West Yorkshire
Emissions Reduction Pathways

elementenergy

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For WYCA

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Emissions pathways scenario results

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- Introduction
- Key findings
- Sector pathways West Yorkshire
- Additional information
- Technical Appendix

Introduction, context and aims

Context and key objectives

Authorities and LEPs within the Leeds City Region (LCR), North and West Yorkshire have strengthened their commitments to local emissions reductions through the declaration of a Climate Emergency and the setting of targets to reach net zero carbon emissions. The region is now in the process of identifying and detailing technology options, measures, policies and interventions required to deliver its targets. This work will contribute to the region's climate strategy through delivering the following objectives:

- Develop technically robust **emissions reductions pathways** (Baseline and 3 net-zero) for the power, buildings, industry, transport, land use and agriculture sectors, to enable LCR and N & W Yorkshire to meet their respective net-zero emission reduction targets.
- Identify key milestones, decision points, **policies and interventions** that can drive the transition toward these outcomes, including timeframes of actions and roles of stakeholders in delivering actions.

Study target audience

- Policy makers – local, regional and national (including politicians)
- Commercial / industrial organisations or project developers in the region
- Domestic consumers who will need to engage with the energy transition
- Local interest/member working groups

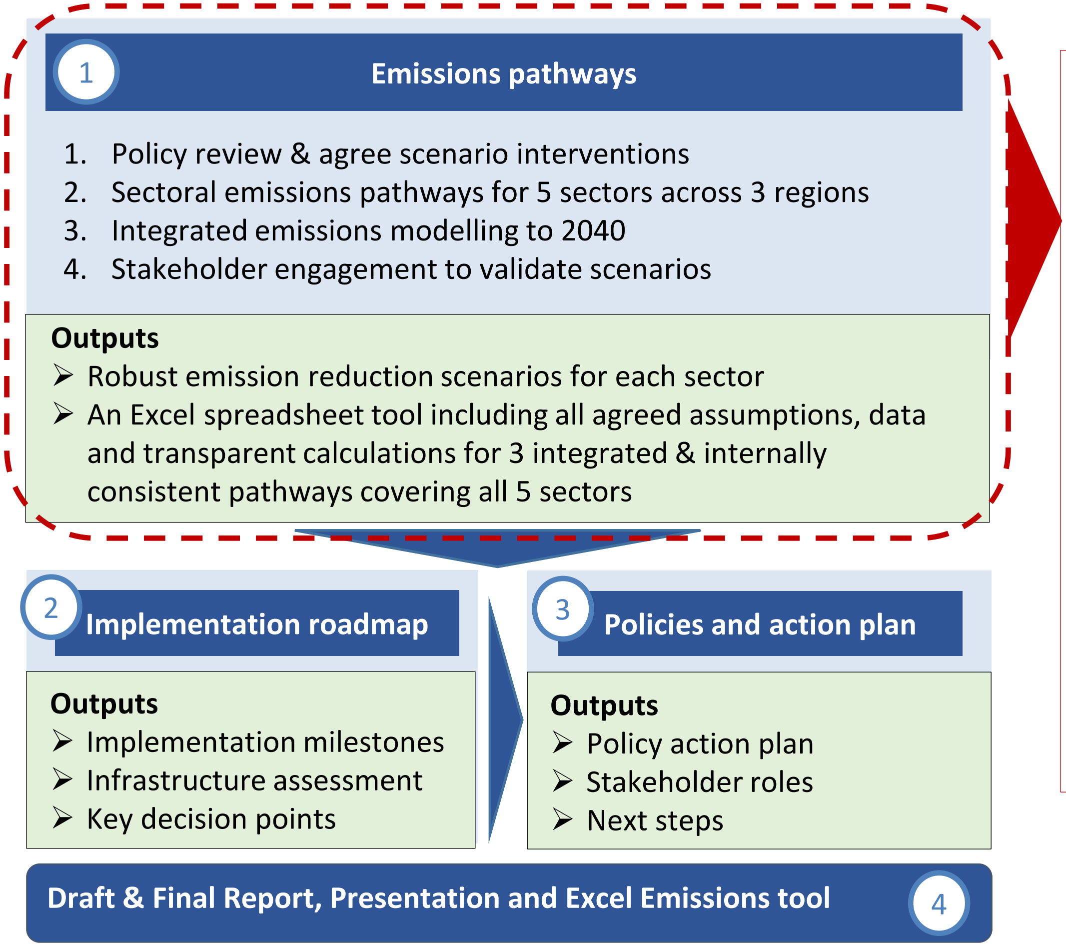
This interim report

The aim of this pack is to present the emissions pathways modelling results for all sectors and scenarios for review (step 1). It is split into 3 subsections / reports:

1. Executive summary key findings pack
2. Main pack of sector and scenario results
3. Technical Appendix for further detail

Tasks, methodology and progress

The diagram below sets out the subtasks and process for the study. Task 1, the emissions pathways modelling, has now been completed. This will be used to inform Tasks 2 and 3.



1 Emissions pathways

1. Policy review & agree scenario interventions
2. Sectoral emissions pathways for 5 sectors across 3 regions
3. Integrated emissions modelling to 2040
4. Stakeholder engagement to validate scenarios

Outputs

- ➢ Robust emission reduction scenarios for each sector
- ➢ An Excel spreadsheet tool including all agreed assumptions, data and transparent calculations for 3 integrated & internally consistent pathways covering all 5 sectors

2 Implementation roadmap

Outputs

- ➢ Implementation milestones
- ➢ Infrastructure assessment
- ➢ Key decision points

3 Policies and action plan

Outputs

- ➢ Policy action plan
- ➢ Stakeholder roles
- ➢ Next steps

Draft & Final Report, Presentation and Excel Emissions tool 4

- **Three emission reduction pathways** are being developed**:**
  - — **One** aiming to reach **net zero as quickly as possible**
  - — **Two** options to reach **net zero in 2038**
- **The net zero target is for the integrated pathway**, covering buildings, transport, industry, power and LULUCF, rather than for each sector individually
- Scenarios will include both **technological change and demand reduction**/behaviour change interventions
- The aim of the scenario development is to **identify the scale** of what needs to be done in the region to achieve net zero

Scope of the study - the study aims to assess the interventions which could enable the region to address the climate emergency

This study aims to assess the technologies, interventions and policies needed to drive reduction in scope 1 and 2 emissions across the region. Due to the extremely broad, cross-sectoral nature of the study, it is necessarily high-level in some areas. Further evidence would be required to support large-scale policy implementation and investment decisions.

Whilst the study allows comparison of the scenarios in terms of emissions, energy, risks and in some places cost, **this study is not intended to enable a decision to be made on which scenario to pursue**. Crucial evidence is still being gathered and important national decisions are being made in the next few years. This does not mean that the region should wait to act, but that it should **take low regrets actions which can support any pathway.**

The study aims to show potential futures for the energy system to capture uncertainties in cost, availability of technology and infrastructure and consumer perception; it does not attempt to 'optimise' the future energy system. The analysis is not spatial, so cannot directly guide location of infrastructure or projects.

Emissions in scope[1]

- ✓ Scope 1 (direct) and scope 2 (electricity consumption) emissions from transport, buildings, industry, LULUCF and agriculture.
- ✓ High-level inclusion of emissions from domestic & international aviation and waste (for completeness but not modelled in detail).
- ✓ Emissions associated with land use and agriculture in the region, including CO_2, N_2O, CH_4.
- ✓ Negative emissions from Drax Bioenergy + CCS and new forest planting inside region.

Emissions out of scope

- Emissions from power *generation* in the region are calculated, but the pathways only include emissions from regional electricity *consumption* at national carbon content[1].
- Emissions from shipping.
- Scope 3 emissions, including embedded emissions in product/service imports
- Emissions offsetting outside region
- Circular economy and full system changes are out of scope of the modelling

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1 Scope suggested is similar to that of BEIS *'Emissions of CO_2 for LA areas dataset'*, however some additional emissions are included (aviation), the sectoral breakdown is different, LULUCF uses an updated methodology and agricultural non-CO2 emissions are included

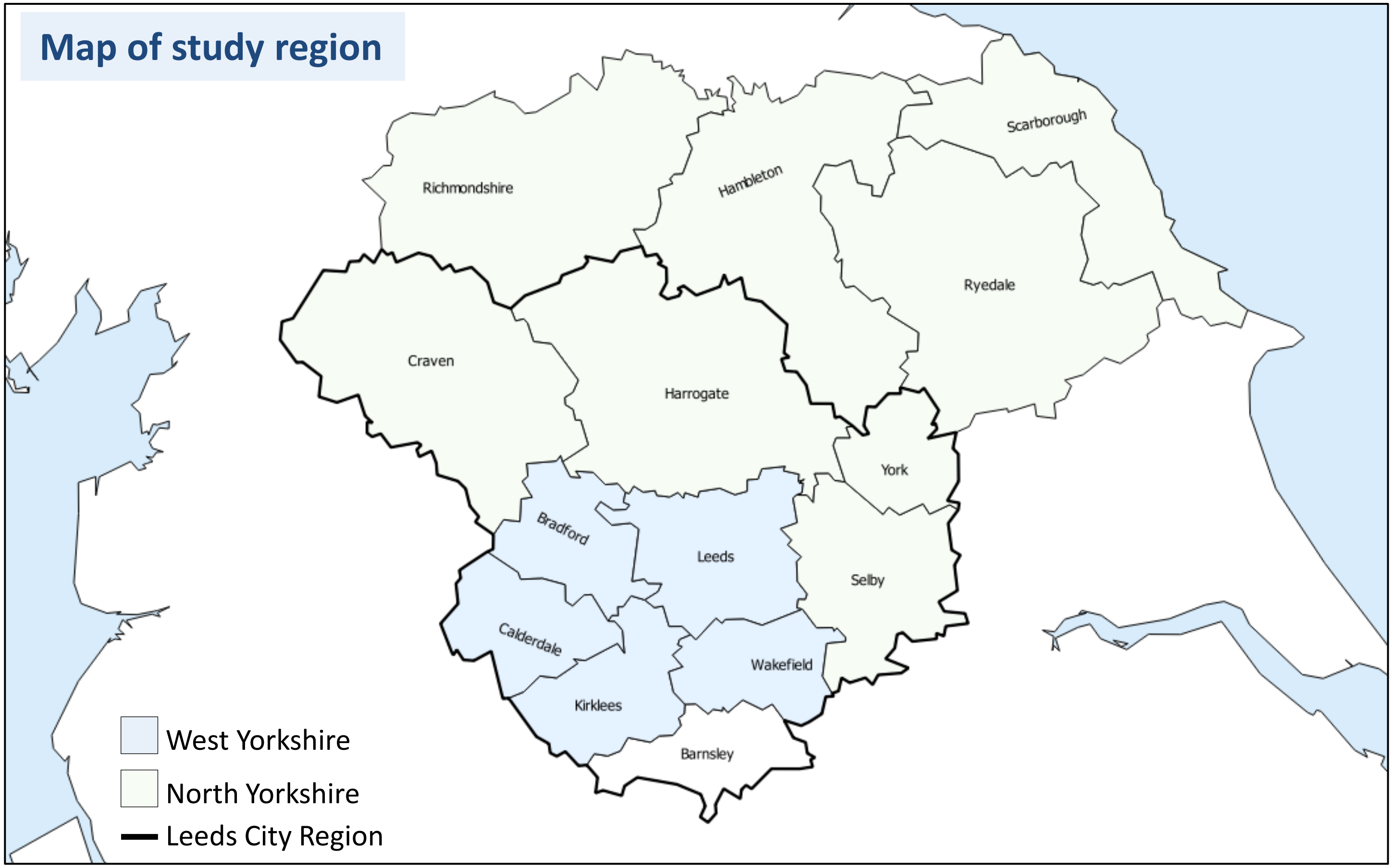
Geography: The full study region includes 14 Local Authorities, with varying decarbonisation ambition

Study region

West Yorkshire

Y&NY

Map of study region



The emissions reduction pathways were modelled for the study region as a whole (green and blue area) and disaggregated into the subregions - West Yorkshire, York and North Yorkshire and Leeds City Region. This pack will present the key results for West Yorkshire and Y&NY separately, using the coloured tags on the left of slides to signpost which subregion is being presented.

Scenario Characteristics: The emissions reduction pathways present a range of visions as to how the region can reach Net-Zero

1- Baseline

The baseline scenario represents the **likely outcome with current policies**. There will be relatively low uptake of most technologies beyond 2025 in the absence of new policies, incentives and regulations.

2- Max Ambition

The Max Ambition scenario assesses how quickly the region could technically reduce emissions. This will necessarily involve **significant electrification** of heat, transport and industry, supported by enabling technologies such as DSR and energy storage. Significant increases in low carbon power generation, with accelerated negative emissions technologies (e.g. BECCS) and ambitious forest planting rates.

3- High H_2

The high hydrogen scenario promotes **large-scale hydrogen and CCS roll-out.** The gas network is repurposed for H_2, enabling significant low carbon hydrogen use in buildings/heat, industry, power and transport. This is supported by land-use measures such as afforestation and bioenergy production; lower electricity system changes (production, distribution and storage) are required.

4- Balanced

The Balanced scenario encompasses a **balanced technology mix across sectors**, with contributions from hydrogen, electrification, bioenergy, CCS and decentralised energy production. This represents how technologies are deployed in parallel, with differing factors impacting their adoption, from location to price or consumer comfort.

BECCS – Bioenergy Carbon Capture and Storage; CCS – Carbon Capture and Storage; DSR - Demand Side Response; H2 - hydrogen

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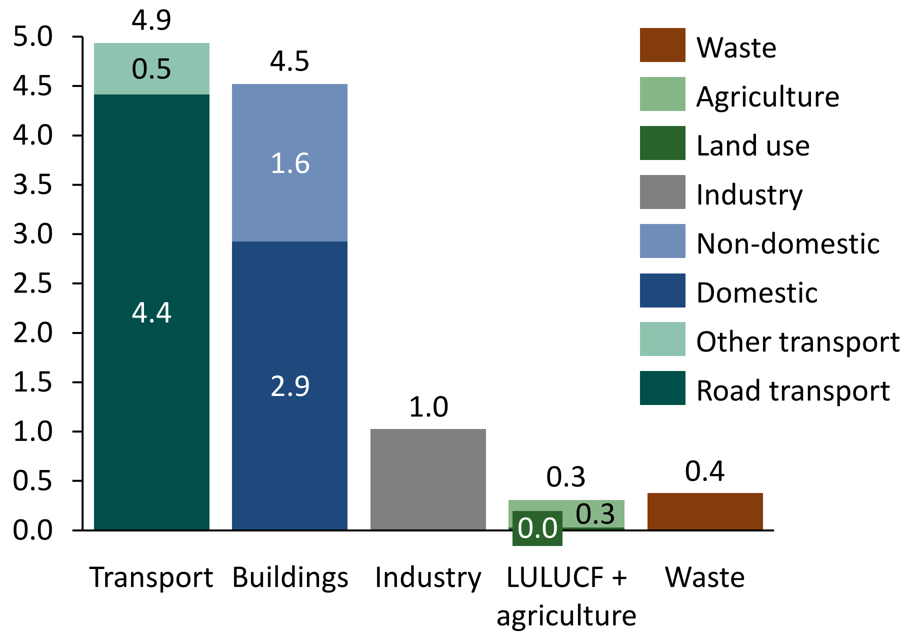
Current emissions by sector – the largest contributions are from road transport and building heat

West Yorkshire

Current emissions MtCO$_2$e/yr*

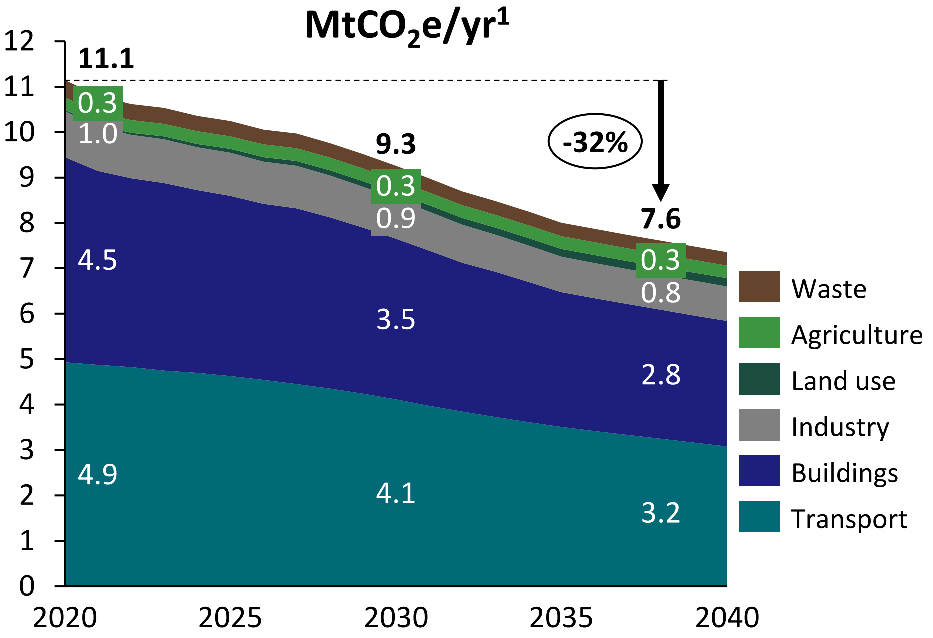


- This graph shows the region’s current emissions (2020), broken down into sectors and key subsectors. More detail within this is shown in the main report sectoral results.
- The scope of emissions included is greater than that in the local authority emissions datasets (see scope slide).
- Due to the urban nature of much of West Yorkshire, there are large contributions from buildings and transport, and limited emissions from and use and agriculture.

- Transport is the largest emitting sector, with emissions currently dominated by road transport, primarily private vehicle use.
- Much of the emissions from buildings and industry are due to heat generation, primarily using natural gas.
- Electricity related emissions (all electricity consuming sectors) will be addressed through decarbonisation of the power sector.
- There is limited heavy industry in the region; the largest heavy industry sectors are glass and chemicals.
- Land use + agriculture emissions are low in the region due to limited land area, much of which is urban.
- Emissions from waste are small, mostly from landfill.

*National electricity carbon content used. Electricity carbon intensity nationally has dropped significantly (43%) between 2017 (latest LA emissions dataset) and 2020, reducing the emissions contribution of electricity use, mostly in buildings and industry. Other transport includes rail, aviation (domestic and international) as well as aircraft support vehicles and emissions from lubricants

Baseline scenario – slow progress results in around 32% emissions reduction by 2038



- This graph shows the region's emissions projection under the baseline scenario, divided into the contribution from each of the sectors. The numbers on the graph show the emissions in 2020, 2030 and 2038 for each sector and the total.
- **The baseline scenario sees a 32% reduction in emissions by 2038, with 7.6 $MtCO_2e/yr$ remaining in 2038.**
- All sectors see slow change due to lack of strong incentives for consumers and businesses to switch to low carbon heat, transport and other practices.

- The transport sector sees the most progress due to the faster development of technically ready and cost-effective solutions, leading to uptake of electric vehicles.
- The majority of the emissions reduction in the buildings and industry sectors is due to **national renewable electricity** and some energy efficiency implementation. **There is slow uptake of low carbon heat** due to high cost, low awareness and consumer behaviour challenges.
- **Agriculture and land use emissions grow due to population growth** leading to urban expansion and an increase in the required food output.
- **Power sector (not shown[1]) emissions reduce by 26%** due to efficiency improvements of energy from waste plants and phasing out of some small fossil generation.
- The remaining emissions in 2038 are still primarily in the transport and buildings sectors.

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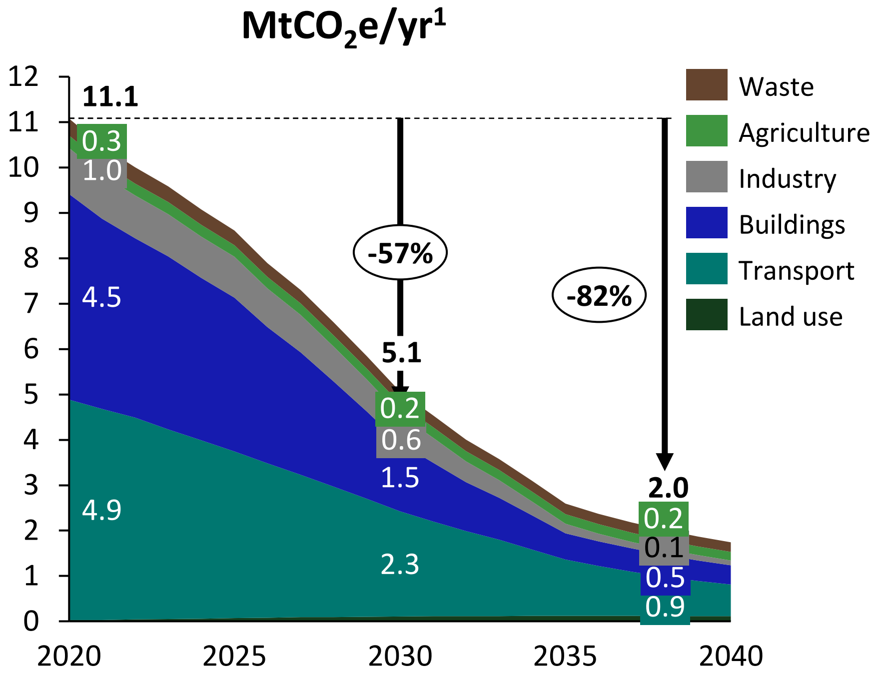
[1] Electricity consumption at national electricity carbon intensity (power generation emissions excluded)

Max ambition scenario – highly ambitious roll out of electric vehicles, active travel, heat pumps & new forest planting makes rapid progress



- This graph shows the region's emissions projection under the Max ambition scenario, divided into the contribution from each of the sectors.
- The scenario sees an **82% reduction in emissions by 2038, with 2.0 MtCO$_2$e/yr remaining in 2038**. To reach net-zero increased ambition around some measures, more speculative options or system changes would be needed.
- All sectors see rapid change, requiring strong incentives for consumers and businesses to switch to low carbon heat, transport and other practices.
- Remaining emission in 2038 are primarily in transport and buildings. However, both sectors use significant electricity, so they will decarbonise further as electricity becomes greener.

- The transport sector sees **rapid uptake of electric vehicles alongside significant consumer and industry behaviour change** to reduce travel demand and to shift journeys from private cars to active and public transport.
- The buildings sector sees **highly ambitious roll out of heat pumps (665k domestic by 2038)** and heat networks, particularly between 2025-2035, and large-scale building efficiency retrofit in the 2020s.
- **Industry focusses on developing new technology** and switching to low carbon fuels (electricity, H$_2$, bioenergy). Hydrogen is available to select industry sites through dedicated pipelines.
- The power sector (not shown[1]) sees the **rapid roll-out of solar PV and onshore wind, as well as energy from waste CCS** by 2030.
- Land use emissions stay steady as forest planting offsets emissions from new urban development. Agricultural emissions struggle to make much headway despite ambitious reduction in meat and dairy consumption.

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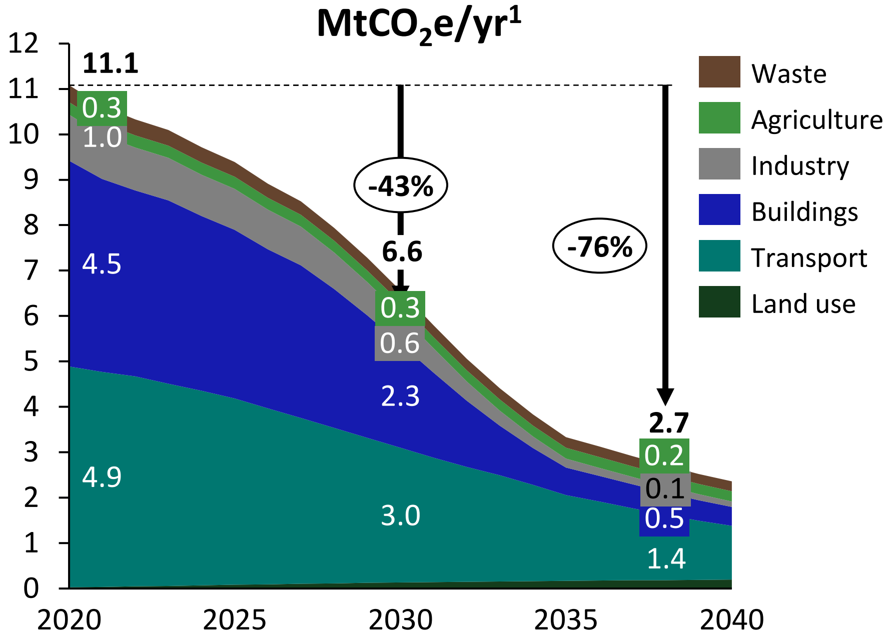
1 Electricity consumption at national electricity carbon intensity (power generation emissions excluded)

High Hydrogen scenario – widespread availability of hydrogen by 2030 enables deployment of hydrogen boilers and fuel cell vehicles

West Yorkshire



- This graph shows the region's emissions projection under the High H_2 scenario, divided into the contribution from each of the sectors.
- The scenario sees a 76% reduction in emissions by 2038, with 2.7 $MtCO_2e/yr$ remaining in 2038.
- All sectors see rapid change, partially enabled by the **transition from natural gas to hydrogen**, used in hydrogen boilers, vehicles and power generation. Hydrogen conversion is a significant infrastructure challenge.
- To reach net-zero increased ambition around some measures, more speculative options or system changes would be needed.

- The transport sector sees significant uptake of **hydrogen fuel cell vehicles**, particularly in the heavy goods vehicle and bus sectors during the 2030s, although battery electric vehicles still form a significant share of the vehicle fleet. Shift of journeys to active and public travel occurs more gradually between 2020-2038.
- The **buildings and industry sectors rely heavily on the conversion of the natural gas grid to hydrogen** from 2028 to supply low carbon heat. In the 2020s hybrid heat pumps and energy efficiency are implemented, and by 2038 there are over **515k homes heated by hydrogen**.
- The power sector (not shown[1]) sees **roll-out of solar PV and onshore wind, as well as energy from waste CCS and CHP facilities** by 2038.
- Land use and agriculture emissions struggle to decarbonise, with space constraints on new forest planting.

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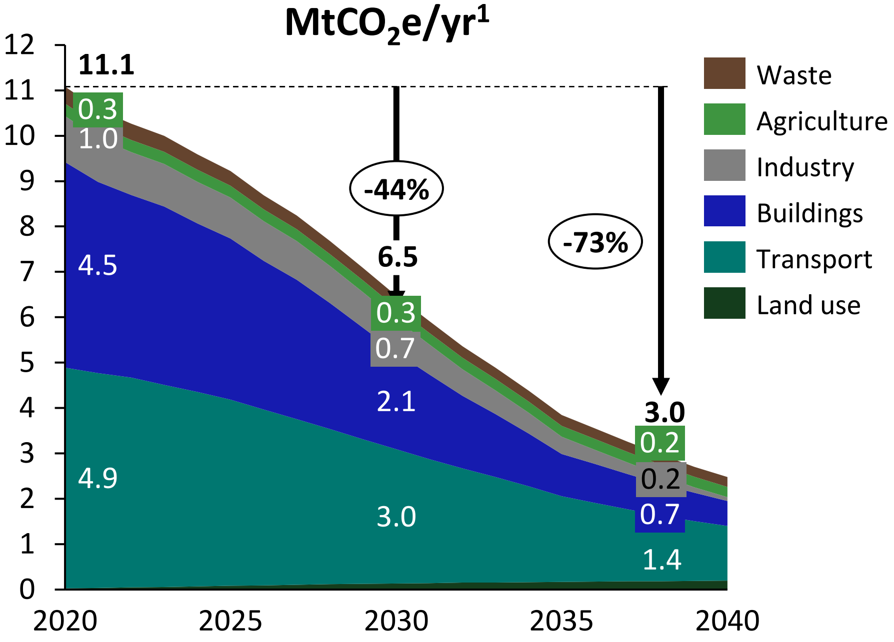
[1] Electricity consumption at national electricity carbon intensity (power generation emissions excluded)

Balanced scenario – the mix of technologies and fuels allows greater choice, with areas differing in their characteristics



West Yorkshire

- This graph shows the region's emissions projection under the Balanced scenario, divided into the contribution from each of the sectors.
- The scenario sees a 73% reduction in emissions by 2038, with 3.0 $MtCO_2e/yr$ remaining in 2038.
- The pathway sees significant electrification of heat and transport, but also introduction of hydrogen in some areas of the gas grid enabling hydrogen boilers; remaining areas of the gas grid remain a blend of natural gas and biomethane.
- Progress is slower than the other scenarios, particularly in the land use sector, representing the uncertainty in feasible rates of deployment.
- To reach net-zero increased ambition around some measures, more speculative options or system changes would be needed.

- The transport sector sees a mixed rollout of hydrogen and electric vehicles across vehicle types, alongside ambitious behaviour change.
- The **buildings and industry sectors rely on a mixture of hydrogen and electric heating technologies**; significant gas usage (natural gas and biomethane) remains in building boilers and industrial sites, resulting in higher emissions in the buildings and industry sectors (0.9 MtCO2e/yr remaining in 2038).
- The power sector (not shown[1]) sees **roll-out of solar PV and onshore wind, as well as energy from waste CCS and CHP facilities** by 2038.
- Land use and agriculture emissions struggle to decarbonise, with space constraints on new forest planting.

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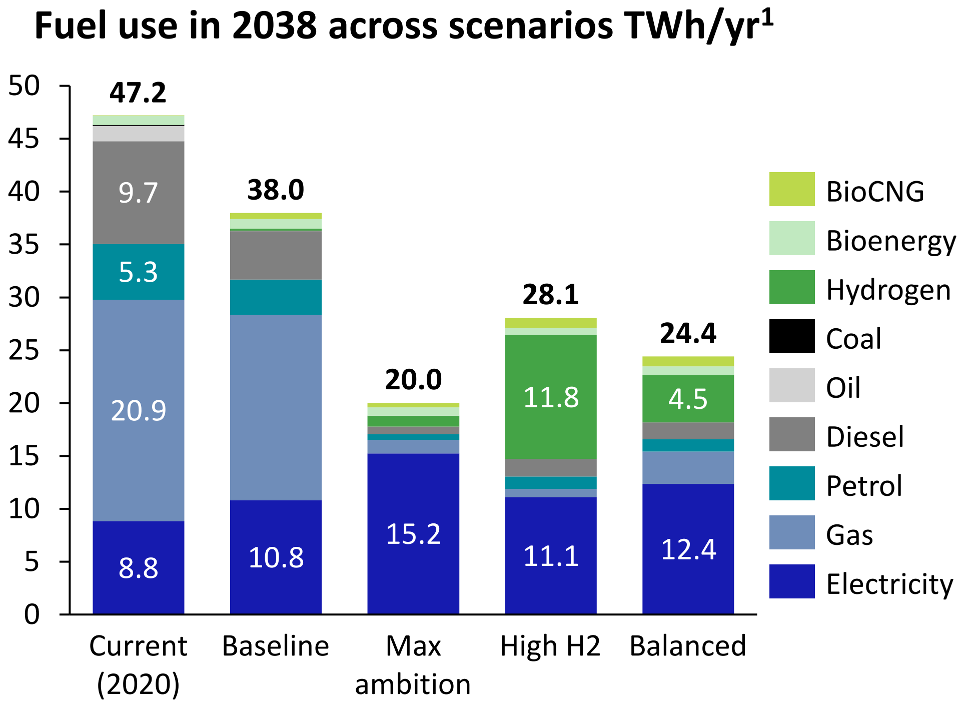
1 Electricity consumption at national electricity carbon intensity (power generation emissions excluded)

Scenario energy – the pathways rely of differing fuel mixes to reach their goals

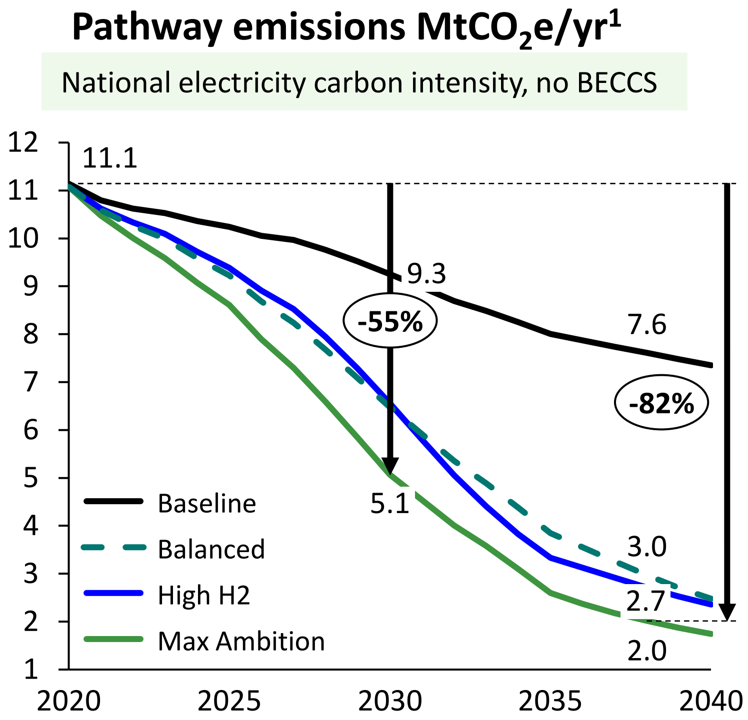


- This graph compares the fuel demand across the scenarios by fuel type. This includes the fuel required for all sectors[1]. The numbers at the top represent the total fuel demand.
- In 2020, the fuel mix is primarily fossil fuel, with a small amount of electricity.
- All emissions reduction scenarios see significant reduction in the total amount of fuel required for end-uses[2], due to increased technology efficiency as well as energy demand reduction measures.
- The transport and buildings sectors are the key components of the energy usage.

- By 2038, the scenarios rely on predominantly electricity and hydrogen, depending on the choices made.
- The Max ambition scenarios sees electrification of heat and transport, leading to a **72% increase in electricity demand between 2020 and 2038**. There is limited hydrogen and bioenergy use.
- In the High hydrogen scenario, with hydrogen widely available in the gas grid, 37% of fuel demand is hydrogen. The increase in electricity demand is only 26%.
- The balanced scenario sees a mix of fuels, with large amounts of electricity, but also hydrogen, bioenergy and some gas grid usage (including biomethane blending).

[1] Aviation fuel is not included as this is not attributed to specific subregions; bioenergy is bio-LPG and biomass in buildings and industry, but excluding power as per other graphs; gas is from the gas grid, a blend of natural gas and biomethane
[2] Note that electricity and hydrogen and are intermediate energy, generated from other energy forms.

Scenario emissions trajectory – emissions reductions occur at different rates across the scenarios due to differing choices



Pathway emissions $MtCO_2e/yr$[1]

National electricity carbon intensity, no BECCS

- This graph compares the emissions trajectories across the scenarios[1]. All pathways make ambitious emissions reductions over the next 2 decades, using different technologies, measures and fuels.
- No pathway reaches net-zero and the emissions remaining in 2038 are 2.0 – 3.0 $MtCO_2e/yr$ depending on the scenario. However, the 2038 emissions could be reduced further through regional power sector decarbonisation[1], greater ambition or innovative technologies.
- The key differences between the scenarios are the technology choice, level of electrification vs hydrogen in heat and transport and rate of technology deployment and behaviour change. More details can be found in the main report and technical Appendix on the underlying assumptions.

- **The Max ambition scenario makes considerably more progress by 2030**, due to ambitious rates of electric vehicle roll-out and uptake of active travel, unprecedented heat pump installation and faster rates of forest planting. Despite this, the emissions are still 51% of the current emissions by 2030, with challenges including misalignment with national policy timing, technology readiness, behaviour change and stock turnover rates.
- The High H_2 and Balanced scenarios make less progress in the next few years, but progress accelerates from the mid-2020s. **The High H_2 scenario sees rapid emissions reductions 2028-2035 as the gas grid is repurposed** for hydrogen, facilitating the switch of buildings, industry and some transport to hydrogen. The Balanced scenario sees steady progress through a mix of technologies deploying at different rates.

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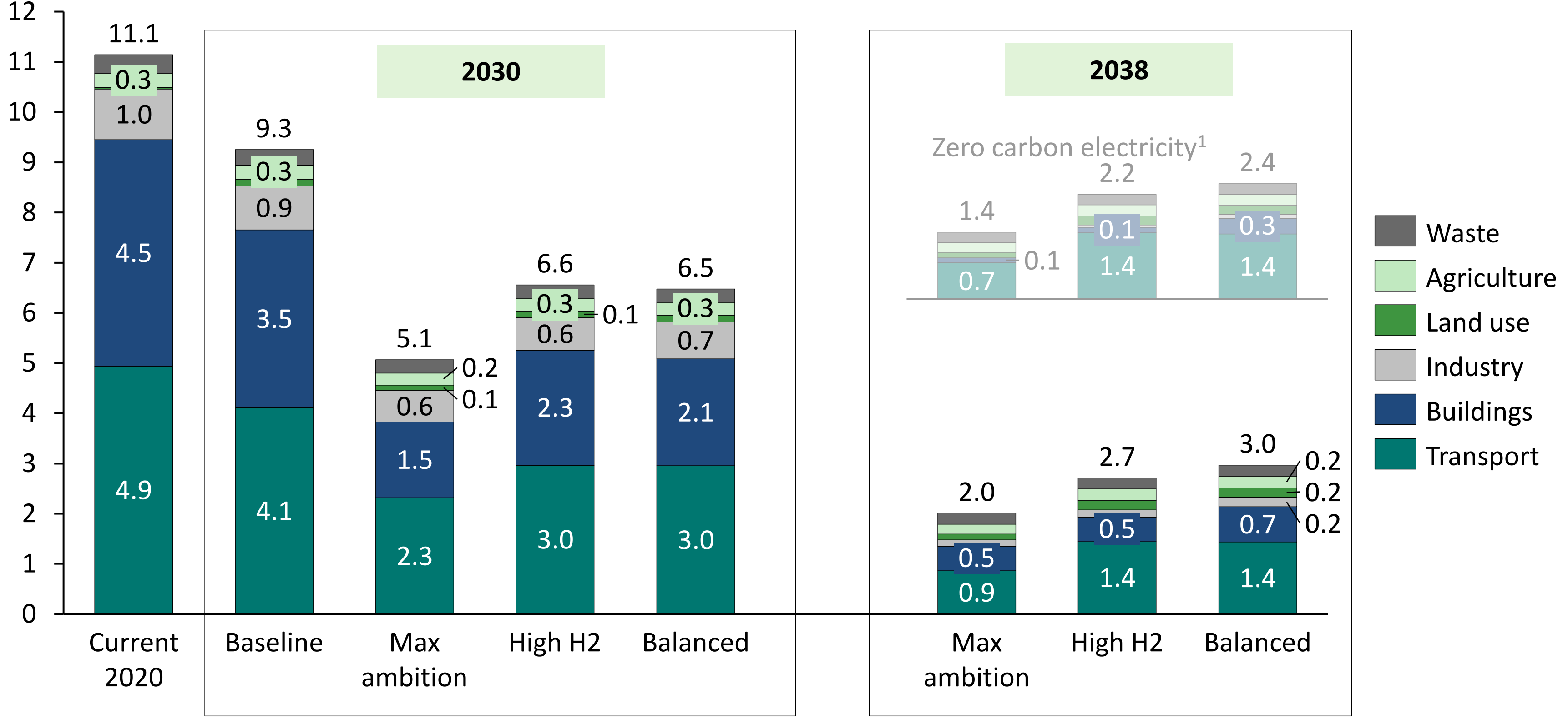
[1] National electricity carbon content is chosen for electricity consumed in the sectors to align with current GHG reporting, and regional power sector emissions are therefore not included.

Remaining emissions are significant in 2030 across sectors, but by 2038 these have reduced significantly

West Yorkshire

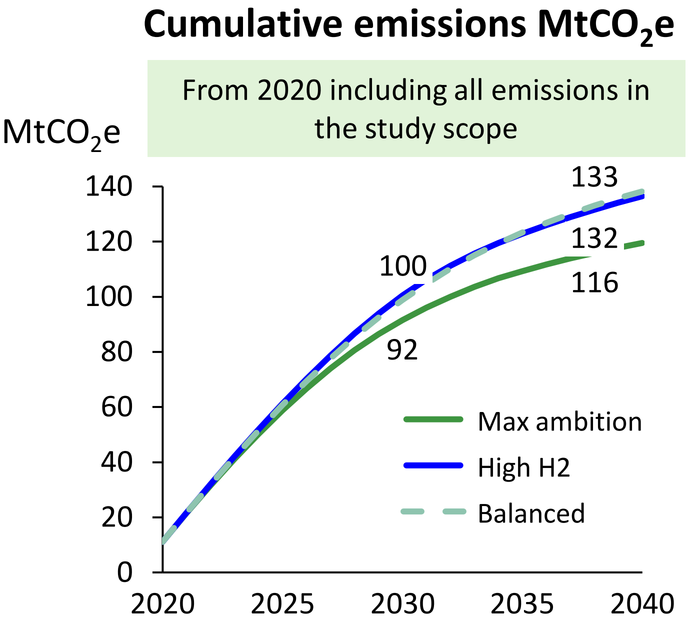
Emissions remaining compared with current $MtCO_2e/yr$

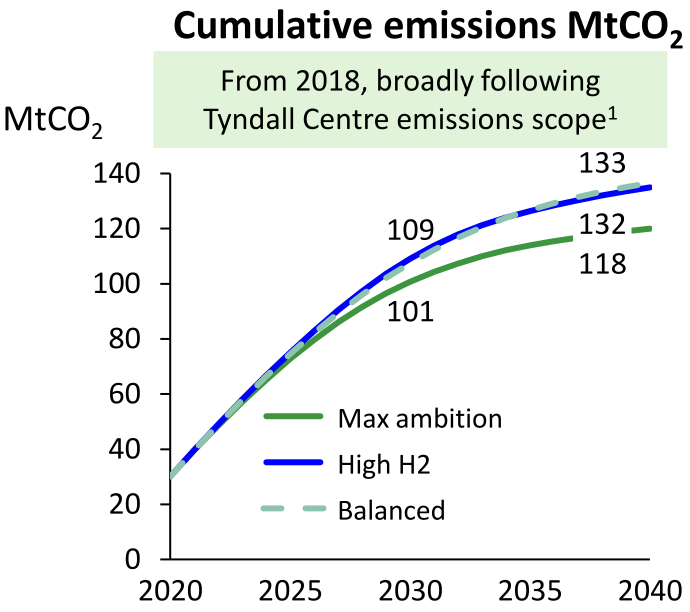


- In 2030 there are significant emissions remaining, with the Max ambition scenario making the most progress through ambitious uptake of active travel, electric vehicles and heat pumps. Industry has made limited progress by 2030 due to the immature state of low carbon technology.
- In 2038, the majority of remaining emissions come from transport and buildings[2]. A key challenge in both sectors is the stock turnover rate, so even strong incentives take time to have an impact.
- More detail on the subsector contribution to remaining emissions can be found in the main report.

BECCS – bioenergy carbon capture and storage; 1 Emissions reduce further with a zero carbon electricity grid; 2 To reach net-zero more speculative options must be explored to offset these emissions

Cumulative emissions rise quickly in the early 2020s, but slow by 2030 as emissions mitigation measures take effect





- From a climate perspective, the net cumulative CO_2 emitted is the key factor, as this is the CO_2 contributing to global warming. The cumulative emissions of all scenarios rise rapidly during the 2020s, but then start to flatten around 2030 as interventions slow emissions.
- For all emissions (left), the **region reaches 116–133 $MtCO_2e$ cumulatively by 2038** depending on the scenario.
- The Tyndall Centre developed a science-based carbon budget for the region based on compliance with the Paris Agreement. The cumulative CO_2 budget is related to the energy system only and excludes land use, agriculture, aviation, waste and non-CO_2 emissions[1]. Under these conditions, the net cumulative carbon emissions are 118-133 $MtCO_2e$ by 2038 depending on the scenario.
    - N+W Yorkshires carbon budget is 134 $MtCO_2$ 2018-2100, and **the combined region breaches this in 2027, but cumulative net emissions fall in the 2030s** (due to negative emissions measures in Y&NY).

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[1] Cumulative carbon budget work is approximate, as Element modelling is not set up for the specific conditions of the Tyndall Centre carbon budgets.

West Yorkshire sees an 82% emissions reduction by 2038, with speculative options required to reach net-zero

West Yorkshire is more densely populated than many areas of the UK, with higher emissions from buildings & transport, but a smaller % of emissions from agriculture & industry. The region faces specific challenges around land area constraints and heat decarbonisation in relatively old homes; it also has limited potential for negative emissions technologies (e.g. BECCS[1], forest planting) to offset remaining emissions in the energy system.

- **West Yorkshire does not reach net-zero emissions under the measures modelled, although emissions could be reduced further through increased ambition, more speculative technologies or system changes[3]. The Max ambition scenario sees an 82% emissions reduction by 2038** and remaining emissions in 2038 are 2.0 $MtCO_2e/yr$[2], primarily in the transport and buildings sectors. The High H2 and Balanced scenarios reach 76% and 73% emissions reduction by 2038 respectively.
- Cumulative emissions[4] reach 116 $MtCO_2e$ by 2038 in the Max ambition scenario, enabling a **cumulative emissions saving of 65 $MtCO_2e$ by 2038 over the baseline scenario**.
- **Without CCS, the annual emissions in 2038 are 0.6 $MtCO_2e/yr$ higher** and the cost to heat buildings is over £1.7 billion higher cumulatively in the High hydrogen scenario.
- **The Max ambition scenario has the lowest cumulative and annual emissions, but requires highly ambitious leadership** and policy to drive extensive change across the economy. It requires over 660k domestic heat pumps and total electricity demand increases by 72% by 2038. Support will be required from national government, both in terms of policy and funding, as well as upgrades to the regional electricity infrastructure.
- **The scenarios take different trajectories as the timing of actions differ**. For example, Max ambition begins electrification early, whereas the High H_2 accelerates progress in the late 2020s as hydrogen is deployed.
- **Key challenges include:** misalignment with national policy timing; rapid building of technology supply chains, skills and infrastructure; enabling consumer awareness, behaviour change and acceptance.
- Decision makers must consider a wide range of factors when comparing pathways, such as air quality, investment, employment & risks. **Key evidence must be gathered** in the next few years around remaining uncertainties.

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1 BECCS: Bioenergy carbon capture and storage; 2 of this, 0.6 MtCO2e/yr is electricity related from electricity consumption at national electricity carbon intensity; 3 Suggestions provided in the main report; 4 emissions in study scope, from 2020

The scale of the challenge – what must happen by 2038 in the Max ambition scenario to meet climate targets?

West Yorkshire

Transport

Sales of zero emissions cars reach ca. 50,000/yr by 2038

Walking increases by 80% & cycling increases 20x compared to today

Public transport capacity increases by 55% compared to today

Buildings & industry

Retrofit of 680k homes to reach EPC C or better

665k heat pumps installed, or 141/day from 2025-2035

Hydrogen equipment developed and deployed for industry

Land use and agriculture

100% peatland restored[1] to minimise emissions

170 hectares of new forest planting

Diet change to reduce meat and dairy consumption by 32%

Power

Solar PV and onshore wind reach 820 MW (43 MW/yr from 2020-2030)

Energy from waste CCS deployed from 2030 (0.2 $MtCO_2$/yr, 2038)

Electricity infrastructure investment enabling 71% higher annual demand

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1 100% lowland peat and 60% upland due to space constraints

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  - Buildings
  - Power
  - Industry
  - LULUCF + agriculture
  - Waste
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Introduction: Main report body and sectoral pathways give further details on the interventions in each sector

The emissions trajectory for each sector is broken down further

- The purpose of this section is to provide an overview of the pathway results for each of the sectors in turn (Transport, Buildings, Power, Industry, Land use and agriculture)

- It is more detailed than the key findings section, as it breaks each sector down into the subsectors and explains some of the key measures and drivers behind the scenarios.

- For each sector, the section covers:
    - Current emissions and state for the region
    - Baseline pathway & then emissions reduction pathways x3, including the emissions remaining in 2030 and 2038
    - Comparison of the pathways and key differences
    - Conclusions and key messages

- The sections finishes with some key supporting information, such as the scope of emissions included, cross-sectoral hydrogen generation, and a summary of bioenergy end-uses.

- For those interested in the details and assumptions, a supporting Technical Appendix can be provided, including the key modelling assumptions

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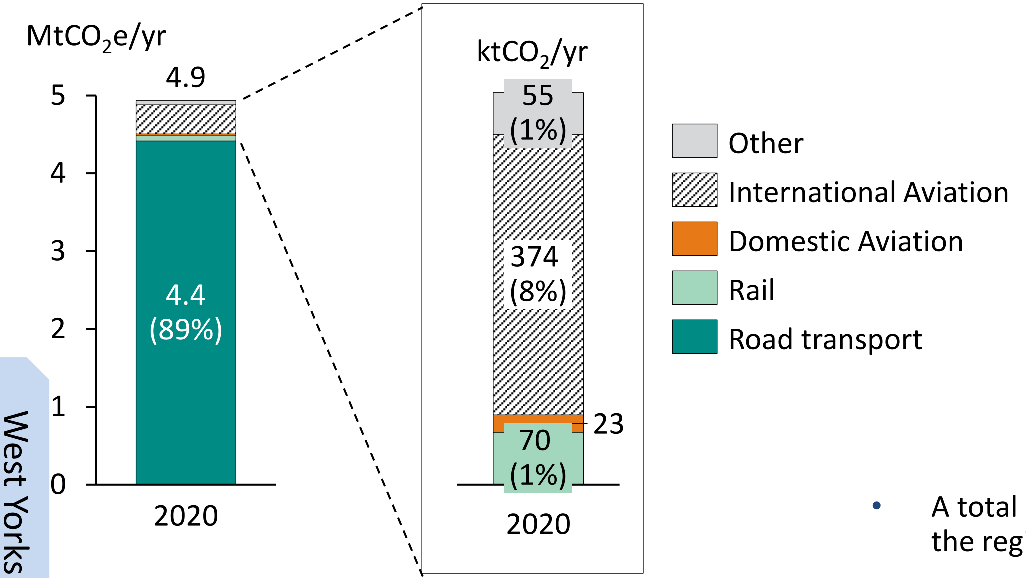
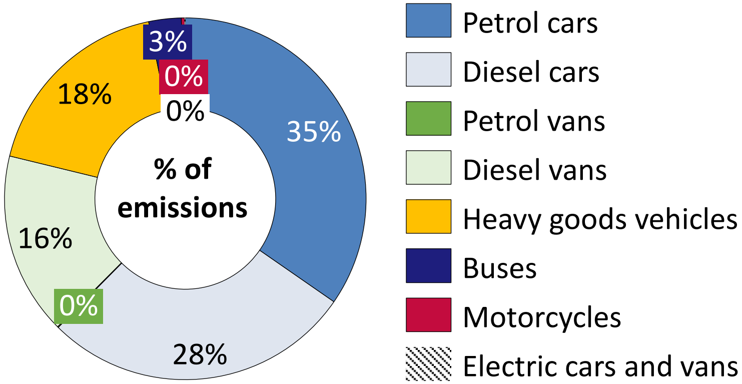
Current (modelled 2020) emissions situation in West Yorkshire - transport

West Yorkshire

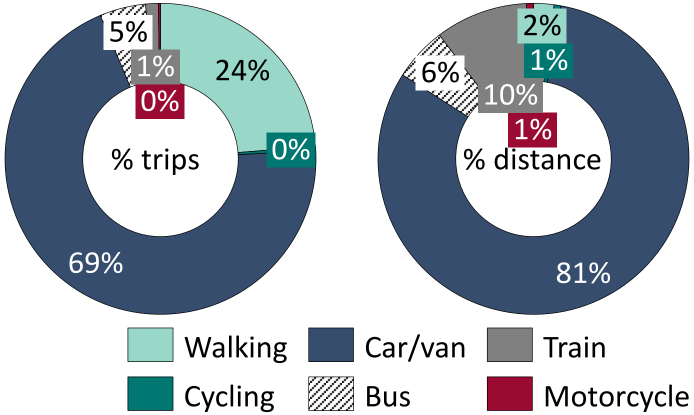
Current emissions in West Yorkshire[1]



Road transport emissions by vehicle and fuel type



Passenger travel by mode[3]

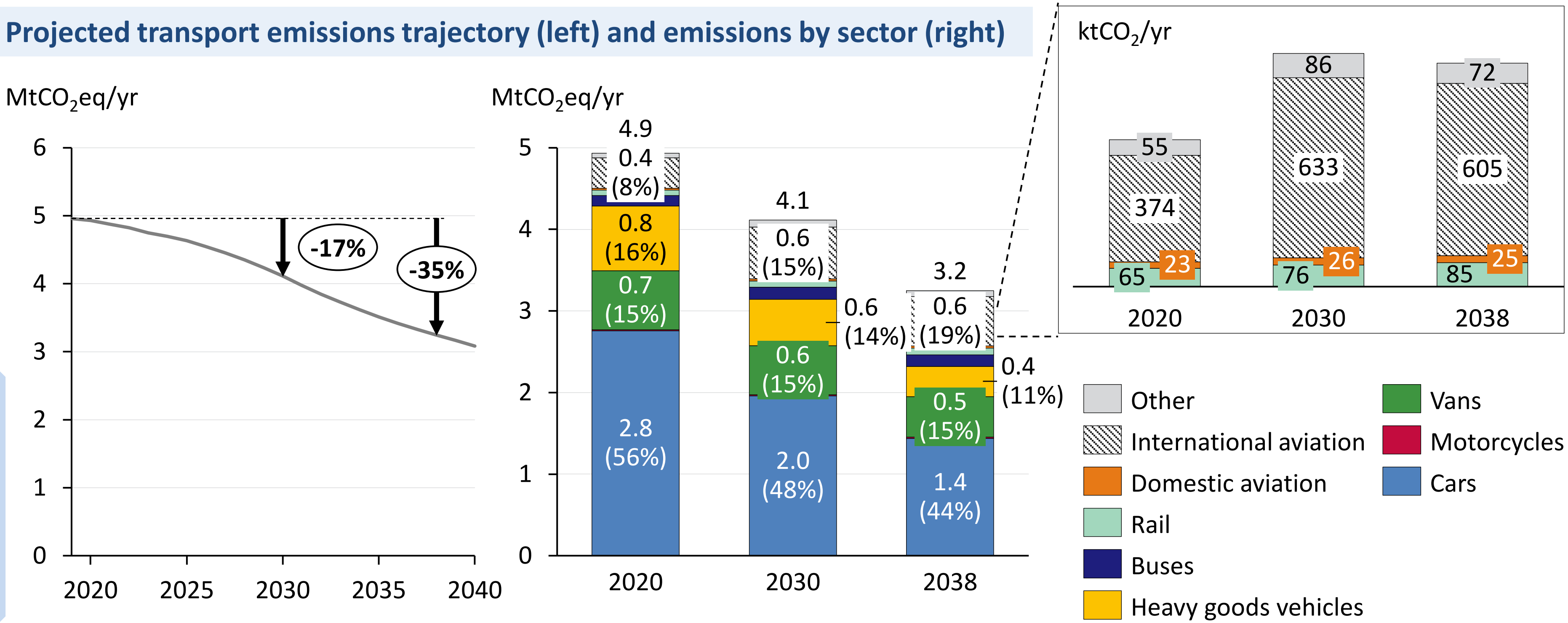


- A total of 4.9 $MtCO_2e/yr$ are emitted across all forms of transport in the region
- **89% of transport emissions are due to road transport,** with more than three-quarters of road transport emissions due to cars and vans; more than 99% of vehicles have conventional fossil fuel engines (less than 0.5% of cars and vans are plug-in hybrids or battery electric)
- **Aviation contributes a relatively large proportion of non-road transport emissions** (76% of non-road transport, 8% of total emissions), modelled to be in line with the proportion of passengers using Leeds Bradford Airport;[2] in contrast, rail contributes only 13% (1% of total transport emissions)
- A higher share of passenger journeys are taken by car in West Yorkshire than the average for England (81% of distance travelled in WY compared to 78% for England), whereas a below average number of journeys use rail (6% of distance travelled by rail in WY compared to 10% for England)[3]

1: Aviation emissions are estimated by scaling from the UK National Inventory in-line with relative passenger numbers; Other transport emissions include coal railways, airport support vehicles and combustion of oils and lubricants; 2. 22.3% in 2017, representing 65% of passengers from Study Region LA's. Source: Civil Aviation Authority statistics; 3. Based on National Travel Survey data for 2016

The Baseline scenario represents the likely outcome with current policies alone, with limited emissions reduction

Projected transport emissions trajectory (left) and emissions by sector (right)



- The Baseline scenario represents the likely outcome if **no additional policies are put in place** to drive low emissions vehicle uptake beyond those in place today;[1] however, considering the UK's commitments to emissions reduction, it is unlikely that this will be the case and as such this scenario should be considered to represent **a realistic lower bound of possible future trajectories** that is **far from reaching national targets.**
- **Under this scenario, total transport emissions decrease by 17% by 2030 and 35% by 2038,** with remaining emissions of 4.1 $MtCO_2e$ in 2030 and 3.2 $MtCO_2e$ in 2038. Cumulative emissions from transport reach 38 $MtCO_2e$ between 2020 and 2030, and 79 $MtCO_2e$ by 2038.
- Road transport experiences the largest decrease in emissions due to uptake of low emissions technologies, whereas non-road transport experiences increased emissions due to increased passenger numbers and limited change in technology.

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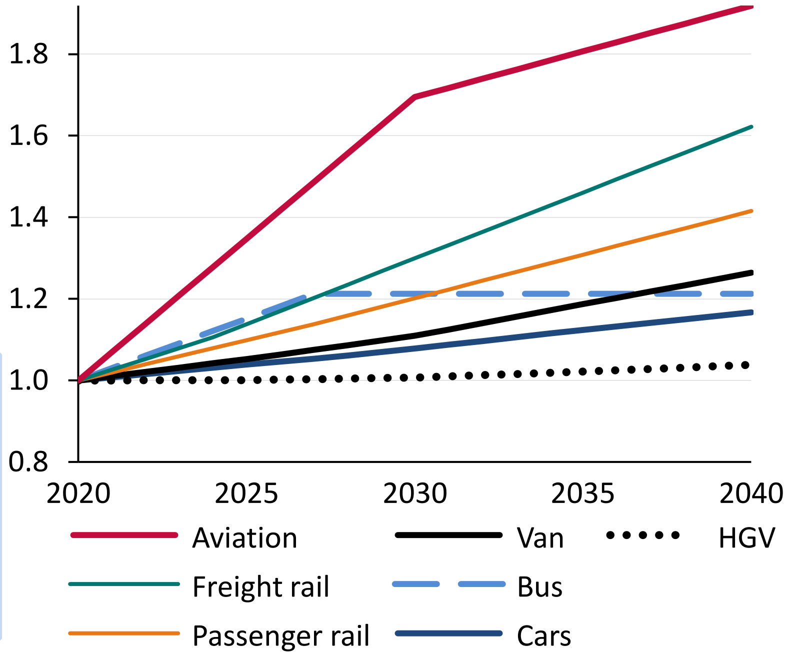
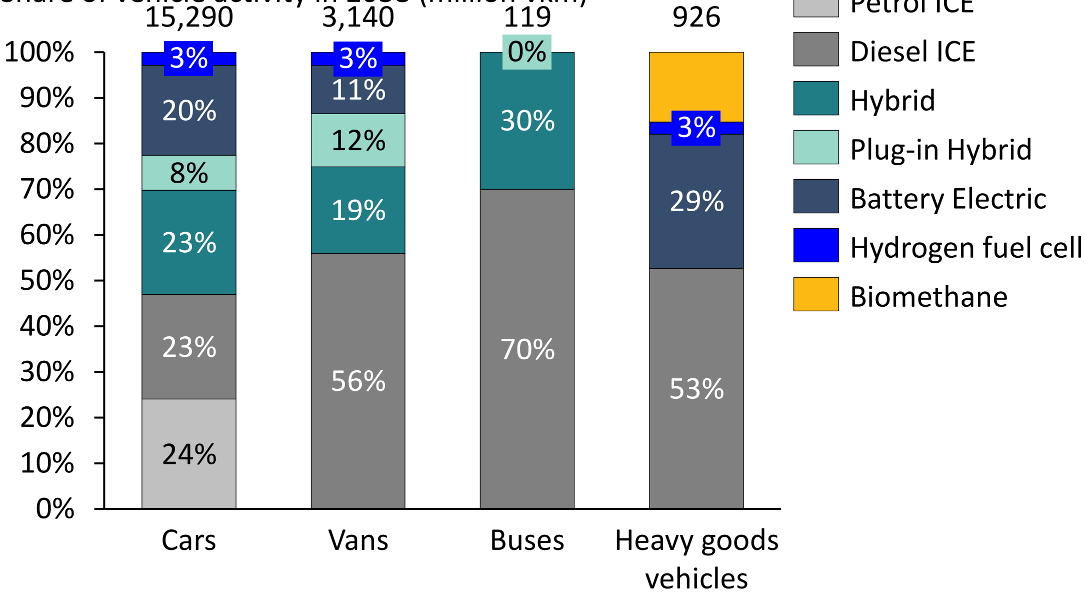
1. This includes existing and announced tax incentives and grants but does not reflect ambitions that do not currently have supporting policy defined, such as targets set out in the government's Road to Zero strategy

Baseline emissions reductions are driven by improvements in conventional technology and limited low emissions vehicle deployment

Travel demand relative to 2020



Share of vehicle activity in 2038 (million vkm)



- Travel demand and activity – represented by vehicle kilometres (vkm), passenger kilometres or freight tonne kilometres[1] – increases across all transport types and private cars are expected to remain the dominant mode of travel (see technical report for detailed assumptions).
- Reductions in emissions are a result of improvements in internal combustion engine (ICE) vehicle fuel efficiencies[2] and a shift away from pure ICEs in road transport
- In the absence of strong national or local policy to drive uptake, the shift to low emissions vehicles is primarily driven by EU manufacturer emissions targets, reductions in battery costs and improvements in electric vehicle range[3]
- Fossil fuel vehicles (including petrol, diesel and hybrid) are still the dominant technology, making up more than half of each vehicle fleet

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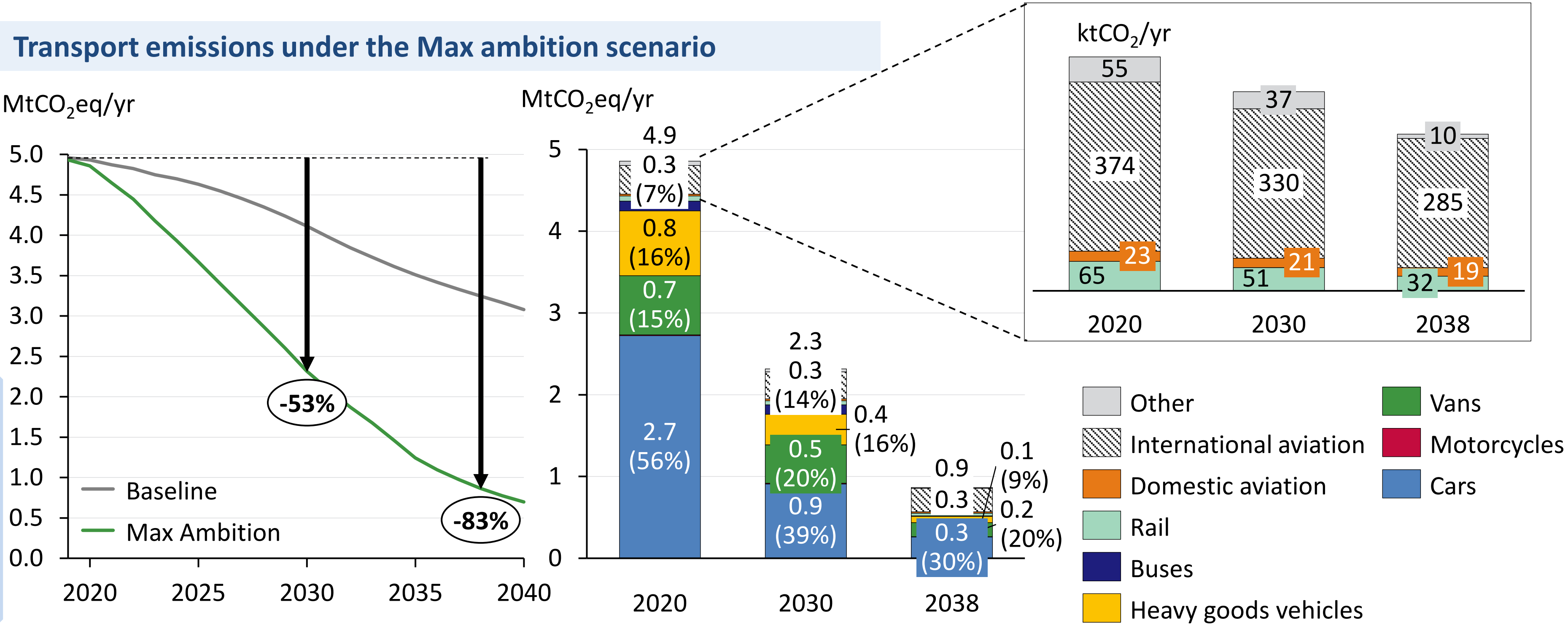
1. Vehicle km, passenger km and tonne km are measures of traffic, passenger and freight flow, determined by multiplying the number of vehicles, passengers or tonnes lifted by the average length of their trips; 2. For example, a diesel car improves by 15% by 2030 compared to 2020; 3. Assumptions in line with Element Energy modelling for DfT (ECCo)

The Max Ambition scenario assesses technology and policy requirements to decarbonise as quickly as possible

West Yorkshire

Transport emissions under the Max ambition scenario



- The Max ambition scenario represents the **fastest feasible rate of emissions reduction**, achieved through a combination of rapid uptake of low emissions technology, reduction in overall travel demand and ambitious shift of both passengers and freight from high emissions modes (e.g. private cars, heavy goods vehicles) to low emissions modes (e.g. walking, cycling, rail)
- **Under this scenario, transport emissions decrease by 53% by 2030 and 83% by 2038,** with remaining emissions of 2.3 $MtCO_2e$ in 2030 and 0.9 $MtCO_2e/yr$ in 2038. Cumulative emissions from transport reach 40 $MtCO_2e$ between 2020 and 2030, and 51 $MtCO_2e$ by 2038 (34% decrease compared to the Baseline).
- All transport types experience decreased emissions; however, as road transport emissions decrease, the relative contribution of rail, aviation and other transport to the overall sector emissions increases, with aviation representing 33% in 2038 compared to 8% in 2020

The Max ambition scenario requires ambitious changes in travel behaviour across all transport types over the next ten years

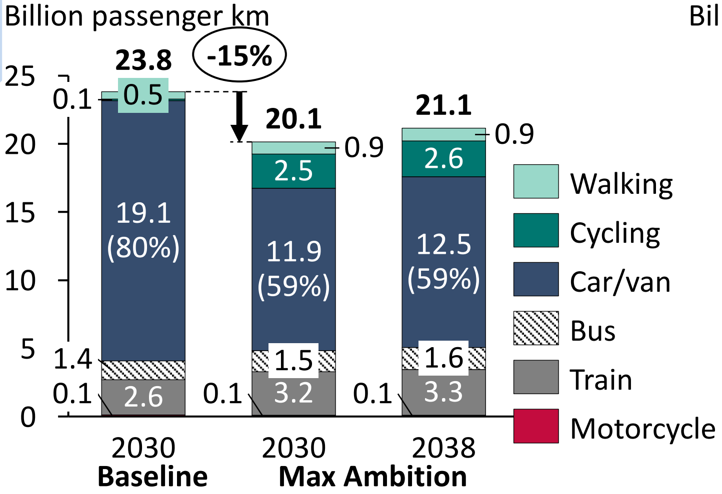
West Yorkshire

- Even with the maximum feasible rate of zero-emission vehicle roll-out, limited vehicle supply and stock turnover rates mean that rapid emissions reduction cannot be achieved through technology alone and must be supported by measures to reduce demand for travel and to shift journeys to more sustainable options
- **Compared to the Baseline**, in this scenario the maximum level of demand reduction and journey shift considered feasible is achieved by 2030, resulting in **private car use decreasing by 43%**, **van activity decreasing by 10%** and **heavy goods vehicle activity decreasing by 20%**[1]
- Significant reductions in passenger travel demand (15%) are assumed to be achieved through measures such as increased home working, teleconferencing, and closer proximity of housing to workplaces and amenities, while freight travel demand is reduced through measures such as consolidation, and reduction in food and consumer goods waste (10% for vans and 11% for heavy goods vehicles).
- **30% of remaining private car use (vkm) is shifted to public, shared and active travel**,[2] requiring (relative to Baseline):
  - **Car sharing to increase,** with 5% of car vehicle km shifting to shared cars (either car clubs or car sharing)
  - **Walking km to increase by over 60%** (890m km in 2030) and **cycling km to increase by almost a factor of 20** (2.5bn km in 2030)
  - **Public transport capacity to increase,** with passenger km increasing by 10% for buses and 20% for trains by 2030

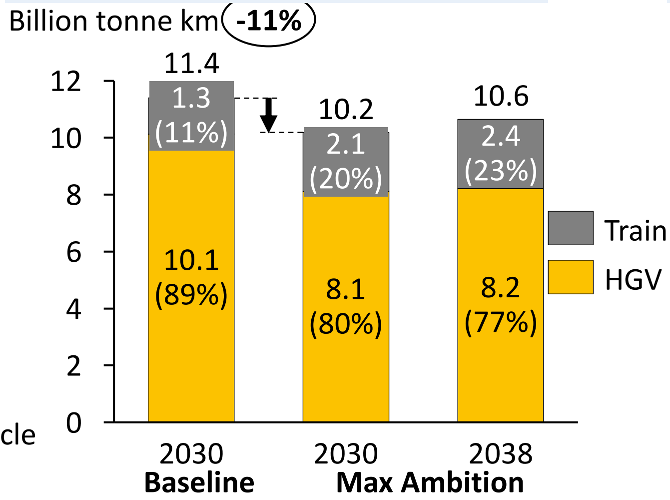
10% of freight is shifted from heavy goods vehicles to rail, while **2% of van traffic is replaced by cycle freight**

Domestic aviation demand is reduced by 20% relative to the Baseline[3] while international aviation is maintained at current levels[4]

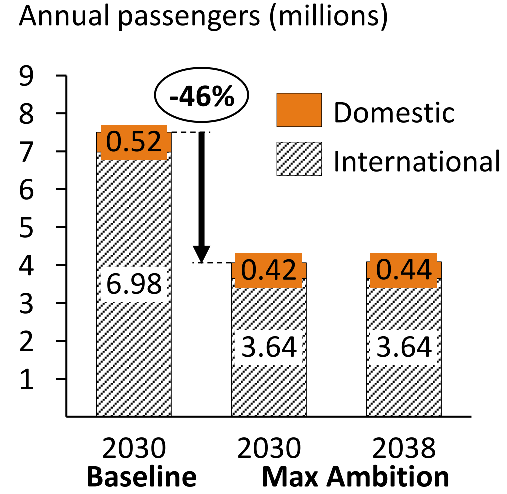
Passenger travel demand



Freight travel demand



Aviation demand (Study Region)[5]



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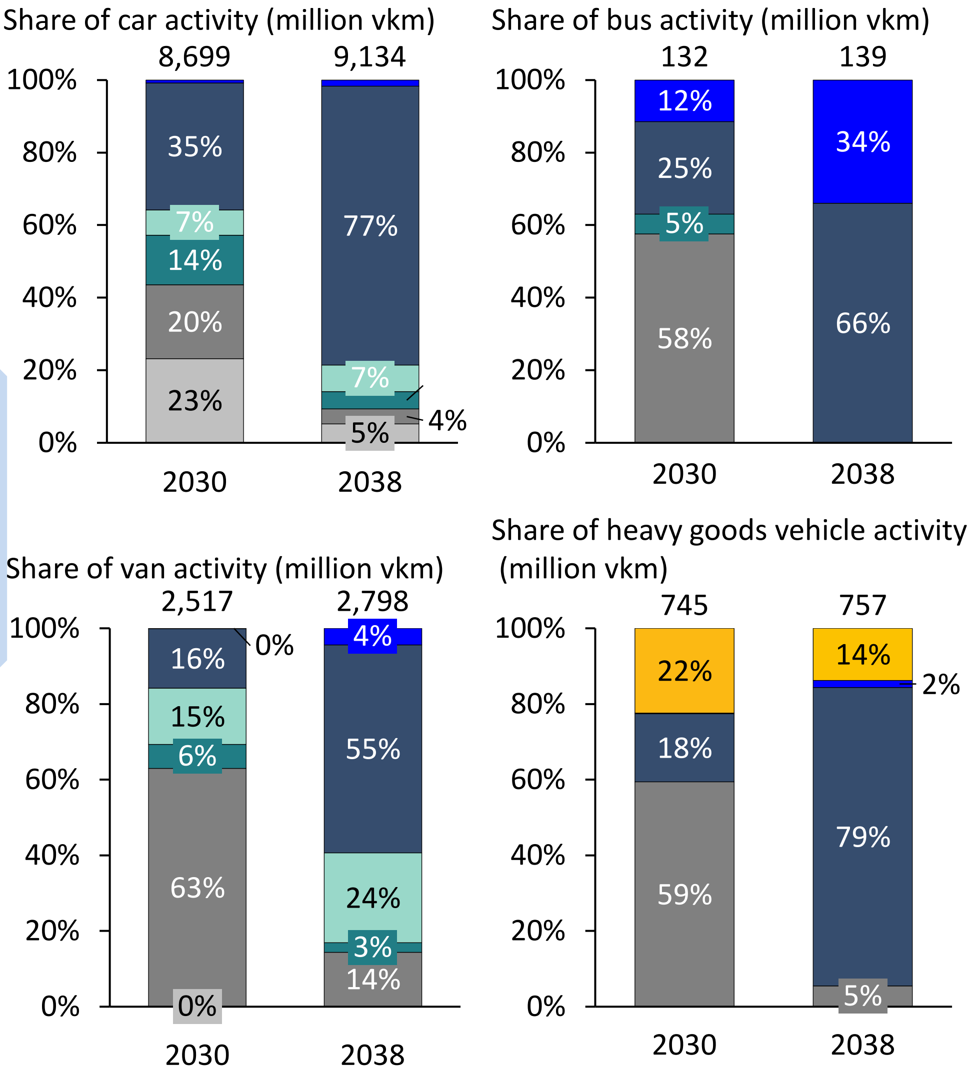
1. See Technical Report for detailed assumptions, travel patterns assumed to stay the same after 2030 but overall travel demand continues to grow; 2. Based on analysis of 2016 National Travel Survey data; see Technical Report for details; 3. Representing a significant reduction primarily in business trips; 4. In line with the Committee on Climate Change's most ambitious scenario, intended to be illustrative of the potential for significant change; 5. Based on total passengers at Leeds Bradford airport, not disaggregated at subregion level

Max ambition: Rapid low emissions technology deployment is required, with significant electrification across all vehicle types

Share of vehicle travel demand by technology type

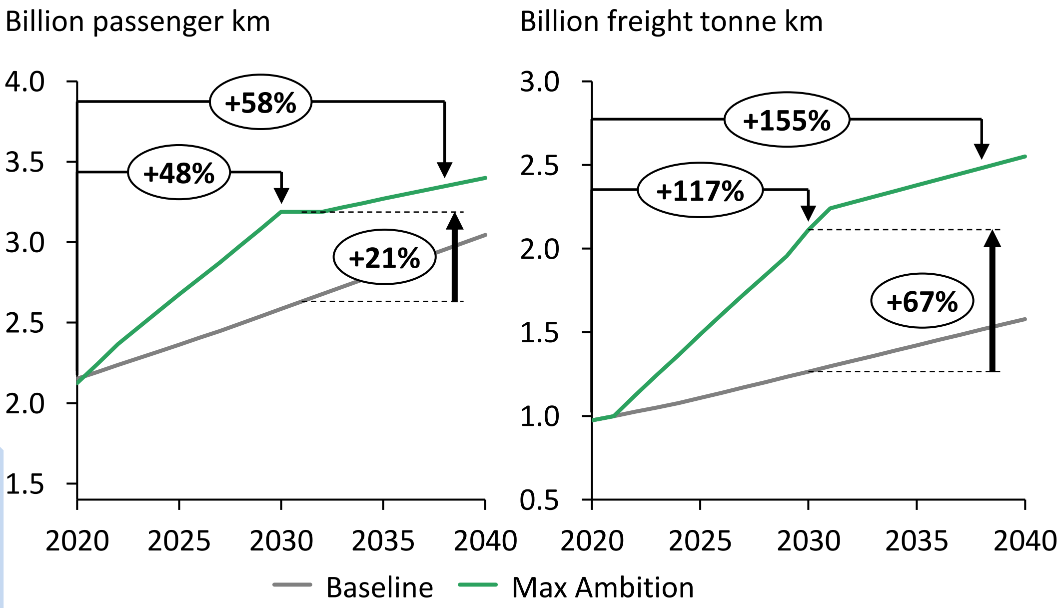
West Yorkshire

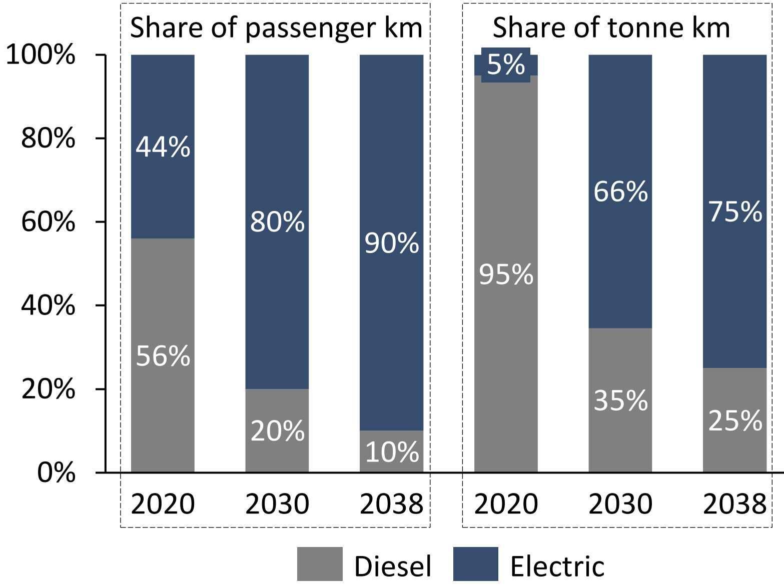


- Low emissions technology rollout follows the fastest rate considered feasible, requiring an **end to conventional petrol and diesel vehicle sales by 2030 for cars and vans**, and 2031 for buses. Plug-in hybrids are removed from sale by 2035.
- For West Yorkshire, reaching this level of technology deployment requires **sales on the order of 20,000 zero emissions cars per year by 2025** in the region, going up to close to 50,000 per year by 2038 (compared to less than 7,000 in 2018)[1]
- Heavy goods vehicles are the hardest sector to decarbonise and sales of combustion engine vehicles continue until 2040; however, a switch to biomethane-fuelled vehicles (bio-compressed natural gas, BioCNG)[2] enables faster emissions reduction and can help to end the sales of diesel engines by the early 2030s.
- Reaching this technology mix requires sales on the order of 300 BioCNG vehicles per year between 2025 and 2030 (total of ca. 3,000 vehicles in the local stock), with **sales of zero emissions heavy goods vehicles** increasing from around 600 per year in 2030 to **close to 2,000 per year by 2038**
- For the whole transport sector in 2038, demand of 0.2 TWh of hydrogen and 2.5 TWh of electricity will need to be met through production and refuelling infrastructure

1. DfT vehicle registration statistics; 2. BioCNG vehicles use an internal combustion engine but use compressed natural gas as a fuel; if the gas is 100% sourced from biomass, well-to-wheel emissions can be 85% lower than diesel; deployed only for vehicles greater than 18 tones gross vehicle weight

Rail capacity must increase to accommodate modal shift of passengers and freight, with electrification mitigating emissions growth





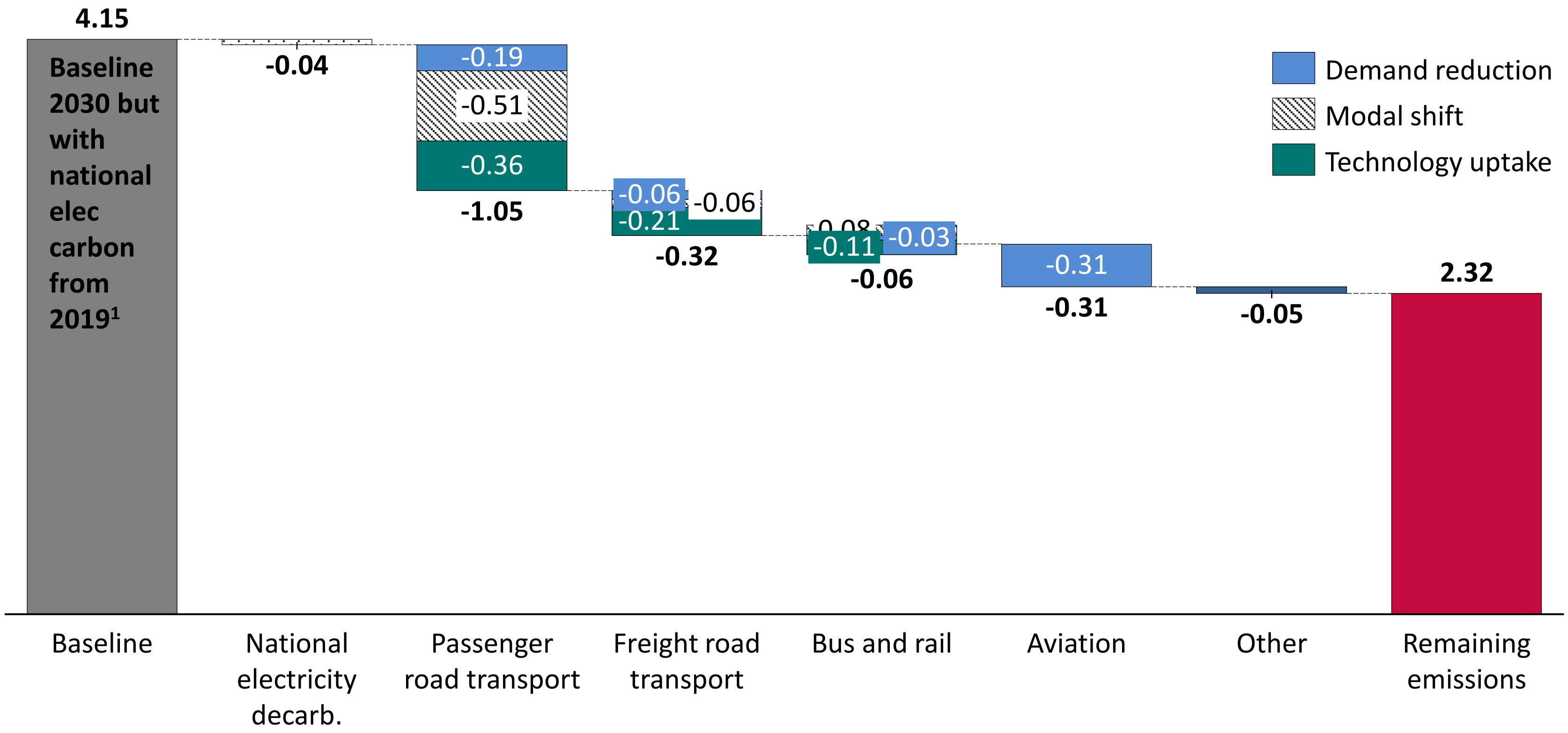
Shift of passenger and freight transport from road to rail results **in rail passenger km increasing by 60%** (reaching ca. 3.4 billion passenger km) **and rail tonne km increasing by 1.5 times** (ca. 2.5 billion tonne km) between 2020 and 2038 (20% more passenger km above the Baseline and 67% increase of freight tonne km above the Baseline).

- While some of the required capacity may be met using current infrastructure on some lines (e.g. by lengthening current trains)[1], increases in infrastructure will also be required, such as through Northern Powerhouse Rail.
- However, it should be noted that passenger km and tonne km are extrapolated based on road vehicle activity data (see Technical report for details), and the analysis assumes that all shifted travel demand remains on rail routes within the region. As such, the analysis does not accurately represent real travel data and should be interpreted as **indicative of the scale of change only.**
- **Significant electrification of both passenger and freight activity is assumed to mitigate emissions**.[2] This degree of electrification refers to the share of activity and not the share of trains or track, and may be achieved through a combination of hybrid diesel trains, electrification of lines and battery electric trains (exact technology mix not modelled in detail here).

1. Based on Leeds City Region Capacity analysis draft report; 2. Current electrification level estimated based on Element Energy analysis of peak passenger loads across Leeds City Region.

Max ambition: In 2030, demand reduction and journey shift contribute nearly half of emissions reductions

- The chart below demonstrates the relative impact of each of the measures modelled under the Max ambition scenario on emissions in 2030.
- In line with the relative contributions to total emissions, passenger transport measures contribute the majority of emissions reductions (57%).
- Due to the limited zero emissions vehicle uptake by 2030, behaviour change is particularly important – contributing net emissions savings of 1.08 $MtCO_2e$ (59% of emissions savings). However, behaviour change is also necessary to support technology roll-out – without behaviour change, up to 30,000 additional zero emissions cars would need to be sold per year to reach the same fleet share.



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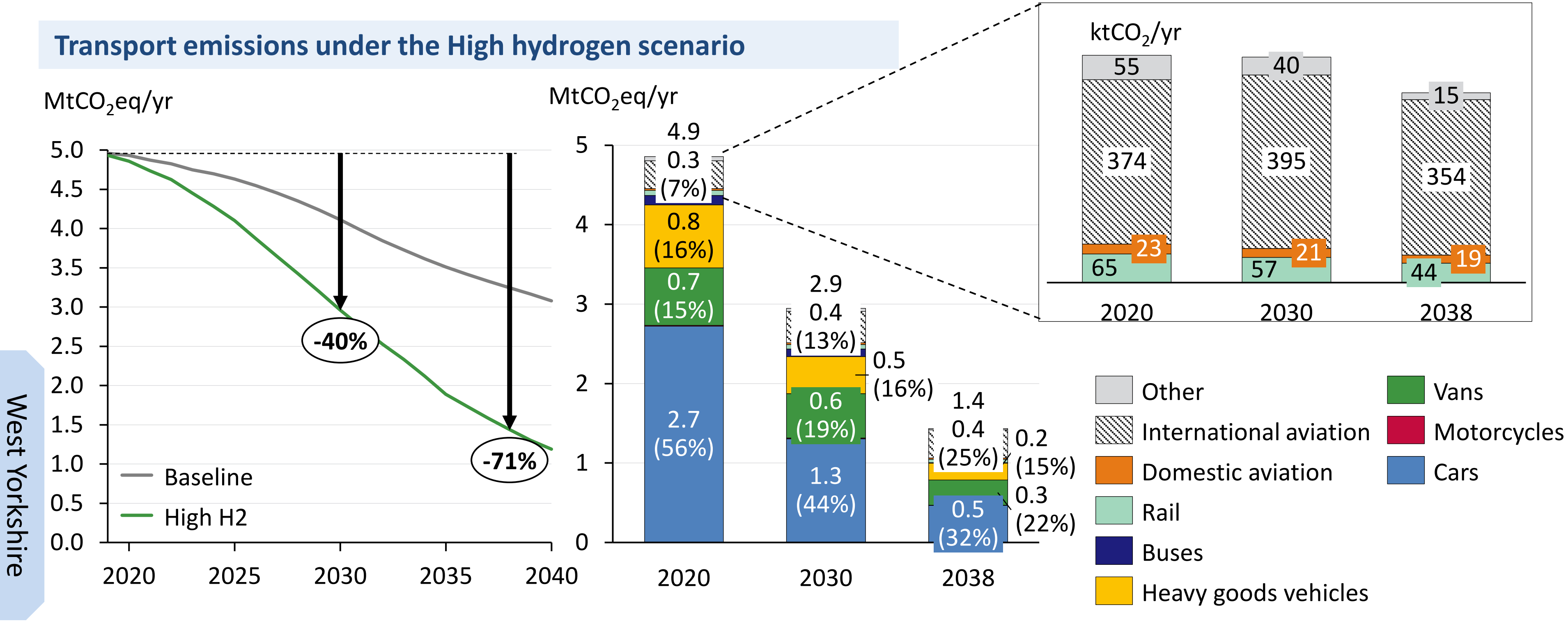
1. Included to indicate the impact of decarbonisation of the national electricity grid; as electric vehicle deployment is low in the Baseline, the contribution of grid decarbonisation is relatively low

The High hydrogen scenario targets significant emissions reduction by 2038, with wider adoption of hydrogen fuel cell vehicles

Transport emissions under the High hydrogen scenario

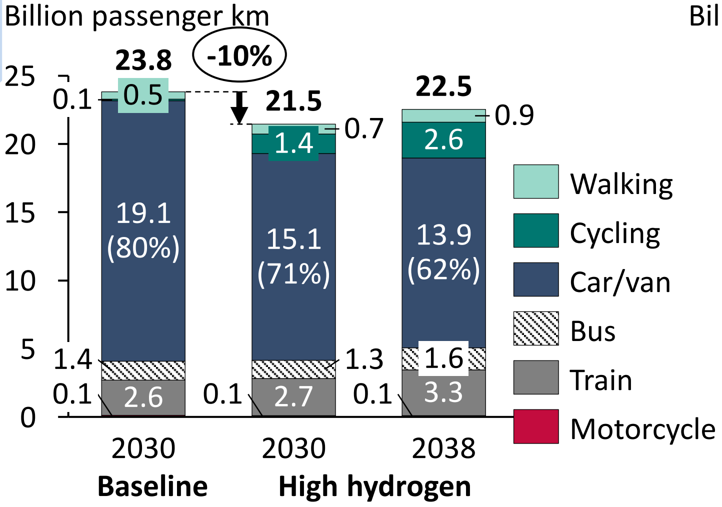


- The High hydrogen scenario represents a trajectory in which hydrogen is widely available for use in transport. Levels of uptake of low emissions vehicles and behaviour change are highly ambitious but are allowed to progress more slowly than in the Max ambition scenario, to reflect a longer transition enabled by the 2038 target.
- **Under this scenario, transport emissions decrease by 40% by 2030 and 71% by 2038,** with remaining emissions of 4.9 $MtCO_2e$ in 2030 and 1.4 $MtCO_2e$/yr in 2038. Cumulative emissions from transport reach 44 $MtCO_2e$ between 2020 and 2030, and 60 $MtCO_2e$ by 2038 (23% decrease compared to the Baseline).
- As for the Max ambition scenario, as road transport emissions decrease, the relative contribution of rail, aviation and other transport to the overall sector emissions increases (35% in 2038 compared to 8% in 2020)

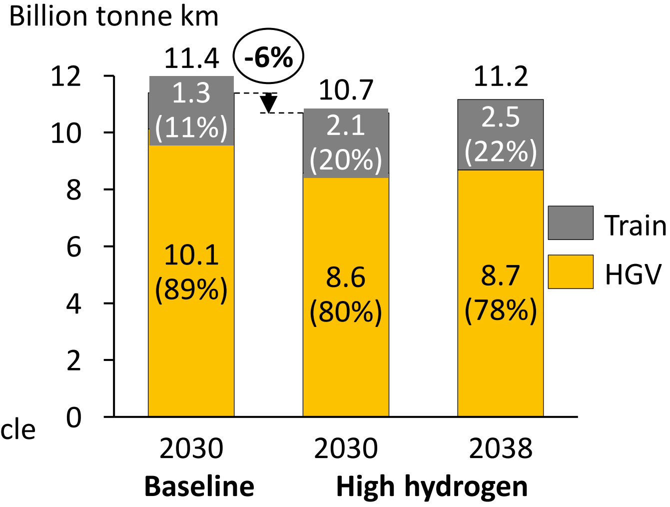
The High hydrogen scenario achieves ambitious changes in travel behaviour across all transport types by 2038

- Compared to the Max ambition scenario, lower but still ambitious levels of demand reduction are assumed for both the High hydrogen and Balanced scenarios: passenger km reduce by 10% compared to the Baseline in 2030 (12% in 2038) while freight travel demand decreases by 7% for heavy goods vehicles.
- For the remaining travel demand, the same level of journey shift to sustainable modes is assumed as in the Max ambition scenario, but the maximum level of passenger behaviour change is achieved by 2038 (8 years later than in the Max ambition)
- **17% of private car use (vkm) is shifted to public, shared and active travel by 2030,** reaching 36% by 2038:[2]
  - **Car sharing:** 3% of car vehicle km shift to shared cars by 2030 (either car clubs or car sharing; 8% by 2038)
  - **Walking:** increases by 34% in 2030 (725m km in 2030; 70% by 2038) and **cycling km increase by a factor of 12** (1.4bn km in 2030; factor of 20 by 2038)
  - **Public transport:** passenger km increase by 5% for trains by 2030 (12% by 2038) and 20% by 2038 for buses
- Overall, compared to the Baseline, **private car use decreases by 24% by 2030 (38% by 2038)**, **van activity decreases by 1%** and **heavy goods vehicle activity decreases by 15%[1]**
- Ambition for domestic aviation demand reduction is assumed to be the same as for the Max ambition scenario (20% relative to the Baseline)[3] while international aviation growth is limited to 25% above current levels[4]

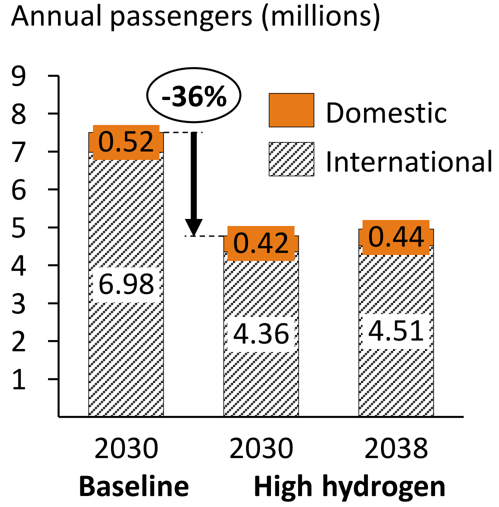
Passenger travel demand



Freight travel demand



Aviation demand (Study Region)[5]

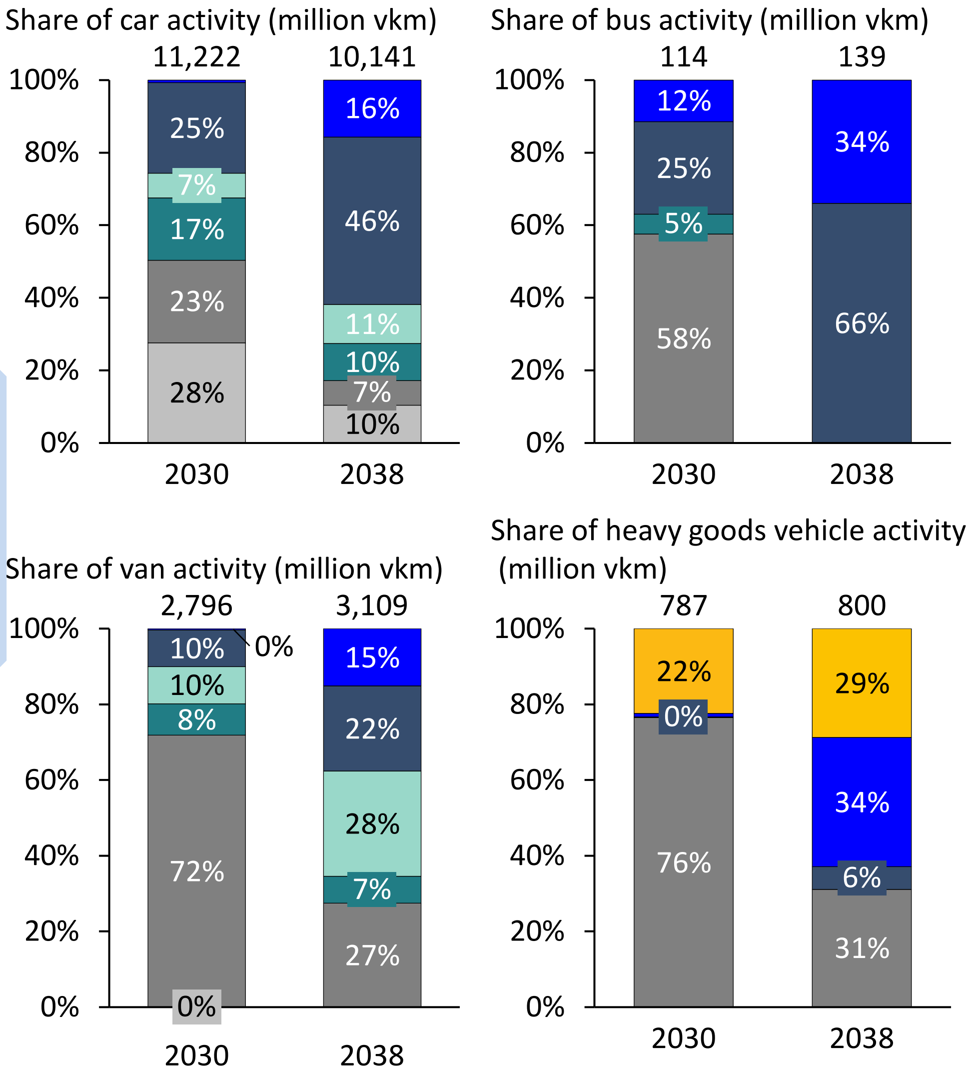


1. See Technical Report for detailed assumptions; 2. Based on analysis of 2016 National Travel Survey data; see Technical Report for details; 3. Representing a significant reduction primarily in business trips; 4. In line with the Committee on Climate Change's recommended growth limit; 5. Based on total passengers at Leeds Bradford Airport, not disaggregated at subregion level

High hydrogen: Widespread low emissions technology deployment is required, with higher deployment of hydrogen across all vehicles

Share of vehicle travel demand by technology type

West Yorkshire



Share of car activity (million vkm)

Share of bus activity (million vkm)

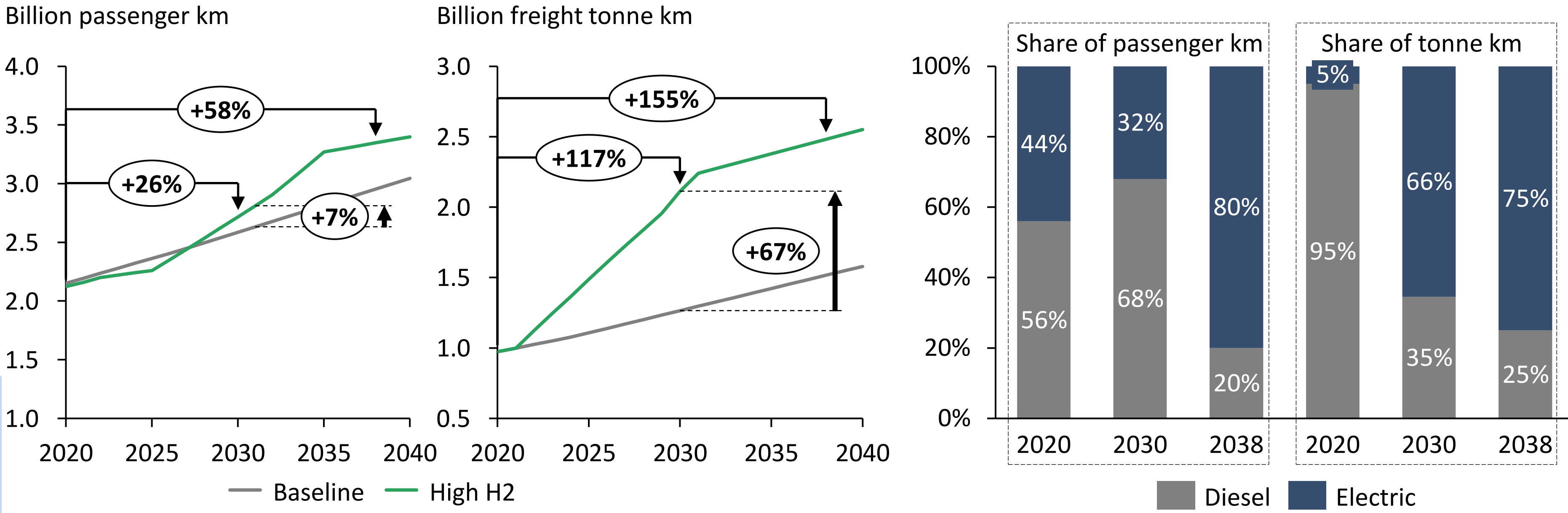
Share of van activity (million vkm)

Share of heavy goods vehicle activity (million vkm)

Petrol ICE	Plug-in Hybrid	Biomethane
Diesel ICE	Battery Electric	
Hybrid	Hydrogen fuel cell	

- In this scenario, **conventional petrol and diesel vehicle sales end by 2035 for cars and vans**, and 2031 for buses. Sales of plug-in hybrids continue beyond 2040.
- Sale of combustion engine vehicles continue beyond 2040 for heavy goods vehicles but biomethane-fuelled vehicles remain an important option to enable the end the sales of diesel engines in the late 2030s.
- Battery electric vehicles still make up a large share of the car and van fleets while hydrogen fuel cell vehicles achieve a significant market share of stock for buses and heavy goods vehicles.
- For West Yorkshire, reaching this level of technology deployment requires:
  - **Sales on the order of 20,000 zero emissions cars per year by 2025** in the region, going up to 40,000 per year by 2038, of which approximately half are hydrogen fuel cell vehicles
  - **Sales of zero emissions heavy goods vehicles** reaching around 1,000 per year in 2038, of which two thirds will be hydrogen fuel cell vehicles
- For the whole transport sector in 2038, demand of 1.1 TWh of hydrogen and 1.2 TWh of electricity will need to be met through production and refuelling infrastructure

Rail capacity must increase to accommodate modal shift of passengers and freight, with electrification mitigating emissions growth



- Compared to the Max ambition scenario, modal shift to rail is slower but still results **in rail passenger km increasing by 60%** (reaching ca. 3.3 billion passenger km) **and rail tonne km increasing by 1.6 times** (ca. 2.5 billion tonne km) by 2038 (12% increase of passenger km above the Baseline and 67% increase of freight tonne km above the Baseline).
- **Electrification of both passenger and freight activity is assumed to progress more slowly but is still significant**. As for the Max ambition, this may be achieved through a combination of hybrid diesel trains, electrification of lines and battery electric trains (exact technology mix not modelled in detail here).
- Hydrogen trains were not modelled as part of this work,[1] however may present an additional option for rural lines that are difficult to electrify. A detailed freight study to explore this option would be required

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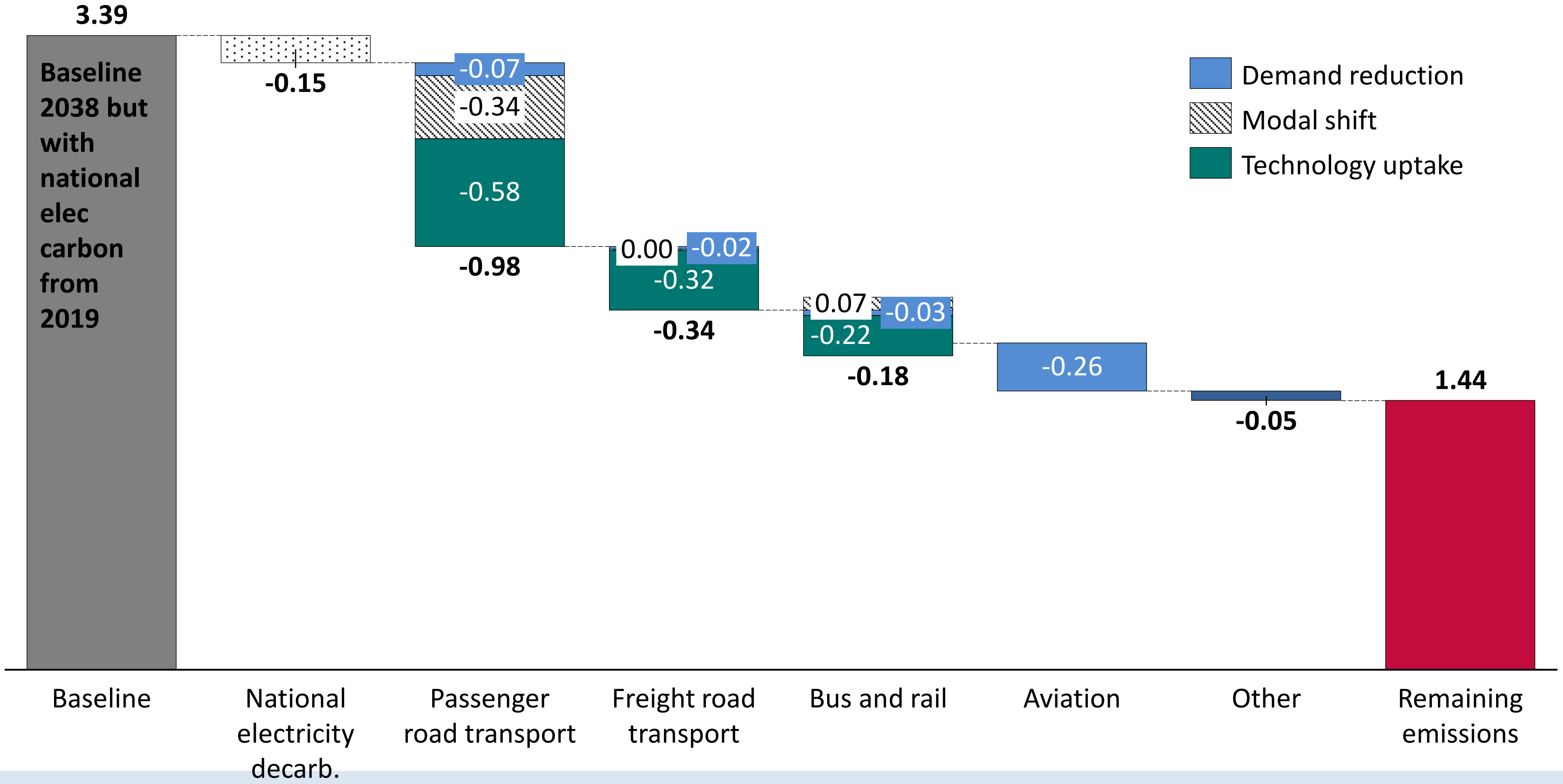
1. As discussed with the steering committee.

High Hydrogen: In 2038, behaviour change contributes just under a third of emissions savings

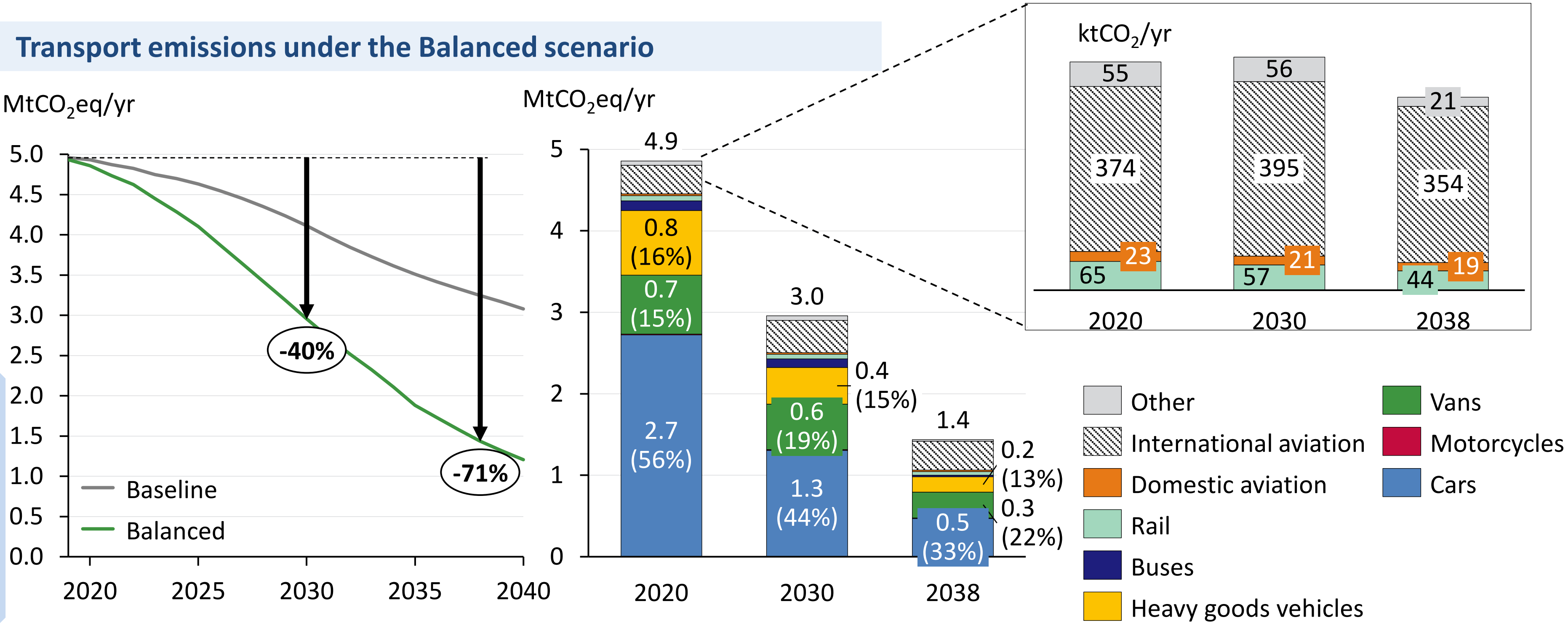
- The chart below demonstrates the relative impact of each of the measures modelled under the High hydrogen scenario on emissions in 2038.
- With more widespread zero emissions vehicle uptake by 2038, behaviour change contributes a lower proportion of the emissions savings (net savings of 0.64 $MtCO_2e$; 32% of emissions savings). However, behaviour change is still necessary to support technology roll-out – without behaviour change, up to 40,000 additional zero emissions cars would need to be sold per year to reach the same fleet share.



The Balanced scenario targets significant emissions reduction by 2038, with a more balanced technology mix

Transport emissions under the Balanced scenario

West Yorkshire

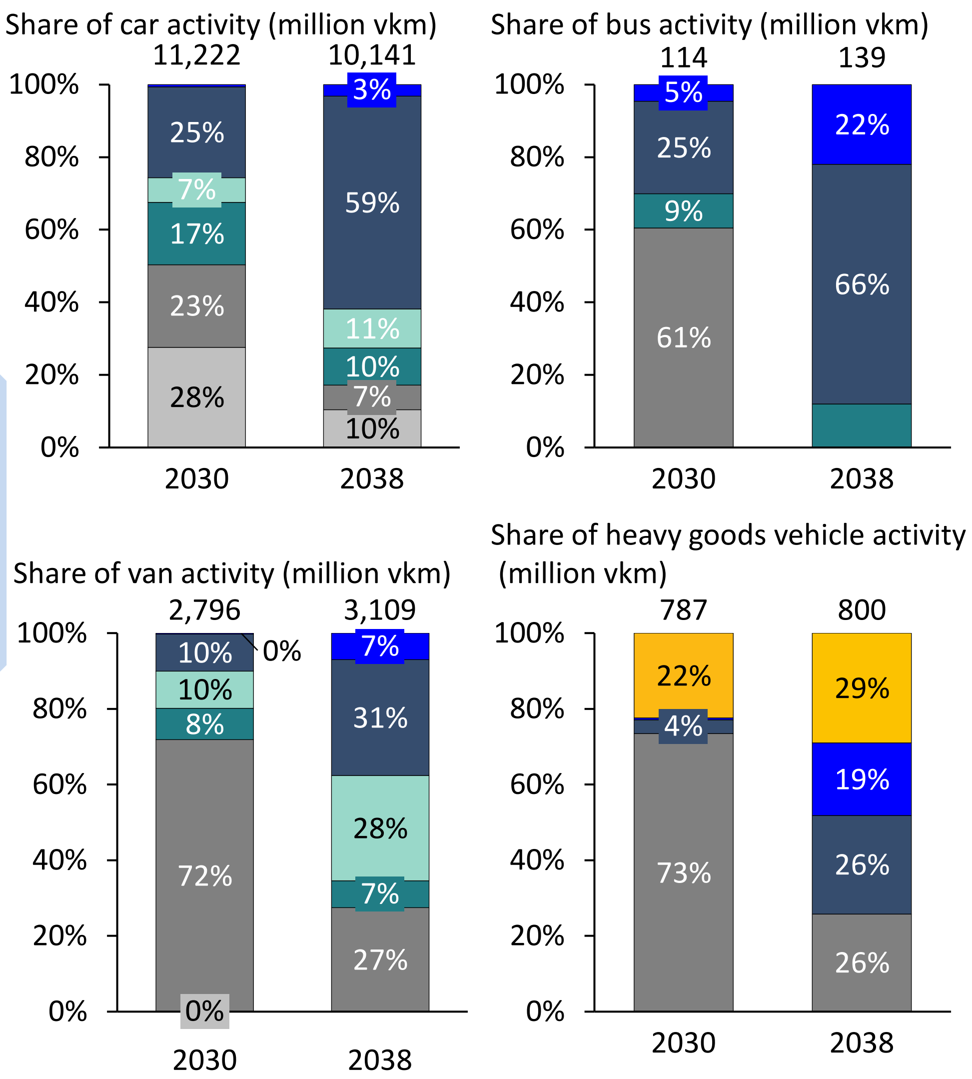


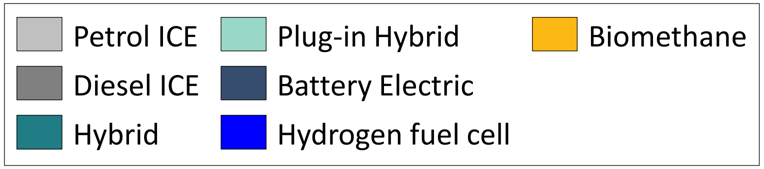
- The Balanced scenario represents a trajectory in which levels of uptake of low emissions vehicles and behaviour change follow the same path as for the High hydrogen scenario, but both hydrogen and battery electric technology are strong options across transport sectors.
- **Under this scenario, transport emissions decrease by 40% by 2030 and 71% by 2038,** with remaining emissions of 3.0 $MtCO_2e$ in 2030 and 1.4 $MtCO_2e/yr$ in 2038. Cumulative emissions from transport reach 45 $MtCO_2e$ between 2020 and 2030, and 62 $MtCO_2e$ by 2038 (22% decrease compared to the Baseline).
- As for the Max ambition scenario, as road transport emissions decrease, the relative contribution of rail, aviation and other transport to the overall sector emissions increases (35% in 2038 compared to 8% in 2020)

Balanced: Widespread low emissions technology deployment is required, with a mix of hydrogen and electric vehicles

West Yorkshire

Share of vehicle travel demand by technology type

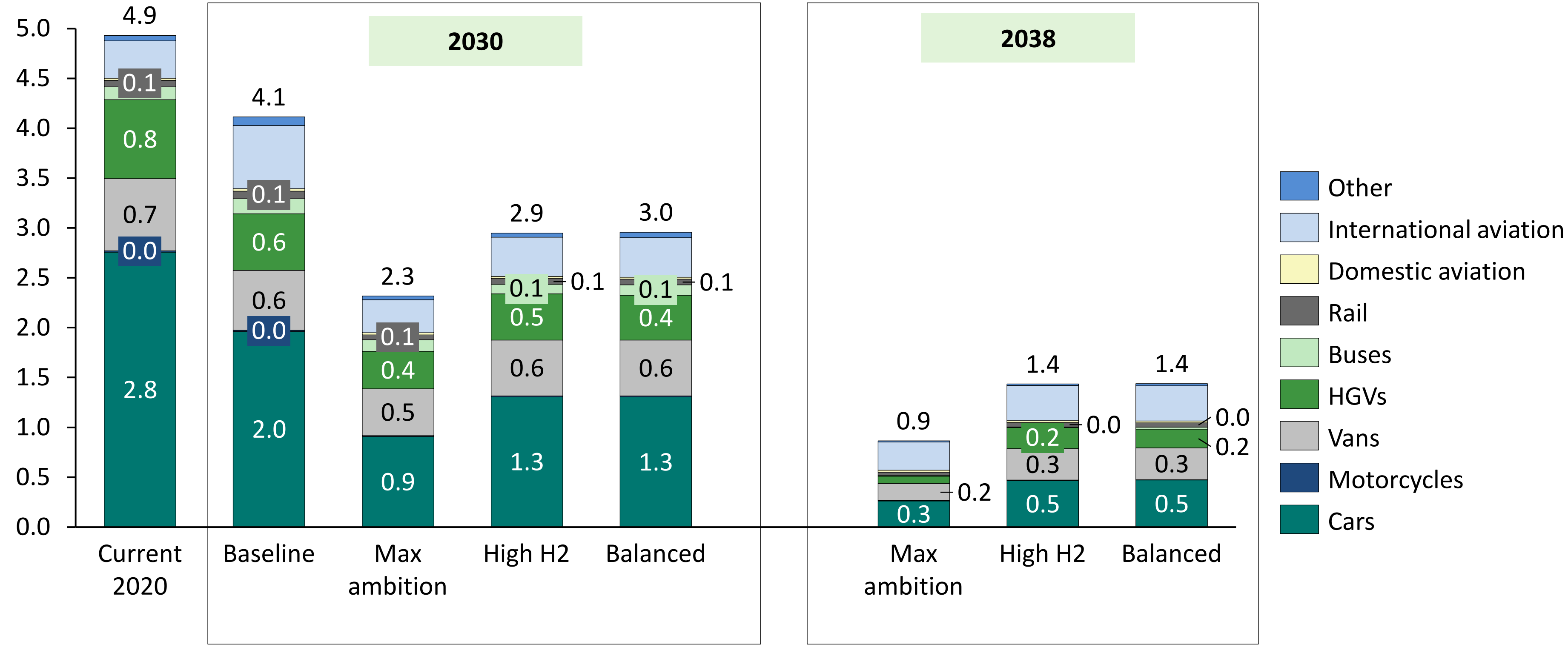




- In this scenario, **conventional petrol and diesel vehicle sales end by 2035 for cars and vans**, but sales of plug-in hybrids continue beyond 2040.
- Sales of diesel buses end in 2031, but sales of hybrid diesel buses are allowed to continue until 2040.
- Biomethane-fuelled vehicles remain an important option for heavy goods vehicles to enable the end of sales of diesel engines; the balance of hydrogen and battery technology leads to higher overall heavy goods vehicle fleet decarbonisation compared to the High hydrogen scenario.
- For West Yorkshire, reaching this level of technology deployment requires:
  - **Sales on the order of 20,000 zero emissions cars per year by 2025** in the region, going up to 40,000 per year by 2038, of which more than 90% are battery electric vehicles
  - **Sales of zero emissions heavy goods vehicles** reach around 1,100 per year in 2038, of which close to 80% will be battery electric vehicles
- For the whole transport sector in 2038, demand of 0.5 TWh of hydrogen and 1.7 TWh of electricity will need to be met through production and refuelling infrastructure

Pathway comparison: All pathways result in remaining emissions by 2038, with the Max ambition scenario achieving highest reductions

Emissions remaining compared with current $MtCO_2e/yr$



- In both 2030 and 2038 there are significant emissions remaining across all transport sectors. To reach net-zero in West Yorkshire by 2038, these would need to be offset by negative emissions in other sectors, or more speculative technologies.
- Cars, vans and heavy goods vehicles still contribute a high share of emissions but, with widespread decarbonisation of road transport, aviation contributes an increasing share (35% of remaining emissions in the High hydrogen and Balanced scenarios)
- The Balanced and High hydrogen scenarios achieve almost the same emissions reduction trajectory, primarily due to employing the same behaviour change trajectories and closing of the gap in emissions differences between hydrogen fuel cell and battery electric vehicles (decarbonizing of hydrogen production and of the national electricity grid).

The Max ambition scenario achieves the greatest decarbonisation but requires the most ambitious supporting policy to achieve

- All three emissions reduction scenarios require ambitious action from West Yorkshire to go beyond current national targets and policy commitments
- The Max ambition scenario delivers the highest emissions reduction (lowest gap to net zero and lowest cumulative emissions) in both 2030 and 2038, but also requires the highest level of behaviour change and greatest level of deployment of low emissions vehicles:
    - Sales of petrol and diesel cars in the region must end by 2030 in Max ambition, compared to 2035 in the High hydrogen and Balanced scenarios – both targets are ahead of current Government ambition (2040) but, if commitments are brought forward to 2035 (currently under consultation), the alignment with national targets would require less action at a local level
    - To reach the required technology deployment, the High hydrogen and Balanced scenarios require fewer zero emission vehicle sales – 40,000 cars per year in 2038 compared to 50,000 per year under Max ambition, and 1,000 zero emission heavy goods vehicles compared to close to 2,000 for the Max ambition scenario
    - Private car use must decrease by 43% by 2030 under Max ambition, compared to 24% under the High hydrogen and Balanced scenarios
    - Accordingly, journey shift to shared, active and public transport occurs faster in the Max ambition scenario, requiring 160 million more walking km, 1 billion more cycling km and 18 million more bus km than in the High hydrogen and Balanced scenarios
    - All scenarios require increases in rail passenger and freight capacity, which will need to be accommodated through expansions of infrastructure and/or service levels. Ambitious levels of electrification will be required to mitigate emissions from rail.
- Reflecting the different technology mixes, the High hydrogen scenario results in the highest demand for hydrogen (1.1 TWh/yr) while the Max ambition has the highest electricity demand (2.5 TWh/yr) by 2038; these energy demands must be met by deployment of appropriate refuelling infrastructure.
- Due to the higher zero emissions technology deployment, the Max ambition scenario has the lowest demand for biomethane for heavy goods vehicles, at 0.4 TWh/yr compared to 0.9 TWh/yr in the Balanced scenario; however, biomethane for transport does not need to be sourced locally under the Renewable Transport Fuel Obligation and therefore does not affect bioenergy considerations in the region.

Agenda

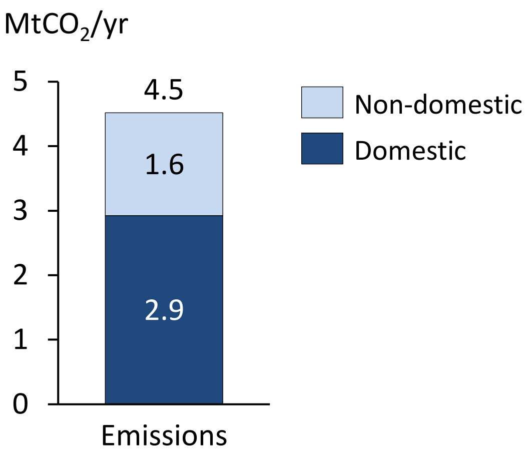
- Introduction
- Key findings
- Sector pathways West Yorkshire
    - Transport
    - Buildings
    - Power
    - Industry
    - LULUCF + agriculture
    - Waste
- Additional information
- Technical Appendix

The current energy and emissions situation in the region - buildings

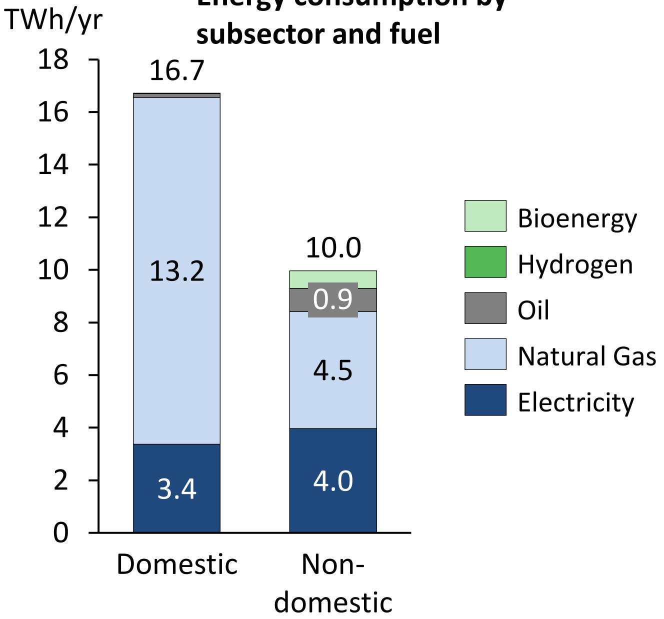
West Yorkshire

- Current emissions from the buildings sector are around 4.5 MtCO2e/yr
- Almost two thirds of the emissions are from domestic buildings
- Non-domestic buildings account for the remainder; this includes energy and emissions from buildings, but not industrial processes that may occur in some of the buildings.
- Natural gas is the most prevalent fuel for heating, with some electricity (and oil) present in off-gas homes. The number of other heating systems (heat pumps, district heating, bioenergy etc) is currently small
- The non-domestic sector uses a greater proportion of electricity due to the higher demands from lighting, cooling and appliances

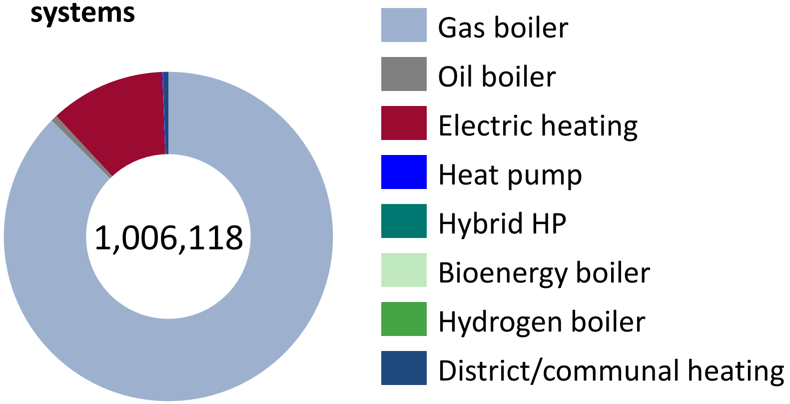
Buildings emissions by subsector



Energy consumption by subsector and fuel



Domestic heating systems



Source: BEIS subnational energy consumption and CO$_2$ emissions datasets; plumplot heating system breakdown & EE modelling
Note that all non-domestic results for the subregions are estimates, as the modelling was completed for the study region

Buildings – West Yorkshire

West Yorkshire building stock characteristics:

- **Most of the homes and businesses (~95%) are connected to the gas network**[1], higher than the national average. This brings strong opportunities for low carbon gas, but also a greater cost challenge against the currently low-cost natural gas heating.
- West Yorkshire has relatively high population density and is more urban than many areas of the UK. There are slightly less detached homes (12% relative to 14% nationally) and more semi & terrace homes (65% relative to 60% nationally) than the national average. This difference is even more pronounced when compared to Y&NY.
- **Higher proportion of very old (pre-1919) homes** (23% relative to 19% nationally); typically these are less well insulated and often more difficult to retrofit.
- The distribution of business unit size and activity is fairly close to the national average, although with slightly lower proportion of activities relating to agriculture and forestry and higher in production.[3]
- **Higher proportion of poor thermal efficiency buildings** - currently 32% of homes are EPC A-C ratings (38% nationally) and 37% of non-domestic buildings (37% nationally)[4], requiring additional ambition around energy efficiency retrofit to maximise number which reach EPC C by 2030.

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1 Off gas statistics LINK 2 Gov NEED LINK 3 ONS UK business workbook LINK 4 Government statistics on energy performance of buildings – LINK

Buildings – emissions types and the key technologies and measures to address them

Buildings sector emissions can be categorized into:

1. **Electricity related emissions,** which will be addressed through decarbonisation in the power sector, supported by installation of efficient technologies to reduce demand. Electricity is used for lighting, appliances, cooling and some heating.
2. **Combustion emissions, from burning fossil fuels for heat.** These are the majority of emissions from buildings and must be addressed primarily by changes within the buildings. Thermal efficiency measures can reduce demand, but low carbon heat technologies must be installed to reach net-zero.

Key low carbon heating technologies are:

- Heat pumps, an efficient form of electric heating. These require reasonably high thermal efficiency standards.
- Hybrid heat pumps, combining a heat pump with a boiler (electric-hydrogen or electric-bioenergy). They reduce peak electricity demand and are feasible with lower thermal efficiency.
- Hydrogen boilers using low carbon hydrogen
- Bioenergy boilers using bioenergy (bio-LPG, biomethane or biomass)
- District/communal heating, with a large low carbon heat source providing heat for multiple buildings / units
- Air-to-air heat pumps, which are reasonably efficient electric and don't require a wet heating system
- Electric resistive/storage heating is a less efficient type of electric heating, but is an option in buildings which are space constrained

Key measures / assumptions:

- **Ambitious energy efficiency** improvements to raise all homes to EPC C or better where possible and cost-effective (Clean Growth Strategy), targeting 25%-35% heat demand reduction in existing buildings by the early 2030s.
- **New buildings** from early-mid 2020s to install low carbon system (heat pump or low carbon DH) and implement high efficiency **District heating in heat dense areas** (above ~30 kWh/m^2, national max potential 19% homes and 45% non-residential[1]), including many flats and commercial buildings (e.g. areas of Leeds). 5-6 years from inception to operation.
- **Off-gas grid buildings** to be supplied by heat pumps, hybrid HP and/or bio-boilers
- **Non-residential buildings** assumed suitable for energy efficiency + either heat pumps or heat networks[1]
- **Hydrogen:** in the High H2 scenario, the gas grid is assumed to be converted to hydrogen from 2028. In the Balanced scenario, some areas are converted in the early 2030s. The Max ambition scenario has no hydrogen in the gas grid.

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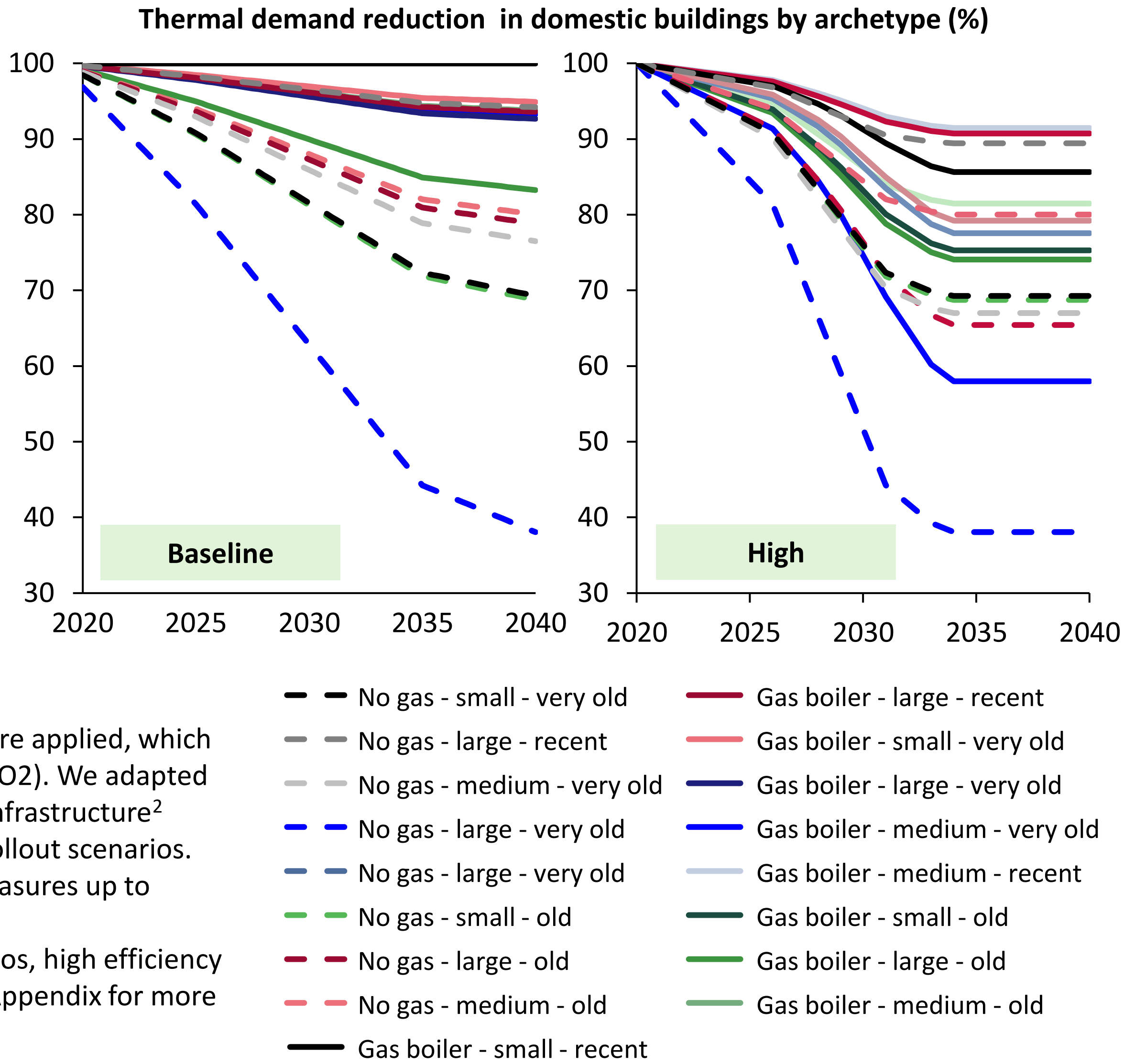
[1] CCC Net-zero technical report

Underpinning measures: Domestic thermal efficiency level is applied according to home archetype

- Domestic energy efficiency measures, such as draft proofing, wall, loft and floor insulation and double/triple glazing, are crucial to reduce energy demand and enable low carbon technology installation.
- This study applies different energy efficiency trajectories to different parts of the domestic stock[1], as home archetype has a large impact on the cost-effective potential of measures. Trajectories are the same for these archetypes in each subregion (but stock differs).
- It should be noted that the work around energy efficiency is necessarily high level due to the extremely broad nature of this study; we have not looked at the individual measures with respect to their deployment levels.


Thermal demand reduction in domestic buildings by archetype (%)

- For the baseline (low), low cost measures are applied, which are cost effective in their own right (<0£/tCO2). We adapted our recent work for the CCC and National Infrastructure[2] Commission to develop energy efficiency rollout scenarios.
- The medium efficiency scenario applies measures up to £150/tCO$_2$ applied (High H2 scenario)
- For the Max ambition and Balanced scenarios, high efficiency is applied, all measures <£400/tCO$_2$ – see Appendix for more detail.

[1] Very old pre-1919; Old 1919-1982; recent since 1982

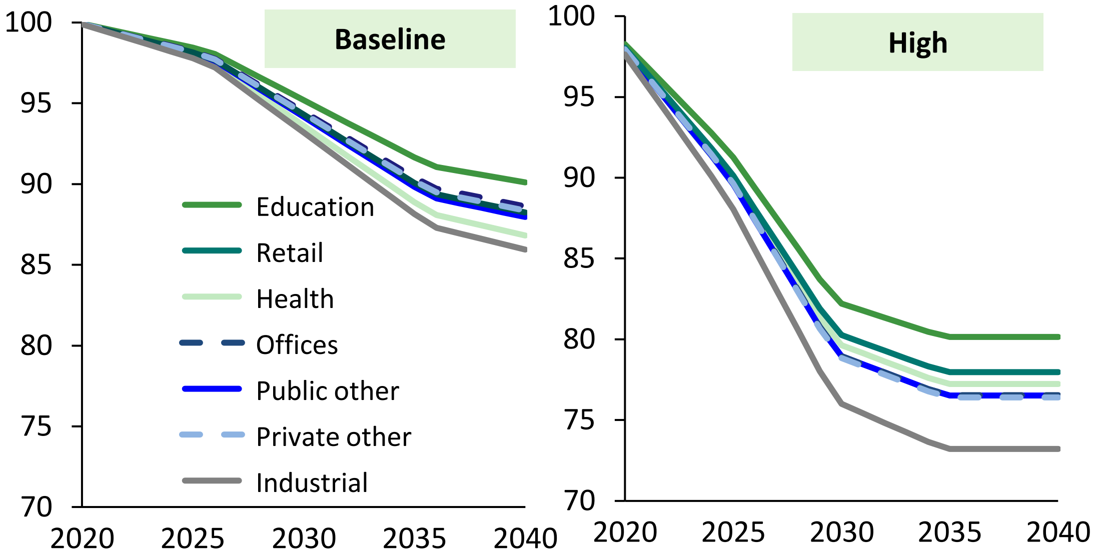
[2] https://www.nic.org.uk/wp-content/uploads/Element-Energy-and-E4techCost-analysis-of-future-heat-infrastructure-Final.pdf ; https://www.theccc.org.uk/publication/analysis-on-abating-direct-emissions-from-hard-to-decarbonise-homes-element-energy-ucl

Underpinning measures: Non-domestic thermal efficiency implementation reduces heat demand considerably

Study region

- For non-domestic energy efficiency measures, we consider ‘Building fabric’ measures (similar to domestic) and ‘Building instrumentation and control’[1].
- This study applies different energy efficiency trajectories to different subsectors of the non-domestic stock, as subsector has an impact on the cost-effective potential of measures. Trajectories are the same for these subsectors in each subregion (but stock differs).
- It should be noted that the work around energy efficiency is necessarily high level due to the extremely broad nature of this study; we have not looked at the individual measures with respect to their deployment levels.

Thermal demand reduction in non-domestic buildings by sector (%)



- The underlying data for thermal energy efficiency in the non-domestic (I&C industrial and commercial buildings) stock is based on data from BEIS’s Building Energy Efficiency Survey (2015 BEES). From this data, we have been able to estimate the savings potential and cost-effectiveness of the measures, as with the domestic stock (in £/tCO2 abated). The cost bands are the same as in the domestic scenarios.
- In the I&C sector, all thermal efficiency measures fall in the ‘low’ and ‘medium’ cost bands i.e. less than £150/tCO_2 abated. The high scenario differentiates itself from the medium scenario by achieving the same abatement potential in a shorter amount of time.
  - For the baseline (low), low cost measures are applied, which are cost effective in their own right.
  - The medium efficiency scenario applies measures up to £150/tCO_2 applied (High H2 scenario)
  - For the Max ambition and Balanced scenarios, high efficiency is applied, all measures <£400/tCO_2

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[1] More information can be found in BEES data https://www.gov.uk/government/publications/building-energy-efficiency-survey-bees
https://www.nic.org.uk/wp-content/uploads/Element-Energy-and-E4techCost-analysis-of-future-heat-infrastructure-Final.pdf ;
Details for non-heat efficiency (significantly lower impact), can be found in the Appendix.

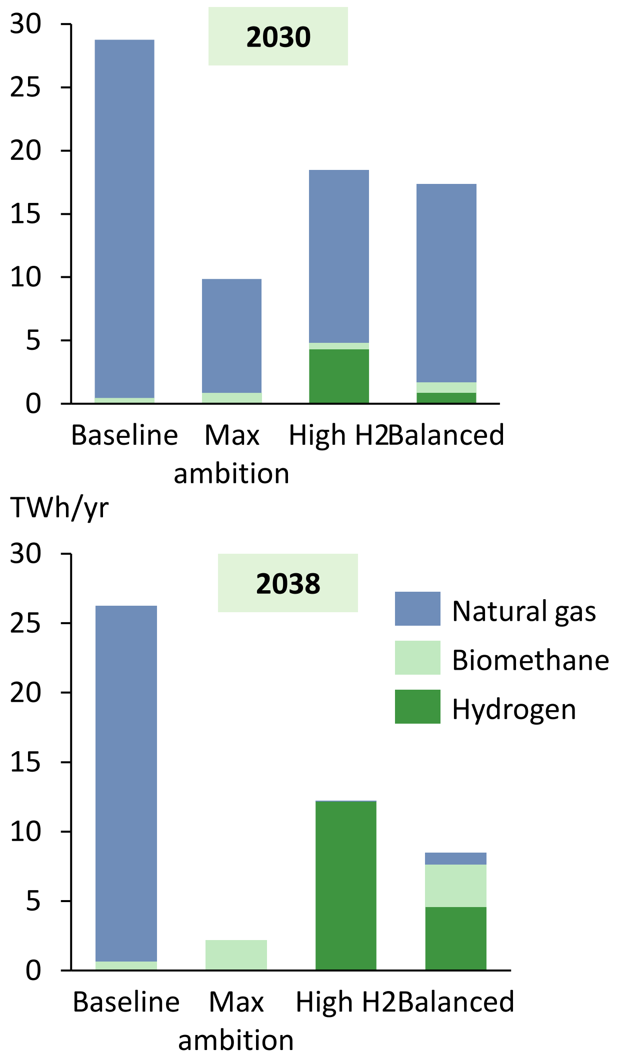
Underpinning measures – the gas grid sees rapid changes in the 2030s, with demand decreasing and greening

Study region

Note that this slide refers to the study region, as the gas grid modelling was non-spatial. The same gas grid composition (natural gas, biomethane, hydrogen) was assumed for all subregions.

- The current natural gas grid will see dramatic changes if net-zero targets are to be met.
- In the Max ambition scenario, most heat and transport are electrified, leaving minimal gas demand by 2038.
- In the High hydrogen scenario, the gas grid is fully converted to hydrogen in 2028-2035, supplying buildings and industry with low carbon hydrogen.
- The Balanced scenario sees some areas of the gas grid converted to hydrogen, some remain a natural gas/biomethane blend and gas demand reduction through electrification.
- The maximum biomethane availability is taken from the NGN pathways work[1], reaching 8.6 TWh/yr in the full NGN network in 2040, scaled to the study region giving 3.6 TWh/yr. This biomethane is used for grid blending.
- Hydrogen is used for blending to a maximum of 20% by volume[2] (~6% by energy), which is thought to be the maximum limit for existing equipment without modification.
- Bioenergy is also used as BioCNG in transport and bio-LPG in off gas grid Hybrid heat pumps, both in relatively small quantities (see technical Appendix for full breakdown).

Gas grid composition TWh/yr

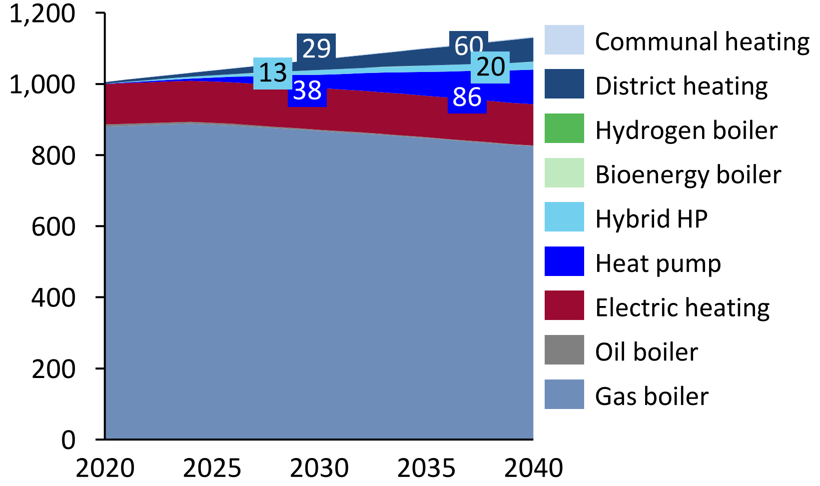


1: Information provided by NGN, based on the ENA Navigant pathways LINK

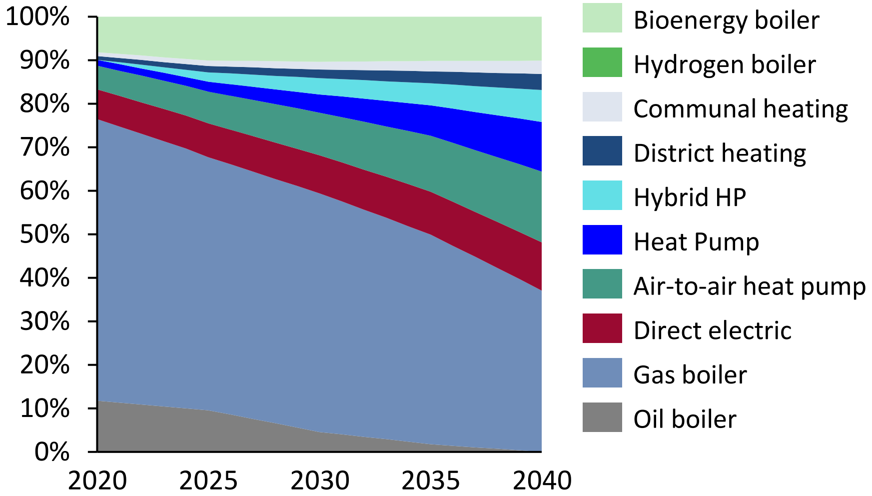
2 The earliest H2 is blended is 2026 in the High H2 scenario. In the Balances scenario it reaches 6% vol by 2032

Buildings – baseline – installation of low carbon heating systems sees slow progress, mostly in the non-domestic sector

Number of heating systems in homes ('000)[1]



Heat supply to non-domestic buildings (% heat)[2]



- **Growth:** It is assumed the number of existing homes remains constant, and the new build rate is determined by the Local Plans for each local authority; 1 million existing homes and 125k new homes by 2038 (11% new). In the non-domestic sector, greater demolition and growth rates see 31% new build by 2038. All scenarios follow this growth rate.
- Heat pumps installations continue at a slow rate, increasing only a little from current rates under the RHI (varying from the same rate to 4x the current rate depending on building archetype).
- District & communal heating increases to 6% buildings by 2038 under current government support schemes
- The non-domestic sector exhibits a more diverse heating mix, with a greater proportion of warm air heating systems. The non-domestic sector sees more progress due to the higher frequency of retrofit and new build. Use of oil, limited in West Yorkshire, drops to zero due to the high emissions and costs.
- New buildings have considerably lower emissions due to high energy efficiency standards and from 2025 installation of only low carbon heating technologies (electric heating, heat pumps and district heating).

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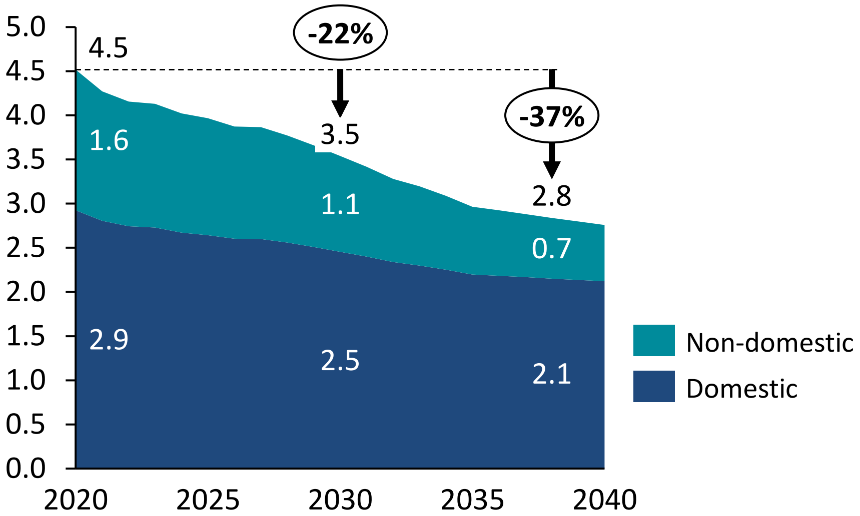
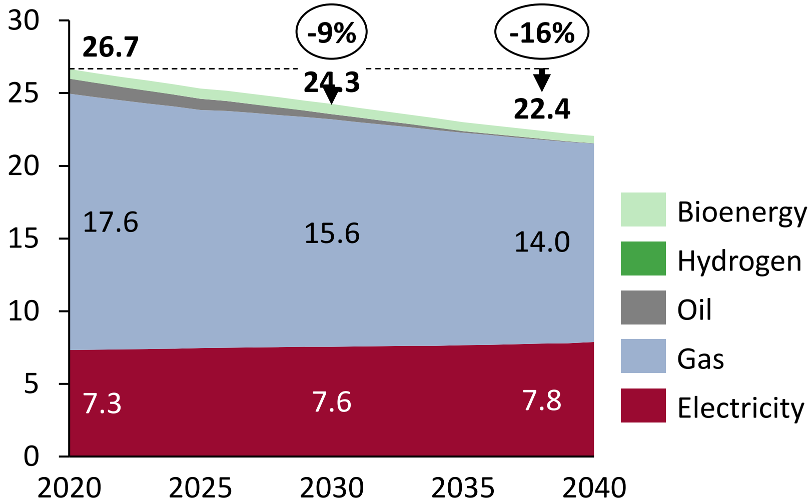
1 Numbers on the chart represent the number of select technologies in 2030 and 2038; 2 The non-domestic building modelling was completed at study region level in GWh, as the source data is in GWh, not number of buildings. The subregion breakdown is an estimate only. 3: Domestic - Element Energy study for Bristol heat LINK non-domestic growth rates following regional subsector growth provided by LCR

Buildings – baseline scenario – energy consumption and emissions both see a steady decrease, but limited progress in heat supply

Emissions from buildings MtCO2e/yr[1]



Fuel demand in buildings TWh/yr

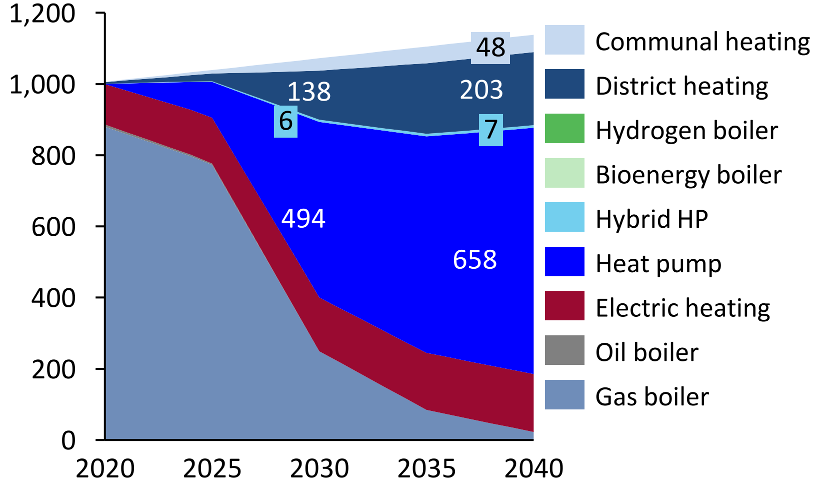


- **Total buildings emissions decrease by around 37% in the baseline scenario, reaching 2.8 MtCO2e/yr by 2038.** The main contribution is decarbonisation of the national electricity grid. Other supporting measures are energy efficiency measures, some non-domestic demolition and a slow uptake of low carbon heat, including district heating.
- **Fuel consumption reduces by 16% by 2038** due primarily to efficiency measures. It remains predominantly natural gas and electricity, with only slow uptake of further electric heating forms and phase out of oil.
- **Solar PV** (building scale): Domestic solar PV installations increase from 30k to 49k by 2038, following NPg 'Steady Progression". Non-domestic solar PV increases at half the rate it did under the Feed In Tarif subsidy (FiT) over the passed 9 years, reaching 63 GWh/yr by 2038. Installations make a small contribution to offsetting electricity emissions in buildings (~4% electricity consumed).
- **Non-heat energy:** The majority is supplied through electricity (~77% non-domestic and almost 100% domestic), for example cooling, ventilation, computing, lighting, appliances and some catering. All applications which currently use electricity remain on electricity (as this will decarbonise). It is assumed that there is an increase of 20% in non-domestic cooling demand[4].
- **The contribution of new buildings to emissions is small** (~4% by 2038), due to higher building standards (inc. potential Future Homes Standard[3]) and greater uptake of low carbon heating (>80% of new build by 2038).

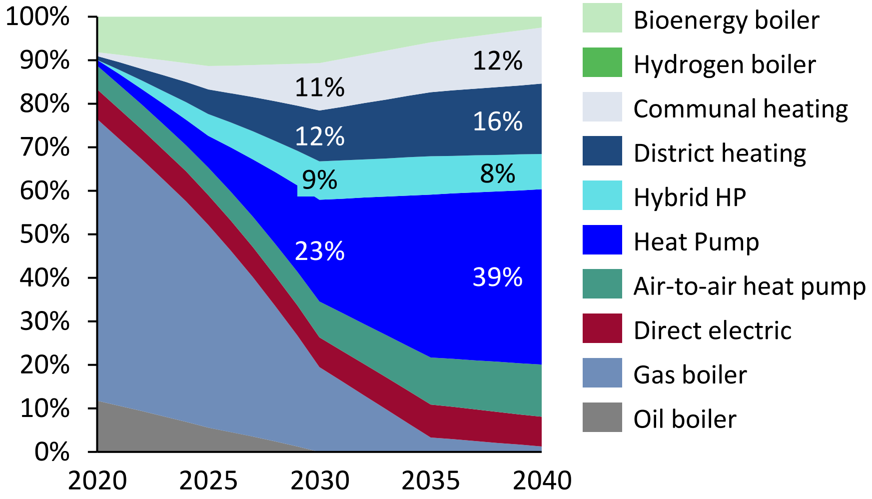
1 - National electricity carbon intensity used 2 - Clean Growth Strategy LINK; 3 - Future Homes Standard LINK 4 – London's Climate action Plan; non-heat energy demand does not fluctuate much

Buildings – Max ambition - to make significant progress in the 2020s, heat pumps are deployed at an unprecedented scale

Number of heating systems in homes ('000)[1]



Heat supply to non-domestic buildings (% heat)[2]



- **The Max ambition scenario focusses on highly ambitious heat pump installation, reaching 500k domestic heat pumps by 2030 and 665k by 2038**. By 2038 heat pumps[3] also serve 47% of non-domestic heat.
- **Hydrogen conversion of the gas grid is not assumed** in this scenario due to the uncertainty and timeframes, so no hydrogen is used for heat in buildings (only large industrial sites). This also limits the roll-out of hybrid heat pumps to a reasonably small proportion, as the supplementary boiler is hydrogen (not readily available) or bioenergy.
- **Oil heating is rapidly phased out** in off-gas buildings (primarily replaced by heat pumps & hybrids) in all scenarios.
- **District & communal heating increases to 250k homes and 28% non-domestic buildings** by 2038. These heat systems are primarily in heat dense / urban areas or multi-building complexes.
- The significant amount of bioenergy used currently is reduced during the 2030s to improve air quality and conserve supply. It may still be used in hybrid heat pumps off the gas grid (e.g. hybrid electricity-bioLPG)
- **Direct electric heating is deployed in buildings which are not suitable for heat pumps**, for example those with space or efficiency constraints. Air-to-air heat pumps are deployed in the non-domestic sector where dry heating systems are required.

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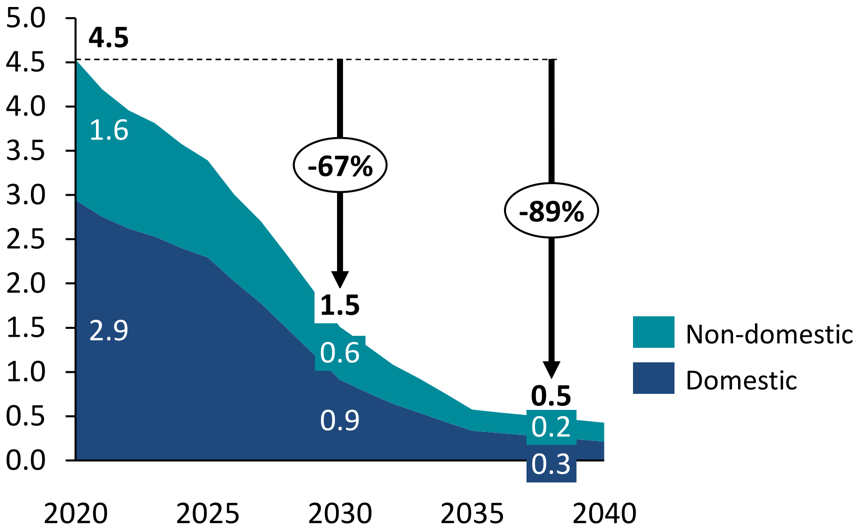
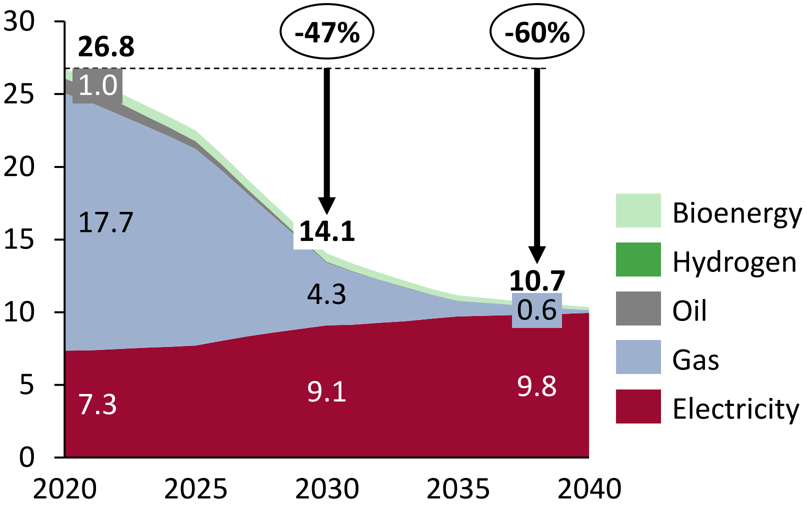
1 Numbers on the chart represent the number of select technologies in 2030 and 2038; 2 The non-domestic building modelling was completed at study region level in GWh, as the source data is in GWh, not number of buildings. The subregion breakdown is an estimate only.
3 heat pumps referring to air-to-water and hybrid air-to-water (not air-to-air)

Buildings – the Max ambition scenario sees rapid emissions reductions due to almost complete electrification

Emissions from buildings MtCO2e/yr[1]



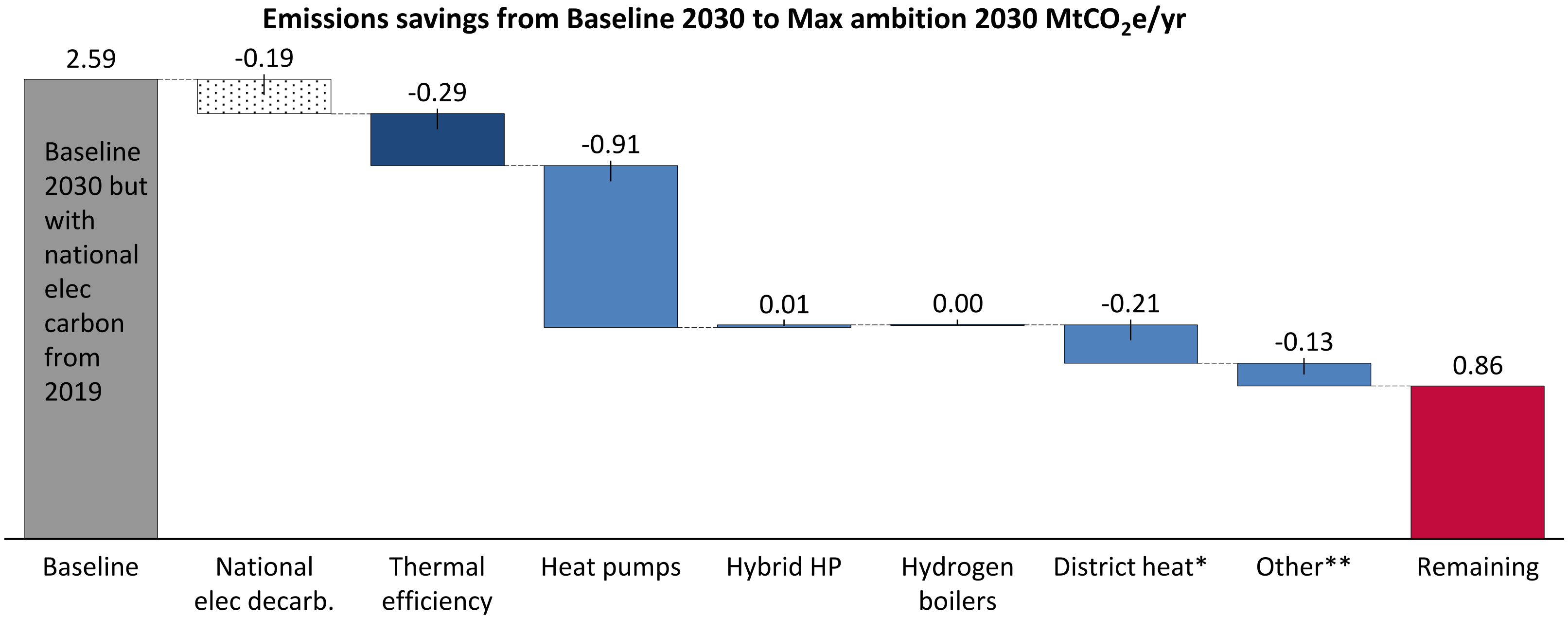
Fuel demand in buildings TWh/yr



- **Total buildings emissions decrease by 67% by 2030 and 89% by 2038, reaching 0.5 $MtCO_2e$/yr.** The main contribution is ambitious deployment of heat pumps, supported by high efficiency measures (required for heat pump installation) and decarbonisation of the national electricity grid.
- **Fuel consumption reduces by 60% by 2038** due to energy efficiency measures and the increased efficiency of heat pumps relative to counterfactual fossil boilers (a gas boiler is ~90% efficient, whereas a heat pump can be over 300% efficient). Oil is phased out by 2030 in all scenarios[2]. By 2038, fuel consumption is almost entirely electricity, and the annual electricity demand has increased by 34%, with implications for electricity generation and distribution infrastructure.
- **Solar PV** (building scale): Domestic solar PV installations increase to 171k by 2038, following NPg 'Community renewables" for all 3 scenarios. Non-domestic solar PV increases at the rate it did under the Feed In Tarif subsidy (FiT) over the passed 9 years, reaching 95 GWh/yr by 2038. Installations make a contribution to offsetting electricity emissions in buildings (~6-9% electricity consumed[4]).
- **Non-heat energy** (appliances, catering etc) switches almost exclusively to electricity, with a small amount of bioenergy.

1 - National electricity carbon intensity used 2 - Clean Growth Strategy LINK; 3 - Future Homes Standard LINK 4 Solar PV installation is the same across the 3 emissions reduction scenarios, but the electricity consumption varies

Contribution of different measures: the largest contribution to the Max ambition scenario by 2030 is heat pump deployment



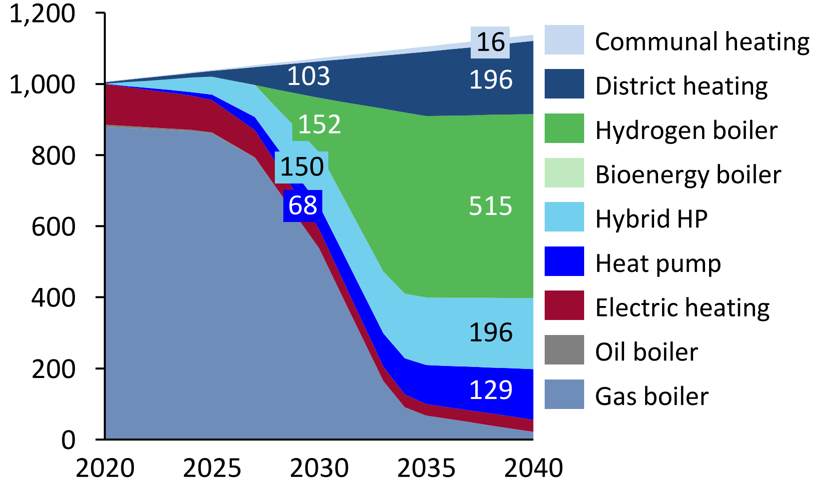
- Waterfall charts are used to give 2 illustrations of the contribution of different measures to emissions reductions in domestic buildings. We examine the Max ambition scenario in 2030 (shown here) and the High H2 scenario in 2038 (later).
- This graph compares the Baseline and Max ambition, **both in 2030**, to show the additional contribution of measures over the baseline [The grey baseline bar includes electricity at the 2019 carbon intensity, and the next bar then reduces this to the 2030 carbon intensity]
- **The greatest emissions saving is from heat pumps, which combined save 0.91 MtCO2e/yr**. These savings will increase as heat pumps continue to be installed after 2030 and as the electricity grid decarbonises further.
- **Thermal efficiency also has large savings over baseline**, especially considering the baseline pathway already includes significant savings from efficiency measures (at a lower level).

These are estimates only, due to the overlap of many measures in contributing to the reductions in each building. It is important when using these figures to be clear on what comparison you are making (e.g. is this the absolute savings, or relative to Baseline etc).

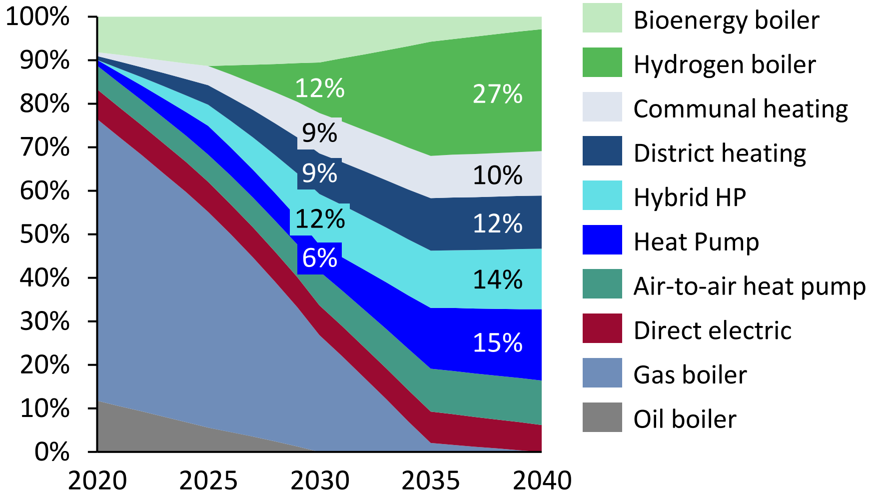
*District heating includes communal heating, which may be a single building (e.g. flats) or site ** Other includes Solar PV, lighting and appliance efficiency, biomass boilers and electric heating. Hybrid HP CO2 change is positive as there are less hybrids in Max ambition than baseline (in Max ambition most heat pumps are full heat pumps)

Buildings – the High H2 scenario sees switchover from natural gas to hydrogen boilers, as well as heat pump installation

Number of heating systems in homes ('000)[1]



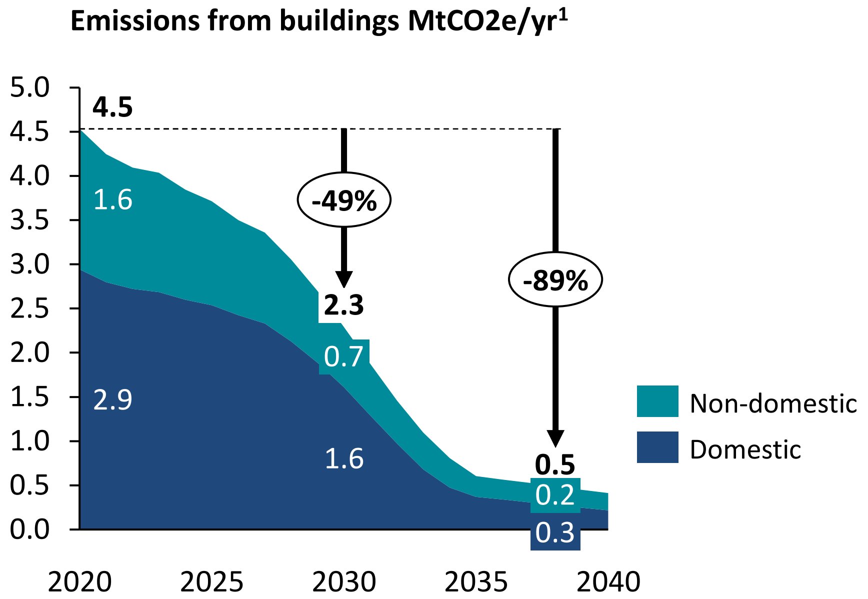
Heat supply to non-domestic buildings (% heat)[2]

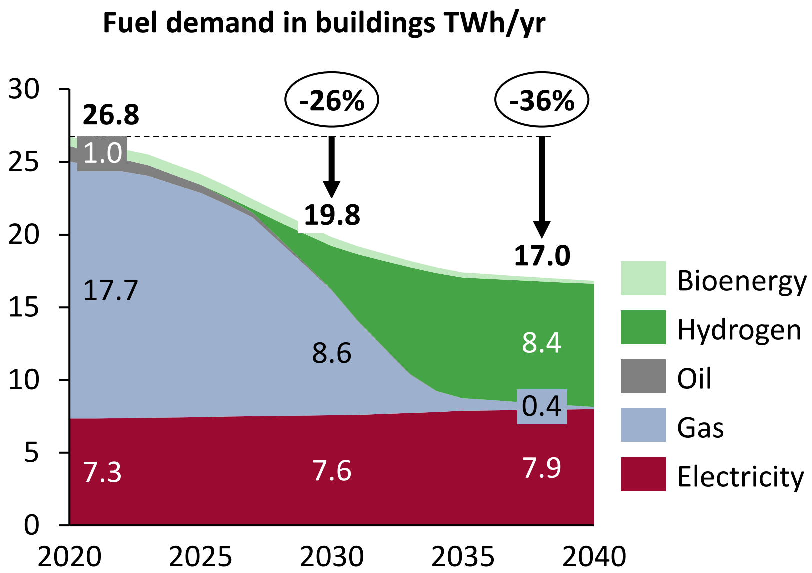


- **The High H2 scenario is driven by the use of hydrogen for heat, including 515k hydrogen boilers in homes and 27% non-domestic heat** supplied by hydrogen boilers by 2038. It relies on conversion of the natural gas grid to hydrogen from 2028. The early 2020s require completion of all safety testing, equipment development, planning and engineering design.
- Hydrogen also enables significant use of hybrid heat pumps (electric-hydrogen) in domestic and non-domestic sectors. Hybrid heat pumps can be rolled out during the 2020s, as they don't require high efficiency standards and can be later converted to hydrogen.
- **District & communal heating increases to 212k homes and 22% non-domestic buildings** by 2038 in heat dense areas. The energy supply utilizes hydrogen fuel as well as electricity.
- The significant amount of bioenergy used currently is reduced during the 2030s to improve air quality and conserve supply. It may still be used in hybrid heat pumps off the gas grid (e.g. hybrid electricity-bioLPG)
- **Direct electric heating is deployed in buildings which are not suitable for heat pumps**, however the quantity required is lower due to the availability of hydrogen in homes on the gas grid.

1 Numbers on the chart represent the number of select technologies in 2030 and 2038; 2 The non-domestic building modelling was completed at study region level in GWh, as the source data is in GWh, not number of buildings. The subregion breakdown is an estimate only.

Buildings – the High H2 scenario utilises hydrogen and electricity to reach 89% emissions reduction

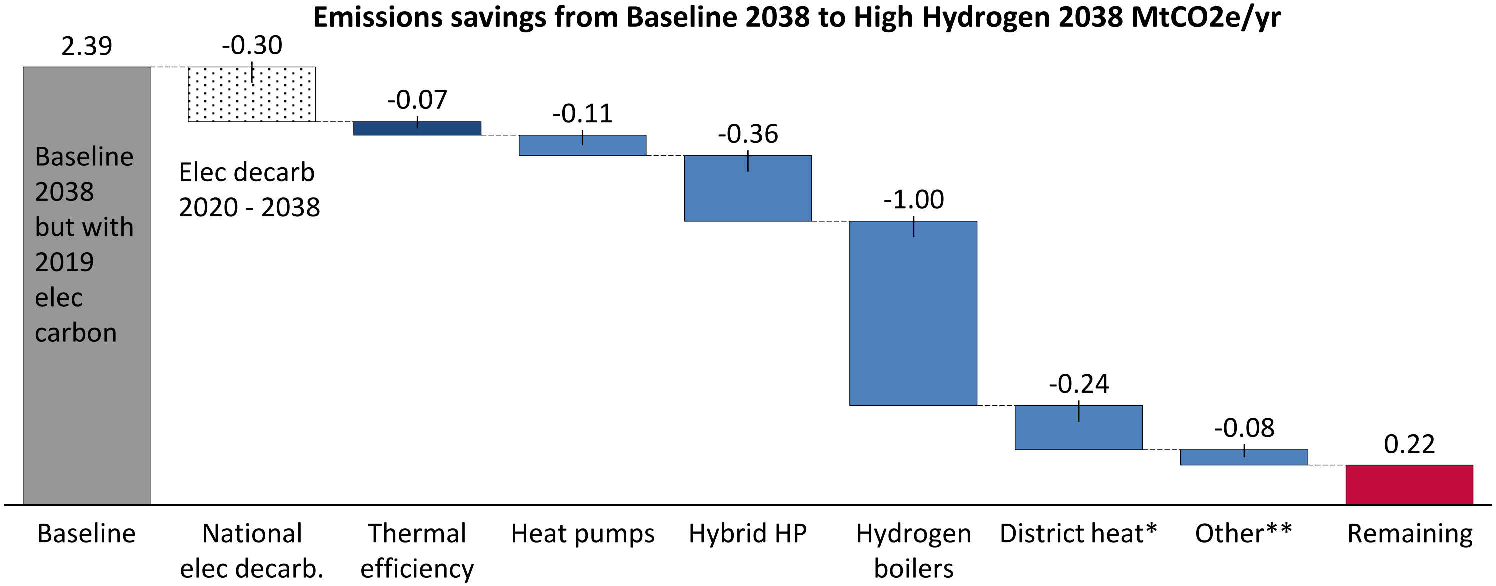




- **Total buildings emissions decrease by 49% by 2030 and 89% 2038, reaching 0.5 MtCO$_2$e/yr.** The main contribution is conversion of the natural gas grid to hydrogen, enabling hydrogen boilers and hybrid heat pumps. The emissions decrease is steady before 2028, then rapidly drops 2028-2035; hydrogen is predominantly supplied through gas reforming with CCS, which has a very low carbon intensity[2], lower than that of national electricity in the 2030s.
- **Fuel consumption reduces by 36% by 2038**; the 2038 fuel demand is higher than the Max ambition scenario as hydrogen boilers are less efficient than heat pumps and lower energy efficiency is required in buildings with gas boilers. By 2038, fuel consumption is around 50% hydrogen and the remainder is mostly electricity. Annual electricity demand has increased by only 8%, reducing the impact on electricity infrastructure over the Max ambition scenario.
- **Non-heat energy** (appliances, catering etc) is currently mostly electricity. Other fuels switch to electricity or hydrogen depending on the application; hydrogen has already been proven in some catering applications.
- Buildings scale solar PV, as in other scenarios, reaches 171k domestic installations and 95 GWh/yr non-domestic generation by 2038.

1 - National electricity carbon intensity used 2 See technical Appendix for H2 production assumptions 2 - Clean Growth Strategy LINK; 3 - Future Homes Standard LINK

Contribution of different measures: the largest contribution to the High H2 scenario by 2038 is hydrogen boilers



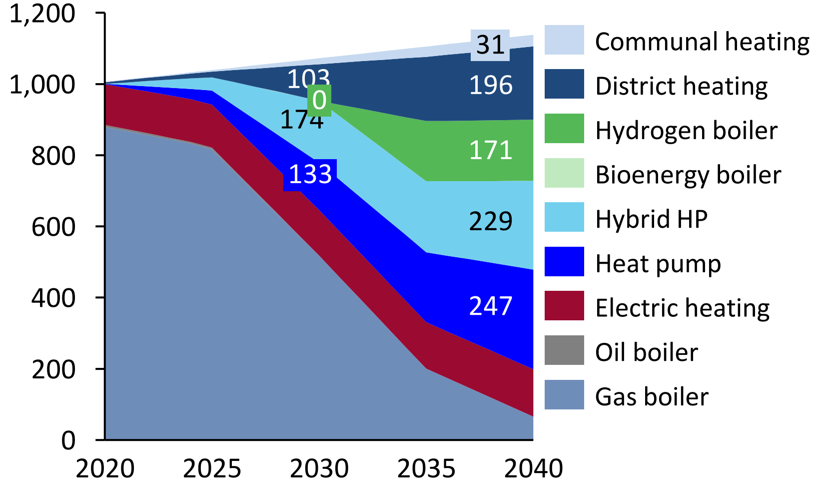
- This chart compares the domestic emissions in the Baseline and High Hydrogen scenarios, both in 2038, to show the additional contribution of measures over the baseline [The grey baseline bar includes electricity at the 2019 carbon intensity]
- **The greatest emissions saving is from hydrogen boilers, which save 1.0 MtCO2e/yr**. The contribution of hydrogen boilers is significantly greater than that of heat pumps for 3 reasons: there are more hydrogen boilers; the hydrogen has lower carbon intensity than electricity; and there are no hydrogen boilers in the baseline scenario (whereas there are some heat pumps).
- Hybrid heat pumps also make a significant contribution of 0.36 MtCO2e/yr.
- **Thermal efficiency has a smaller emissions saving** than in Max ambition (2030) for 2 reasons: the High H2 scenario has thermal efficiency applied to a lesser extent; by 2038 the baseline scenario has slightly 'caught up' in energy efficiency since 2030.
- National electricity decarbonisation has made greater emissions savings by 2038 than by 2030.

These are estimates only, due to the overlap of many measures in contributing to the reductions in each building. It is important when using these figures to be clear on what comparison you are making (e.g. is this the absolute savings, or relative to Baseline etc).

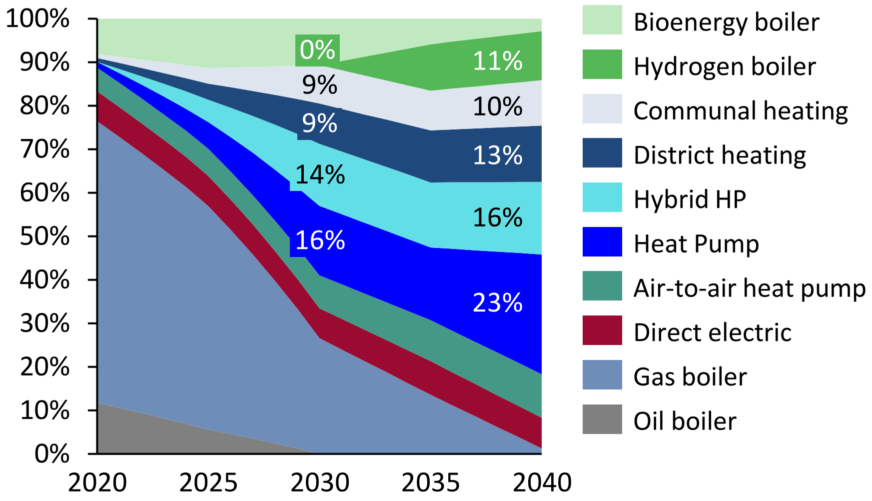
*District heating includes communal heating, which may be a single building (e.g. flats) or site
** Other includes Solar PV, lighting and appliance efficiency, biomass boilers and electric heating

Buildings – the Balanced scenarios sees a wide range of heat technologies deployed

Number of heating systems in homes ('000)[1]



Heat supply to non-domestic buildings (% heat)[2]



- **The Balanced scenario sees installation of multiple different heating systems, using both electricity and hydrogen.** Hydrogen becomes available from 2030, as areas of the gas grid are converted.
- **By 2038, there are around 475k heat pumps and 170k hydrogen boilers in domestic homes.** Many of the hybrid heat pumps will use hydrogen as their supplementary fuel, although those off-gas will use bioenergy.
- The non-domestic sector sees 11% heat supplied by hydrogen, 16% by hybrid heat pumps (using hydrogen) and 23% through full heat pumps by 2038.
- **The Balanced scenario offers a greater range of technology options** for some buildings and is likely to result in a more resilient energy system. However, effort is split across many areas and more infrastructure investment may be needed.
- **District & communal heating increases to 227k homes and 23% non-domestic buildings** by 2038 in heat dense areas. The energy supply utilizes primarily heat pumps, but some hydrogen boilers for peaking (times of high demand, certain areas).
- Direct electric heating is deployed in buildings which are not suitable for heat pumps; the number of buildings assumed is between that of the Max ambition and High H2 scenarios

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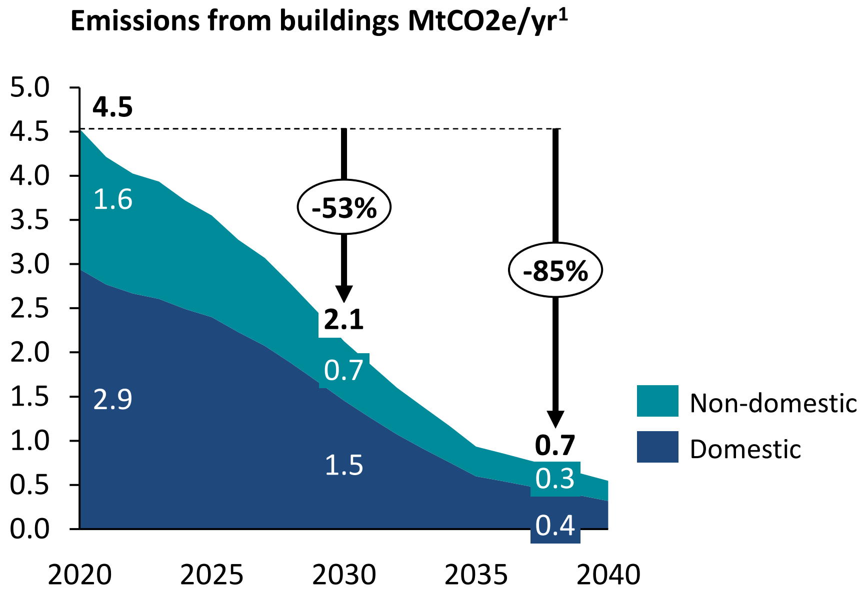
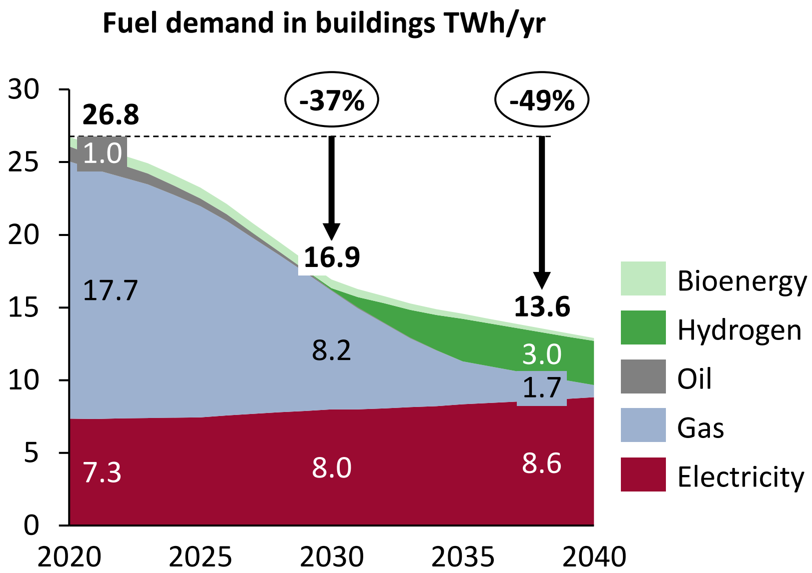
1 Numbers on the chart represent the number of select technologies in 2030 and 2038; 2 The non-domestic building modelling was completed at study region level in GWh, as the source data is in GWh, not number of buildings. The subregion breakdown is an estimate only.

Buildings – the Balanced scenario sees significant electrification and reduces emissions by 84% by 2038



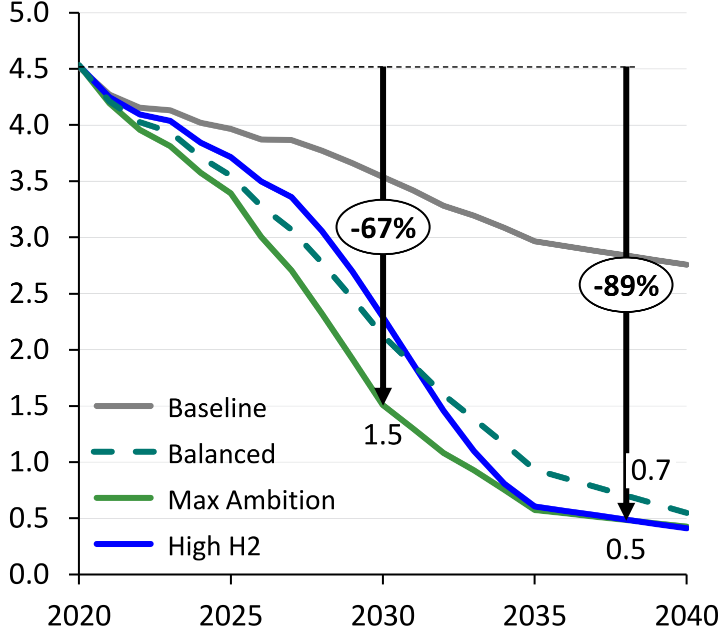


- **Total buildings emissions decrease by 53% by 2030 and 85% 2038, reaching 0.7 MtCO$_2$e/yr.** There are contributions from both conversion of areas of the gas grid to hydrogen and high installation rates of heat pumps from 2025. Supporting measures are high levels of energy efficiency (both thermal and electrical) and decarbonisation of the national electricity grid.
- **Fuel consumption reduces by 49% by 2038, which is intermediate between the reductions seen in the other scenarios.** Again, the reductions are due to both building level efficiency measures and improved heating system efficiency. By 2038, fuel consumption is mostly electricity, which some hydrogen and remaining use of the gas grid; the gas grid carbon intensity has reduced significantly due to biomethane blending. Annual electricity demand has increased by 17% by 2038.
- **Non-heat energy** (appliances, catering etc) not already electricity switch fuel, primarily to electricity, but a small amount of hydrogen and bioenergy is used depending on the application.
- Buildings scale solar PV: 171k domestic installations and 95 GWh/yr non-domestic generation by 2038.
- The Balanced scenario has slightly higher 2038 emissions due to some remaining natural gas use.

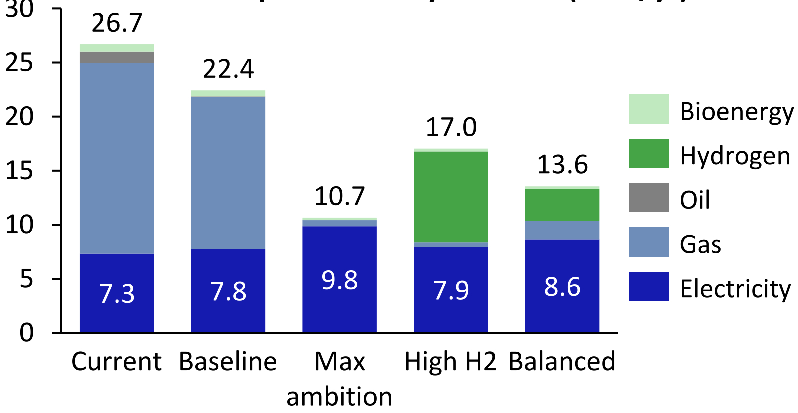
1 - National electricity carbon intensity used 2 See technical Appendix for H2 production assumptions 2 - Clean Growth Strategy LINK; 3 - Future Homes Standard LINK

Buildings scenario comparison – the extent of electrification vs hydrogen conversion is the main difference

Emissions from buildings MtCO2e/yr[1]



Fuel consumption 2038 by scenario (TWh/yr)



- **The Max ambition scenario is focused on rapid and extensive deployment of heat pumps,** supported by ambitious energy efficiency improvements. It reaches 67% emissions reduction by 2030 and 89% by 2038. There is no hydrogen for heat, so homes which are not in heat network areas and are not suitable for heat pumps use electric storage heating. Fuel consumption is almost entirely electricity by 2038.
    - Key infrastructure requirements sit in the electricity grid and generation assets, and this is the key risk to the rate of change
- **The High hydrogen scenario relies on conversion of the natural gas grid to hydrogen** to enable hydrogen boilers and hybrid heat pumps. Emissions reductions are slow before hydrogen becomes available from 2028 but accelerate to reach 89% emissions reduction by 2038. A greater amount of fuel is required to heat homes than in other scenarios, but lower electricity consumption means lower electricity infrastructure upgrades.
    - Gas grid conversion to hydrogen, and the retrofit / replacement of gas boilers is a large infrastructure and coordination challenge in a relatively short period; electricity demand is low.
- **The Balanced scenario represents a technology mix**, with hydrogen boilers in areas of gas grid conversion, significant heat pumps and hybrids and some remaining gas boilers using a blend of natural gas and biomethane. Direct electric storage heating plays a role, primarily in space constrained homes. Emissions reach 0.7$MtCO_2e$/yr by 2038 and fuel consumption is primarily electricity, supplemented by other fuels.
    - The mix of infrastructure required, from electricity and hydrogen to district heating, creates a challenge but also likely a more resilient energy system.

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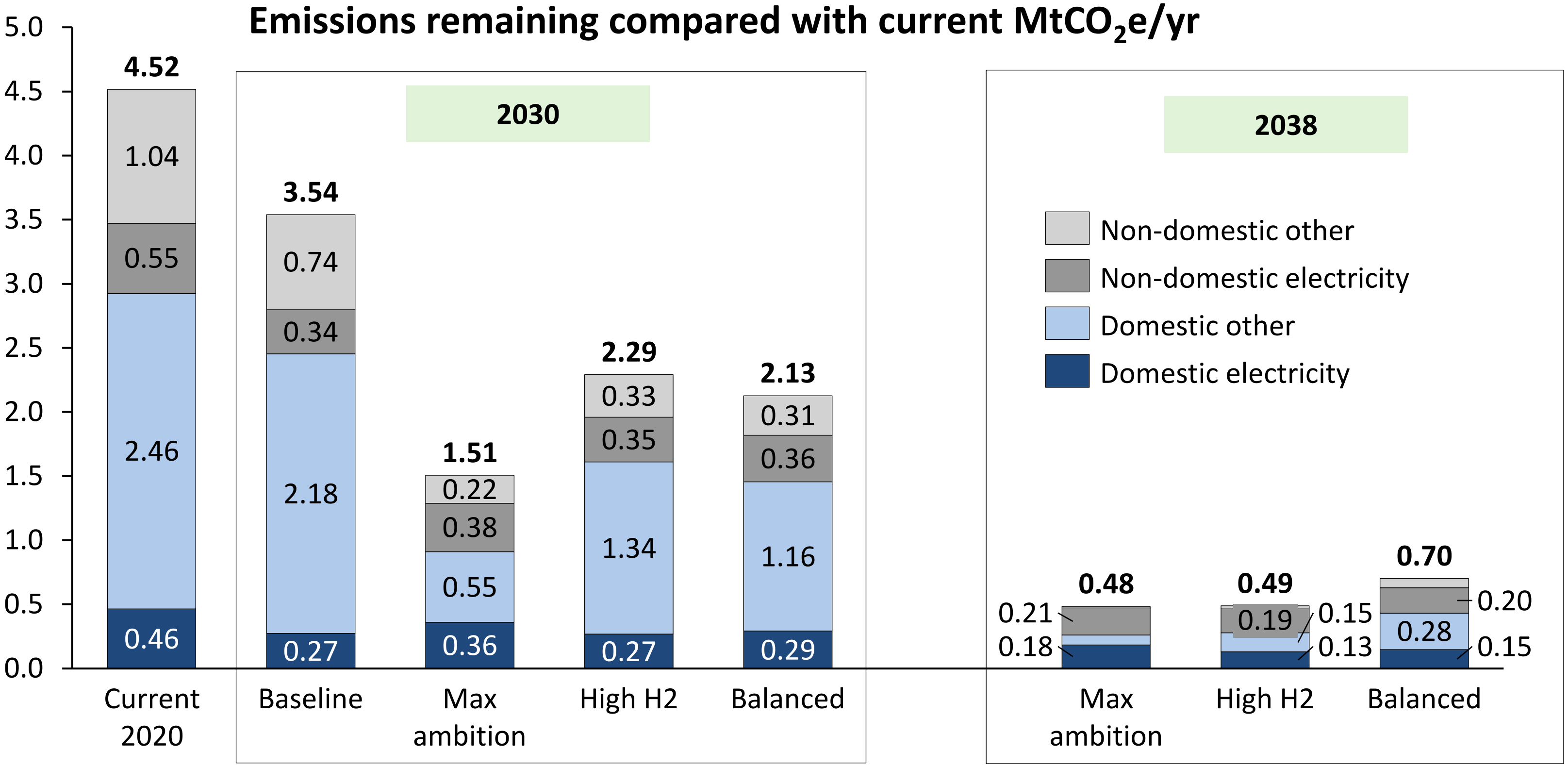
[1] National electricity carbon intensity (HMT Green Book) is used in all scenarios

Remaining emissions in 2038 are primarily electricity-related



- **In 2030, all scenarios see significant emissions remaining,** although the Max ambition scenario has made the most progress on combustion emissions through heat pumps and thermal efficiency.
- **In 2038, the majority of remaining emissions are from electricity use** at non-zero carbon intensity (for both heat and non-heat applications), but some combustion emissions remain.
  - Electricity-related emissions are highest in the Max ambition scenario, with barely any other fuels used
  - the High H2 scenario also sees a small amount of emissions from hydrogen generation[1]
  - the Balanced scenario has the highest 2038 emissions, from electricity, residual natural gas usage and hydrogen

Electricity related emissions could be ‘offset’ through further renewable electricity generation in the region

Please note that assumptions and modelling were done for the study region, so subregion level results are indicative

[1] From hydrogen generation, rather than combustion

Buildings – key messages

- **The buildings sector emissions reduce by 67% by 2030 and 89% by 2038 in the Max ambition scenario, leaving just 0.5 $MtCO_2e$/yr.** This could be reduced further through regional renewable electricity to ‘offset’ electricity related emissions[1].
- **The majority of emissions from buildings arise from heat generation**. Low carbon heating options include heat pumps, hybrid heat pumps, district/communal heating, hydrogen boilers or bioenergy.
- **The majority of buildings in West Yorkshire are connected to the gas grid, facilitating low carbon gas solutions.**
- **Ambitious energy efficiency improvements** are needed in the 2020s, retrofitting over 675k homes, to reduce energy demand and support the technical feasibility of low carbon heating systems such as heat pumps.
- **The Max ambition scenario focusses on highly ambitious heat pump[2] installation, reaching 500k domestic heat pumps by 2030 and 665k by 2038**. By 2038 heat pumps also serve 47% of non-domestic heat. This is supported by deployment of district heating in urban areas and electric storage heating in space constrained homes. By 2038, fuel consumption is almost entirely electricity, and the **annual electricity demand has increased by 34%,** with implications for electricity generation and distribution infrastructure.
- **The High H2 scenario is driven by the use of hydrogen for heat, including 515k hydrogen boilers in homes and 27% non-domestic heat** supplied by hydrogen boilers by 2038. Emissions reductions are slow during the 2020s, but rapid from 2028 as hydrogen deploys; hybrid heat pumps should be deployed during the 2020s to then utilise the H2 after conversion. There are considerable uncertainties around the cost, infrastructure and consumer perception of hydrogen, but it has the advantage of reducing the additional strain on the electricity grid and minimizing consumer behaviour change required.
- **The balanced scenario sees a mix of technologies**, with heat pumps and hybrids installed rapidly from the mid-2020s, and hydrogen boilers in the early 2030s. District heating is used mainly for heat dense urban areas. Annual electricity demand increases by 17% by 2038. This scenario sees opportunities in greater consumer choice and a likely more resilient system.
- **Emissions remaining in 2038 in the buildings sector are largely electricity related**, so will reduce as the national electricity grid decarbonises. The High H2 has some emissions from hydrogen (production emissions) and the Balanced scenarios sees some emissions remaining from residual natural gas usage and hydrogen.
- **Key challenges remain** around infrastructure (electricity system, hydrogen and district heating), quality and consumer acceptance of heat pumps and achieving the high thermal efficiency required.

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[1] national electricity carbon intensity is used in line with GHG reporting
[2] heat pumps referring to air-to-water and hybrid air-to-water (not air-to-air)

Buildings – there are significant challenges remaining

The challenge to be addressed is huge, both in terms of capacity and cost

Key challenges remain in all scenarios around:

- Infrastructure (electricity system, hydrogen & district heating)
- Quality and consumer acceptance of heat pumps, as well as consumer acceptance of hydrogen
- Achieving the high thermal efficiency standards required to underpin heat pump deployment
- Investment and high cost to consumers

The Max ambition scenario stretches what could be deemed feasible. This case assumes no hydrogen in the gas grid, so it relies on electrification of most heat, primarily through installation of heat pumps & hybrid heat pumps by 2030. The challenges with the rapid timing are:

- **The natural turnover rate of heating systems is typically around 15 years**, so many must be replaced early, adding additional cost of technology scrappage
- **Misalignment with current national policy and the national 2050 target.** For example the RHI is delivering only ‘000s heat pumps (<0.5% stock) per year across the country, so significant additional incentives would be needed locally. The 2050 target implies national policy will aim for transition over that timeframe, rather than pushing in the 2020s for early heating system replacement.
- **Limited existing heating system regulation** currently and many existing buildings won’t pass through the planning system e.g. owner occupier homes. This gives limited control over consumers choices.
- **The supply chain for new heating system technologies is not currently fully developed**, so requires support for regional training programs and developing heat pump manufacture relationships

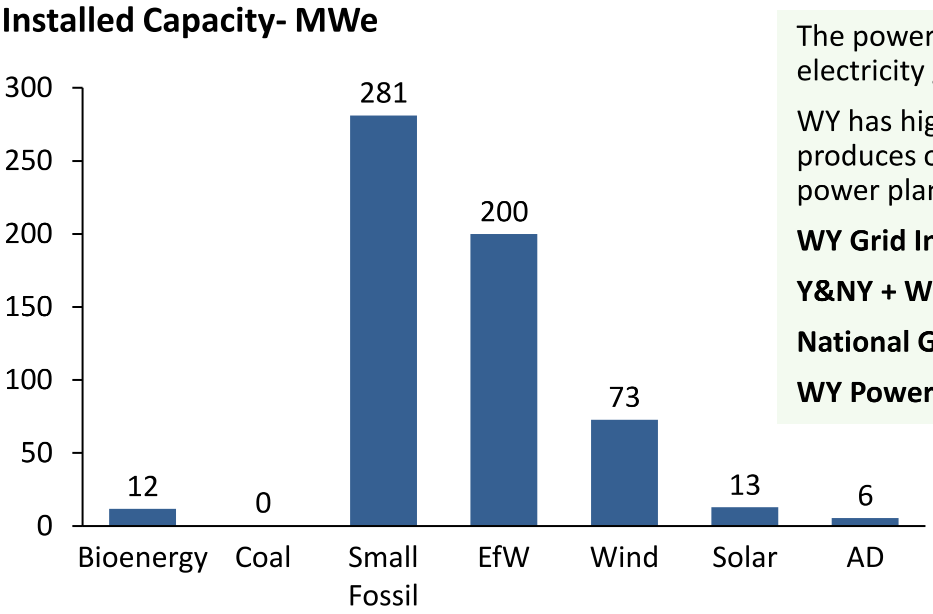
The policy tasks will look in further detail at the level of incentives and support needed regionally and nationally to realise these changes.

Agenda

- Introduction
- Key findings
- Sector pathways West Yorkshire
  - Transport
  - Buildings
  - Power
  - Industry
  - LULUCF + agriculture
  - Waste
- Additional information
- Technical Appendix

Power sector- current (2020 as modelled) capacity, generation and emissions of West Yorkshire

West Yorkshire



The power sector comprises of both centralised and decentralised electricity generation except for rooftop solar PV.

WY has higher regional grid carbon intensity than the national average and produces only a quarter of the power it consumes. It lacks large-scale power plants and contains smaller distributed generators.

WY Grid Intensity: ~217 gCO2/kWh

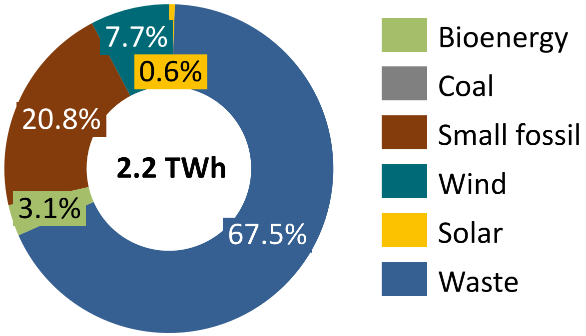
Y&NY + WY + Barnsley Grid Intensity: ~82 gCO2/kWh

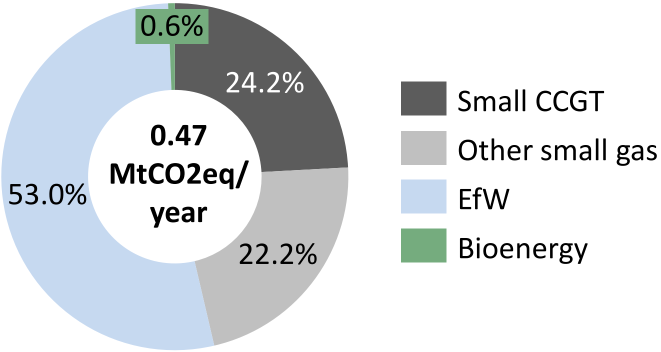
National Grid Intensity: ~128 gCO2/kWh

WY Power Imports: 75.7%

Power Generation: Energy from waste dominates power generation, followed by small –scale fossil and onshore wind.

Emissions: Emissions are almost equally divided between small scale fossil generators and various types of energy from waste.

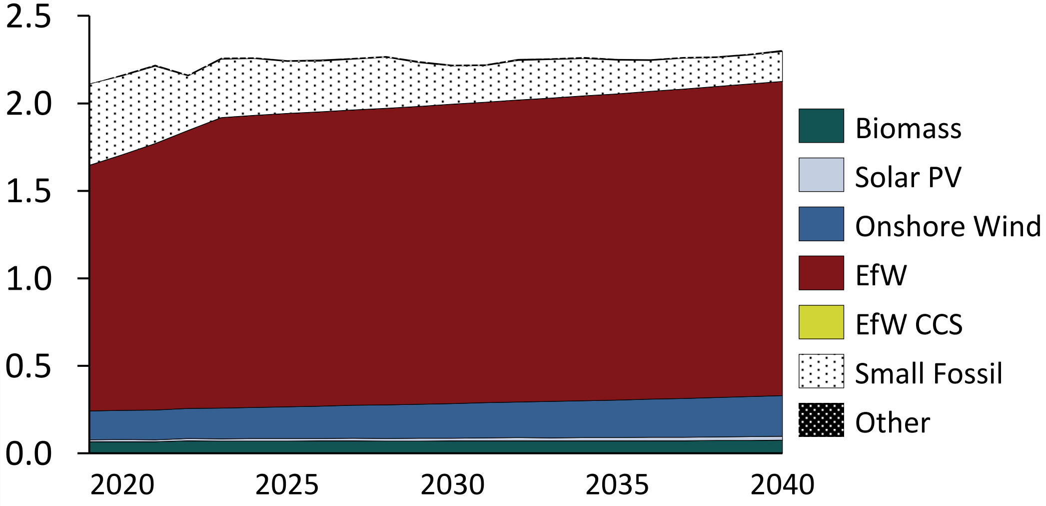




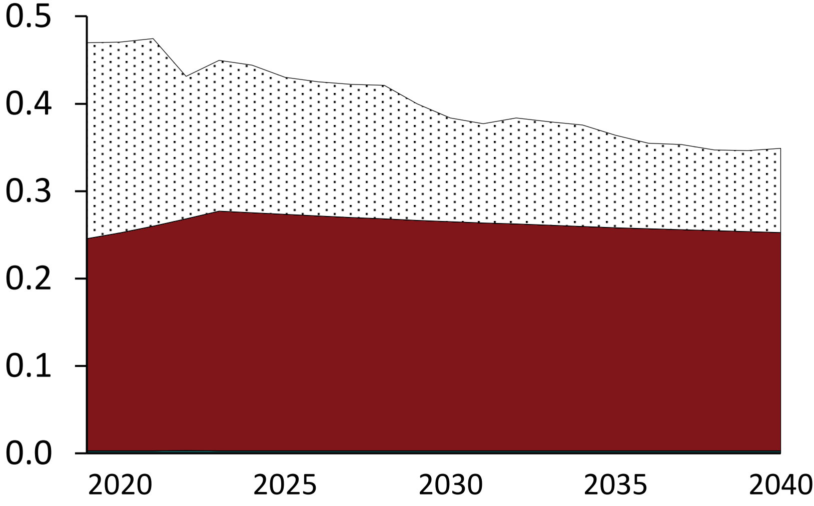
Baseline pathway – a slow power generation increase is accompanied by modest emission reductions from curbing small fossil capacity

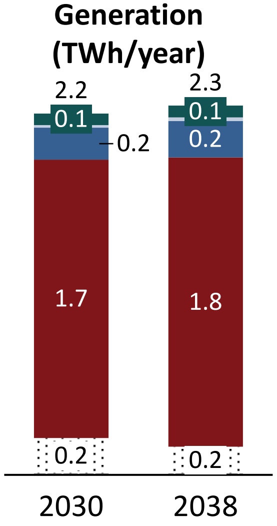
West Yorkshire

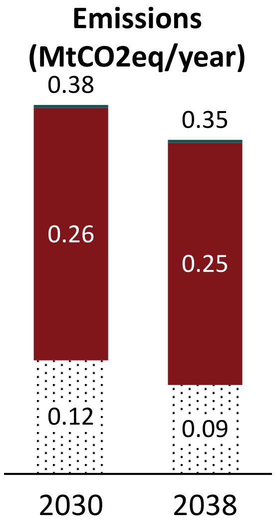
Generation- TWh/year



Emissions- MtCO2eq/year





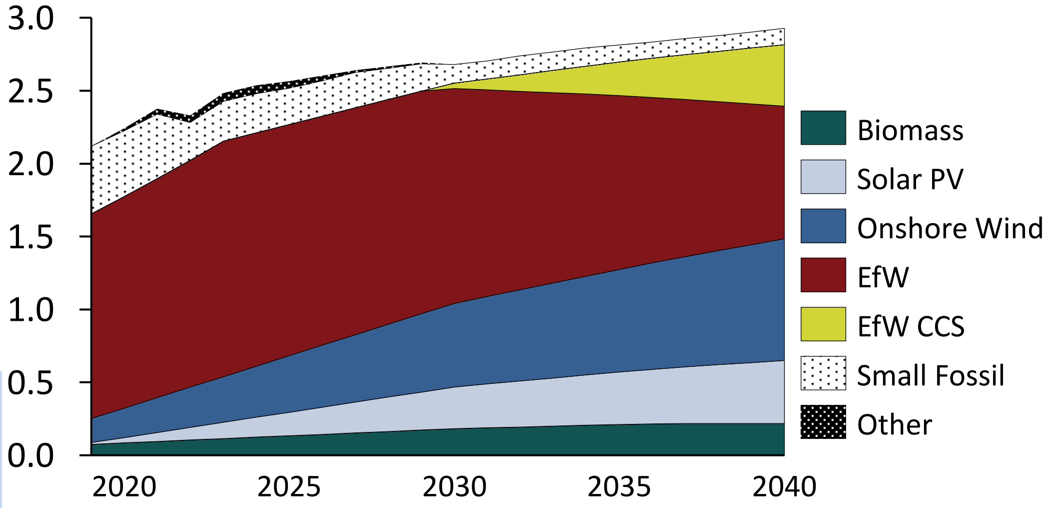


- The baseline scenario in West Yorkshire sees slow uptake of distributed technologies such as solar, offshore wind, AD and EfW. Landfill gas and small fossil capacities shrink. CCS is not included in the baseline due to lack of financial support.
- Power generation increases very slowly: 5% in 2038 compared to 2020.
- Over the same period emissions are reduced by 26%, mostly due to reduction of capacities and operation rates of small fossil fuel generators and improvements in EfW efficiency.
- Baseline electricity consumption in WY is 10.8 TWh/year in 2038, which implies that 78% of demand must be met by net imports from the national grid and region becomes more dependent on outside sources.

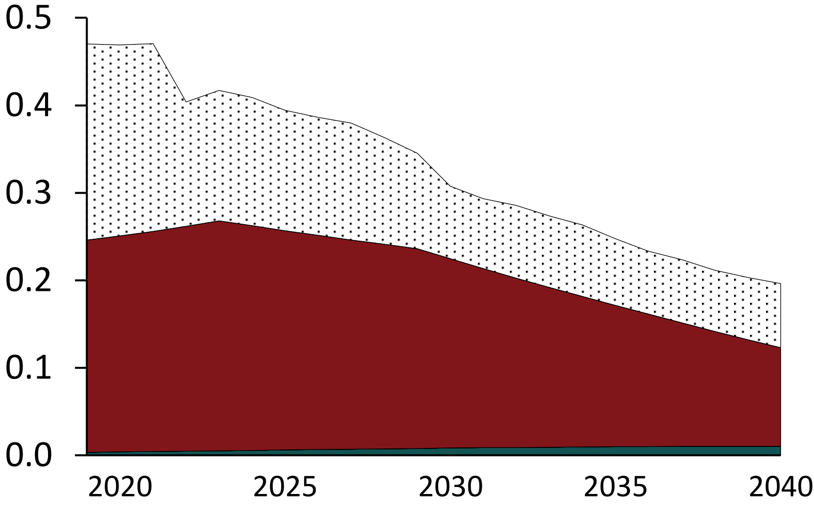
Max Ambition – accelerated technology rollout results in sharper emission reduction and ramp-up of generation

West Yorkshire

Generation- TWh/year

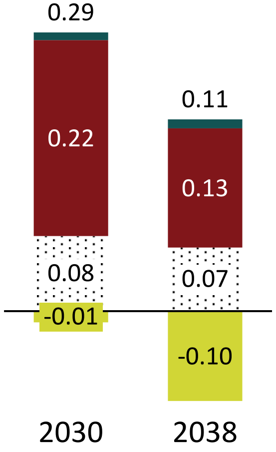


Emissions*- MtCO2eq/year



Generation (TWh/year)

Emissions (MtCO2eq/year)

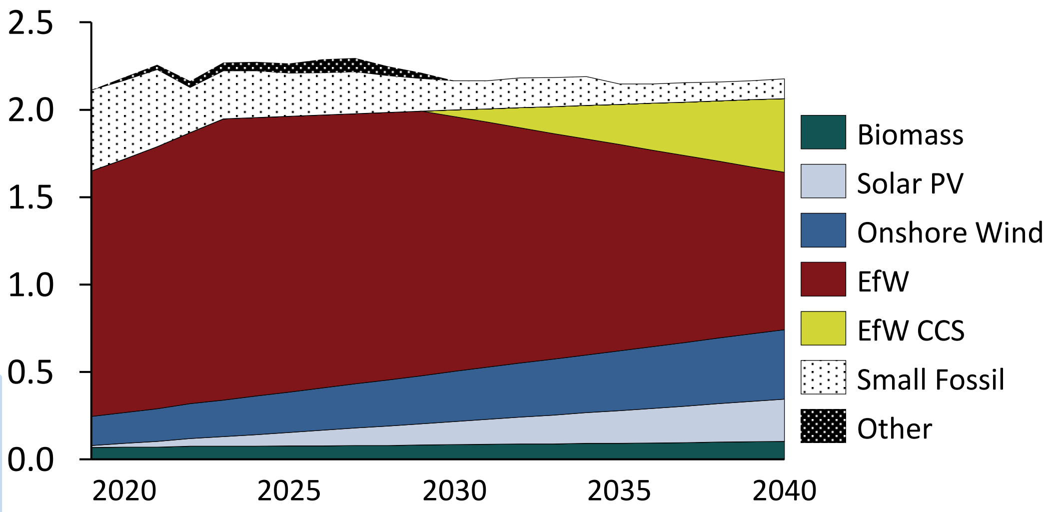


- The Max Ambition Scenario accelerates deployment of low carbon technologies to achieve rapid decarbonization in 2020s.
- Power generation increases significantly: 28% from 2020 to 2038.
- Over the same period emissions are reduced by 76%, mostly due to reduction of capacities and operation rates of small fossil fuel generators and deployment of EfW plants with CCS retrofits, providing negative emissions.
- Max Ambition electricity consumption in WY is 15.2 TWh/year in 2038, which implies that **81% of demand must be met by net imports from the national grid** and the region becomes slightly more dependent on outside sources compared to baseline. High population and urbanization are some of the factors behind rapid increase in power demand in WY.

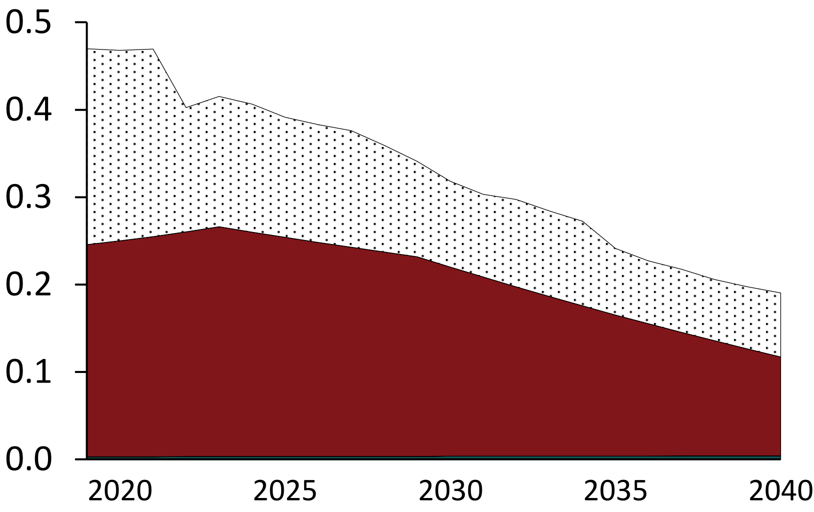
* Only positive emissions displayed; negative emissions from EfW CCS is omitted from the graph.

High H2 Scenario – decarbonization is achieved via minimal impact on total power generation in West Yorkshire

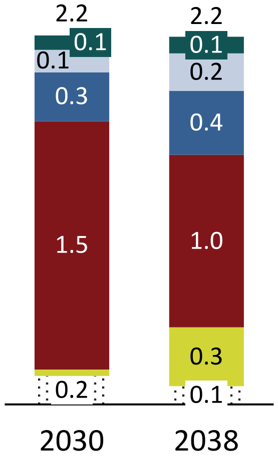
Generation- TWh/year



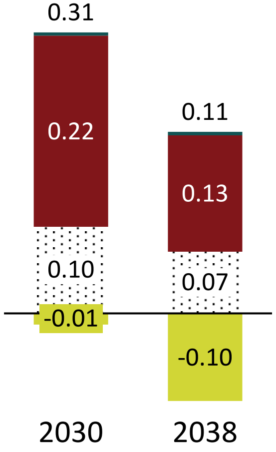
Emissions*- MtCO2eq/year



Generation (TWh/year)



Emissions (MtCO2eq/year)

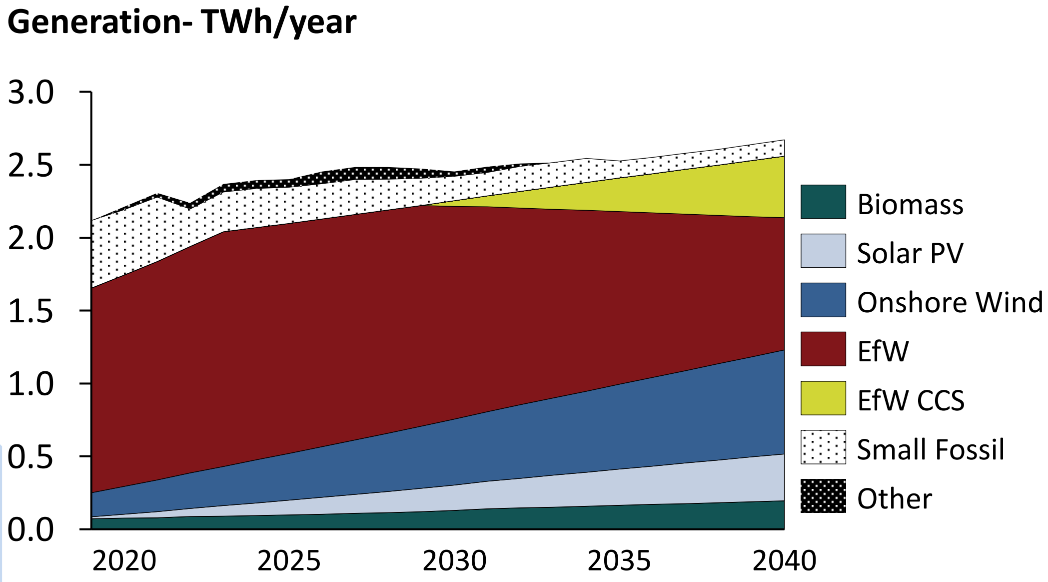


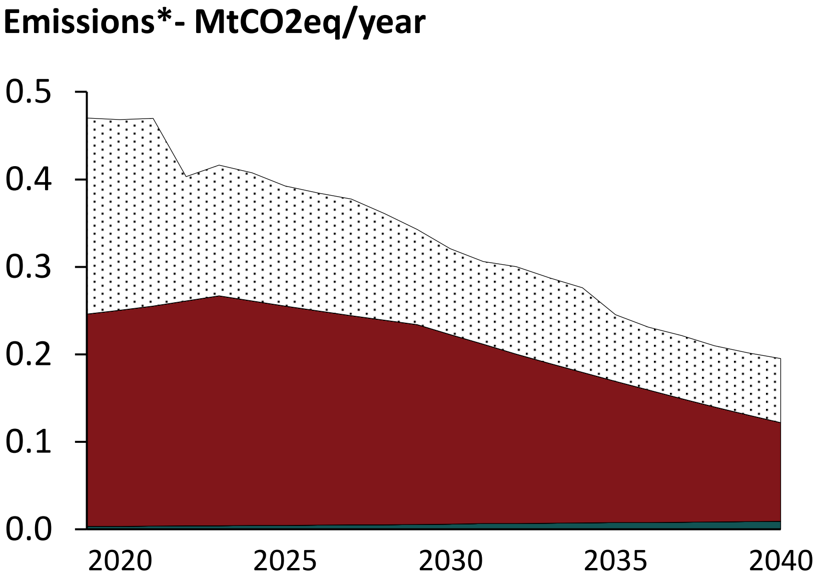
- The High H2 Scenario reduces electrification in other sectors thereby limiting WY's power demand growth. Hydrogen is assumed to be produced and consumed for power in other regions with better CCS connections, therefore WY is minimally affected.
- Power generation stagnates over the model period where renewables uptake offsets fall in small fossil fuel generation.
- Total emissions decrease by 77% in 2038 compared to 2020. mostly due to reduction of capacities and operation rates of small fossil fuel generators and deployment of EfW plants with CCS retrofits, providing negative emissions.
- High H2 Scenario electricity consumption in WY is 11.1 TWh/year in 2038, which implies that 81% of demand must be met by net imports from the national grid and the region becomes more dependent on outside sources compared to baseline. High population and urbanization are some of the factors behind rapid increase in power demand in WY.

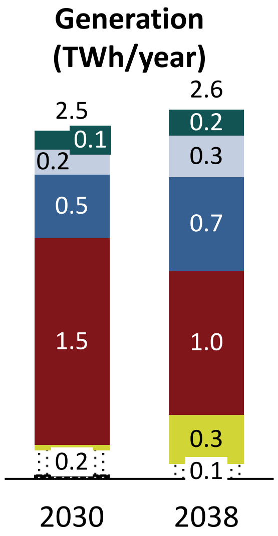
* Only positive emissions displayed; negative emissions from EfW CCS is omitted from the graph.

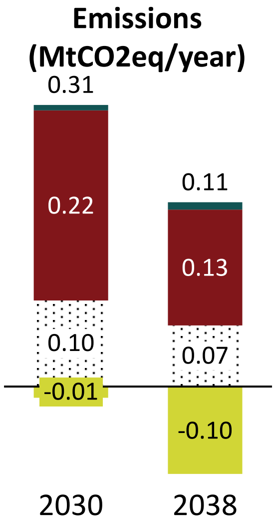
Balanced Scenario – modest increase in electricity output is achieved along with similar levels of decarbonization as to other scenarios

West Yorkshire


Generation- TWh/year


Emissions*- MtCO2eq/year


Generation (TWh/year)

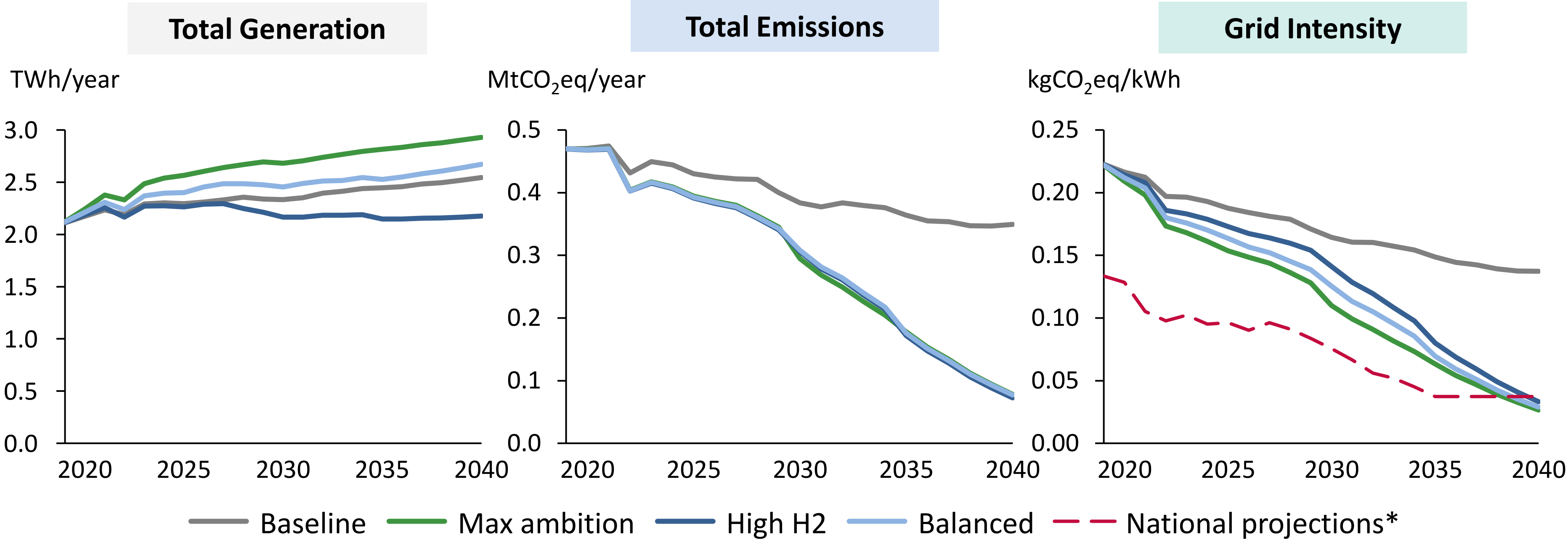

Emissions (MtCO2eq/year)

- Balanced Scenario aims to deploy higher amounts of decentralised technologies, more evenly split over time, to meet an electrification level in between the other 2 scenarios.
- Power generation increases by 18%, between 2020 and 2038.
- Over the same period emissions are reduced by 76%, mostly due to reduction of capacities and operation rates of small fossil fuel generators and deployment of EfW plants with CCS retrofits, providing negative emissions.
- Max Ambition electricity consumption in WY is 12.4 TWh/year in 2038, which implies that 79% of demand must be met by net imports from the national grid and the region becomes slightly more dependent on outside sources compared to baseline. High population and urbanization are some of the factors behind rapid increase in power demand in WY.

* Only positive emissions displayed; negative emissions from EfW CCS is omitted from the graph.

All 3 scenarios follow the same emissions trajectory with moderate differences in total power output

West Yorkshire

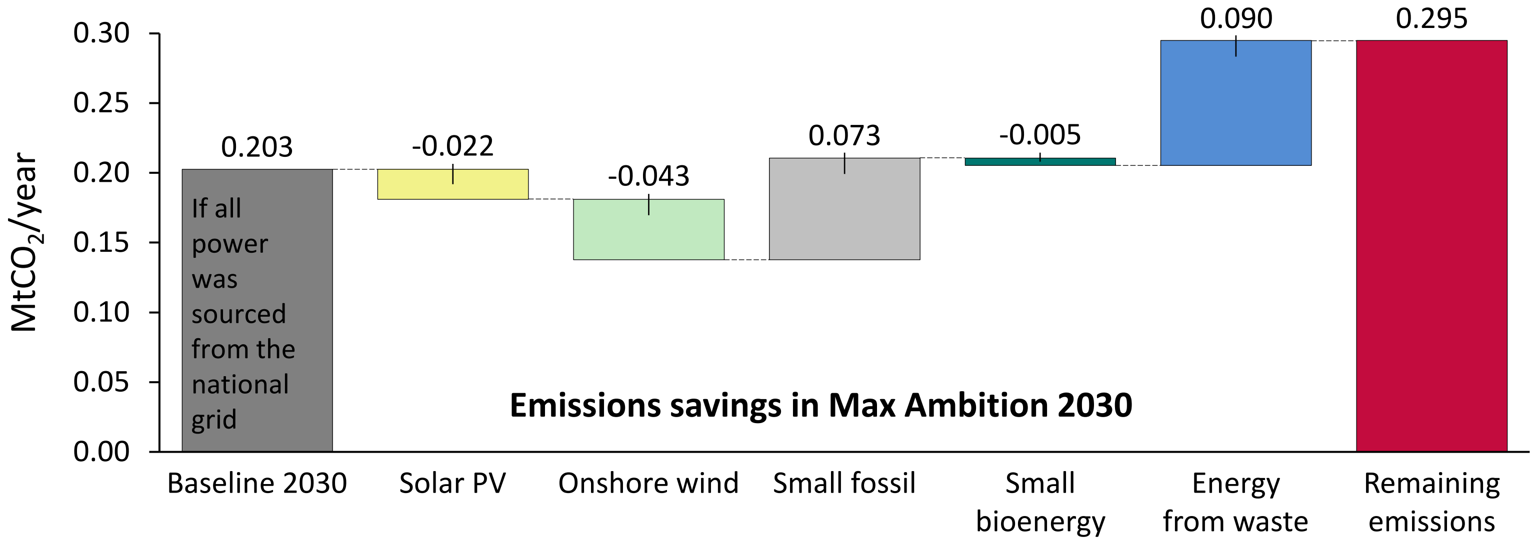


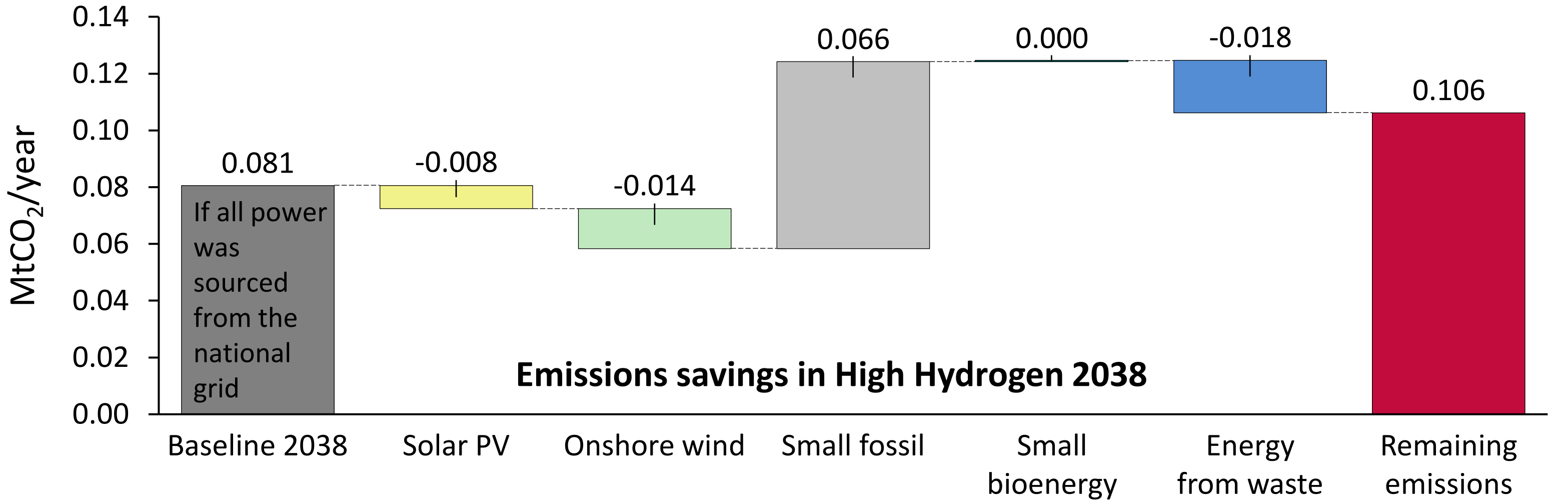
- All 3 scenarios fallow almost the exact same decarbonisation pathway and achieve similar levels of total emissions reduction in 2038 (~69%) compared to the baseline. These results can be explained by similar levels of capacity reduction of small fossil plants and deployment of EfW facilities across scenarios.
- Non-power sectors require more electricity in the Max Ambition Scenario, therefore this scenario maximizes generation by ramping up renewables, dedicated bioenergy and AD plants. The high H2 scenario ends up with slightly less generation than the baseline because the new hydrogen plants are build outside of West Yorkshire and this scenario requires lower levels of renewables.
- The scenarios also reach similar regional grid carbon intensity levels (0.39-0.049 kgCO2eq/kWh). The regional grid intensity is expected to be higher than the national average projections throughout the model period until right after 2038 where regional and national grid intensities catch up. Max Ambition results in lower grid intensity due to its higher electricity production.
- West Yorkshire power sector is unlikely to become zero emissions without mitigating emissions from unabated EfW facilities, either through closure or further CCS retrofits. Lack of BECCS or other negative emissions limit the ability of the region to remove its residual emissions.

*Based on Treasury's Green Book supplementary appraisal guidance on valuing energy use and greenhouse gas emissions.

Waterfall charts showing changes in emissions due to each technology for Max Ambition 2030 and High H2 2038

West Yorkshire





Please see next slide for explanation and notes. Note that these are estimates only.

Positive values indicate increase in emissions compared to national grid.

Notes for power sector waterfall charts

- The charts show the effect of each technology on emissions, compared to sourcing power from the national grid, in WY for one year: 2030 for Max Ambition and 2038 for High H2.
- The baseline figure shows how much CO2 would be emitted if all the power **generated** in the region in that particular year was sourced from the national grid, at the grid intensity for that given year according to the Treasury Green Book's Supplementary Guidance. Since the grid is expected to decarbonise over time, the 2038 baseline emissions are lower than 2030.
- Each bar represents how much CO2 each technology saves/emits compared to importing from the grid. Positive values represent technologies that emit more than the grid average at that time. These technologies are still needed to achieve the power production levels required in the scenarios.
- Small fossil incudes small CCGTs, small oil and small gas plants. Small biomass includes dedicated biomass, and biomass AD plants. Energy from waste (EfW) includes electricity only EfW, EfW CHP, EfW CCS, waste based AD and power from cooking oil, sewage sludge digestion and landfill gas.
- Other CCS related technologies such as CCS CCGTs, BECCS (Drax) and Hydrogen are not included as they are not deployed in West Yorkshire.
- Note that waterfall graphs are estimates and represent one particular way of illustrating the scenarios. Savings for some technologies appear to be very small or non-existent. This means that the technology emits the same amount of CO2 as the grid, which is already decarbonised to a great extent in 2030s.
- **Although West Yorkshire appears to emit more carbon under these scenarios than it would emit if all electricity was imported from the grid, it should be recognised that not all regions in the UK are expected to decarbonise to the same extent. Lack of early connection to CCS facilities, among other factors, limit the de-carbonization of WY to below national grid average, which still provides significant savings. It should be noted that national grid averages also include renewables like offshore wind, which is omitted from this model.**

Power – Key Messages for West Yorkshire

- **Most of the current emissions arise from energy from waste, small fossil generators and wind.** These small-scale distributed generators, along with solar and EfW CCS are likely to dominate the future power sector in WY.
- **Reduction in unabated small fossil capacity is likely to offset some of new capacity additions,** leading to stagnation of total regional power output in the High H2 Scenario and a 29% increase in the Max Ambition Scenario.
- In 2038 decarbonization scenarios **remaining emissions are mostly from EfW plants.** Just under half of these emissions may be removed by **installing CCS on 28% the initial EfW plants (44 MW)** to generate negative emissions. Eliminating all emissions or achieving net negative emissions will likely require significant EfW CCS deployment, new technologies (such as BECCS or direct air capture) or paying other regions for carbon credits.
- **The modest renewable capacity in the region must expand very rapidly to reduce grid intensity.** Despite representing 0.84% of UK's land and 3.5% of UK's population, solar (~0.1% of UK) and onshore wind (~0.57%) capacity in the region is very limited. Significant support is required to add up to 217% and 23% of the current wind and solar capacity, respectively, every year until 2030 in the Max Ambition Scenario.
- **West Yorkshire is likely to stay as a significant power importer,** although efforts should be made to contribute to national power generation as much as possible. Compared to some of the neighboring regions, WY is not the optimum location for building large-scale low-carbon power plants. With a sizable population and electricity consumption, WY may have to keep importing >80% of its power and contribute to further decarbonization efforts by collaborating with other regions which have larger generator fleets.
- **Disabling CCS significantly increases emissions without changing power output** across scenarios. CCS is only used on some EfW facilities in WY and their omission does not impact overall electricity production. However, the region would lose its only negative emission opportunity without CCS resulting in 150% higher power sector emissions in 2038 compared to the CCS case.

Power – WY is positioned to decarbonize by replacing its unabated small-scale generators with low-carbon alternatives

West Yorkshire characteristics of power generation assets:

- **WY has no centralized large-scale gas power plants.** Its power fleet mainly consists of distributed assets such as energy from waste, small fossil generators and onshore wind.
- **WY depends heavily on power imports** as it generates only 0.7% of UK's power despite consuming 2.8% of it.
- **Disproportionately low solar and onshore wind assets** represent the lack of renewable energy roll-out in WY. Despite having 0.84% of UK land and 3.49% of UK population, solar and onshore wind capacities are only ~0.10% and ~0.57% of the UK total, respectively.
- **The region has a large and modern Energy from Waste fleet** which represented ~12% of UK's waste processing capacity in mid 2019. The two Ferrybridge Multifuel facilities (138 MW combined) and Leeds Recycling and ERF CHP plant (11.6 MW) are all built after 2015 and are very efficient plants.
- **Small-scale fossil generation is relatively abundant in West Yorkshire**, which has 74% of oil generators, 52% of small gas generators and both small (50 MW) CCGTs of the total study region consisting of North and West Yorkshire + Barnsley.

The scale and rate of change for power generation in West Yorkshire:

- In the Max Ambition Scenario **solar PV and onshore wind capacities in the region must increase by 27 MW and 16 MW every year until 2030**, which corresponds to 217% and 23% of currently installed capacity, respectively. In 2038, total land area required for solar PV and onshore wind correspond to 0.5% and 5.0% of total WY land area, respectively*.
- **Small scale fossil generation capacity must be reduced by 44% by 2030** in the Max Ambition Scenario, which is 26% of total installed power capacity in West Yorkshire in 2019.
- In all decarbonization scenarios **more than a quarter of the existing EfW capacity (44 MW) is converted to CCS** starting from 2030, while the EfW CHP capacity is expanded by 63% by 2038.
- Very swift action is needed to **deploy initial CO2 transport infrastructure by 2030** to allow for generating negative emissions through EfW CCS facilities (~0.2 MtCO2/year). Ths infrastructure may connect to larger future CO2 infrastructures in nearby locations, such as at Drax, Selby.

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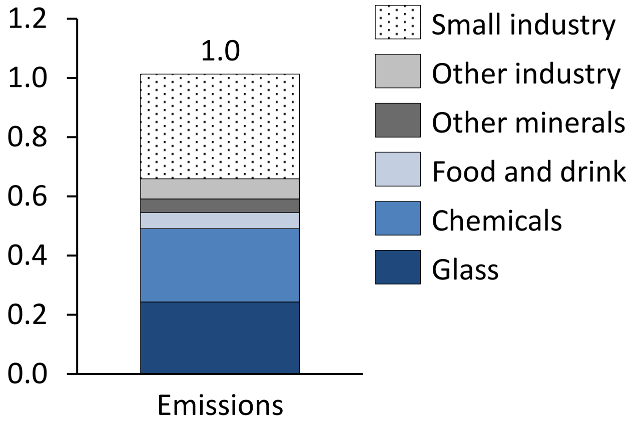
* For wind, this covers all the area between turbines. For both technologies the covered land area can also be used for other purposes such as agriculture, forestry, etc. Further studies are needed to assess the full impact on land availability.

Agenda

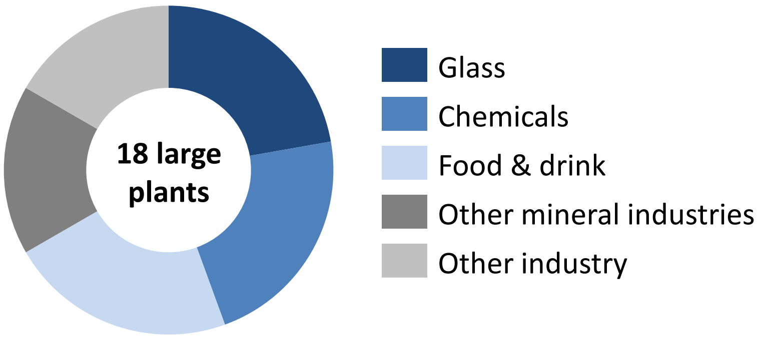
Current energy and emissions situation in the region - industry

- "Heavy Industry" in the context of this study relates to large, energy and emissions intensive sites (approximately the 18 largest in West Yorkshire).
- Other energy and emissions from industrial processes are included in the "Small industry" category.
- The commercial sites and building related emissions from small industry sites are included in the non-domestic buildings sector.
- Industrial emissions in the region are small, at 1.0 MtCO2e/yr, due to the limited heavy industry.
- The heavy industry is spread over the local authorities, but with a cluster in Knottingley .

Industrial emissions by sector MtCO$_2$/yr

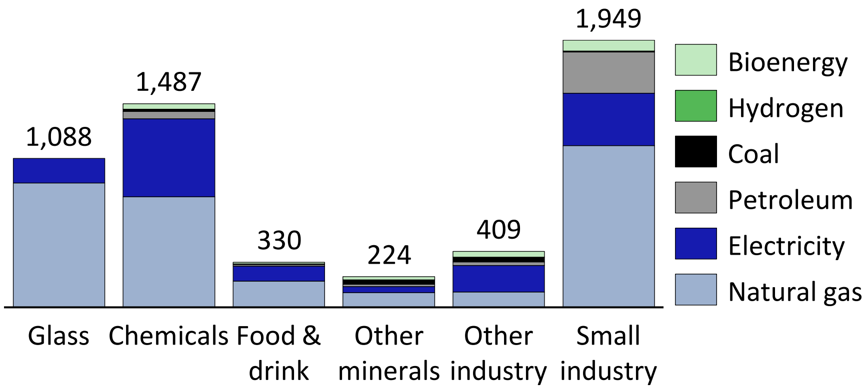


Energy intensive Industry: The primary heavy industry sectors in the region are large glass and chemicals plants, with some smaller food and drink and other minerals sites[1]



Energy consumption is dominated by natural gas and electricity. Small industry has the largest energy usage.

Industrial energy by sector & fuel (estimate only) GWh/yr



Source: NAEI point source emissions, ECUK fuel breakdown, discussion with British Glass

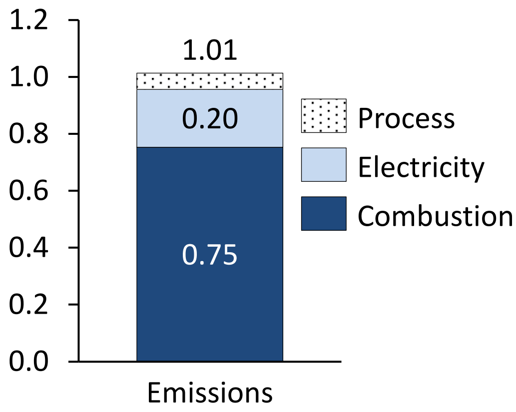
Note that combustion emissions are CO$_2$eq as other GHG are included in fuel emissions factors and process emissions are just CO$_2$ as agreed

[1] The "other minerals" sector is minerals excluding glass and covers sectors such as ceramics, building products, lime and asphalt

Industry – the majority of emissions are from fuel combustion and can be addressed through using low carbon fuels

The largest and most challenging portion of emissions is combustion emissions

Industry emissions $MtCO_2e/yr$



- **Process emissions are directly from the raw materials** or process, so can only be addressed by CCS or through changing the production process, both challenging solutions. The majority of process emissions in the region are from the glass sector.
- **Electricity related emissions will be addressed through decarbonisation in the power sector**, supported by installation of efficient technologies to reduce demand.
- **Combustion emissions are from burning fossil fuels**; they are the majority of industry emissions and are usually associate with heat generation. They can be reduced through energy efficiency and can be addressed through fuel switching to low carbon fuels (electricity, hydrogen or bioenergy). However, currently many industrial applications don't have new equipment developed to run on low carbon fuels, so RD&D is required to address the technical barriers. It may be costly due to the need to retrofit equipment and the likely higher fuel cost of low carbon fuels.

Key Features and assumptions for industry (see technical Appendix for more detail):

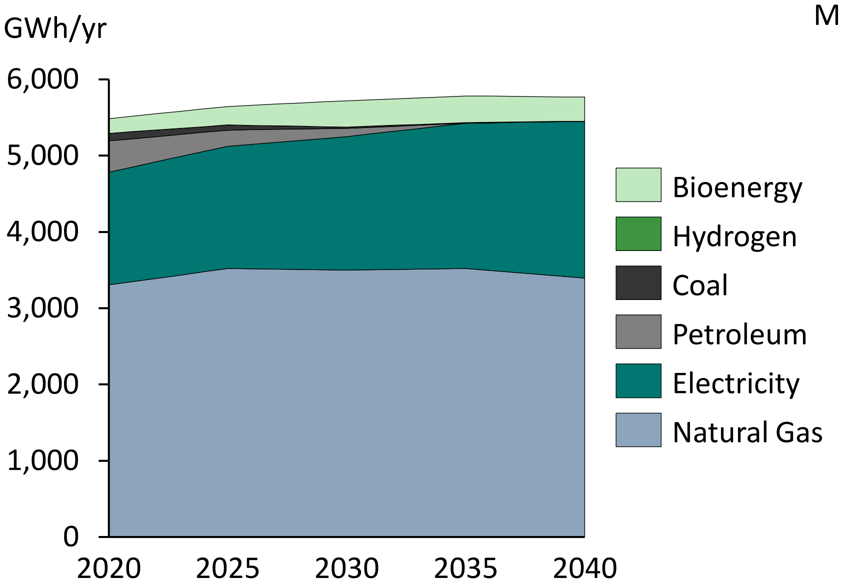
- **Energy and resource efficiency:** range of improvements (based on Max Tech[1], CCC & UKERC, and regional work) to reduce the energy consumption of industrial sites e.g. through waste heat recovery, increased recycling rates etc.
- **Hydrogen fuel switching is possible** for many applications currently using natural gas[2] e.g. food and drink, glass, chemicals. Hydrogen production begins at scale in the late 2020s (near Humber) and can either be distributed through new pipelines, or through conversion of the current natural gas grid.
- **Electrification** of low temperature heat and heat on smaller sites; in the Max Ambition Pathway rapid deployment of further electrification options will be required (technology development accelerated)
- **CCS on large sites** and/or in sectors with process emissions, in this case glass and chemicals. CCS is anticipated to first be available near the Humber e.g. at Drax (or Teesside), just before 2030, with infrastructure expanding during the 2030s.
- **Bioenergy and waste** for some applications, particularly those with limited alternatives. Bioenergy is particularly effective in sectors where it can be combined with CCS to provide negative emissions through BECCS.

[1] Industrial decarbonisation and energy efficiency roadmaps to 2050

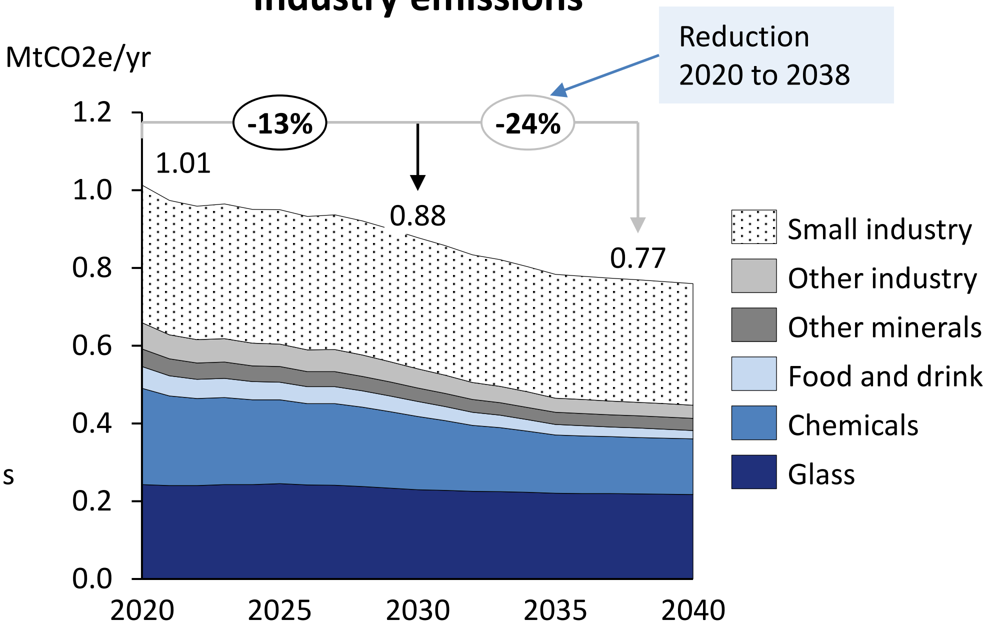
Note that combustion emissions are CO_2eq as other GHG are included in fuel emissions factors and process emissions are just CO_2 as agreed

Industry – The Baseline scenario sees limited change, with emissions reductions mostly from electricity decarbonisation

Industry energy consumption

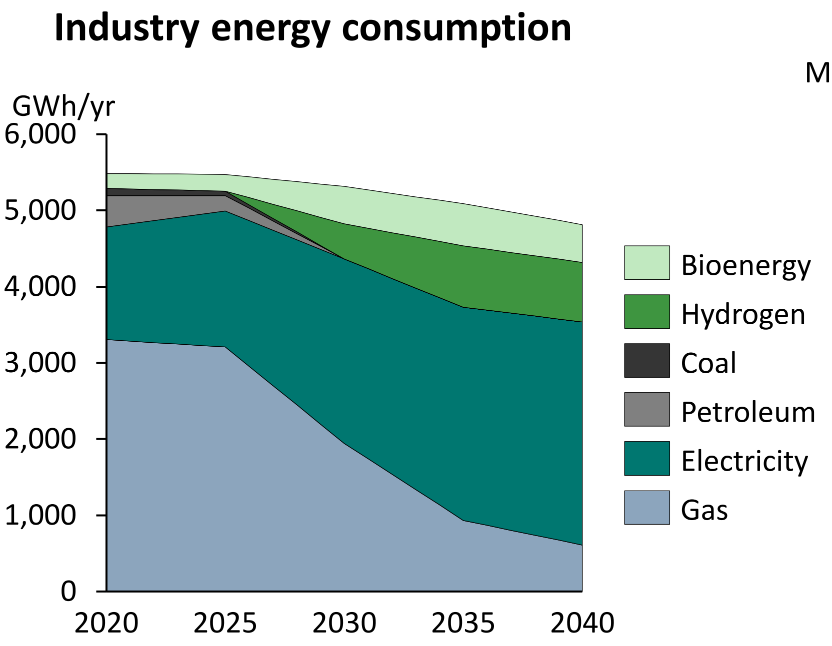


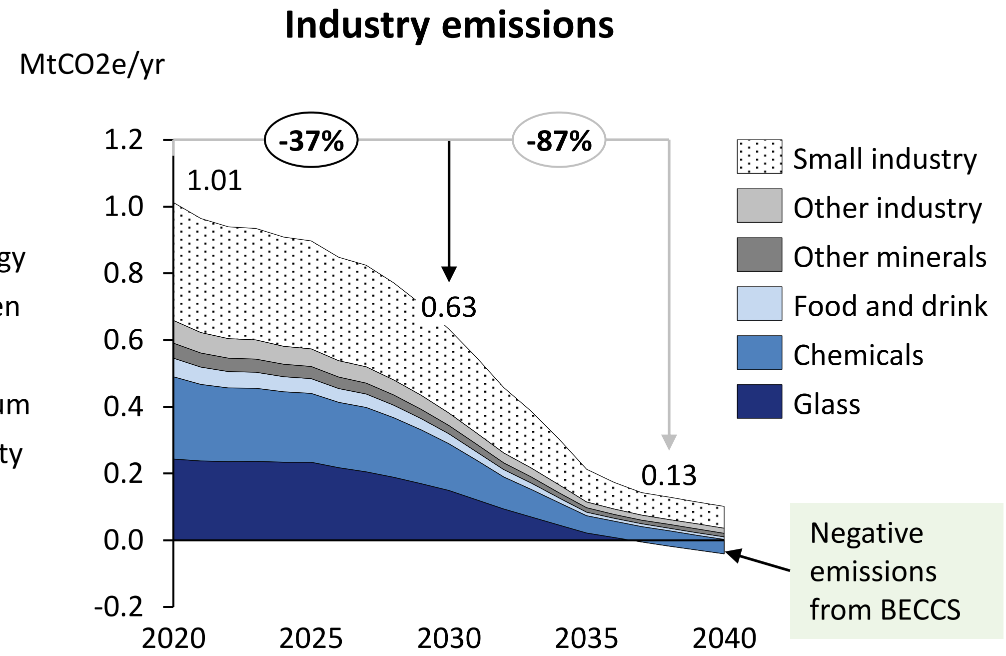
Industry emissions



- Industry growth follows regional growth forecasts by subsector (from 0-30% across heavy industry)
- Energy efficiency and resource efficiency reach <15% reduction in energy consumption each, which almost offsets the growth leading to a stable energy demand
- **Fuel switching to low carbon fuels is limited** and focused primarily on phasing out coal/oil and a small amount of electrification of heat. Energy consumption remains primarily natural gas and electricity.
- CCS – there is not currently sufficient policy to develop any CCS projects so we assume **no CCS in the baseline scenario**
- Process emissions remain a challenge in glass, with small reductions from increased recycling rates
- **Industry emissions reduce by 24% by 2038 (to 0.77 MtCO2e/yr).** The emissions reduction is primarily due to decarbonisation of the electricity consumed, following the national electricity carbon intensity projections.

Industry – The Max ambition see progress accelerate from the mid-2020s, to reach 87% emissions reduction by 2038


Industry energy consumption


Industry emissions

Negative emissions from BECCS

- The Max ambition scenario sees **rapid emissions reduction from 2025, reaching 87% reduction by 2038 to 0.13 MtCO$_2$e/yr**
- Energy efficiency and resource efficiency reach 15%-40% reduction in energy consumption each[1], which more than offsets the growth, leading to reduction in energy demand. The same efficiency is applied across the 3 emissions reduction scenarios.
- In all scenarios, **oil and coal are phased out in the 2020s**, replaced with electricity, bioenergy, waste (or gas in medium-term)
- **Natural gas is replaced from the mid-2020s onwards** with electricity, hydrogen or bioenergy. Some ‘gas’ use remains in 2038, which will have low carbon intensity due to significant biomethane blending.
- **CCS is implemented during the 2030s** to large plants in the glass and chemicals sectors (up to 5 plants[2]); other sectors do not have large enough plants to make CCS cost-effective in this region.
- CCS enables **negative emissions in glass plants burning bioenergy (BECCS)** by 2038, highest in the Max ambition scenario.

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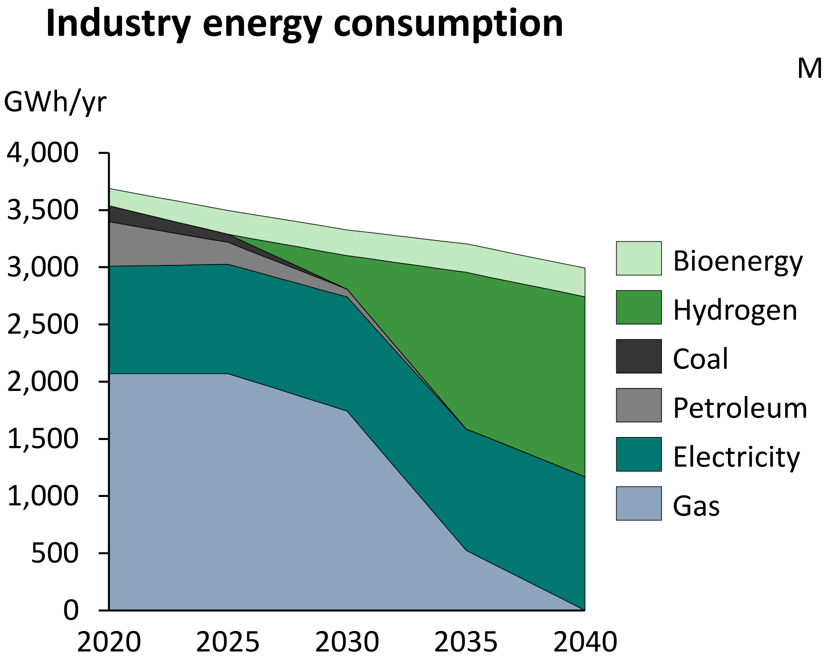
[1] See technical Appendix or model for details

[2] Please note that assumptions and modelling were done for the study region, so subregion level results are indicative. They do not account for the small number of plants in the subregions and therefore the discrete nature of solutions.

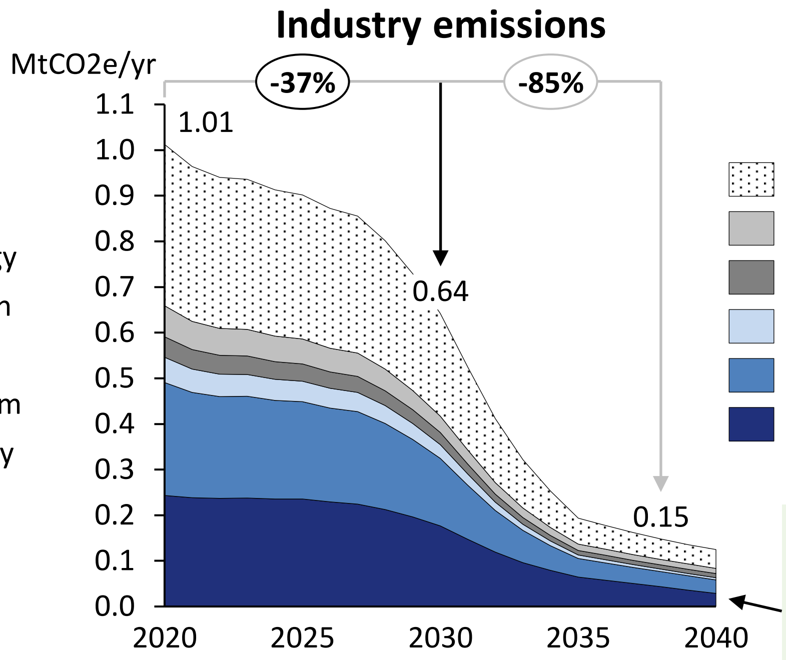
Industry – The High H2 scenario sees slower emissions reductions in the 2020s, but rapid hydrogen conversion 2028-2035

West Yorkshire

Industry energy consumption



Industry emissions



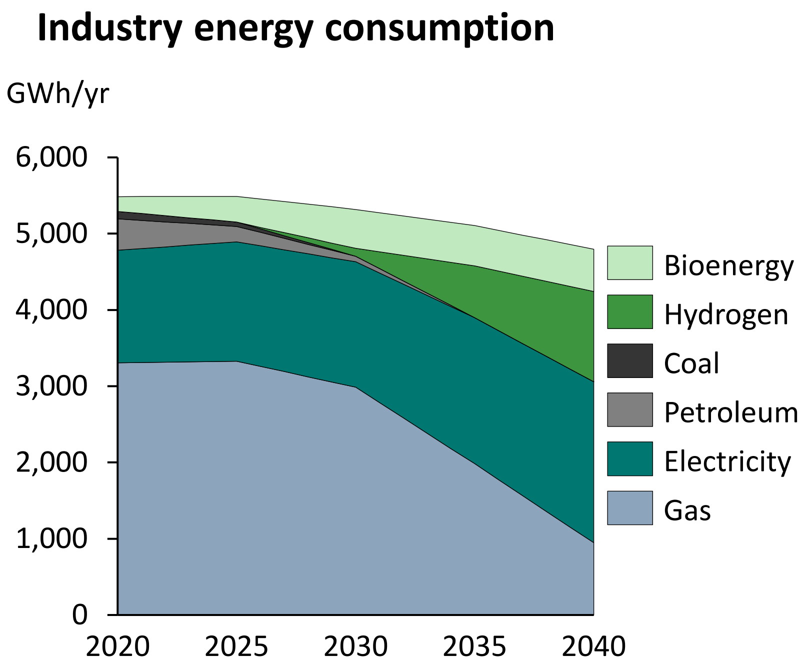
Negative emissions from BECCS offsetting some glass

- The High H2 scenario sees **emissions reduce by 85% by 2038 to 0.15 MtCO$_2$e/yr**
- However, the **decarbonisation occurs later than the Max ambition scenario, starting in the late 2020s when hydrogen becomes available at scale.** This causes rapid decarbonisation 2028-2035, with near zero carbon H2 (lower carbon intensity than electricity). There is less electrification of heat in the 2020s than the Max ambition scenario.
- Similar energy efficiency and resource efficiency are applied, and oil and coal are mostly phased out in the 2020s.
- **Fuel use is almost entirely electricity and hydrogen; no natural gas use remains** by 2040, as the gas grid has been converted to H2, so all applications use H2 or alternative fuels.
- **CCS is implemented during the 2030s, but only on glass plants switching to bioenergy,** as all fossil fuel use is phased out in this scenario due to hydrogen conversion. This means there are remaining process emissions in the glass sector, and there is a lower BECCS contribution in the high H2 scenario, increasing final 2038 emissions.

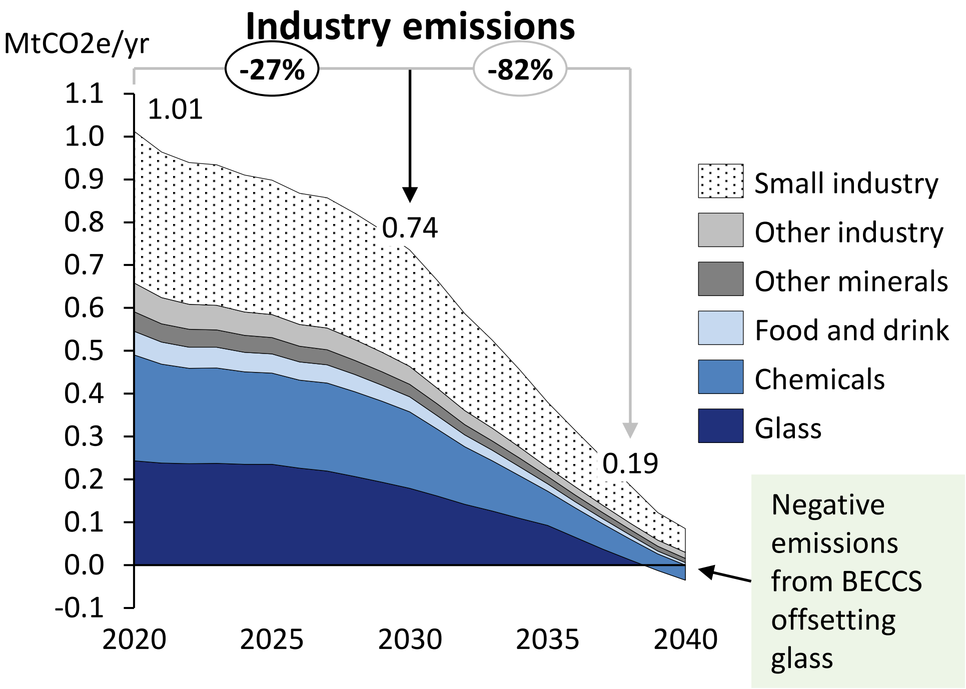
1 See technical Appendix or model for details

2 Please note that assumptions and modelling were done for the study region, so subregion level results are indicative. They do not account for the small number of plants in the subregions and therefore the discrete nature of solutions.

Industry – The Balanced scenario makes slow progress in the 2020s, but makes use of a range of fuels in the 2030s



Industry energy consumption



Industry emissions

Negative emissions from BECCS offsetting glass

- The Balanced scenario sees **emissions reduce to 82% by 2038 to 0.19 MtCO$_2$e/yr**
- Progress in the 2020s is slower than other scenarios, with the majority of emissions reductions coming from energy efficiency and decarbonisation of the electricity grid. Only some glass plants are using hydrogen by 2030 through dedicated pipelines.
- During the 2030s, the decarbonisation rate increases as equipment RD&D means more applications are commercially available for low carbon fuels, and hydrogen becomes more widely available.
- By 2038, industry is using a **mix of hydrogen, bioenergy, hydrogen and significant gas**; the gas from the gas grid has low carbon intensity due to **biomethane blending**. This uses valuable biomethane resources.
- **CCS is implemented** again at the largest chemicals plants and at the glass plants which are using bioenergy or natural gas.
- Emissions remaining in 2038 are largely electricity-related emissions in all scenarios due to electricity consumption at non-zero carbon intensity; this will be addressed by further power sector progress (nationally).

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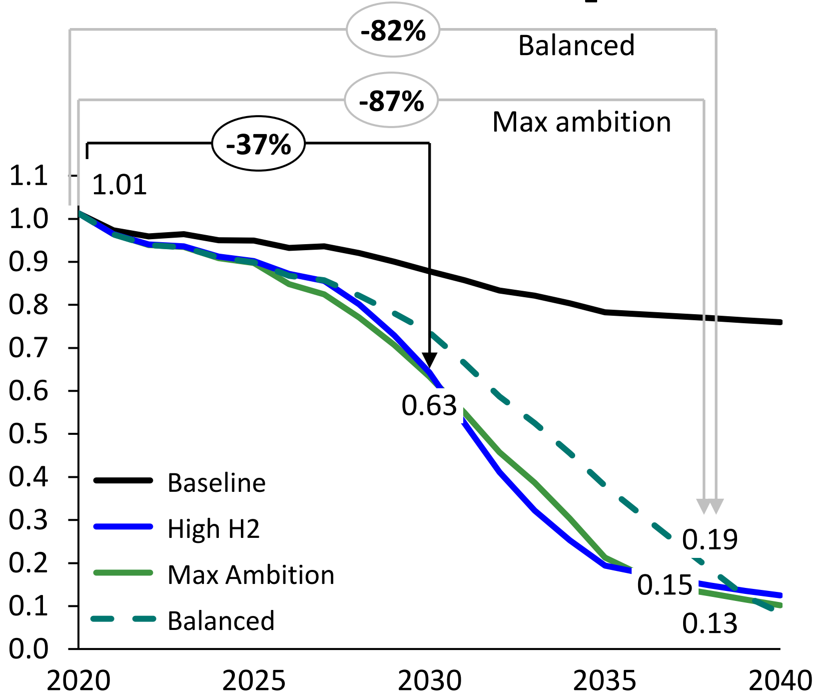
1 See technical Appendix or model for details

2 Please note that assumptions and modelling were done for the study region, so subregion level results are indicative. They do not account for the small number of plants in the subregions and therefore the discrete nature of solutions.

Industry – fuel switching and CCS mostly deploy in the 2030s due to technology availability timescales

Emissions from industry $MtCO_2e/yr$



- The chart shows the emissions projections for the industry sector across the scenarios.
- The numbers represent the total annual net emissions in 2020, 2030 (Max ambition) and 2038; the arrows show the % change from 2020.
- All emissions reduction scenarios see implementation of energy and resource efficiency at a similar level.
- The total emissions in the industry sector decrease by up to 37% by 2030 and reach only **0.13 MtCO2e/yr by 2038 in the Max ambition scenario.**

- The Max ambition scenario makes quickest progress, with **early measures including further efficiency, electrification** of some heat and coal/oil replacement with either natural gas, electricity or bioenergy. Significant BECCS in the glass sector offsets some electricity-related emissions, mostly in the Max ambition and Balanced scenarios.
- **The High H2 scenario undergoes rapid change from 2028 to 2035** as many sites undergo the switch from natural gas to hydrogen, which is now widely available. Hydrogen has a lower fuel carbon intensity than electricity in the 2030s[1]. This allows the High H2 scenario to reduce emissions to below the Max ambition (temporarily).
- The Balanced scenario sees limited progress in the 2020s, but catches up with the other scenarios in the 2030s as hydrogen and CCS become available and **gas grid decarbonisation (biomethane blending) supports sites which haven't switched fuel**.

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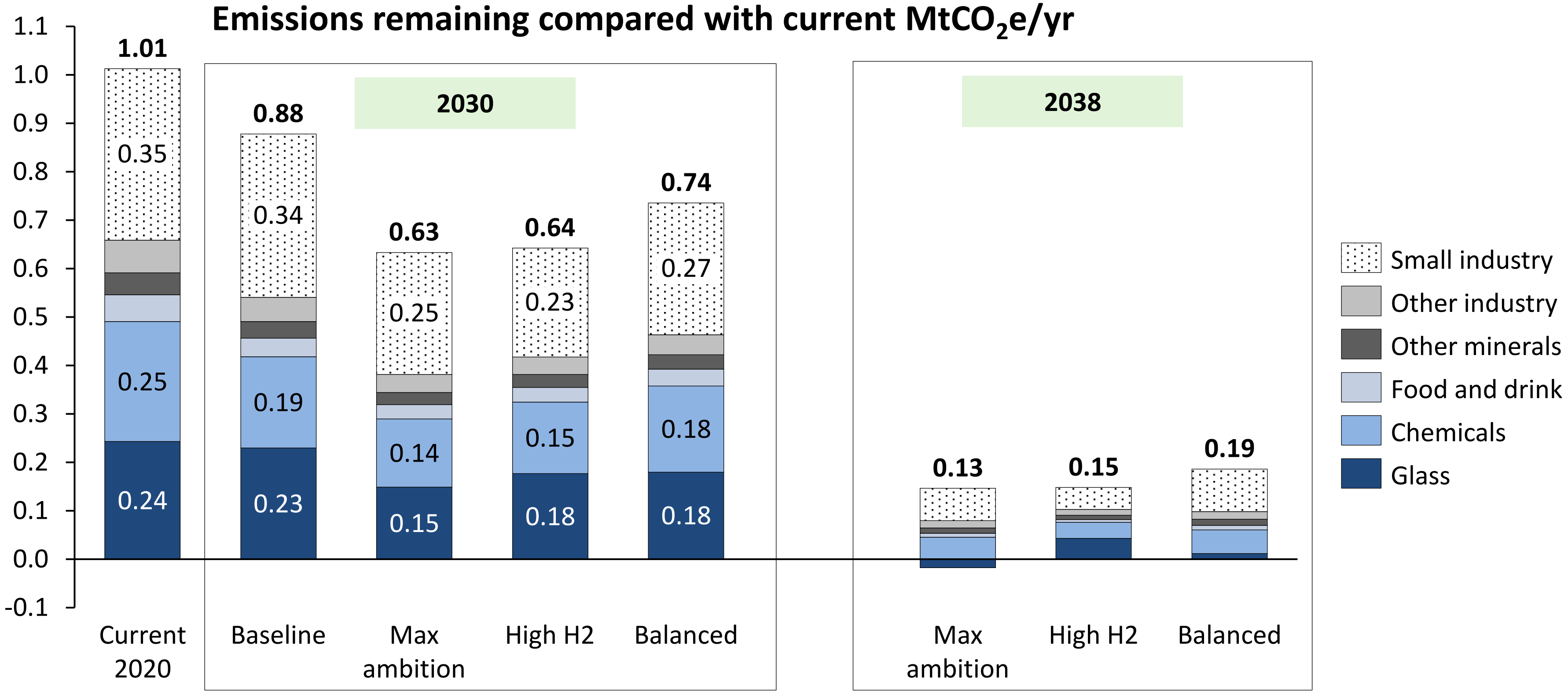
1 due to high CCS capture rates and biogas blending into the feedstock, see technical Appendix.

Please note that assumptions and modelling were done for the study region, so subregion level results are indicative

Remaining emissions are significant in 2030 across scenarios, but by 2038 equipment and solutions become available

West Yorkshire



- **Due to technology readiness, industry decarbonises slowly in the 2020s**, with only limited equipment available to reach maximum 37% reduction by 2030, through efficiency and some electrification of heat. During the 2030s, emerging technologies become commercially ready and hydrogen and CCS become available at certain sites.
- **In 2038, the majority of remaining emissions are from electricity use at non-zero carbon intensity**.
  - Electricity-related emissions are highest in the Max ambition scenario, but are offset by some BECCS;
  - the High H2 scenario sees process emissions remaining from the glass sector;
  - the Balanced scenario has the highest residual gas usage

Industry – West Yorkshire heavy industry, focused on the glass and chemicals sectors, must explore multiple low carbon options

West Yorkshire industry characteristics

- **West Yorkshire has limited heavy industry**. It is geographically split between the local authorities, but with a glass cluster in Knottingley and chemicals sites in Bradford. There are 17 medium-large plants in total[1]
- **The largest heavy industry sectors are glass and chemicals,** with 4 medium-large plants in the region each.
- The breakdown of business activities is relatively similar to the national average, although there is lower agriculture, forestry and fishing (2% compared with a UK average of 5% units), and slightly higher business units in the production sector. The majority (91%) are less than 20 people.
- Only four industrial sites in West Yorkshire have emissions of 50 $MtCO_2$/yr or over (glass and chemicals), so **CCS has limited potential in West Yorkshire industry,** but may be possible on some smaller sites.

The scale of change for industry in West Yorkshire:

- Early potential for hydrogen use could be sites in Knottingly due to their proximity to planned hydrogen production in Selby[2] and sectoral H_2 potential / research[3]. The first plant starts using hydrogen through dedicated new pipelines in 2026.
- The Max ambition scenario sees **coal phased out by 2030 and oil shortly afterwards,** being primarily switched to electricity or bioenergy and waste.
- Industrial electricity consumption almost doubles (**95% increase) in the Max ambition scenario**, despite efficiency measures.
- In the High hydrogen scenario, **hydrogen supplies 45% of industrial energy by 2038 (2.2 TWh/yr)**, requiring large scale generation and distribution infrastructure to be developed swiftly.
- Due to the lower technology readiness levels (TRL), **industrial RD&D projects must be supported immediately** to ensure solutions are available by 2030 for a wide range of industrial applications.

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1 NAEI point source emissions 2017 LINK

2 Zero Carbon Humber initiative LINK LINK 3 Dependent on fast progress in RD&D of equipment

Industry – key messages

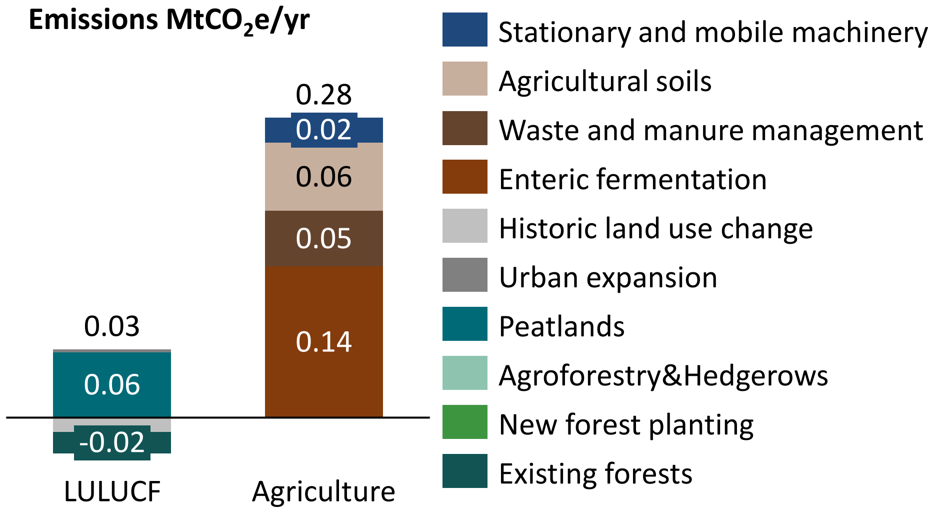
- **There is limited heavy industry in the region**; the sectors most represented are glass and chemicals and there is a cluster of industry in Knottingley.
- **The industry sector sees slow progress in the 2020s** due to significant RD&D being required to develop commercially ready solutions; the progress is primarily phase out of coal and oil, efficiency improvements and some electrification of heat.
- **By 2038 the emissions have reduced by up to 87% to 0.13 MtCO$_2$e/yr** due primarily to fuel switching to low carbon fuel (electricity, hydrogen or bioenergy) in the 2030s. Electricity is considered low carbon as the national power sector is decarbonising.
- **In 2038, the majority of remaining emissions are from electricity use at non-zero carbon intensity,** but there are contributions from residual natural gas usage and process emissions.
- The scenarios use similar technologies and measures, but at differing levels and timeframes:
  - **The Max ambition scenario focusses on early electrification of heat,** followed by some later hydrogen, bioenergy and CCS application (including BECCS).
  - **The High H2 scenario undergoes rapid change from 2028 to 2035** as many sites undergo the switch from natural gas to hydrogen.
  - The Balanced scenario sees the slowest progress in the 2020s, but accelerates in the 2030s as hydrogen and CCS become available and **gas grid decarbonisation (biomethane blending) supports sites which haven't switched fuel**.
- **Solutions are very sector and application specific, with RD&D needed and considerable uncertainty on feasible pathways**
  - The Glass sector utilizes all main technology options across the scenarios, with likely implementation of hybrid furnaces (electric-gas or electric-bio-oil) and potentially later CCS.
  - The chemicals sector relies on significant electrification and hydrogen, with CCS implemented in large plants where natural gas use remains.
- Depending on the scenario the electricity demand increase could be as much as 95%, or hydrogen could supply >45% energy.
- **Hydrogen and CCS infrastructure will be geographically specific**, with it likely nucleating near the Humber in Selby. Hydrogen and/or CO$_2$ pipelines may extend from there to nearby industrial plants in the late 2020s or early 2030s. Teesside is an alternative industrial cluster which may see infrastructure development in the 2020s.

Agenda

- Introduction
- Key findings
- Sector pathways West Yorkshire
  - Transport
  - Buildings
  - Power
  - Industry
  - LULUCF + agriculture
  - Waste
- Additional information
- Technical Appendix

Current emissions situation in the region – LULUCF and Agriculture
Emissions from land use and agriculture in WY are small

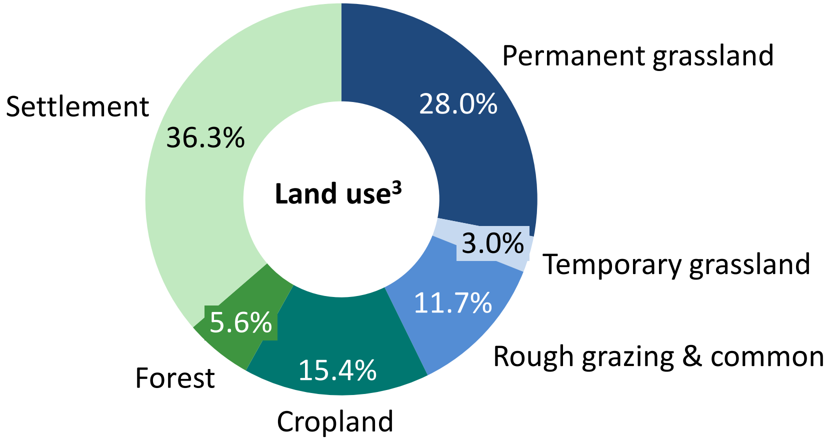
West Yorkshire



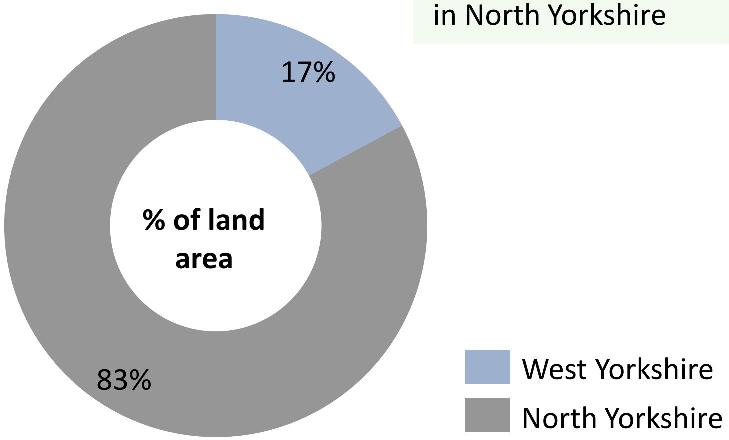
Land Use, Land Use Change and Forestry (LULUCF)
Covers carbon stock changes in soil, vegetation and timber and GHG emissions from non-agri land management

Agriculture
Covers emissions associated with livestock, manure, fertilizer, agricultural land management

- source of CH_4 and N_2O, the primary greenhouse gases (And included in this
- Limited CO_2 emissions and energy consumption, primarily from agricultural machinery



The majority of the land area of the study region is in North Yorkshire



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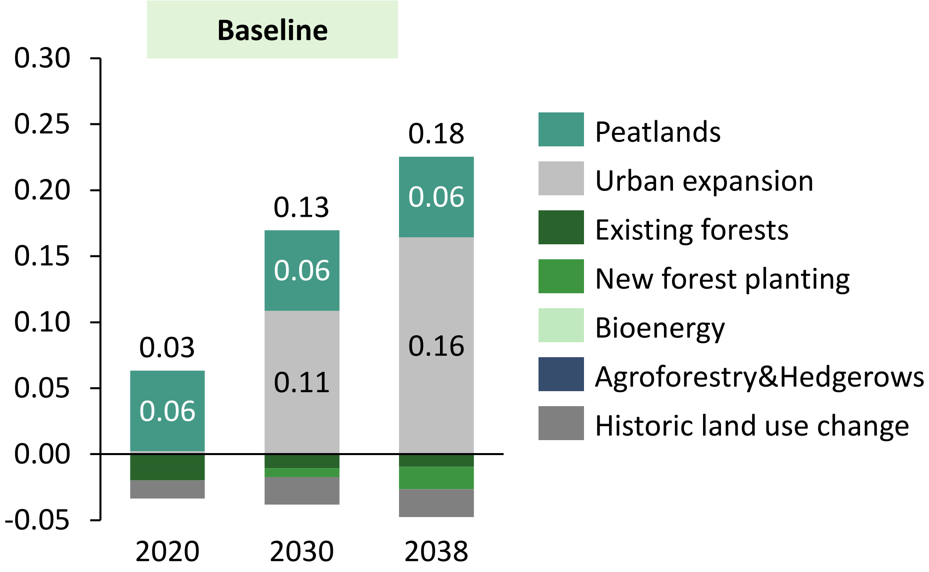
1 Source: BEIS GHG emissions inventory and subnational energy consumption and CO_2 emissions datasets 2017, combined with new methodology. 2 Agriculture area/number data is for 2016 (most recently published regionally disaggregated data).
3 Note that peat soils can sit within any of the categories

LULUCF Baseline: LULUCF emissions increase due to urban expansion

West Yorkshire

Emissions projection MtCO2e/yr

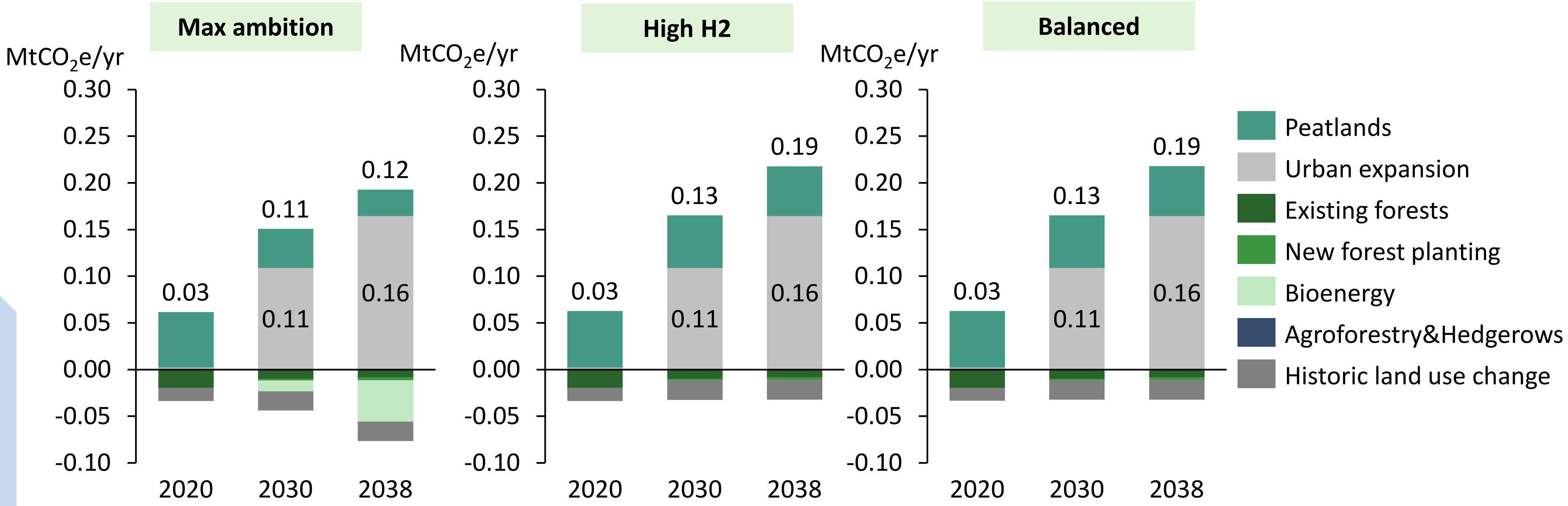


- The chart shows the emissions change from the land use sector in the baseline scenario. The bars are split into contributions from the 7 main subsectors.
- The numbers on each bar show the total net emissions, once the positive and negative contributions have been summed.
- Current land use emissions are dominated by peatlands as the main positive source. Peatlands in Yorkshire have a lower carbon intensity than the national average due to their location/type, but there is a high proportion of peatland.
- The total **emissions in the land use sector increase by 0.15 $MtCO_2e/yr$ by 2038 in the baseline scenario**, primarily due to urban expansion.

- For all scenarios, it is assumed that the area of **urban development** increases in line with the projected human population for the region (ONS statistics). The area required for urban development is upscaled from that required for housing. The same projections are used across all scenarios.
- **West Yorkshire has very limited potential for applying land-based mitigation activities** because of the projected increase in population and therefore demand for urban development.
- The baseline scenario assumes no increase in bioenergy or implementation agroforestry.
- Forest planting rates have been adjusted to take account of the aspirational targets for afforestation in the region for the White Rose Forest initiative.
- Whilst there are some peatland restoration activities ongoing, which are likely to be improving the emissions associated with peatlands, there is limited evidence as to the quantitative magnitude, so the baseline scenario assumes no change in the associated emissions. However, the emissions reduction scenarios do include this impact.

LULUCF progress from bioenergy crops, forest planting and peatland restoration is insufficient to offset urban expansion emissions

Emissions projection MtCO2e/yr



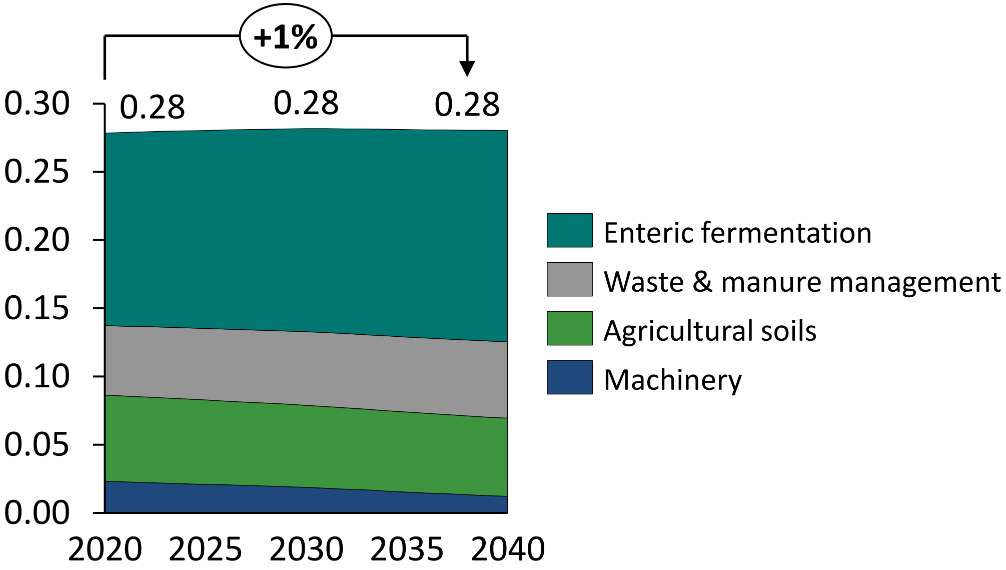
- The scenarios see LULUCF emissions **increase over time from 0.03 to 0.12MtCO$_2$e/yr by 2038** even in the Max ambition scenario.
- Emissions reductions from new forest planting, peatland restoration and bioenergy crops are insufficient to offset the increase in emissions due to urban expansion.
- Many measures have not been applied due to constraints on land area availability in the region.
- In all scenarios, forest area increases by ~170 ha 2020 - 2038. However this is a very small contribution to emissions reduction in West Yorkshire compared with the larger area in YNY.
- Peatland restoration aims to restore 100% lowland peat and 60% of upland peat by 2038 in the Max ambition scenario.
- Agroforestry measures include up to 9% of cropland converted to alley cropping[2], 11% of permanent and rough grazing converted to woodland grazing by 2038. WY does not increase hedgerow length due to insufficient permanent grassland available.
- Bioenergy crops reach over 5.7 kha by 2038 in the Max ambition scenario, but are not implemented in other scenarios

1 This refers to new hedgerows which will be taking up carbon (existing hedgerows are assumed to be in steady state and carbon neutral) 2 more trees on cropland, for example field boundaries or alley cropping

Agricultural emissions increase in the baseline scenario due to population growth requiring greater production

West Yorkshire

Agriculture emissions $MtCO_2e/yr$



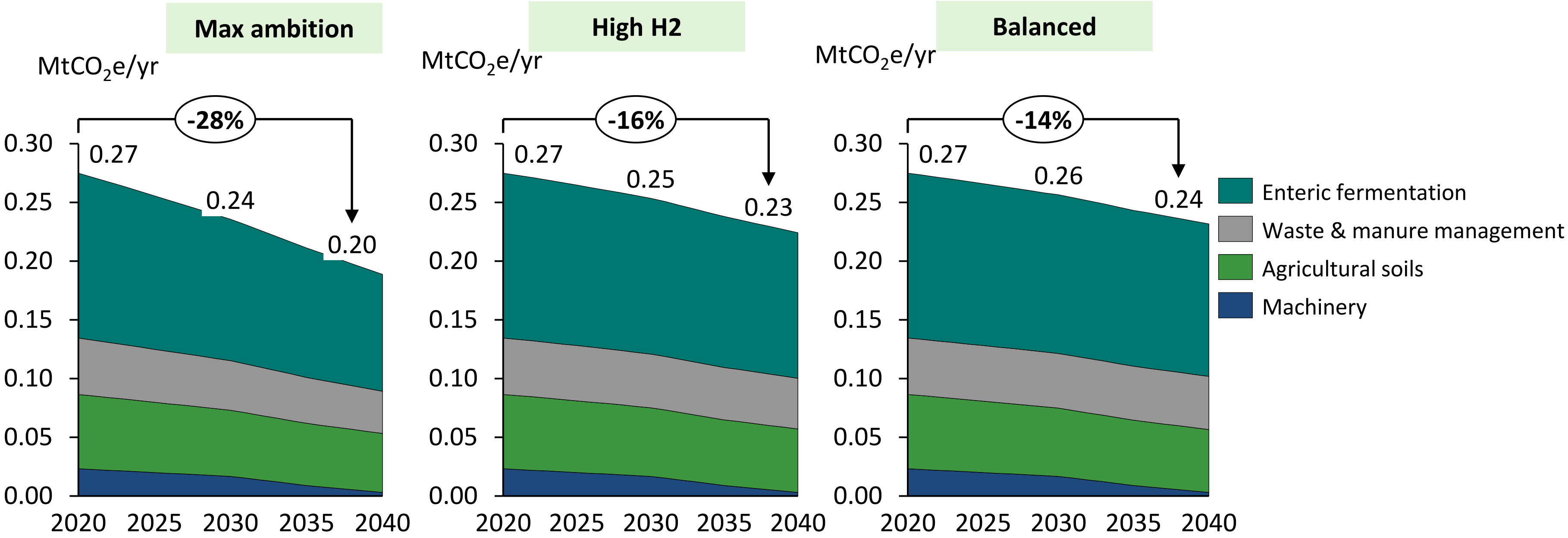
- The chart shows the emissions change from the agriculture sector in the baseline scenario. The graph is split into contributions from the 4 main subsectors.
- The numbers represent the total annual emissions form the agriculture sector in 2020, 2030 and 2038.
- Current agricultural emissions are dominated by enteric fermentation and agricultural soils.
- The majority of the emissions from the sector are CH_4 and N_20, rather than CO_2 (CO_2 is predominantly from machinery)
- The total **emissions in the agriculture sector increase by 1% by 2038 in the baseline scenario.**

- Agricultural emissions in West Yorkshire are very limited, at only 0.28 $MtCO_2e/yr$.
- Agricultural emissions struggle to decarbonise, partially due to the timescales of many mitigation measures. However, agricultural land management practices are crucial in supporting emissions reductions in other sectors, such as land use.
- It is assumed that the region maintains per capita agricultural production in study region, therefore agricultural output must increase to feed a growing population.
- Agricultural yield increases slowly, following the current trend, in the baseline scenario.
- The baseline scenario does not assume significant agricultural innovation in terms of either farming practices or technology development.
- Agricultural machinery makes some progress through fuel switching, but some machinery is still petrol/diesel by 2038.
- The slow progress is insufficient to offset the increase in production required, leading to an increase in emissions overall.

Thomson, Misslebrook et al (2018).

Agriculture sees some emissions reduction through increased agricultural efficiency, diet change and food waste reduction

Agriculture emissions $MtCO_2e/yr$

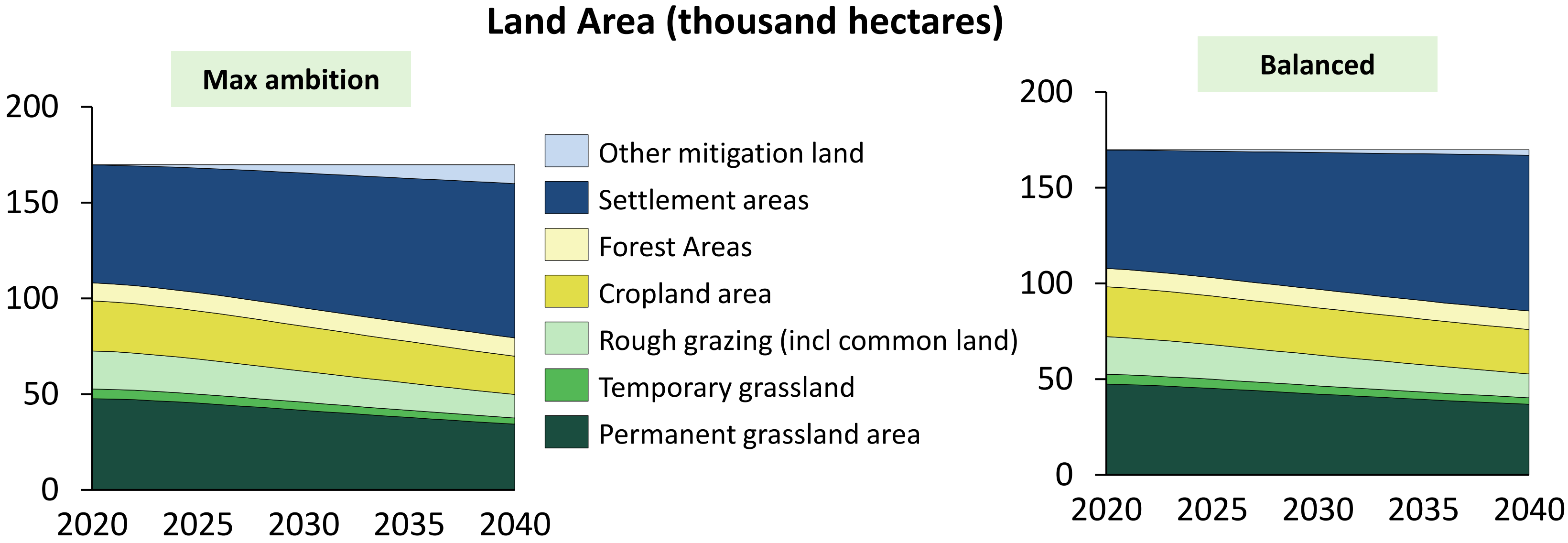


West Yorkshire

- Agricultural emissions struggle to decarbonise, partially due to the timescales of many mitigation measures. Livestock directly produces emissions from the animal, so there are limited options to mitigate these beyond diet change. However agricultural changes play a crucial role in the emissions reductions in the land use sector and in generating bioenergy for the energy sectors.
- **Even under the highest ambition, only a 28% reduction in emissions is seen by 2038.**
- Measures include increased stocking density, improved crop yields, Nitrogen use efficiency, food waste reduction, diet change and manure management (see Technical Appendix for more detail).
- The Max ambition scenario has greatest emission reductions because it has higher ambition for diet change and food waste reduction (32% reduction in red meat and dairy consumption and 35% reduction in food waste by 2038). This not only reduces emissions from livestock, but also spares more land for land-based mitigation activities
- The Balanced scenario assumes only 13% reduction in meat and dairy consumption and sees lower ambition in food waste reduction, stocking density and indoor horticulture.

Thomson, Misslebrook et al (2018).

Land use and agriculture Land area is dominated by grassland and increasing settlement area leaving little spare for mitigation



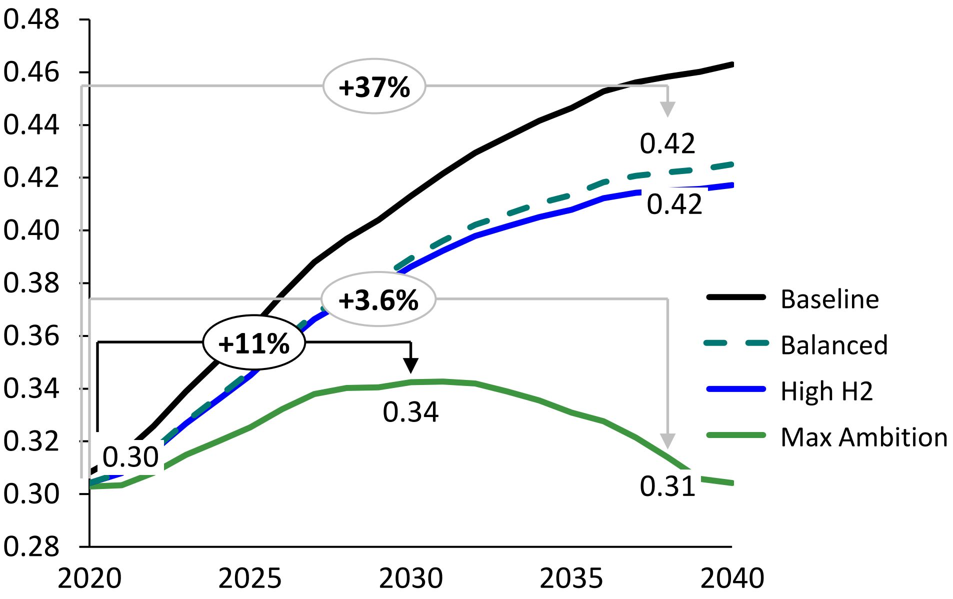
- WY has very limited land available for additional mitigation activities because of other demands on land due to population increase leading to urban development and requiring greater agricultural production.
- There is a reduction in grassland, grazing land and cropland areas (for example through increased agricultural efficiency and diet change) to make space for forest area and other mitigation land. Permanent grassland is in highest demand for conversion to urban and forested land. Forest area increases by only 180 hectares by 2038.
- Not all land spared by agricultural mitigation has been used for land-based mitigation, leaving a small ‘buffer’ in the Max ambition scenario for:
  - possible future land losses, e.g. due to flooding, loss of forest due to natural disturbances and pests;
  - or for additional mitigation, solar PV or wind power, “re-wilding” or increased agricultural production.

  In WY this amount of surplus land is around 16 kha in the Max ambition scenario in 2038, with the High H2 and Balanced scenarios at 1 and 0 kha surplus respectively.
- Note that peatland can sit within any of the land area categories. Mitigation from peat restoration comes from restoration of cropland and intensive grassland on peat soils and restoration of degraded upland peat soils.

Density of housing development is based on study region average densities from the Ministry of Housing, Communities and Local Government (MHCLG) (21.85 dwellings/hectare, range 17.17-31.91)

LULUCF and Agriculture – the land use sector becomes net-negative, offsetting the majority of agricultural emissions

Emissions projection LULUCF + agri MtCO2e/yr



- The chart shows the emissions change from the land use and agriculture sectors combined across the scenarios.
- The numbers represent the total annual net emissions form the combined sector in 2020, 2030 (Max ambition) and 2038.
- Current emissions are dominated by enteric fermentation, agricultural soils & peatland
- The total **emissions in the combined LULUCF and agriculture sector increase by 11% by 2030 but only 3.6% overall by 2038 in the Max ambition scenario.**
- Other scenarios see larger increases in emissions.

- The Max ambition scenario sees the combined land use and agriculture sectors increase to a peak at 2030, but then reduce again to around 2020 levels, so making **no contribution to the regions emissions reductions.**
- The increase in emissions is primarily due to urban expansion.
- Emissions reductions are dominated by peatland restoration, bioenergy crops and diet change away from meat and dairy.
- Land use emissions face challenges in limited land availability to apply measures such as new forest planting and agroforestry.
- Agricultural emissions (mainly non-CO_2) struggle to decarbonise, partially as the timescales of many mitigation measures may be decades and partly as some emissions are directly from livestock, so particularly challenging to mitigate.
- The main differences in the agricultural scenarios are the extent of diet change, food waste reduction and agricultural innovation.
- The main differences in the LULUCF scenarios are around the rate of bioenergy crop planting and peatland restoration; the Max ambition scenario makes most progress as greater diet change frees up more land for these activities.
- More details on the underpinning assumptions can be found in the Technical Appendix.

AFOLU: Agriculture, Forestry and other land use

Agriculture and land use – West Yorkshire has difficult decisions to make around land use to prioritise measures

West Yorkshire land and agricultural characteristics:

- **West Yorkshire has limited potential for land-based emissions mitigation,** because of its smaller land area, high projected population growth and therefore limited land availability for new forests or other actives.
- **West Yorkshire is urban in character compared with the UK average.** The population density is 13.6 person/ha in NY compared with 2.7 in the UK and 4.3 in England. The land area of WY is ~170 kha, which is 0.7% of the UK.
- Low agricultural emissions in the area nevertheless are challenging to mitigate
- Forest planting is possible to a certain extent through initiatives such as White Rose Forest, but difficult choices must be made on competing land uses.
- **West Yorkshire may choose to outsource some of its land uses** to other, more rural regions, to allow space for land based mitigation activities as well as activities such as solar PV or wind electricity generation, hydrogen and CCS infrastructure and bioenergy production.

The scale of change for agriculture and land use in West Yorkshire:

The highest levels of ambition include:

- **~170 hectares of new forest planting** between now and 2038
- **5.7 kha of bioenergy crops** planted between now and 2038
- **100% of peatland restored by 2038**, although not all upland peat may be possible
- **32% reduction in red meat and dairy consumption** and 35% reduction in food waste by 2038
- By 2038, 9% of cropland converted to alley cropping and 11% of permanent and rough grazing converted to woodland grazing.
- **7% increase in animal stocking density** by 2038.

Land use and agriculture – key messages

- The emissions from **land use and agriculture in the region are only a small contribution** to the overall emissions (currently 0.3 MtCO2e/yr).
- **The emissions in the land use and agriculture sector make little progress by 2038, having increased by 3.6%,** so do not come close to reaching the net-zero by the target 2038.
- **The scenarios see LULUCF emissions increase over time in all scenarios due mainly to urban expansion**.
    - The main emissions reduction is from peatland restoration and bioenergy crops
    - Land use emissions face challenges in limited land availability to apply measures such as new forest planting and agroforestry.
- Even under the highest ambition**, only a 28% reduction in agricultural emissions is seen by 2038, with 0.2 MtCO$_2$e/yr remaining.**
    - Agricultural emissions struggle to decarbonise, partially due to the timescales of many mitigation measures.
    - The main contribution is diet change away from meat and dairy, which not only reduces the emissions from meat and dairy production, but also frees up land for other mitigation activities.
- The Max ambition scenario has greater emission reductions than the High hydrogen and Balanced scenarios because it has higher ambition for diet change and food waste reduction, sparing more land for land-based mitigation activities.
- **West Yorkshire has very limited potential for applying land-based mitigation activities** because of the projected increase in population and therefore demand for urban development and agricultural output. Many measures have not been applied due to space constraints. This could be addressed by **increasing the density of urban development, or outsourcing agricultural production** to other areas of the UK, with knock-on impacts on employment. If this route were chosen, additional emissions reductions could be realised through further measures such as increased forest planting.
- **There must be trade-offs in the choice of land use** between uses that provide employment (e.g. agriculture), uses that reduce emissions in the sector (e.g. forests), other mitigation uses (e.g. solar PV) and land for urban development or infrastructure.

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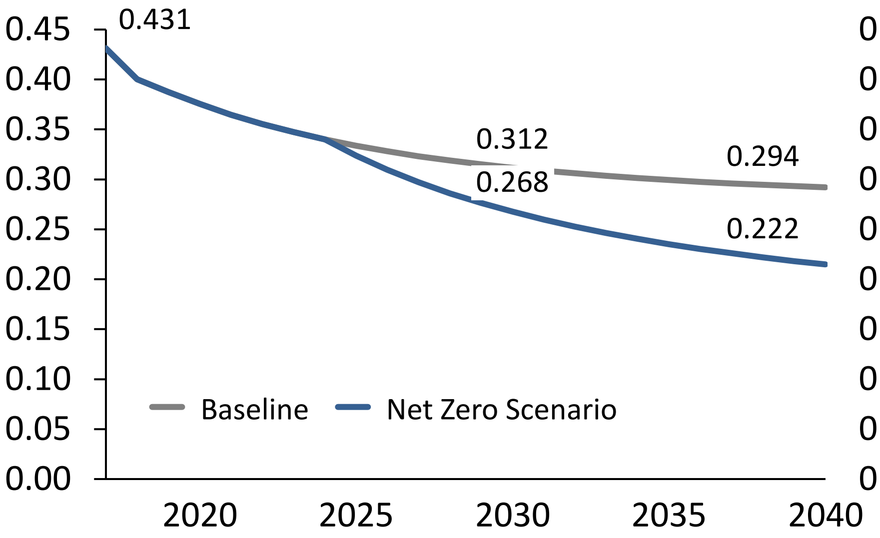
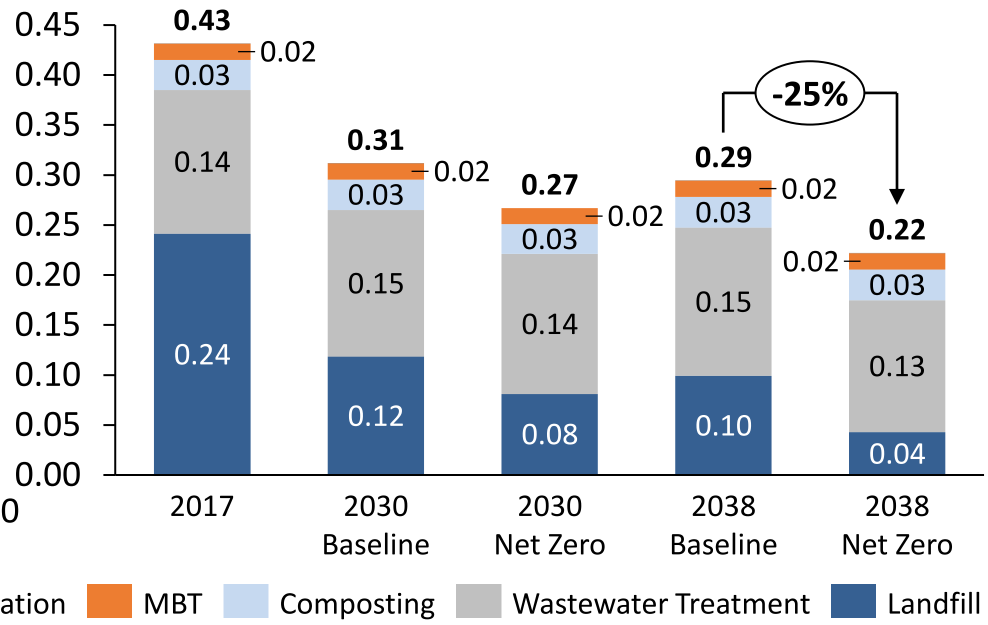
Waste: following CCC's net zero modelling, emissions reduce by 49% by 2038 compared to 2017 and by 25% compared to the baseline in 2038

West Yorkshire

Total Emissions- MtCO2eq/year



Breakdown- MtCO2eq/year



- Current waste sector emissions and decarbonisation pathways are based on CCC's Net Zero Report (2019) and the Further Ambition Scenario within it. Only one Net Zero waste scenario is created for this study for simplification purposes.
- The distribution of waste emissions at regional level is obtained by proportioning England-level emissions according to the tonnes of waste disposed in the region through each technology*. Wastewater treatment emissions are distributed according to population.
- Composting, MBT (mechanical biological treatment) and waste incineration emissions stay almost constant over the period.
- Compared to baseline, wastewater treatment emissions reduce by 11% by 2038 due to efficiency and process improvements. These actions may result in cost savings or may be achieved at zero net cost.
- Landfill emissions constitute the largest reductions (31% by 2030 and 57% by 2038 over the baseline) due to the England-level targets set by CCC's Further Ambition Scenarios: 20% reduction in avoidable food waste, eliminating 5 key biodegradable waste streams sent to landfill and increasing recycling of municipal waste to 70% by 2025.

MBT: Mechanical biological treatment
* Wastewater treatment emissions are distributed according to population.

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Scenario features (1/2) – the Max ambition scenario enables regional leadership but faces challenges in cost and rapid behaviour change

The table below (over 2 slides) compares key features of the scenarios in terms of benefits, challenges, investment, infrastructure and consumer considerations. It is not intended to show a "winner" or to provide an exhaustive list of features on which to evaluate a pathway.

	Max ambition	High H2	Balanced	All scenarios
Key benefits & opportunities	• Fastest emissions reduction • Regional leadership in climate emergency enabling export of skills	• Regional leadership in hydrogen and CCS technology and skills • Potential for regional export of low carbon hydrogen and electricity	• Flexible, resilient energy system relying on multiple fuels / technologies • More consumer choice	• Health benefits of active travel and reduced air pollution • New forest planting improves landscape and supports environment
Key risks & challenges	• Required electricity system upgrades (generation, network, DSR, storage) delayed, restricting heat pump & EV deployment • Consumer acceptance of heat pumps (visual/noise concerns, behaviour change, level of service etc.). • Poor quality heat pump installation impacts comfort • High energy efficiency requirements not met • Consumer resistance to diet change	• Large-scale H2 production (or CCS) is not available / viable in time, causing delays in emissions reduction. • Reliance on natural gas import for H2 production impacts energy security. • Many H2 applications are at early stages • Consumers perceive hydrogen as unsafe or the switchover as inconvenient	• Many of the risks of the Max ambition & High H2 scenarios, but generally at a reduced level due to the wider range of technologies deployed. • Risk of higher costs in some areas due to deployment of multiple types of infrastructure	• Competing land uses may restrict forest planting and hinder progress in LULUCF • Low carbon equipment for industry is not technically proven • Requirement for consumer behaviour change • Misalignment with national policy timing • Rapid building of supply chains and infrastructure

Scenario features (2/2) – scenarios differ in the profile and focus of investment, infrastructure and consumer change

	Max ambition	High H2	Balanced
Cost & investment	High capital cost due to: • Rapid deployment causing scrappage and an 'un-optimised' system • High capital cost of heat pumps Cost is focused largely in buildings, with smaller infrastructure changes	• Uncertain cost, depending largely on hydrogen fuel cost. • High investment required in H2 & CCS infrastructure, with significantly lower building level capital costs • H2 refuelling infrastructure investment alongside EV charging	Some applications will be lower cost due to the ability to choose most cost-effective technology/fuel/ intervention for the application
Infrastructure, skills & coordination	• Rapid electricity network reinforcements alongside battery storage, DSR & renewable generation • Early heat pump installer training and supply chain development • Rapid EV charge point deployment	• Hydrogen generation, distribution and end-use technology deployment • Lower electricity system impacts • Skills around installation and operation of hydrogen technologies	• Some investment required in both electricity and hydrogen infrastructure • Wider range of skills required
Consumer considerations	• Rapid behaviour change required e.g. mode shift to active travel, diet change, heat pumps • Limited consumer choice due to timeframes of transition ruling out some technologies	• Consumer acceptance of hydrogen and CCS uncertain • Lower behaviour change required in homes, businesses and industry (H2 boilers)	• Potential for greater consumer choice due to availability of multiple fuels and technologies • Equality between consumers who have hydrogen and those who don't must be considered.

- The scenarios differ in the extent of change required, and whether the change is primarily for the consumers (buildings and transport) or in the infrastructure system.
- The investment profile also differs, with differing cost breakdown between technology capital cost, fuel cost, infrastructure and other resources.

This study allows high-level comparison of the pathways, but should not be used to 'choose a scenario/pathway'

Whilst in some places we compare the scenarios in terms of emissions, energy, technologies or cost, this study is not intended to enable a decision to be made on which scenario to pursue. A pathway should not be chosen immediately, for a number of reasons:

1. The study is not detailed enough to have considered all factors which have implications for which the 'optimal' scenario is. For example, a detailed spatial infrastructure assessment would be needed, including high resolution temporal modelling of the electricity network impacts and the associated infrastructure costs, to have full visibility of some important costs and constraints.
2. There is some crucial evidence not yet in place on certain technologies. For example, there are still research and demonstration steps required to prove the feasibility and viability of hydrogen for heat.
3. The pathway followed in Yorkshire will be impacted by some important national decisions during the 2020s. These will impact the national government incentives and the availability of infrastructure and fuels.

This does not mean the region should wait to act, but should **take low regrets actions which can support any pathway, and gather further evidence to support a decision.**

The scenarios are there to represent different potential pathways, depending on a number of uncertainties in technology development, cost, policy and consumer preference/behaviour.

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No CCS sensitivity – without CCS, the region's emissions could be 4.2 $MtCO_2e$/yr greater in 2038, not reaching net-zero

CCS is widely accepted as being essential to meet net-zero targets. However, progress in the UK has been slow, with no full-chain projects deployed yet. CCS is assumed in all emissions reduction scenarios in this study, however a high-level indicative assessment was done on the impact of CCS not materializing:

- **Power sector emissions will be significantly higher**, as natural gas and bioenergy turbines won't be able to use CCS to minimize their emissions. Emissions from power generation in the region could be as much as 1.65 $MtCO_2e$/yr higher in 2038 without CCS[1] (before accounting for BECCS).
- There will be **no BECCS at Drax, so no portion of negative emission** can be attributed to the region. For Y&NY and LCR, this removes the -3.37 $MtCO_2e$/yr of negative emissions (West Yorkshire claims no negative emissions).
- **Hydrogen generation through natural gas reforming with CCS will not be possible**. It is unlikely new reformation plants would be built without CCS, so H_2 would likely be produced entirely through electrolysis, with higher cost and limits on scale in the medium term. If all H_2 were produced through electrolysis, the cost of heating buildings in the High H2 scenario would increase by over £3bn cumulatively in the study region (and under our assumptions the CO_2 emissions also increase). This hydrogen is also not likely to be used for power production.
- **Industrial decarbonisation would either be less effective or more expensive**. In this estimation we assume the same fuel mix, simply without CCS applied to flue gases. This increases industrial emissions in the study region in 2038 by around 0.23 $MtCO_2e$/yr, almost doubling the remaining emissions.

Approx. increase in 2038 emissions without CCS

Study region	MtCO2e/yr
Max ambition	3.6
High H2	4.2
Balanced	3.8
West Yorkshire	
Max ambition	0.1
High H2	0.6
Balanced	0.2
Y&NY	
Max ambition	3.4
High H2	3.6
Balanced	3.5

Without CCS no subregion would reach net-zero by 2038 and the emissions could be up to 4.2 MtCO2e/yr higher for the study region

More information on the impact of not having CCS on the power sector is provided in the Technical Appendix

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[1] Note that these emissions are not accounted in the scenario emissions (only electricity consumption emissions at national carbon intensity) so this does not in itself impact the pathway emissions.

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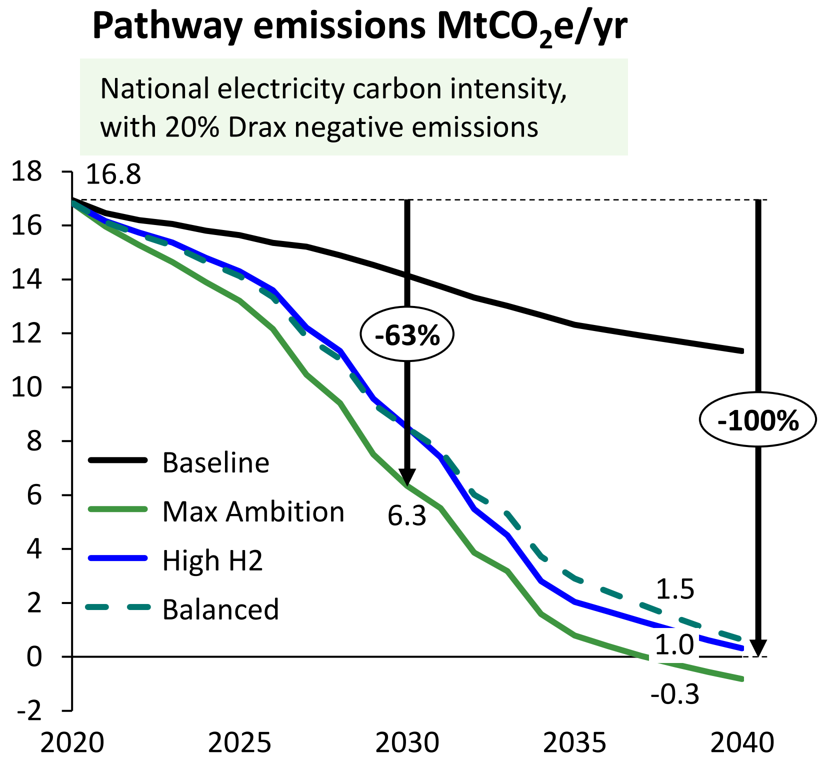
Leeds City Region – scenario emissions

- This graph compares the emissions trajectories across the scenarios. All pathways make ambitious emissions reductions over the next 2 decades, using different technologies, measures and fuels.
- The pathways include 20% of the negative emissions from Drax BECCS plant[1,2] as with Y&NY. This relies on retrofit of the bioenergy turbines with CCS. New forest planting activities also provide negative emissions.
- **The Max ambition pathway reduces emissions by 63% by 2030 and reaches net-zero by 2038**; the other scenarios don't reach net-zero until just after 2040, with 1.0 and 1.5 MtCO2e/yr remaining in 2038 in the High H2 an Balanced scenarios respectively.
- The key differences between the scenarios are the technology choice, level of electrification vs hydrogen in heat and transport and rate of technology deployment and behaviour change.



- **The Max ambition scenario makes considerably more progress by 2030**, due to ambitious rates of electric vehicle roll-out and uptake of active travel, unprecedented heat pump installation and faster rates of forest planting. Despite this, the emissions are still 39% of the current emissions by 2030, with challenges including misalignment with national policy timing, technology readiness, behaviour change and stock turnover rates.
- The High H_2 and Balanced scenarios make less progress in the next few years, but progress accelerates from the mid-2020s. **The High H_2 scenario sees rapid emissions reductions 2028-2035 as the gas grid is repurposed** for hydrogen, facilitating the switch of buildings, industry and some transport to hydrogen. The Balanced scenario sees steady progress through a mix of technologies deploying at different rates.

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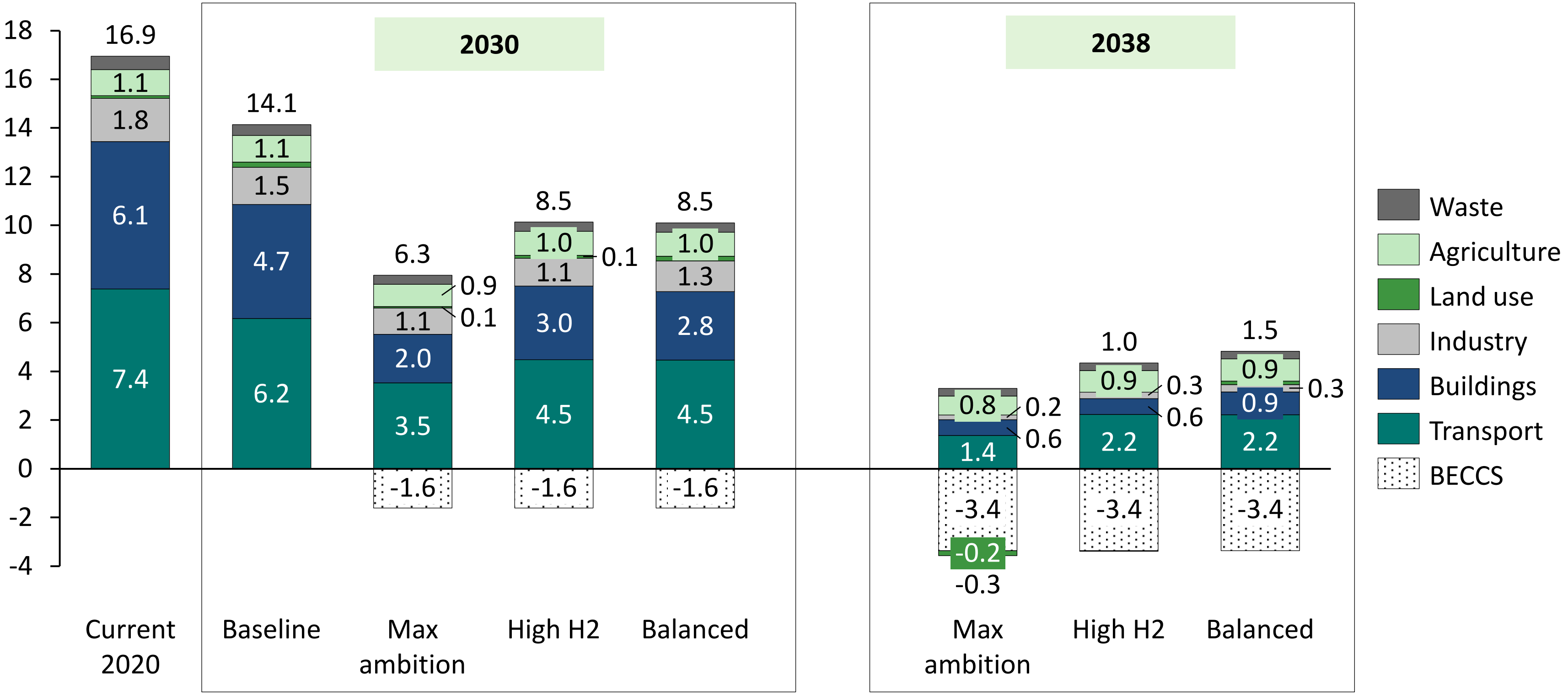
1 BECCS: Bioenergy Carbon Capture and Storage, NET Negative emissions technology 2 The net-zero date is highly sensitive to the % BECCS selected; 20% is used as it is the proportion of generated electricity in N Yorkshire that is consumed in NY in the Max ambition pathway by 2040

Leeds City Region - Remaining emissions in 2030 and 2038

Emissions remaining compared with current MtCO$_2$e/yr



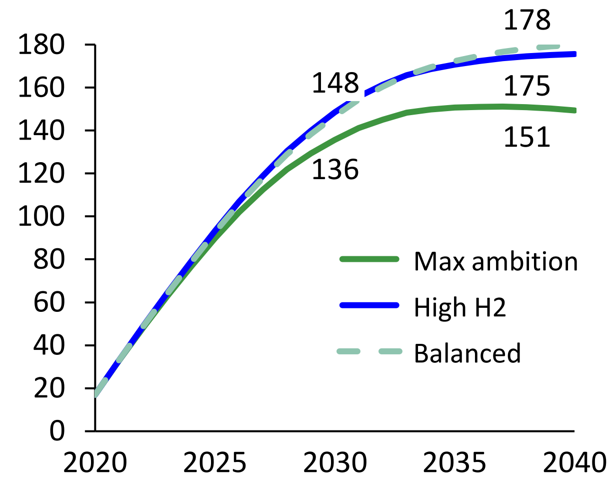
- In 2030 there are significant emissions remaining, particularly in transport and buildings. A key challenge in buildings and transport is the stock turnover rate.
- In 2038, transport and agriculture play significant roles. Transport is hindered by slow progress in aviation and in agriculture a challenge is the time taken for both change (e.g. diet change) and for changes to take effect.
- In the Max ambition scenario, remaining emissions are offset by negative emissions from BECCS and new forest planting to provide a net-zero region.

BECCS – bioenergy carbon capture and storage

Leeds City Region – Cumulative emissions

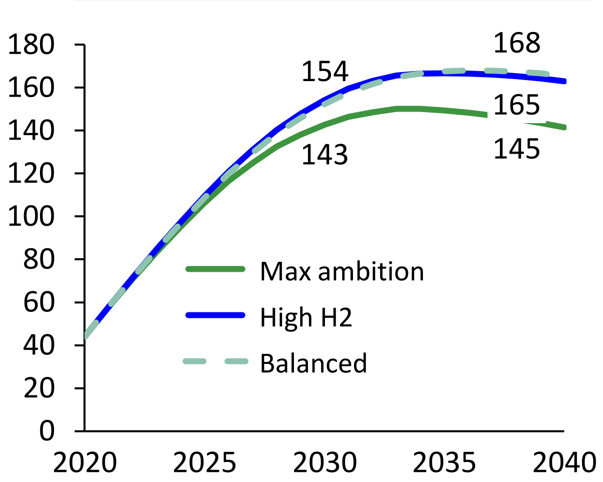
Cumulative emissions $MtCO_2e$

From 2020 including all emissions in the study scope



Cumulative emissions $MtCO_2$

From 2018, broadly following Tyndall Centre emissions scope[1]



- From a climate perspective, the net cumulative CO_2 emitted is the key factor, as this is the CO_2 contributing to global warming. The cumulative emissions of all scenarios rise rapidly during the 2020s, but then flatten around 2030 as interventions slow emissions and as BECCS is implemented.
- For all emissions (left), the **region reaches 151 – 178 $MtCO_2e$ cumulatively by 2038** depending on the scenario.
- The Tyndall Centre developed a science-based carbon budget for the region based on compliance with the Paris Agreement. The cumulative CO_2 budget is related to the energy system only and excludes land use, agriculture, aviation, waste and non-CO_2 emissions[1]. Under these conditions, the LCR net cumulative carbon emissions are 145 – 168 $MtCO_2e$ by 2038 depending on the scenario.
  - The LCR carbon budget is 118 $MtCO_2$ 2018-2100 (112.8 by 2038), and **the region breaches this in 2026, but cumulative net emissions fall in the late 2030s** (due to negative emissions measures).

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[1] Cumulative carbon budget work is approximate, as Element modelling is not set up for the specific conditions of the Tyndall Centre carbon budgets.

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There are options to further reduce emissions, but many of these are speculative and further evidence is needed

Whilst the emissions scenarios have modelled a wide range of measures to reduce emissions, there are some additional options which could be explored to further mitigate emissions. Some of these are changes to the scope and assumptions on the energy system, while others are speculative options from less mature technologies or concepts.

- **Even more ambitious renewable electricity generation** (e.g. solar PV and onshore wind) to offset remaining electricity related emissions from the national grid.
- **Offsetting emissions through negative emissions methods, which include**
  - Further BECCS in the industry sector to produce negative emissions – e.g. large glass plants (primarily West Yorkshire)
  - Further BECCS in hydrogen generation and end-use through biogas blending
  - **Direct air capture** with CCS – CO_2 is captured directly from the atmosphere and used or stored. This provides negative emissions to offset remaining emissions from the region. This will depend on the development of cost-effective capture technologies and significant CO_2 transport infrastructure.
  - **Increased forest planting:** West Yorkshire has space constraints looking forward as population grows; this limits measures such as new forest planting. Increasing the density of urban development and outsourcing some agriculture to other areas of the UK could be used to free up space for new forest planting and peatland restoration, thus reducing emissions. These measures must be completed as soon as possible to realise the emissions reductions in time.
- **Innovative land management and further diet change**, including novel proteins
- **Transport:** quicker lifestyle change than modelled, e.g. following the COVID pandemic, the shift to remote working and decrease in business trips, including decreased aviation.
- **Circular economy system changes,** for example to reduce material consumption, processing and disposal. This primarily impacts the industry and waste sectors, including further waste prevention and diversion, new product design and new processing methods.
- **Changes in construction materials to reduce emissions and store carbon in new buildings** – for example, increased use of wood-based materials or aggregates made from CO_2 (Carbon capture and utilisation - CCU)
- **Carbon offsetting** outside the region (e.g. through supporting emissions reduction schemes elsewhere) – this is a short-medium term solution only.

All of these options require detailed assessment to fully understand the impact, scale and wider implications.

What areas of the modelling and results are at sub regional level (West Yorkshire and York & North Yorkshire separately)?

Sector	Notes on sub-regional level of information
Transport	• Travel activity (vehicle km and modal share) is derived and modelled at subregion level • Vehicle uptake and broad demand reduction assumptions are applied across the study region[1] • Rail emissions are modelled relative to historic emissions, based on modelled change in rail activity at subregion level; however, assumptions of proportion of freight activity and split of diesel/electricity are estimated and applied at the study region level • Aviation emissions are modelled at study region level and disaggregated to subregions afterwards
Buildings	• Domestic building stock and pathways are built up individually for the subregions • Non-domestic modelling is as the full study region, based on energy (not building number). This is disaggregated afterwards to estimate the energy and emissions for each subregion. • Assumptions are specific to the building type, not the region, but this translates through the domestic stock
Power	• Current power assets are fully mapped to subregions and modelling is mostly on a subregional basis • New assets are placed based on a combination of factors: land area, current power plant planning applications, current capacity of power technology in subregion • Spatial feasibility assessment of power assets is not completed (e.g. wind generation in National Parks)
Industry	• Industry emissions are separated by subregion, with better spatial resolution over the heavy industry (70% emissions) than small industry, which is estimated by business units. The subregion breakdown of fuel and emissions going forward is approximate as assumptions are based on the study region as a whole and the small number of plants in each subregion was not modelled individually.
LULUCF & agriculture	• LULUCF and agriculture pathways are based on local authority level land mapping • Assumptions are based on land type and agricultural activity (rather than region) but are adjusted to reflect space constraints by sub region.

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1. Some small variations for subregions are applied where possible and appropriate

Scope of emissions in region to be included (Agreed)

In Scope

- ✓ Fuel combustion for heat in industry and buildings, including district heating
- ✓ Transport emissions from road kms travelled in the region on a well-to-wheel basis.
- ✓ Transport emissions from rail and aviation (considered at a high-level)
- ✓ Emissions from electricity consumed in the region at national electricity carbon content
- ✓ Emissions from producing hydrogen (for hydrogen consumed in the region)
- ✓ Industrial emissions captured through CCS will be removed from the inventory.
- ✓ Emissions associated with agriculture and land use in the region, including CO_2, N_2O, CH_4.
- ✓ Negative emissions from BECCS, new forest planting and bioenergy crops inside the region

Out of scope

- CO_2 emissions associated with electricity generation and export (surplus power).
- Emissions from shipping
- Scope 3 embedded emissions in product/service imports
- Non-CO_2 GHG emissions from buildings, transport, industry, power (except those from fuel combustion)
- Emissions offsetting outside region
- Only a % of the negative emissions of national projects e.g. Drax can be allocated to the region
- Fundamental economy changes and circular economy analysis

NET: Negative Emissions Technology

Glossary and Terminology

Term	Meaning
AD	Anaerobic digestion
BECCS	Bioenergy with carbon capture and storage
BEV	Battery electric vehicle
BioCNG	Compressed natural gas, 100% biomethane
Capex	Capital expenditure
CCGT	Combined cycle gas turbine (power plant)
CCS	Carbon capture and storage
CHP	Combined heat and power
CO_2	Carbon dioxide
DSR	Demand side response
EfW	Energy from waste
EV	Electric vehicle
FCEV/H2FC	(Hydrogen) Fuel Cell Electric vehicle
H2	Hydrogen (as a fuel)
H2GT	Hydrogen gas turbine (power plant)
Ha (kha)	Hectares (land area)
HGV	Heavy good vehicle
HHP	Hybrid heat pump

Term	Meaning
kW (MW, GW)	Kilowatt – unit of power
kWh (MWh etc)	Kilowatt hour – unit of energy
LPG	Liquefied petroleum gas
LULUCF	Land Use, Land Use Change and Forestry
MBT	Mechanical biological treatment (of waste)
$MtCO_2e/yr$	Mega tonnes of CO_2 equivalent per year
Opex	Operational expenditure
Passenger km	Passenger travel activity (number of passengers x average distance travelled)
PHEV	Plug in hybrid electric vehicle
(Solar) PV	Solar Photovoltaic (electricity generation)
R&D	Research and development
T&S	Transport and storage
Tonne km	Freight travel activity (tonnes lifted x average distance transported)
Vehicle km, vkm	Vehicle transport activity (number of vehicles x average distance travelled)
Y&NY	York and North Yorkshire
£m	£ million

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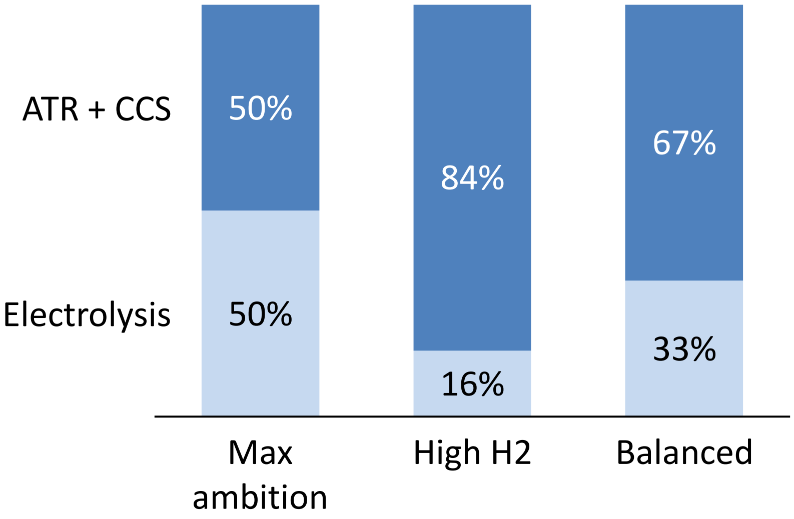
Introduction: The technical Appendix provides the key assumptions

- The purpose of this section is to provide further details to support the results. These include a summary of the modelling methodology, key information sources and key assumptions.
- This section is intended for a technical audience, so uses more technical terminology and assumes a level of existing knowledge on the sector. It also assumes knowledge of the study, so the reader should read the main report prior to, or in conjunction with, this Technical Appendix.
- We begin with some general assumptions around fuels, such as hydrogen, bioenergy and emissions factors.
- We then come to each sector in turn (Transport, Buildings, Power, Industry, Land use and agriculture) and provide more detail on the scenario modelling. For each sector, the section covers:
  - Summary of the modelling methodology and key information sources
  - Key assumptions in general and for each subsector or technology
  - Any additional details which are useful to a technical audience.

Hydrogen production assumptions

- The volume of hydrogen produced by each method varies by scenario. Natural gas reforming (ATR = autothermal reforming) with CCS is primarily used for bulk hydrogen for heat, and is the dominant method in the High hydrogen scenario. The production split is guided by the CCC scenarios[1]
- The carbon intensity of each production method varies over time.
  - For electrolysis it is determined by the carbon intensity of the electricity grid and the efficiency of the electrolyser.
  - For ATR we include upstream CO_2 emissions from natural gas production (which start at 0.025 $kgCO_2/kWh_{NG}$ and drop by 67% by 2040) and the production emissions not captured through CCS
- The model contains the option to blend 5% biogas into the ATR process to further reduce emissions. At default this is included.
- The input energy (natural gas, electricity and biogas) are additional energy demands to produce the hydrogen

Hydrogen production method breakdown by 2040



Carbon intensity of Hydrogen $kgCO_2/kWh_{H2}$

	2020	**2040**
Reforming (ATR) + CCS	0.046	0.018
Reforming + CCS + 5% biogas	0.029	0.001
Electrolysis	0.217	0.050

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[1] CCC Government led scenario estimates 84% from gas reforming. CCC People led scenario estimates 50% electrolysis.

Bioenergy supply and demand: the region must ramp up bioenergy supply pathways and prioritise end-uses

Study region
West Yorkshire
Y&NY

Bioenergy has many potential end uses in the energy system:

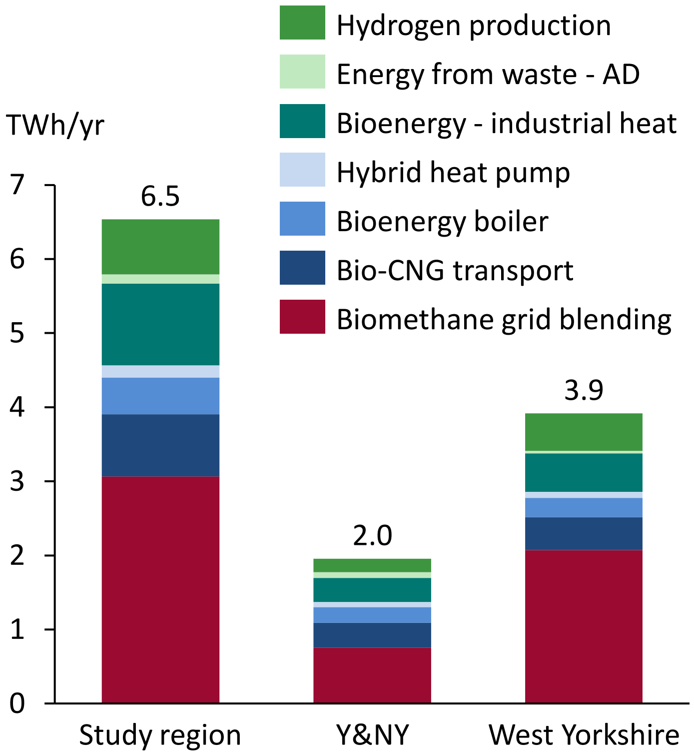
- Biomethane for gas grid blending to reduce carbon intensity
- Bio-CNG in transport in the short-medium term
- Bioenergy (biomass or bio-LPG) in boilers or hybrid heat pumps, particularly off gas-grid
- Industrial heat generation (all forms, targeting BECCS)
- Electricity generation (AD gas or biomass/BECCS[1])
- Hydrogen production (e.g. biogas blending in ATR feedstock)

The graphs shows the maximum bioenergy end-use requirement in 2038, although no single scenario reaches this level.

UK bioenergy projections remain uncertain. The CCC bioenergy resource scenarios[2] project that the UK supply would range from 132 – 145 TWh/yr **in 2035** (290 TWh/yr including imports).

Scaling by land area suggests that N&W Yorkshire should be supplying approximately **5.5 - 6 TWh/yr of this by 2035** (UK supply only). Of this, most bioenergy generation (4.5-4.9 TWh/yr) is attributed to Y&NY due to the large land area, allowing it to oversupply bioenergy to support more densely populated areas.

Bioenergy end uses (maximum) 2038 TWh/yr[3]



Bioenergy must be prioritised for the most valuable end uses, including where the CO_2 is sequestered and where it decarbonises the hardest to decarbonise subsectors. For example, in the long term:

- Wood as a construction material (beyond the scope of this study)
- Bioenergy + CCS (BECCS) in power, industry, hydrogen production (all modelled) and aviation biofuels

In the medium term, bio-CNG, biomethane grid blending & bioenergy boilers/HHP off-gas support decarbonisation of hard-to-decarbonise sectors. Use for power generation (without CCS) may not be the most valuable use going forwards.

A full energy balance of potential bioenergy sources by type and end-uses for each region is beyond the scope of the project

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[1] End-uses graph excludes Drax (~50TWh/y), as the biomass is imported and it dwarfs all other uses in the region

[2] CCC Biomass in a low carbon economy 2018 LINK;

[3] Maximum amount across scenarios, not all incurred at once; Note that the subregion breakdown is estimated for some sectors

Assumptions on the carbon intensity of fuels

Carbon intensity of fuels	2020	2030	2038
Electricity	0.184	0.081	0.040
Natural gas	0.184	0.184	0.184
Coal	0.332	0.332	0.332
Diesel	0.245	0.245	0.245
Petrol	0.234	0.234	0.234
Fuel oil industry	0.268	0.268	0.268
Burning oil domestic	0.247	0.247	0.247
LPG	0.214	0.214	0.214
Biomass solid	0.016	0.016	0.016
Biomethane	0.028	0.028	0.028
Hydrogen - Baseline	0.217	0.119	0.052
Hydrogen - Max ambition 2030	0.217	0.094	0.030
Hydrogen - High hydrogen 2038	0.217	0.044	0.012
Hydrogen - Balanced 2038	0.217	0.069	0.021
Regional gas grid - Baseline	0.184	0.182	0.180
Regional gas grid - Max ambition 2030	0.184	0.171	0.028
Regional gas grid - High hydrogen 2038	0.184	0.152	0.026
Regional gas grid - Balanced 2038	0.184	0.172	0.078

- The carbon intensity of most fuels is from the Government GHG reporting documents LINK
- The national electricity carbon intensity is from the HMT Green Book projections
- The Hydrogen carbon intensity is calculated from the assumed supply sources, with the breakdown between electrolysis and methane reforming varying by scenario
- The regional gas grid carbon intensity is calculated by scenario through the blend of natural gas, biomethane and hydrogen. The maximum availability of biomethane is from the NGN projections and hydrogen is limited to 20% by volume.

What has changed in the modelling since the steering group review?

Added to modelling / slides

- More detail on subregional breakdown to allow separate sections for Y&NY vs West Yorkshire.
- Extended key findings / executive summary, including visual on extent of measures
- Indicative waterfall charts to more clearly show the emissions contribution of measures/interventions
- No CCS high-level sensitivities for power and for the scenarios as a whole to see impact on emissions
- No new build CCGT sensitivity for power
- Indicative land area requirements of solar and onshore wind in the power sector

Adapted in modelling / slides

- Transport – adjustments to rail assumptions to assign more freight to Y&NY; updated HGV scenarios in line with new projections for CCC; minor change to petrol emissions to account for E10 introduction.
- Buildings sector: Accelerated thermal efficiency timeframes to prioritise these in 2020s as an enabling action (due to policy task start). Minor correction to total H2 use in detached homes.
- Power sector - some adaptions to build rate to address feedback on level of ambition in Max ambition scenario and level of uncertainty around CCGTs in the region. Also to better reflect the electricity demand between scenarios.
- Adapted LULUCF bioenergy emissions reductions to ensure no double counting between generation and end-use of bioenergy in different sectors.

Agenda

Transport Pathways: method summary (see next slide for references)

Road transport

1. Vehicle km by subregion and vehicle type built from DfT datasets[1]*
2. Current passenger modal share (walking, cycling, car, bus, motorcycle, train) derived at subregion level from analysis of National Travel Survey data (2016)[2]
3. Average passenger occupancy (number of passengers per vehicle) estimated for the whole study region based on total passenger km per mode[3] divided by total vehicle km
4. Current passenger km per mode estimated at subregion level using vehicle km and average occupancy, with walking, cycling and train passenger km scaled to match modal share analysis.
5. Average freight capacity (tonnes per vehicle) for heavy goods vehicles estimated for the whole study region to be in line with UK data;[4] for simplicity of modelling, van freight capacity is set to 1 but is not intended to reflect real behaviour
6. Tonne km per mode estimated at subregion level using vehicle km and average freight capacity
7. Car and van fleet share by fuel type based on consumer choice modelling[5]
8. Bus fleet share projections by fuel type based on those developed for WYCA Zero Emission Bus Roadmap
9. Heavy goods vehicle fleet share projections by fuel type based on modelling developed for Committee on Climate Change[6]
10. Emissions and energy consumption calculated based on fleet average real world fuel consumption,[7] well-to-wheel emissions factors and energy density[8]

Rail

1. Passenger km derived at subregion level from road transport data (see box, left)
2. Freight tonne km derived for the whole study region to be 10% of total heavy goods vehicle and rail goods moved, in line with UK average,[9] and disaggregated to each subregion based on analysis of freight train activity[10]
3. Passenger km fuel share estimated based on analysis of Leeds City Region passenger loads and line electrification[11]; freight fuel share assumed to be in line with UK average[12]
4. Emissions calculated at subregion level relative to historic diesel emissions,[13] with electric rail emissions estimated based on relative CO_2 intensity[14] adjusted for future grid decarbonisation and with share of emissions assigned to freight assumed to be in line with UK average[15]

Aviation

1. Domestic and international passenger data for Leeds Bradford Airport based on Civil Aviation Authority statistics[16]
2. Aviation fuel efficiency improvements modelled in line with analysis developed for the Committee on Climate Change[17]
3. Emissions calculated relative to historic emissions[18] and disaggregated to subregions based on relative passenger share[19]

Other transport

1. Emissions calculated relative to historic emissions,[20] with lubricant emissions decreasing in line with fossil fuel vehicles

*Full vehicle breakdown available for West Yorkshire, North Yorkshire van, heavy goods vehicle, bus and motorcycle data extrapolated from "All motor vehicles" data based on Yorkshire and the Humber distribution (car data accurate)

Transport pathways – Key sources and references

1. DfT road traffic statistics Table TRA0206 and LA-level data
2. National Travel Survey, 2002-2016: Special Licence Access, study numbers 7553 and 7804
3. Table NTS9904 miles per person per year for Yorkshire and the Humber multiplied by population from ONS data
4. Tables RFS0110 and RFS0111, DfT road freight statistics; note that this data refers to activity of goods vehicles only (80% of heavy goods vehicle stock) but it is assumed that goods vehicles account for majority of heavy goods vehicle road activity
5. ECCo, developed for DfT
6. Analysis to provide costs, efficiencies and roll-out trajectories for zero emission HGVs, buses and coaches (2020, under review); shift of diesel to biomethane based on modelling for gas distribution network operator (2018, shared with DfT)
7. Analysis considers variation in fuel consumption and mileage travelled with age of vehicles, and incorporates improvements in fuel efficiency in new vehicles
8. Fossil fuel data: UK greenhouse gas conversion factors, including adjustment to account for introduction of E10 petrol from 2021; Biomethane: Element Energy Well-to-Wheel modelling developed for gas DNO; Hydrogen: production emissions in line with wider modelling, distribution emissions added assuming hydrogen is delivered to refuelling stations by truck
9. Table 13.2 Office of Rail and Road
10. Element Energy analysis of routes in North of England Freight Study, Network Rail
11. Leeds City Region Rail Capacity Analysis Draft Report
12. Table 2.101, Office of Rail and Road
13. BEIS LA CO_2 emissions dataset
14. Only diesel emissions are reported in the dataset for rail; electric rail emissions are included under the industrial and commercial sector and therefore must be estimated. Relative emissions intensity based on https://www.carbonindependent.org/files/aea_enviro_rep.pdf
15. Office of Rail and Road statistics
16. Civil Aviation Authority Tables 12_1 and 12_2
17. ATA (2018)
18. Emissions estimated by scaling UK aviation emissions (BEIS UK CO_2 inventory and statistical release) based on Leeds Bradford airport relative passenger share (Civil Aviation Authority statistics; 1.4% of international, 2% domestic)
19. Passenger share in 2017: 1.7% North Yorkshire, 22.3% West Yorkshire, 59.5% South Yorkshire and 16.6% Other, Civil Aviation Authority survey; Emissions distributed according to relative passenger share within Study Region (5% North Yorkshire, 65% West Yorkshire, 30% Barnsley based on population share of South Yorkshire)
20. BEIS LA CO_2 emissions dataset; share of emissions attributed to aircraft support vehicles estimated based on UK CO_2 inventory, with remaining emissions approximated to all be due to lubricants.

Transport pathways – Baseline demand growth assumptions

West Yorkshire

Sector	Unit	2020	2030	2038	Growth (2020 – 2038)	Source
Walking	Million passenger km	528	541	552	5%	Growth in line with population growth, ONS projections
Cycling		119	122	125	5%	
Cars	Million vehicle km	13,321	14,364	15,314	15%	DfT Reference scenario
Vans		2,546	2,824	3,140	23%	
Heavy goods vehicles		897	904	926	3%	
Buses		98	119	119	21%	Increase of 25% over 2019, in line with WYCA ZE Bus Roadmap
Motorcycles		104	112	119	15%	EE assumption (in line with cars)
Passenger rail	Million passenger km	2,151	2,584	2,952	37%	Government Office of Science forecasts
Freight rail	Million tonne km	973	1,264	1,516	56%	Network Rail Freight forecasts
Domestic aviation*	Million passenger km	162	185	205	28%	DfT UK aviation forecasts
International aviation*	Million passengers	4.0	7.0	7.7	94%	

*Whole study region

Transport pathways – Baseline demand growth assumptions

Sector	Unit	2020	2030	2038	Growth (2020 – 2038)	Source
Walking	Million passenger km	262	268	271	3%	Growth in line with population growth, ONS projections
Cycling		87	89	90	3%	
Cars	Million vehicle km	7,936	8,648	9,212	16%	DfT Reference scenario
Vans		1,631	1,810	2,012	23%	
Heavy goods vehicles		682	686	703	3%	
Buses		54	53	53	-3%	
Motorcycles		117	129	137	16%	EE assumption (in line with cars)
Passenger rail	Million passenger km	750	911	1,039	39%	Government Office of Science forecasts
Freight rail	Million tonne km	1,092	1,419	1,701	56%	Network Rail Freight forecasts
Domestic aviation*	Million passenger km	162	185	205	28%	DfT UK aviation forecasts
International aviation*	Million passengers	4.0	7.0	7.7	94%	

Y&NY

*Whole study region

Transport – Emissions pathways demand reduction and modal share assumptions

Demand reduction assumptions were applied relative to the Baseline scenario in all cases.

- **For passenger transport**, this reflects removal of trips through increased home working and teleconferencing, as well as reduction in trip length due to greater co-location of housing with workplaces and amenities. Overall demand reductions of 17% was applied in the Max ambition to reflect higher ambition, and 12% in the High hydrogen and Balanced.
- **For freight transport**, improved efficiency through consolidation was considered feasible in large urban areas, with 10% reduction in van and truck use assumed for these areas (2% reduction for the region overall). Further reduction of freight demand was assumed through consumer behaviour measures such as reductions in food and consumer goods waste and further operational efficiency (5% in High hydrogen and Balanced, 10% in Max ambition); in the Max ambition this was applied to both van and truck fleets, whereas it was only applied to truck fleets in the High hydrogen and Balanced scenarios.
- **For domestic aviation** passenger demand was reduced by 25% by 2040
- **For international aviation** demand reductions were applied in line with the Committee on Climate Change (CCC) Net Zero report. The High hydrogen and Balanced scenarios reflect the CCC's recommended level of growth reduction, limiting growth to 25% above current levels. For the Max ambition, growth was limited to maintain passenger numbers at current levels, to illustrate the impact of a more speculative and highly ambitious demand reduction level.

Modal shift of both passenger and freight were assumed for the emission reduction pathways

- **For passenger transport,** shift to active, public and shared transport was modelled (see next slides for detailed assumptions and methodology). The Baseline scenario assumes modal share only changes in line with growth demand assumptions. The Max ambition scenario targets maximum modal shift by 2030, and the High hydrogen and Balanced target maximum shift by 2038
- **For freight transport,** all emissions reduction pathways modal shift of 10% of tonne km from road to rail was considered feasible based on the proportion of goods moved into and out of the region from regions with rail links and/or ports. The shift of tonne km was assumed to apply to heavy goods vehicles in the heaviest segment (>18t gross vehicle weight) as these are primarily used for long haul trips. Modal shift from vans to cycle freight was assumed in all urban areas, equivalent to 1-2% of van km over each subregion. For all emissions reduction pathways, maximum freight modal shift was assumed by 2030.
- Shift of freight from road to river was out of scope of this study.

Transport pathways – Passenger modal share assessment methodology

Car journeys in the National Travel Survey dataset were assessed to estimate the potential for switching to another mode, with trips reallocated according to the following priority: walk > cycle > bus > train > shared car

Active travel

Adapted from similar analysis by TfL[1,2]

Trips were excluded from active travel if:

- Trip started between 20:00 and 06:00
- Trip purpose was to escort someone or for travelling to healthcare
- The trip consisted of more than one stage

Trips were considered feasible for walking if they were less than 2 km and feasible for cycling if they were less than 8 km or 10 km if for commuting. Active transport modes are assumed to include all modes of transport that are fully powered by the user but also modes such as electric bikes and electric push scooters where the user is assisted by mechanical propulsion.

Public and shared transport

Trips were assumed to switch to buses if they were up to 30 km and start and end in a major urban area. Trips were assumed to switch to trains if they were greater than 10 km and start and end in a major urban area (population greater than 50,000). Trips were switched to shared cars (e.g. car clubs, lift-sharing etc) if they start or end in an urban location, are greater than 10 km and unsuitable for conventional public or active transport.

Limitations of the approach

The analysis is based on trips reported to begin in the region and is therefore necessarily an approximation of travel behaviour since vehicle activity data includes all travel occurring within and through the region and subregions. The analysis also does not consider age, encumbrance (e.g. carriage of luggage or equipment) or disability of passengers which may affect which trips can be shifted. As such, it can be considered a maximum level of shift under the assumption that infrastructure is in place to ensure highest accessibility.

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1. Analysis of cycling potential, 2016; 2. Analysis of walking potential, 2016

Transport pathways – Passenger modal share assumptions

West Yorkshire

Scenario	Mode	2020	2025	2030	2035	2038
Baseline	Walking	2%	2%	2%	2%	2%
	Cycling	1%	1%	1%	0%	0%
	Car (private)	81%	81%	80%	80%	80%
	Car (shared)	0%	0%	0%	0%	0%
	Motorcycle	0%	0%	0%	0%	0%
	Bus	5%	6%	6%	6%	5%
	Train	10%	10%	11%	11%	12%
Max ambition	Walking	2%	3%	4%	4%	4%
	Cycling	1%	6%	12%	12%	12%
	Car (private)	82%	68%	54%	54%	54%
	Car (shared)	0%	3%	5%	5%	5%
	Motorcycle	0%	0%	1%	1%	1%
	Bus	5%	6%	8%	8%	8%
	Train	10%	13%	16%	16%	16%
High hydrogen and Balanced	Walking	2%	3%	3%	4%	4%
	Cycling	1%	2%	7%	12%	12%
	Car (private)	82%	79%	68%	56%	56%
	Car (shared)	0%	1%	3%	5%	5%
	Motorcycle	0%	0%	0%	0%	0%
	Bus	5%	5%	6%	7%	7%
	Train	10%	10%	13%	15%	15%

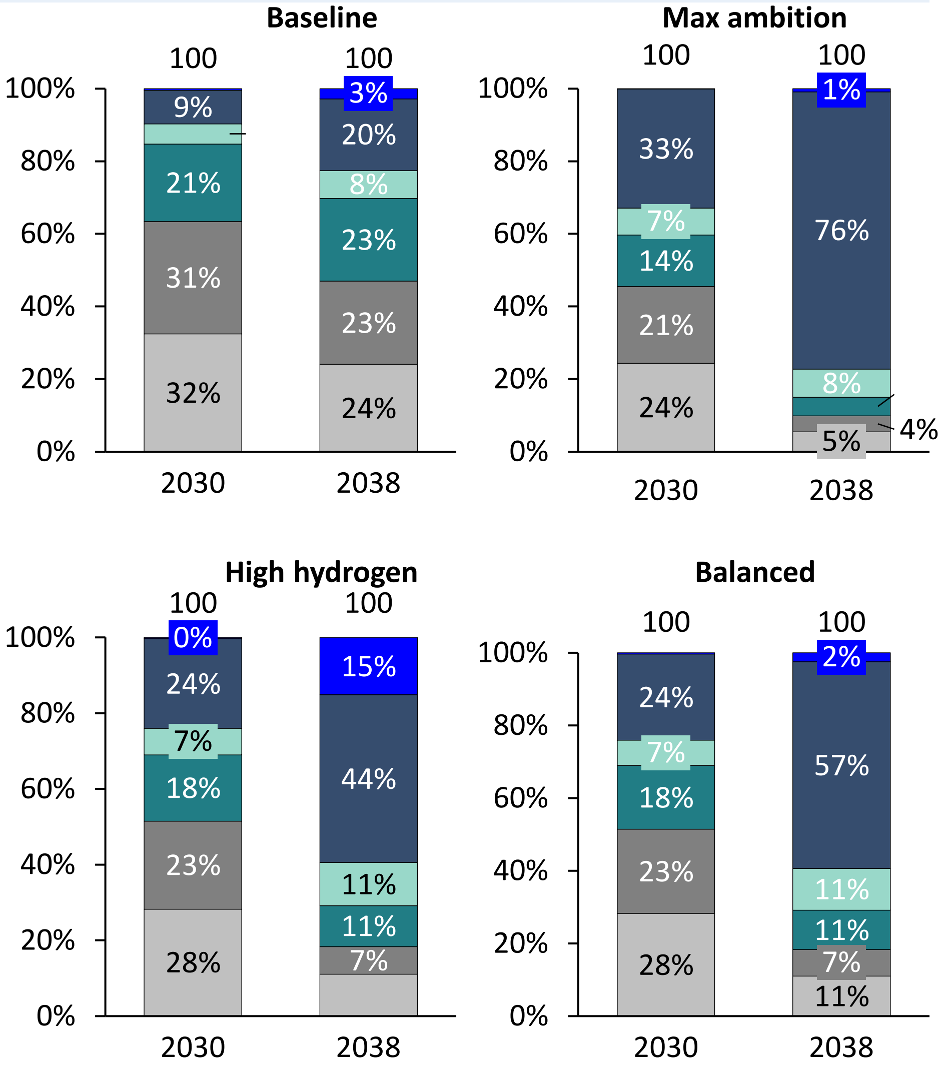
Transport pathways – Passenger modal share assumptions

- The Baseline scenario assumes modal share only changes in line with growth demand assumptions
- The Max ambition scenario targets maximum modal shift by 2030, and the High hydrogen and Balanced target maximum shift by 2038

Scenario	Mode	2020	2025	2030	2035	2038
Baseline	Walking	2%	2%	2%	2%	2%
	Cycling	1%	1%	1%	1%	1%
	Car (private)	85%	85%	85%	85%	85%
	Car (shared)	0%	0%	0%	0%	0%
	Motorcycle	1%	1%	1%	1%	1%
	Bus	5%	5%	5%	4%	4%
	Train	6%	6%	7%	7%	7%
Max ambition	Walking	2%	3%	3%	3%	3%
	Cycling	1%	3%	6%	6%	6%
	Car (private)	85%	69%	52%	52%	52%
	Car (shared)	0%	7%	14%	14%	14%
	Motorcycle	1%	1%	1%	1%	1%
	Bus	5%	7%	8%	8%	8%
	Train	6%	11%	16%	16%	16%
High hydrogen and Balanced	Walking	2%	2%	3%	3%	3%
	Cycling	1%	1%	3%	6%	6%
	Car (private)	85%	82%	68%	54%	54%
	Car (shared)	0%	2%	8%	14%	14%
	Motorcycle	1%	1%	1%	1%	1%
	Bus	5%	5%	7%	8%	8%
	Train	6%	7%	11%	15%	15%

Transport technology projections by sector: Cars

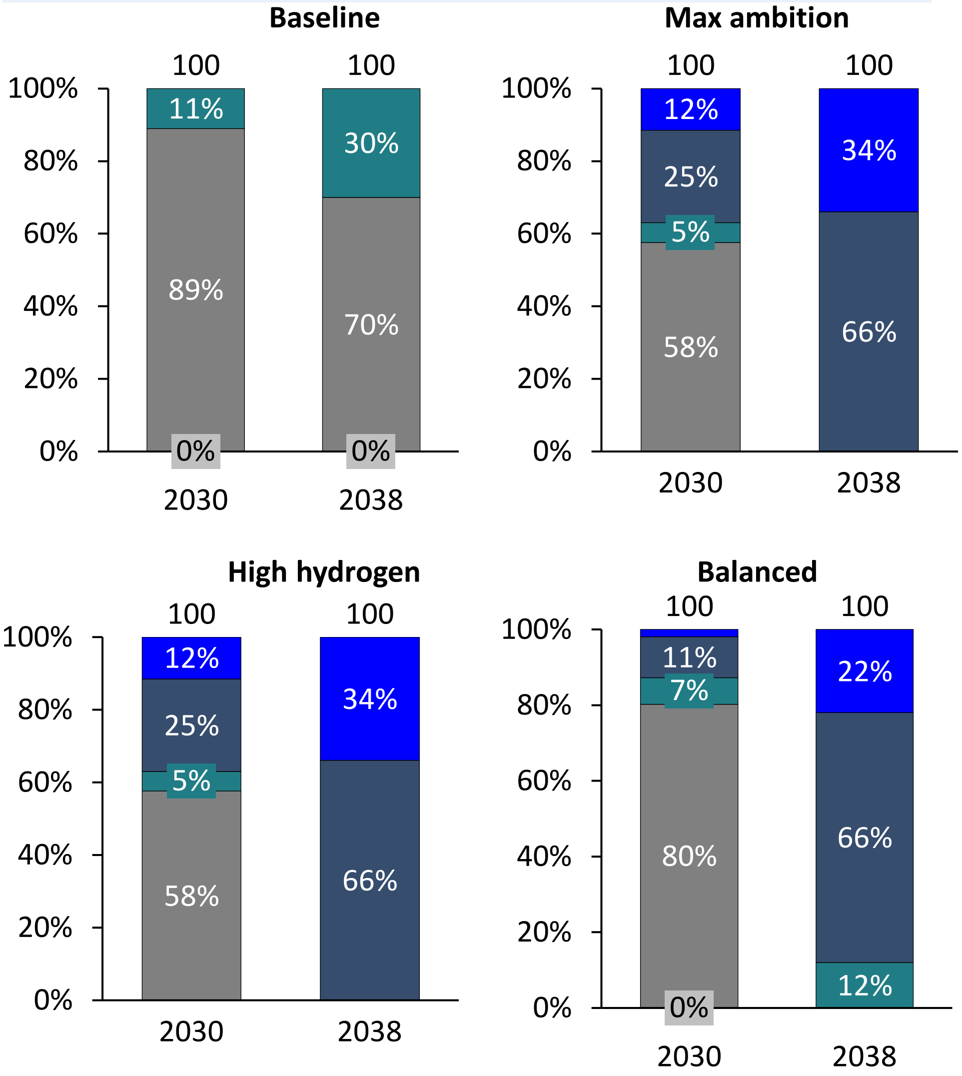
Share of vehicle stock by technology type (private cars)



- **In the Baseline,** uptake of low emissions vehicles is driven purely by consumer choice, and is forecast to achieve a market share of 29% of sales by 2030 (43% by 2040) – note that this is lower than the Government's Road to Zero target.
- **The Max Ambition** scenario follows the fastest rate of low emissions vehicles considered feasible, with sales of internal combustion engine vehicles (including hybrids) ending in 2030
- **The High hydrogen and Balanced scenarios** follow a slower rate of uptake, reaching 70% ultra-low emissions vehicle sales by 2030 and sales of ICE vehicles ending in 2035
- All scenarios have a high proportion of battery electric powertrains, with the High Hydrogen scenario representing a 50% swing in sales to hydrogen fuel cell vehicles from 2030 compared to the Balanced scenario
- **Shared cars:** are only assumed to be deployed at scale in the emissions reduction pathways. Zero emission vehicle uptake is higher for these vehicles based on shorter lifetimes (due to higher mileage) and greater ability to incentivise this sector to decarbonise. Shared cars reach 100% zero emission vehicles by 2038, with 85% battery electric.

Transport technology projections by sector : Buses

Share of vehicle stock by technology type



- **In the Baseline scenario** the fleet uptake forecast is in line with the Base Scenario developed for the WYCA Zero Emission Bus Roadmap, with no zero emissions procurement and buses replaced with Euro VI diesel or diesel hybrids within the business as usual vehicle replacement cycle; all diesel buses are Euro VI standard by 2030
- **The Max Ambition and High Hydrogen scenarios** follow the highest rate of zero emission vehicle uptake in the WYCA Zero Emission Bus Roadmap, with sales of diesel and hybrid vehicles ending in 2030
- **The Balanced scenario** follows a slower rate of zero emission vehicle uptake[1] to illustrate the impact of a more balanced vehicle mix, allowing a small share of hybrids to remain in the fleet to 2038

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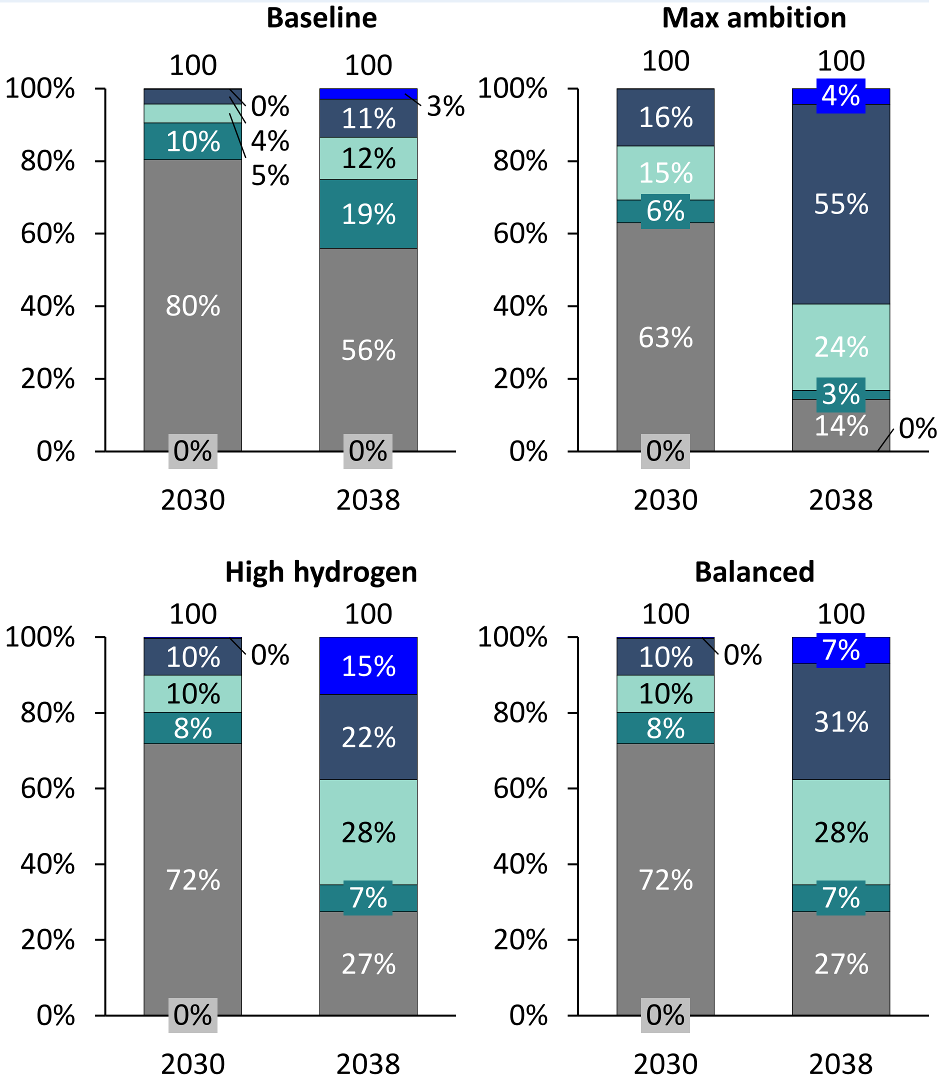
[1] Based on the Gradual ZE Transition pathway in the WYCA ZE Bus Roadmap

Transport technology projections by sector: Vans

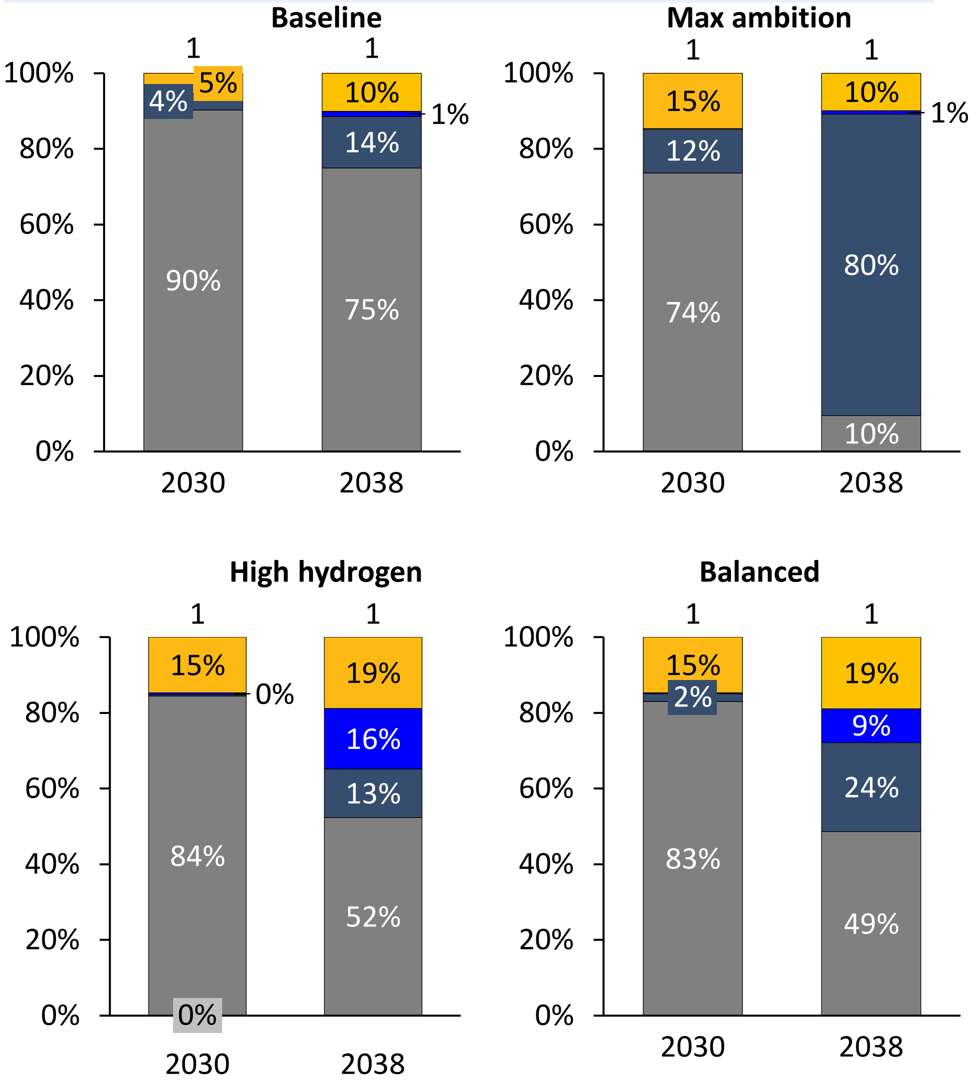
Share of vehicle stock by technology type



- **In the Baseline:** As for cars, the uptake of ultra low emissions vehicles^{2} follows consumer-choice under current policies, and is forecast to achieve a market share of 23% of sales by 2030 (41% by 2040)
- **The Maximum Ambition scenario** follows the fastest rate of low emissions vehicles considered feasible, with sales of internal combustion engine vehicles (including hybrids) ending in 2030
- **The High hydrogen and Balanced scenarios** follow a slower rate of uptake, reaching 70% ultra-low emissions vehicle sales by 2030 and sales of ICE vehicles ending in 2035
- All scenarios have a high proportion of battery electric powertrains, with the High Hydrogen scenario representing a 50% swing in sales to hydrogen fuel cell vehicles from 2030 compared to the Balanced scenario

Transport technology projections by sector : Heavy goods vehicles

Share of vehicle stock by technology type[1]



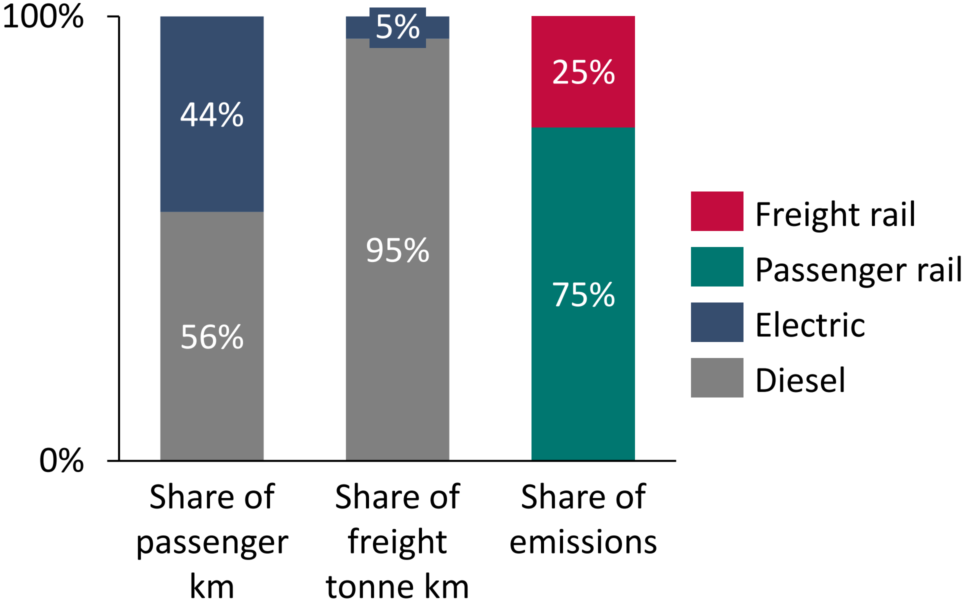
- All scenarios consider biomethane uptake in the heaviest segments (>18 tonnes gross vehicle weight) as a low emissions[2] option for decarbonisation in the short-to-medium term. Biomethane uptake is based on the proportion of UK fleets with known strong interest in gas technology, and assumed to be driven by reduced fuel duty compared to diesel (currently 50%) and EU emissions targets (introduced 2019)
- **In the Baseline** the majority of zero emission vehicles sold are assumed to be battery electric as battery prices and technology benefit from rollout in the light vehicle markets
- **In Max ambition** the fastest rate of infrastructure and vehicle rollout is achieved through supportive policy and funding. Battery electric and hydrogen fuel cell vehicles are assumed to both experience cost reductions and technology improvements.
- **In the High hydrogen and Balanced** scenarios fast infrastructure and vehicle rollout is achieved through supportive policy.
- The high hydrogen scenario assumes that fuel cell vehicles are favoured over battery electric as hydrogen is assumed to be widely available and vehicle technology improves. The Balanced scenario represents a scenario where both battery electric and fuel cell vehicles become cost-effective

1. Note that vehicle stock and vehicle activity are not equivalent for heavy goods vehicles, since the heaviest vehicles account for a higher share of vehicle km travelled than their share of stock; this distinction is accounted for in the modelling; 2. Up to 85% reduction in well-to-wheel emissions compared to equivalent diesel vehicles

Transport technology projections by sector: Rail

- The majority of current passenger and freight km are assumed to be carried by diesel powertrains[1] and the baseline scenario assumes that no further electrification occurs
- The assumed highest electrification of passenger services (90% under Max ambition and 80% under High hydrogen and Balanced) assumption was based on Element Energy analysis of regional passenger services and is assumed to be achieved by 2030 under Maximum Ambition and by 2038 in the 2038 scenarios
- Hydrogen was considered out of scope for this study but could be a viable option for rural lines; a dedicated freight study would need to be carried out.

Assumed baseline fuel share and emissions by transport type[1]



[1] Passenger km fuel share based on Element Energy analysis of regional passenger services; freight fuel and emissions share in line with UK average (Source: Office of Rail and Road);

Agenda

- Introduction
- Key findings
- Sector pathways West Yorkshire
- Additional information
- Technical Appendix
  - General
  - Transport
  - Buildings
  - Power
  - Industry
  - Land use
  - Waste

Buildings Pathways: method summary

Domestic buildings

1. Domestic building stock model built from national datasets such as NEED and ONS[1], broken down into building types, age and current fuel type -> building archetypes
2. Heat demand per building estimated from national assumptions by building archetype. Final fuel consumption then scaled to match Local authority energy datasets[1]
3. New building stock projections provided by N&W Yorkshire teams and domestic demolition assumed to be zero
4. Energy efficiency measures applied to each building archetype based on EE analysis for the CCC net-zero technical report and for the NIC, as well as the CGS[2,3,4,5].
5. Low carbon heating system installation in each building archetype based on EE analysis for the CCC[5], but accelerated to decarbonise more rapidly; roll-out rates moderate for next few years, then accelerate after planning following targets in CGS and CCC recommendations[2,3,4,8].
6. New buildings have high efficiency standards; they continue to install some gas boilers for next few years, but from 2025 all new build must install low carbon heat, primarily heat pumps[6].
7. Solar PV projections based on National Grid Future Energy scenarios[7].

Non-domestic buildings

1. Non-domestic building stock defined in terms of energy use (ECUK data[9]) by building archetype by end-use application
2. Number and floor area as supplementary information from government datasets[10].
3. Non-domestic growth rate follows subsector SIC growth provided by LCR team
4. BEES, ECUK and BEIS datasets used to assess current fuel demand breakdown by sector/application[9,11].
5. Energy efficiency assumptions (heat and non-heat) from EE analysis for the National Infrastructure commission, based on the BEES datasets and cost of efficiency measures[4,11].
6. Heating system projections based on a range of sources, including non-domestic subsector current state (BEES), CCC analysis and recommendations and CGS[2,3,11].

Key sources and references

1. NEED LINK ONS subnational statistics LINK LINK and Plumplot LINK BEIS subnational energy consumption statistics LINK
2. CCC Net-zero reports LINK
3. Clean Growth strategy LINK
4. EE for National Infrastructure Commission LINK
5. Element Energy work for CCC on hard-to-decarbonise homes LINK
6. Future homes standard LINK and Second Cost Optimal report LINK
7. National Grid FES and NPg DFES LINK LINK
8. H21 LINK and ZCH LINK
9. Energy Consumption in the UK ECUK dataset LINK
10. ONS UK business workbook LINK and floorspace LINK
11. BEES LINK
12. Published statistics including FiT RHI

Buildings Pathways: additional assumptions

Key buildings measures

Key measures assumed:

- **Ambitious energy efficiency** improvements to raise all homes to EPC C or better where possible and cost-effective (Clean Growth Strategy), targeting 25%-35% heat demand reduction in existing buildings on average.
- **New buildings** from early-mid 2020s to install low carbon system (heat pump or low carbon DH) and implement high efficiency standards
- **District heating in heat dense areas** (above ~30 kWh/m^2, national max potential 19% homes and 45% non-residential[1]), including many flats and commercial buildings (e.g. areas of Leeds, Bradford, York). 5-6 years from inception to operation. No spatial analysis was completed in this study.
- **Off-gas grid buildings** to be supplied primarily by heat pumps, hybrid HP and/or bio-boilers[1A] (primarily in North Yorkshire)
- **Hydrogen for heat[2]** not available in domestic homes until 2028 in the High H2 scenario. The Max ambition scenario assumes no H2 conversion of the gas grid and the Balanced scenario assumes areas of grid conversion from 2030.

Assumptions

Heating system efficiency	2020	2038
Gas boiler	0.86	0.90
Oil boiler	0.84	0.90
Direct electric	1.00	1.00
Air-to-air heat pump	3.38	3.38
Heat pump (air-to-water)	2.65	3.58
Hybrid heat pump	2.29	3.04
Hydrogen boiler	0.86	4.00
Bioenergy boiler	0.85	0.90

Further assumptions:

- Hybrid heat pumps are assumed to rely 80% on the heat pump and 20% on a boiler, such as natural gas or bio-LPG
- District/communal heating heat supply is initially assumed to be primarily gas CHP for existing units, but by 2030 the majority of heat is supplied by large scale heat pumps, supported by hydrogen if available.
- Non-domestic cooling demand is assumed to increase by 20% by 2038 (Arup 2018).
- Non-domestic non-heat applications are primarily using electricity. Those that use other fuels (e.g. some catering) are assumed to switch to electricity in most cases, or a small amount of hydrogen where available.

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1 Source: Element Energy work for CCC Net-Zero on hard-to-decarbonise homes and CCC Net-Zero report; 1A eg bioLPG
2: ZCH CCUS first installation 2027 and scale-up CCUS and hydrogen from 2028 onwards; H21 conversion of heat 2028-2034

Buildings Pathways: scenario measures comparison

Scenario				
Intervention	Baseline	Max ambition	High H2	Balanced
Energy efficiency	Low	High	Medium/High	High
Heat pumps	Low	Max	Medium	Medium/High
Hybrid heat pumps	Low	Low	High	High
Hydrogen boilers	None	None	High	Medium
Direct electric heating	Medium	High	Low	Medium
District/communal heating	Low	High	High	High
Bioenergy[1]	Medium	Medium	Medium	Medium

The table above gives an indication where the effort is focused in each scenario

The Max ambition scenario focusses on maximum deployment of heat pumps. This is supported by district/communal heating and electric storage heating, particularly in space constrained urban homes. There are no hydrogen boilers and limited hybrid heat pumps due to the assumptions that the gas grid is not converted to hydrogen.

The high hydrogen scenario focuses on gas grid conversion to hydrogen to enable large-scale hydrogen boiler installation from 2028. This is supplemented by hybrid heat pumps and district/communal heating. Slightly lower energy efficiency ambition is assumed due to the lower levels of heat pumps requiring high thermal standards.

The balanced scenario involves a mix of technologies, with partial gas grid conversion enabling some hydrogen boilers, some gas boilers supplied by biomethane, and high hybrid heat pumps using H2, bio-LPG or biomethane, again supplemented with district/communal heating.

[1] Bioenergy is a limited resource and is used in different ways across the scenarios (biomass/bio-LPG boilers, bio-LPG hybrid heat pumps, biomethane in the gas grid, biogas used in hydrogen production) See bioenergy slide in "additional information"

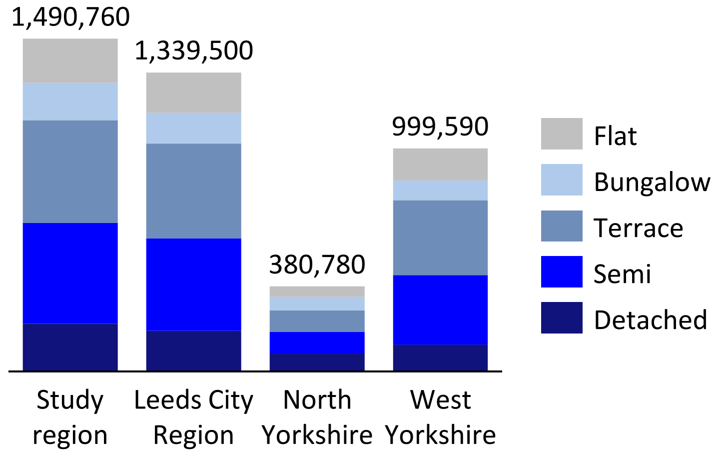
Building stock assumptions and data

The buildings sector is split into 12 different building archetypes to allow differing assumptions to be applied

Domestic

- As discussed in the method summary, a domestic building stock model built from national datasets such as NEED and ONS[1], broken down into building type, age and current fuel type. This forms building archetypes.
- The graph to the right shows the breakdown by building type. The stock model was estimated by subregion separately.
- The domestic sector is dominated by terrace and semi-detached homes, with detached homes representing a larger share of emissions than number.

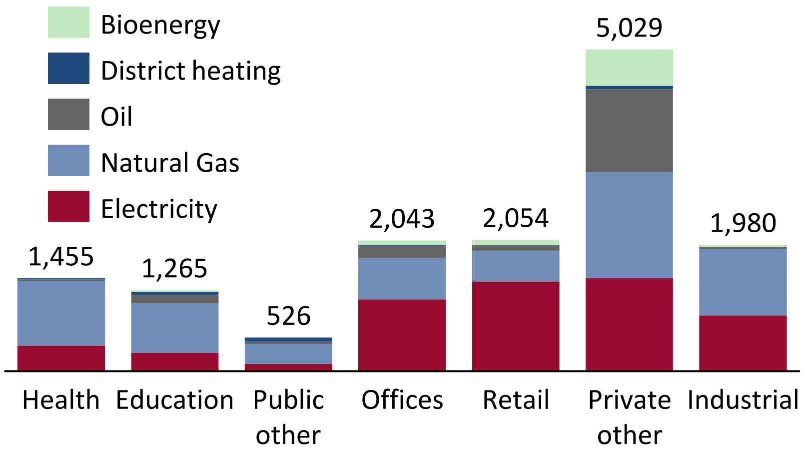
Domestic building stock by type (number)



Non-domestic

- In contrast, the non-domestic building stock is built up by sector type and current fuel consumption, from the ECUK and BEES datasets (these are both national and are scaled to the region by looking at the proportion of each non-domestic sector that exists in the study region)[2,3,4].
- Different assumptions are applied to each sector.
- The non-domestic sector is dominated by privately owned buildings, such as offices, retail, catering and restaurants.

Energy consumption estimate for non-domestic buildings by sector (GWh/yr)



1 NEED LINK ONS subnational statistics LINK LINK; 2 Energy Consumption in the UK ECUK dataset LINK; 3 ONS UK business workbook LINK and floorspace LINK; 4 BEES LINK

Domestic energy efficiency assumptions - deployment scenarios are based on the cost-effectiveness of measures

We used our recent building stock models for the CCC and National Infrastructure Commission to develop energy efficiency rollout scenarios. The energy efficiency measures have been divided into three cost-effectiveness bands: Low cost, Medium cost, High cost measures, and technical potential, which are deployed over different timepoints, as below (i.e. low cost measures can be rolled out faster to meet Clean Growth Strategy aims).

Cost-effectiveness band	Cost effectiveness range (£/tCO_2 abated)
Low cost	<0
Medium cost	0-150
High cost	150-400
Technical potential	>400

The rate of deployment was adapted to accelerate implementation so that the majority of interventions were complete by the early 2030s. The results are shown in the main results pack.

The cost effectiveness bands have been used to develop three different deployment scenarios, as below:

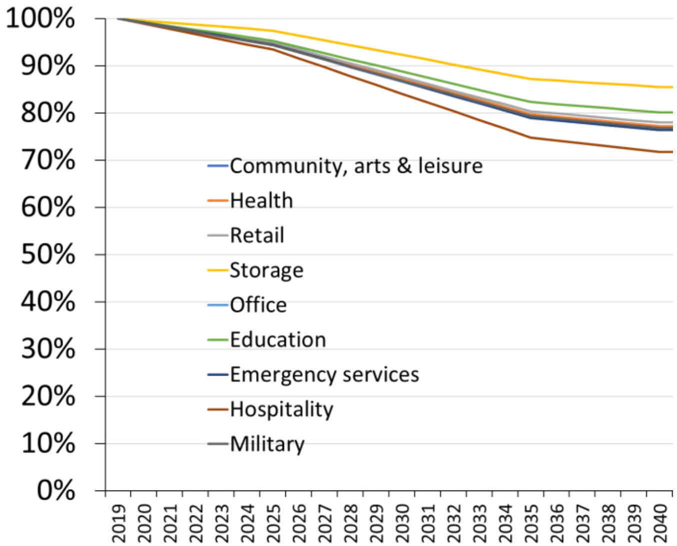
Scenario	Description
Low cost energy efficiency (Baseline scenario)	Low cost energy efficiency measures only applied
Medium cost energy efficiency (High H2 scenario)	Low and Medium cost energy efficiency measures applied
High cost energy efficiency (Max ambition & balanced)	Low, Medium and High cost energy efficiency measures applied

https://www.nic.org.uk/wp-content/uploads/Element-Energy-and-E4techCost-analysis-of-future-heat-infrastructure-Final.pdf ;
https://www.theccc.org.uk/publication/analysis-on-abating-direct-emissions-from-hard-to-decarbonise-homes-element-energy-ucl/

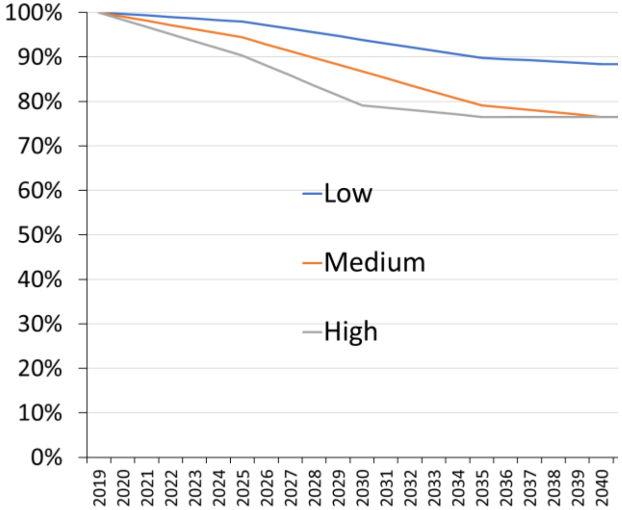
Thermal energy efficiency in the non-domestic stock

- The underlying data for thermal energy efficiency in the I&C (Industrial and Commercial) stock is based on data from BEIS's Building Energy Efficiency Survey. From this data, we have been able to estimate the savings potential and cost-effectiveness of the measures, as with the domestic stock (in £/tCO_2 abated). The cost bands are the same as in the domestic scenarios.
- For thermal energy efficiency, we consider 'Building instrumentation and control' and 'Building fabric' measures. The graph below left shows the medium cost scenario, broken down by sub-sector.
- In the I&C sector, all thermal efficiency measures fall in the 'low' and 'medium' cost bands i.e. less than £150/tCO_2 abated. The high scenario differentiates itself from the medium scenario by achieving the same abatement potential in a shorter amount of time.
- In the 'Offices' sector, an estimated 23% thermal savings can be made through the application of building fabric measures and through building instrumentation and control. Scenarios for each sub-sector have been developed.

Medium cost scenario, all sectors



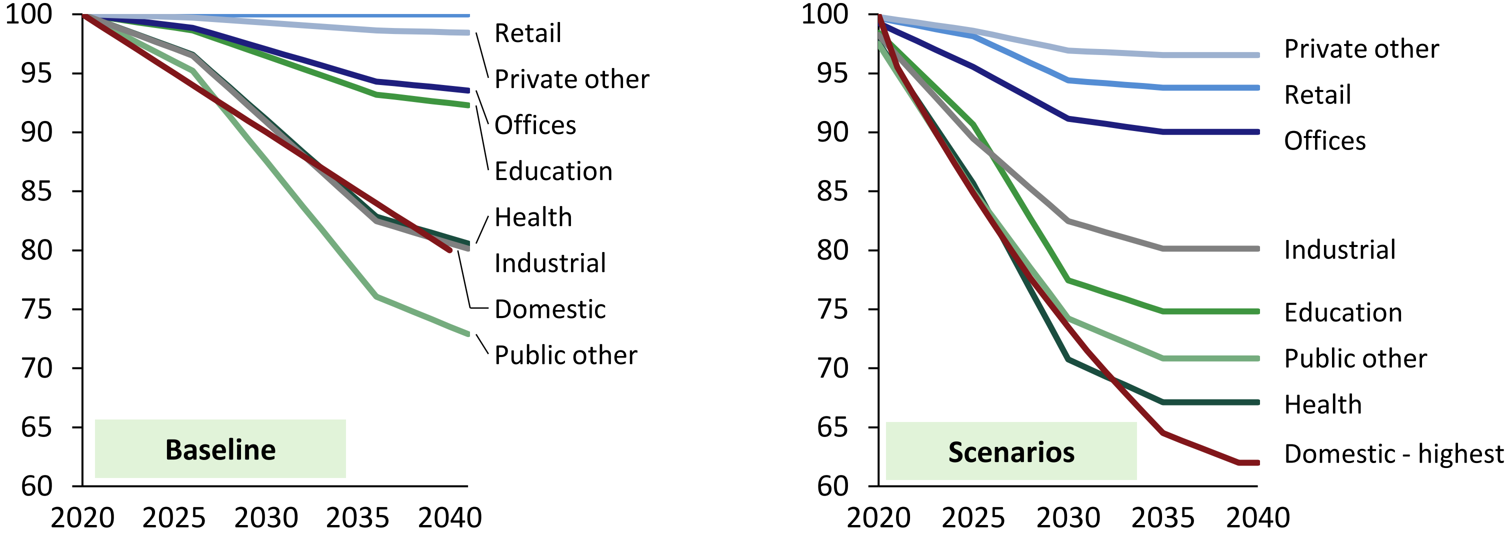
Low, medium and high scenarios.
Sector: Offices



Electrical efficiency measures assumptions

Study region

Efficiency measures for electrical non-heat activities by subsector (% of 2020 energy demand)



- Electrical efficiency measures reduce electricity demand for applications such as lighting, cooling, appliances and electric catering. This supports electricity infrastructure, reducing the cost of upgrades.
- **Non-domestic**: The underlying data for electrical efficiency in the I&C stock is based on data from BEIS's Building Energy Efficiency Survey (2015).
- For domestic, electrical efficiency was taken from the modelling underpinning London's Climate Action plan. This includes efficiency in home lighting and appliances. Electrical efficiency is not as urgent, because heat decarbonisation and technologies do not rely on any electrical efficiency having been completed.
- The baseline scenario follows a less ambition path (left), while all emissions scenarios follow the more ambitious energy efficiency pathway (right).

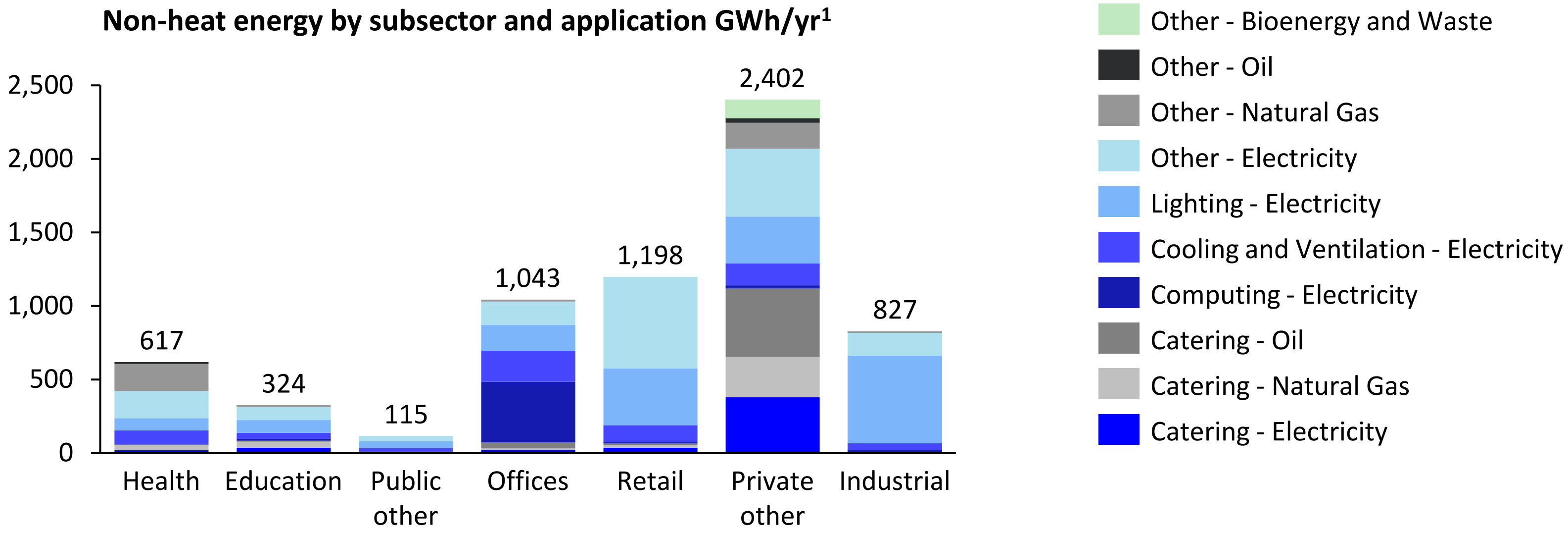
It should be noted that the work around energy efficiency is necessarily high level due to the extremely broad nature of this study; we have not looked at the individual measures with respect to their deployment levels.

BEES data https://www.gov.uk/government/publications/building-energy-efficiency-survey-bees

Buildings – non-domestic stock - non-heat energy

Study region

Non-heat energy by subsector and application GWh/yr[1]



- The graph shows the estimated current non-domestic non-heat fuel consumption (ECUK) for the study region to give an idea of the other applications and their fuel breakdown (included in the final energy and emissions results). Direct emissions are a small proportion of those from the buildings sector.
- The majority of non-heat energy is supplied through electricity (~77% non-domestic and almost 100% domestic), shown in blue on the graph.
- Key applications are cooling, ventilation, computing, lighting, appliances and some catering.
- All applications which currently use electricity remain on electricity (as this will decarbonise).
- It is assumed that there is an increase of 20% in non-domestic cooling demand[1].
- We assume the phase out of oil and later natural gas, replacing this with electricity and a small amount of hydrogen and/or bioenergy.

1 Adapted from ECUK

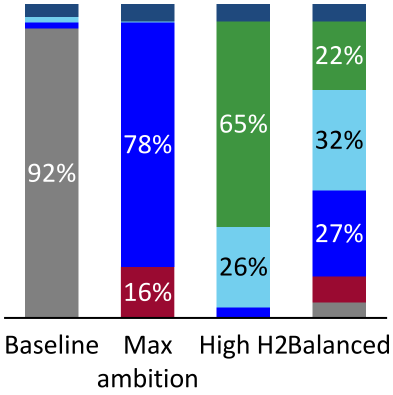
2: Arup WP2 CAP Technical Assistance for London Work Package 2

Buildings – domestic heating system assumptions (1/2)

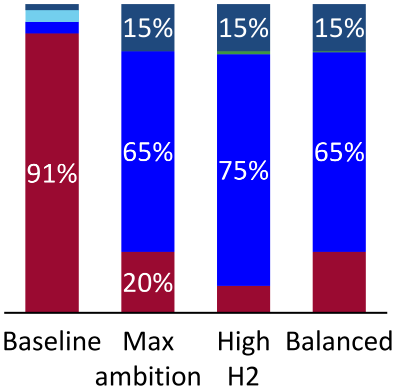
Study region

Detached homes 2040

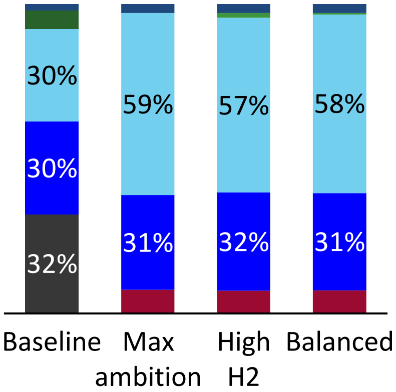
Detached homes currently with gas counterfactual (~89%/73%)



Detached homes currently with electricity counterfactual (~9%/9%)



Detached homes currently with off-gas oil, LPG or bioenergy (~1%/19%)



- 🟦 Communal heating
- 🟦 District heating
- 🟩 Hydrogen boiler
- 🟩 Bioenergy boiler
- 🟦 Hybrid HP
- 🟦 Heat pump
- 🟥 Electric heating
- ⬛ Oil boiler
- ⬛ Gas boiler

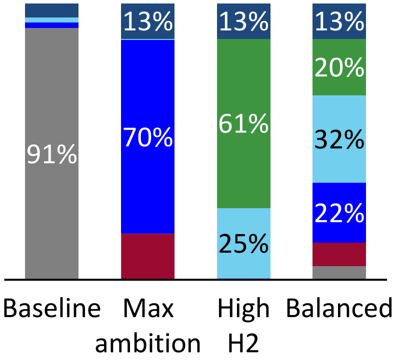
These charts show the 2040 heating system breakdown for each home archetype. The archetype distinction in this case includes the home type (e.g. detached) and the current heating system (e.g. gas boiler).

These assumptions are the same for all subregions, but the stock breakdown differs, and therefore the end result differs.

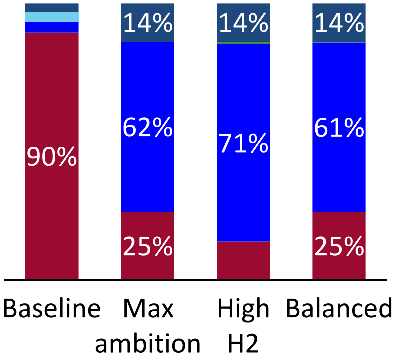
The % in the graph title is the proportion of that home type with that counterfactual heating system. Blue is WY, green Y&NY.

Semi detached 2040

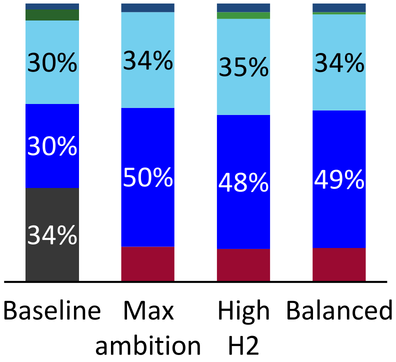
Currently with gas counterfactual (~89%/73%)



Currently with electricity counterfactual (~9%/9%)



Currently with off-gas oil, LPG or bioenergy (~1%/19%)



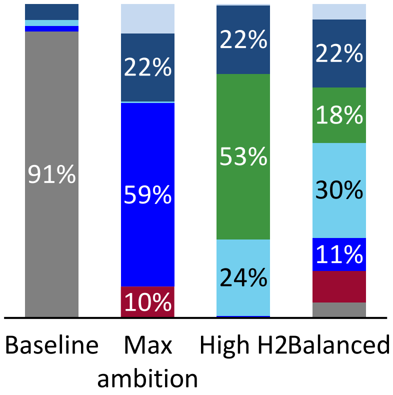
Note that "Heat pump" and "Hybrid HP" both refer to air-to-water heat pumps. Hybrids may be electric-gas, electric-H2 or electric-bioLPG

Buildings – domestic heating system assumptions (2/2)

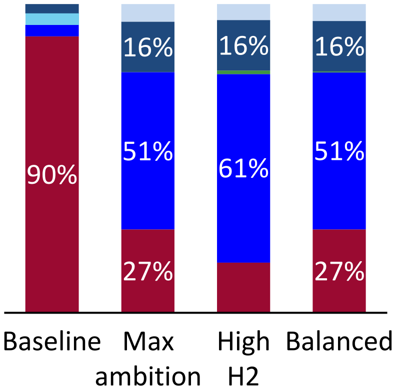
Study region

Terrace homes 2040

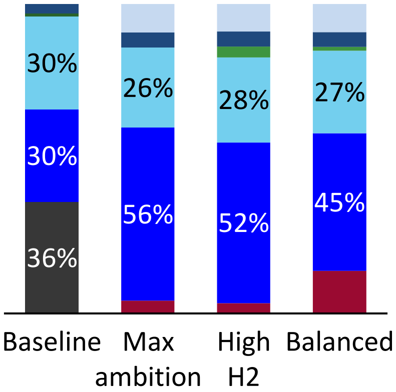
Homes currently with gas counterfactual (~89%/88%)



Homes currently with electricity counterfactual (~11%/12%)

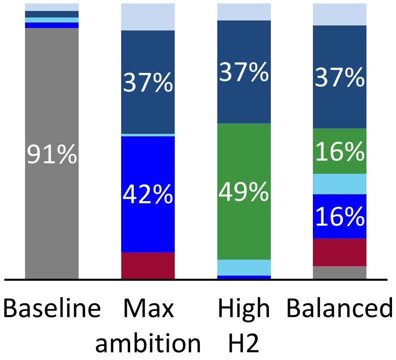


Homes currently with off-gas oil, LPG or bioenergy (<1%)

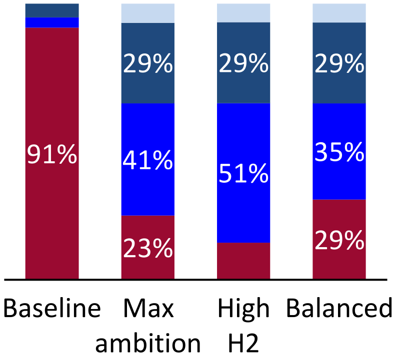


Flats 2040

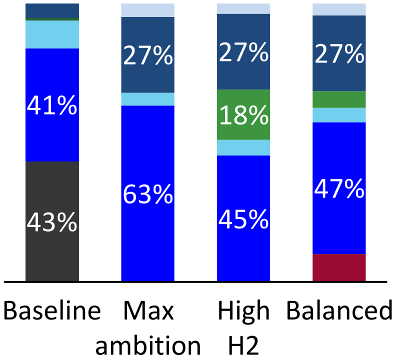
Flats currently with gas counterfactual (~83%/81%)



Flats currently with electricity counterfactual (~17%/19%)



Flats currently with off-gas oil, LPG or bioenergy (<1%)



- ■ Communal heating
- ■ District heating
- ■ Hydrogen boiler
- ■ Bioenergy boiler
- ■ Hybrid HP
- ■ Heat pump
- ■ Electric heating
- ■ Oil boiler
- ■ Gas boiler

These charts show the 2040 heating system breakdown for each home archetype. The archetype distinction in this case includes the home type (e.g. detached) and the current heating system (e.g. gas boiler).

These assumptions are the same for all subregions, but the stock breakdown differs, and therefore the end result differs.

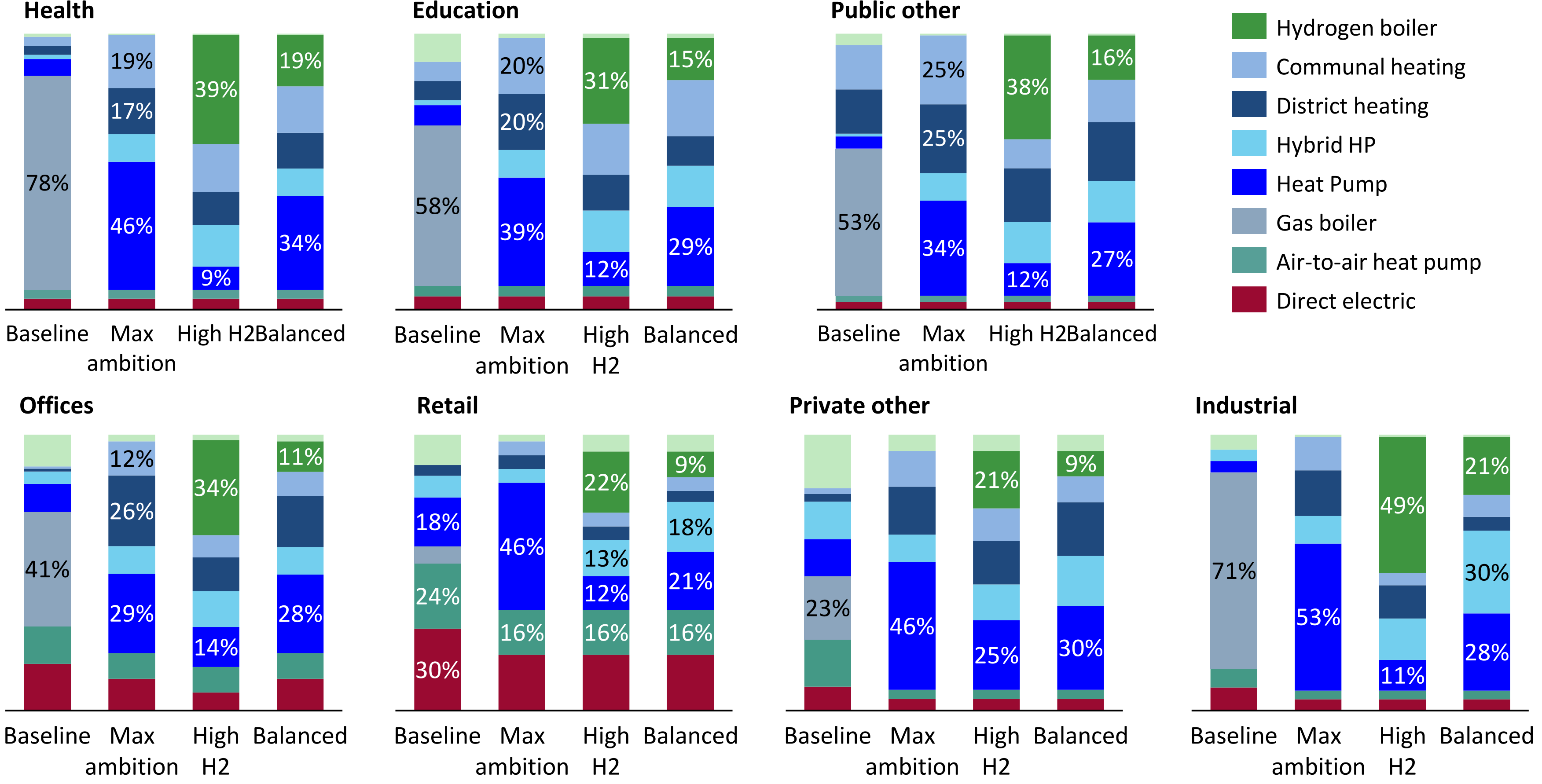
The % in the graph title is the proportion of that home type with that counterfactual heating system. Blue is WY, green Y&NY.

Note that "Heat pump" and "Hybrid HP" both refer to air-to-water heat pumps. Hybrids may be electric-gas, electric-H2 or electric-bioLPG

Buildings – non-domestic heating system assumptions

Study region

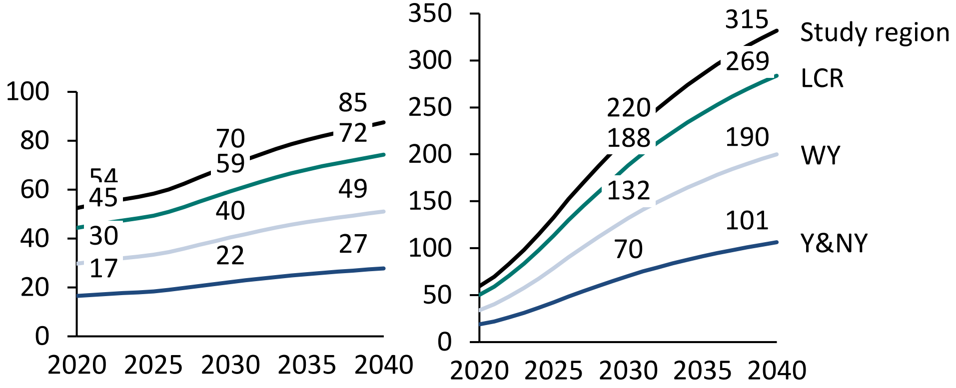
Heating system Breakdown in 2040 by heat delivered



The non-domestic heating system options are broadly similar to domestic homes. Some building types e.g. retail, have a significant proportion of dry heating systems. Non-domestic properties are typically in more urban areas, so a higher proportion of district heating may be achieved. Many large multi-building complexes (eg Universities and hospitals) have the potential for communal heating systems. It should be noted that there is limited information on the breakdown of current heating systems in the non-domestic sector, leading to greater uncertainty.

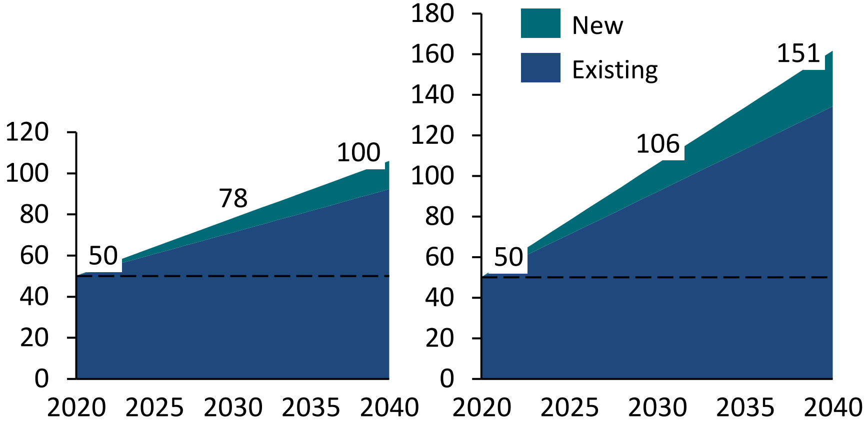
Building scale solar PV assumptions

Number of domestic installations by subregion ('000s)



Baseline **Scenarios**

Non-domestic solar PV – electricity produced GWh/yr



Baseline **Scenarios**

- Domestic solar PV installations for each local authority follow the Northern PowerGrid projections. The baseline scenario follows the "Steady progression" trajectory, and all 3 emissions reduction scenarios follow the "Community renewables" trajectory.
- Non-domestic solar PV, modelled as capacity/energy delivered, uses data from the Feed In Tarif subsidy (FiT) scheme to estimate potential deployment projections. In the baseline scenario, the generation increases at half the rate it did under the Feed In Tarif subsidy (now removed) over the past 9 years. Although the FiT is no longer in place, the cost has decreased sufficiently for installations to continue unsubsidised. The emissions reductions scenarios see solar PV be deployed at the same rate as under the FiT.
- Solar PV is assumed to be installed on new buildings at build – around 15% new buildings, varying by subsector (e.g. 25% of private non-domestic, 15% detached homes and 5% flats).
- The electricity produced at a building scale is subtracted from the building electricity demand before calculating emissions from buildings (i.e. it is netted off before the demand from the electricity grid).
- Solar PV is assumed to be installed on new buildings at build – around 20-50% new buildings, varying by subsector.

Sources: Domestic projections from National Grid FES and NPg DFES LINK LINK Non-domestic projections based in FiT data uptake rates

Back-to-back homes are a challenge in areas of Yorkshire, but solutions are developing

Intro

Yorkshire has a high number of back-to-back terrace homes, which are not typical across many areas of the UK. These have a number of features which may make them harder to decarbonise than other homes types. There is uncertainty as to best pathway, both technically and financially, but solutions must be developed urgently.

The challenge[1]

There are a number of challenges associated with back-to-backs making them harder to retrofit and decarbonise, such as[1]:

- Space constraints, restricting heating system choice and internal wall insulation
- Access limitations and visual disruption concerns on the front wall
- Solid walls (or hard-to-fill cavity walls), which are more expensive to insulate
- Some are low value with low income households -> affordability challenges

Solutions[1] (HP = heat pump)

Heating systems applicable to space constrained homes (in close proximity):

- District heating and communal heat pumps (external large heat pump serving a whole terrace)
- Hydrogen boilers
- Direct electric storage or panel heaters
- Hybrid HP or HP using high density thermal storage (depending how constrained & thermally efficient). For back-to-backs there is a visual challenge.

Heating systems applicable to low efficiency homes:

- Hybrid heat pump
- Hydrogen boilers
- Communal HPs (if high enough temperature or supplemented by some direct electric heating)

Efficiency measures:

- Thin solid wall insulation
- Loft insulation, glazing etc.
- Novel methods being developed e.g. some Energiesprong methods and those in research[2]

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[1] Hard-to-decarbonise homes, Element Energy and UCL for CCC, LINK

[2] Engagement with ECITB and review of the Energiesprong approach LINK

Agenda

- Introduction
- Key findings
- Sector pathways West Yorkshire
- Additional information
- Technical Appendix
  - General
  - Transport
  - Buildings
  - Power
  - Industry
  - Land use
  - Waste

Power Pathways: method summary

Distributed generators

1. The power sector is modelled by determining current and future installed capacities, load factors and emissions intensities of all generation technologies, which are then used to calculate total emissions and generation by each technology as well as the regional grid intensity.
2. 2019 capacities of solar PV and cooking oil generation are taken from the Renewable Energy Planning Database[1], whereas capacities for onshore wind, small bioenergy, sewage sludge and landfill gas are taken from LA statistics[2].
3. Electricity only and CHP Energy from Waste (EfW) capacities and short-term growth rates are based on a UK market review[3]. For these technologies, a single decarbonization scenario is created where a third of all new capacity is assumed to be CHP plants. Total capacity is capped by UK waste gap analysis and by 2040 half of all capacity is converted to EfW CCS, in accordance with CCC[4].
4. Solar and onshore wind capacities are determined by taking a percentage of new added UK capacities in National Grid's Future Energy Scenarios (FES)[5] according to the land area of the study region, and the deployment accelerated to account for regional net-zero targets. FES are also used to calculate capacities of dedicated bioenergy, AD and landfill gas generation, as well as battery storage installations.
5. Capacities of small fossil generation are taken from NPg's resource register[6].
6. Renewable technologies are assumed to have a constant load factor equal to past regional averages[7].

Large centralized plants

1. Drax coal power generation is assumed to cease in 2021, as its capacity contract runs out.
2. Drax biomass turbines are retrofitted with CCS, starting from 2027. BECCS runs at baseload creating negative emissions. These are excluded from power sector calculations and are handled separately in the model. It is assumed that only non-CO2 GHGs count towards net emissions from bio-based feedstocks[8].
3. A new large-scale gas power plant is assumed to be build in North Yorkshire in 2023/24, in accordance with Drax's plans. This plant is fitted with CCS in early 2030s.
4. A 300 MW hydrogen power plant is built in 2030 in Balanced and Max Ambition Scenarios, followed by another 2 plants in High H2. Plants run during peak demand and H2 is sourced from natural gas + CCS.

Key sources and references

1. December 2019 Renewable Energy Planning Database LINK
2. Renewable electricity by local authority, BEIS 2019 LINK
3. Tolvik 2018 UK Energy from Waste Statistics LINK
4. CCC 2019 Net Zero Report LINK
5. National Grid Future Energy Scenarios 2019 LINK
6. Northern Powergrid system wide resource register 2019 LINK
7. DUKES 6.5: Digest of UK Energy Statistics LINK
8. UK GHG Conversion Factors, BEIS & Defra LINK

Power Pathways: scenario measures comparison

	Scenario*			
Intervention	Baseline	Max ambition	High H2	Balanced
Solar PV & Onshore wind	Low	High	Medium	High
Large Gas & Gas CCS	Medium	High	Medium	Medium
Bioenergy with CCS (BECCS)	None	High	High	High
Hydrogen	None	Medium	High	Medium
Energy from waste	High	Low	Low	Low
Energy from waste with CCS	None	High	High	High
Small fossil	Low	Low	Low	Low
Small bioenergy & AD	Low	High	Medium	High
Demand side response	Low	High	Medium	High
Electricity storage	Low	High	Medium	High

The table above gives an indication where the effort is focused in each scenario

All scenarios phase out coal by 2021, retrofit Drax's biomass turbines with CCS to achieve negative emissions through BECCS and build a new large gas power plant, which is retrofitted with CCS in early 2030s. Ambition level of energy from waste (EfW) technologies are the same across scenarios since this is driven by the waste sector to a degree. Scenarios slow down EfW build rate by mid-2020s and retrofit them with CCS. Small fossil generators shrink in size or utilization rate across all scenarios.

The Max Ambition Scenario achieves fastest emissions reduction through accelerated renewables, bioenergy and AD uptake. High electrification increases power demand significantly, which is partially offset by building a larger gas power plant with CCS. Decentralized technologies are favoured, including storage and demand side response (DSR).

The High Hydrogen Scenario builds more hydrogen generation assets as the economy replaces natural gas by hydrogen to a large extend. Many other technologies are more limited in size as power demand does not increase as much as in other scenarios.

The Balanced Scenario is similar to the Max Ambition scenario in the sense that increased electrification require high renewable uptake, but adaption rates are spread across the model timeline more evenly and less total power output is achieved.

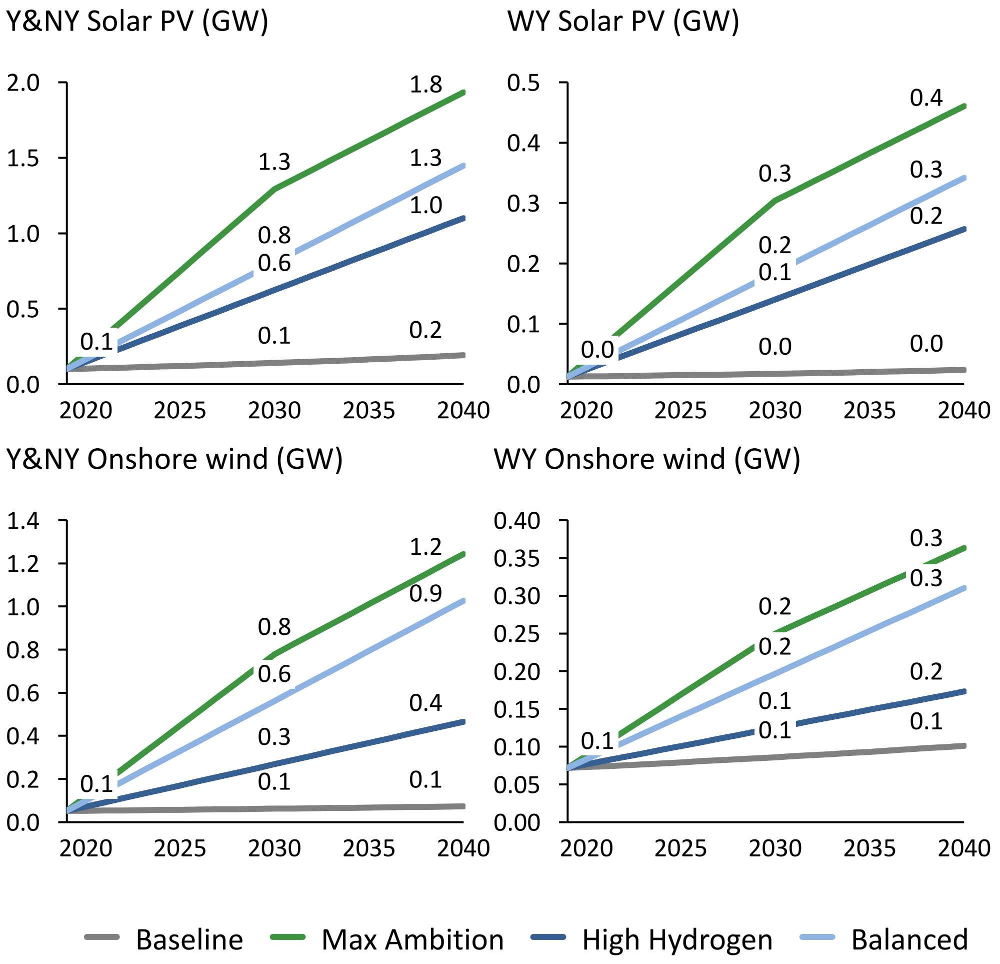
* Low/Medium/High classification is relative to each technology.

Solar PV and onshore wind assumptions/data

Study region

West Yorkshire

Y&NY



- The graphs on the left show the installed capacities of solar and on shore wind in each scenario, rooftop PV is not included in the power sector.
- Current solar and wind capacities are taken from the 2019 Renewable Energy Planning Database and 2019 BEIS Renewable Energy by LA data, respectively.
- Future capacities are based on National Grid Future Energy Scenarios. Baseline is based on % growth in FES Steady Progress, the Balanced Scenario is based on FES Community Renewables and the High H2 scenario is based on FES Two Degrees. All scenarios accelerate FES scenarios and achieve 2050 targets by 2040. The Max Ambition Scenario is also based on FES Community Renewables, but accelerates growth until 2030.
- In all 3 decarbonization scenarios UK-wide added capacity is distributed to study regions depending on total land area. WY and Y&NY are 0.8% and 3.4% of the total UK land, respectively.
- Solar and wind load factors are taken to be 10.7% and 26.2% respectively. These are 3 year averages (2016-18) for Yorkshire & Humber as taken from UK regional renewables statistics[1].
- It is assumed that each MW of solar PV have a footprint of 2 ha. Onshore wind takes around 25 ha per MW, however, only 1.2% of this is direct use and the remaining is space between turbines. It is possible to use this area for other purposes, like agriculture, concurrently.

1- https://www.gov.uk/government/statistics/regional-renewable-statistics

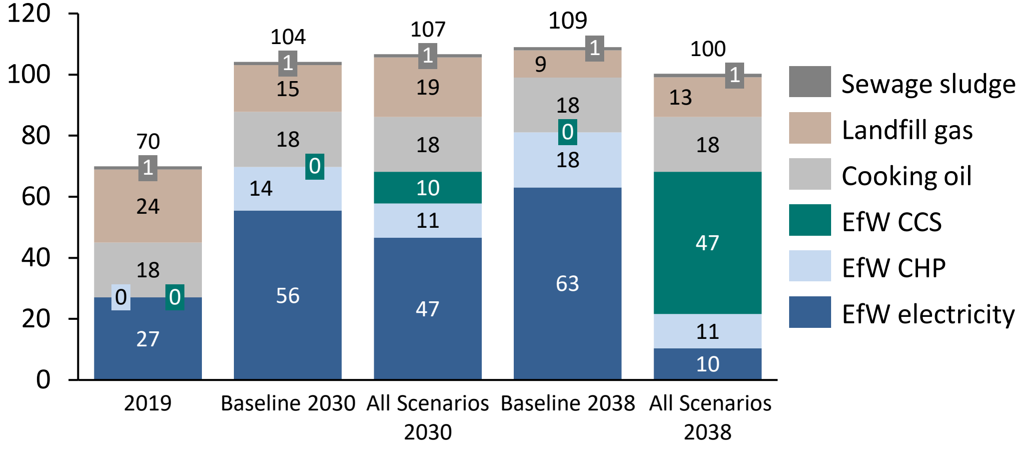
Energy from waste assumptions/data

Study region

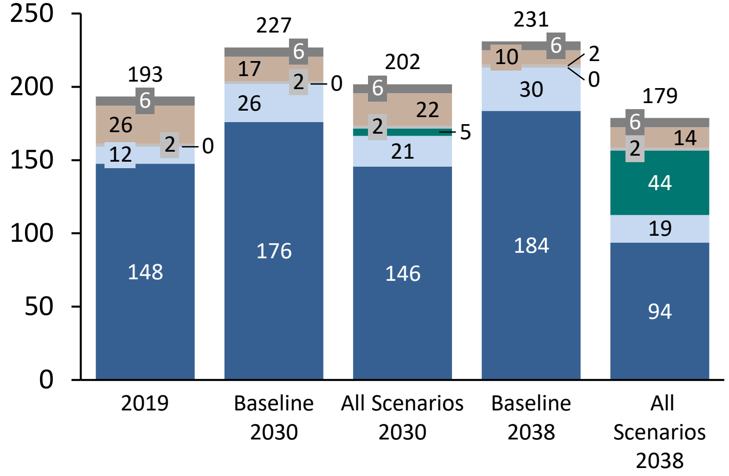
West Yorkshire

Y&NY

Y&NY Capacities, MW



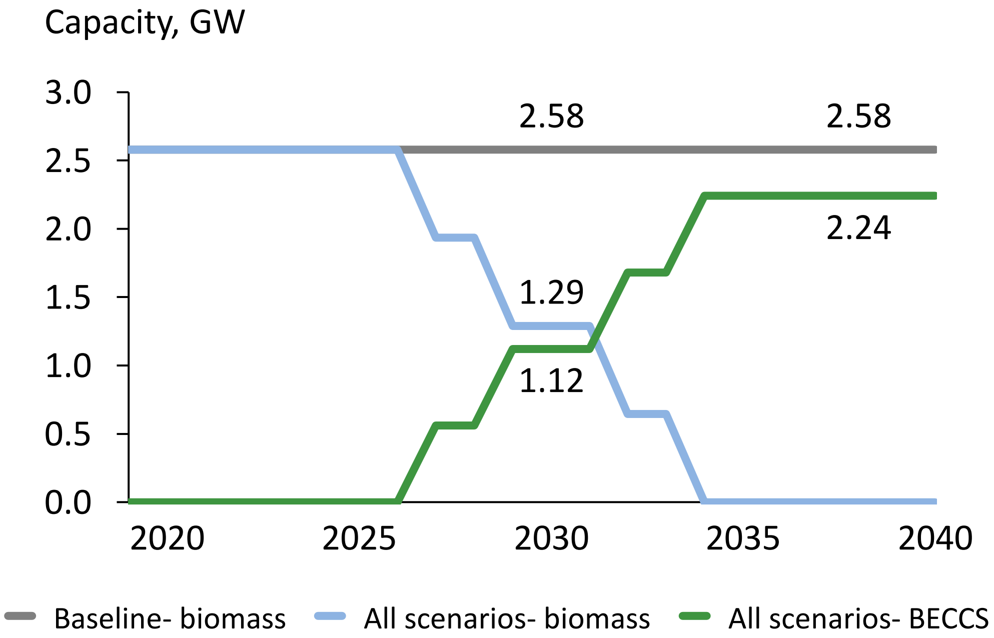
WY Capacities, MW



- The above graph shows capacities of various energy from waste (EfW) technologies in both regions over the timescales.
- Capacities of cooking oil and sewage sludge are assumed constant. Capacity of landfill gas is taken from National Grid Future Energy Scenarios (FES) consumer evolution and community renewables scenarios for baseline and all other scenarios, respectively.
- Load factors of these technologies are assumed to be the average load factor of each technology for the Yorkshire and the Humber region, as taken from Digest of UK Energy Statistics.
- Current electricity only EfW and EfW CHP capacities are taken from Tolvik's 2018 UK Energy from Waste review. This report is also used to find capacity growth until 2023. A 1% growth rate is assumed after 2023 for baseline. For the decarbonization scenarios, capacity is reduced in accordance with the projected waste availability in CCC's Net Zero report. A third of all new capacity is assumed to be EfW CHP, which are more efficient. It is also assumed that from 2030 electricity only EfW plants retrofit CCS to increase EfW CCS capacity to 50% by 2050, which is another CCC target (for 2050). EfW plants are assumed to continue operating at current load factors (~90%).
- CCS capture rate is assumed to be 90%. Biogenic components of the waste is assumed to be zero carbon and all emissions are assumed to be from non-biogenic components. EfW CCS plants also generate net negative emissions which are calculated by subtracting remaining non-biogenic emissions from captured biogenic emissions. A speculative option would be new improved capture technologies to reach higher capture rates (98%) and reduce emissions further.

Drax bioenergy and BECCS assumptions/data

- Drax has 4 biomass turbines each with a net capacity of 645 MW for a total capacity of 2.58 GW.
- According to the company's annual report, 2019 load factor for its biomass turbines was 59.3%, which is close to previous years In our model we assume that this load factor stays constant.
- Drax publicly announced a roadmap for retrofitting one of its turbines with CCS by 2027 and a second turbine by 2029. Our model follows this timeline and converts the remaining 2 turbines in 2032 and 2034, as shown on the graph.
- It is assumed that net output of BECCS turbines are 12.8% lower than unabated biomass turbines*. Hence, each biomass turbine converts to 560 MW BECCS turbine.



- Drax biomass turbines are assumed to be 40% efficient, indicating BECCS efficiency of 35%. BECCS is assumed to operate as a baseload generator (90%) to maximize negative emissions. It is also assumed that CO2 capture rate will start at 90% and after 2030 linearly increase to 95% by 2040, in accordance with CCC's Net Zero Report (95% capture by 2050).
- It is assumed that CO2 emitted from biomass combustion is zero net emissions since it is absorbed during plant growth. However, the non-CO2 GHGs still produce some positive emissions as calculated from 2019 UK GHG conversion factors by BEIS and DEFRA.
- Biomass emissions factors are combined with efficiencies to calculate final emissions factors. It is assumed that the captured part of the biomass CO2 content produces negative emissions, approximately amounting to 911 gCO2e/kWh in 2030, going up to 964 gCO2e/kWh in 2040.

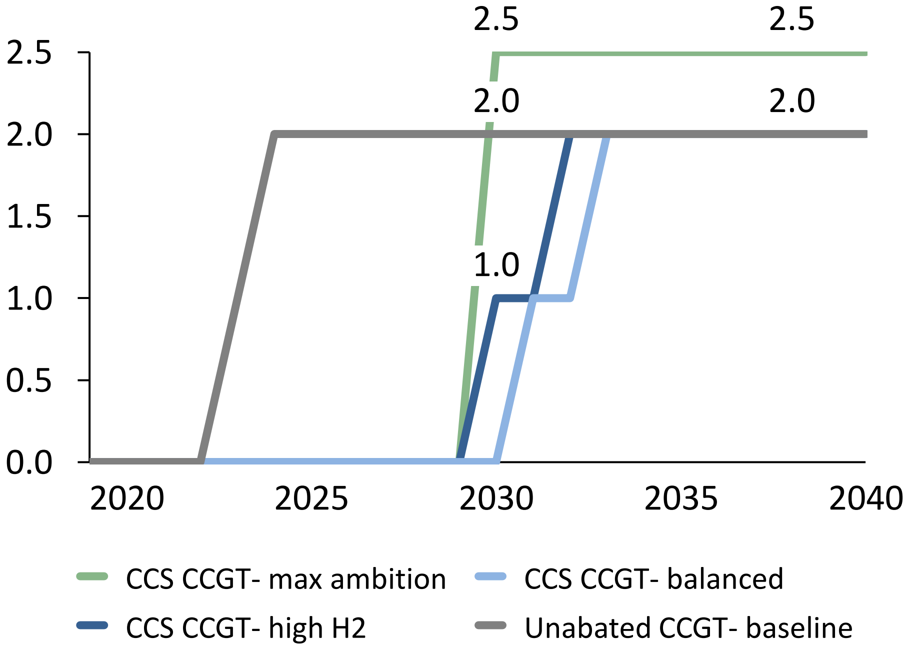
* Wood, 2018. Assessing the Cost Reduction Potential and Competitiveness of Novel (Next Generation) UK Carbon Capture Technology

Large-scale fossil generation assumptions/data

Study region

- Drax has a coal generation capacity of 1290 MW in North Yorkshire. In 2019, load factor of coal was only 5.3%. It is assumed that in 2020 this will be halved and by 2021 coal operations will cease.
- In our model, we assume that a new 2 GW CCGT capacity will be build in 2023/2024 in two equal instalments in the baseline, high H2 and Balanced scenarios. This capacity is increased to 2.5 GW for Max Ambition, in order to satisfy higher power demand. Drax is proposing to build two 1.8 GW CCGTs (gas turbines) to replace coal turbines in 2023/24, but equally there are other organisations planning CCGTs (in Y&NY), so this assumption is not relying on Drax.
- In the baseline, this unabated plant runs as it is, but in decarbonization scenarios it is converted to a CCS CCGT. Max Ambition achieves this retrofit in one go in 2030. In the High H2 scenario the transitions happens in 2030-32 and in the Balanced Scenario the transition happens in 2031-33. It is assumed that the High H2 scenario builds CO2 infrastructure faster than the Balanced scenario.

CCGT capacity, GW



Y&NY

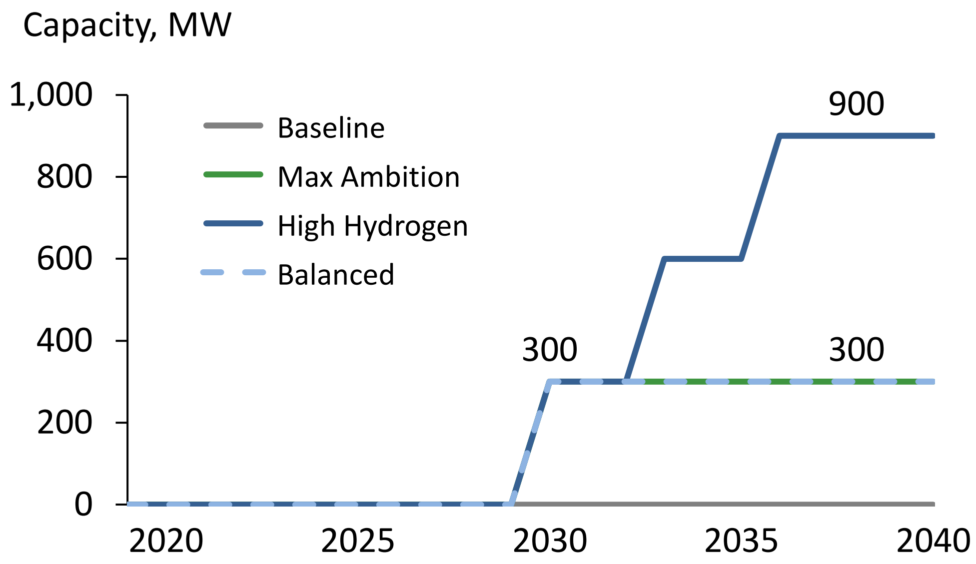
- It is assumed that the capture rate of CCS will increase linearly from 90% in 2030 to 95% in 2040. Furthermore, total capacity of the plant is assumed to stay constant after the retrofit, implying that an outside source will be supplying energy for capture. Efficiencies of a modern unabated CCGT and a first-of-a-kind CCS CCGT are taken as 59.8% and 52.6%, respectively[1].
- Load factors of CCGT CCS is taken as constant at 70%, which is the load factor of CCS CCGT in 2035 in BEIS Energy and Emissions Projections. It is expected that initial CCS plants will run closer to baseload generation.
- Load factor of the new unabated CCGT is expected to be higher than the average UK fleet since it would be a very efficient plant. It is observed that the 4 newest large scale CCGTs (build after 2010) had 78% higher average load factor in 2018 compared to the total UK fleet[2]. The average CCGT load factor is assumed to be the same as National Grid's Steady Progress Scenario in FES, which is then multiplied by 78% to estimate the load factor of the new unabated CCGT.

1- Uniper Technologies, 2018. BEIS: CCUS Technical Advisory- Report on Assumptions

2- National grid final load factors: https://www.nationalgrideso.com/document/157476/download

Hydrogen power assumptions

- Hydrogen turbines (H2GTs) capable of burning 100% hydrogen without a need for dilution or post-combustion NOx removal are assumed to be developed by 2030 when the first plant is deployed.
- As can be seen in the graph, Max Ambition and Balanced scenarios deploy 300 MW of H2GT in 2030 whereas High H2 Scenario deploys a total of 900 MW in 3 instalments.
- 300 MW is chosen as a standard size as current OCGT plants, which are similar in function to future H2GT plants are usually planed for around 300 MW.
- Hydrogen for power is assumed to be produced by steam methane reforming with CCS as electrolytic hydrogen is expected to be more expensive and would not be very efficient when converted back to electricity. Hence it is assumed that these plants would likely be near Selby, to utilise the planned hydrogen production facility.



- Hydrogen is expected to operate at low load factors, providing electricity during peak demand. It is assumed that H2GTs operate at the same load factor as transmission level CCGTs in National Grid's 2019 Future Energy Scenarios- Steady Progression Scenario[1]. This load factor decreases from 15.9% in 2030 to 10.0% in 2038.
- All new H2GT capacity is assumed to be build in North Yorkshire, potentially in Selby, close to Drax. This area is likely to be part of an early cluster and have an established CO2 T&S infrastructure.

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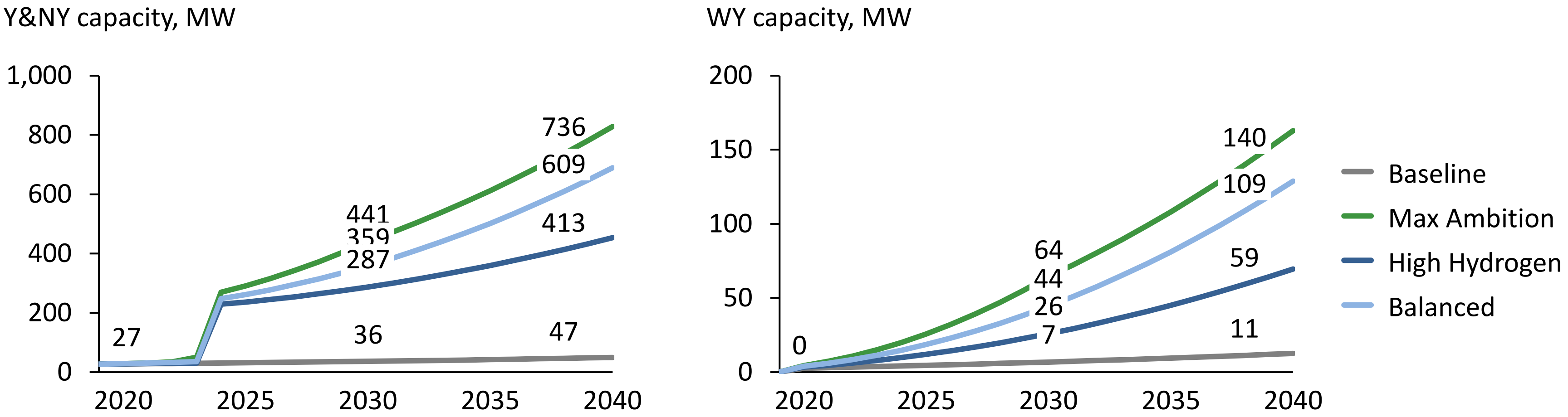
[1] National Grid 2019 Future Energy Scenarios

Battery storage and demand side response are effective supplementary tools to reduce peak demand and save costs



The study analysis doesn't include infrastructure, so storage and DSR technologies are not a core component of the study, but rather an enabling technology. They are included here at a high-level to provide an idea of the role and level of deployment in the study region.

- Both electricity storage and demand side response (DSR) technologies are considered and deployed in National Grid's Future Energy Scenarios[1]. Since this model utilizes NG FES for many power technologies, the effects of storage and DSR are indirectly accounted for.
- DSR is willingness of consumers to shift their consumption due to external signals, such as price. It adds flexibility to the system and usually reduces peak demand, as well as infrastructure requirements. FES quantifies these benefits by stating that residential DSR reduces peak demand by 10% in 2030s and 13.5% in 2050 in the Community Renewables Scenario (which is closer to Max Ambition and Balanced Scenarios). This equates to a reduction of 1.6 GW of UK's peak demand.
- FES includes 3 types of power storage technologies. Of these, pumped hydro storage is not likely to be deployed in the study region due to site restrictions and compressed air and liquid air capacities in FES are fairly small outside of the Two Degrees Scenario. Battery storage is expected to be the most widely deployed technology in the region.
- The above graphs show capacities of battery storage in both study regions across scenarios. Y&NY starts with a 27 MW existing plant and is assumed to host a 200 MW battery commissioning in 2024 (the spike on the graph) alongside the new CCGT plant at Drax. Otherwise uptake is assumed to be more smooth. Battery uptake rates are based on NG FES scenarios and are calculated based on the ratio of solar and onshore wind capacities to battery capacities. It is assumed that storage follows renewable generation and therefore Max Ambition results in the highest battery capacity.

Study region
West Yorkshire
Y&NY

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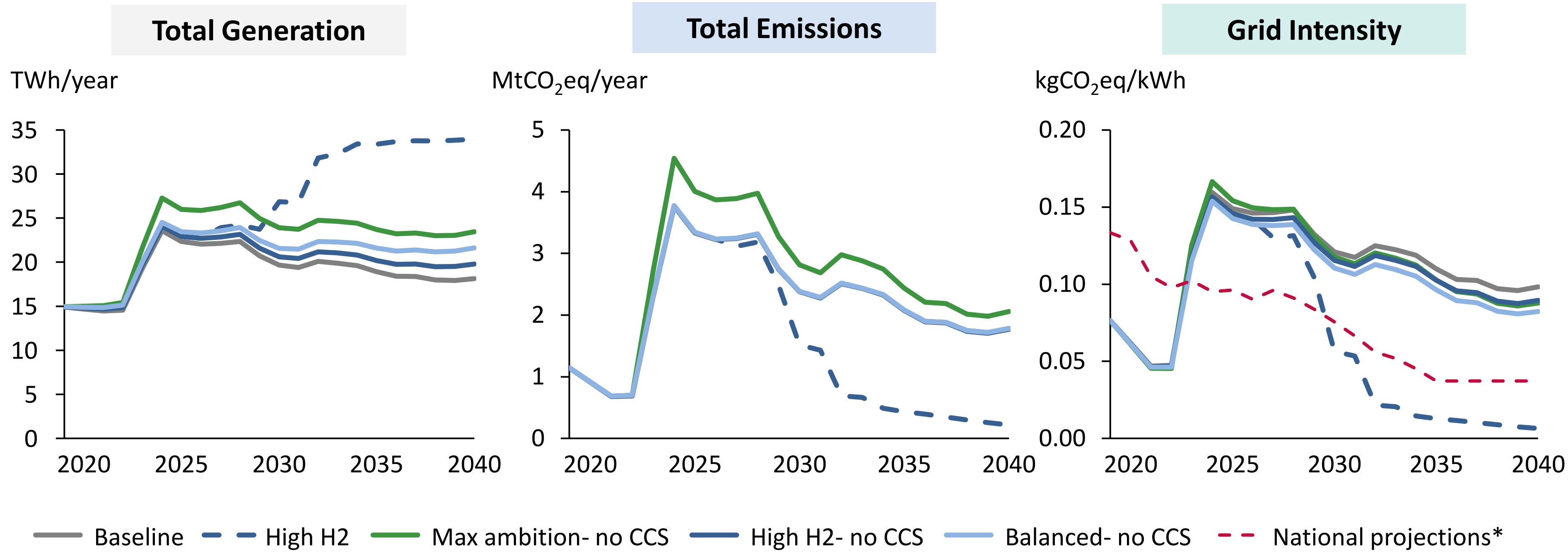
[1] National Grid 2019 Future Energy Scenarios

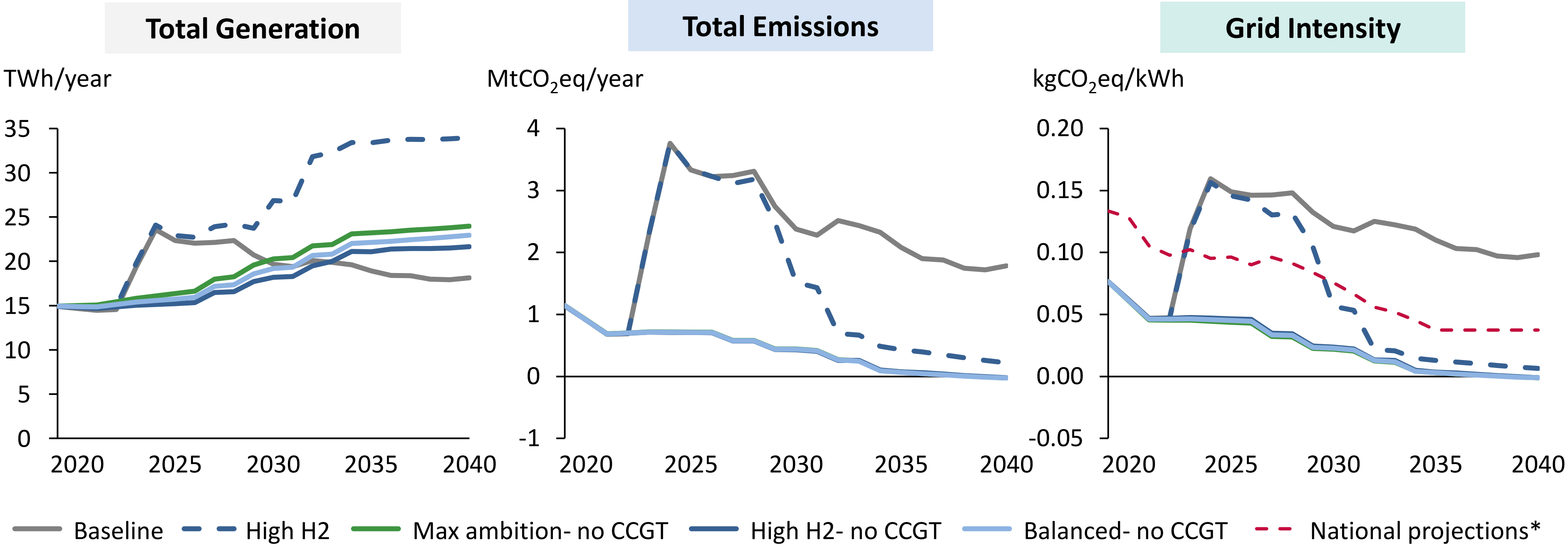
Power – no CCS high-level sensitivity Y&NY



- This slide shows the summary outputs of a high-level sensitivity analysis where CCS is disabled from all scenarios. Baseline and the regular high H2 scenario with CCS are included as references. Under this sensitivity Drax biomass units continue operating like today, new CCGT which are built in the future do not retrofit CCS and there is no hydrogen in power generation. Furthermore, all EfW plants continue operations without CCS retrofits. All other factors are kept constant.
- Power generation is significantly lower without CCS as hydrogen is missing and Drax biomass and future unabated CCGT plants operate at lower utilization rates as they are not low-carbon enough to continually run as baseload. Consequently, power export of the region decreases to 68%-74% across scenarios in 2038.
- Total emissions are similar to the baseline case as similar levels of unabated technologies are deployed. Grid intensities are slightly less than the baseline scenario since decarbonisation pathways still deploy renewables, bioenergy, AD, etc.
- In reality, if CCS is not allowed in the region, new CCGTs may not be built or other technologies may be deployed instead, therefore a more holistic new study is needed to assess the full impact of a no CCS future.

*Based on Treasury's Green Book supplementary appraisal guidance on valuing energy use and greenhouse gas emissions.

Power – no CCGT high-level sensitivity Y&NY



- **These graphs exclude negative emissions from BECCS** (BECCS is taken as zero emissions).
- This slide shows the summary outputs of a sensitivity analysis where future CCGTs are disabled from all scenarios. Baseline and the regular high H2 scenario with CCS are included as references. Under this sensitivity, large-scale CCGT plants planned for the first half of 2020s are not built. Consequently, there is no need to retrofit them with CCS. All other factors stay constant, including BECCS.
- Power generation is reduced in a similar way to the no CCS sensitivity. This time, other CCS technologies are allowed to run, but there is no unabated CCGT. Similarly, power export capacity of the region is reduced to 69% - 76% in 2038.
- Contrary to the no CCS sensitivity, disallowing future CCGTs does not mean the power sector cannot reach net-zero. There are net-negative grid intensities (from EfW CCS) even without accounting for BECCS negative emissions. Therefore, opting out of future CCS CCGTs present a trade-off between reduced power generation and eliminating all residual power sector emissions in the region.
- In reality, if CCGTs are not allowed in the region, other technologies (which may or may not be zero emissions) would be needed in Y&NY or in other parts of the UK, therefore a more holistic new study is needed to assess the full impact of a no CCGT future.

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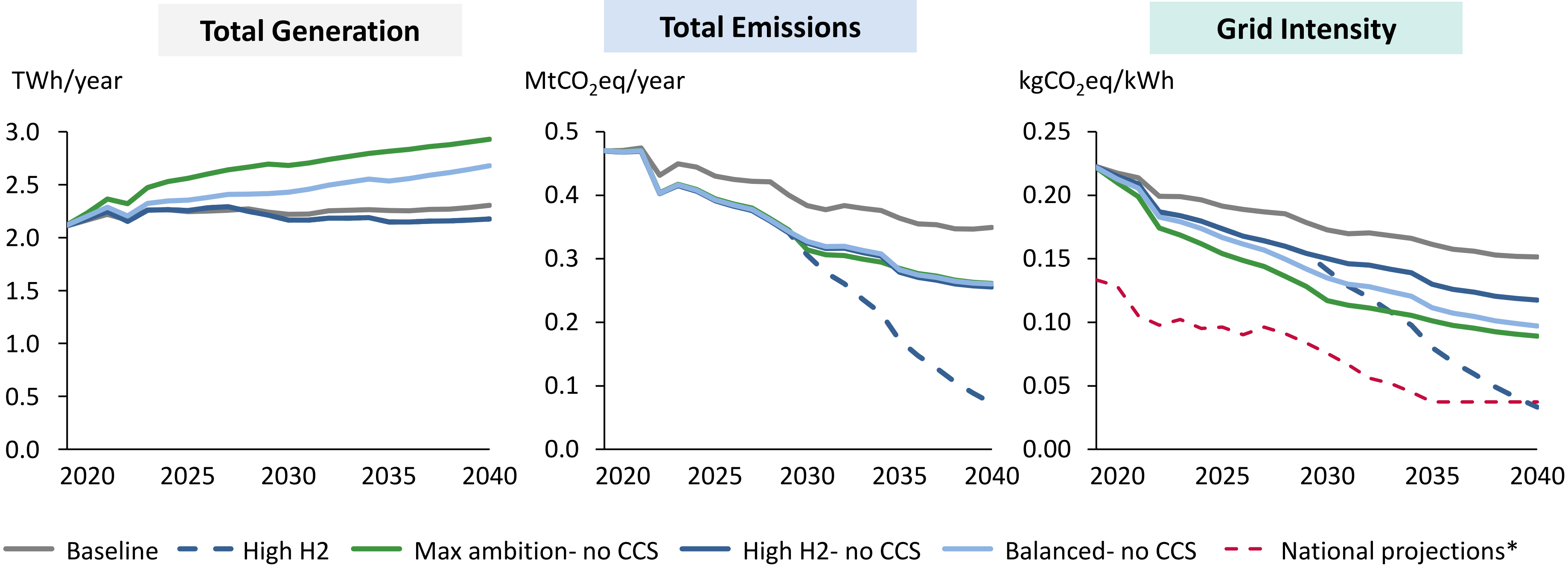
*Based on Treasury's Green Book supplementary appraisal guidance on valuing energy use and greenhouse gas emissions.

Power – no CCS on Energy from Waste sensitivity (West Yorkshire)



- This slide shows the summary outputs of a sensitivity analysis where CCS is disabled from all scenarios. Baseline and the regular high H2 scenario with CCS are included as references. In West Yorkshire, CCS is only deployed on EfW plants, amounting to 28% of the fleet by 2038. Under this sensitivity, it is assumed that these plants will continue operating as electricity only or CHP EfW plants.
- Power generation is unaffected by the exclusion of CCS from EfW plants, since the capacity and utilization rates of EfW facilities are unaffected by the retrofits of CCS in the model.
- On the other hand, emissions of all scenarios are significantly higher without the negative emissions provided by EfW CCS plants. Without CCS, emissions are reduced by ~24% over the baseline in 2038 while ~69% reduction is achieved by inclusion of CCS. Consequently, all scenarios lead to regional grid intensities higher than the predicted national average, whereas the CCS scenarios manage to equal national average by 2038.
- In reality, if CCS is not allowed in the region, investment may be directed towards other technologies, therefore a more holistic new study is needed to assess the full impact of a no CCS future.

*Based on Treasury's Green Book supplementary appraisal guidance on valuing energy use and greenhouse gas emissions.

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- Key findings
- Sector pathways West Yorkshire
- Additional information
- Technical Appendix
  - General
  - Transport
  - Buildings
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Industry Pathways: measures and assumptions

Key industry measures and assumptions

- **Energy and resource efficiency:** range of improvements based on Max Tech[1], CCC & UKERC, and regional work (e.g. ESDP WP4 Leeds University). Measures include energy and process management, BAT implementation, waste heat recovery, leakage prevention and resource efficiency (e.g. increased recycling rates).
- **Hydrogen fuel switching** for many applications currently using natural gas e.g. food and drink, steel, chemicals. **Hydrogen production** begins at scale in the late 2020s (near Humber), enabling a small number of sites in the Max Ambition pathway; in the High Hydrogen scenario large areas of the gas grid are converted during the early 2030s to enable widespread hydrogen use.
- **Electrification** of low temperature heat and heat on smaller sites; in the Max Ambition Pathway rapid deployment of further electrification options will be required (technology development accelerated)
- **CCS on large sites** in sectors with process emissions, such as glass and chemicals. Other sectors do not have plants large enough for CCS to be cost-effective. Capture rates start at 85% in the 2020s and reach 95% by 2035.
- **Bioenergy and waste** for some applications, particularly those with limited alternatives.

Method summary

1. Take regional emissions of large point sources (emissions intensive industry) and categorise by subsector and region[1]
2. Estimate the energy consumption and fuel breakdown of these large sites using fuel emissions factors and ECUK fuel breakdown by sector. Add on the electricity consumption for each sector (no direct emissions).[2]
3. Add 'small industry' fuel as that remining in the non-domestic sector of the local authority energy datasets once non-domestic buildings are removed[3]. Use the government employment and business count datasets to understand a rough distribution of sectors within small businesses[4].
4. Apply industry growth factors supplied by LCR by SIC code
5. Apply energy efficiency and resource efficiency measures from a number of sources, primarily the industrial decarbonisation roadmaps by sector[5,6,7]
6. Apply net-zero solutions by industry sector (shown later), either fuel switching to hydrogen, electricity, bioenergy; or CCS application[5,7,8,9]

1.NAEI Point source emissions LINK
2. Energy Consumption in the UK ECUK dataset LINK
3. BEIS subnational energy consumption statistics LINK
4.ONS UK business workbook LINK and floorspace LINK
5. Industrial decarbonisation and energy efficiency roadmaps LINK
6. Discussions on resource efficiency LINK LINK
7.CCC Net-zero reports LINK and associated EE analsyis
8. EE for BEIS Hy4Heat WP6 LINK
9.EE for BEIS CO2 capture in industry LINK
10.H21 LINK and ZCH LINK

Industry Pathways: deep decarbonisation requires fuel switching and/or CCUS. Infrastructure must be developed rapidly.

	Scenario			
Intervention	Baseline	Max ambition	High H2	Balanced
Energy and process efficiency	Low	High	High	High
CCS	None	High (not by 2030)	Medium	High
Hydrogen fuel	None	Medium	High	Medium
Electrification	Low	High	Medium	Medium
Bioenergy and waste	Low	High	Medium	High

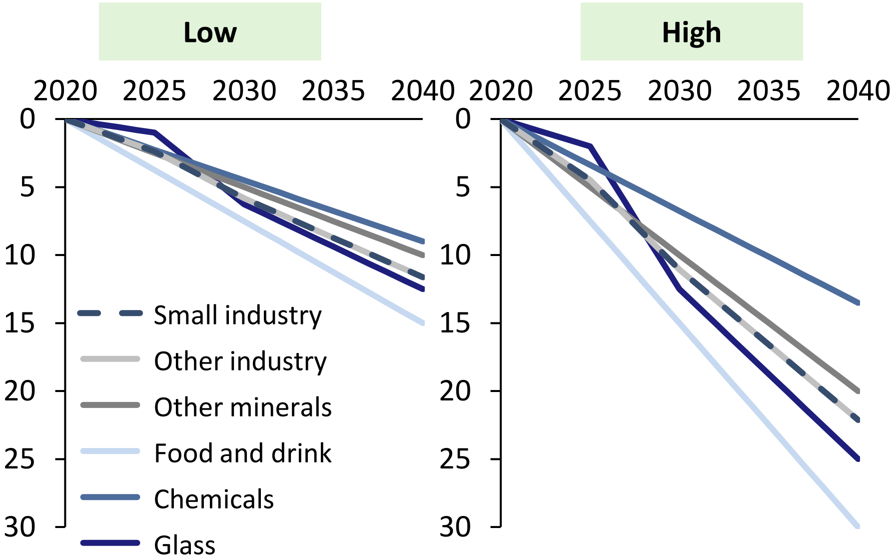
Sectors:

- **Glass:** the largest plants in the region, with natural gas furnaces producing the majority of the emissions. The glass industry is researching hydrogen, biofuel, electrification and CCS, with all options thought possible. No solutions are commercially ready or proven at full-scale yet.
- **Chemicals:** range of scales in the region. Mostly boilers and furnaces; many applications can fuel switch to hydrogen or electricity. Large plants could consider CCS, particularly if near to existing infrastructure.
- **Food and drink:** large number of small and medium plants, with primarily boilers and ovens. Many applications could be electrified, or switched to hydrogen where available, but RD&D is needed.
- **Other mineral industries:** common activities include drying, firing and milling with equipment including driers and kilns as well as electric grinders. Hydrogen could replace natural gas where available.
- **Other industry:** range of sites, with the majority being small and medium size. Emissions reduction solutions will be applied by proportion.
- **Small industry**: too small for CCS, but fuel switching to hydrogen and electrification in different proportions by scenario depending on fuel availability

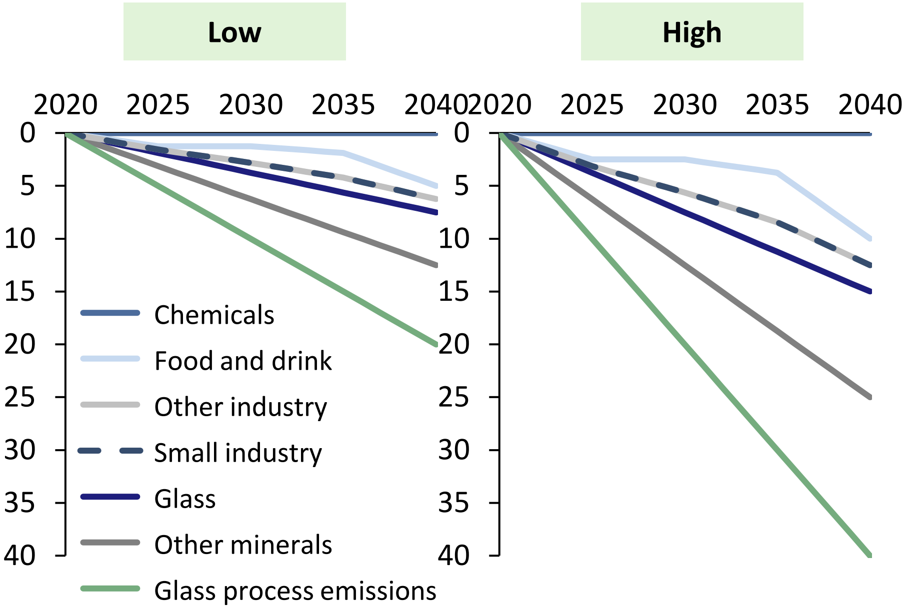
1 IDEER Industrial Decarbonisation and Energy Efficiency Roadmaps; RD&D is research development and demonstration
2 Element Energy Analysis for CCC Net-Zero Technical report and BEIS Hy4Heat WP6

Industry – continued energy and resource efficiency makes some progress with technology improvement

Energy reduction on industrial sites due to efficiency measures (%)



Energy reduction on industrial sites due to resource efficiency (%)



- Significant energy efficiency and waste heat recovery has already been completed on industrial sites, but there is still potential for further improvement in some applications. A range of measures were considered in the IDEER to 2050[1] by subsector; for the baseline pathway we assume half of the potential measures are implemented in most sectors by 2038 and **all** in the emissions reduction scenarios (excluding measures such as fuel switching which are considered elsewhere in the analysis).
- Resource efficiency includes reductions in material inputs, increased recycling and switching of material end-uses. *It should be noted that the level of evidence around this is low, so these estimates contain large uncertainties.*

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[1] https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050

For the glass sector information was provided by British Glass, including increased recycling rates and additional measures to reduce energy consumption.

Industry – Input assumptions – for industry, we alter the fuel mix and dictate the proportion of emissions with CCS applied

Examples of the assumptions in the industrial subsectors

Glass sector – Max ambition

Glass	2020	2025	2030	2035	2040
Natural gas	83%	80%	35%	10%	10%
Electricity	17%	20%	25%	25%	25%
Petroleum	0%	0%	0%	0%	0%
Coal	0%	0%	0%	0%	0%
Hydrogen	0%	0%	15%	30%	30%
Bioenergy	0%	0%	25%	35%	35%
Total	*100%*	*100%*	*100%*	*100%*	*100%*
CCS - natural gas	0%	0%	0%	50%	100%
CCS - bioenergy	0%	0%	0%	50%	100%
CCS - process emissions	0%	0%	0%	30%	60%

Small industry – High H2

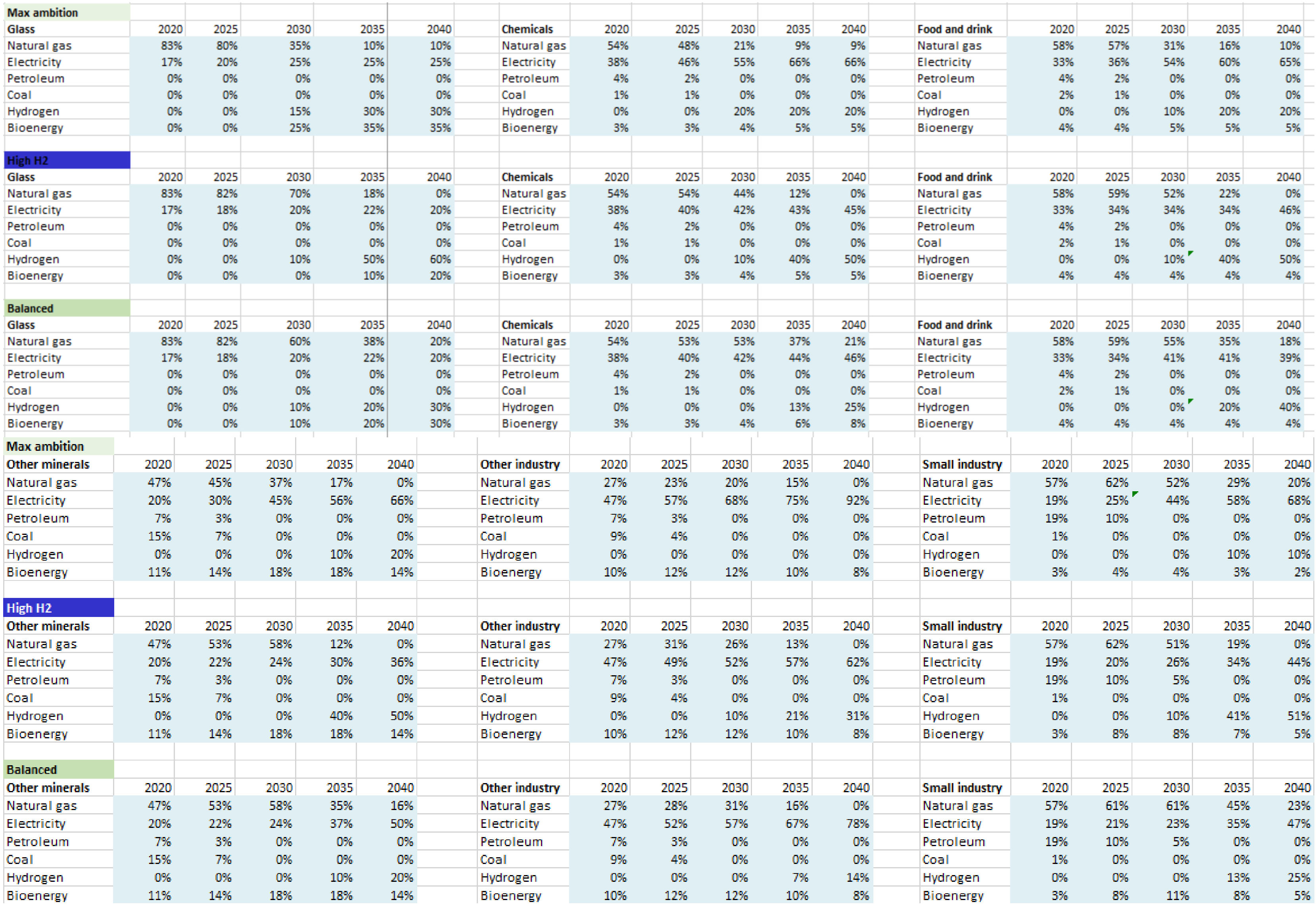
Small industry	2020	2025	2030	2035	2040
Natural gas	57%	66%	66%	36%	0%
Electricity	19%	20%	21%	26%	32%
Petroleum	20%	10%	5%	0%	0%
Coal	1%	0%	0%	0%	0%
Hydrogen	0%	0%	5%	35%	65%
Bioenergy	3%	4%	4%	3%	2%
Total	*100%*	*100%*	*100%*	*100%*	*100%*
CCS - natural gas	0%	0%	0%	0%	0%
CCS - bioenergy	0%	0%	0%	0%	0%
CCS - process emissions	0%	0%	0%	0%	0%

- Industry key assumptions are input as:
  - the changing proportion of fuels over time in each scenario and subsector (white cells)
  - the proportion of natural gas, bioenergy and process emissions which have CCS applied (grey cells)
- The assumptions are based on both Element Energy work for the CCC and BEIS and also the Industrial Decarbonisation and Energy efficiency roadmaps to 2050.
- The full breakdown of assumptions across fuels, subsectors and scenarios is provided on the next slide
- **Please note that low carbon technologies in the industry sector are mostly very immature and low TRL, so there is a large uncertainty around the measures and pathways applied. Further RD&D and evidence gathering is needed for industry to make decisions and roadmaps.** The pathways are highly ambitious and rely on funding availability for the necessary trials and to support industry in the cost of conversion.

1 IDEER Industrial Decarbonisation and Energy Efficiency Roadmaps;
2 Element Energy Analysis for CCC Net-Zero Technical report and BEIS Hy4Heat WP6;

Industry assumptions – fuel mix by sector and scenario over time

Study region



Max ambition

Glass	2020	2025	2030	2035	2040	Chemicals	2020	2025	2030	2035	2040	Food and drink	2020	2025	2030	2035	2040
Natural gas	83%	80%	35%	10%	10%	Natural gas	54%	48%	21%	9%	9%	Natural gas	58%	57%	31%	16%	10%
Electricity	17%	20%	25%	25%	25%	Electricity	38%	46%	55%	66%	66%	Electricity	33%	36%	54%	60%	65%
Petroleum	0%	0%	0%	0%	0%	Petroleum	4%	2%	0%	0%	0%	Petroleum	4%	2%	0%	0%	0%
Coal	0%	0%	0%	0%	0%	Coal	1%	1%	0%	0%	0%	Coal	2%	1%	0%	0%	0%
Hydrogen	0%	0%	15%	30%	30%	Hydrogen	0%	0%	20%	20%	20%	Hydrogen	0%	0%	10%	20%	20%
Bioenergy	0%	0%	25%	35%	35%	Bioenergy	3%	3%	4%	5%	5%	Bioenergy	4%	4%	5%	5%	5%

High H2

Glass	2020	2025	2030	2035	2040	Chemicals	2020	2025	2030	2035	2040	Food and drink	2020	2025	2030	2035	2040
Natural gas	83%	82%	70%	18%	0%	Natural gas	54%	54%	44%	12%	0%	Natural gas	58%	59%	52%	22%	0%
Electricity	17%	18%	20%	22%	20%	Electricity	38%	40%	42%	43%	45%	Electricity	33%	34%	34%	34%	46%
Petroleum	0%	0%	0%	0%	0%	Petroleum	4%	2%	0%	0%	0%	Petroleum	4%	2%	0%	0%	0%
Coal	0%	0%	0%	0%	0%	Coal	1%	1%	0%	0%	0%	Coal	2%	1%	0%	0%	0%
Hydrogen	0%	0%	10%	50%	60%	Hydrogen	0%	0%	10%	40%	50%	Hydrogen	0%	0%	10%	40%	50%
Bioenergy	0%	0%	0%	10%	20%	Bioenergy	3%	3%	4%	5%	5%	Bioenergy	4%	4%	4%	4%	4%

Balanced

Glass	2020	2025	2030	2035	2040	Chemicals	2020	2025	2030	2035	2040	Food and drink	2020	2025	2030	2035	2040
Natural gas	83%	82%	60%	38%	20%	Natural gas	54%	53%	53%	37%	21%	Natural gas	58%	59%	55%	35%	18%
Electricity	17%	18%	20%	22%	20%	Electricity	38%	40%	42%	44%	46%	Electricity	33%	34%	41%	41%	39%
Petroleum	0%	0%	0%	0%	0%	Petroleum	4%	2%	0%	0%	0%	Petroleum	4%	2%	0%	0%	0%
Coal	0%	0%	0%	0%	0%	Coal	1%	1%	0%	0%	0%	Coal	2%	1%	0%	0%	0%
Hydrogen	0%	0%	10%	20%	30%	Hydrogen	0%	0%	0%	13%	25%	Hydrogen	0%	0%	0%	20%	40%
Bioenergy	0%	0%	10%	20%	30%	Bioenergy	3%	3%	4%	6%	8%	Bioenergy	4%	4%	4%	4%	4%

Max ambition

Other minerals	2020	2025	2030	2035	2040	Other industry	2020	2025	2030	2035	2040	Small industry	2020	2025	2030	2035	2040
Natural gas	47%	45%	37%	17%	0%	Natural gas	27%	23%	20%	15%	0%	Natural gas	57%	62%	52%	29%	20%
Electricity	20%	30%	45%	56%	66%	Electricity	47%	57%	68%	75%	92%	Electricity	19%	25%	44%	58%	68%
Petroleum	7%	3%	0%	0%	0%	Petroleum	7%	3%	0%	0%	0%	Petroleum	19%	10%	0%	0%	0%
Coal	15%	7%	0%	0%	0%	Coal	9%	4%	0%	0%	0%	Coal	1%	0%	0%	0%	0%
Hydrogen	0%	0%	0%	10%	20%	Hydrogen	0%	0%	0%	0%	0%	Hydrogen	0%	0%	0%	10%	10%
Bioenergy	11%	14%	18%	18%	14%	Bioenergy	10%	12%	12%	10%	8%	Bioenergy	3%	4%	4%	3%	2%

High H2

Other minerals	2020	2025	2030	2035	2040	Other industry	2020	2025	2030	2035	2040	Small industry	2020	2025	2030	2035	2040
Natural gas	47%	53%	58%	12%	0%	Natural gas	27%	31%	26%	13%	0%	Natural gas	57%	62%	51%	19%	0%
Electricity	20%	22%	24%	30%	36%	Electricity	47%	49%	52%	57%	62%	Electricity	19%	20%	26%	34%	44%
Petroleum	7%	3%	0%	0%	0%	Petroleum	7%	3%	0%	0%	0%	Petroleum	19%	10%	5%	0%	0%
Coal	15%	7%	0%	0%	0%	Coal	9%	4%	0%	0%	0%	Coal	1%	0%	0%	0%	0%
Hydrogen	0%	0%	0%	40%	50%	Hydrogen	0%	0%	10%	21%	31%	Hydrogen	0%	0%	10%	41%	51%
Bioenergy	11%	14%	18%	18%	14%	Bioenergy	10%	12%	12%	10%	8%	Bioenergy	3%	8%	8%	7%	5%

Balanced

Other minerals	2020	2025	2030	2035	2040	Other industry	2020	2025	2030	2035	2040	Small industry	2020	2025	2030	2035	2040
Natural gas	47%	53%	58%	35%	16%	Natural gas	27%	28%	31%	16%	0%	Natural gas	57%	61%	61%	45%	23%
Electricity	20%	22%	24%	37%	50%	Electricity	47%	52%	57%	67%	78%	Electricity	19%	21%	23%	35%	47%
Petroleum	7%	3%	0%	0%	0%	Petroleum	7%	3%	0%	0%	0%	Petroleum	19%	10%	5%	0%	0%
Coal	15%	7%	0%	0%	0%	Coal	9%	4%	0%	0%	0%	Coal	1%	0%	0%	0%	0%
Hydrogen	0%	0%	0%	10%	20%	Hydrogen	0%	0%	0%	7%	14%	Hydrogen	0%	0%	0%	13%	25%
Bioenergy	11%	14%	18%	18%	14%	Bioenergy	10%	12%	12%	10%	8%	Bioenergy	3%	8%	11%	8%	5%

Industry assumptions are based on multiple sources and the latest discussions, but there is large uncertainty in the technology and feasible timeframes for industry to decarbonise

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LULUCF + agriculture pathways: scenarios and measures

Scenario				
Intervention	Baseline	Max ambition	High H2	Balanced
New forest planting	Low	High	Max	Medium
Peatland Restoration	Low	High	High/Medium	Medium
Hedgerow increase	None	High	High	Medium
Agroforestry	None	High	High/Medium	Medium
Biomass crops	None	High	High/Medium	Medium
Agricultural farming practices	Low	High	High	Medium
Agricultural technology development	Low	High	High	Medium
Diet change	Low	High	Medium	Medium
Machinery fuel switching	Low	High	High	High

Land Use and agriculture modelling is based on work completed by CEH and partners for the CCC net-zero technical report[1,2], as well as other modelling and GHG methodology developed by CEH. This is applied to the study region by assessing the regional land area for different applications, number of livestock etc[5].

The table above gives an indication where the effort is focused in each scenario

Key Data sources:

1. CCC Net-zero reports LINK
2. CEH for CCC land use scenarios LINK
3. UK greenhouse gas emissions statistics LINK
4. Further analysis on land use and agriculture such as LINK LINK
5. CEH Land cover map LINK
6. Internal CEH data and methodology

The Max ambition scenario focusses on maximum deployment of all measures. It is particularly worth noting the highest ambition in diet change; the reduced meat and dairy consumption not only reduces emissions from livestock, but frees up land from livestock and growing of animal feed, which can then be used for land based mitigation activities.

The high hydrogen scenario still sees high levels of ambition across many measures. The diet change assumed is lower, allowing less land for other measures. However, it still assumes High levels of new forest planting, hedgerow increase and biomass crops, supported by technology development.

The balanced scenario assumes lower levels of ambition, to represent the uncertainty over what level is achievable. Many of the land use measures are applied at medium levels of ambition, resulting in less negative emissions from the land use sector, particularly from new forest planting.

The low, medium and high assumptions are detailed in the coming slides.

LULUCF + agriculture pathways: assumptions (1/3)

Key Assumptions:

- **Measures based on CCC pathways** adapted for study area using region-specific land cover and livestock numbers.
- Net GHG emissions/removals from afforestation and historic land use change that occurred before 2020 are included in net emissions from each scenario
- Takes account of **predicted population growth** in region to 2038; increase in number of households by local authority (Office for National Statistics) (1,408,000 in 2017 to 1,564,000 in 2039 for whole study region). Proportion of housing built on non-previously developed land (i.e. greenspace) from MHCLG Land Use Change statistics (regional average of 49%). The area required for urban development is upscaled from that required for housing. Density of housing development is based on study region average densities from the Ministry of Housing, Communities and Local Government (MHCLG) (21.85 dwellings/hectare, range 17.17-31.91).
- **Assumes agricultural production per capita is maintained** at same level within region (no outsourcing to other parts of UK or abroad). This is based on calorie intake, so red meat or dairy production can be replaced by pork, poultry or plant-based food production whilst maintained overall agricultural production. In addition, yield can increase through improved practices to reduce the land area required to meet the output. Breaking this assumption would mean a loss of agricultural production, requiring food to be imported from other regions/countries and outsourcing GHG emissions associated with that food production to other regions.
- There is **no loss of productive land area** in the region up to 2038 (e.g. coastal erosion/flooding)[2]
- The effects of climate change on crops/trees/livestock, e.g. on growth rates, disease, are not included
- Low ambition (BAU)- carries forward current rates of activity; Medium ambition implements currently available measures; Max ambition assumes increased uptake or uptake of more radical / novel measures
- **Forest planting rates** have been adjusted to take account of the aspirational targets for afforestation in the region for the White Rose Forest initiative (18 kha of afforestation by 2038). Reporting of forest net emissions have been split into those arising from the management and growth of forest in existence in 2016 (small net sink), and those arising from forest planted after 2016 (small increasing sink).
- It is assumed that there can be rapid scale-up of tree and bioenergy crop planting rates and peatland restoration rates in the region- all require suitable planting material (seeds/rhizomes) and skilled workforce.
- Moorland burning has not been explicitly considered as well managed burning should not degrade carbon stocks in soils, but the scientific literature is still unclear and it is likely that not all burning is well managed e.g. good practice would not burn on blanket bogs, but actually this practice may be quite widespread.

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1 Quantifying the impact of future land use scenarios to 2050 report for CCC (2018)

2 Different agricultural types take account of land capability; some land uses are more amenable to flooding

LULUCF + agriculture pathways: assumptions (2/3)

New forest planting

Takes account of aspirational target in White Rose Forest

- Low: ~14 kha by 2038
- Medium: ~10 by 2030, ~22 kha by 2038
- High: ~ 18 by 2030, ~39 kha by 2038

Peatland restoration

- Medium: Restore 25% lowland peat by 2038, 50% of upland peat by 2038
- High/Medium: Restore 50% lowland peat by 2038, 100% of upland peat by 2038 (Restore 50% upland peat in West Yorkshire)
- High: Restore 100% lowland peat by 2038, 100% of upland peat by 2038 (Restore 60% upland peat in West Yorkshire due to space constraints)

Hedgerow increase

Increase length of hedgerows in region- this only occurs on permanent or temporary grassland

- Medium: 7% increase by 2038*
- High: 13% increase by 2038*

(*No increase in West Yorkshire due to space constraints)

Agroforestry

More trees on cropland, for example field boundaries or alley cropping

- Medium: 5% of cropland converted to alley cropping by 2050, 5% of permanent and rough grazing converted to woodland grazing by 2050
- High/Medium: 8% of cropland converted to alley cropping by 2050, 10% of permanent and rough grazing converted to woodland grazing
- High: 15% of cropland converted to alley cropping by 2050, 20% of permanent and rough grazing converted to woodland grazing. *The equivalent numbers for 2038 are 9% of cropland converted to alley cropping and 11% of grassland converted to woodland grazing.*

Biomass crops

There is very limited amount of timber/fuel for forests modelled in the time period (only producing outputs post-2038) so only Miscanthus and Short Rotation Coppice can produce fuel before 2038. Area planted is split ~ equally between Miscanthus, Short Rotation Coppice and Short Rotation Forestry.

- Medium: ~18 kha by 2038
- Medium+ : ~22 kha by 2038 (insufficient land available to implement High)
- High: ~53 kha by 2038

A delay in the implementation of agroforestry and SRF is assumed (post-2020) due to delays in uptake.

1 Quantifying the impact of future land use scenarios to 2050 report for CCC (2018)

LULUCF + agriculture pathways: assumptions (3/3)

Detailed information on the levels of ambition in agricultural practices and technology (.e.g nitrogen use efficiency, livestock emissions, are given in Thomson, Misslebrook et al (2018).

Agricultural technology development

Measures not affecting available land use: Nitrogen use efficiency, livestock emissions, manure management

Measures affecting land availability:

- Move horticulture indoors (10% Medium, 50% High by 2050 or 5.7%, 28% by 2038)
- Food waste reduction (Medium - 20% by 2050 Medium, and High - 50% by 2050; 20% or 35% by 2038)
  - Reduces area required for horticulture and milled wheat production
  - Reduces area required for livestock grazing
  - Reduces cropping area required for livestock fodder
- Increased stocking density (10% increase in upland stocking density Medium, 10% increase and upland and lowland stocking density by 2050. High; 7% by 2038)
  - Reduces area of grassland required for grazing on pasture and rough grazing
- Improved crop yields
  - reduces area of cropland required to maintain yields

Diet change

20% reduction by 2050 (Medium), 50% reduction by 2050 (High). This is 13% or 32% by 2038.

Red meat and dairy consumption reduction – replaced by poultry, pork and vegetable consumption

- Reduces livestock numbers
- Reduces cropping area required for livestock fodder
- Increases crop area required for pig and poultry feed and vegetable production
- Reduces area of grassland required for livestock grazing

Diet change spares the most amount of agricultural land, followed by increased stocking density and food waste reduction.

1 Quantifying the impact of future land use scenarios to 2050 report for CCC (2018)

LULUCF + agriculture pathways: land spared by agricultural mitigation

Scenarios are based on the land spared from agricultural mitigation activities being used for land-based mitigation activities. Not all the land spared by agricultural mitigation has been used for land-based mitigation. This leaves a ‘buffer’ for possible future land losses, e.g. due to flooding, natural disturbances and pests. The excess land could be used for additional mitigation, “re-wilding” or increased agricultural production.

Diet change spares the most amount of agricultural land, followed by increased stocking density, increased crop yields and food waste reduction. Permanent grassland is in highest demand for conversion to urban and forested land.

Land spared by agricultural mitigation, kha	Max Ambition		High H2		Balanced	
Agricultural mitigation measure	**2030**	**2038**	**2030**	**2038**	**2030**	**2038**
Move horticulture indoors	0.5	0.9	0.1	0.2	0.1	0.2
Replace red meat and dairy with pig, pork and plant-based protein	119	213	47	84	47	84
Reduce food waste	20	26	21	29	19	18
Intensify grazing systems (stocking density)	36	47	41	65	30	47
Increase crop yields	80	119	6.0	12	6.0	12

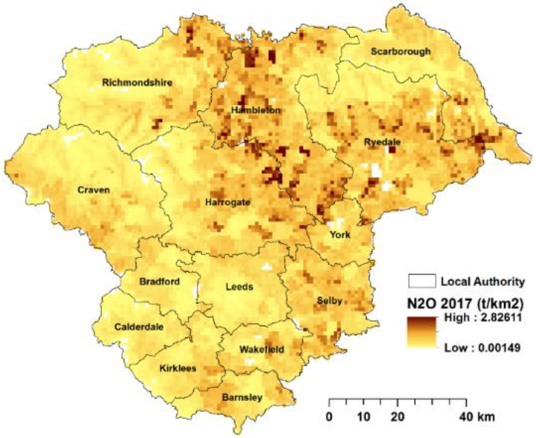
Land spared by agricultural type and region, kha		Max Ambition		H2		Balanced	
Land Use type	Region	2030	2038	2030	2038	2030	2038
Permanent grassland area	West Yorkshire	10.9	18.6	5.9	9.8	4.2	7.0
	Leeds City Region	50.6	87.0	25.9	43.8	19.8	33.3
	North Yorkshire	83.8	144.5	42.0	71.4	32.7	55.5
Temporary grassland	West Yorkshire	1.9	3.3	0.9	1.6	0.8	1.3
	Leeds City Region	9.2	16.0	4.4	7.5	3.6	6.2
	North Yorkshire	15.2	26.6	7.1	12.3	6.0	10.4
Rough grazing (incl common land)	West Yorkshire	5.3	8.0	4.5	7.2	4.5	7.0
	Leeds City Region	24.9	38.2	20.1	32.2	20.0	31.6
	North Yorkshire	44.6	67.9	37.0	59.0	36.8	57.8
Cropland area	West Yorkshire	9.3	13.2	1.9	3.1	1.8	2.5
	Leeds City Region	35.9	51.0	7.2	11.6	6.7	9.1
	North Yorkshire	83.5	117.5	16.1	25.5	14.8	19.4

Emissions of CO_2, CH_4 and N_2O from agriculture, forest and other land

Study region

National GHG Inventory[1] sectors- used for domestic and international reporting

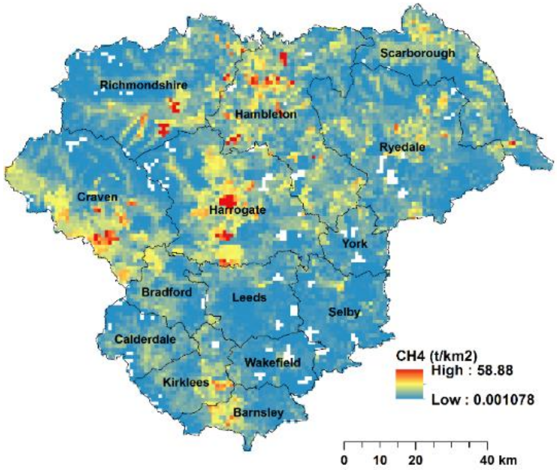
- Land Use, Land Use Change and Forestry (LULUCF)
  - Covers carbon stock changes in soil, vegetation and timber and GHG emissions from non-agri land management
  - net sink of CO_2
- Agriculture
  - livestock, manure and fertilizer
  - source of CH_4 and N_2O
- Variation in data availability for region



https://naei.beis.gov.uk/data/map-uk-das

NOTE: This project will include emissions from modified peatlands (grazed, drained, peat extraction)

- current reporting of peatland emissions in the LULUCF inventory is limited.
- UK has elected to report these emissions by 2022[2].
- Study region has a very high proportion of peat (~9%)
  - Source of GHG emissions, shifting LULUCF sector from a sink into a source.
  - Peatland restoration will reduce emissions, as peatlands in a natural (undrained) state are a long-term sink for C.
  - Have completed further analysis on the type/location of peat in Yorkshire to improve results.



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[1] BEIS GHG inventory https://www.gov.uk/government/statistics/uk-local-authority-and-regional-carbon-dioxide-emissions-national-statistics-2005-to-2017 [2] See recent CEH study https://naei.beis.gov.uk/reports/reports?report_id=980

Agenda

- Introduction
- Key findings
- Sector pathways West Yorkshire
- Additional information
- Technical Appendix
  - General
  - Transport
  - Buildings
  - Power
  - Industry
  - Land use
  - Waste

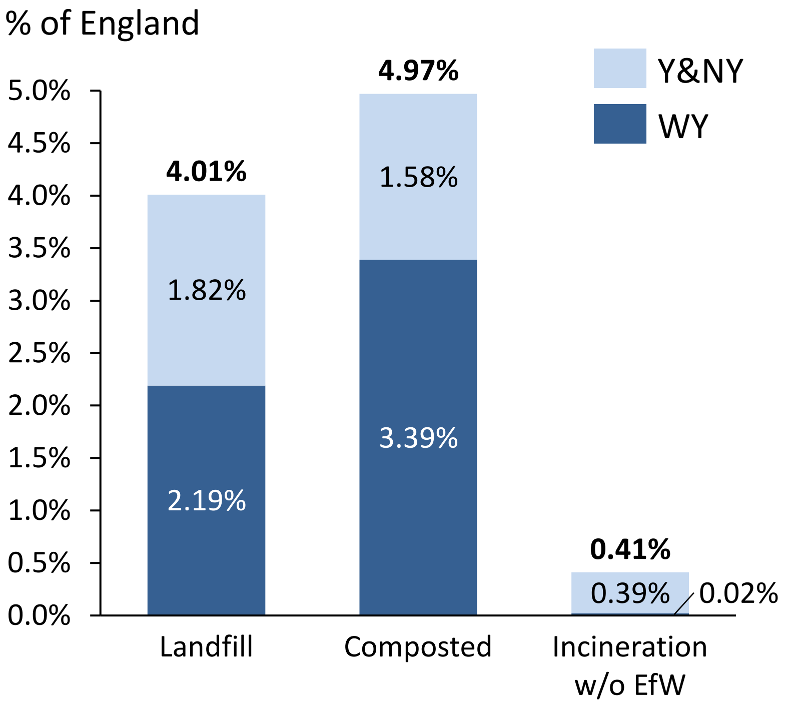
Waste pathways: method summary

Study region

Rationale for waste modelling

1. The waste sector, out of scope for this study, is modelled at a very high level in order to have a comprehensive regional model. Only a baseline and a single emissions reduction scenario are created.
2. The CCC's Net Zero Report[1] forms the basis of the model. The report identifies 6 waste emission types. AD is removed from the model due to it being in the power sector.
3. CCC's forecast do not change England-level emissions from waste incineration, composting and mechanical biological treatment (MBT), therefore these emissions are kept constant in the model.
4. Landfill and wastewater treatment emissions are reduced by the same ratio as the CCC model.
5. Current wastewater emissions are estimated by regional population. West Yorkshire is therefore assumed to have 3.5% of UK's emissions and Y&NY has 1.2%.
6. Current emissions from landfill, composting, incineration and MBT are estimated from local authority waste disposal data[2]. Total tonnes of waste disposed through each pathway is compared to the England total to calculate the % of emissions attributable to the study regions. These are shown in the figure.
7. When waste percentages are compared with population it is apparent that Waste Yorkshire sends 60% less waste per capita to landfill compared to York & North Yorkshire.
8. MBT emissions are assumed to be distributed by the same % as waste sent to composting.

Regional waste disposal methods



Key sources and references

1. CCC 2019 Net Zero Report LINK
2. Local Authority Collected Waste Statistics, 2019 Defra LINK