bulk of the fall in emissions in the 2000s can be attributed to domestic energy efficiency improvements, which had begun to slow down as a result of policy changes in 2013 (UK CCC, 2014); other factors likely to have contributed to the decline in this period include high energy prices and the 2008 recession (UK CCC, 2015). However, since 2014 direct emissions from residential buildings in Wales have shown few signs of reducing.

Cutting residential buildings emissions will mean reducing energy use in homes, large amounts of which is currently wasted due to a lack of insulation and inefficient heating systems. This is unsurprising given that Wales has some of the oldest and

least efficient housing stock in Europe (Green et al., 2020), with over half of dwellings having an EPC rating of less than C (Welsh Government, 2019b). Almost a third of dwellings in Wales are constructed of solid walls, largely before 1929; of these properties, just 18% are insulated, compared to 68% of dwellings with cavity walls (Robinson et al., 2023). Since 2008, the proportion of homes in Wales rated EPC C or better has increased from 5% to 28%, but the trend has been flat since 2013, with the median EPC ratings of existing dwellings in Wales changing by less than one percentage point (UK CCC, 2020a). This mirrors trends across the UK, which has seen uptake of energy efficiency improvements in homes continuing to stall since its peak in 2012, when the UK Government substantially scaled back its support for residential energy efficiency improvements (UK CCC, 2022a).

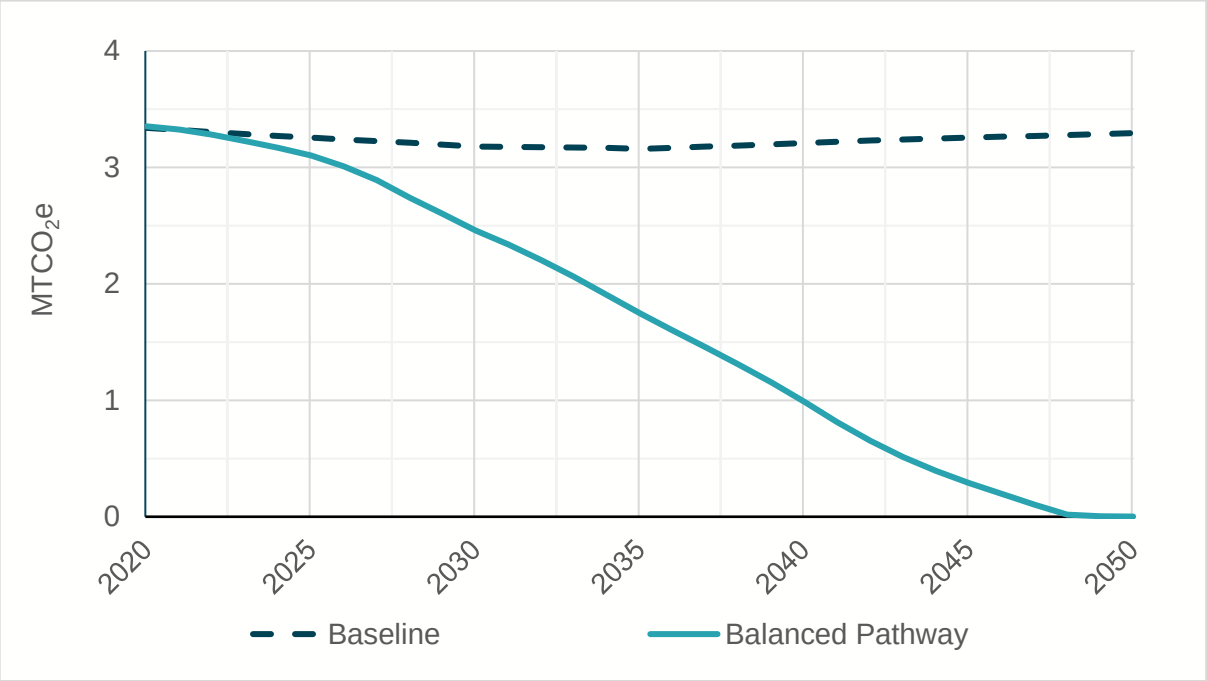
Significant falls in residential buildings emissions will also depend on a switch away from the use of fossil fuels to renewable sources for domestic heating. Currently, approximately 80% of energy use in housing in Wales is due to space heating and domestic hot water use, mainly using gas fired central heating systems (Robinson et al., 2023). In 2019, renewable heat generation was 2.3 TWh, equivalent to 14% of Welsh domestic heat demand. Half of renewable heat generation came from biomass, with just 7% from the 8,000 heat pumps in Wales in 2019 (Welsh Government, 2020a).

Residential buildings emissions in the balanced pathway

The balanced pathway sees Wales' residential buildings emissions falling by 45% from the baseline to 1.4MtCO_2e in 2035, and by almost 100% to near zero in 2050. Slightly under half of the fall in emissions happens between 2020 and 2035, driven by a combination of behaviour change, energy efficiency measures and shifts to low carbon heating.

About 30% of the fall in emissions by 2035 occurs as a result of behaviour change and increased energy efficiency in homes. The model assumes moderate levels of behaviour change influencing domestic energy demand, with a 3% reduction in space heat demand resulting from uptake of measures such as smarter heating management and low flow shower heads. In the balanced pathway scenario, uptake of energy efficiency improvements rapidly increases across all tenure types, with 60% of all owner occupied dwellings meeting EPC C standards by 2035 and all new homes meeting ultra-high energy efficiency standards by 2025 at the latest. The remaining 70% of abatement up to 2035 results from the transition to low carbon heat, with 80% of heat installations in Wales being low carbon by 2030, with a large reliance on heat pumps which make up 75% of new low carbon heat installations.

Figure 6: Wales residential buildings emissions, baseline and balanced pathway



Implications for accelerating emissions reduction

The balanced pathway involves a relatively small role for reductions in energy demand driven by behavioural and energy efficiency measures, with a 12% reduction in heat demand by 2050 (compared to 22% in the most ambitious modelled scenario). The CCC explicitly describes this as a conservative estimate reflecting how measures are currently performing when installed in existing homes, indicating that higher savings could be achieved by greater progress in reducing the performance gap (the gap between how measures perform in homes 'as designed' compared to as actually built), innovation, and public engagement (UK CCC, 2020d). This higher end estimate for reductions in heat demand from homes leads to faster and deeper cuts to residential buildings emissions in the tailwinds scenario.

Even with a relatively smaller role for energy efficiency improvements as a source of abatement, the balanced pathway assumes retrofit installations happen at significant pace and scale, with almost 400,000 existing homes across Wales receiving roof or wall insulation by 2035. While comparable Wales-level figures are unavailable, UK-wide uptake of energy efficiency measures in homes has seen little progress in the last decade and is well below its peak in 2012; the CCC notes that 2012 levels of uptake would have to be quickly surpassed to align with rates of progress in the balanced pathway. The scenario also assumes that several regulatory levers are

deployed in the 2020s to drive uptake across different tenure types, including the introduction of new standards for mortgage lenders by 2025 and energy efficiency regulations for all house sales by 2028. While the Welsh Government has powers to set standards for new dwellings, energy efficiency regulations for the private rented sector are reserved to Westminster. Moreover, at the current housing turnover rate, measures encompassing house sales and lending standards would still only be likely to reach 60% of owner occupiers by 2035, so additional incentives will still be needed to ensure a high uptake of efficiency measures among homeowners (see van der Heijden, 2022).

While demand reduction plays a proportionally more significant role in nearer-term abatement, the largest and fastest falls in residential buildings emissions in the balanced pathway happen from 2028 onwards. This is when low carbon heat becomes the dominant source of emissions reduction, responsible for 70% of abatement in the pathway between now and 2035. Logically, whatever levels of progress are made on reducing energy demand, there is no pathway to deep and sustained cuts in residential buildings emissions without decarbonising domestic heating. But the transition away from fossil fuel heat in homes presents a substantial technological and policy challenge, with the need to scale up new markets and supply chains from current low levels constraining potential for earlier large-scale deployment, alongside current skills gaps and the need for retrofit measures to prepare Wales' housing stock for the transition to low carbon heating. These constraints are recognised in the balanced pathway's timetable for phase-out dates, with sales of domestic oil boilers ending in 2028 and sales of gas boilers in 2033. This balances the need to scale up heat pump supply chains sustainably and complete the retrofit programme in time with the impact of ongoing emissions from new gas boilers installed before the cut-off (assuming an average 15-year boiler lifespan). These lifetime emissions mean that any delay in scaling up supply chains and skills and preparing the housing stock in the 2020s puts the pathway to net zero in jeopardy if new gas boilers continue to be sold and installed in Wales later than 2033. Even though this is still a decade away, it is important to recognise the scale of growth that will be needed to align with the 68,000 heat pumps installed every year in Wales by 2035 in the balanced pathway; in 2019 there were just 8,000 heat pumps in Wales and less than 700 new installations (Welsh Government, 2020a).

Agriculture

Current and historic emissions trends

Agricultural emissions include those from livestock, agricultural soils, stationary combustion sources and off-road machinery (Department for Business, Energy, and

Industrial Strategy, 2022). Agricultural emissions in Wales have fallen 10% since 1990, driven by a decrease in both synthetic fertiliser use and in the number of animals (Department for Business, Energy, and Industrial Strategy, 2022). However, the total proportion of emissions accounted for by the agricultural sector as a whole have increased from 13% in 1990 to 15% in 2019, representing both the slow rate of progress in this sector and the faster pace in other sectors.

Methane, arising from enteric fermentation in livestock, and nitrous oxide, relating to the use of fertilisers, are the dominant types of emissions in the sector. Across the UK, agriculture accounted for 69% of total nitrous oxide emissions, and 48% of all methane emissions in 2020, compared to only about 1.7% of total carbon dioxide emissions (Department for Environment, Food, and Rural Affairs, 2022). The 20% fall in estimated nitrous oxide emissions across the UK over the last twenty years has been driven by reductions in the application of nitrogen fertilisers, particularly on grassland. However, after significant reductions in nitrous oxide emissions until around 2006, emissions levels from nitrous oxide have remained fairly stable since.

Similarly, a large proportion of the estimated 15% fall in methane emissions across the UK since 1990 can be attributed to reductions in the number of cattle and sheep: the number of sheep and lambs in Wales reached a peak of 12 million in 1999, before falling over the next ten years to around 8 million in 2009 (Department for Environment, Food, and Rural Affairs, 2022; Welsh Government, 2022c). However, the long-term fall in methane emissions has stalled and remained at similar levels since around 2009 (Department for Environment, Food, and Rural Affairs, 2022). This stalling in the reduction of methane emissions is reflected in livestock trends: there was a 14% increase in the number of sheep and lambs in Wales between 2009 and 2022, and the total number of cattle has remained at similar levels since around 2007, despite an overall fall of about 14% compared to 1998 levels (Welsh Government, 2022c).

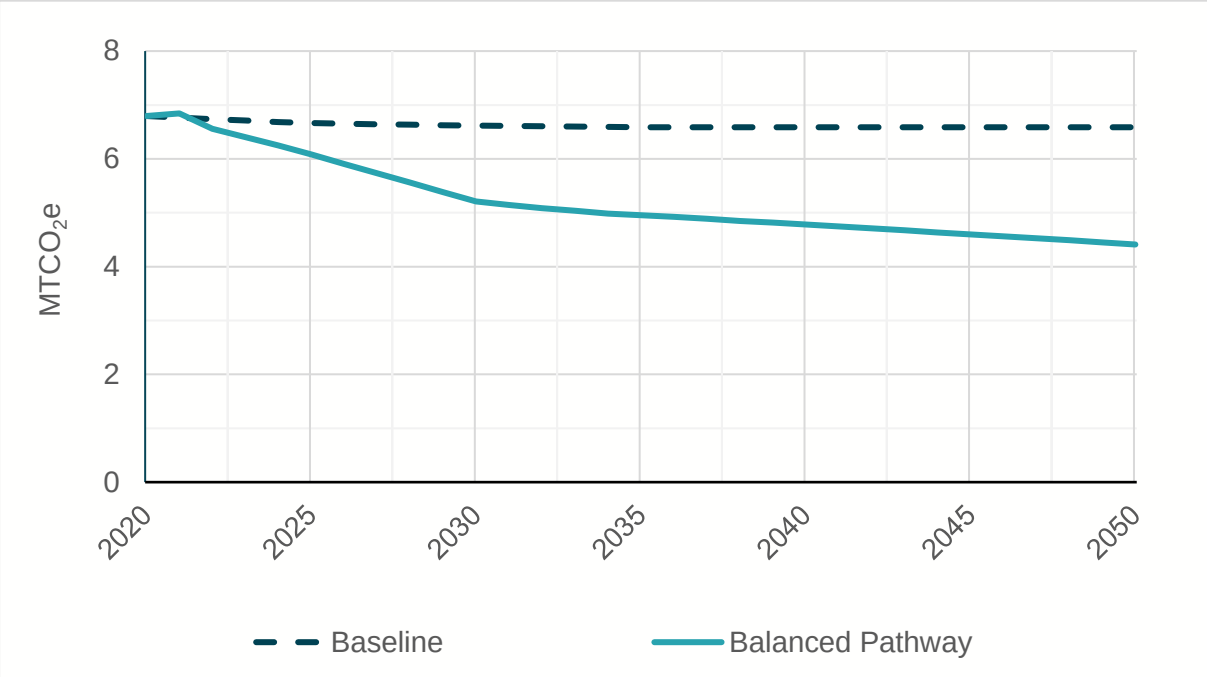
Carbon dioxide emissions from agriculture relate primarily to fuel use: across the UK there has been an overall decrease in carbon dioxide emissions from the sector of around 15% since 1990 (Department for Environment, Food, and Rural Affairs, 2022). Agriculture accounts for around 3-4% of annual energy use in Wales, however consumption has been increasing both in Wales and across the UK since 2011 (Welsh Government, 2022d). 55% of energy consumption in the sector is petroleum, with gas accounting for 22% and electricity accounting for 23%. Increased reductions of CO_2 emissions in the sector will require a substantial switch to more sustainable fuel sources.

Agricultural emissions in the balanced pathway

The CCC's balanced pathway assumes that land is prioritised to meet housing and food production needs ahead of climate objectives, modelling changes in both behaviours and farming practices needed to reduce emissions from the Welsh agricultural sector between now and 2050. There are two key areas emphasised in the pathway, each contributing different levels of abatement in the agricultural sector:

1. Options to release land from agriculture, comprised of agricultural productivity and consumer behaviour change; and
2. Low carbon farming practices and energy use.

Figure 7: Wales agricultural emissions, baseline and balanced pathway



In the balanced pathway, agricultural emissions in Wales reduce by around 25% from the baseline to around 5 $MTCO_2e$ in 2035 and fall by around a third compared to the baseline to approximately 4.4 $MTCO_2e$ in 2050. These relatively high levels of residual emissions in 2050 reflect the CCC's assumptions about how much and how quickly progress can be made in decarbonising agriculture in Wales. However, there is debate about the optimal level of, and timeframe, for reductions in agricultural emissions. Indeed, other net zero scenarios have been modelled for Welsh agriculture which result in lower agricultural emissions in 2050 (Harrison et al, 2022).

Almost 60% of the fall in Welsh agricultural emissions in the balanced pathway by 2035 is driven by consumer behaviour change: namely dietary change and reductions in food waste. 4% of emissions reductions are driven by measures to

improve agricultural productivity: increased crop yields, higher livestock stocking rates, and moving horticulture indoors. Both consumer behaviour change and improvements in agricultural productivity allow agricultural land to be used for other uses, such as sequestering carbon.

Nearly a third of emissions reductions are driven by increased uptake of low carbon farming practices. Low carbon farming practices in the balanced pathway include 18 measures relating to livestock, soil, and waste management, based on analysis of their abatement potential and cost-effectiveness (Eory et al., 2020). The balanced pathway assumes uptake rates of 50-75% for these practices.

The final 7% of emissions reductions in Welsh agricultural emissions by 2035 is driven by changes to energy use on farms, in both buildings and machinery. Modelled emissions savings are also achieved through an increase in biofuels and electrification in farm machinery from the mid-2030s, with hydrogen fuel cells deployed from 2030 in larger machinery. The model also assumes that farm buildings switch to heat pumps and hydrogen for cooling and heating.

Implications for accelerating emissions reduction

The balanced pathway makes a series of assumptions about the speed and scale of changes in the agricultural sector, and what is considered feasible while maintaining the current level of per capita food production and the projected increase in land used for settlements.

Land release measures including dietary changes and reduction in food waste account for a majority of the abatement in the agriculture sector. The balanced pathway assumes a 35% reduction in meat and dairy consumption by 2050, rising to 50% in the CCC's 'widespread engagement,' 'widespread innovation' and 'tailwinds' scenarios. This has implications for livestock numbers and the amount of land currently used for grazing, with the balanced pathway assuming a fall in the number of cattle, sheep, pigs and poultry in the UK of between 6% and 24% by 2035. Any fall in livestock could significantly impact Welsh farmers, as livestock products currently account for 81% (£1.4 billion) of Wales' gross agricultural output (Devenish, 2022). The CCC's exploratory scenarios assume that farmers do not increase meat and dairy exports as a result of dietary changes within the UK, instead reducing livestock production and increasing crops where possible. However, 79% of land in Wales is classified as Less Favoured Areas (LFA), where farming is considered less productive due to geographic, soil, or climatic conditions (Devenish, 2022). Cattle and sheep grazing on LFA land is currently the most common farm type in Wales, accounting for 25% of all farms, whereas only 2% of all current farms in Wales are dedicated to crops and horticulture (Devenish 2022). Reductions in the number of

animals is likely to significantly affect those grazing on LFA land as they are unable to grow crops as an alternative. It is therefore important to consider the potential impact of these changes on Welsh farmers and farming communities, as a reduction in the number of livestock is likely to affect a significant number of Welsh farms, which are currently the least profitable in Wales (Devenish, 2022).

In the balanced pathway, wheat yields increase from an average of 8 tonnes/hectare at present, to 11 tonnes/hectare by 2050 (with equivalent increases for other crops). One option in the CCC's 'tailwinds' scenario involves crop breeding, which could lead to even higher yields of 13 tonnes/hectare for wheat by 2050 and thereby free up more agricultural land for other uses. However, it is uncertain how changes in climate may impact crop yields leading up to 2050. Demand for land on which to grow crops may be increased if there are negative climate impacts, including reduced water availability and increased soil erosion (UK CCC, 2020e). In this 'climate risk' scenario, modelled by the CCC to assess potential implications of a changing climate, increased demand for land to grow crops is offset by a further reduction in the number of livestock and a subsequent further reduction in the consumption of meat and dairy products. When considering options to decarbonise the agricultural sector, it remains vital to consider future impacts of a changing climate on the sector, and the ensuing effects on the Welsh farming system.

Lastly, options to implement low carbon practices differ in their uptake rate, depending on the ease of implementation on individual farms. In the balanced pathway, uptake rates vary from between 50% (for measures such as grass leys and genetic improvement in livestock using genomics), and 75% (for measures including cover crops and high-starch diets for dairy cows) (Eory et al., 2020). In the more ambitious CCC pathways, it is assumed that uptake of low-carbon farming practices is higher, through either progress in innovation, or higher levels of behaviour change. However, CCC analysis suggests that there is little variation in abatement between the different scenarios (UK CCC, 2020e); therefore, encouraging practices which rely on changes in behaviour may provide abatement in the agricultural sector at a lower cost and with less reliance on technological development. A focus on behavioural measures could therefore allow for easier and earlier government intervention.

Land Use, Land Use Change and Forestry (LULUCF)

Current and historic emissions trends

The land use, land use change and forestry (LULUCF) sector includes emissions from forests, cropland, grassland, settlements, and the harvesting of wood, as well as changes to how land is used (Department for Business, Energy, and Industrial Strategy, 2022). The sector also includes removals of emissions as some land uses act as carbon sinks.

In 2019 emissions data for Wales the LULUCF sector acted as a carbon sink, removing around 1% of Welsh emissions. However, changes to how peatland emissions are calculated within the emissions inventory mean the sector is now likely to act as a small source of emissions. Emissions across the UK in the sector have reduced by around two thirds since 1990, primarily due to reductions in CO_2 from cropland, although there has been little progress since 2008 (Brown et al., 2021).

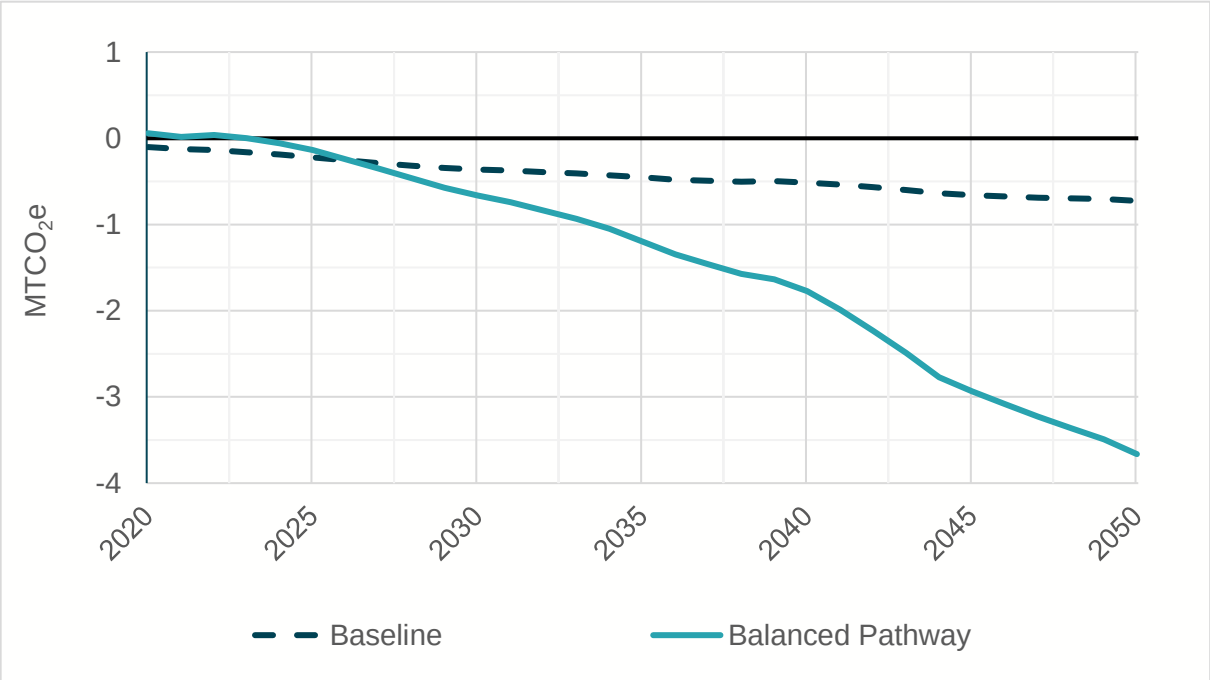
In fact, the size of the LULUCF sink in Wales decreased marginally between 2008 and 2018, reflecting the lack of action in new tree planting. The Welsh Government has identified afforestation as a key goal which is essential to mitigate the impacts of climate change while providing a range of other benefits, including creating jobs, addressing the nature emergency, increasing wellbeing, and addressing issues with air quality (Welsh Government, 2021e). The Welsh Government has set a target of around 5,000 hectares of tree planting per year, however, annual woodland creation has not exceeded 2,000 hectares in Wales since 1975. Progress is, however, being made in other key areas, such as peatlands. In its first two years, the National Peatland Action Programme restored over 1650 hectares of public and private land, surpassing its initial targets (Natural Resources Wales, 2022).

The contribution of other sources of abatement, including the role of marine and coastal ecosystems, remains uncertain, as limitations in the data mean it is not currently possible to present a carbon budget for Welsh waters (Armstrong et al., 2020). The CCC note that carbon accumulation, storage and emissions are best understood in salt marsh and seagrass, which could make a small contribution to greenhouse gas abatement if they are created and restored; however, areas with higher potential sequestration benefits, such as kelp and marine sediments, remain poorly understood and are harder to quantify in the context of abatement (UK CCC, 2022b).

LULUCF emissions in the balanced pathway

In the balanced pathway the LULUCF sector remains a net source of emissions for Wales until 2024, after which it becomes a net carbon sink which increases in size from this date, more than doubling after 2035 to remove approximately 3.6 $MtCO_2e$ of emissions in Wales by 2050. Measures to reduce LULUCF emissions and increase sequestration in Wales achieve approximately 1.1 $MtCO_2e$ of emissions savings by 2035.

Figure 8: Wales LULUCF emissions, baseline and balanced pathway



Of this reduction in Welsh LULUCF emissions by 2035, 60% is driven by new afforestation. Afforestation is anticipated to play a larger role in LULUCF emissions reductions in Wales than in the UK as a whole, with the balanced pathway scenario assuming tree-planting reaches 4,500 hectares per year in 2035, rising to 7,500 hectares per year by 2050.

Around 15% of reductions are driven by the planting of energy crops, with 20,000 hectares of miscanthus, short rotation coppice, and short rotation forestry planted by 2035, rising to a cumulative total of 56,000 hectares by 2050 (however, the optimal level of energy crop production will depend on demand for bioenergy). 10% of emissions reductions are driven by agro-forestry measures, and 4% are driven by extending hedgerows. Trees and shrubs integrated onto 10% of UK farmland by 2050, and the total length of hedgerows on farms extended 20% by 2035, and 40% by 2050.

Only 11% of LULUCF emissions reductions in Wales in 2035 are driven by peatland restoration. This is considerably less than the relative contribution of restored peatland to emissions reductions across the UK as a whole, as Wales currently has very low emissions associated with degraded peatland compared to the rest of the UK (UK CCC, 2020a). In the balanced pathway 64% of peatland area in Wales is restored by 2035, rising to 84% in 2050 (UK CCC, 2020a). Other policy measures include an end to the extraction of peat, and a ban on its sale; the Welsh Government (2022e) has already announced its intention to implement these measures.

Implications for accelerating emissions reduction

The National Peatland Action Programme has surpassed initial targets, and good progress continues to be made on restoring peatland in Wales, with additional focuses on data monitoring and stakeholder engagement (Natural Resources Wales, 2022). Achieving further policy objectives will require coordination with the UK Government, for example, banning the sale of peat for domestic use. However, action taken in this area is likely to have a smaller impact in Wales than in the rest of the UK.

In comparison, forestry accounts for the vast majority of emissions reductions in Wales by 2050, meaning action taken to increase the carbon sink in this area is likely to have a greater proportional impact. However, progress remains well behind both the Welsh Government's targets, and the assumed level of tree planting set out in the balanced pathway. Analysis suggests that, across the UK, planting trees at the rate assumed in the balanced pathway would increase woodland coverage from the current level of around 13% of land area, to between 17-20% of land area by 2050: 20% is considered the upper bound of what is feasible in terms of tree planting. Wales has a current level of forest coverage which is comparable to the UK average, meaning that the total land area covered is unlikely to be dissimilar for Wales in 2050.

The agro-forestry and hedgerow measures outlined as options in the balanced pathway involve changes to farming practices. As well as carbon sequestration, these measures have other benefits including improving water quality, improving soil structure, enhancing biodiversity, and improving livestock welfare. On the other hand, planting bioenergy crops could negatively impact biodiversity, soil health, and water quality. Ensuring that the potential benefits are maximised, and risks minimised, largely depends on those managing the land where they are implemented. Therefore, ensuring that farmers possess the necessary skills to implement these measures is crucial, and is currently considered a key skills gap (Notman et al., forthcoming). As well as the requisite skills, land-focused measures on agricultural land will also

require investment, and while the measures to reduce emissions from the LULUCF sector deliver a higher ratio of benefits to costs in Wales compared to England, the CCC notes that these measures are not cost effective from the perspective of farmers. A package of support to strengthen farmers' ability to implement these solutions will be necessary to accelerate emissions reduction: the new Sustainable Farming Scheme may provide an opportunity to provide this (Welsh Government, 2022f).

Surface Transport

Current and historic emissions trends

The surface transport sector covers emissions related to road and rail. Most of the emissions associated with this sector are from petrol and diesel in road transport (Department for Business, Energy, and Industrial Strategy, 2022).

With its significant dependence on oil as a source of fuel, the surface transport sector poses one of the biggest barriers to the transition to net zero in Wales. The sector has seen little sign of emissions reducing since 1990 and remains one of Wales' highest emitting sectors, accounting for 16% of Welsh emissions in 2019 (NAEI, 2020). While surface transport emissions make up a smaller proportion of total emissions in Wales than in the UK as a whole (where they represent 21%), this is not due to a more carbon-efficient surface transport sector, but rather reflects the proportionately larger role for sectors such as agriculture and manufacturing and construction in Wales' overall emissions profile. Indeed, surface transport emissions per person are higher for Wales than the UK average (UK CCC, 2020a).

The lack of progress reducing surface transport emissions in the last three decades comes despite improvements in vehicle efficiency and modest growth in sales of low emissions vehicles (UK CCC, 2020a) and can be explained by the year-on-year growth in the total volume of road traffic that occurred over the same period. In 2019, the total volume of road traffic in Wales increased by 1.5% to 32.1 billion vehicle kilometres, the highest figure on record (Welsh Government, 2020b). Passenger car journeys accounted for almost 80% of this figure and were responsible for 64% of Wales' total surface transport emissions (Welsh Government, 2020b, NAEI, 2020, WCPP analysis).

The dominant role played by car journeys in slowing reductions in Wales' surface transport emissions is also apparent in the change in emissions which occurred in 2020. In this first year of the Covid-19 pandemic, both periods of travel restrictions and voluntary behaviour change to suppress transmission of the virus substantially reduced the demand for travel in Wales. This led to a 23% fall in total road traffic, a

26% fall in passenger car journeys and a 22% decline in total Welsh surface transport emissions (Welsh Government, 2021f; NAEI, 2021). In the same year, pedal cycle volume increased by almost 70%, the largest increase in Wales since records began (Welsh Government, 2021f).

Although this report does mainly not explore data beyond 2019, the Covid-19 pandemic resulted in significant societal changes affecting travel demand which are important to consider. Although Welsh emissions data are not currently available beyond 2020, indications are that surface transport emissions bounced back in 2021 but remain lower than they were before the pandemic. Road traffic increased by 13% in 2021 but remained below pre-pandemic levels (Welsh Government, 2022g). UK emissions data also shows that surface transport emissions for the whole of the UK increased by 10% in 2021 but remained significantly lower than pre-pandemic levels; UK emissions data for 2022 will not be published until later in 2023 (UK CCC, 2022a).

While the long-term impact of the pandemic on travel demand and associated emissions is difficult to predict, the clearest implication of all these trends is that Wales' surface transport emissions will not fall in any substantial way without either a large increase in the uptake of low emissions vehicles – reducing the number and proportion of fossil fuel vehicles on Wales' roads – or a significant reduction in total road traffic, alongside further improvements in vehicle efficiency (or, more likely, some combination of these). Clearly, the transition to low emissions vehicles and demand reduction for other types of road traffic will also have a role to play, alongside rail decarbonisation – but it is increased uptake of low emissions *cars* and reduction in demand for *car journeys* in particular that will be critical to reducing Wales' surface transport emissions.

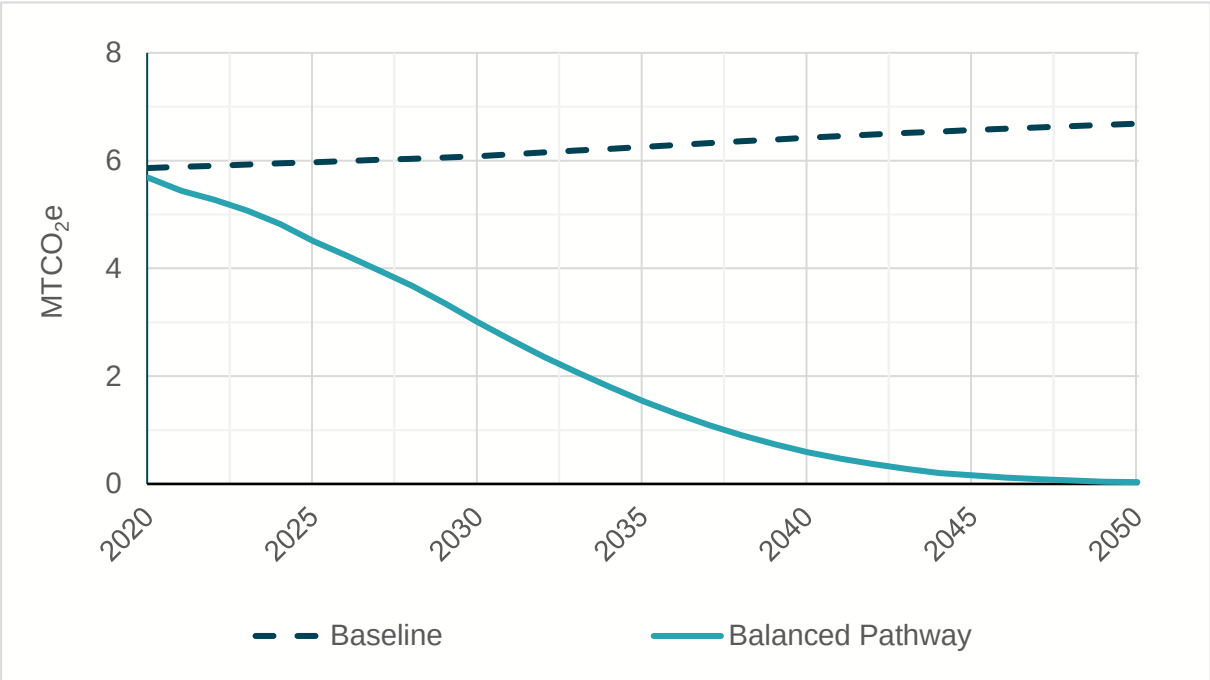
Surface transport emissions in the balanced pathway

The balanced pathway models the effects on emissions of a series of behavioural and technological changes affecting the Welsh surface transport sector between now and 2050. The pathway emphasises four main sources of abatement making differing levels of contribution to emissions savings for surface transport:

- Uptake of low emissions vehicles;
- Reductions in demand for travel;
- Increases in vehicle efficiency; and
- Rail decarbonisation.

The pathway sees emissions from surface transport fall by 75% from the baseline to 1.5 metric tonnes of CO_2 equivalent in 2035, and a further 25% to near zero in 2050. Over two thirds of the modelled fall in emissions occurs before 2035.

Figure 9: Wales surface transport emissions, baseline and balanced pathway



In the balanced pathway 78% of emissions reductions by 2035 are driven by uptake of low emissions vehicles. Fully electric cars account for almost half of new sales by 2025 and close to 100% by 2030, and UK Government legislation phases out the sale of petrol and diesel cars entirely by 2032. 17% of the fall in emissions by 2035 comes from reductions in demand for travel, through a combination of societal and technological changes (such as increased homeworking) reducing overall demand for travel; modal shift from car travel to public transport, walking and cycling; and reductions in HGV demand driven by logistics and operational improvements. A further 3% of emissions savings by 2035 comes from efficiency improvements for new petrol and diesel vehicles, with a 12% reduction in the carbon intensity of new petrol and diesel cars by 2030 and the carbon intensity of HGVs falling by 21% in the same time period. The final 2% of emissions savings is driven by the decarbonisation of rail transport, through a combination of railway electrification and the introduction of battery-electric, hydrogen-powered and hybrid trains, with diesel trains for passenger routes phased out by 2040 and a very limited role for diesel freight trains beyond this date.

Implications for accelerating emissions reduction

The balanced pathway draws on a series of assumptions about what pace and scale of technological and behavioural changes affecting surface transport can be considered to be plausible based on current evidence. The modelling for the pathway also highlights varying levels of certainty about the future role and viability of specific technologies to the decarbonisation of road and rail transport, as well as drawing

attention to the nature and scale of infrastructure investment needed to support these, including:

- The installation of around 22,000 electric charging points for cars and vans in Wales by 2035, rising to around 32,000 charging points by 2050;
- Upgrades to reinforce the electricity distribution network beginning in the 2020s, to meet the substantial demand added to the grid by electric vehicle charging;
- From the early 2020s, commercial scale trials of different technologies for low emissions HGVs, followed by substantial infrastructure development including installing a network of 300 ultra-rapid HGV charge points and 100 hydrogen refuelling stations across the UK by 2035 (disaggregated figures for Wales are unavailable); and
- Railway electrification progressing at a rate of 200 km a year and reaching 55% of the UK rail network by 2050 (disaggregated figures for Wales are unavailable).

The balanced pathway for Wales involves considerable levels of ambition in the pace of the infrastructure roll out to support the transition to electric vehicles. This is unsurprising given this scenario's large reliance on uptake of electric vehicles to cutting surface transport emissions. Current evidence suggests that Wales is underperforming in this area, with the lowest levels of electric vehicle ownership in the UK (electric cars made up less than 7% of new car sales in 2021, compared to 48% of new sales by 2025 required under the balanced pathway), and just 575 public charge points for electric cars available across Wales in 2020 (Welsh Government, 2021g).

The large role played by uptake of low emissions vehicles in the balanced pathway also partly reflects the CCC's assumptions about how much reduction in demand for travel is realistically achievable. Demand reduction plays a more significant role in the CCC's tailwinds scenario, with demand for car travel falling twice as fast compared to the balanced pathway, reducing 16% by 2035 and 34% by 2050, the maximum levels of demand reduction assumed to be possible across all the CCC's modelled scenarios. These assumptions about the scope for reducing demand for travel over the next few decades draw on and consider a range of different sources of data and academic evidence, including data from the National Travel Survey, data on car occupancy, and studies estimating the proportion of car journeys which could realistically be displaced by walking and cycling (Neves & Brand, 2019).

However, options may still exist to go further and faster than the CCC pathways in accelerating modal shift and reducing travel demand (see Table 10 below), making Wales proportionally less reliant on uptake of low emissions vehicles to achieve

reductions in surface transport emissions. Relevant to this question is the fact that much of the evidence for the CCC's modelling assumptions on demand reduction pre-dates the pandemic, which has seen significant societal changes affecting travel demand, some of which may prove to be longer term or even permanent. There is also considerable debate in the wider research and policy community about the extent to which policymakers should focus on technical solutions for decarbonising the transport system versus policies aimed at influencing the demand for travel and modal shift. Some experts advocate a much greater emphasis on the latter, cautioning that widespread electrification of surface transport has so far proved to be a very incremental process that is likely to be too slow to meet climate mitigation targets (Brand et al., 2021).

Table 10: Evidence on options to influence demand for travel

Modal shift to active travel

- International comparisons suggest that there is scope to encourage more trips by bike. 26% of all journeys in the Netherlands are cycled, compared to 1-2% in the UK, though this rises to 29% in some cities with high cycling rates.
- In 2019, over 20% of car journeys were less than 2 miles and 59% were under 5 miles. A study in Cardiff concluded that active travel could realistically displace around 40% of car journeys of less than 3 miles.
- If e-bikes become more widespread, their considerably greater range offers potential to shift a higher number of journeys away from cars.
- Active travel schemes have been implemented across the UK and internationally in recent years, but there is limited robust evidence evaluating their effects on modal shift.

Modal shift to public transport

- Bus and rail account for 5% and 4% of all journeys. A recent study found that public transport usage within major cities could rise by 6% by 2030.
- Pre-pandemic, the number of journeys made by bus in Wales had stabilised in recent years following a long term decline in bus usage. Bus patronage declined by an average of 11% per decade for the last four decades. The pandemic saw a sustained drop in demand for many forms of public transport, with car usage recovering more quickly after the lifting of travel restrictions. Medium-term effects on public transport usage are not yet certain.
- Over the past decade, the average cost of driving has risen by less than average wages, whereas rail and bus fares have increased more steeply. A 2017 UK study linked the 2011 freeze in fuel duty to a 4% rise in traffic levels, 60 million fewer rail journeys and 200 million fewer bus journeys that year.

Societal and technological changes

- In April 2020, 47% of people in the UK did some work at home. A recent study estimated that 43% of UK jobs can be done entirely from home. There is also wide scope to reduce business trips through greater use of technology.
- The average number of shopping trips per person had been declining steeply until recent years. Average shopping trip length for cars has also fallen, probably reflecting a shift to online retail. This may be partially offset by increases in leisure journeys and the extra van traffic associated with online deliveries.

Increase in car occupancy and reductions in car ownership

- Shared cars and shared trips can also reduce car travel demand. Currently two thirds of car trips are undertaken without any passengers and utilisation rates for shared mobility are low, at around 3-4% of journeys.
- High-occupancy vehicle lanes have been shown to reduce vehicle trips by between 4% and 30%.
- Across the different pathways, the CCC assumes car ownership will continue to grow in line with population and GDP, with demand reduction realised through a fall in kilometres driven by each car. This signals opportunities to deliver further emissions reduction through schemes to reduce car ownership.`

Source: UK CCC (2020f)

References

Brand, C., et al. (2020). **Road to zero or road to nowhere? Disrupting transport and energy in a zero carbon world.** Energy Policy 139.

Brown, P., *et al*. (2021). **UK Greenhouse Gas Inventory, 1990 to 2019: Annual Report for Submission under the Framework Convention on Climate Change.** Ricardo Energy and Environment. Retrieved from : **https://ukair.defra.gov.uk/assets/documents/reports/cat09/2105061125_ukghgi-90-19_Main_Issue_1.pdf**

CITB Wales (2021). **Construction Skills Network: Labour Market Intelligence Report.** Retrieved from: **https://www.citb.co.uk/media/n15bpq0n/wales.pdf**

Corbyn, C. (2021). Climate change: The path to zero emissions. Senedd Research. Retrieved from: https://research.senedd.wales/research-articles/climate-change-the-path-to-zero-emissions/

Department for Business, Energy, and Industrial Strategy (2017). **Electricity generation and supply figures for Scotland, Wales, Northern Ireland and England, 2013 to 2016.** Retrieved from: **https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/669787/Regional_Electricity_Generation_and_Supply.pdf**

Department for Business, Energy, and Industrial Strategy (2020a). **The ten point plan for a green industrial revolution.** Retrieved from: **https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution**

Department for Business, Energy and Industrial Strategy (2020b). **Electricity generation costs 2020.** Retrieved from: **https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/911817/electricity-generation-cost-report-2020.pdf**

Department for Environment, Food and Rural Affairs (2022). **Agri-climate report 2022.** Retrieved from: **https://www.gov.uk/government/statistics/agri-climate-report-2022/agri-climate-report-2022**

Devenish, K. (2022). **The Farming Sector in Wales.** Senedd Research. Retrieved from: **https://research.senedd.wales/media/iuch3jz1/22-47-farming-sector-in-wales.pdf**

Element Energy (2020). **Deep-Decarbonisation Pathways for UK Industry.** Retrieved from: **https://www.theccc.org.uk/wp-content/uploads/2020/12/Element-Energy-Deep-Decarbonisation-Pathways-for-UK-Industry.pdf**

Eory, V., Maire, J., MacLeod, M., Sykes, A., Barnes, A., Rees, R.M., Topp, C.F.E., Wall, E. (2020). **Non-CO_2 abatement in the UK agricultural sector by 2050: Summary report submitted to support the 6th carbon budget in the UK.** Scotland's Rural College. Retrieved from: **https://www.theccc.org.uk/wp-content/uploads/2020/12/Non-CO2-abatement-in-the-UK-agricultural-sector-by-2050-Scottish-Rural-College.pdf**

Green, E., et al. (2020). **Decarbonising the Welsh housing stock: From practice to policy.** Buildings & Cities 1,1, pp.277–292.

IPPC (2019). **Special report: Global warming of 1.5ºC.** Retrieved from: **https://www.ipcc.ch/sr15/**

IPPC (2022). **Climate change 2022: Impacts, adaptation and vulnerability.** Retrieved from: **https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/**

van der Heijden, J. (2022). **A governance response: from persuasive to coercive?** in Wilkinson, S. and Sayce, S. (eds). Resilient Building Retrofits: Combatting the climate crisis. Abindgon: Taylor & Francis, pp.85-101

Harrison, P. A., et al. (2022). **ERAMMP Report-60: ERAMMP Integrated Modelling Platform (IMP) Land Use Scenarios**. Retrieved from: **https://erammp.wales/en/resources**

High, M. **Carbon Capture Utilisation and Storage (CCUS) in Wales.** Senedd Research. Retrieved from: **https://research.senedd.wales/media/ikvfevf4/22-60-ccus-briefing.pdf**

NAEI (2021). **Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland, 1990-2020**. Retrieved from: **https://naei.beis.gov.uk/reports/reports?section_id=4**

Natural Resources Wales (2022). **The National Peatland Action Programme.** Retrieved from: **https://naturalresources.wales/evidence-and-data/maps/the-national-peatland-action-programme/?lang=en**

Neves, A. & Brand, C. (2019). **Assessing the potential for carbon emissions savings from replacing short car trips with walking and cycling using a mixed GPS-travel diary approach.** Transportation Research Part A: Policy and Practice 123, 130-146.

Notman, G., Coles-Riley, J., Tilley, H., and Price, J. (forthcoming). **Net zero skills: Insights and evidence from emissions sectors in Wales.** Wales Centre for Public Policy. Retrieved from: **https://www.wcpp.org.uk/publication/net-zero-skills-insights-and-evidence-from-emissions-sectors-in-wales/**

Robinson, D., Tilley, H., Price, J., Lloyd, A. (2023). **Housing stock energy modelling: Towards a model for Wales**. Wales Centre for Public Policy. Retrieved from: **https://www.wcpp.org.uk/publication/housing-stock-energy-modelling-towards-a-model-for-wales/**

Silva, L., Price, J., and Tilley, H. (2022). **Developing Skills for a just transition**. Wales Centre for Public Policy. Retrieved from: **https://www.wcpp.org.uk/wp-content/uploads/2022/08/Developing-skills-for-a-just-transition.pdf**

StatsWales (2022). **Iron and steel production by year, measure and area.** Retrieved from: **https://statswales.gov.wales/Catalogue/Business-Economy-and-Labour-Market/Economic-Indices/Indices-of-Production-and-Construction/ironandsteelproduction-by-year-measure-area**

UK CCC (2013). **Reducing emissions from buildings.** Retrieved from: **https://www.theccc.org.uk/wp-content/uploads/2013/12/1785b-CCC_TechRep_Singles_Chap3_1.pdf**

UK CCC (2015). **Buildings factsheet**. Retrieved from: **https://www.theccc.org.uk/wp-content/uploads/2014/08/Fact-sheet-buildings-updated-July-2015.pdf**

UK CCC (2017). Building a low-carbon economy in Wales – setting Welsh climate targets. Retrieved from: https://www.theccc.org.uk/publication/building-low-carbon-economy-wales-setting-welsh-carbon-targets/

UK CCC (2020a). **Advice Report: The path to a Net Zero Wales.** Retrieved from: **https://www.theccc.org.uk/wp-content/uploads/2020/12/Advice-Report-The-path-to-a-Net-Zero-Wales.pdf**

UK CCC (2020b). **The Sixth Carbon Budget: Electricity Generation.** Retrieved from: **https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Electricity-generation.pdf**

UK CCC (2020c). **The Sixth Carbon Budget: Manufacturing and Construction.** Retrieved from: **https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Manufacturing-and-construction.pdf**

UK CCC (2020d). **The Sixth Carbon Budget: Buildings.** Retrieved from: **https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Buildings.pdf**

UK CCC (2020e). **The Sixth Carbon Budget: Agriculture & land use, land-use change and forestry (LULUCF).** Retrieved from: **https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Agriculture-land-use-land-use-change-forestry.pdf**

UK CCC (2020f). **The Sixth Carbon Budget: Surface Transport.** Retrieved from: **https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Surface-transport.pdf**

UK CCC (2022a). **2021 progress report to Parliament.** Retrieved from: **https://www.theccc.org.uk/publication/2021-progress-report-to-parliament/**

UK CCC (2022b). **Briefing: Blue Carbon.** Retrieved from: **https://www.theccc.org.uk/publication/briefing-blue-carbon/**

Welsh Government (2019a). **Prosperity for all: A low carbon Wales.** Retrieved from: **https://gov.wales/sites/default/files/publications/2019-06/low-carbon-delivery-plan_1.pdf**

Welsh Government (2019b). **Welsh Housing Conditions Survey (energy efficiency of dwellings): April 2017 to March 2018.** Retrieved from: **https://www.gov.wales/welsh-housing-conditions-survey-energy-efficiency-dwellings-april-2017-march-2018**

Welsh Government (2020a). **Energy Generation in Wales 2019.** Retrieved from: **https://www.gov.wales/sites/default/files/publications/2021-01/energy-generation-in-wales-2019.pdf**

Welsh Government (2020b). **Road traffic: 2019**. Retrieved from: **https://www.gov.wales/sites/default/files/pdf-versions/2021/8/1/1629733299/road-traffic-2019.pdf**

Welsh Government (2021a). **Net zero Wales carbon budget 2.** Retrieved from: **https://gov.wales/sites/default/files/publications/2021-10/net-zero-wales-carbon-budget-2-2021-25.pdf**

Welsh Government (2021b). **Net zero Wales sustainability appraisal.** Retrieved from: **https://gov.wales/sites/default/files/publications/2021-10/net-zero-wales-sustainability-appraisal.pdf**

Welsh Government (2021c). **Climate change targets and carbon budgets.** Retrieved from: **https://gov.wales/climate-change-targets-and-carbon-budgets**

Welsh Government (2021d). **The cooperation agreement: 2021.** Retrieved from: **https://gov.wales/sites/default/files/publications/2021-11/cooperation-agreement-2021.pdf**

Welsh Government (2021e). **Written Statement: Trees and Timber.** Retrieved from: **https://www.gov.wales/written-statement-trees-and-timber**

Welsh Government (2021f). **Road traffic: 2020**. Retrieved from: **https://www.gov.wales/sites/default/files/pdf-versions/2022/11/1/1669028003/road-traffic-2020.pdf**

Welsh Government (2021g). **Electric vehicle charging strategy for Wales**. Retrieved from: **https://www.gov.wales/sites/default/files/publications/2021-03/electric-vehicle-charging-strategy-wales.pdf**

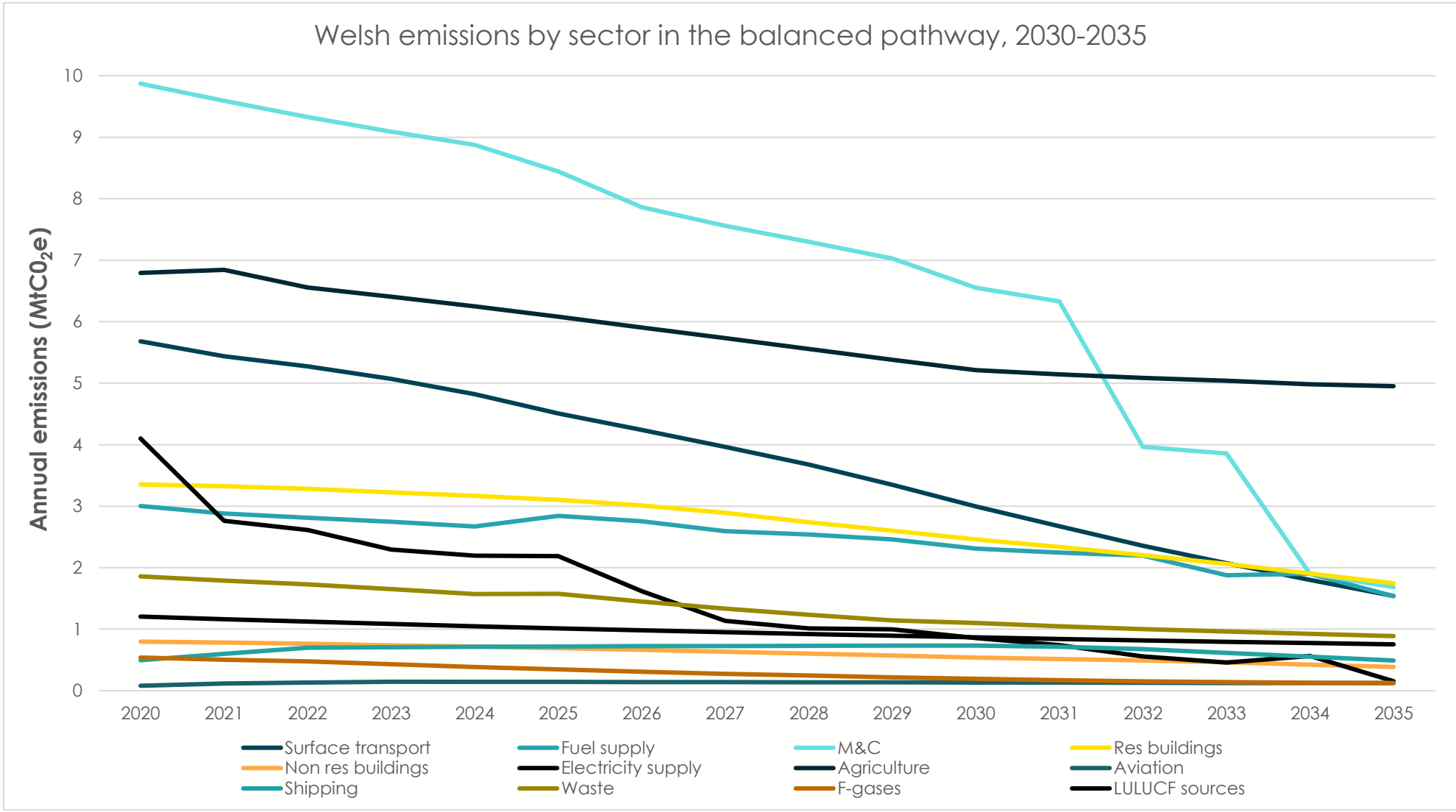
Welsh Government (2022a). **Written statement: Leading the commitment to examine the impact on society and sectors of net zero by 2035.** Retrieved from: **https://gov.wales/written-statement-leading-commitment-examine-impact-society-and-sectors-net-zero-2035**

Welsh Government (2022b). **Energy Generation in Wales 2020.** Retrieved from: **https://www.gov.wales/sites/default/files/publications/2022-06/energy-generation-in-wales-2020.pdf**

Welsh Government (2022c) **June 2022 Survey of Agriculture and Horticulture: Results for Wales.** Retrieved from: **https://www.gov.wales/sites/default/files/statistics-and-research/2022-11/survey-agriculture-and-horticulture-june-2022-005.pdf**

Welsh Government (2022d) **Energy Use in Wales: Second Edition.** Retrieved from: **https://www.gov.wales/sites/default/files/publications/2022-06/energy-use-wales-report.pdf**

Annex


Welsh emissions by sector in the balanced pathway, 2030-2035
Annual emissions (MtCO2e)
10
9
8
7
6
5
4
3
2
1
0
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
Surface transport
Fuel supply
M&C
Res buildings
Non res buildings
Electricity supply
Agriculture
Aviation
Shipping
Waste
F-gases
LULUCF sources

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